U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

REVIEW / COMMENT DOCUMENTATION

Document # Rev: NRC-2017-0168 **Date:** 6/18/2018 **Title:** High Energy Arcing Faults (HEAFs) in Electrical Equipment Phase 2

Comments shall be:
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* LEGIBLE AND REPRODUCIBLE
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1	NEI	No changes	4.1/1	The HEAF event that occurred at SONGS-2/3 was the result of incomplete breaker contact parting resulting in an extended arc at the breaker contact.	The cause of the SONGS event is not discussed in the draft test plan, and no changes to the test plan were made.
2	NEI	Clarification in test plan Section 3	4.3/3	The discussion states that the KEMA source is limited to 2,200 MVA but it also states that it is insufficient to deliver the current necessary to simulate events at Robinson and Diablo Canyon. From a practical standpoint, most medium voltage switchgears have ratings of 500 MVA with some having higher ratings. The design basis calculations that are necessary to demonstrate compliance with the requirements of GDC 17 must show that maximum possible fault conditions at the buses are within their MVA ratings. The discussion in the test plan raises questions as to whether the fault conditions being imposed on the equipment, when analyzed using the same methods as would be required in design basis calculation shows that the MVA being delivered is within the equipment rating. The information presented in the test plan suggests that excessive fault conditions could be imposed. Exposing equipment to such conditions would result in a test that does not reflect the conditions in the US nuclear fleet.	The 2,250 MVA referred to the KEMA Laboratories' generator maximum available generator power, not the power delivered to the equipment. The KEMA power distribution is equipped with current and power-limiting components, allowing precise adjustment of delivered power to any level within that rating. The actual power delivered to the test equipment in each test will be documented in the test report and will not exceed the MVA rating of the equipment being tested.
2a	NEI	Addition of decrement curve for medium voltage tests will be considered for future addition to the test plan (pending information provided by EPRI)	4.3/3	The performance of a generator under faulted conditions is sometimes represented in a short circuit decrement curve. This curve shows a peak short circuit current and a decay that is a function of the machine sub-transient and transient reactance and their associated time constants. It is unclear if 2,200 MVA that is quoted in the test plan reflects the peak of this decrement curve or at some other point. An understanding of this behavior is critical to understanding and confirming the applicability of the test of actual plant conditions.	2,250 MVA is the maximum available generator power. It is a nominal rating only. KEMA Laboratories uses a process of super excitation to compensate for the decreasing rotational energy of the generator during energy delivery, thus the short circuit decrement curve is not the power delivered to the test enclosure. This technique, routinely used at KEMA, is based on superimposing an additional excitation source during testing to boost the generated DC field. This process compensates for reduction in the field by adding a supplementary source of DC power, allowing for steady output current from the generator. The energy delivered to the enclosure in phase one testing was specified by NRC staff, recorded by KEMA's measurement equipment and reported with the test results. There was no test performed at 2,250 MVA. Based on discussion from the HEAF Public Workshop held April 18-19, 2018 a decrement curve (to be provided by EPRI) will be considered for a future medium voltage test.
2b	NEI	No changes	General	Where in the test planning process is confirmation that the test conditions – MVA, current, and decay of any asymmetrically component is representative of the conditions in the US nuclear fleet.	The test conditions specified in the Phase II draft test plan come from two places: 1) U.S. operating experience, including review of plant electrical distribution equipment

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					ratings and available fault current, and 2) the needs of the international partners participating in and contributing to the HEAF test program. Based on discussion from the HEAF Public Workshop held April 18-19, 2018 a decrement curve (to be provided by EPRI) will be considered for a future medium voltage test.
3	NEI	No changes	5	The performance of a generator under faulted conditions as noted in comment 2a is dynamic. The information provided in Section 5 (40 kA at 480 V for 8s, and 25 kA at 4.160 kV for 4s) suggests that substantially higher fault conditions were imposed. More details regarding the imposed electrical conditions that are anticipated for this test are necessary. These parameters can be calculated consistent with that which would typically be done to demonstrate compliance with GDC 17. Such a calculation should demonstrate the peak asymmetrical current (typically at half cycle) is within the equipment rating as well as the peak MVA.	In general, the performance of a generator under faulted conditions is dynamic; however, the KEMA Laboratories short-circuit generator uses super excitation to compensate for rotational speed decay. In regard to the peak asymmetrical current, this is inherently enveloped by the laboratory power supply. The KEMA laboratory is also equipped with full control of point-on-wave current initiation, allowing precise control of prospective peak current.
4	NEI	No changes	4.4/multiple	The scope of test durations inherently envelopes the case where protective devices that may be available to terminate the HEAF event have failed. It is unclear whether the scope of the test and the measuring and monitoring equipment will have sufficient time resolution to address the cases where protective devices are available to terminate the event.	It is not disputed that operating experience shows the majority of arcing fault events are quickly terminated by protective devices; however such events are not the subject of this test program. This test program is designed to evaluate the impact of NUREG/CR-6850 "bin 16" events; i.e. arcing faults that are not quickly interrupted by circuit protection schemes. Arcing faults that are quickly interrupted are usually classified as "arc flashes" instead of "HEAFs," and are counted in bin 15--if they are counted as challenging events at all. Only those events that see extended durations and extensive damage are counted toward the HEAF frequency of bin 16, and it is those events that this test program seeks to quantify. The availability of protective devices is already credited in calculating the bin 16 frequency. If the deterministic ZOI were to account for the availability of circuit protection, then plants would be taking double credit--once in the exclusion of quickly-terminated events from bin 16, and once in the ZOI damage model. This aspect of HEAF events is a current area of work through a joint EPRI/NRC Memorandum of Understanding group

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					project. The definition of HEAF events and the frequency will be further refined and clarified.
4a	NEI	No changes	4.4/multiple	It is unknown whether the results of this test will lead to the imposition of a deterministic HEAF ZOI and does not allow any consideration of the availability of protective devices that would quickly terminate. Depending on design details, the tripping of breakers to terminate HEAF event could be as fast 0.08 seconds. In some applications, given failure of the primary breaker, the backup breaker would trip within 2 seconds. The 2 second threshold is a typical criterion for the maximum allowed delay on tripping a transformer supply breaker on a ‘thru-fault’ condition.	Arc events which only last for 0.08 seconds do not constitute the HEAF frequency bin. The definition and appropriateness of HEAF binning concerns an area of work being performed under the EPRI/NRC MOU. Future work and refinement towards counting guidance for HEAF will be commensurate with frequency bins, consistent with any revision to a ZOI method.
4b	NEI	Change to Section 4.1- equipment ratings not to be exceeded	4.4/multiple	The test plan seems to be focused on exposing the equipment to short circuit conditions that approach (and possibly exceed their rating). It is unclear how these results can be applied to cases where the actual plant conditions are such that the fault conditions are substantially less than the equipment rating. For many plants, the analysis of the medium voltage switchgear shows that the peak short circuit MVA occurs only when the EDG is paralleled for testing. In such cases, the short circuit during normal operating conditions is substantially less – resulting in notable margin the equipment rating.	None of the testing to be performed will subject any equipment to conditions that exceed their ratings. As discussed above (See NEI Comment #2), there is a large margin included in the fault conditions imposed on the equipment.
5	NEI	Change to Section 6- addition of breaker	6/1	The test plan indicates that the test enclosure will contain only a bus bar and no other internal features. It is unclear how the lack of a physical breaker and variability with respect to location of the actual bus bars in medium and low voltage switchgears will influence the test results. It would seem the available void space within the enclosure would affect the behavior of any transient conditions. The spacing of the bars themselves relative to the outer walls of the enclosure and any ventilation opens (louvers) could introduce additional influences that may reduce or exaggerate the consequences outside the enclosure. It is not clear how these variables can or will be considered when post-processing of the test results and developing HEAF ZOI application guidance is developed.	NRC staff agrees that there exists a high degree of variability in arcing fault scenarios. Ideally, each potential variable (bus bar spacing, louvres, etc.) would be subject to experimentation, and its effect incorporated into any physical model. In practice, isolating each variable is cost prohibitive. For precisely this reason, the NRC hosted a phenomena identification and ranking table (PIRT) exercise in February of 2017. The NRC invited all participating OECD countries, EPRI, KEMA and NIST to the PIRT. The PIRT panelists identified the variables that are expected to have the most significant impact on the resulting damage from a HEAF event. This research is documented in NUREG-2218. NRC staff agrees that the presence of a physical breaker may have an impact on the results. The test program has been modified to include circuit breakers in all electrical enclosures to be tested.

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1	NEI letter dated 05/17/2018	Test Parameter changes	General Comment	… it is critical that any follow-on testing involve configurations that accurately reflect plant design and operations in order to provide realistic insights.	The April 18th- 19th public workshop provided the industry with a document for stakeholder feedback. This specific concern was raised during the workshop and changes to the test plan have been made to ensure subsequent tests are performed to realistic plant conditions.
2	NEI letter dated 05/17/2018	No changes	General Comment	These tests should be performed using as realistic as possible fault conditions (e.g., fault current magnitude, duration, DC offset, decay, etc.). The NRC should consider HEAF testing to incorporate monitoring for parameters that are used as input for commercially available arc-flash protection relays. These parameters typically include light intensity (sensed by point sensors or fiber optic cable) and sound pressure (by point sensors).	There are several commercially available systems for arc fault protection that do incorporate light intensity as part of the operating characteristics. However, the RES staff is currently not aware of any nuclear power plant (NPP) in the operating fleet that is using such a mitigation technique. The test program does not intend to test protective relay performance or provide design solutions. The test program intends to test “as built”, “as operated” equipment. The durations of arc faults are informed by operating experience.
3	NEI letter dated 05/17/2018	Test Parameter changes	General Comment	The OE doesn’t support the “realism” of an 8 second arcing event at this voltage level. Out of the OE that is being referenced, only the Fort Calhoun event had a long fault duration at the 480V level. That fault duration itself (42 seconds) was due to a severe design deficiency (misaligned stabs and zone select interface jumpers not being disabled). This event is not representative of an actual fault event where one or even two protection levels misoperate. For this reason performing the 8 second test does not follow the mission for phase 2 testing, which is “realism.” In addition, considering all the OE, the Fort Calhoun event at 42 seconds is obviously an anomaly (next longest is 12 seconds), and thus would normally be removed from any statistical sample. In a scenario with single breaker misoperation, the protection upstream of the supply transformer will typically operate much faster than 8 seconds. While it is true that upstream protection will operate in the thermal region, for high fault current levels detailed in the test plan the trip times will be closer to 4 seconds or even much shorter. NRC representatives mentioned during the April 18-19 workshop that the longer testing, exceeding 4 seconds, could not be performed at the Medium Voltage level (MV) due to testing center limitations. Since the testing center is able to test for longer durations at LV, a longer test (8 seconds) was being done at LV. No testing should be done for sake of	The Fort Calhoun was the only domestic low voltage OE where the fault duration lasted in excess of the testing parameter of 8 seconds. However, there is international experience documented in the OECD Fire Project – Topical Report No. 1 “Analysis of High Energy Arcing Faults (HEAF) Fire Events” where the fault persisted for 8.5 seconds. While the NRC staff agrees that these extended duration HEAF events for low voltage cases may be less common, there is no statistical basis for removing these events from analysis based on the limited data available for the low voltage HEAF events. The incorporation of plant system design, fault protection schemes and a detailed fault timing analysis is a current area of research work being undertaken by the NRC and EPRI under a Memorandum of Understanding agreement to account for scenario specific arc fault timing analysis. Through discussions at the April 18-19 workshop the staff decided to focus the low voltage testing parameters on the 2 to 4 second range for the majority of test cases. This provides a better representation of the low voltage arc conditions from OE and will provide 1 to 1 comparison points between the low and medium voltage scenarios. However, the NRC staff still intends to test a limited number of low voltage cases at durations longer than 4 seconds. These extended duration

