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REVIEW / COMMENT DOCUMENTATION

Commenter: Kelli Voelsing **Phone:** **Document #, Rev:** SAND2018-0706 O, DRAFT 0002

Discipline/Department: EPRI **Date:** 5/4/2018 **Title:** Aluminum High Energy Arc Fault (HEAF) Particle Size Characterization Test Plan - DRAFT

Comments shall be:

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Comment No.	Document Number Section / Paragraph	Review Comments (Print)/Basis for Comment	Comment Disposition / Resolution	Change to Document
1	General	The test plan repeated discusses “particle” characterization. However, based on the various historic tests and analysis documents, the major concern appears to be the vapor cloud of aluminum that forms through high-temperature arcing and oxidation. It is not evident in the test plan how the intended instrumentation will support characterization of the vapor cloud. Recommendation: If the term “particle” – as used in the test plan – is intended to include vapor particles, this fact should be clarified. If the instrumentation is not geared toward characterizing the vaporized material while in the vapor phase, it is not clear how the test plan aligns with the identified concern.	From Section 1.1 Objectives: “The measurements from these experiments will be used to support development of a HEAF/Aluminum combustion energy balance model to characterize the HEAF hazard.” This model is intended to estimate the additional energy release from aluminum involvement during a HEAF event. Therefore, the test plan is NOT attempting to characterize the particles in the vapor cloud remote from the arc.	Clarification added to “overview of test plan” and “objectives” sections of the report.
2	General	Since the test plan objective is to better characterize the aluminum particle size, production, and morphology during a HEAF, the general reference to the IEEE Standard C37.20.7 is not relevant as the testing, setup, conduct deviates more than follows the IEEE guide. Examples include: • General/global reference: o Example: Section 2.2 “Experimental Setup”, first paragraph. ”Twenty tests will be performed per IEEE C37.20.7”. • Shorting wire gauge does not follow IEEE C37.20.7:	Agree. This was a mis-communication of the NRCs request to use common terminology from the guide “shorting wire” and not to follow the test procedure in the guide.	Test plan corrected to clearly document test procedure.

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		o Section 2.3, second paragraph states “wire per IEEE C37.20.7…”; however, o Sections 1.3 and 24 states shorting wire will be #6 AWG, which is a deviation from IEEE C37.20.7 (and cited by Section 2.4.3): □ 10 AWG for low-voltage gear □ 24 AWG for medium-voltage gear o Test plan provides no basis or reason from shorting wire size deviation. Recommendation: Stating up front that the proposed test plan is of a research and experimental nature regarding the behavioral characteristics of extreme/severe aluminum HEAF events and not intended to follow or meet the IEEE Standard C37.20.7 which is for the design and production of metal-enclosed switchgear.		
3	Page viii & §1.3	It is recommended that clarification be added to the “Overview of Test Plan” and Section 1.3 “General Approach” to describe how the results of this experimentation will be used. Recommendation:	From Section 1.1 Objectives: “The measurements from these experiments will be used to support development of a HEAF/Aluminum combustion energy balance model to characterize the HEAF hazard.”	Clarification added in overview of testing and section 1.3

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		Consider adding the following clarifications: • The small scale tests are not representative of actual installed equipment and thus test results are not intended to predict overall equipment performance during a HEAF event for actual electrical distribution system (EDS) equipment • The purpose of these small scale tests is to better characterize at a micro-level the phenomena of aluminum arcing (particle size, distribution, production, and morphology) so that instrumentation and test design for the OECD Phase 2 testing is optimized • The small scale test results should be used only for the intended purpose and should not be extrapolated to predict performance of actual equipment with respect to HEAF response or full-scale damage	This model is intended to estimate the additional energy release from aluminum during a HEAF event.	
4	Page viii	The word “configurations” is not the correct terminology in the following sentence: “The experimental setup was developed based on prior work by KEMA and SNL[1] for phase-to ground and phase-to-phase electrical circuit configurations". Recommendation: Revise sentence to read: “The experimental setup was developed based on prior work by KEMA and SNL[1] for phase-to ground and phase-to-phase electrical faults."	Agreed	Changed as suggested.

