High Energy Arcing Faults (HEAF) Working Group Status Update

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Purpose

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- Provide overview of NRC/EPRI working group (WG) activities and progress
  - WG Mission
  - PRA modeling approach / update
  - Lessons learned from operational experience review
  - Testing approach
  - Project Plan

NRC / EPRI Working Group (WG)
Charter

- Mission Statement
  - To improve understanding of risk from electrical arcing fault hazards in nuclear power plants (NPPs).
- Goals
  - Better understand key factors contributing to:
    - Occurrence
    - Severity
  - Advance HEAF fire PRA modeling
    - Based on experimental data, operating experience, and engineering judgement
    - Ignition frequency
    - Zone of influence (ZOI)
  - Analyze plant impact and risk implications
- Weekly Meetings

NRC / EPRI WG

Team

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EPRI

- Ken Fleischer (Fleischer Consultants)
- Dane Lovelace (Jensen Hughes)
- Shannon Lovvern (TVA)
- Tom Short (EPRI)
- Marko Randelovic (EPRI)
- Ashley Lindeman (EPRI)

NRC

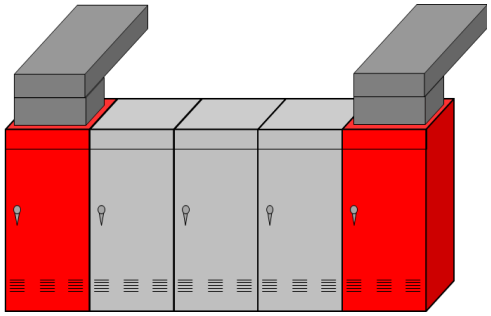
- Dr. JS Hyslop (NRC)
- Dr. Chris LaFleur (SNL)
- Nicholas Melly (NRC)
- Kenn Miller (NRC)
- Gabriel Taylor (NRC)

Project Managers	**Project Sponsors**
Kelli Voelsing (EPRI)	Tina Taylor (EPRI)
Mark Henry Salley (NRC)	Michael Cheok (NRC)

NRC/EPRI WG

Activities

- EPRI/NRC HEAF Methodology Report
  - Extensive OpE review
    - Fault Duration
    - Fault Location
  - HEAF Fire Ignition Frequency
    - 1E vs. Non-1E investigation
  - HEAF redefinition to fit OpE and modeling uses
  - Risk Model Development
    - Event Trees
    - HEAF Non-Suppression Curve
    - HEAF modeling guidance
    - Data Analysis



NRC/EPRI WG Activities

Operating History (OpE review)

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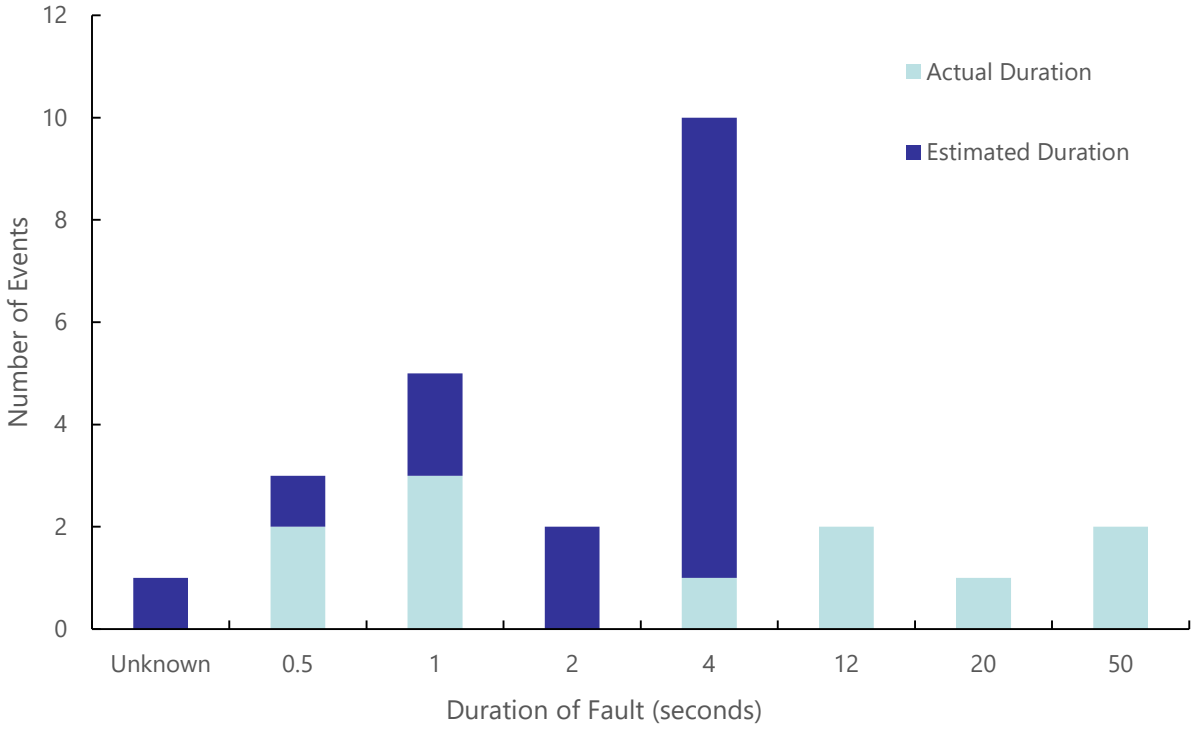
- Research and test durations are based on operating experience
- Millisecond fault occurrences are **not** part of the HEAF frequency bins
- OpE Review identified additional generator fed faults than previously known