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				testing without OE basis. If the test is performed at 8 seconds at LV, it should be categorized as 'experimental' and not utilized to develop revised ZOI (Zone of Influence) and frequency for PRA.	low voltage tests will be used as data points to extrapolate potential damage conditions for the medium voltage conditions where extended duration events can be postulated based on plant design. There is OE of longer duration arcing events for medium voltage events up to 11 seconds (Robinson; 3/27/2010 ~8-10 seconds, Diablo Canyon; 5/15/2000 ~11 seconds). However, it is currently well beyond the capabilities of the testing laboratory to replicate these extended duration fault conditions. The arc duration has been documented as a primary parameter of interest in both the PIRT report and through discussions at the April 18-19 workshop with industry representatives and will be essential for the creation of a dynamic zone of influence and the creation of modeling techniques which can be used to determine scenario specific HEAF damage states.
4	NEI letter dated 05/17/2018	No changes	General Comment	A test at 2 seconds would be more interesting to the industry since the switchgear is designed for a 2 second fault event. Most testing is done with a duration of 0.1 -1 second per IEEE C37 hence it would be a new test and not repetitive.	The National Fire Protection Association (NFPA) and the Institute of Electrical and Electronic Engineers (IEEE) in colloabation with their research partners have performed a significant amount of testing under 2 seconds in duration. The focus of this research is to complement that data in a region where higher energy faults are occurring and limited data exists. The NRC plans to work with NFPA and IEEE to review the short duration testing.
5	NEI letter dated 05/17/2018	No changes	General Comment	Multiple licensees use a high impedance grounding system to limit the fault current. This test plan does not specify the ground configuration, and so no comparison to the installed plant configuration can be made.	Plants utilize several grounding configurations within their power distribution system. This topic was discussed at the April 18-19 workshop. An outcome of those discussions was that test grounding configuration was not important (unanimously ranked 'low' by stakeholders), with the exception of its influence on frequency. It was determined that the testing should use whatever grounding configuration ensures other test parameters are achieved (e.g., voltage, current, duration, etc.).
6	NEI letter dated 05/17/2018	No changes	General Comment	The test methodology eliminates any component but the tested material/simulated bus bars. No bus bars are used in nuclear plants that are not connected to something else – transformers, buses with other components etc. Additionally, the bus bars are typically the strong part of the circuit, not the weak link.	While the testing does not connect the bus bars to operating equipment the effect of this equipment is taken into account when stipulating the fault conditions which will be experienced at the point of initiation for the arc. Operating experience has repeatedly shown that arcing events do occur on the bus bars

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					and the frequency used in PRA's is directly linked to the operating experience in NUREG-2169 bins 15 & 16.
7	NEI letter dated 05/17/2018	Addition of decrement curve for medium voltage tests will be considered for future addition to the test plan (pending information provided by EPRI)	General Comment	The testing plan should be revised following consideration of other sources of analysis, research, design, and protection relating to HEAF, specifically IEEE Standard C37.20.7, IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults (may be relevant as to future test parameters – arc- duration, current decay, DC offset, fault current, energy dissipation, etc.; may also be relevant as to effectiveness of energy dissipation features such as intended by provision of directed vents, louvers, lifting panels, blowout panels, etc.)	Through discussions at the April 18-19 workshop it was decided to work with EPRI to evaluate incorporating the current decay into the current test plan. Other aspects of IEEE C37.20.7, IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults are irrelevant for the testing because the features such as directed vents, louvers, lifting panels and blowout panels are not currently used in the operating NPP fleet electrical enclosures. The NRC RES staff is currently unaware of any electrical switchgear enclosures which meet the guidance presented in IEEE C37.20.7 in the current operating fleet. The guide was first approved by the American National Standards Institute in 2008 with a predominant focus on personnel protection. These design requirements post-date the current fleet of operating NPP's.
8	NEI letter dated 05/17/2018	No changes	General Comment	Regarding test results as reported in CNSI-R2017-7: Test 4, 5, & 6, Westinghouse DS (480V) w/ aluminum – tests results were not extraordinary, arc duration was 9, 300+, & 300+ milliseconds	Test 4, 5, 6 & 7 were designed to be tested for 3000 milliseconds, 4000 milliseconds, 4000 milliseconds, and 4000 milliseconds respectively. These tests were considered failed tests due to the inability to maintain an arc for the intended duration and do not reflect the damage states typically associated with HEAF events. Therefore there was no ability to evaluate the impact of the material properties influence on the state of damage.
9	NEI letter dated 05/17/2018	No changes	General Comment	Regarding test results as reported in CNSI-R2017-7: Test 23, "IP-20" (480V) w/ aluminum – test result was "extraordinary", arc duration was 7000+ milliseconds. It is legitimate to question the "extraordinary" test results where the arc duration was maintained for more than a couple of seconds, specifically for Test 23, where a typical plant design would provide electrical protection for the switchgear (e.g., one or two upstream breakers with protective relaying, etc.).	Arc duration alone cannot explain the results from Test 23. The duration for Test 3 was 8128 milliseconds on copper conductors and the results vastly differed from that of Test 23 with aluminum. This comparison of test results based and the material properties of the bus bar is what led the NRC research staff to question the impact of the conductive medium as an influencing factor for damage states. Additionally, it can be seen through the video footage of the events that the involvement of the aluminum conductors occurs quickly in the respective tests.

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10	NEI letter dated 05/17/2018	No changes	General Comment	Regarding test results as reported in CNSI-R2017-7: Test 26, copper bus bars (4160V) w/ aluminum duct – test result was “extraordinary” arc duration was 4000+ milliseconds. It is legitimate that the arc duration for Test 26 may represent actual conditions, as a typical plant design may provide power to the bus bar directly from the power source (e.g., Main Generator, etc.) without any in-between electrical protection.	Event duration corresponds to relevant operating experience at medium voltage bus bar events (See Diablo Canyon 05/15/2000).
11	NEI letter dated 05/17/2018	No changes	General Comment	Correlation of CNSI-R2017-7 (Test 23, IP-20) with the testing documented in KEMA 15201-B (trial 16, Finland Cabinet 1 LV Switchgear) is based on test date 10/16/2015, since there is no “Test 23” identified in KEMA 15201-B, and since no specific manufacturer or model number is provided for the applicable switchgear associated with Test 23 in CNSI-R2017-7 or KEMA 15201-B. The Test 23 specimen is identified as “IP-20,” which represents a generic international Ingress Protection (IP) rating, equivalent to a NEMA enclosure rating in the USA. IP20 signifies protection from touch by fingers and objects greater than 12 millimeters, not protection from liquids. IP20 is not waterproof or even spray proof, and may not be typical of US installations, which would likely use no less than IP22, protected from touch by fingers and objects greater than 12 millimeters; protected from water spray less than 15 degrees from vertical.	Unclear how this characteristic or design standard has any impact on electrical behavior of arcing events.
12	NEI letter dated 05/17/2018	No changes	General Comment	Test 23 and Test 26 were performed in an open test cell (open to outdoor environment) in the month of October. The documentation in CNSI-R2017-7 and KEMA 15201-B does not specify how the test specimens and/or monitoring instruments were stored or when the test rig was set up in the test cell. One must wonder if condensation might have occurred on the test cell walls, the test specimens, and/or the monitoring instruments given the typical Pennsylvania weather in October (cold nights, warm days). Furthermore, one also must wonder if condensation, if present, played any part in the “extraordinary” test results noted in Test 23 and Test 26. This may be a similar concern for future testing.	Test 26 was not performed in October. Test 26 was performed in January. All test specimens were stored and prepared prior to testing in an environmentally controlled storage space/workshop and only moved into the open to outdoor environment on the day of testing. The test cell has three walls and a roof, with only one side opening facing the control room. The test equipment is located under the roof protection.
13	NEI letter dated	No changes	General Comment	Test 23 and Test 26 were performed in an open test cell (open to outdoor environment) in the month of October. One must wonder how and if the relative humidity played any part in the “extraordinary” test	Test 26 was not performed in October. Test 26 was performed in January.

