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March 4, 2016

MEMORANDUM TO: Richard P. Correia, Director
Division of Risk Analysis
Office of Nuclear Regulatory Research

FROM: Joseph G. Giitter, Director **/RA/**
Division of Risk Assessment
Office of Nuclear Reactor Regulation

SUBJECT: PATH FORWARD FOR REGULATORY TREATMENT OF HIGH ENERGY ARCING FAULT TESTS RESULTS THAT INVOLVE ALUMINUM

The purpose of this memorandum is to communicate the path forward for the regulatory use of the information from the recent high energy arcing fault, or HEAF, testing performed by the U. S. Nuclear Regulatory Commission (NRC)'s, Office of Nuclear Regulatory Research (RES). Specifically, the testing that included aluminum components appeared to exceed the expected damage footprint (or zone of influence) described in nuclear power plant regulatory documents. Enclosure 1 to this memorandum is a summary of the staff's evaluation of whether those results constitute an immediate safety concern

The purpose of this memorandum is also to request that RES begin the generic issues process in accordance with NRC Management Directive (MD) 6.4, "Generic Issues Process." A more detailed white paper supporting this summary is provided as Enclosure 2.

Please contact Daniel Frumkin or Harold Barrett of my staff if you require any additional information.

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ENCLOSURE 1

SUMMARY OF EVALUATION OF ALUMINUM IN HIGH ENERGY ARCING FAULTS –

DISCUSSION OF IMMEDIATE SAFETY CONCERN

In October of 2015 and February of 2016, the U. S. Nuclear Regulatory Commission NRC's Office of Nuclear Regulatory Research (RES) performed full scale testing of electrical components under electrically faulted conditions. These two tests included aluminum components which resulted in exceeding the expected damage footprint (or zone of influence) described in NRC endorsed guidance documents. The following bullets outline the reasons that no action is being immediately required of the licensed nuclear power plants.

- Fire protection programs at nuclear power plants utilize the concept of defense-in-depth to assure that there are multiple barriers to assuring the ability to safely shut down a nuclear plant during and following a fire.
- Plant components, specifically properly designed fuses and circuit breakers, prevent high energy events,
- While we do not know how prevalent aluminum components are in electrical distribution systems used in US nuclear power plants, the staff believes that percentage to be low. The majority of components in use utilize copper conductors/bus bars.
- Based on the observations of the two tests that had aluminum present, the tests may not been a complete representation of plant configurations and conditions.
- The aluminum tests resulted in deposition of aluminum combustion byproducts throughout the test enclosure which would require risk analysts to assume the failure of electrical equipment in the fire area. Existing methods require licensees to consider the impact of soot and smoke products on equipment in the affected fire area, which would also result in the assumption that other equipment in the area could be failed.
- Over half the nuclear fleet (those plants that did not adopt National Fire Protection Association (NFPA) Standard 805) is licensed using very conservative deterministic assumptions that assume that any fire in the plant damages all equipment within a fire area. Sufficient equipment and capability has been provided to meet all required functions using equipment outside the fire area. The increased zone of influence (ZOI) due to aluminum would not impact their analyses.
- Of the remaining plants (those that have or are in the process of transitioning to a RI/PB fire protection program in accordance with 10 CFR 50.48(c) and NFPA 805) a significant number of fire areas utilize a deterministic solution using the same very conservative assumptions (whole burnout of the fire area).
- Although aluminum components may result in a larger ZOI, that larger ZOI may not result in substantially higher risk. In many cases, the current ZOI results in a large damage footprint, resulting in the complete loss of one division of equipment (all the equipment powered from the same electrical division). The addition of several feet to the ZOI would not result in any increase in risk if all the important cables had already been damaged.
- Plants have contingency plans for loss of large areas due to fire and explosions.

Based on the above bullets, and as supported by the more detailed discussion in Enclosure 2, the currently available information from this testing does not represent an immediate safety concern and therefore, the staff does not recommend any immediate action to be required on the part of the nuclear power plant licensees.

