Generic Issue (GI) Program Status for PRE-GI-018 Related to High Energy Arcing Faults involving Aluminum

Kenneth Hamburger

January 23, 2019

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- First floor access okay without escort
  - Anywhere else requires NRC escort
- Fire and emergencies
  - Follow NRC staff/security direction

Meeting Logistics

- Meeting transcribed
  - Please identify yourself when speaking (every time)
  - Please speak into the microphones
- Webinar participation
- Facilitated
  - Keep the meeting on schedule and on topic
- Public comments

High Energy Arcing Faults Involving Aluminum Meeting Objectives

Mark Henry Salley, P.E.
Branch Chief
Office of Nuclear Regulatory Research
January 23, 2019

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Objectives

- Communication
- PRE-GI-018 status update
- Confirmatory testing to-date
  - Share some early observations from September 2018 medium-voltage tests
- Next series of confirmatory tests
  - Planning stages
  - Target date late summer/early fall 2019
- Draft NRC/EPRI Working Group charter
- Open discussion
  - Thoughts, ideas, and suggestions

Generic Issue (GI) Program Status for PRE-GI-018 Related to High Energy Arcing Faults involving Aluminum

Stan Gardocki
GI Program Manager
Office of Nuclear Regulatory Research
January 23, 2019

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GI Program Three Stages

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Issue submitted to GI Program

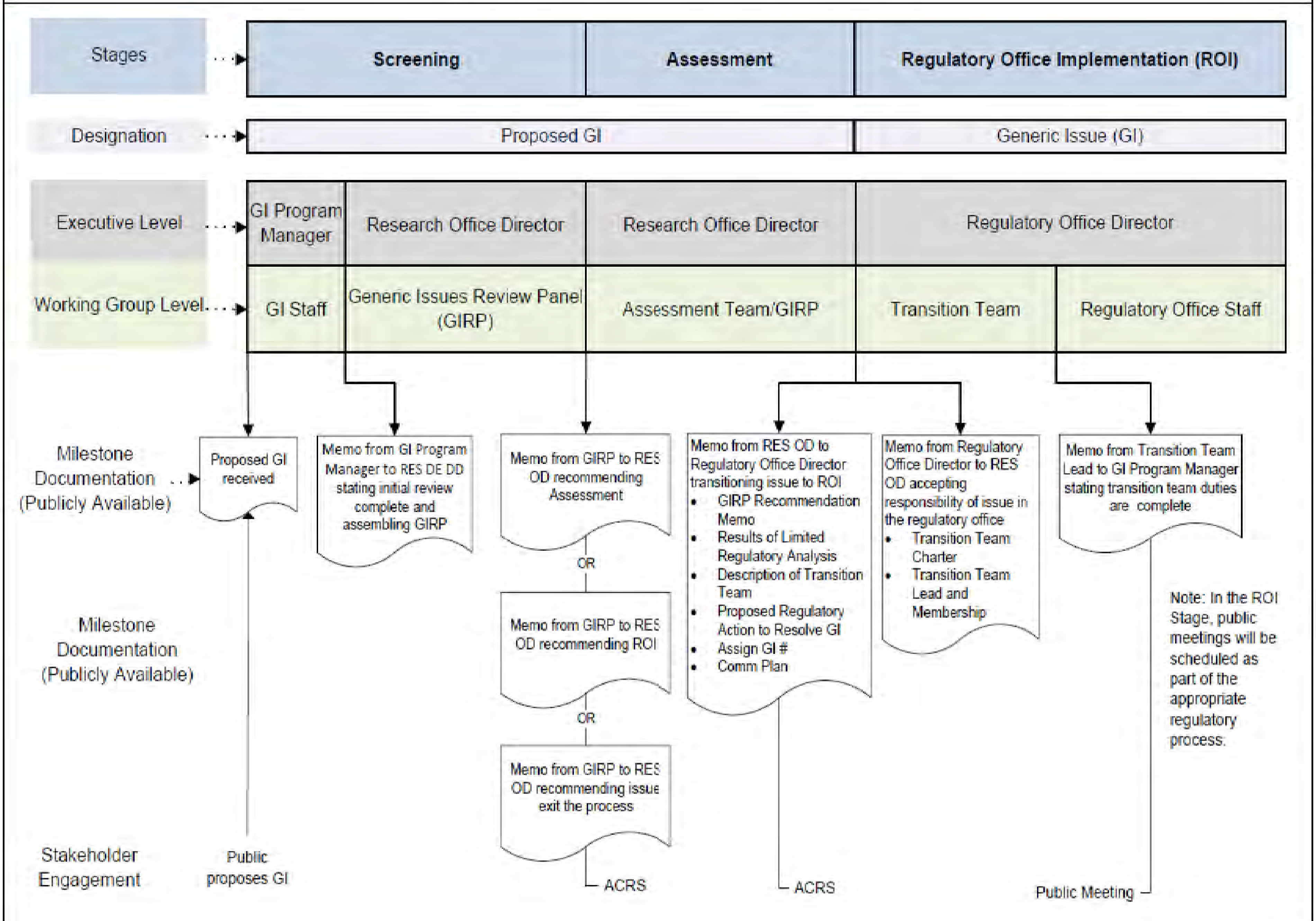
Screening → **Assessment** → **Implementation**

Issue exits program when issue fails to meet screening criteria, for example:

- Referred to other regulatory process for action
- Referred for additional long-term research

Or closed when licensees' actions completed and verified

Generic Issues Process Overview



PRE-GI-018 Activities To-Date

- March 4, 2016 - NRR performed a safety review and determined no immediate actions required (ML16064A250)
- May 6, 2016 - RES submitted into the GI Program (ML16126A096)
- May 17, 2016 - GI Program Staff initial screening complete, recommended forming review board (GIRP) (ML16132A415)
- July 15, 2017 - GIRP issued screening report that determined the seven screening criteria were met, recommended proceed to assessment stage (ML16349A027)
- August 22, 2018 - GIRP issued assessment plan (ML18172A185)

PRE-GI-018 Next Steps

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- GIRP will issue an Assessment Report to determine whether the issue should continue to next stage, regulatory office implementation (ROI)
- If yes, then a transition team is formed, issue moves out of RES into appropriate regulatory office, NRR
- NRR determines the necessary regulatory actions (example: issue appropriate generic communications)
- Based upon potential regulatory requirements (if applicable), licensees may have to take actions
- Based on potential regulatory actions, NRR will determine if public meeting will be held