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	05/17/2018			results noted in Test 23 and Test 26. The level of relative humidity may impact how easily an arc can be established. In plant application, the test specimens such as these (switchgear and some bus bars) are typically located in areas where the relative humidity is maintained relatively constant. The test facility is capable of "allows breakdown testing as a function of gas composition and atmospheric/surface contaminants (e.g. humidity, saltwater spray, oil vapors and other atmospheric contaminants)." Humidity is not specified. Is what has been seen in Phase 1 actually metal water reaction? Results may vary widely depending on humidity or other contaminants. This may be a similar concern for future testing.	Humidity was recorded on each day of testing and will be reported in the Phase 2 testing report. There is operating experience where humidity and potentially saltwater spray has played an initiating role in HEAF events (See Narora fire event 1993). This topic was discussed at the April 18-19 workshop. An outcome of those discussions was that atmospheric conditions was not important (ranked 'low' by 10 stakeholders and medium by 1), with an additional note to the influence on frequency of occurrence.
14	NEI letter dated 05/17/2018	No changes	General Comment	The documentation in CNSI-R2017-7 and KEMA 15201-B does not specify how the test specimens were procured or maintained, their service life, service conditions, or service history, or if and how the test specimens were modified to accommodate testing. These variables might have an influence on the "extraordinary" test results noted in Test 23 and Test 26. This may be a similar concern for future testing.	All equipment was procured through donation or purchased by the NRC from operating NPP's. All modifications to equipment conditions was documented. Each tested piece of equipment underwent hi-pot testing to ensure that the arc could be reliably initiated where intended.
15	NEI letter dated 05/17/2018	No changes	General Comment	The documentation in CNSI-R2017-7 and KEMA 15201-B does not specify if electromagnetic interference (EMI) or electromagnetic pulse (EPM) was monitored during testing. It is possible that either or both phenomena impacted the HEAF energy release, and if either or both phenomena had any influence on the "extraordinary" test results noted in Test 23 and Test 26. This may be a similar concern for future testing.	All HEAF tests produce EMI and EMP effects not just the ones associated with the "extraordinary" results. All events from operating experience in real plant conditions are also accompanied by EMI and EMP effects. EMI monitoring is under current discussion for the phase 2 of testing. The influence of EMI was evident in the pressure recording measurements and has led to alternative means of pressure investigation i.e. the use of shielding and fiber optic cables. In plant events are also accompanied by EMI and EMP conditions.
16	NEI letter dated 05/17/2018	No changes	General Comment	There exists a concern regarding plants which credit ERFBS which is located within the HEAF ZOI (copper or aluminum) as part of their fire protection program, deterministic or performance based. Specifically, the concern is for the impact of HEAF explosion and subsequent fire to ERFBS located within the ZOI. This event may cause damage to the ERFBS and may also damage (due to HEAF explosion and subsequent fire) the circuits protected by the ERFBS, thereby resulting in spurious operation or loss of required function. It does not appear that this failure mode and adverse impact is considered by	• CSNI-R2017-7 does not base its conclusions based only on 2 out of 2 tests. The report characterizes the influence of aluminum as follows; "The experiments where aluminum was consumed during the HEAF resulted in more severe physical damage to equipment than those involving only copper and steel at any voltage level. In both experiments where aluminum was consumed during the HEAF,

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				deterministic regulation (Appendix R), since Appendix R fire area analyses are based on an assumed “worst-case” whole area burn from a floor-based fire and the deterministic analysis does not consider HEAF explosion. Furthermore, it does not appear that this failure mode and adverse impact is adequately addressed in the performance-based HEAF ZOI treatment guidance (NUREG/CR-6850), since performance-based treatment guidance may only address failure of ERFBS with respect to fire propagation, but not failure of circuits protected by ERFBS thereby resulting in spurious operation or loss of required function. The test results as reported in CNSI-R2017-7 are not appropriately characterized. It is not 2 of 2 tests involving aluminum that exhibited “extraordinary” test results. There were 5 tests involving aluminum, and 3 of these tests did not exhibit any “extraordinary” test results beyond the current Fire PRA treatment for HEAF ZOI in NUREG/CR-6850. Furthermore, the “white haze” attributed with electrical failures in the “extraordinary” aluminum tests has not yet been confirmed as the actual cause of these electrical failures, nor to my knowledge is there any experience of “whitewashing the entire room with the white haze” in any of the recorded plant HEAFs, although some localized aluminum oxide, splatter, slag, etc. has been noted in the associated fire event reports.	measurement devices were damaged or the maximum measuring range was exceeded. These instruments were unable to measure the actual maximum temperature and heat flux.” Tests 4, 5, 6 & 7 were designed to be tested for 3000 milliseconds, 4000 milliseconds, 4000 milliseconds, and 4000 milliseconds respectively. These tests were considered failed tests due to the inability to maintain an arc for the intended duration. Additionally, only minimal amounts of aluminum were able to be consumed during the event due to the duration of the arc. The test result conclusions took into account all the available data from all of the 26 tests to reach generic conclusions and recommendations for future testing. The tests involving aluminum were clear outliers to damage states when evaluating test cases performed under similar conditions (See; Test 3 vs Test 23) • The “white haze” attributed with electrical failures in the “extraordinary” aluminum tests has not yet been confirmed and is a current area deemed important by the PIRT panel and being evaluated as part of Pre-GI-0018 “PROPOSED GENERIC ISSUE ON HIGH ENERGY FAULTS INVOLVING ALUMINUM COMPONENTS”. There is operating experience which also points to the influencing effect of this conductive byproduct and coating characteristic in several events. For example; ○ Fort Calhoun Station, Unit 1 - June 7, 2011 “The investigation also determined that combustion products from the fire caused a fault on the island bus side of the bus-tie breaker (BT-1B4A), which resulted in an overcurrent condition through two breakers (feeder breaker 1B3A and bus tie breaker BT1B3A).” (ADAMS Accession No. ML113010208), and “Fort Calhoun Station - NRC Special Inspection

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					Report 05000285/2011014; Finding of Preliminary High Safety Significance" (ADAMS Accession No. ML12072A128). o Columbia Generating Station August 5, 2009 The faulted bus section was located above the medium voltage switchgear SM-3 and damage from the molten metal produced by the fault included another high voltage bus and other cables in the area of switchgears SH-5 and SH-6. (ADAMS Accession No. ML092870468), and "Columbia Generating Station - NRC Special Inspection Report 05000397/2009010" (ADAMS Accession No. ML093580158). Zion Nuclear Power Station, Units 1 and 2- April 3, 1994 After the termination of the fire, the licensee performed an assessment of the damage to the main generator and associated bus ducts. The A and B phase isophase bus ducts showed signs of excessive arcing. The corners of the 90-degree turns on both phase housings were blown outward, and aluminum spatter covered the general area of the fault… Samples of molten metal and fire residue obtained from the A and B phase bus ducts and the C phase lead box were analyzed. The intent of this examination was to identify the presence of any conductive foreign material which may have contributed to the flashover of the A and B phases. Nothing out of the ordinary was found in this investigation. The majority of the material examined was identified as aluminum. The white powder found in the ducts was identified as aluminum oxide. The aluminum deposits were a result of the arcing that occurred on the A and B phases, which are fabricated from aluminum. (Legacy ADAMS Accession No. 9801210070).
17	NEI letter dated 05/17/2018	No changes	General Comment	Furthermore, any future NRC discussion or presentation regarding industry HEAF events should endeavor to accurately note that the long duration of the arc-fault events at Fort Calhoun and Robinson were caused or compounded by human performance errors.	Human Error compounding fire event occurrences is not outside the scope of fire PRA's nor should it used to influence frequency of occurrence. NUREG-2169 addresses the influence of testing and maintenance on fire frequency with an established rule set to account for events caused by plant

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					personnel which are quickly discovered and suppressed. HEAF events typically do not meet these exclusionary criteria due to the rapid development and suppression challenges associated with the immediate electrical energy release.
18	NEI letter dated 05/17/2018	No changes	General Comment	Issues Related to the interpretation of test results The HEAF frequencies need to be developed to reflect both the testing configuration and the plant configuration. For example, large HEAF ZOI events only protected by a single breaker should be not be apply to HEAF events protected by two breakers. Large HEAF ZOI that have durations of faults greater than 4 seconds should only count events where the fault was greater than 4 seconds. It appears that the target fault durations were orders of magnitude greater than what industry protection schemes would allow. They were also greater than the short-circuit rating of the transformers themselves. It is not physically possible to get these faults. The criteria for the new bin classifications needs enhancement to reduce subjectivity as much as is possible. The criteria need to bound and bin, without ambiguity, subjectivity, or debate, all relevant arc fault events to date. • No damage to component itself – no fire internal, no fire external • Damage to component itself – no fire internal, no fire external, damage to external components • Damage to component itself – no fire internal, no fire external • Damage to component itself – fire internal, no fire external • Damage to component itself – fire internal, fire external • Event compounded by human error (Fort Calhoun, Robinson) • Others The use of “energy” as a metric may be one enhancement to the bin classification criteria, but this may also be misleading given that arc-fault energy is released over time. Total energy release may meet or exceed a set threshold, but the impact from this energy release will depend on the arc-fault duration and the changing arc-current.	All the topics discussed in the “Issues Related to the interpretation of test results’ are areas of current work being addressed separately from the phase 2 testing program. Those efforts are being performed under a Memorandum of Understanding with EPRI. The definitions and binning associated with HEAF events was discussed at the April 18 – 19 public workshop and will be issued as a joint NUREG to capture many of the ideas listed. This work will be done in parallel to the testing program.

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				For the population of plant circuit breakers that, if failed, could allow propagation of an arc-fault into a HEAF event (a challenging fire event), presumably breaker failures within this population are already counted as “fail to trip on valid demand” random component failures in the Internal Events PRA. The implications of possible double counting of these failures in the Fire PRA should be addressed As previously documented, many of the HEAF events that contribute to the HEAF frequency involve one or more breaker malfunctions that fail to clear the fault – it is requested that this statement is reflected in revised frequency for PRA. It is further suggested that a revised ZOI only be documented hand-in-hand with the revised frequency for PRA.	
19	NEI letter dated 05/17/2018	No changes	General Comment	During the Turkey Point event, it is notable that no other mechanical damage was identified within the effective radius of the pressure wave generated by the HEAF. It is likely there are several other components and features located within the effective radius of the pressure wave that could possibly have been damaged (e.g., electrical penetrations, junction and terminal boxes, placards and signs, etc.). It seems odd that a fire door was the only component located outside of the switchgear that was adversely impacted by the pressure wave.	Information Notice 2018-09 “Electrical Arc Flash Caused by Foreign Material Damages Fire Door” explains the Turkey Point event in detail. Pressure influences are a current area of research and will be evaluated in the Phase 2 of testing. Room barrier integrity is a staple of the defense in depth principals and is relied upon heavily in the creation of fire PRA scenarios.
20	NEI letter dated 05/17/2018	No changes	General Comment	The previously-discussed test results were compared to the 2010 Robinson Fire and having inspected the Robinson Fire damage. The Robinson HEAF damage was significantly less than predicted with the current HEAF model. For example thermoplastic cables about 3 inches from the HEAF Cabinet were undamaged, but did show evidence of some heating. These cables were sent to NRC Research, where the lack of cable damage was confirmed. The letter provided by NRC Research stated that based upon the cables it summarized that "NUREG/CR 6850 is likely overstating the damage in the zone of influence".	The cables which were sent to the NRC Office of Research did not include spatial reference information as to where the cables were located in relation to the HEAF initiation point as such the NRC letter that is referenced above (ML121070714) states’ “The electrical cables exposed to the Robinson HEAF event which were sent to Sandia for analysis did not show the type of damage which is proposed in Appendix M of NUREG/CR6850. When tested for continuity, the cable taken from the first tray did not display insulation degradation between conductors. Appendix M of NUREG/CR-6850 denotes that any tray within 1.5 m (5’) vertical distance of the top of the cabinet will be ignited and damaged at time T=0. The first cable tray at Robinson was located 3” above the top of the cabinet. The model in Appendix M of NUREG/CR-6850