ENCLOSURE 2

WHITE PAPER - EVALUATION OF ALUMINUM IN HIGH ENERGY ARCING FAULTS

Characterize the Emergent Issue

High Energy Arcing Faults (HEAF) have occurred in both US and foreign nuclear power plants (NPP). Existing guidance and analytical models used for fire safety analysis applications were based on information from one HEAF event at a US NPP. The testing was intended to provide a better understanding of the HEAF phenomena and provide confirmatory testing for the zone of influence risk analysis. HEAF testing potentially identified conditions where existing analytical models are non-conservative. Currently, 16 plants have made the transition to a risk-informed, performance-based fire protection program using these methods. Each plant has evaluated variances from the nuclear safety separation requirements of NFPA 805 and shown them to be acceptable.

Based on recent HEAF testing performed by the NRC's Office of Nuclear Regulatory Research (RES), some unexpected results were obtained when equipment that included components made of aluminum were subjected to HEAF conditions:

- One test included a thin wall switchgear unit (supplied from Finland, "Finnish cabinet") utilizing aluminum bus bars that caused substantially more damage to the switchgear enclosure with the video recording of the event indicating that the zone of influence (ZOI) of the HEAF event may be larger than the current requirements for HEAF analysis in guidance currently in use in NUREG/CR-6850.
- Another test included a section of bus duct removed from the decommissioned Zion nuclear plant ("Zion bus") that utilized copper bus bars inside an aluminum bus duct enclosure. The HEAF test was set up with the bus duct section blanked off with a fire retardant wooden board that did not withstand the explosive discharge of energy/gases, resulting in a large discharge (jet) of arcing energy and products substantially beyond the expected ZOI in the current analysis method (~ 30 feet).

Also, HEAF testing and at least one operational event (HEAF at H. B. Robinson on March 28, 2010) have also identified the possibility that the current methodology for determining HEAF ZOI may be non-conservative for conditions other than the presence of aluminum. The following discussion regarding possible risk impacts of increased ZOI also apply to those situations as well.

Based on the physical damage to the test specimens observed and the video recordings of the tests, it appears that the presence of aluminum in either the bus bars (inside the Finnish cabinet) or the bus duct housing (Zion bus), may cause a more energetic plasma development that under some circumstances may cause a larger amount of cabinet damage and/or the transport of gaseous high energy particles\plasma farther than previously assumed. This may cause HEAF scenarios performed using the current NUREG/CR-6850 methods to be non-conservative, thereby underestimating the HEAF risk.

The current methodology to perform Fire probabilistic risk assessment (PRA) provided in NUREG/CR-6850 requires analysts to address HEAF events. All plants that have either already transitioned or are in the process of transitioning to NFPA 805 utilize this current methodology. HEAF events at many NFPA 805 plants are included in some of the high risk scenarios documented in the NFPA 805 license amendment report, Attachment W. The HEAF scenarios form a part of the engineering analyses performed to demonstrate, using the Fire Risk Evaluation performance-based approach, that variances from the deterministic requirements (VFDRs) of NFPA 805 are acceptable from a risk, defense-in-depth and safety margin standpoint. The analyses performed to evaluate the "delta-risk" of these variances evaluated HEAF scenarios and determined, based on the ZOI recommended by the guidance, that the increase in risk from not protecting the equipment/cables was acceptable. If the ZOI with the presence of aluminum needs to be significantly larger, subsequent evaluation may indicate that additional modifications may be required to maintain an acceptable risk profile.

Over half the nuclear fleet (those plants that did not adopt NFPA 805) is licensed using very conservative deterministic assumptions that assume that any fire in the plant damages all equipment within a fire area. Sufficient equipment and capability has been provided to meet all required functions using equipment outside the fire area. The increased ZOI due to aluminum would not impact their analyses.

For those plants that have transitioned to a performance-based fire protection program under 10 CFR 50.48(c) and NFPA 805, any non-conservatisms discovered as a result of this HEAF issue would mean that the current baseline risk model at plants that have aluminum components may underestimate the risk. Any performance-based analyses performed using that baseline model that involved HEAF scenarios involving aluminum components may also underestimate the risk.

