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CONSIDERATIONS FOR IMPROVING FIRE PRA TREATMENT OF HIGH-ENERGY ARCING FAULTS[1]

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ABSTRACT

The United States and the international community have experienced fire events because of high-energy arcing faults from electrical equipment in nuclear power plants [1, 2]. These events tend to produce damage rapidly in the immediate vicinity of the electrical fault and can produce secondary fires and challenge the effectiveness of fire suppression activities. The Office of Nuclear Regulatory Research (RES) of the NRC and the Electric Power Research Institute (EPRI) have developed a first-of-a-kind approach to evaluate the risk significance of fires and damage from high-energy arcing faults occurring in electrical cabinets subject to this phenomenon [2]. This approach was rule-based and developed from empirical information gleaned from available fire reports and the limited knowledge of the phenomenon itself.

RES has embarked on a more comprehensive literature review beyond that done for its work with EPRI to identify information that could potentially lead to improvements in this rule-based approach. This paper will discuss the new information identified for this type of event, and the implications for an improved approach to evaluate the risk significance of high-energy arcing faults. This paper specifically examines high-energy arcing faults from cabinets, although these faults have also occurred in transformers or bus ducts. Potential areas for improving the approach to evaluating high-energy arcing faults in electrical cabinets beyond those gleaned from the literature search will be identified. This paper will also identify the specific benefits of performing a more realistic assessment.

1 EXAMPLE OF A HIGH-ENERGY ARCING FAULT EVENT

On February 3, 2001, while operators at the San Onofre Nuclear Generating Station (SONGS) were in the process of transferring nonsafety buses from startup to auxiliary transformers, an arcing fault occurred in a 4160-volt (V) circuit breaker between the nonsafety-related bus and the auxiliary transformer. Ionized gases from vaporized, conductive material

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propagated to a nearby circuit breaker cubicle, producing a secondary arcing fault and fire. Firefighters arrived at the switchgear room and observed that the room was completely filled with heavy smoke, with essentially no visibility. They discharged portable Halon and dry chemical fire extinguishers through vents in the cabinet, and later it was reported to the control room that no flames were visible (i.e., the fire was out). Approximately 1 hour later, the cabinet door to the switchgear was opened, and firefighters saw flames inside. Once again, they applied portable extinguishers. Although an earlier request by the fire brigade to apply water was denied since the 125-V direct current was energized on the cabinets, permission was granted to apply a hose stream about 20 minutes after the switchgear cabinet was opened. As a result, the fire was extinguished. Overall, the fire lasted approximately 3 hours [3–5].

Examination of the aftermath of the arc fault revealed that the cabinet door was physically blown off of the switchgear cabinet. The internal cabinet and its material were charred substantially. Those cables in the tray immediately above the cabinet were destroyed by the explosion/high-intensity fire resulting from the arcing fault. Damage continued to cables in the two higher trays above the cabinet. Instrument gauges were also charred on the front of a cabinet across the aisle from the cabinet experiencing the arcing fault.

The SONGS event is not unique. High-energy arcing fault (HEAF) events have occurred at several nuclear power plants in the United States as well as abroad. The conditional core damage probabilities of HEAF events (given that the fire has occurred) have ranged from a high value of $2x10^{-3}$ for the 2001 Maanshan event in Taiwan that produced a 2-hour station blackout, to a value below $1x10^{-6}$ for the SONGS event which occurred in the process of transferring nonsafety buses from the station transformer to the auxiliary transformer [1]. In certain cases in the United States and abroad, these energetic events have melted and vaporized electrical equipment designed to interrupt faults of 250 to 1000 megavoltamperes [1]. The fire and its damage have extended beyond the cabinet in which the arc originated as a result of ionized gases propagating to neighboring switchgear and uncontained blasts [1]. Furthermore, suppression has been complicated, relying on water after failed attempts with extinguishers.