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					would over estimate the risks associated with damage to the first cable tray located within the ZOI. It should be noted that, based on the post fire analysis plant pictures, the level of damage on the cables exposed directly to the fire appears to be much greater than the sample that was shipped to SNL. This implies that the cable shipped to SNL for analysis were not from the area of greatest heat impact. It is unclear at this point whether the cables at the greatest heat impact area would have shown the same conduit continuity. Based on the lack of specific location information to accompany the cables shipped to SNL, it is impossible to determine the applicability of this guidance in appendix M of NUREG/CR-6850." Based on the information received the conclusions of the report document several recommendations for future efforts including (1) setting up direct communication between the laboratory, research project manager and utility site representative responsible for the event evaluation and shipment of the component(s), (2) a better understanding on what components will provided the most useful information, and (3) how to ship the component(s) to the laboratory without potentially inducing shipping damage.
21	NEI letter dated 05/17/2018	No changes	General Comment	Comments Regarding the Premise of USNRC IN 2017-04: The information notice states: This program has shown that HEAF tests involving aluminum resulted in a significantly larger release of energy than HEAF tests involving copper. This aluminum involvement includes components, subcomponents, or parts that form part of the normal current-carrying pathway (such as bus bars, breaker armatures, contacts, cable, etc.), or components, subcomponents, or parts that could become involved in the fault current pathway as a result of a ground fault (housings, structural framework, adapters, cradles, wireways, conduits, draw-out or racking mechanisms, etc.). In addition to larger energy release during the HEAF event when aluminum is involved, RES staff also observed dispersal of electrically conductive aluminum byproducts	The wording of the information notice was intended to be all inclusive due to the limited information available based on a limited number of tests performed. Suggestions contained in information notices are not NRC requirements. Further guidance and clarification as to the aluminum components to be considered will be developed based on the results of the Phase 2 of testing.

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				throughout the area. This byproduct was conductive and caused short circuiting and grounding of electrical equipment in the area. Through the testing program, RES staff observed that HEAF tests involving aluminum damaged test measurement and recording equipment and the electrical supply of the test facility well beyond the damage limits approximated in NUREG/CR-6850 (EPRI 1011989). The second part of the paragraph appears to be too broadly worded and vague: “or components, subcomponents, or parts that could become involved in the fault current pathway.” There is no guidance provided or specific test data that points to “what could become involved in the fault current pathway.” It would be hard to tell which miscellaneous aluminum parts became involved in the fault current pathway from inspecting a breaker cubicle that has exploded/vaporized - to tell if any of the miscellaneous aluminum parts vaporized/ejected due to becoming involved in the fault current pathway, or as a consequence of the resulting explosion and/or temperature rise in the cubicle. However, the empirical test results would suggest that if aluminum components, subcomponents, or parts were contained within the representative “typical” switchgear that was tested containing only copper “bus bars, breaker armatures, contacts, cable,” then these aluminum components, subcomponents, or parts apparently did not contribute to HEAF damage beyond that which was expected (prior to test) for switchgear only containing copper “bus bars, breaker armatures, contacts, cable.” Thus, any such aluminum components, subcomponents, or parts should not be considered to “become involved in the fault current pathway,” where said items are contained within a “typical” switchgear containing only copper “bus bars, breaker armatures, contacts, cable.” The empirical test results would also suggest that any such aluminum items did not also contribute to the unexpected HEAF damage that was observed in tests of switchgear containing only aluminum “bus bars, breaker armatures, contacts, cable.” Rather than the above statement from the information notice, the position based on the empirical test results presented in the body of	

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				CSNI-R-2017-7 should be: If the switchgear does not contain aluminum “bus bars, breaker armatures, contacts, cable,” then the HEAF event should be selected for copper. The other miscellaneous “components, subcomponents, or parts” do not influence the HEAF damage any differently, regardless of what material the “bus bars, breaker armatures, contacts, cable” are constructed of	
1	Korea	No changes	3	We (Korea consortium) understood that one of HEAF project objectives is to modify the ZOI in NUREG/CR-6850 Chapter M with experiment results. And the objective of test plan also is that the HEAF experimental data may be used by the NRC GIRP to determine the adequacy of existing HEAF ZOIs. But we can’t find the detail description of ZOI methodology in the HEAF2 test plan. To meet the objective, a methodology of ZOI should be formulated in before and described in the HEAF2 test plan.	A detailed description of the current HEAF evaluation methodology can be found in NUREG/CR-6850 and associated supplements. It is incorporated in the test plan by reference. The test plan methodology is to quantify and determine the threat posed by the HEAF hazard (thermal heat flux, projectile characteristics, particle/fume dielectric characteristics, pressure wave, etc.) When combined with the vulnerability of the targets to these threats, a ZOI could be determined. The current test plan will quantify the threats, not the vulnerabilities. The results and data of this test program will be analyzed and a detailed methodology for HEAF damage states will be developed with EPRI under the MOU. Member Countries of the HEAF Phase II project will serve as Peer Reviewers to the new methodology.
2	Korea	No changes	4.4	First phase of arcing fault is short and rapid release of electrical energy and it is own damage characteristics. All most same measurement devices of previous HEAF test are used in HEAF2 test and Test data in previous HEAF test may not be shown in first phase of arcing fault phenomena. Issues of previous HEAF test such as temperature, heat flux and pressure during first phase of arcing fault should be described in the draft test plan.	Pressure measurements from Phase 1 suffered from noise. Developments from KEMA and NRA/Leidos will be incorporated into phase 2 to provide valid cabinet pressure measurements. The modified plate thermometers (PTs) in Phase I worked well for the initial HEAF phenomena except under extreme conditions. The new thermal capacitance slugs are designed to capture the thermal conditions that exceed the PTs capabilities. In addition to this, arc particle characteristics will be evaluated closely during a parallel Sandia National Laboratories small scale testing program.
3	Korea	Parameter Change	Table 3	In previous HEAF test, the range of voltage, current and arc duration are 480 ~ 10,000 V, 15 ~ 50 kA, and 2 ~ 9 sec. respectively. In draft test plan, voltage of 480 V, 4160 V, current of 23 kA, 32 kA are	The test matrix was designed to include experimental comparisons at low and medium voltages and the influence of aluminum. In order to have a reasonable number of

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				selected as test variables. Are there any reasons for such variable selection and what is the representative of the selected test variables?	experiments, the nominal voltages needed to be limited. The NRC staff performed parameter search on a limited number of available U.S. operating nuclear power plants (NPPs) to determine appropriate parameters for voltage and current. That sample plant data can be found at ADAMS #ML18081B300. The final test plan reflects testing being performed at 480V and 6.9kV and fault currents between 25kA and 32kA.
4	Korea	No changes	Figure 1, Figure 2	Nuclear power plants normally adopted the electrical cabinets with current range between 20 kA and 50 kA. So we suggest to change 32 kA into 50 kA or add 50 kA in test plan and also to change 23 kA into 32 kA related to the bus duct testing plan.	The final test plan reflects testing being performed at 480V and 6.9kV and fault currents between 25kA and 32kA.
5	Korea	No changes	General	We can only participate by providing electrical cabinets to be tested instead of money.	The terms of participation are detailed in the Terms of Reference document. In kind contribution of equipment is acceptable.
1	IRSN	Scope Change for OECD participation	4.4	Choice of aluminum material. We fully understand the need for the NRC to study aluminum as material, but we have several comments. In France the majority of Bus Bars for electrical cabinets are made of copper or “white copper”. It seems to me that this should also be the case for some other European partner. On the other hand for the Bus Duct, there is some aluminum bus but with only a steel enclosure and, therefore, I agree with CRIEPI's comment No. 6. The matrix could be simplified for the sake of representativeness for all partners and the global cost of the program. It could be envisaged to carry out all the tests with copper Bus Bar and to select the most penalizing in terms of ZOI to carry out tests with an aluminum bus bar. Below is an example of a test matrix with 14 tests instead of 24 for electrical cabinets. Concerning the duct buses the same method could be applied and the following matrix defined 5 tests instead of 8.	As discussed at the preceding OECD/NEA HEAF working group meeting in Fall 2017, the exploration of aluminum impact is primarily a concern for the United States. As a result, the test plan scope was revised to limit the number of aluminum tests performed under the OECD/NEA umbrella, and the NRC will likely supplement the test program with additional aluminum testing.
2	IRSN	Change to Section 6- addition of breaker	6	Concerning the circuit breakers, my opinion is divided. They are not necessary for the quantification of the ZOI but allow a more realistic configuration, as said by CRIEPI. We prefer to carry out a comparison test with and without circuit breaker to quantify the influence of this type of equipment on the HEAF and the ZOI. If the influence is really negligible we would make a substantial saving on the overall cost of the program.	The test plan has been modified to include breakers inside the enclosures. See NEI comment #5