Assessment Plan Timeline

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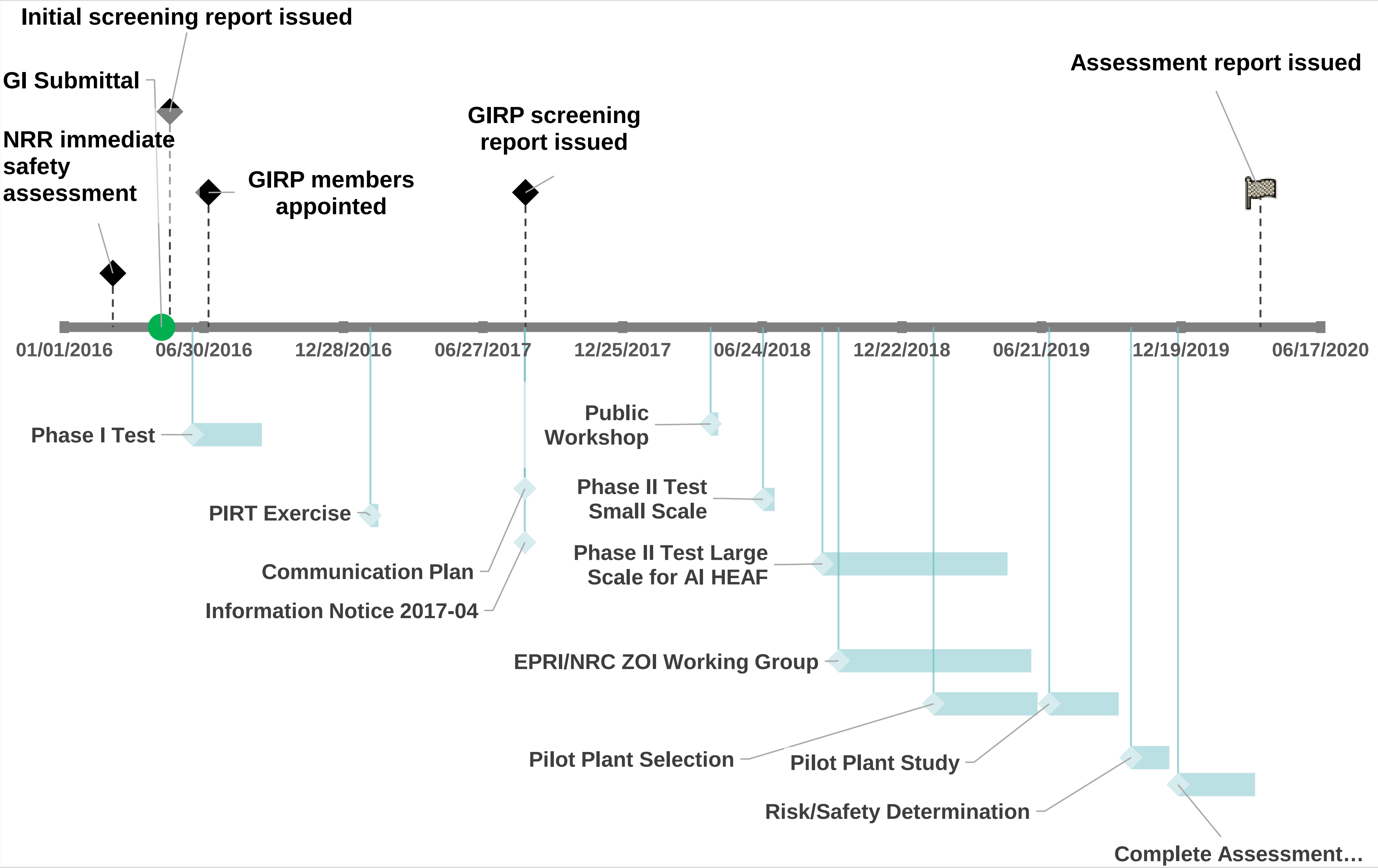

High Energy Arcing Faults (HEAF) AL Phase II Confirmatory Testing Preliminary Observations

Nicholas Melly
Office of Nuclear Regulatory Research
Division of Risk Analysis
January 23, 2019

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Purpose

- Provide an overview of the High Energy Arcing Fault (HEAF) confirmatory testing performed for PRE-GI-018
- Discuss preliminary insights and project goals
- Discuss future testing parameters, schedule and milestones

Phase II Draft Test Plan

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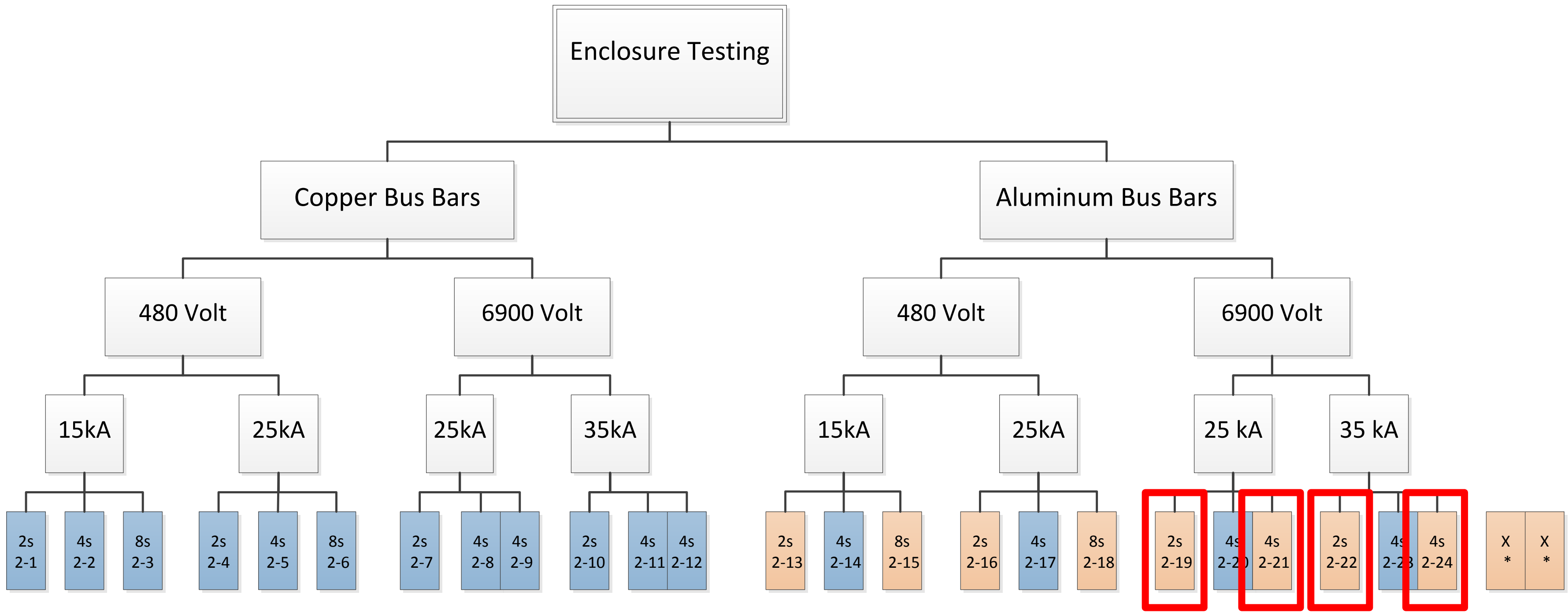
- Public Comment Period
  - OECD/NEA Phase I members for comment on June 30, 2017
  - Federal Register notice (82 FR 36006) published on August 2, 2017
  - Public comment period closed September 1, 2017

Phase II Draft Test Plan

- Official Public Comment Period
  - Federal Register notice (82 FR 36006) published on August 2, 2017
  - Public comment period closed September 1, 2017
    - 5 comments from NEI
    - 32 comments from OECD
  - 29 Additional comments received from EPRI on January 12, 2018
  - 28 Additional comments received from NEI on May 17, 2018
  - 4 Additional comments received from industry technical expert on May 17, 2018
- 98 comments received in total
  - International and U.S. Industry
- All comments dispositioned and publically released
  - ML18233A469

HEAF Phase II
Test Structure - Enclosures



Legend

- OECD/NEA HEAF Phase 2 Tests
- US NRC Specific Spplemental Testing driven by Generic Issue Aluminum HEAF Program
- * Uncommitted tests to explore unanticipated results/enhance repetition if necessary

Measurement Limitations

- Melting point of Inconel approximately 2,400°F (1,325°C)
- No measurement locations beyond 3 ft.