Arcing events are not limited to the nuclear industry. Large residential complexes have reported fire incidents associated with HEAF in switchgear, resulting in the loss of electrical services for some 10,000 residents for several days [6]. Other arc events involving power cables and electrical equipment have been documented throughout the telecommunications industry. Incidents such as the 1975 fire at the New York City telephone exchange and the Hinsdale, Illinois, telephone central office fire in 1988 dramatically illustrate the need for automatic and manual firefighting procedures [7]. The fire at the New York City telephone exchange ultimately resulted in the replacement of 66 miles of cables, the manual cleaning of over 10 million electromechanical relays, and the replacement of spalled concrete. The incident at Hinsdale resulted in a property fire loss of $40–$60 million over the 30-by-40-foot fire area [7]. Another HEAF incident involving cables running from a 480-V main bus was reported at Watts Bar Hydroelectric Plant in 2002. The cables, which were severed as a result of the arcing and ensuing fire, caused “a loss of communications, fire annunciation systems, and most importantly, power transmission” [8]. These incidents clearly indicate that other industries besides nuclear have an interest in addressing the HEAF phenomenon and understanding the associated risk.

2 EMPIRICALLY BASED MODEL IN NUREG/CR-6850

The Office of Nuclear Regulatory Research/Electric Power Research Institute (RES/EPRI) model used to address HEAFs in NUREG/CR-6850 [2] is divided into two distinct phases. The initial phase consists of a rapid release of electrical energy from the arcing fault and produces immediate damage close to the fault. The second phase consists of the ensuing, rapidly developing fire and has the characteristics of a rapidly developing fire. Because of the rapid release of energy and consequential damage in the initial phase, suppression activities are not assumed to prevent damage proximate to the source. With respect to the ensuing fire in the secondary phase, suppression is credited consistent with the treatment for the ensuing fire.

The proximity within which immediate damage occurs from an electrical arc within a cabinet is defined as the initial zone of influence. The initial zone of influence for an arcing fault within a cabinet is applied in the following manner:

- The cabinet or cabinet section in which the fault occurs will be blown open by the initial energy release.
- The next adjoining switchgear or load center cubicles will be assumed to trip open.
- Unprotected cables that enter into the top of a panel in an open-air configuration will ignite.
- Unprotected cables in the first overhead cable tray will be ignited concurrent with the initial arcing fault provided that this first tray is within 5 vertical feet of the top of the cabinet.
- Vulnerable components or movable/operable structural elements located within 3 feet horizontally of either the front or rear panels/doors, and at or below the top of the faulting cabinet section will suffer physical damage and functional failure.
- Exposed cables, or other exposed flammable or combustible materials or transient fuel materials located within the same region (3 feet horizontally), will be ignited.

In practice, not all HEAF events display comparable damage. This is accounted for in the NUREG/CR-6850 model via the fire frequency which captures only those actual fire events that displayed the potential to cause significant damage outside the cabinet in which the arc occurred.

3 INSIGHTS FROM HIGH-ENERGY ARCING FAULT LITERATURE REVIEW

The current literature focuses on the conditions under which an arcing fault can occur and the mechanism and phenomenology it exhibits. Some recent work has also focused on worker safety (e.g., the effectiveness of personal protective equipment). Except for studies that have investigated the potential for the ignition of worker clothing, no experimental studies identified in the literature search evaluated the effects of the HEAF beyond the cabinet of origin, including effects on nearby combustibles. Most of the research is driven by concerns about personnel safety, protection of property, and ensuring continuity of operation.

A majority of the initial HEAF experiments during the early 1900s were basic and typically executed on lower voltage equipment (less than 600 V) [9]. Electrical manufacturing companies conducted many of these types of tests in order to improve the reliability of their equipment (i.e., switchgear and transformers). Primitive data acquisition tools, poorly described experimental procedures, and a lack of detailed assumptions limit the usefulness of this early research.

Research steadily increased as more HEAF events in low-voltage systems were reported throughout the power industry. Kaufmann and Page [10] described incidents involving alternating current electrical equipment and explained that serious injuries and large losses may occur, despite low failure rates for these devices. Kaufmann concluded that it was better to overprotect a system and suffer occasional nuisance tripping rather than risk total burnout. Other researchers, such as Shields [11] and Dunki-Jacobs [12], reviewed arcing faults on low-voltage systems and offered insights into preventing these occurrences. Shields provided interesting accounts of severe damage to electrical components resulting from high-energy discharges, which were then referred to as "burndown." These authors suggested that standardized maintenance, improving equipment designs by compartmentalization, and the use of ground-sensor relaying or ground fault protection would reduce catastrophic arcing events. Other reviews of HEAF events have recommended periodic inspections and tests for degraded electrical insulation, dirt, moisture, and sluggish circuit breakers to prevent HEAFs [1].