Plant	Event	Event classification	Event Duration
Palo Verde (M Voltage)	7/6/1988	Arc Blast	**0.75 sec** (actual duration)
DC Cook (M Voltage)	7/13/1990	HEAF	Likely **≤0.5 sec**
Waterford (M Voltage)	6/10/1995	HEAF	**4-8 sec** (estimated: generator fed)
SONGS (M Voltage)	2/3/2001	HEAF	**4-8 sec** (estimated: generator fed)
Prairie Island (M Voltage)	8/3/2001	HEAF	**4-8 sec** (estimated: generator fed)
Robinson (M Voltage)	3/28/2010	HEAF	1st Event: **20 sec** (actual HEAF duration)
Robinson (M Voltage)	3/28/2010	HEAF	2nd Event: 3 Min high impedance fault followed by unknown duration HEAF event
Palo Verde(M Voltage)	7/3/2013	HEAF	Estimated < **2 seconds** (however, photo evidence that protection may have operated much faster)
Brunswick (M Voltage)	2/7/2016	Arc Blast	0.15 sec (estimated duration)
Yankee Rowe (L Voltage)	8/2/1984	HEAF	Unknown
Fort Calhoun (L Voltage)	6/7/2011	HEAF	**42 sec** (actual duration)
River Bend (L Voltage)	2/12/2011	HEAF	**12 Sec**

Fault Characteristics

Fault Duration



- Investigation of OpE event duration to ensure testing and modeling efforts representative

Evaluation of the US OE

Low Voltage

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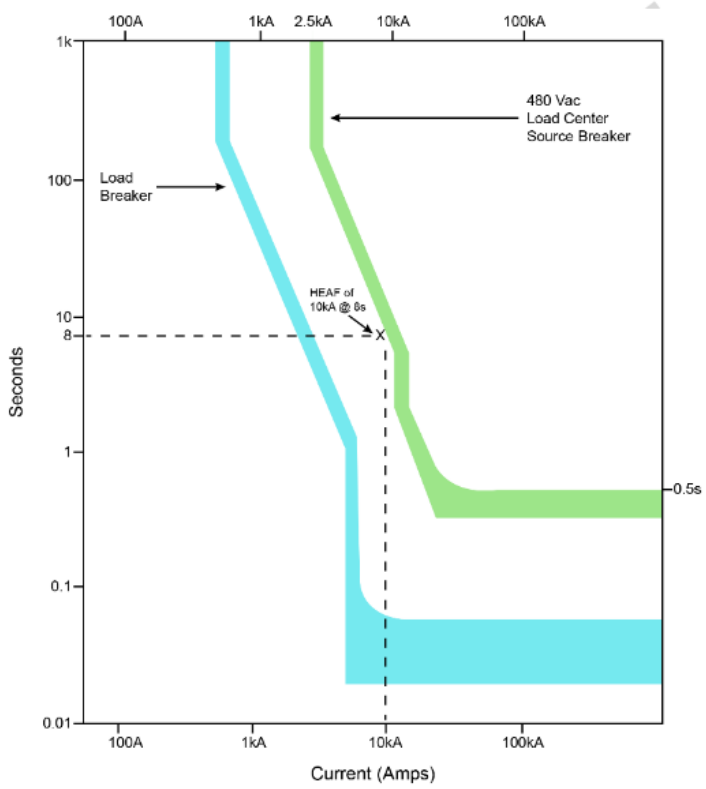
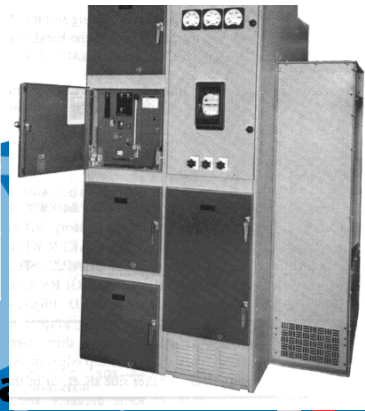
- Low voltage cabinets were procured using input and recommendations from the WG
- Testing parameters will be adjusted accordingly to mimic faults from OpE
  - Current WG activity to investigate typical protective device setpoints