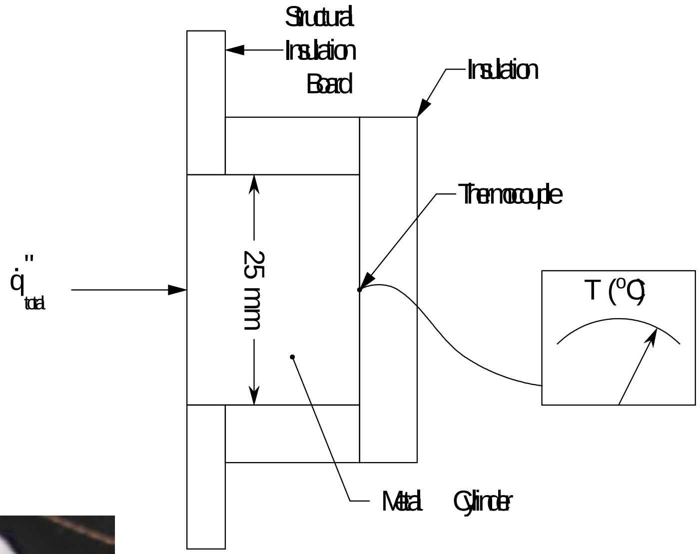
Before

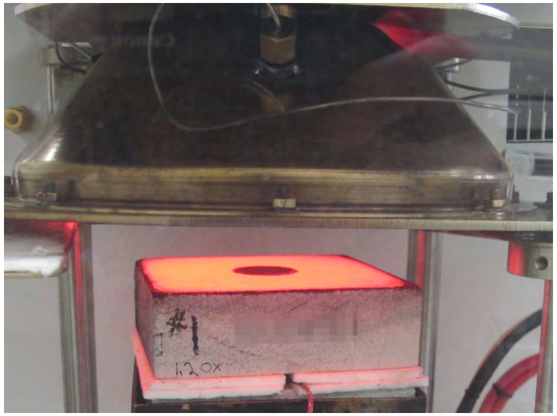
After

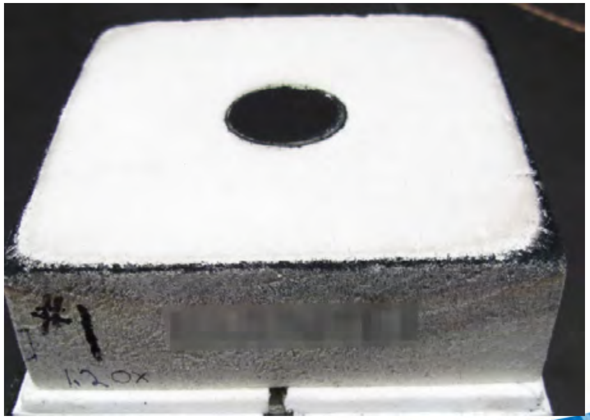
Phase II Improvements

Tungsten Slug Calorimeter

- 1 in. diameter tungsten slug
- Durable for high incident heat fluxes in direct arc plume environment
- Calcium Silicate insulating board



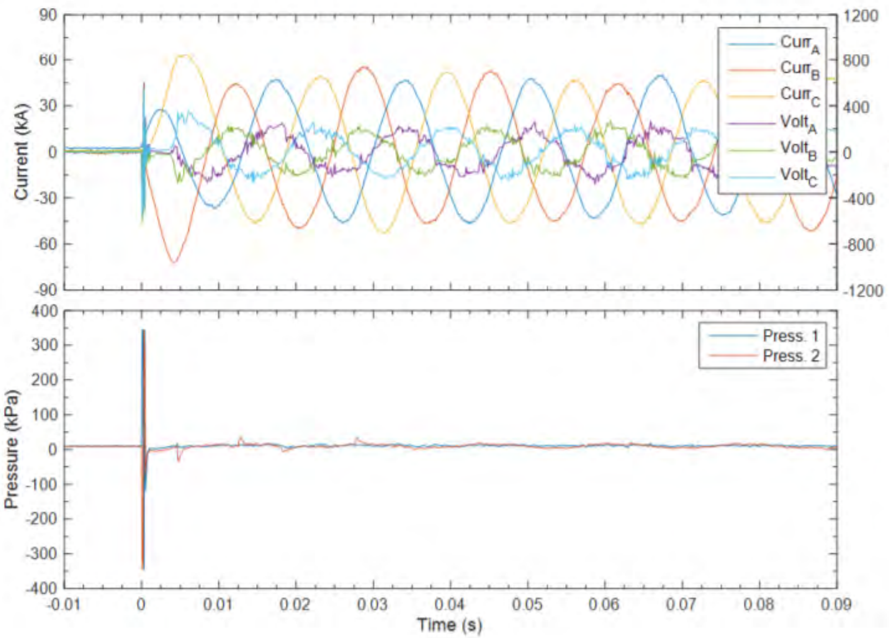




Phase One (I) Pressure

Electromagnetic Interference (EMI)

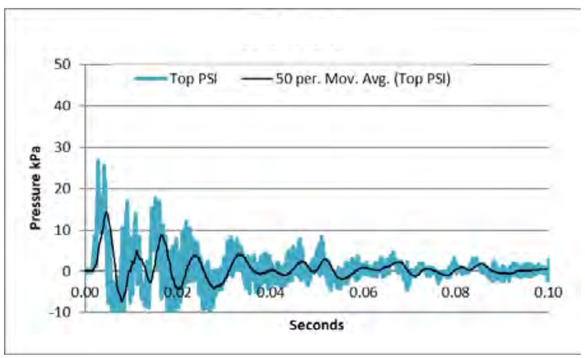
- EMI tends to be most severe during large changes in current, voltage, and arc activity, and these are the same periods where large changes are expected in enclosure pressure
- Positive and negative pressure peaks occur at the onset of the arc, and are of similar magnitude
- New techniques have been developed for Phase II of testing

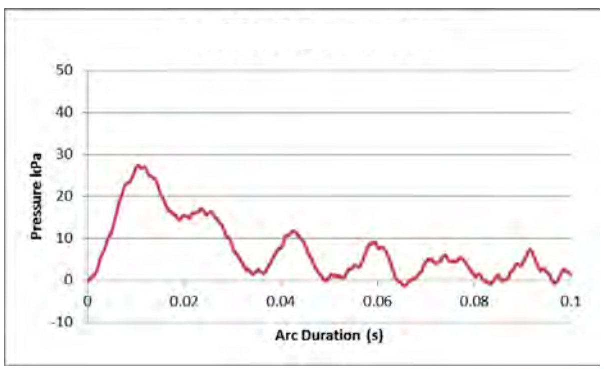


Pressure Phase Two (II)

- Strain-gauge type sensor
- Dynisco Pressure Transducer PT150-50

- Quartz type gauge
- Fiber Optic Cabling
- Omega PX-329





Infrared(IR) Camera Capabilities

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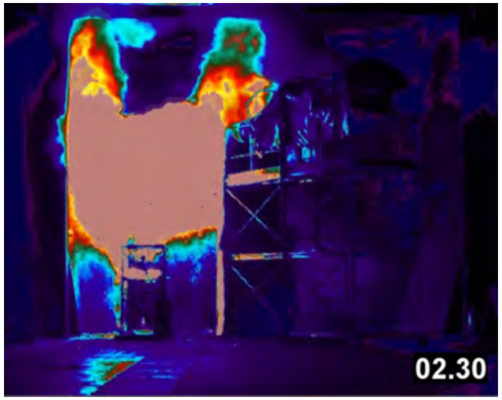
- Non-intrusive temperature measurement
  - Using video as test data
- Visualization through smoke
- Speed – rapid event
- Dynamic temperature range
  - Ambient to >2000 ^{o}C
- Compromises
  - Resolution – field of view
  - Speed
  - Temperature Range (Dynamic Range)

IR Camera Improvements

- Phase I Camera Capabilities
  - High Speed Recording
  - Limited Temperature Range
  - High Resolution
- Phase II Camera Capabilities
  - Greater Temperature Range
  - Higher Resolution



Data Collection

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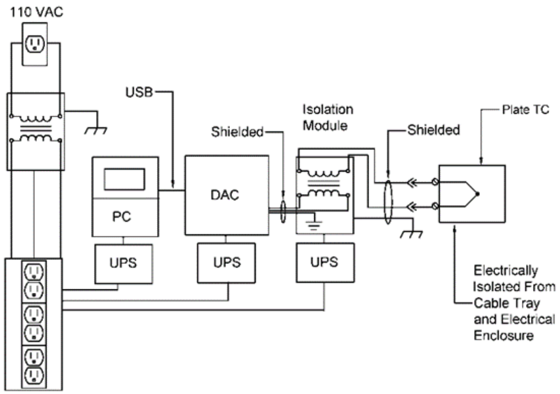
- Phase II of testing will use an isolated data acquisition system with an independent power supply
- Redundant systems will be available for possible arc shorting consequences
- 72 channels