In the late 1970s, Stanback [13] performed laboratory experiments on 277/480-V single and multiple phase systems to develop a crude means to estimate the burning damage associated with an arc to ground. The distance from the busbars to ground varied from 1 to 4 inches, while the current ranged from 3,000 to 26,000 amperes. The busbars were made of copper or aluminum, and the housing unit was constructed of steel. Based on his observations, a stable arc was difficult to establish with increased spacing between the busbar and enclosure, with an increase in available current, and with an increase in the number of busbars. Since an estimation of burning damage was Stanback's focus, he did not thoroughly explain the reasons for these results. The experiments illustrated the random nature of arcing faults. Other researchers calculated that arcs having less than 38 percent of the available bolted fault current will self-extinguish, though Stanback's experiments showed that there was no consistency to this theory. Stanback's experiments showed that many arcs did indeed extinguish with less than the 38 percent but also that arcs may not necessarily be self-sustaining with greater available bolted fault currents.

Stanback hypothesized "a formula for the approximate prediction of maximum probable burning damage," given in units of cubic inches, relating the extent of damage to the arc duration and current as follows:

$$Y = A I_{arc}^{1.5} t \qquad (1)$$

For Equation 1, the burning damage was represented by Y, a material constant was given as A, and the arc current and arc duration were given as I_{arc} and t, respectively. One purpose of this equation is to estimate the burn damage of a particular busbar or housing material. Also, looking at comparisons between equipment materials, expected current, and the potential burn damage makes it possible to evaluate costs based on specific design considerations to mitigate arc occurrences and possible damages of an arc. Stanback stressed that this equation was only verified for 277/480-V systems and should not be applied to other voltages.

Other significant pieces of work addressed the safety concerns related to electrical hazards. Lee [14] provided a comprehensive study of the effects of HEAF on workers. He presented the nature of this phenomenon which included the voltage reaction through an electrical system during an incident. Though Lee provided estimated safety distances, he warned that higher voltages could potentially lead to longer arcs. To address the intense radiative heat produced during an HEAF event, he developed tables relating temperature to the effects on human skin to show the effects of tissue tolerance. These tables showed that fatal burns and major burns may occur at distances of 5 and 10 feet, respectively. Lee's research provided valuable insights into the hazards and consequences of arc exposure. Many of the correlations used in his work ultimately provided the framework for various electrical safety standards, such as Institute of Electrical and Electronic Engineers (IEEE) 1584 [15] and National Fire Protection Association (NFPA) 70E [16], which were developed to provide guidelines for installing, maintaining, and servicing high-powered equipment. Other considerations, such as clothing and flame retardant materials, were also being developed and prescribed to protect personnel working on energized equipment.

In terms of worker safety, Jones et al. [17] performed 38 tests at the Paul Gubany High Power Laboratory in Ellisville, Missouri, to simulate realistic conditions leading to an arc fault. For example, two mannequin workers were dressed in ordinary cotton clothing and outfitted with safety glasses, hard hats, and leather gloves. One was positioned 2 feet away at the chest, with arms extended to the equipment. The equipment doors were left open for several tests to simulate work or troubleshooting. Fault initiation was intended to simulate tools (e.g., wrench or screwdriver) unintentionally contacting the equipment.

These tests by Jones et al. which simulated realistic conditions supported Dunki-Jacobs' [12] prediction that the arc would travel away from the source. Even tests that attempted to force the arc toward the source resulted in the same outcome. Theoretically, the arc always travels away from the source because of the electromagnetic forces created by the high current flows. This is important for workers who may be positioned by the equipment during an arc event. Investigating the damage after the tests, the site of the arc initiation was witnessed to be minimal compared to the region of damage where the arc stabilized. The energy at the point where the arc stabilizes may actually lead investigators to conclude that the short circuit started at the end of the travel path rather than its true initiation site. The arc escalation in some of these tests created upstream secondary faults. For one of the tests, the report states, "the magnetic forces created by the flowing currents moved the wires upstream of the initial fault with enough force to damage insulation or tear conductors from their terminations creating additional short circuits." The authors conclude that more research and testing are required to determine the voltage level, insulation type, and construction where bus insulation may help extinguish or sustain an arc once established.