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5	§1.2, page 1	First paragraph: This paragraph implies that rate of HEAF events are increasing as a result of aging; however, there have been other non-aging causes have been attributed to failed barriers, human errors, and design errors (i.e., the HEAF would have occurred regardless of the age of equipment). Recommendation: acknowledging other HEAFs initiators such as multiple failed barriers, design errors, human errors, etc.	Document reference is in error. Reference document doesn't make such a statement.	Deleted.
6	§1.2, Page 1	The meaning of "holding rack" is not clear. Does "holding rack" refer to the breaker compartment or to the breaker stabs and fingers? Recommendation: Clarify the term "holding rack" according to standard electrical terminology.	Agree	Changed wording to switchgear sprouts and breaker main connections
7	§1.2, Page 1	Nuclear power plants contain primarily medium-voltage gear. There are not many, if any, greater than 35kV pieces of equipment within the plant. Recommendation: Revise sentence to state "NPPs within the United States (US) widely use medium-voltage bus bars which are typically housed within a bus duct or rated cabinet"	Agreed	Added sentence to clarify and changed high to medium where applicable

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8	§1.2, Page 2	Second paragraph, 5th sentence: What is meant by "*non-mechanical destructive forms as well"* as it relates to expanding the zone of influence (ZOI)? Recommendation: Recommend providing a non-mechanical destructive example	Agreed	Examples provided
9	Page 2	There is typically not high-voltage equipment within the plant. Recommendation: High–voltage equipment" should be replaced with "medium-voltage equipment"	Agreed	Changed to medium voltage where applicable
10	§1.2, Page 3	The fourth to last sentence in Section 1.2 discusses the use of the small scale test results to predict fundamental equipment failure criteria, specifically both ignition and functionality. Recommendation: This statement should be removed – the test configuration does not represent real equipment	Clarified. The intent is to capture information to inform critical flux (temperature) for ignition and failure of secondary equipment (cables). The current data used to inform the critical damage thresholds are limited and likely not applicable to the high energy short duration events.	Added clarification that this information is for target characterization and not source term characterization.

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		(either mechanically or electrically) and thus the small-scale test results should not be extrapolated to predict equipment performance. The small-scale tests should be used only for the intended purpose, i.e., characterize arc behavior and product formation for aluminum.		
11	§2.2, Page 5	The test plan provides detailed information about instrumentation but is general with respect to the actual test configuration/equipment. While it is understood that the primary purpose of the test is not to characterize the system response (electrically), the full electrical test configuration should be specified, including the power source, connecting cables, grounding, etc. The test plan does not address the extent to which the voltage, current, X/R ratio, system reactance, voltage and current wave shape, harmonics, DC offset, and electrical transients affect the outcome of HEAF events involving aluminum. Recommendation: The standard parameters associated with the electrical system analysis should be characterized to	The power system characteristic will be documented in the report of test.	New section added (2.14) to describe what will be included in the report of tests.

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		determine short circuit behavior and performance. This information should be readily available for the ACD Lab equipment (e.g., MacroAmp power supplies, HILO V & I sources, trek amplifiers, and Glassman power supplies).		
12	Figure 2, Page 6	Dimensions provided for the test mock-up have no units. Recommendation: Recommend identifying somewhere the units of measurement	Agree	A photo of the actual testing configuration replaced Figure 2. The dimensions are described in the text.
13	§2.4, Page 7	Are the bus bar dimensions 3 mm x 1 mm? This is not much larger than a rectangular metal rod. Recommendation: Verify bus bar dimensions in Section 2.4 and Table 1. Stated size in test plan is extremely small.	This is scaled testing, the bus bars are much smaller than what you find in the plant. The bus bar dimensions were scaled to scale the energy and to allow for more precise mass loss measurements.	No Change.
14	Table 1, Page 8	The proposed durations are too short to develop meaningful data and conclusions. HEAF events that have lasted for several seconds are the most challenging from a damage and aluminum oxidation	The purpose of this test is not to simulate the total energy release from a real event (duration), but to characterize the particles released during the arcing. The test objectives do not necessitate long	No Change

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		concern. The short duration tests will not create the same thermal environment as a real HEAF event, so it will be difficult to extrapolate any conclusions related to rate of erosion, size of particles, or percentage of eroded aluminum that oxidizes. As a point of reference, Stanback (1) derived a model of the amount of aluminum eroded during an arcing event. Stanback found the following relationship: $Y = 1.519E\text{-}6 \times I_{arc}^{1.5}$ Where; Y = burn rate of bus work, in^3/sec (1 in^3/sec = 16.387 cm^3/sec) I_{arc} = rms arcing fault current, A For the nine Sandia tests planned with aluminum electrodes, the median predicted lost aluminum is 0.035 cm^3 (0.002 in^3). That is 1 cm of the planned electrode. The worst-case test has a predicted loss of 0.56 cm^3 (0.034 in^3). That is not much material. As a comparison, in the worst medium-voltage test of HEAFs performed at KEMA, 2000 cm^3 of aluminum was eroded. (1) Stanback, H. I. J., "Predicting Damage From 277-V Single Phase to Ground Arcing Faults," IEEE	duration arcs, although the NRC acknowledge that long duration arcs have occurred in commercial nuclear power plants. Sandia and the NRC are aware of the literature identified, however, that literature makes no distinction or reference to a non-linear relationship among aluminum erosion rate and any parameter of interest (duration, current, voltage, etc.). The testing limitation on duration is one of the reasons why the bus bars have been scaled down in the testing. The NRC agrees that longer durations or broader range of durations would be beneficial, however, testing limitations will not support longer durations without having an effect on other parameters of interest (current, voltage).	