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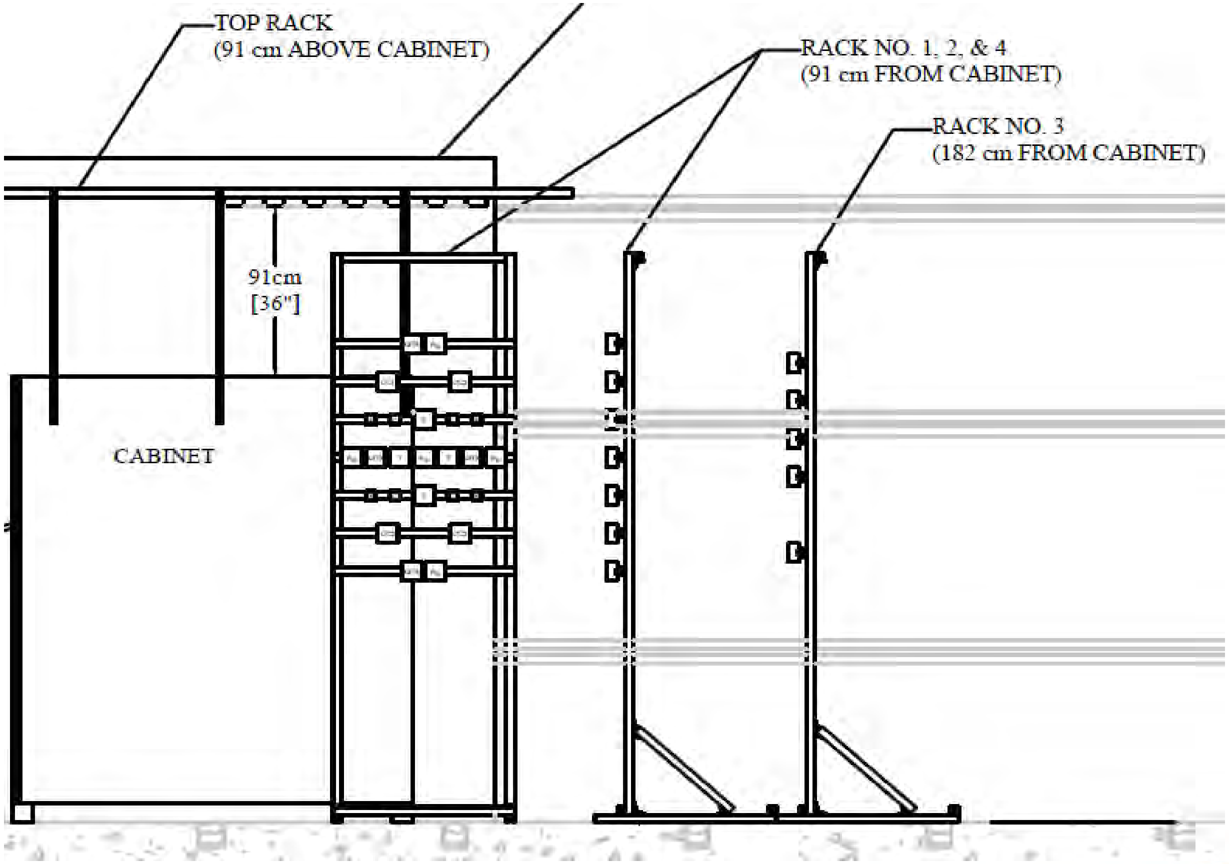
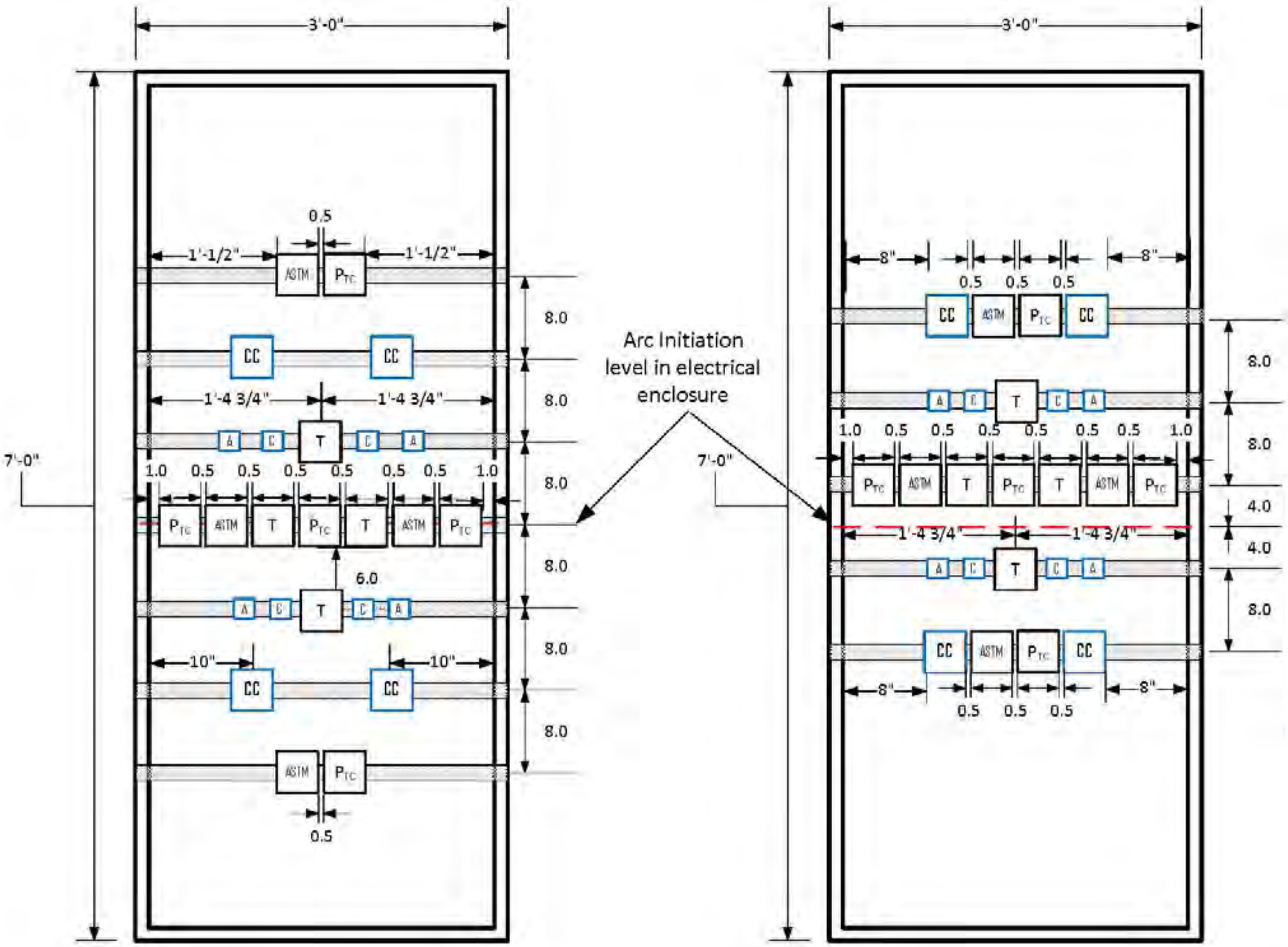
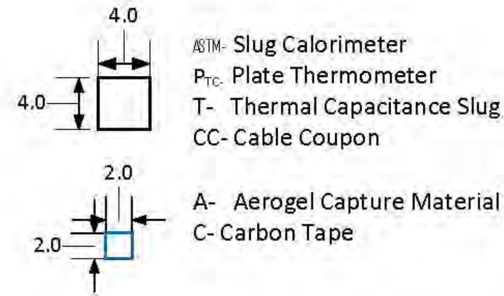
Test Setup



TOP RACK
(91 cm ABOVE CABINET)
RACK NO. 1, 2, & 4
(91 cm FROM CABINET)
RACK NO. 3
(182 cm FROM CABINET)
91cm
[36"]
CABINET