Plant	Event	Event classification	Event Duration
Germany (L Voltage)	5/30/1986	HEAF	**8.5 Sec**
Yankee Rowe (L Voltage)	8/2/1984	HEAF	Unknown
Fort Calhoun (L Voltage)	6/7/2011	HEAF	**42 sec** (actual duration)
River Bend (L Voltage)	2/12/2011	HEAF	**12 Sec**

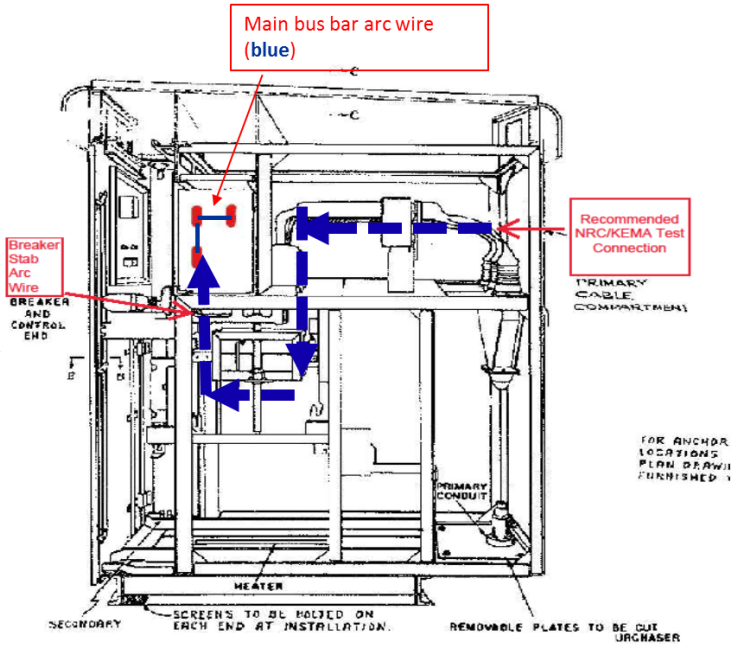


Ref. Westinghouse I.B. 33-790-1E

NRC/EPRI WG Activities

Testing- Supply vs. Load

- Fall 2018 testing followed IEEE guidance with respect to arc wire location and size
- Working group review of OE on medium voltage switchgear revealed
  - majority of the medium voltage switchgear events occurred in the supply switchgear configuration and involved main bus work
- Configuration and equipment type has been identified as parameters of interest
- Working group is currently discussing options to most accurately reflect realism in a testing environment



NRC/EPRI WG Activities

Frequency Review

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- Event Frequency classification
- Need for clear definitions
  - Subdivide Bin 16 (NUREG/CR-6850)
  - Arc Fault Class 1 (Arc Flash)
  - Arc Fault Class 2 (Arc Blast)
  - Arc Fault Class 3 (HEAF)
- NRC working with NFPA/IEEE & EPRI Working Group
  - Continued discussion to finalize definitions for arc fault events
- Updated frequencies for HEAF events to be developed by the NRC/EPRI HEAF WG to coincide with the ZOI methodology and event tree modeling approach

Arc Fault Classifications

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Protective System Performance (Duration)	Arc Severity Classifications	Arc Fault Class 1 (Arc Flash)	Arc Fault Class 2 (Arc Blast/HEAF)
	Arc duration limited by proper electrical protection design		
	Arc Fault Class 3 (HEAF)		
	Arc duration persists for an extended duration indicative of a level of circuit protection failure and/or protection design flaw		

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NRC/EPRI WG Activities

PRA Risk Model Development

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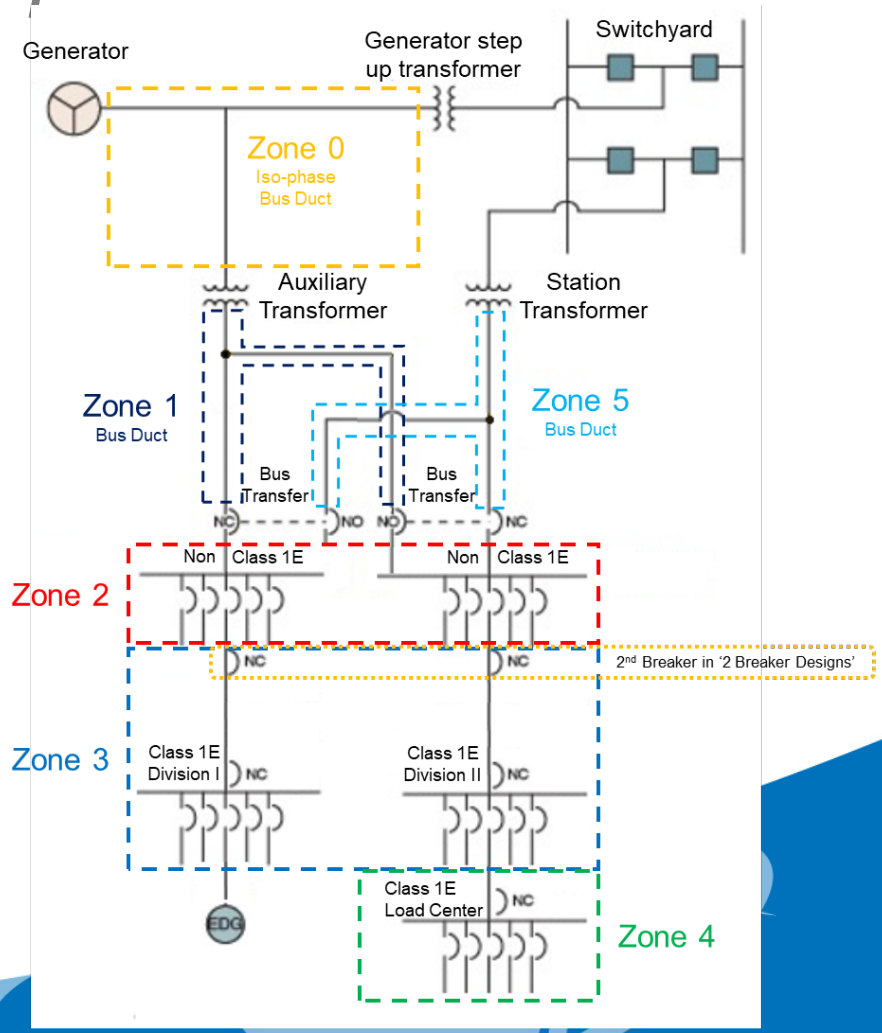
- Approach being developed by the WG to incorporate plant design with ZOI and HEAF susceptibility
- More accurate reflection of realism
- Major improvement over a one size fits all model
- Currently in the developmental stage with WG