This issue is limited in scope to SSCs (switchgear, bus ducts and other high-current carrying electrical equipment and associated "targets") that have been analyzed for HEAFs in risk-informed/performance-based (RI/PB) fire protection programs using the currently accepted methods presented in NUREG/CR-6850 and NFPA 805 Frequently Asked Question (FAQ) 07-0035.

The potential impacts to these SSCs is that the risk analysis and any VFDR delta risk evaluations performed during the transition to the RI/PB fire protection programs may be non-conservative, thereby underestimating the risk of HEAFs.

The regulation that may be challenged by this issue is 10 CFR 50.48(c) and NFPA 805.

<u>Define Decision Options</u>

The key boundary conditions for the assessment of aluminum HEAF risk are as follows:

- The presence of aluminum in electrical distribution equipment may result in more equipment/cables being damaged as a result of a HEAF than currently assumed in performance-based fire protection analyses.

- The presence of aluminum in electrical distribution equipment has no impact on the performance of that equipment while performing its design function, since nothing related to the use of aluminum components causes the component or any part of the component to become inoperable or incapable of performing its design function in the event of any design basis accident or natural phenomenon (this is not an Equipment Qualification, Seismic Qualification, or Quality Control and/or Quality Assurance issue).
- The issue has been identified as a result of research performed to better understand the HEAF phenomenon. The NRC staff is not aware of any operational event involving aluminum that would lead analysts to conclude that the current HEAF model is non-conservative.
- The analysis tools and techniques applicable to the issue are NUREG/CR-6850 Appendix M, "Appendix for Chapter 11, High Energy Arcing Faults" and NFPA 805 Frequently Asked Question 07-0035, "Bus Duct Counting Guidance for High Energy Arcing Faults."

Prior to defining options for evaluating this issue, it makes sense to document exactly what we know about this phenomenon and how it may relate to the existing analysis guidance.

- One HEAF test involved a switchgear cabinet from Finland that utilized aluminum bus bar sections inside a thin metal (steel) cabinet. The test was videotaped from several different angles (some fairly close ~ 10 – 15 feet, some farther away ~ 30+ feet), allowing analysts to visually see the HEAF event to get a better idea of the ZOI. The test resulted in failure of the several of walls of the cabinet such that the plasma created by the arcing fault moved out of the cabinet a significant distance. Temperature sensors located approximately 3' away horizontally were permanently damaged by the hot gas mixture. The video taken further away shows the vapor/plasma cloud migrating well beyond the current analytical limit of 3' horizontal, 5' vertical distance for the ZOI.

  However, since the temperature detectors, located ~3' away from the cabinet, were damaged and without any other temperature and/or heat flux instrumentation, we don't know the extent of the conditions within the "video-indicated" ZOI. Since this test involved a thin walled cabinet, we also don't know if the aluminum-influenced plasma/hot gas mixture would have breached the walls of a more robust cabinet.

  Also, switchgear vertical sections are typically grouped together (vertical sections placed closely together) to form a multi-compartmented long cabinet. If the tested cabinet had been one of the vertical sections other than the ends, it is possible that the observed transport of hot gases/plasma would not have progressed as seen in the test video. The gases/plasma may have breached the wall between two vertical sections, and allowed the mixture to move into the next cabinet. Based on the video, it appears that the hot gases/plasma breached the top of the cabinet, but it was not clear whether the current guidance distance of 5' vertical was exceeded.

- Another HEAF test involved a bus duct section from the Zion nuclear plant, currently undergoing decommissioning. The bus duct section included copper bus bars enclosed within an aluminum bus duct housing. The bus duct section was placed on some blocks on the floor of the test enclosure, and where the bus duct would have normally been connected to other bus duct sections, the end was covered with a chemically treated plywood board. Immediately upon energizing the HEAF, the hot gas mixture forced the plywood board away, allowing the arc and associated hot gas/plasma mixture to "jet" out of the bus duct, blowing hot gas/molten metal linearly where the bus duct connection would have been. The hot gases/plasma shot out approximately 30' away.