Phase II Instrumentation





Instrument	Per Rack	Per Test	Total Week	NIST DAQ
Plate TC	5	25	100	Yes
ASTM Slug	4	20	80	No
Thermal Capacitance Slug (Tungsten)	4	20	80	Yes
Cable Coupon	4	20	80	No
Carbon Tape	4	20	80	No
AeroGel	4	20	80	No
Total Instruments	25	125	500	

Sandia Camera Angles

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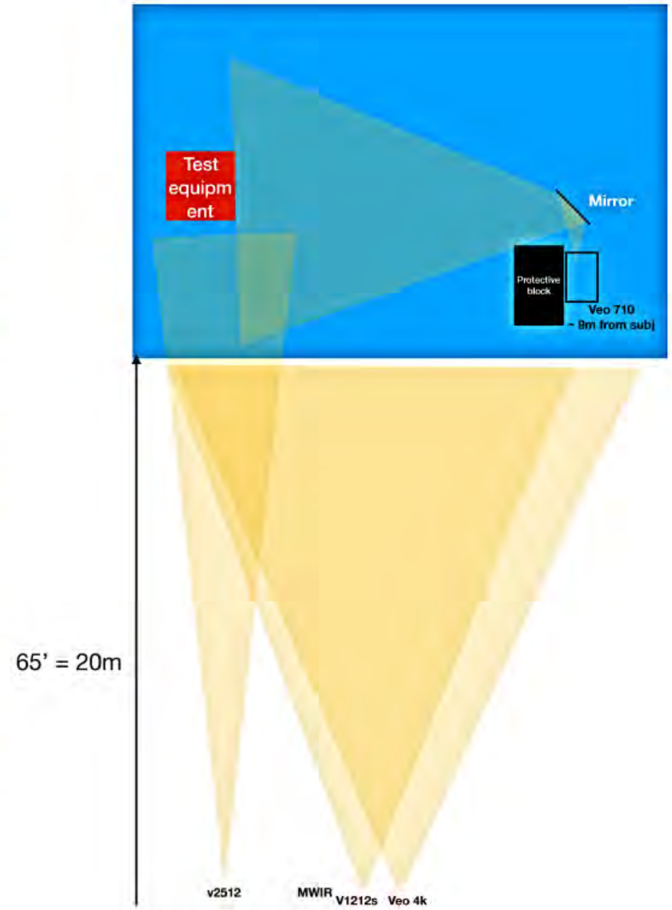
Top down view



Top down view
Test cell 7 low voltage: 9m W x 7m D x 8m H
Test Cell 9: Med Voltage: 10m W x 10m D x 11m H

Weights and Measures

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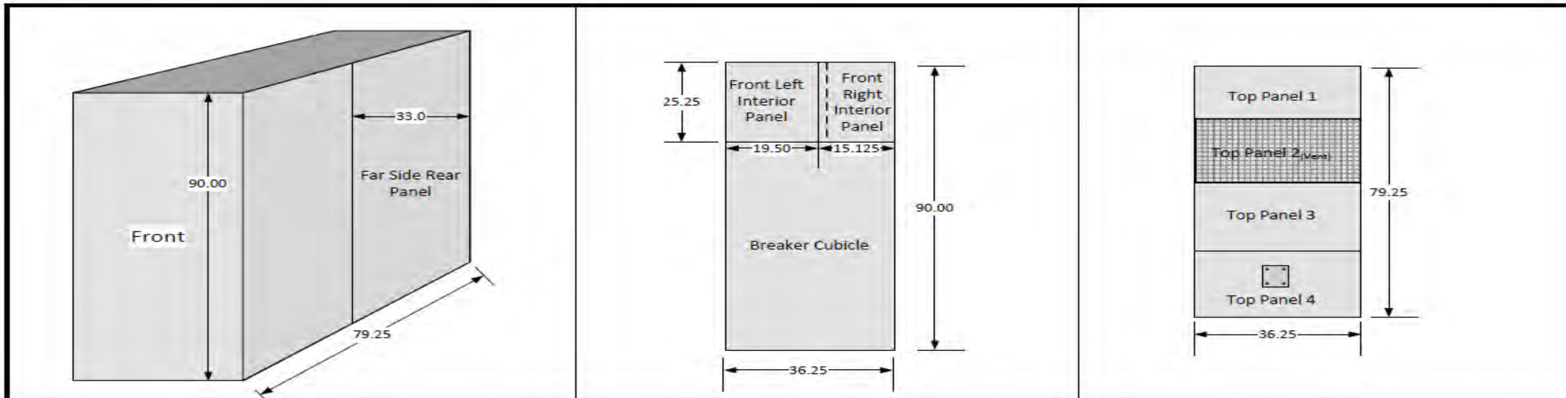

Figure 1 | Figure 2 | Figure 3

Cabinet Panel Weights and Measurements		Pre-Test		Post-Test	
		BSI scale (kg)	NIST scale (g)	BSI scale (kg)	NIST scale (g)
Figure 1	Far Side Rear Panel	44	N/A		
Figure 2	Front Left Interior Panel	6	6228.5		
	Front Right Interior Panel	5	4869.5		
Figure 3	Top Panel 1	6	5672		
	Top Panel 2 (Vent)	1	1012		
	Top Panel 3	14	14906.5		
	Top Panel 4	11	11397.5		

Notes:

NRC Generic Issue Testing
Test #1-5001D

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Phase II HEAF Testing

Medium Voltage Equipment

- Single compartment GE Magne-blast M-36 metal clad switchgear containing aluminum busbar

Phase II HEAF Testing

Pre Test Arrangement

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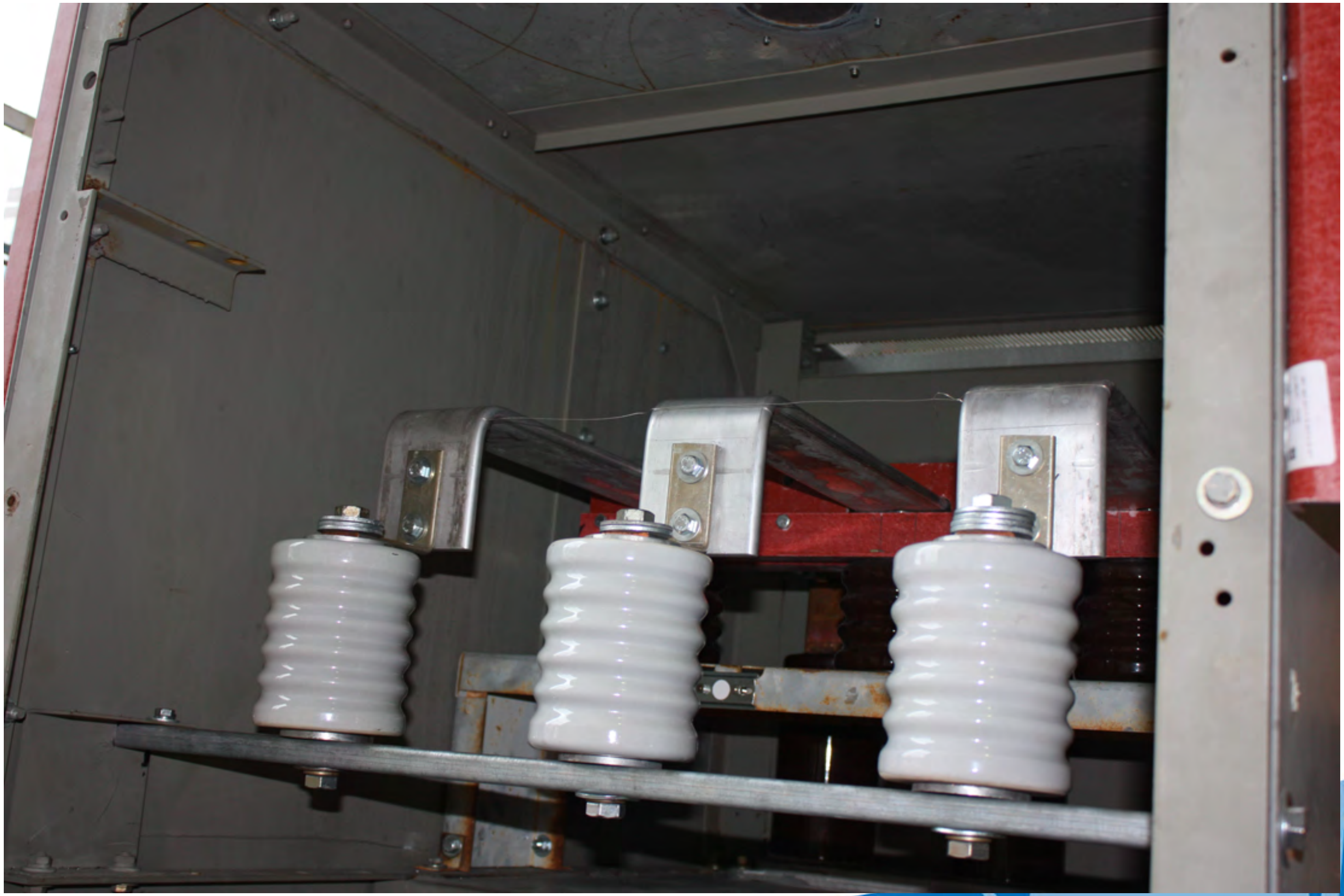
Phase II HEAF Testing
Shorting Wire