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		Transactions on Industry Applications, vol. IA-13, no. 4, pp. 307-14, July-August 1977. Recommendation: Perform longer duration tests. Instead of 4- and 8-millisecond durations, aim for durations of several seconds.		
15	Table 1, Page 8	Use the higher end currents to maximize erosion and match conditions of the most severe HEAF events. Recommendation: Test at one higher end current (either 12, 20, or 29 kA) to maximize bus bar erosion.	As discussed during the April HEAF workshop, the parameters of the testing related to system voltage would be minimized and a surrogate of bus bar gap spacing would be used instead. Revisions to matrix has increased the proportion of tests at higher currents and longer durations.	The Matrix has been revised to provide less system voltage level variation, to include bus bar gap spacing variation.
16	Table 1, Page 8	In Table 1, the following rows are missing whether the test is AC or DC: • Row 8 • Row 12 • Row 16 Fill in the missing table elements regarding AC/DC testing in Table 1 Recommendation:	Since these columns were redundant to other columns “DC current [A]” and “AC scaled current [kA]” the columns identified in the comment have been deleted. In its place a comment column has been added to indicate tests parameter comparisons.	Deleted column and replaced with comment column.

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		Fill in the missing table elements regarding AC/DC testing in Table 1.		
17	Tabel 1, Page 8	The durations of 4 ms and 8 ms are extremely short. These times are shorter than the fastest clearing time of any overcurrent protective device and hundreds of times shorter than the test durations of large-scale testing. Recommendation: Provide a technical basis to demonstrate that the test durations of 4 ms and 8 ms are adequate to support the test objectives.	The testing apparatus has these limitations. Preliminary testing using durations shorter than those specified in the test plan have been conducted and have shown bus bar mass loss and particle emission. Therefore, the durations specified in the test plan are adequate to develop arc generated bus bar particulate.	No Change.
18	Section 2.4, Page 8	The last paragraph of this section indicates that data collection will occur at 20 ms or lower. However, the arc duration (4 ms or 8 ms) is much shorter that the stated upper limit of data sampling. Recommendation: The data recording should be much faster than the test arc duration. This aspect of the test should be clarified, including the required sampling rate to meet test objectives. It is suggested that sampling should be at the micro-second level not millisecond level.	Agree	Sampling frequency changed in document.

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19	Section 2.4, Page 8	Last paragraph, what is meant by "…*which is consistent with personnel options from IEEE HEAF events*"? Recommendation: This cannot be understood as written. Recommend rewording for clarity.	Agree	The text was deleted.
20	Table 1, Page 9	10,000 V is not standard voltage. Recommend selecting a voltage in the medium-voltage range and use throughout test. Recommendation: Use standard medium-voltage range (either 4160V or 6900V) for test voltage.	Eliminated per discussion during April HEAF Workshop. 6.9kV will be used for majority of medium voltage and only a few 4.16kV tests will be used for comparative purposes.	Test matrix updated.
21	Figure 4, Page 11	Figure 4 description: "…analyzed by collecting **as** from the arc flash region…" should be "analyzed by collecting **gas** from the arc flash region". Recommendation:	Agree	Changed per comment

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		Recommend correcting typo.		
22	§2.10, Page 11	Many “XXX”x are used. Was this intended to be filled in later? Recommendation: Recommend updating when final test plan is issued.	Agree.	Discussion on aluminum alloy types was deleted and the aluminum alloy selected was justified.
23	§2.11, Page 11	Item 2 states that the “*Full event can last 1-4 seconds.*” Recommendation: Recommend updating the duration depending on the intended “*Target Arc-Duration*” in Table 1.	Information is not relevant. High speed video will recorded entire arcing event duration.	Clarified that high speed will record entire event.
24	§2.11, Page 12	2nd full paragraph (below the three bullets). “*agnostic*” appears to be a typo? Recommendation: Recommend correcting.	Agree.	Word changed to “diagnostic”

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25	§2.12, Page 12	Item 6: If applicable, consider expanding for specifics: • Melted slag • Ejected, non-melted fragments, shrapnel Recommendation: If there is the possibility of performing oxidation calculations (of vaporized/consumed material); the testing will need to collect all available non-oxidized material to ensure volumetric calculations are as accurate as possible.	Agree in part. The testing will collect bus bar fragments (parts and pieces) and document via measurement mass of those particles, however the suggested oxidation calculations will not be performed due to cost.	Added documentation and measurement of bus bar fragments (part and pieces).