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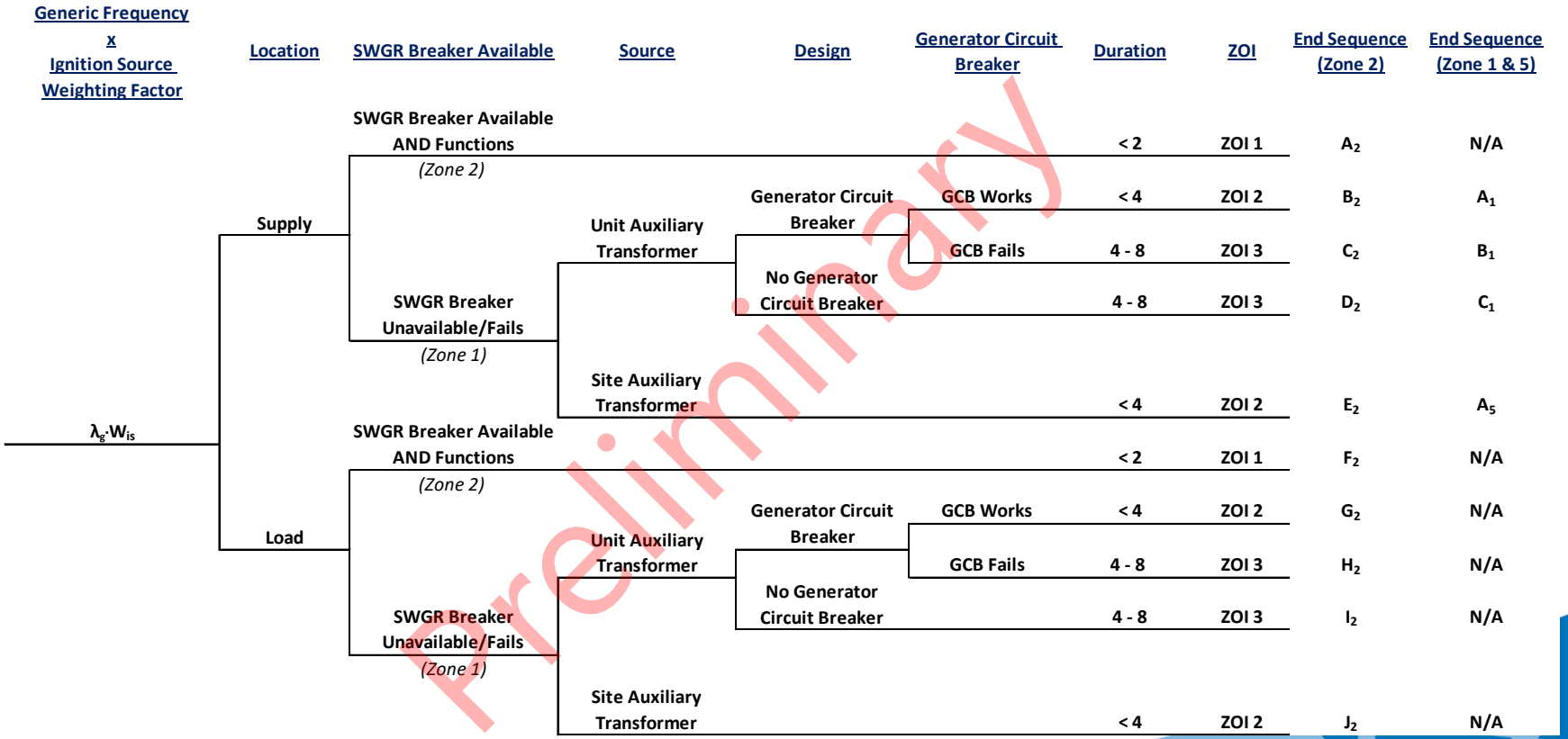
NRC/EPRI WG Activities