Phase II HEAF Testing

Post Test Observations

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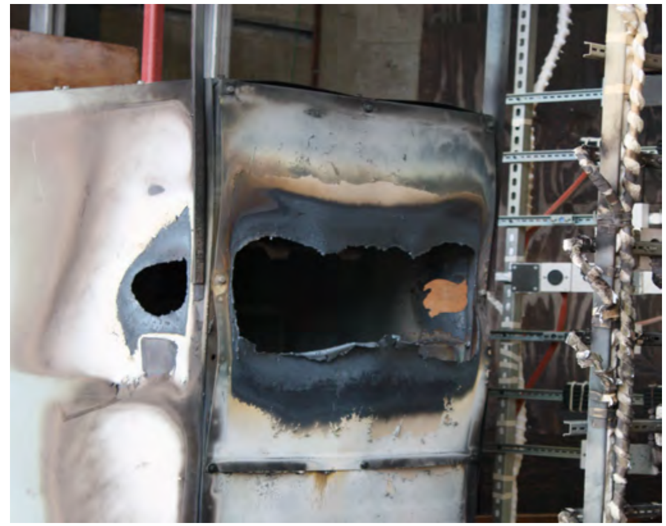
2-19
2s,
25kA



2-22
2s,
35kA

2-21
4s,
25kA

2-24
4s,
35kA

Phase II HEAF Testing
Post Test Observations

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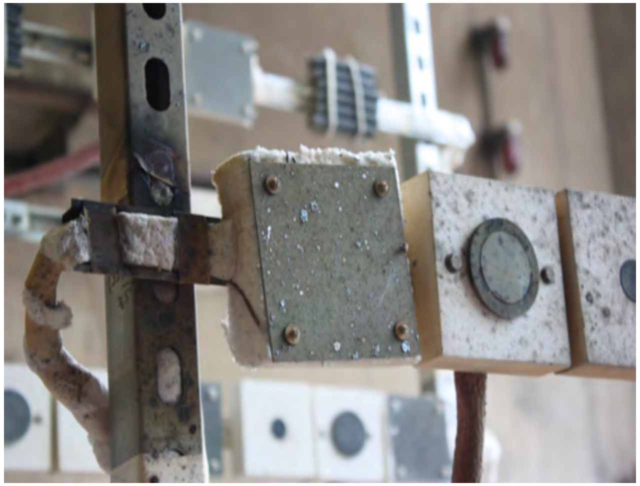

2-19

2-22

2-21

2-24

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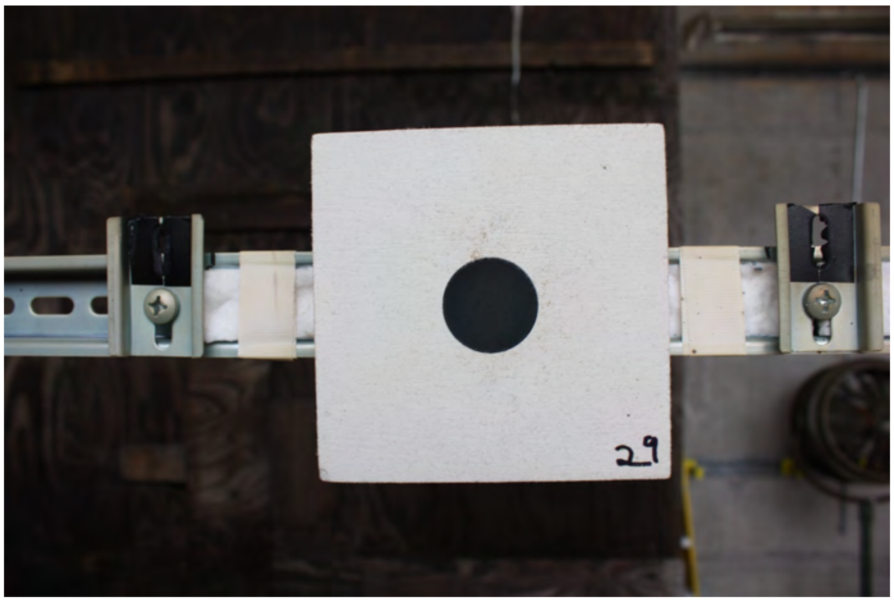
Tungsten Thermocouple Damage State/ Survivability



Before

After

Plate Thermocouple Damage State/ Survivability

ASTM F1959 Thermocouple Damage State/Survivability

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Before

After

HEAF Deposition

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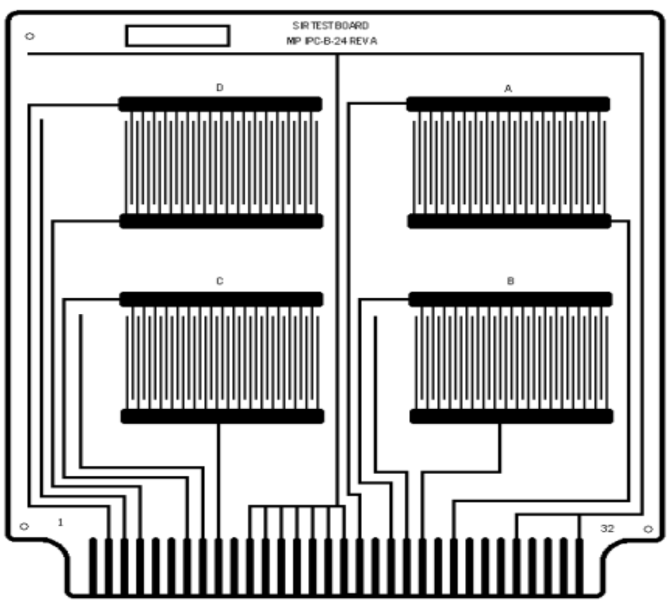
Metal Ejecta

New Measurement for Future Tests Cloud Particulate Conductivity

- IPC Standard IPC-TM-650 https://www.ipc.org/TM/2.6.3.3b.pdf
- NIST Tech Note https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1985.pdf



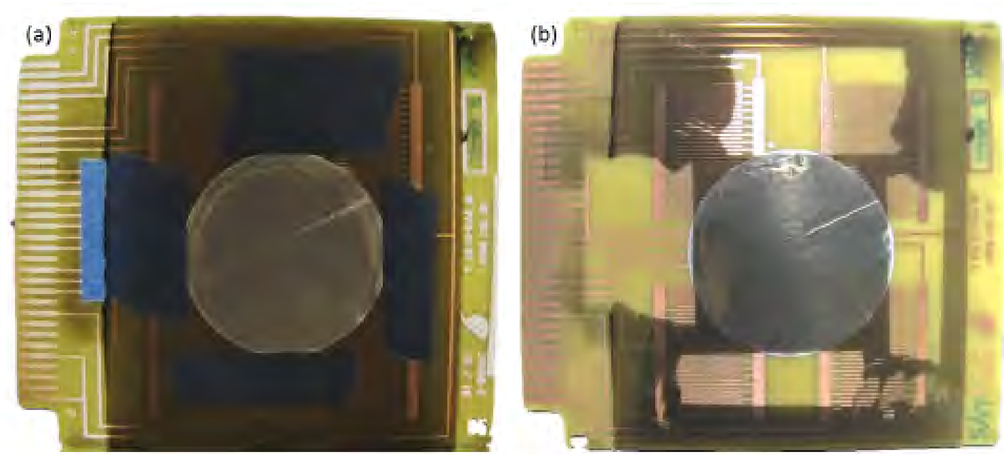


Fig. 15. Photographs of deposition on the foil circle taped to board 3 for 0.055 SLM fuel flow, 3 SLM flow in channel, ΔT of 200 °C, vertical orientation, (a) before and (b) after tape removal.