Additionally, the results from the Jones et al. [17] experiments confirm that single-phase faults are much more difficult to sustain than three-phase faults. Single-phase arcing faults produce very little or no ionized arc plasma which is required to maintain the arc current. In contrast, three-phase arcing faults produce a constant source of arc plasma that has a great possibility of maintaining the HEAF. Results from the experiments also show that solid-state protective overload relays could reduce arc fault energy and the damage associated with the fault and were significantly less expensive than a 480-V high-resistance grounded system. Identical experiments were performed on motor control centers (MCCs) with and without current-limiting devices. Significantly less damage (i.e., the doors maintained integrity and there was only minimum pitting on the busbars) occurred when these devices were installed. When they were removed, a violent arc destroyed the MCC. The comparable tests show that current-limiting fuses play a significant role in arc suppression.

Gammon and Matthews [18] describe arc faults relative to short circuits as "the magnitude of the current is limited by the resistance of the arc and may also be limited by the impedance of a ground path. This lower level fault current is often insufficient to immediately trip overcurrent devices, resulting in the escalation of the arcing fault, increased system damage, tremendous release of energy, and threat to human life." To improve understanding of the problem, researchers began devising more applicable and elaborate experiments with improved data acquisition equipment. It was again noted that the arcs occurring on three-phase systems were easier to sustain than on single-phase systems because of the higher magnetic forces. As a result of these conclusions about three-phase systems, more complex experiments were conducted. Issues such as metal vaporization of electrodes and compartment walls, pressure wave formation, thermal and mechanical stresses on the equipment, design of compartments and interior materials, and devices to suppress arcs and limit current were investigated.

One particularly interesting study focused on the effect of dielectric mediums and the electrode material on compliance standards for gas-filled switching equipment. To comply with specific standards, manufacturers had to show that specific equipment could withstand mechanical stresses after an arc event. It was noted that sulfur hexafluoride (SF_6) and air, two acceptable gases used for compliance, showed dramatic differences in pressure characteristics that arise during a fault [19]. For the switchgear containing SF_6, maximum pressure rise was reached at 100 milliseconds (ms) when using either the copper or iron electrodes. When switching to air, the maximum pressure rise was recorded at 50 ms. This paper confirmed the statement in the International Electrotechnical Commission (IEC) standard [20] that there will be a different pressure rise if the arc fault tests are completed with air rather than SF_6. The authors explained that when an arc fault occurs, shock waves will develop and spread out from the arc core. The pressure waves spread out in the volume of the medium with the speed of sound plus the velocity of flow within it. Since (1) the velocity of the flow can be higher in air than in SF_6, (2) the size of the pressure wave is dependent on the energy behind the pressure wave, and (3) the density of the SF_6 is almost 5 times greater than the density of air, the velocity of flow must be almost 3 times greater in air than in SF_6 (if the static pressure which the transducers measure is 50 percent higher). It is through benchmark studies of this nature that understanding and advancement in HEAF research may take place.

Computers have recently been used to analyze electrical systems. Some programs have been developed to look at current increases and the potential for an arcing event. The major goal of this particular research is to identify conditions leading up to a high-energy release and then attempt to prevent the event from occurring. Finite element analysis tools have been used to look at the mechanical stresses in switchgear and transformers [21], which has led to development of vacuum interrupters that have produced better interruption capabilities, improved reliability and operational life, and a decrease in product cost. Computational fluid dynamics (CFD) has also been used to measure the pressure and temperature increase within switchgear rooms [22]. The CFD model allowed for exact representation of specific room and equipment configurations and considered the ionization and gas dissociation in the event of a fault. The simulation seemed to have pressure increases which were comparable to their experiments, but the limitations of the models as well as the experiments were not discussed in any significant detail. The gas properties (i.e., the ionization and dissociation) were not directly compared to experimental values. This CFD model presents reasonable pressure results on an arc event; however, fires were not evaluated.

From the perspective of suppression, Halon fixed fire suppression systems have been used in industrial settings to respond to electrical fires. Since these systems have been largely phased out because of environmental concerns, limited research has been performed on alternatives such as water mist. Mawhinney [23] analyzed the effectiveness of these systems for switchgear applications. From the experiments, he was able to show that water mist systems outside of equipment did not greatly impact the fire event and ultimately caused water damage. It was shown that water mist systems would operate best if the nozzles were directly over the housing of the faulting components. Furthermore, the literature search confirmed that in some cases fuels are limited to the initiating component, and under those circumstances, hand-held extinguishers are effective should those fires not self-extinguish.