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3	IRSN	No changes	6	In the case of electrical cabinets, we believe that they should be as simple as possible but mainly all identical and with a good degree of sealing, representative of high-voltage cabinets. The fact that partners want to transfer some cabinets to the NRC to carry out the program is not necessarily a good thing, un-less of course to deliver all the electrical cabinets of a campaign.	NRC staff agrees that the homogeneity of cabinets is important to increase repeatability and limit the introduction of additional variability of results. However, a limited number of countries have indicated that their participation is contingent upon being able to donate equipment in lieu of monetary contributions. In an effort to accommodate the program partners and limit cabinet variability, the agreement calls for equipment to be donated in multiples, and purchased equipment will be identical or very similar to the extent possible.
4	IRSN	No changes	4.4	The majority of HEAFs in electrical cabinets are held with high voltage and 380 V does not represent a real case for France. For example, two tensions could be envisaged: • Minimum voltage but> 1kV • Maximum usable voltage (???)	The majority of HEAF events in the US are also experienced in medium voltage cabinets however the HEAF guidance development and application in probabilistic methods includes all electrical enclosures 440 and above. Phase II of testing will collect data on the representative voltage cases and address the frequency split and potential damage state differences in follow on analysis efforts. The test program scope does not allow itself to evaluate threshold initiation and extinction parameters.
5	IRSN	Addtion of Section 8.2- Multiple cabinet lineup		GRS's remark about cabinet targets with adjacent or opposite cabinets is very interesting, but these configuration should increase the cost of the program considerably. This option should be budget.	Section 8.2 has been added to address the configurations associated with multiple cabinets in a lineup.
6	IRSN	Test Matrix change with explanation	4.4	A last comment concerning the arc duration, is 8 s should be considered as a representative one?	As discussed in the response to the NEI comment regarding arc duration, the subject of this test program is arcing faults that are not quickly terminated by circuit protection devices. Within that scope, arcing durations of several seconds are to be expected, and have been observed. Extended duration events have also been observed in non-US plants as well as phase I of HEAF testing. Based upon discussion in the April 2018 workshop it was agreed that the majority of the low voltage testing will be performed on the 2 to 4 second range cases. This provides a better representation of the low voltage arc conditions from operating experience and will provide 1 to 1 comparison points between the low and medium voltage scenarios. There

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					will be limited number of low voltage cases tested at durations longer than 4 seconds. These extended duration low voltage tests will be used as data points to extrapolate potential damage conditions for the medium voltage conditions where extended duration events can be postulated based on plant design.
1	GRS	No changes	General	In general, the test plan is enough detailed and meaningful. Moreover, background with the HEAF operating experience and the history of the OECD HEAF activities are outlined in a comprehensive way deriving the indication that further HEAF experiments are needed. However, the needs of different member countries having participated in the HEAF experimental program do not come out clearly.	Once the testing has been completed and the NRC and EPRI derived new HEAF ZOI models all member countries will benefit from this information.
2	GRS	No changes	4	The general experimental approach with arc initiation, currents and voltages of the arcs, arc durations needed for getting ensuing fires and the measurements foreseen are clearly outlined in enough detail with good arguments.	No response required.
3	GRS	No changes	4.4	It clearly comes out that a comparison of components with and without Aluminum is intended as a main results from the HEAF experiments. The number of experiments foreseen (probably 35) is sufficient to gain insights on different phenomena as well as for performing repeating experiments.	No response required.
4	GRS	Scope Change for OECD	4.4	The arc durations for cabinet tests (2 s, 4 s and 8 s) are meaningful and correlated to the international operating experience. For the bus bars, only two different arc durations (1 s, 3 s) have been chosen, a third arc duration (5 s or 6 s) may be useful.	Two bus duct tests at a third duration (5s) have been added to the test plan, and will be conducted if resources allow.
5	GRS	No changes	4.4	Measuring equipment chosen does reflect clearly the outcome of the first test series. Positioning of measuring devices in different distances from the component to be tested provides an excellent means to check if the ZOI assumed within safety assessment needs to be adapted.	No response required.
6a	GRS	Parameter Change	4.4	Two aspects are critical from German and probably other European institutions view-point, in particular concerning the cabinet arcing experiments: Only components on voltage levels of 480 V and 4160 V are intended to be tested. These components only reflect U.S. types of cabinets and bus ducts, while in Europe and perhaps also in Asia, components with other voltage levels are installed in NPPs. Typically, the lower voltage	The test plan has been modified to test enclosures at 480V and 6.9kV.

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				level components in Germany cover 380 V to 400 V, the higher level breaker cabinets typically are on a voltage level of 6 V to 6.7 kV. Such components were already provided during the HEAF experiments, at least by France and Korea. The voltage levels chosen so far for the tests are not representative for European components.	
6b	GRS	Additon of Section 8.2- Multiple Cabinet Lineup		Although discussed differently during the PIRT exercise as well as at the last HEAF meeting in May 2017 in Helsinki, up to now no cabinet experiments with multiple cabinets either side by side (with an air gap or directly adjacent) or opposite to each other (back to back with only a small gap or front to front separated by a walkway) are foreseen, although these are the typical configurations in nuclear installations which need to be analyzed.	Section 8.2 has been added to address the configurations associated with multiple cabinets in a lineup.
7	GRS	Additon of Section 8.2 Multiple Cabinet Lineup	4.4	The stronger focus on bus bars in line with the U.S. interests is understandable; however, one of the PIRT reflections was the international interest in electrical cabinet arc experiments with banks of cabinets. PIRT members mentioned that such configurations better represent the real situation in nuclear installations. It was proposed that in case of such cabinet tests some of the cabinets in a multiple cabinet configuration may be re-placed by dummy cabinets for saving money and being able to perform more tests. This also needs to be considered in the test program.	Section 8.2 has been added to address the configurations associated with multiple cabinets in a lineup.
8	GRS	No changes	General	In conclusion, it has to be clearly stated that in the frame of an OECD project, the experimental program has to reflect the needs of potential partners. So far this is not yet the case. From the German viewpoint, for participation in the HEAF Phase 2 project, the test plan has to be changed accordingly. Moreover, the insights from the HEAF PIRT exercise need to be reflected more explicitly.	The test plan has evolved from the one first reviewed by the OECD member countries to incorporate their needs.
1	CRIEPI	Change to Section 6- Addition of circuit breaker	3	Comment: Objective of the test plan should be made clear. Opinion: NRC's proposal seems to seek the ZOI for the first phase of the HEAF phenomena, such as instant pressure and energy release, the scattering of the vaporized conductive particles and the projectile from the cabinet because the circuit breaker will not be installed. Nevertheless, due to the lack of the CB (Circuit Breaker), the pressure transfer path and maximum value will be considerably affected, and this fact will lead the uncertainty of the evaluation results from the point of view of the realistic configuration. If NRC also consider the second phase of the HEAF phenomena, the	The test program has been modified to include circuit breakers in all electrical enclosures to be tested.

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				CB and internal structure should be considered even if we have to bear the decrease of the number of the test.	
2	CRIEPI	Change to Section 6- Addition of circuit breaker	4.1	Comment: What is the corresponding HEAF scenario? Opinion: If the CB will not be installed, what kind of the HEAF scenario will meet to this arc initiation condition? (Arc occurrence at the primary terminal in the cable room or at the secondary bushing in the postulated CB?). We believe the compatibility of the real cabinet should be assured up to some extent.	The test program has been modified to include circuit breakers in all electrical enclosures to be tested. Arc initiation location will be selected when enclosures are procured to reflect operating experience and accommodate measurement reliability.
3	CRIEPI	No changes	4.4	Comment: The feasibility of the measurement should be considered. Opinion: According to the HEAF pahse1, the effectiveness of thermal measurement seems to be not clear. Moreover, in the proposal, some challenging measurement seems to be included. So, the feasibility study, such as calibration tests should be shown before installation to the test.	Feasibility studies are being performed by NIST in a cone calorimeter. Small scale testing is being performed at Sandia National Laboratories in a separate NRC funded test program to characterize arc particulate.
4	CRIEPI	Parameter Change	Table 4	Comment: The 4160V condition seem to be too low. Opinion: In Japan, we have no use of 4160V cabinet. We prefer higher voltage, such as 6.9kV.	The test plan has been modified to test enclosures at 480V and 6.9kV. This will address the needs of all member countries.
5	CRIEPI	No changes (evaluated mid test series)	Table 4	Comment: Test parameter should be decreased to optimize the number of the test. Opinion: As key design parameter may be "Arc Energy" according to our findings from our HEAF tests, the value multiplied by the current and time will be the preferable parameter. So, we propose the use of one current level (such as 32kA) with the wide range of the arc duration time. Moreover, we found the linearity between the arc energy and the value multiplied by the current and time. So, if we could see the same tendency, the number of the repeatability test can be minimized. * Right hand figure shows our test results, which had been executed under the arc current of the 20kA and 45kA. It seems that linear relationship between arc duration and arc energy were obtained, so we believe the influence of arc current will be negligible. => It may be caused by different test condition.(e.g. 20kA : non-seismic, 40kA : Seismic-proof, different cabinet, etc). We think that higher arc current results in higher arc energy during same arc duration. More detail data and test condition shall be provided to conclude that the influence of arc current will be negligible.	The test data will be evaluated and discussed at subsequent meetings to evaluate if current is a primary driver and parameter of interest in terms of arc energy.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

REVIEW / COMMENT DOCUMENTATION

Document # Rev: NRC-2017-0168 **Date:** 6/18/2018 **Title:** High Energy Arcing Faults (HEAFs) in Electrical Equipment Phase 2

Comments shall be:
* CLEARLY STATED AS A MATTER OF FACT (OR A SPECIFIC QUESTION)
* LEGIBLE AND REPRODUCIBLE
* COMPLETE AND INCLUDE A REFERENCE TO THE AFFECTED DOCUMENT
* FOCUSED TO A SPECIFIC PROBLEM OR DEFIENCY

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6	CRIEPI	Scope Change for OECD	Table 5	Comment: The use of aluminum for bus duct material will not be realistic. Opinion: In Japan, we have no use of bus duct made of aluminum. So, copper bus with Al enclosure or Al bus with Al enclosure can be eliminated to optimize the test matrix.	Initial indications from the USA indicate that bus bars very commonly use aluminum housing materials. The bus bars and use of aluminum housing has been shifted primarily towards the US only portion of the test program.
7	CRIEPI	Change to Section 6-Addition of circuit breaker	6	Comment: Use of CB is essential. Opinion: In Japan, all of our HEAF tests is compatible to the standard or code approved internationally. So, to assure the reliability of the test results, the use of CB should be important.	See NEI comment #5
8	CRIEPI	No changes	7	Comment: The feasibility of the measurement should be considered. Opinion: The same comment as #3.	See CRIEPI comment #3
9	CRIEPI	No changes	7.6	Comment: Compartment pressure measurement will not be necessary. Opinion: As many arc test had been executed in the closed condition world-widely, and the empirical formula and the numerical tools have been developed, the literature works will be enough.	New pressure measurement techniques will be use for Phase II of testing. Recent U.S. operating experience has shown the importance of room pressure build up for room integrity.
10	CRIEPI	Change to Section 6-Addition of circuit breaker	8.1	Comment: Use of CB is essential. Opinion: The same comment as #7.	See NEI comment #5
11	CRIEPI	Parameter Change	Table 8	Comment: Reconsider the test parameter Opinion: Application of higher voltage will be preferable. By applying unique current level, the expected arc energy should be selected as a dominant parameter.	The test matrix was designed to include experimental repeatability with the study of HEAF at low and medium voltages and the influence of aluminum. In order to have a reasonable number of experiments, the nominal voltages needed to be limited. The NRC staff performed parameter search on a limited number of available U.S. operating nuclear power plants (NPPs) to determine appropriate parameters for voltage and current. That sample plant data can be found at ADAMS #ML18081B300. The final test plan reflects testing being performed at 480V-6.9kV and 25kA-32kA respectively to accommodate all members.
12	CRIEPI	No changes	General	Comment: Optimization of the test program Opinion: In Japan, HEAF requirement was newly imposed in 8th August. So, Japanese industries are obliged to execute the good number of the HEAF tests using the high and low voltage switchgears	See NEI comment #6