HEAF Phase II Next Test Series

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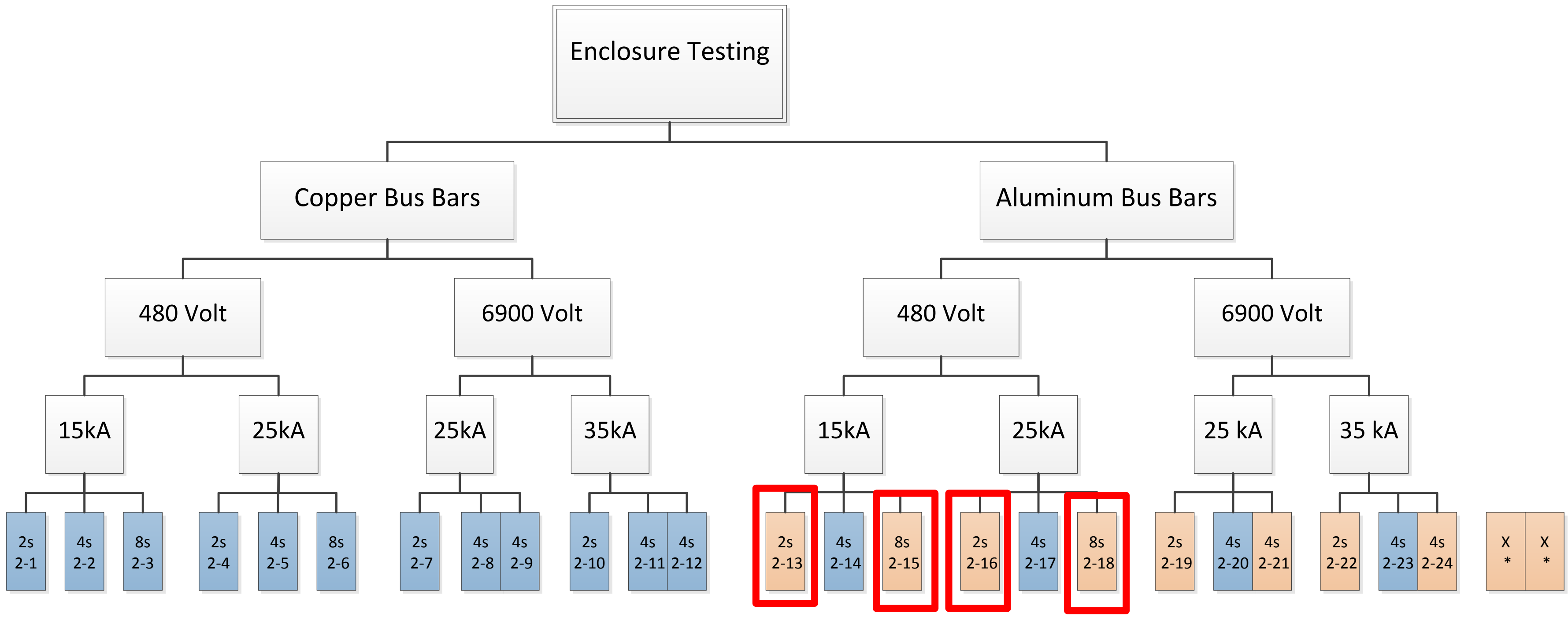

Legend

- OECD/NEA HEAF Phase 2 Tests
- US NRC Specific Spplemental Testing driven by Generic Issue Aluminum HEAF Program
- * Uncommitted tests to explore unanticipated results/enhance repetition if necessary

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HEAF Phase II
Next Test Series

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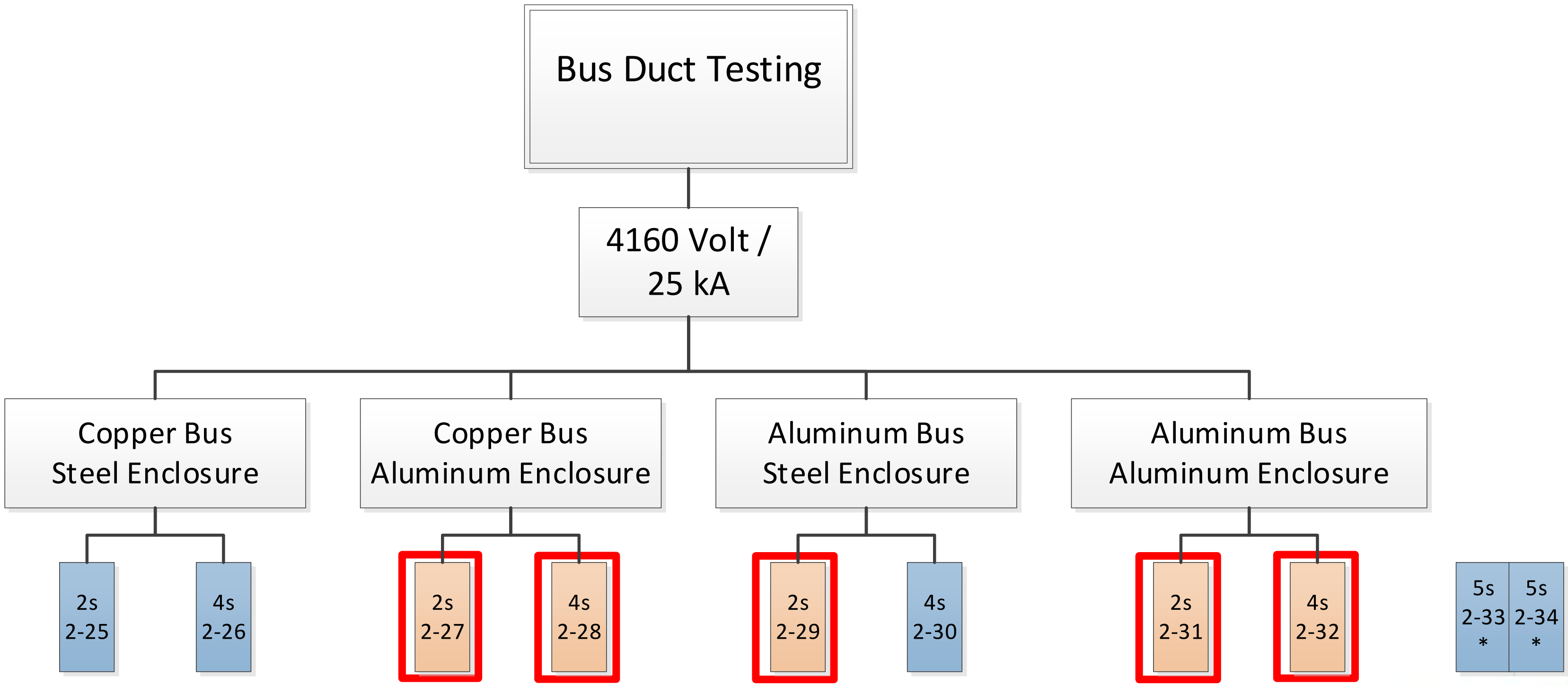