As a result, with respect to fire probabilistic risk assessment (PRA), correlations developed to characterize the arc flash event, including those that estimate the heat flux level that would be experienced as a function of distance from the arc, could prove useful. However, it should be noted that the studies performed on the effects of these arc flashes have assessed the potential for inducing flash burns to exposed skin and igniting worker's clothing, rather than assessing the ability to ignite secondary combustibles typically encountered in a nuclear plant (e.g., cables). The study of reported incidents, such as the 1995 Waterford Generating Station fire, has shown that fire may spread to additional electrical equipment, cables, or transient materials within the vicinity of the arc event [24]. However, the current literature provides no information that can be directly translated to fire ignition frequency of HEAF events, to establishment of a more refined zone of influence for the initial stage of the HEAF, or to suppression reliability assessments.

4 POTENTIAL AREAS FOR IMPROVEMENT OF HIGH-ENERGY ARCING FAULT APPROACH

The HEAF assessment approach developed in NUREG/CR-6850 is primarily an empirical model. As such, it depicts observations, primarily based on a single event, and characterizes a damaging zone of influence from this event. Given the variation in current and voltage level, insulation type, and cabinet design, a mechanistic model is needed to capture these variations. This mechanistic model would begin with arc initiation and characterize the released energy and initial damage through empirical or phenomenological means (e.g., an explosion), accounting for additional arcing from ionized products and damage from ejected material. Additionally, the model would establish the proper initial conditions for the enduring fire. Thus, characteristics such as arc duration and heat release rates produced from enduring arcs are expected to be important factors.

To prevent or alleviate HEAF effects, manufacturers have been working to develop arc arrestors and arc detection methods and to improve composite materials in the switchgear interior. The experiments conducted by Jones et al. [17] indicated that research and testing are required to determine the voltage level, insulation type, and construction where bus insulation may help extinguish or sustain arc once established. The use of such devices would likely impact estimates of fire ignition frequency for such events, but no methods currently exist to account for the presence, or absence, of such equipment.

The existing NUREG/CR-6850 approach does not credit fixed suppression systems to prevent the initial phase of damage. However, these systems can be credited for the secondary fire. Since Halon is being phased out of various industries because of environmental concerns, people have been searching for alternative means to extinguish fires that occur in switchgear. Water has effectively extinguished fires according to HEAF event reports; however, the common practice of de-energizing the affected and nearby equipment beforehand delays the fire brigade [1]. Water can also damage other nearby electrical equipment not otherwise harmed by the HEAF event. Also, other extinguishing agents such as carbon dioxide (CO_2) may not completely remove the heat from the equipment and lead to re-ignition.

Many documented HEAF incidents do not actually escalate to a significant level and may be suppressed by hand-held extinguishers. However, fire incidents such as those at Waterford and SONGS have shown that portable extinguishers have limitations and can delay effective suppression [24]. In an attempt to suppress the fire at SONGS, portable dry chemical and Halon extinguishers were discharged repeatedly, while CO_2 extinguishers were also applied during the Waterford fire. Also in both cases, the initial request to apply water to the fire was rejected to avoid potentially energized equipment. Hose lines were finally used after all other extinguishing methods were exhausted, and the fire was quenched rapidly. Currently, the NUREG/CR-6850 approach does not distinguish between fire suppression agents, methods, and protocols that could help limit the extent of fire damage.

A comparison between CO_2, FM200 (clean agent), dry chemicals, and mist systems in extinguishing fires in energized switchgears would provide a baseline for assessing the effectiveness of suppression systems, fire containment, and reliability. It should be noted that one set of experiments [23] suggests that automatic mist suppression within a cabinet may limit the fire to the initiating cabinet; however, this conclusion is limited by the assumption that the fixed system will not be impacted by the HEAF. Other means to extinguish a fire within switchgear may experience a similar failure, but unfortunately, this was not addressed in the reviewed literature.

The HEAF model in NUREG/CR-6850 does not discuss credit for automatic fire suppression systems placed in energized equipment, in particular switchgear. There have been limited studies on such configurations. However, one issue that was not directly addressed in the literature review was the potential for system failure after an arc event occurs. Considering the massive amounts of energy and pressure produced by an HEAF, a fixed suppression system may be rendered useless. For example, an HEAF could render an installed system useless by repositioning discharge nozzles or severing the delivery system. Researching more effective measures to extinguish a fire within switchgear would prevent the need for manual intervention and thus create an improved fire response time.