However, we do not know how the HEAF would have behaved had the tested bus duct section been connected to the bus duct in the plant. While the observed hot gas/plasma jet may have blown down the bus duct enclosure, we do not know if the presence of the aluminum housing would have influenced the behavior of the HEAF or not. If the tested bus duct was connected to the bus duct in the plant, it may have behaved similar to other events that have occurred in bus ducts such as the event at the Columbia Generating Plant in 2009 or the Diablo Canyon plant in 2000. Because the tested configuration did not replicate the conditions at the plant, it is inconclusive if the ZOI for the HEAF event needs to be changed or not.

- In both tests involving aluminum, a major impact from the HEAF was a significant layer of aluminum combustion byproducts that plated out on all surfaces within the test enclosure, including electrical equipment. This aluminum combustion byproduct, possibly aluminum oxide, layer was sufficient to cause problems with the test facility and required a major cleanup activity to correct.

Although the testing has shown that the presence of aluminum may impact the ZOI for HEAF events, there are several considerations that would tend to indicate that this may not be as risk significant as would otherwise be the case:

- Fire protection programs at nuclear power plants utilize the concept of defense-in-depth to assure that there are multiple barriers to assuring the ability to safely shut down a nuclear plant during and following a fire. Each fire protection program utilizes three main elements to address fire risk:
    (1) Preventing fires from starting - *The presence of aluminum <u>does not</u> change the first echelon of defense. HEAF events will continue to occur at the same frequency.*
    (2) Rapidly detecting fires and controlling and extinguishing promptly those fires that do occur - *The presence of aluminum <u>may</u> impact the second echelon of defense since any aluminum present could act as a fuel and become a source for a higher heat release rate and result in a very difficult fire to put out. However, the continued burning of aluminum components is not expected to substantially increase the damage footprint from that already assumed in the existing methodology. The remaining secondary fire (those non-aluminum components and secondary fuels ignited by the HEAF such as cable trays) will react the same and respond to fire-fighting efforts in the same way as non-aluminum HEAFs.*
    (3) Providing an adequate level of fire protection for structures, systems and components so that a fire that is not promptly extinguished will not prevent

essential plant safety functions from being performed - *The presence of aluminum* <u>*may*</u> *impact the third echelon of defense since a performance-based analytical process is used to demonstrate acceptable risk for those fires that do occur.*

- While we do not know how prevalent aluminum components are in electrical distribution systems used in US nuclear power plants, the staff believes that percentage to be low. The majority of components in use utilize copper conductors/bus bars.
- Based on the observations of the two tests that had aluminum present, an additional factor that may have had a significant impact on the ZOI was that the metal cabinet walls in the Finnish cabinet were very thin sheet metal on an outside wall of the switchgear unit. In the configuration used in most plants, multiple cabinets would be arranged next to each other to form a long cabinet (each breaker unit would be a vertical unit with multiple vertical units placed one next to the other to form a long switchgear unit) and in some cases two rows of cabinets are installed back to back (some Motor Control Centers or MCCs are installed with a front section and a back section). In these configurations, much of the additional ZOI observed in the testing would be into the next vertical unit, which would already be assumed damaged in the existing guidance (other equipment three feet horizontally on either side is assumed damaged in the HEAF). In addition, many of the higher voltage switchgear equipment (4 kV, 7 kV) utilize much heavier steel enclosures.
- The aluminum tests resulted in deposition of aluminum combustion byproducts throughout the test enclosure which would require risk analysts to assume the failure of electrical equipment in the fire area. Existing methods require licensees to consider the impact of soot and smoke products on equipment in the affected fire area, which would also result in the assumption that other equipment in the area could be failed. Other operational events have indicated that additional electrical failures can occur as a result of soot buildup on electrical equipment (Fort Calhoun breaker fire on 6/7/11). Licensees are required to consider the impacts of smoke and soot on the performance of equipment credited to meet the nuclear safety performance criteria.
- Over half the nuclear fleet (those plants that did not adopt NFPA 805) is licensed using very conservative deterministic assumptions that assume that any fire in the plant damages all equipment within a fire area. Sufficient equipment and capability has been provided to meet all required functions using equipment outside the fire area. The increased ZOI due to aluminum would not impact their analyses.
- Of the remaining plants (those that have or are in the process of transitioning to a RI/PB fire protection program in accordance with 10 CFR 50.48(c) and NFPA 805) a significant number of fire areas utilize a deterministic solution using the same very conservative assumptions (whole burnout of the fire area). The increased ZOI due to aluminum would not impact the ability to meet safety goals in these fire areas.
- Although aluminum may result in a larger ZOI, that larger ZOI may not result in substantially higher risk. In many cases, the current ZOI results in a large damage footprint, resulting in the complete loss of one division of equipment (all the equipment powered from the same electrical division). The addition of several feet to the ZOI would