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				to demonstrate the design base condition. From Japanese industry side, considering the financial aspect and the avoidance of the duplicable research activities, we are expecting the original outcome, especially for the appropriate methodology to setup the ZOI for 1st and 2nd HEAF phenomena under the international consensus.	
13	CRIEPI	Scope Change for OECD	General	Comment: Financial aspect Our possibility: CRIEPI will participate as a representative of Japanese utilities. As annual payment in FYH2018 seems to be difficult due to the late negotiation with stake-folders, CRIRPI can only bear the budget by annual installment payment through FYH 2019 to 2021.	Scope reduced for OECD members. Reflected in the test matrix.
1	EPRI	No Changes	General Comment	Further exploration into aluminum oxidation has been noted in the test plan without specificity. From the published test reports, significant aluminum oxidation was only observed in test conditions imposing severe arcing methods (i.e., extended duration faults beyond the rating of switchgear and breakers). This test plan should investigate the threshold at which there is potential for significant oxidation of aluminum to occur. For example, in NUREG/IA-0470 only two out of seven cases had higher energy release by the oxidation than by the arc, so scenarios with postulated high oxidation were less common. Potential factors to consider include; rated short-time withstand current, credible arc location, loss of primary breaker, and proper operation of back up breaker.	The proposed test plan will investigate the range of credible arc faults and durations experienced from a review of operating experience. Short duration faults i.e. 2 second arcs will also be explored for the aluminum oxidation effects. All tests will assume the loss of the primary breaker or an alignment where no breaker protection is available allowing for extended duration arcing events. Threshold values such as minimum voltage to sustain an arc or minimum duration to evaluate oxidation levels is currently not feasible with the amount of tests described in the test program to evaluate primary parameters of interest. Particle collection and post test analysis will be explained for the full scale series.
2	EPRI	No Changes	Page 8, Section 1: *Background* [2nd paragraph]	The PIRT list was ordered by priority (high importance/low state of knowledge). The first scenario, which is presumably one of the most important scenarios is “HEAF occurring in an electrical enclosure with a cable tray passing over the enclosure.” This scenario is not addressed in the test plan. The test plan should be modified to include testing of electrical enclosures with overhead cable trays. Sufficient testing of this equipment could provide valuable information concerning the potential ZOI validation.	Limited amounts of damage information was obtained by mock cable tray arrangements in the first phase of testing. No cable trays will be added to the test plan. It was decided to measure more scientific Heat Flux information will be collected at various locations around the electrical enclosure to collect exposure data which will then be applied to different target fragility information. Cable coupons will be positioned on the instrumentation test racks.
3	EPRI	No Changes	Page 8, Section 1:	“Arc mitigation” - The test plan does not acknowledge protective devices (e.g., circuit breakers) as arcing mitigation devices. Circuit breakers are acknowledged by IEEE Std. C37.20-2007 as arc duration	See NEI Comment #4

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			Background [3rd bullet]	limiting devices with some tests utilizing the breaker to control the arc duration. The test plan should include a discussion on why protective devices are not considered in the test plan for arc duration control.	
4	EPRI	No Changes	Page 9, Section 4: *Experimental Approach*	The test plan should investigate if medium-voltage switchgear (equipped with either a copper or aluminum bus bar) can tolerate a HEAF per IEEE Std. C37.20-2007 guidance. The test plan should be modified to include two control specimens; one medium-voltage switchgear containing copper bus bars and one containing aluminum bus bars, respectively, to be tested per IEEE Std. C37.20-2007 using a protective device (circuit breaker) or other IEEE acceptable method to limit the arc duration to 0.5 seconds using 24 AWG arcing wire.	No tests will be performed at durations below 2 seconds. The purpose of the tests is not to validate performance according to the EEE Std. C37.20-2007 guidance.
5	EPRI	No Changes	Page 9, Section 4: *Experimental Approach*	It is important to understand the phenomenological causes and impacts of differences between copper and aluminum oxidation in HEAF scenarios. It should be confirmed in the test plan that the electrical cabinets containing aluminum bus bars and copper bus bars will be identical with respect to design, dimension, etc. with the exception of the bus bar material used (i.e. aluminum bus or copper bus). This is critical to the investigation of the aluminum oxidation phenomena.	The tests will be performed as close to identical as possible in an attempt to limit variability for comparative purposes.
6	EPRI	Change to Section 4.1- Wire Size	Page 9, Section 4.1: *Arc Initiation/Location* [1st paragraph]	IEEE Std. C37.20.7-2007 & Corrigendum 1, Clause 5.3 states the arc shall be initiated by a 24 AWG copper wire for medium voltage gear. The test plan specifies the use of 10 AWG copper wire for medium voltage gear, and yet references IEEE Std. C37.20.7-2007. The test plan should address the change in wire size and basis (or justification). Corrigendum 1 also states the wire should be ASTM Class K fine strand.	Medium voltage arcs (>1000V) will be initiated using a 0.51 mm diameter (24 AWG) stranded copper wire, strung across the three phases of power within the electrical cabinet, at the desired initial arc location per the IEEE guide for Testing Metal-Enclosed Switchgear
7	EPRI	No Changes	Page 9, Section 4.1: *Arc Initiation/Lo*	The test plan states operating experience from HEAF events will be used to select representative arc locations within the enclosure. This departs from IEEE Std. C37.20.7-2007 Section 5.3 that states the point of initiation shall be located at the furthest accessible point from the	The NRC used the guide as the basis for the initiation of the arcing events but the investigation differs from the goals of the IEEE guide. The NRC testing is attempting to replicate OpE events and has different goals than the IEEE guide. All

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			cation [1st paragraph]	supply within the compartment under test. What is the basis for the deviation from the standard? The concern with this approach is allowing electrical enclosure modifications (similar to the MCC Tests 1, 2, and 3 in NUREG/ IA-0470 that removed up to 24" inches of arc chute to achieve the targeted arc duration). Test plan should require for every change in arc initiation location as to which OE event is based off, of or if it is intended to be exploratory and not representative of a credible scenario (e.g., enclosure modification). Additionally, the test plan should include documentation of enclosure modifications. This would include an assessment if the modified gear remains representative of a typical, actual plant installation. For example, in NUREG/IA-0470 Section 3.3 MCC Tests 2 and 3, removed 24" of arc chute to allow the arc to continue for the full duration of 2 seconds. This is an example where this modification is not representative of actual installation.	cabinets tested will be representative of a credible scenario with limited modifications. The NUREG/IA-0470 series tests were performed by JNRA and contractors with a specific phenomena under investigation. Minimal cabinet modifications will take place and all will be documented in the test report.
8	EPRI	No Changes	Page 10, Section 4.2: *Arc Current/Voltage* Page 11, Section 4.3 *Duration* Page 16, Section 5 *Experimental Facility*	Additional parameters of the KEMA power source should be captured to determine IEEE fault parameters. This data can be used to correlate to actual station short-circuit behavior. The test plan should model the capability and expectations of the KEMA Laboratory power source (not just current amplitude and duration) so IEEE fault parameters can be determined (e.g., ½ - cycle, 5-cycle, and 30-cycle currents, voltage profile, and X/R for the test configuration).	All KEMA power source parameters will be documented and reported in the final test report.
9	EPRI	Change to Section 4.3-Test Durations	Page 10, Section 4.3: *Duration* [1st & 2nd paragraphs]	In regards to the OE statement that protective devices have not always worked as designed. That is a credible failure scenario. However, it should be acknowledged that the backup protection (e.g. next upstream breaker in a selectively coordinated system or "breaker failure" scheme) is expected to operate to clear the fault (which the design factors in the additional clearing time when selecting equipment ratings). According to the durations proposed (and also tested in Phase 1), the testing makes an implicit assumption that both primary and backup breaker protection has failed. From EPRI's review of operating	The test duration parameters are based on OpE both US and international. There is one international operating experience event documented in the OECD FIRE Project - Topical Report No. 1 (http://www.oecd-nea.org/nsd/docs/2013/csni-r2013-6.pdf) that experienced and 8 second fault duration. The backup protection device timing will be associated with the fault current and resistance which is largely an unknown parameter.

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				experience, the majority of long duration faults are due to generator coast down. There have been limited instances (2-3 events) in the operating history in which primary and backup protection have failed, representing multiple failed barriers. Characterizing all HEAFs in this manner (all protection has failed) is bounding, but is excessive considering all HEAF events. The use of bounding data in probabilistic risk assessment is troublesome as the testing is set up to represent the less likely / higher consequence scenarios. The testing should represent the range of expected outcomes and not the most severe. Aside from the Fort Calhoun event (which may be described as a sputtering fault), what is the basis for the extensive durations in the 480 V tests? Are the durations chosen based on operating experience or capabilities of the laboratory power source? Recommend that the duration parameter for the 480 V tests be re-examined to better cover the range of scenarios expected.	Based on the April 18 -19, 2018 NRC public workshop the test plan has been modified to reflect that the majority of the low voltage testing will be performed on the 2 to 4 second range cases. This provides a better representation of the low voltage arc conditions from operating experience and will provide 1 to 1 comparison points between the low and medium voltage scenarios. There will be limited number of low voltage cases tested at durations longer than 4 seconds. These extended duration low voltage tests will be used as data points to extrapolate potential damage conditions for the medium voltage conditions where extended duration events can be postulated based on plant design. The arc duration has been documented as a primary parameter of interest in both the PIRT report and through extensive discussions at the April 18 -19, 2018 NRC public workshop and will support improvements to modeling techniques which can be used to determine scenario specific HEAF damage states.
10	EPRI	No Changes	Page 11, Section 4.3 Figure 1 Figure 2	The draft test plan proposes arc duration of up to 8 seconds for low voltage enclosure testing, up to 4 seconds for medium voltage enclosure testing, and up to 3 seconds for bus duct testing. These proposed arc durations exceed typical switchgear and circuit breaker short-time current withstand ratings and IEEE C37.20.7- 2007 test guidance as follows: · Switchgear short-time current withstand rating is typically 2 seconds · Circuit breaker short-time current withstand rating is typically 3 seconds. · IEEE Std. C37.20.7-2007, Section 4.3 states preferred arc duration of 0.5 seconds. Test durations greater than 1.0 seconds is considered unnecessary. Test results may not be meaningful and applied if they exceed both equipment ratings and IEEE arc testing guidance. Similar to the comment for page 9, Section 4 “Experimental Approach”. The test plan should be modified to include two control specimens; one medium-voltage switchgear containing copper bus bars and one containing aluminum bus bars, respectively, to be tested per IEEE Std. C37.20-2007 using a protective device (circuit breaker) or other IEEE	See HEAF definition- The NRC is not attempting to replicate industry qualification tests. All test information will be used to create a methodology that can be applied to durations of various lengths of time. The full spectrum from 1-8 seconds will be investigated in order to develop a comprehensive HEAF methodology.