Fire growth and consequential damage beyond the electrical cabinet in which the arc arises is a unique and poorly understood problem. The literature search revealed no systematic investigation of these behaviors other than anecdotal accounts of fire damage during actual events. Damage to cables and equipment by high-energy impulses from arcing faults or from the expulsion of molten metals has been shown to be different from that caused by fires alone. Analyzing the fire growth from the initiating switchgear to adjacent switchgear during prolonged arcing is another area that could be explored. Consequently, the production and effects of ionized products of combustion are not confined to the immediate vicinity of the arc. As in the discussion of the development of an arc, a mechanistic model that captures the entire fire scenario would predict variations in these effects from different types of cabinets.

With respect to the frequency model, NUREG/CR-6850 assumes that the lowest voltage to produce an HEAF is 440 V. Notably, experiments have been conducted in HEAF at 277 V in single-phase systems [13], although the single-phase faults at this voltage are difficult to sustain, as they produce little ionization. A mechanistic model could provide an additional basis for a lower limit for significant HEAF fires, in addition to event data, while at the same time recognizing the apparent differences in severity and damage potential between single-phase and three-phase systems.

Before incorporating this information into a risk model, benchmarking experiments need to be performed for many of these issues. For example, quantifying the specific phenomenological effects, such as the influence of current and voltage from an HEAF event, and the impact on the ensuing fire would further develop concepts to define the risk of an arc within specific energized equipment. A comprehensive analysis of suppression systems would provide insights into effectiveness, containment, and reliability to manage fire events. Ionized soot production may initiate additional shorts. Without a greater understanding of HEAF events and phenomena, a more realistic refinement to the approach in NUREG/CR-6850 will be difficult.

5 CONCLUSION

Significant events both within the United States and abroad have resulted from HEAFs. Damage has extended beyond the switchgear cabinet in which the initial arc occurred to cables in the overhead and neighboring switchgear cabinets. Plant operations have been complicated by station blackout conditions or loss of offsite power, although some effects have been less significant. Also, delayed suppression has likely contributed to more severe fires for some events. Reviews of events have generally shown that these incidents are independent of manufacturer.

The earliest of the HEAF-type studies identified in this literature review were found to provide poorly defined methodologies, inadequate data acquisition equipment, and poorly justified assumptions. This weakness is typical of experimental studies performed before the advent of modern testing and data acquisition techniques. Recent research, based on better experimental techniques and tools, has improved our understanding of the arc phenomenon itself. For example, these studies have contributed to the development of correlations to support the characterization of the arc fault based on voltage levels and phase separation distances. With respect to design, manufacturers have improved switchgear to incorporate internal component partitioning, different insulating mediums, and alternative housing alloys meant to contain an arc more effectively. Studies supporting these design improvement activities have shown greater functionality and fewer occurrences of HEAFs for the power distribution industry.

However, when looking at the dynamic nature of HEAF, many factors are still not well understood. These factors are important to developing a mechanistic approach, which is the next step to improving the NUREG/CR-6850 approach for HEAFs. A mechanistic approach can address important variations in cabinet design, voltage and current, and other features. Such an approach needs to characterize the initial impulse from the arc and establish the initial conditions for the enduring fire. The existing research beyond NUREG/CR-6850 is sharply limited in scope and has not adequately addressed the key factors in fire PRA. While some aspects of the existing research can be applied to the fire PRA approaches, such as correlations for arc characterization to estimate flash heat flux levels, additional research on arc modeling, including secondary arcing (e.g., as seen in the SONGS event), would greatly assist in the understanding of HEAFs and the development of a mechanistic approach. Further research should also be performed on the characteristics that produce damage beyond the cabinet, including the behavior of an enduring fire produced by the HEAF and the effectiveness and timing of fire suppression.

In conclusion, more information is needed to produce a mechanistic fire PRA model for HEAFs to assess event behavior. With the exception of those studies that have investigated actual HEAF events, the past research has focused exclusively on the initial arc fault event itself. Issues that go beyond the initial arc fault event include characterization of the potential for ignition of secondary combustibles (other than worker clothing), characterization of the fire growth and intensity following the enduring fire, and the effectiveness and timing of fire suppression efforts. Experimental studies to further investigate arc fault issues are needed.

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