not result in any increase in risk if all the important cables had already been damaged. Since many of these scenarios involve secondary fires in cable trays above medium voltage switchgear, many high risk cables would already have been captured by the existing risk analysis. Thus, the incremental increase in risk due to this issue would be small.

- Plants have contingency plans for loss of large areas due to fire and explosions.

Based on the preceding discussion, the NRC staff does not believe that the potential increased ZOI due to the presence of aluminum in low and medium voltage electrical equipment is an immediate safety concern for plants with a RI/PB fire protection program.

Even though the testing has identified a potential concern with regard to the presence of aluminum, there is insufficient information for the staff to require regulatory action at this time.

To address this issue, the staff recommends that the following actions be taken:

1. Communications – The unexpected test results should be communicated to the industry and other stakeholders in order to inform them that aluminum components in electrical distribution equipment may make a difference in HEAF scenarios.

2. Information Gathering – A major unknown at this time is the prevalence of aluminum components in electrical distribution equipment. The NRC staff recommends reaching out to the industry to obtain this information so it may be used in future decision making.

3. Guidance Development – Although the NRC staff does not believe that this issue rises to the level of an immediate safety concern, there is the potential that current HEAF models are non-conservative. A prudent action would be to revise the guidance to address the larger ZOI seen during the testing in a two-step process:
    a. <u>Short Term</u> – One option is to use a joint industry/NRC Expert Elicitation process, make informed judgments of the need for increased HEAF ZOI and develop interim guidance to be used in RI/PB fire protection programs until further testing and/or analyses provide a technically justifiable long term solution.
    b. <u>Long Term (may change based on choice of short term actions)</u> -
        i. To address knowns and unknowns, perform/assemble a Phenomenon Identification and Ranking Table (PIRT) team to review the existing operational event and research test results to determine what we currently know, what we don't know and identify the need for and specific type of testing to be performed.
        ii. Based on the results of the PIRT, perform additional focused HEAF testing specifically designed to quantify the ZOI applicable when aluminum components are present.
        iii. Form a team of experts to develop revised guidance (using either a Working Group as was done for cabinet heat release rates or using an Expert Elicitation as was done for the hot short probabilities) using the new HEAF testing on aluminum components.

4. Licensee resolution – NFPA 805 licensees are required to utilize methods acceptable to the NRC staff when developing their Fire PRAs. NFPA 805 licensees are also required to maintain the Fire PRA consistent with the As-Built, As-Operated and Maintained plant, and incorporate operating experience. NFPA 805 requires the licensees to maintain configuration management of the supporting Fire PRA analyses through a maintenance/update/upgrade process. Once an accepted method has been developed and communicated to licensees, they must evaluate the impact of that method on their analyses and incorporate the method if it would make a material impact.

5. Long Term performance-monitoring – Long term maintenance of the Fire PRA is subject to inspection during the various fire protection inspections. Licensees are also required to inform the NRC staff of the status of their risk analyses as part of any risk-informed licensing submittal (Risk-Informed Tech Specs, 50.69, Risk-Informed Appendix J, etc.).