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				acceptable method to limit the arc duration to 0.5 seconds using 24 AWG arcing wire.	
11	EPRI	No Changes	Page 11, Table 2: *Metrology*	Strength: The use of a wide variety of M&TE to record and monitor the HEAF event. This is a significant improvement over the IEEE Std. C37.02-2007, Section 5.4 "*Indicators (for observing the thermal effects of gases)*".	No response required
12	EPRI	Change to Section 4.1 - equipment ratings not to be exceeded	Page 12 regarding "…possible variations in equipment …" and Table 3	Test plan, nor Table 3 include the short-time current withstand rating of electrical cabinets and bus ducts selected to be tested. Therefore, it cannot be ascertained if the arc exposure (magnitude and duration) are within the equipment ratings. Include short-time current withstand rating of electrical cabinets and bus ducts to verify that the test current amplitude is within equipment ratings, or if not within the equipment rating, provide basis/reason for exceedance.	All tests will be performed within the electrical cabinet equipment ratings, and the equipment ratings will be reported in the final test report.
13	EPRI	No Changes	Page 12, regarding "…possible variations in equipment …" and Table 3	Gauge of electrical cabinet is not mentioned in the test plan. Gauge of electrical cabinet should be addressed in the test plan and selected to be representative of the entire line (e.g. thinnest gauge).	Electrical enclosures will be procured based on recommendations from the April 18 -19, 2018 NRC public workshop and are intended to be representative of the current NPP operating fleet. Electrical enclosure specifications will be shared with EPRI under the NRC MOU prior to testing and all parameters will be documented in the final report.
14	EPRI	No Changes	Page 12, Table 3: *Potential experiment al variables*	Table 3 is not specific to the combination of delta & wye systems and grounded vs. ungrounded (floating). It should be confirmed that the intended the test power connections will represent typical plant configurations. Ungrounded delta systems are used in nuclear power plants; however, unground wye systems are uncommon. The test plan should be updated to clearly define the specific power supply configurations and grounding methods to be used (including cabinet grounding). IEEE Std. C37.20-2007 Sections 5.1.1.d, 5.1.5.d, and 5.2.6 provide additional guidance on grounding connections.	Power system configuration and grounding configuration were determined to be a minor parameter of importance at the April 18 -19, 2018 NRC public workshop. The final report will document the specific power supply configurations and grounding methods used in each test series.
15	EPRI	Test Parameters Change	Page 13, Figure 1: *Electrical cabinet experiment*	Figure 1 provides two current levels for the 480 V tests. The higher current outlined in tests D, E, F, P, Q, and R are listed as 32kA. Test plan should confirm that 32kA does not exceed the switchgear withstand rating for the device under test (DUT).	All tests will be performed within the electrical cabinet equipment ratings. The low voltage test will be tested at 15kA and 25 kA based on the NRC staff parameter search on a limited number of available U.S. operating nuclear power

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			al conditions		plants (NPPs). That sample plant data can be found at ADAMS #ML18081B300.
16	EPRI	Change to Section 6- Addition of Circuit Breakers	Page 16, Section 6: *Electrical Cabinets*	The test plan indicates that cabinet/electrical enclosure will be devoid of breakers: IEEE Std. C37.20-2007, Clause 5.1.1 "*Considerations for all equipment*" recommends minimizing the free volume. The absence of a breaker in the cubicle is unrepresentative of actual equipment configuration. This also presents an increase in free volume. Test plan should consider using a mock circuit breaker in the cubicle with the arc, even if the breaker is not used for arc interruption.	See NEI comment #5
17	EPRI	No Changes	Page 16, Section 6: *Electrical Cabinets* [2nd paragraph]	The test plan allows relocation of the arc wire if arc is not sustained for the desired duration (the arc wire may be moved to another location). Per IEEE Std. C37.20-2007, Clause 5.3, the point of initiation shall be located at the furthest accessible point from the supply within the compartment under test. The test plan should acknowledge this departure from the IEEE standard along with the basis. Arc re-location should address if the location is considered a credible fault initiation location (e.g. exposed metal surface in insulation transition points).	The test plan and report will acknowledge rational for moving the arc location. The NRC tests do not intend to replicate the IEEE guide.
18	EPRI	No Changes	Page 17, Section 7: *Instrumentation and DAQ*	There were many M&TE failures in previous HEAF tests (NUREG/IA-0470 and NEA/CSNI/R(2017)7). It should be confirmed that the M&TE lessons learned from: 1. NUREG/IA-0470, Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena. 2. NEA/CSNI/R(2017)7, Report on the Testing Phase (2014-2016) of the High Energy Arcing Fault Events (HEAF) Project have been incorporated in this Phase 2 test plan to ensure preventable sensor failures.	This is currently being taken into consideration by the NIST technical lead. The importance of reliable data measurement is a primary focus for Phase II of testing.
19	EPRI	Change to Instrument Rack Design	Page 18, Section 7.2, Figure	The mesh size of the instrument rack does not appear to meet the guidance of IEEE Std. C37.20-2007, Section 5.4.3, which is approximately 3" x 3". The intent is sufficient area to allow gases to pass freely through the instrument rack. Figure 8 appears to cause	The test series will not replicate IEEE Std. C37.20-2007 for the indicator mounting racks. The instrument racks are being designed to allow for maximum pass through while maintaining a sufficient amount of instrumentation. The

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			8: *Slug Calorimeter*	unnecessary restriction. It is recommended to follow IEEE Std. C37.20-2007 for the indicator mounting racks. It eliminates one more variable to be accounted for in attempting to correlate results from the testing to IEEE Std. C37.20-2007.	instrumentation racks will use cross bars to mount instrumentation rather than a mesh design.
20	EPRI	No Changes	Page 20, Section 7.6: *Compartment Pressure Measurement*	The attempt to collect pressure measurement within sealed compartments deviates from the other objectives of the test plan (determination of escaping plasma and gases from the electrical cabinet and the conditions resulting in ensuing fires). If the proposed test is included, the test plan should state the purpose of the sealed compartment pressure monitoring as it relates to the other objectives of Phase 2 HEAF testing.	The test plan internal pressure measurements will be used to evaluate possible room pressure increases like that documented at Turkey Point Information Notice 2018-09 validate existing pressure models. The use of a sealed compartment is currently outside the scope of the current test plan and will be evaluated further based on the results of the internal pressure monitoring.
21	EPRI	No Changes	Page 20, Section 7.8: *Targets*	The NRC draft test plan does not include black cotton cloth targets as recommended by IEEE Std. C37.20-2007, Clause 5.4 "*Indicators (for observing the effects of thermal gases)*" as a comparison. It is recommended to include black cotton cloth targets as recommended by IEEE Std. C37.20-2007, Clause 5.4 "Indicators (for observing the effects of thermal gases)" for evaluation against IEEE Std. C37.20-2007 acceptance criteria. This provides an opportunity to observe the material's response to the more severe tests, while also providing an opportunity to directly compare to the control specimens subjected to the IEEE Std. guidelines.	The NRC tests do not intend to replicate the IEEE standard. The cloth targets are primarily used as indicators for PPE concerns such as protective clothing. While comparisons may be able to be made very little information as to the ZOI will be able to be gleaned from the IEEE cloth targets.
22	EPRI	No Changes	Page 23, Section 8.1: *Electrical Cabinet Setup*	First paragraph and Figure 15: It is not clear how the cable samples are prepared. The size, orientation, mass, cable jacket material, cable insulation material, and fire retardancy should be specified in the test plan.	Cable sample material and preparation will be fully documented in the final test report. Candidate cable coupon materials can be found in Table 3.1 and Table 3.2 of NUREG-7197.
23	EPRI	No Changes	Page 25, Figure 18: *Bus Duct Illustration – Continuity Break*	The non-segregated bus bar gap should be defined. Recommend specifying the bus bar gap dimension so that test results can be correlated to similar designs.	Electrical enclosures will be procured based on recommendations from the April 18 -19, 2018 NRC public workshop and are intended to be representative of the current NPP operating fleet. Electrical enclosure specifications will be shared with EPRI under the NRC MOU prior to testing and all parameters will be documented in the final report.

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24	EPRI	No Changes	Page 25, Section 9: *Experiment s*	Mass (weight & dimension) of the copper and aluminum bus bars should be captured prior to the experiments for post-test weight and dimension for accurately calculating the “lost” material due to oxidation. This will enable accurate oxidation calculation/assessments (e.g., Aluminum oxidation rate (30.9kJ/g of A2lO3). Note: Even if the test cabinets are already assembled, bus bar dimensions and weight could be obtained from the factory. Note: Post-test should also subtract any separated material that was not oxidized (e.g., melted splatter, separated fragments, etc.). Capture weight and dimension of the copper and aluminum bus bars pre and post-test to accurately calculate lost material due to oxidation.	Pre and post test measurements are currently planned for this test program to capture the weight and dimension of the bus bar material.
25	EPRI	No Changes	Page 28: *References*	NUREG/SR-XXXX “*An International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arc Faults (HEAFs) DRAFT*” has not been published. Due to its importance in the creation of the HEAF Phase 2 test plan, it should be published as soon as practical.	An International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arcing Faults (HEAFs) (NUREG-2218) was published in January 2018 and can be found at https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2218/index.html
26	EPRI	No Changes	General Comment	Draft test plan does not provide the detail if any current transformers (CT) will be included as part of the electrical cabinets undergoing testing. Open circuit of CTs are problematic. If any current transformers (CT) are included in the mock test equipment, there should a requirement to short the CT secondary if they are in the primary current path.	Any CT's within the test enclosure will be shorted on the secondary or removed.
27	EPRI	No Changes	General Comment	Draft test plan does not specify recording ambient temperature prior to test. Consider recording ambient temperature prior to test.	All relevant ambient conditions will be monitored and reported in the Phase II test series including but not limited to ambient temperature, humidity, and pressure.
28	EPRI		General Comment	Items of concern-The first was inclusion of the Shearon Harris isophase event in the justification for the study. The concern is that the event did not involve a phase-to-phase fault (both phases that failed, failed to ground). While probably not the author’s intent, associating isophase (a non-safety related system) with a regulatory issue may cause concern on a licensee or outside observer that this design is subject to HEAF’s. This is not the case as the isophase design and that of the connecting components and relaying scheme preclude this from	This test program does not plan to specifically look at testing iso-phase HEAF events. However, operating experience shows that HEAF events in iso-phase systems are credible events. NUREG/CR-6850 Supplement 1 documents information including frequency, zone of influence and guidance concerning iso-phase bus ducts.