Risk Model Development



HEAF Phase II Testing

Measurement

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- Temperature and Heat Flux
  - Both parameters will be modeled at multiple distances away from the arc location
  - Will aid in a dynamic ZOI creation
  - Link to SNL Fragility criteria testing (to be discussed in the afternoon)
- Pressure (improved measurement techniques developed)
  - Potential to measure impact on room pressure currently being explored
- Damage Zone
- Furthest extent of damage
  - Thermal (i.e. ensuing fire damage / smoke damage)
  - Physical (i.e. thrown cabinet door, shrapnel)
- Conductivity
  - SNL Measurements
  - Other Options

HEAF Phase II Testing
Measurement (continued)

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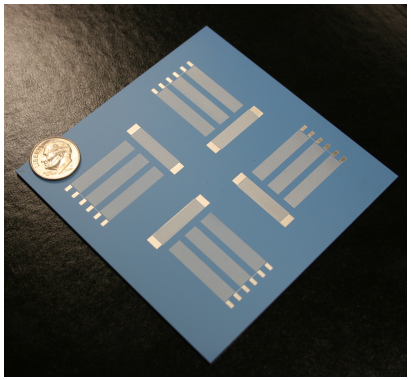
- Mass of Material Vaporized
  - Measurements pre- and post-testing to validate computer models and theory equations of vaporized material
  - Potential to develop approximate energy release models from classical energy conversion models
- Cable Sample Material
  - Cable samples placed at varying distances away from enclosure
- Byproduct Testing
  - Samples
    - Carbon Tape & Aerogel used in 2018
    - Carbon Tape & Silicon/Quartz in 2019
  - Conductivity measurements for aluminum deposited on surfaces
  - Spectroscopy
- Heat Release Rate (HRR) measurement is impratical based on lessons learned in phase I testing

HEAF Phase II Testing

Surface Conductivity Measurements

- SNL has experience with this type of measurement
- Surface conductivity
  - Passive measurements
  - Interdigitated resistivity measurement structures
    - Parallel conductive traces
    - Evaluate voltage holdoff/surface flashover properties
  - Concentric ring surface resistance measurement (ASTM D257)
  - This instrumentation will address the potential for failu of electronic equipment exposed to the arc ejecta or smoke generated by the HEAF event



HEAF Phase II Testing

Air Conductivity Measurements

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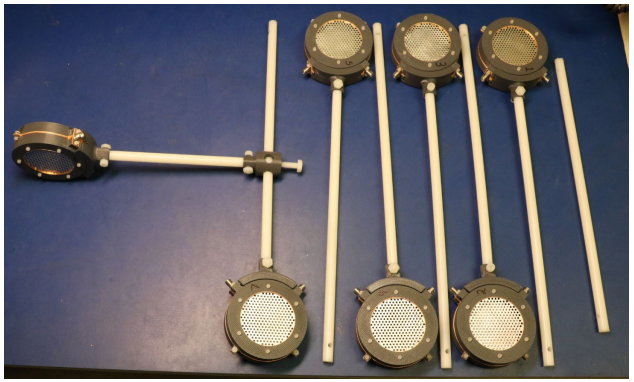
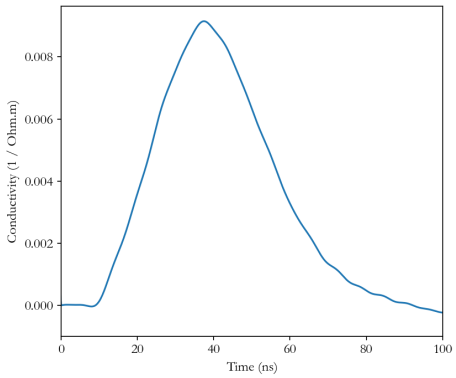
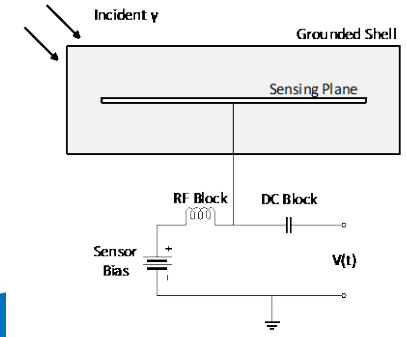


- Conductivity sensor
  - Active measurement
  - Mesh design for EMI rejection
  - Air conductance measured as voltage in circuit





