BACKGROUND

IDENTIFICATION OF POSSIBLE NONCONSERVATIVE MODELING AND FIRE HAZARD ANALYSIS ASSUMPTIONS WHEN ELECTRICAL EQUIPMENT CONTAINING ALUMINUM COMPONENTS ARE SUBJECTED TO HEAF CONDITIONS

High Energy Arc Faults (HEAF) events are defined as energetic or explosive electrical equipment faults characterized by a rapid release of energy in the form of heat, light, vaporized metal and pressure increase due to high current arcs between energized electrical conductors or between energized electrical components and neutral or ground. HEAF events may also result in projectiles being ejected from the electrical component or cabinet of origin and result in fire. The energetic fault scenario consists of two distinct phases. First phase: short, rapid release of electrical energy which may result in projectiles (from damaged electrical components or housing) and/or fire(s) involving the electrical device itself, as well as any external exposed combustibles, such as overhead exposed cable trays or nearby panels, that may be ignited during the energetic phase. Second phase (the ensuing fire(s)): is treated similarly to other postulated fires as specified in NUREG/CR-6850, EPRI 1011989.

Recent international HEAF testing was performed by the Office of Nuclear Regulatory Research (RES) in collaboration with other countries under a Nuclear Energy Agency (NEA) program and the National institute of Standards and Technology (NIST) to confirm the zone of influence (ZOI) for HEAF's that was specified in NUREG/CR-6850, EPRI 1011989. A total of 26 tests were performed, most electrical equipment with copper components, which exhibited similar damage states to those postulated in the current guidance. However, some unexpected results were obtained when equipment that included components made of aluminum were tested:

- One test included a low voltage (480 V) thin wall switchgear cabinet unit utilizing aluminum bus bars that caused substantially more damage to the switchgear enclosure than in similar tests utilizing copper bus bars. The video recording of the event indicated that the ZOI of the HEAF event is much larger than the current guidance postulates for damage in Appendix M "High Energy Arc Faults" of NUREG/CR-6850, EPRI 1011989. In addition to the larger ZOI, portions of the laboratory test cell were coated in a conductive aluminum combustion byproducts. This coating caused damage to the facility and shorted out electrical equipment due to "plating" effects[1].
- Another test included a section of bus duct removed from the decommissioned Zion nuclear plant that utilized medium voltage (4.16 kV) non-segregated copper bus bars inside an aluminum bus duct enclosure. The HEAF test was set up with the bus duct section closed off with a piece of insulating material referred to as "red board." During the arc, the red board was not able to withstand the explosive discharge of energy/gases, resulting in a large discharge (jet) of arcing energy and products (~ 30 feet), substantially beyond the expected ZOI in the current analysis method. Coating of the laboratory test cell by aluminum combustion byproducts was also observed during this test.

Based on the observed physical damage to the test specimens and the video recordings of the tests, it appears that the presence of aluminum in either the bus bars or the bus duct housing,

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1 The plating effects appear to be conductive aluminum particles from the HEAF event that cause short circuits in exposed electrical equipment.

can cause a more energetic plasma arc and subsequent metal fire. Under some circumstances this may cause a larger amount of cabinet damage and/or cause the transport of gaseous high energy particles/plasma farther than previously assumed.

For those nuclear power plants that have transitioned to a performance-based fire protection program under 10 CFR 50.48(c) and National Fire Protection Association (NFPA) standard 805, HEAF events constitute some of the high risk scenarios. The recent international tests suggest that HEAF scenarios involving aluminum components may have a zone of influence that is not bounded by the current guidance in NUREG/CR-6850 EPRI 1011989 “EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Volume 2: Detailed Methodology”, thereby underestimating the risk from HEAF events. Additionally, mitigation techniques have been used as part of the transition to NFPA 805 including “HEAF shields[2]” which theoretically enable a NPP to mitigate damage conditions and reduce the risk of a particular scenario. “HEAF shields” currently in use are based solely on engineering judgment and have no design basis, no qualification tests, no test standards, no acceptance criteria and minimal regulatory footprint. Subsequent evaluation may be needed to evaluate these HEAF scenarios in order to maintain an acceptable risk profile. 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 would underestimate the risk.

For Non NFPA 805 Licensees, 10 CFR Appendix A, General Design Criteria (GDC) 3, Fire Protection requires “Fire protection. Structures, systems and components (SSCs) important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions.” It is believed that fire hazard analysis (FHA) performed to satisfy this requirement may not have considered HEAFs as “explosions” or considered the coating phenomena witnessed in testing as a failure mode. Therefore certain engineering assumptions (e.g. separation criteria, fire growth and spread, fire protection features and systems, etc.…). used to evaluate the requirements and/or exemptions granted to 10 CFR 50.58(a) Appendix R III G in accordance with Title 10, Section 50.12, of the Code of Federal Regulations (10 CFR 50.12), "Specific Exemptions" may need to be re-examined for potential safety impacts based on new information from the international testing.

CURRENT CONDITIONS

- The staff does not know how prevalent the use of aluminum is in electrical distribution systems 480 volt and above installed in US NPPs, there may be significant amounts used, however it is believed the majority of components use copper conductors/bus bars. (Excluded from scope of generic issue)
- Based on anecdotal information from knowledgeable staff, aluminum has been identified as a bus duct enclosure material or within electrical switchgear equipment 480 V and above within several NPPs including but not limited to; Arkansas Nuclear One, Browns Ferry, Catawba, Columbia, Diablo Canyon, Fort Calhoun, Hope Creek , Hatch, Kewanee Sheron Harris, VC Summer.
- The Office of Nuclear Regulatory Research (RES) has performed a preliminary risk analysis to investigate the effect of increasing the ZOI of HEAF events and determined

2 HEAF shields are some form of physical barrier that prevents damage to secondary targets from HEAF events

that the impact could be significant depending on various plant to plant configuration issues.

POSSIBLE OUTCOMES

- 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.

- Information Gathering – A major unknown at this time is the prevalence of aluminum components in electrical distribution equipment, their location in the NPP and their relationship to Structures, Systems, and Components (SSCs) important to safety. The NRC staff needs to reach out to the industry to obtain this information so it may be used in future decision making.

- Licensee resolution –
    - Appendix R- Based on the new information from this test program, exemptions from the fire protection rule, in accordance with the requirements of Title 10, Section 50.12, of the Code of Federal Regulations (10 CFR 50.12), "Specific Exemptions” should be re-examined for potential safety impacts.
    - Based on the new information from this test program assumptions and the engineering judgement used to accept “HEAF shields” need to be re-examined for potential safety impacts. If HEAF shields are going to be used in NPPs, licenses should develop a design basis, test method, acceptance criteria and other minimum quality assurance requirements for regulatory acceptance and assurance they will protect adjacent equipment.
- Guidance Development –There is the potential that current HEAF models are non-conservative particularly in estimating a ZOI. A prudent action would be to revise the guidance to address the larger ZOI seen during the testing and evaluate the impact of this increase for licensees.