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				such an event. Additionally, the isophase bus, in my experience, is not located in an area that a failure would impact any safety-related equipment and thus should not be considered as being able to prevent a safety function to be fulfilled.	While many iso-phase systems are located in locations which would not impact safety-related equipment that is not universally true and should be considered as part of the PRA.
29	EPRI		General Comment	items of concern- The second area of concern is that three-phase bolted bus faults that were performed in Phase 1 and planned for Phase 2 do not appear to take in to account the impedance of the connected loads at the source or the termination. The energy of a zero impedance fault that is a concern would be limited by the configuration's impedance and is not really representative of actual plant conditions. My suggestion is that a reasonable impedance should be estimated and included in the test configuration to properly quantify the energy created by the experiment.	The KEMA power delivery system includes configurable impedances. While this may not represent all individual plant designs this information will be documented in the test report. This item was discussed in the April 18th-19th public workshop to deliver representative system currents, voltages and durations.
1	NEI	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	Since bus bar spacing is dependent on the gear that is available for testing, and can vary from what is installed at nuclear plants in the US, when the test results and PRA frequencies are documented the deviation in bus bar spacing with respect to those in IEEE 1584 and in the industry should be documented and evaluated.	For the large scale test program all bus bar spacing measurements, weights, and initial cabinet design specifications will be fully documented and reported in the test results. The cabinet procurement will be discussed with EPRI prior to full scale testing with the goal of being representative of equipment represented in NPP's.
2	NEI	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	The plan states that the test setup will be in an enclosure. Several figures depict the dimensions. If these figures are accurate, the enclosure is snugged up to the bus bar and will reflect the blast back on the bus bar, effectively doubling it.	Comment resolved in small-scale comment resolution.

REVIEW / COMMENT DOCUMENTATION

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3	NEI	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	No artificial enclosures should be used on end of buses. If the bus does not terminate in a cabinet, then do not cap the ends. The buses at the plants are generally long runs with no blanked off ends.	Per the discussions during the April workshop, the bus ducts will be terminated into a cabinet or follow a configuration similar to recent industry bus duct testing.
4	NEI	Addition of decrement curve for medium voltage tests will be considered for future addition to the test plan (pending information provided by EPRI)	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	The fault current profile utilized for testing at MV should resemble a typical generator behavior (ie. decrement curve). Typically MV gears have grounding transformers or grounding resistors on the neutral. This limits the phase to ground fault current to lower levels. Since NRC is performing phase to phase testing and the ground resistors only limit the phase to ground current, the testing procedure is not impacted by the presence of the ground resistor. However, presence of these phase-to-ground current limiting devices should be used to lower the probability of an arcing event at the MV voltage level	For the large scale test program a decrement curve (to be provided by EPRI) will be evaluated for future tests.
5	NEI	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	Consider matching the location of the instrument racks being used to monitor the HEAF to match the existing ZOI's that were used in 6850 and FAQ 35. The material coupons on the instrument rack should include both steel and aluminum.	For the large scale test program the material coupons to be used consist of aerogel, carbon tape and cable samples. There is no current plan to have or evaluate the material properties of steel or aluminum subjected to HEAF energy on the instrumentation stands. It is unclear from the comment what the intended purpose and outcome of such proposed effort. Rack location will be approximately in 3-foot increments extending from the side of the enclosure.

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6	NEI	Change to Section 4.1 - equipment ratings not to be exceeded	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	Regarding the tests exceeding equipment ratings, it seems the duration of fault currents would exceed the equipment ratings. Provide more specifics for this statement and the ratings discussed.	The proposed arcing duration for the large scale test program does not intend to demonstrate equipment ratings. The durations were selected based on operating experience. The April 2018 workshop led to a test plan change to reduce the number of low voltage tests to be performed at 8 seconds.
7	NEI	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	Provide specifics on the type of cables that will be tested, i.e., thermoset, thermoplastic, IEEE 383 or not, etc. Alternatively, include in the test plan the requirement to document the relevant properties of the cable(s) that were tested.	Candidate cable coupon materials can be found in Table 3.1 and Table 3.2 of NUREG-7197 and will be fully documented in the test report.
1	Beaver Valley Nuclear Power Station	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	In the overall general context of HEAF, prior industry experience has indicated that single phase arcing faults are much mote difficult to sustain than three-phase arcing faults. Experimental results in this area have indicated that arcing line to ground faults are characterized as a discontinuous sinusoidal waveform. Additionally, these tests have confirmed that single-phase arcing faults pass through a current zero twice a cycle during which time they produce no ionized arc plasma, which is required to maintain the arc current flowing. Comparatively, three-phase arcing faults, produce a constant source of arc plasma that can more easily maintain the arcing fault. However, evolving faults have been shown to manifest themselves originally as single-phase faults which subsequently . develop into multiple-phase faults. Based upon known evidence of fault evolution that involves different combinations of faulted phases, it is proposed that test sequence objectives be reviewed in the context of ultimately applying the results, or findings, to help identify what steps the industry should pursue that would improve methods to limit the energy of the postulated HEAF at its origination.	Based on operating experience three the testing will be performed by initiating a three phase arcing fault per IEEE Std. C37.20-2007. Threshold values and arc fault progression are not feasible with the current scope and number of tests. The goal of the test program is to evaluate the damage phenomena associated with the longer duration HEAF events which show progression to three phase faults.

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2	Beaver Valley Nuclear Power Station	Additional Instrumentation being considered	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	Another dynamic that is an extremely important aspect of HEAF involves magnetic forces created by induced currents. These magnetic forces have been demonstrated to have impelled wires upstream of the HEAF with enough force to damage insulation or tear the conductors from their terminations, creating additional short circuits. This sequence has been proven by means of stage fault testing in the industry which utilized high-speed film recording ·technologies· that captured the progression. Therefore, a correlation is desired to be quantified based on, HEAF experimentation objectives with respect to these magnetic forces and resultant ejected particle emission and physical movement. The Zone Of influence implications involving induced current magnetics is sought to be more formally addressed by means of HEAF test experimentation, which would capture and record these magnetic field forces (magnitudes and direction over time) with additional monitoring of consequential multiple short circuit events as a likely or credible manifestation, throughout the conduct of the testing. It is proposed that magnetic field monitoring instrumentation would thereby enable a more precise identification of specific switchgear design attributes that can be enhanced to address subsequent fault occurrences due to an originating HEAF.	Magnetic field monitoring instrumentation is a current area of additional instrumentation being evaluated with the potential of addition into the test plan.
3	Beaver Valley Nuclear Power Station	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	Historically there has been considerable experimental verification of only a minimal rise in conductor temperature with respect to HEAFs involving bare copper bus as correlated with the monitored arc travel rate. Moreover, with regards to prior insulated bus testing, the voltage gradients are well within the dielectric withstand capability of the bus's insulation system. It is desired that HEAF experimentations be designed that would deliver results to the industry that more precisely characterizes the performance insofar as the manner in which insulated bus structures extinguish the arc and therefore possibly minimize damage. That is, in the design of the HEAF test experimentation, it is desired that results afford more specific determination of the relationships between voltage level, insulation type, and construction where bus insulation may help extinguish or sustain an arc once established. At present, as applied specifically to the scenario of an arc "blast," (nomenclature borrowed from page 2 of SAND2018-0706 0) versus an arching "fault," there is an opportunity to expand present-day industry knowledge and understanding as to the degree that existing insulated bus in the 600- Volt class of equipment	Insulation material impacts towards the relationships between voltage level, insulation type, and construction where bus insulation may help extinguish or sustain an arc once established is not in the current scope of testing. The KEMA facility pre establishes a duration for the purpose of testing. Investigation of extinguishment factors is not currently feasible within the test matrix.

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#	Commenter	Change to Document	Document Number/ Section	Review Comments (Print)/Basis for Comment	Comment Disposition / Resolution
				appears to provide significant safety advantages over non-insulated bus.	
4	Beaver Valley Nuclear Power Station	No Changes	Comment Generated from Small Scale Testing FRN SAND2018-0706 O, DRAFT 0002	A more detailed elaboration or description of specific individual key test plan parameters should be itemized in the test plan in an organized format. Information is desired as to the HEAF parameter significance to be addressed as part of the overall test plan. For each HEAF parameter categorized in terms of its significance, there should be established the documented test plan steps to address each of the individual HEAF parameters. Such an identified HEAF parameter-specific significance or ranking would focus more directly upon the importance of the correlation between each of the separate test parameters (i.e., measured quantities, monitored components, etc.) with respect to the overall stated objective of the test plan. Along with this, and in association with each of the parameters identified by significance, a summary of test plan steps designed to address each of the parameters individually would then establish the effectiveness of how thorough the test configurations and actions would be in contributing to support the final test plan results or findings. Therefore, .supplementary HEAF test plan information and data would be broken down in an itemized format addressing stated test objectives in terms of the specific HEAF test parameter identification, and in association with this, the HEAF test parameter significr;1nce (or ranking in terms of its importance). Further insight would then be advantageous if test sequences are correlated and then summarized for each of the identified and ranked HEAF test parameters.	The current test plan was developed to highlight the parameters of interest based upon previous testing insights as well as information obtained during the International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arcing Faults (HEAFs) (NUREG-2218). Section 8.1 reflects the testing orientation to address the parameters of interest. Further explanation and an evaluation of the test results will be documented in multiple follow-on NUREG publications to analyze the data obtained and implement new method development.