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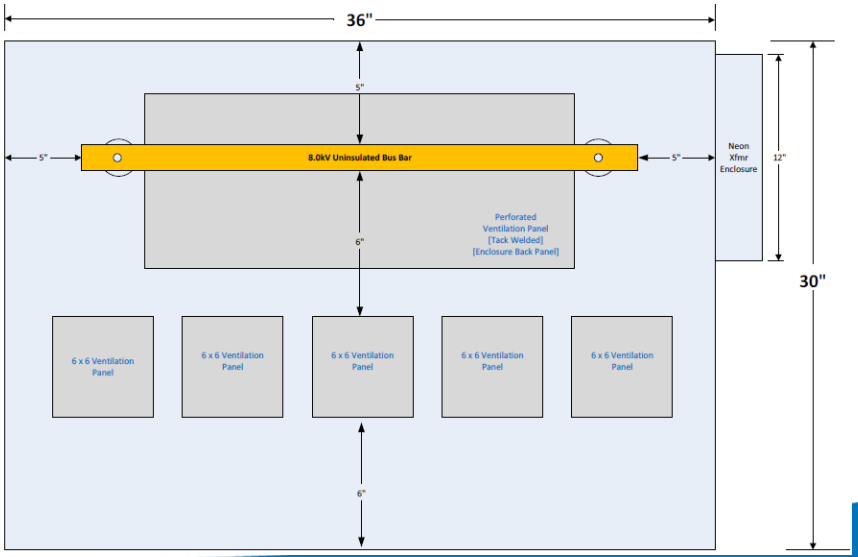
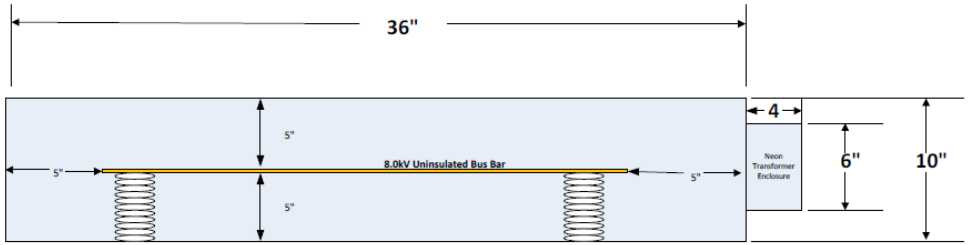
Mock Switchgear Test Unit

Evaluate flashover (arc-over)

- Purpose of the Mock Switchgear Test Unit (MSTU) is to verify if liberal amounts of aluminum combustion cloud byproduct/debris is sufficient to cause collateral damage (flashover) in nearby/adjacent medium voltage.
- To the extent practical, the MSTU is to represent typical switchgear with respect to voltage, bus bar spacing and standoff insulators to ground
- MSTUs are portable, re-usable and do not require excessive power
- Provides prototypical configuration to evaluate flashover





Mock Switchgear Test Unit

Evaluate flashover (arc-over)

- Design of the MSTU is based on a bounding approach to which type electrical distribution system (EDS) is most vulnerable to a flashover or tracking phenomenon out of:
  - Wye system (solidly grounded)
  - Wye system (resistance grounded)
  - Wye (ungrounded neutral)
  - Delta (ungrounded)
  - Uninsulated bus bars

HEAF Phase II Testing

Conductivity- Benefits and Limitations

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Type	Benefit	Limitation
Surface Conductivity	Known Measurement Technique Can measures hold off / break down in addition to surface resistance	Passive design Does not measure air conductivity Requires failure criteria of components which may require additional testing or engineering judgment
Air Conductivity	Active instrumentation	Limited number to deploy
Mock Switchgear	Close simulation of plant equipment	Bounding result (Exclusionary)

Phase II Tests

Electrical Enclosures

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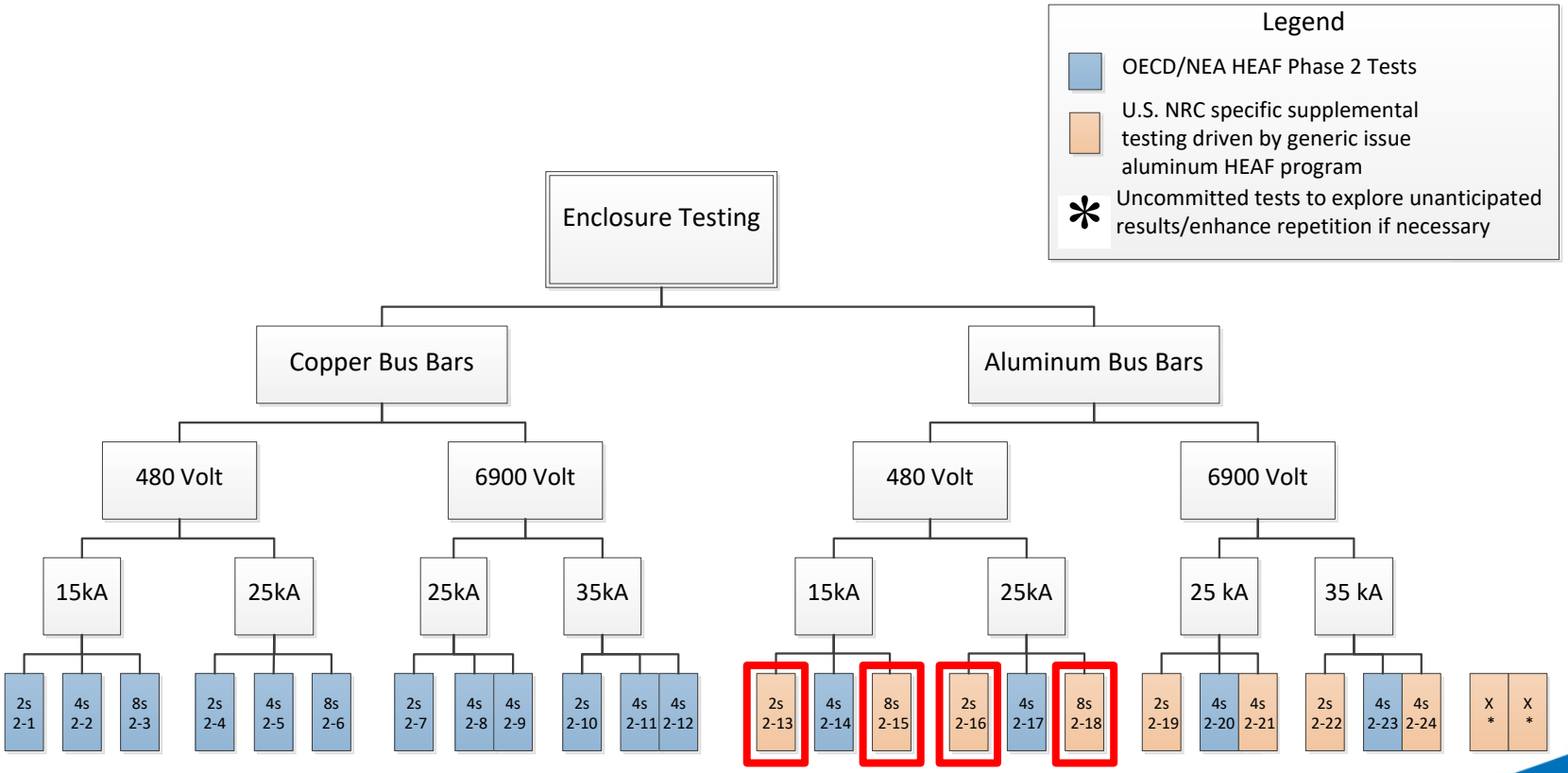

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Phase II Tests

Bus Ducts

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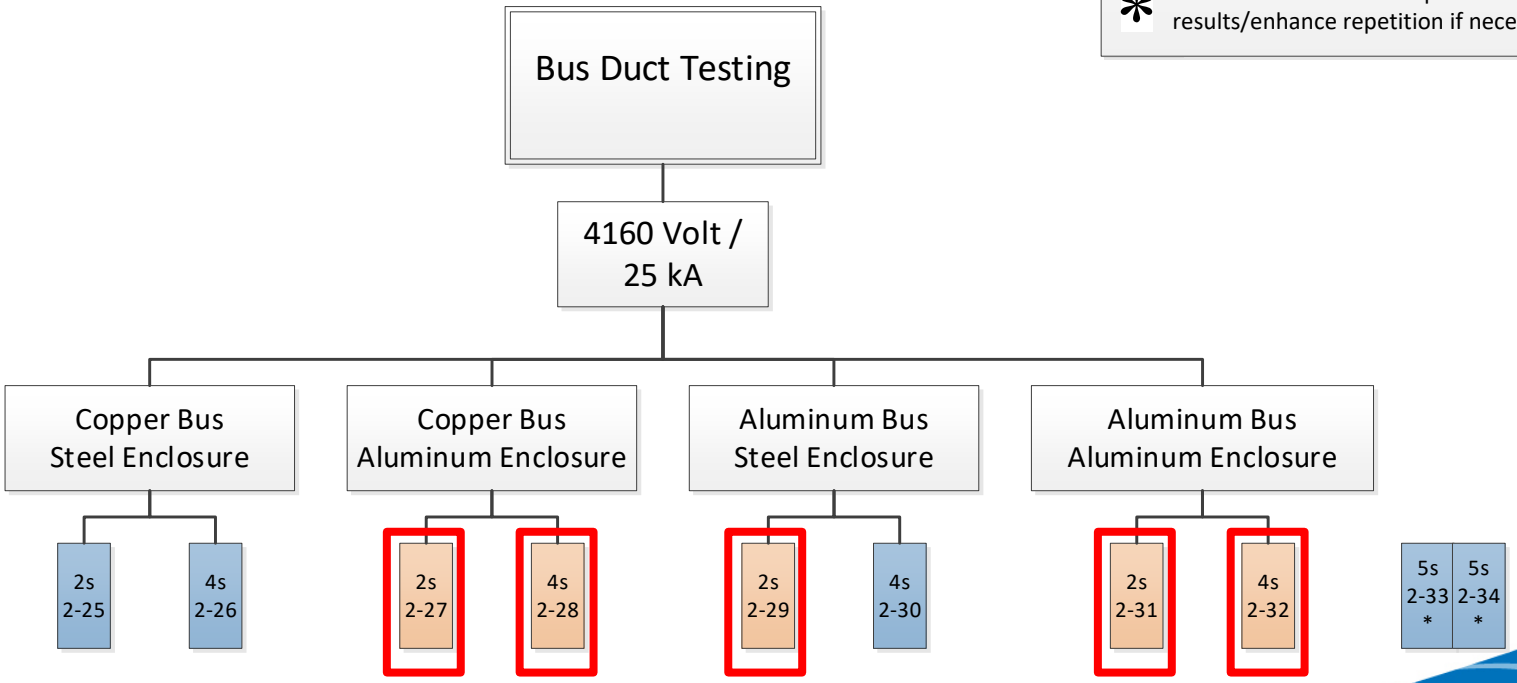
Legend
- OECD/NEA HEAF Phase 2 Tests
- U.S. NRC specific supplemental testing driven by generic issue aluminum HEAF program
- * Uncommitted tests to explore unanticipated results/enhance repetition if necessary



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Phase II

Test plan re-evaluation

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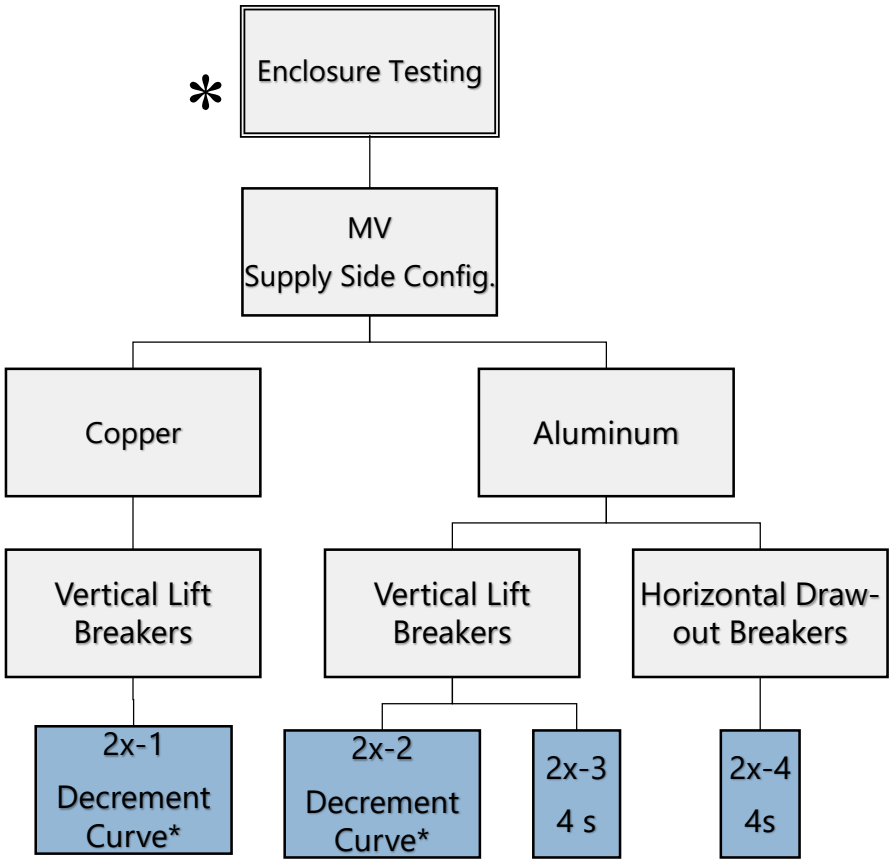
- New information used as identified to re-evaluate objectives of test plan
- Changes being proposed to focus on
  - Configuration
    - Arc location
    - Equipment design
  - Decrement
  - Arc Current
  - Duration

Phase II Tests

Electrical Enclosures- Spring 2020



- Focus of decrement curve testing is to be representative of NPP OpE and generator characteristics to determine appropriate testing conditions
- Decrement tests
  - 2x-1
  - 2x-2
- Confirmatory tests
  - 2x-3
  - 2x-4

* Working Group recommendations for both equipment procurement, test design conditions and applicability to plant realism has been incorporated into the upcoming Summer 2019 and Spring 2020 and test series and will continue to be actively incorporated into future testing

Project Plan

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- Project plan is being developed to capture all components of the HEAF research program and how they fit together
  - History
  - Scoping/Literature Studies
  - Phase I Testing
  - Small Scale Testing
  - Phase II Testing
  - Modeling and Analytical Work
- NRC webpage will be hosted for easy reference and tracking
  - This will be in addition to the Generic Issues Dashboard site