Legend

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NRC/OECD Phase II Actions

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- Public Comment Period Closes... September 2, 2017 (Completed)
- OECD Comment Period.................................... August 31 / September 15, 2017 (Completed)
- OECD HEAF Meeting.. October 12, 2017 (Completed)
- HEAF Workshop .... April 18-19, 2018 (Completed)
- OECD HEAF Meeting.. April 23, 2018 (Completed)
- Comment Resolution .... May 11, 2018 (Completed)
- Final Test Plan..September 1, 2018 (Completed)
- Signed International Agreement ....Spring 2019 (Target)
- International Equipment Delivery...Spring 2019 (Target)
- Initial Test Series.. September 10-14, 2018 (Completed)
- Second Series of Tests
  (To correspond w/ International OECD Meeting)....................... Spring- May 2019 (Target)
- Remaining Tests.. 2019/ 2020/ 2021

High Energy Arcing Faults (HEAF) AL Future Planning and Equipment Selection

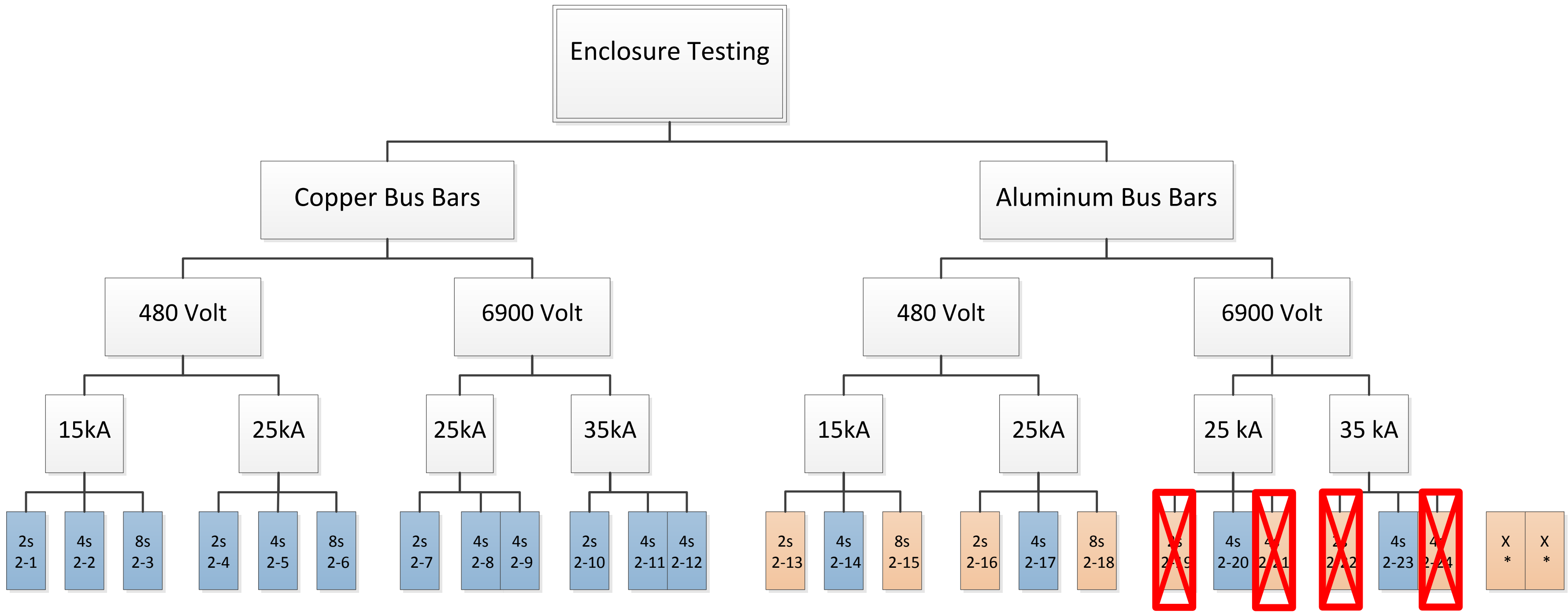
Gabriel Taylor & Kenn Miller
Office of Nuclear Regulatory Research
January 23, 2019

Purpose

- Communicate NRC planned equipment types for testing
- Solicit feedback from stakeholders

HEAF Phase II - PERFORMED

September tests



Legend

- OECD/NEA HEAF Phase 2 Tests
- US NRC Specific Spplemental Testing driven by Generic Issue Aluminum HEAF Program
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HEAF Phase II - PLANNED

Low Voltage

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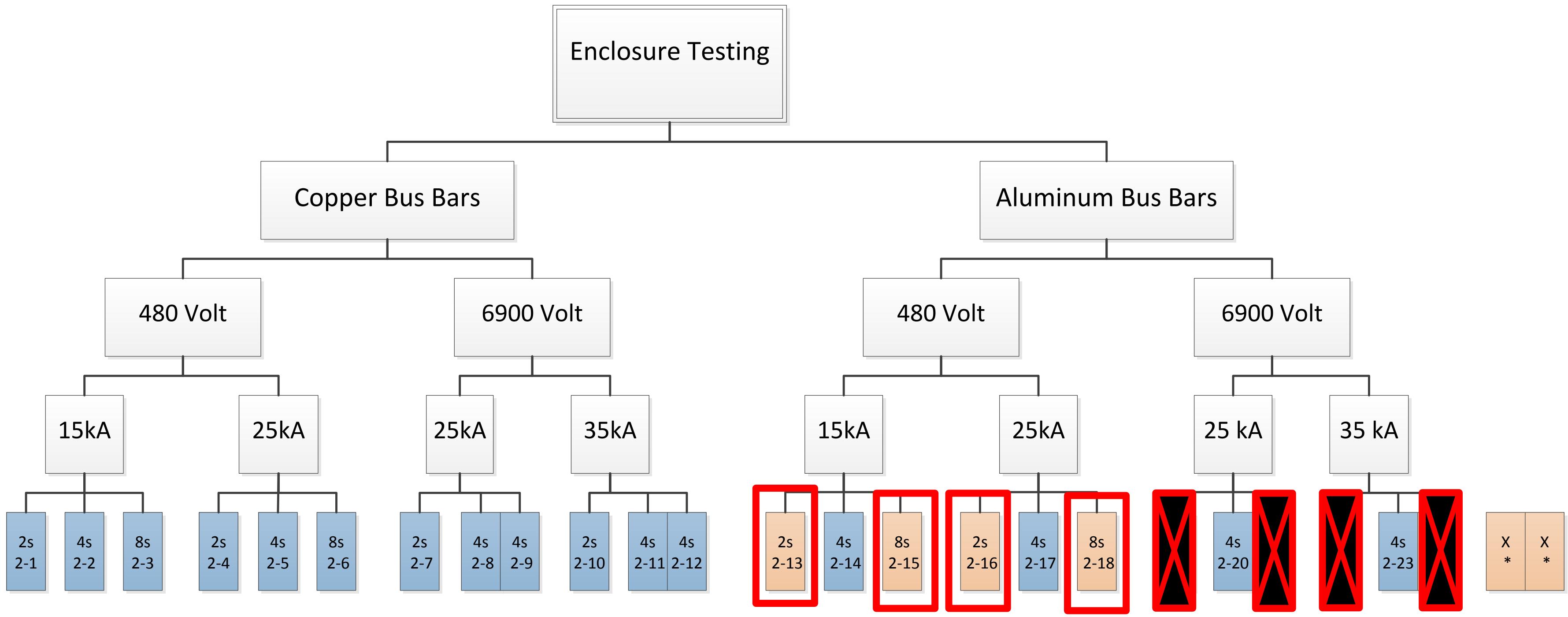

Legend

- OECD/NEA HEAF Phase 2 Tests
- US NRC Specific Spplemental Testing driven by Generic Issue Aluminum HEAF Program
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Low Voltage Enclosures

Aluminum Bus

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- Westinghouse DS switchgear
- GE AK Series

- 1600A or 2000A frame size
- 42kA to 65kA interrupting capacity

HEAF Phase II - PLANNED

MV Bus Ducts

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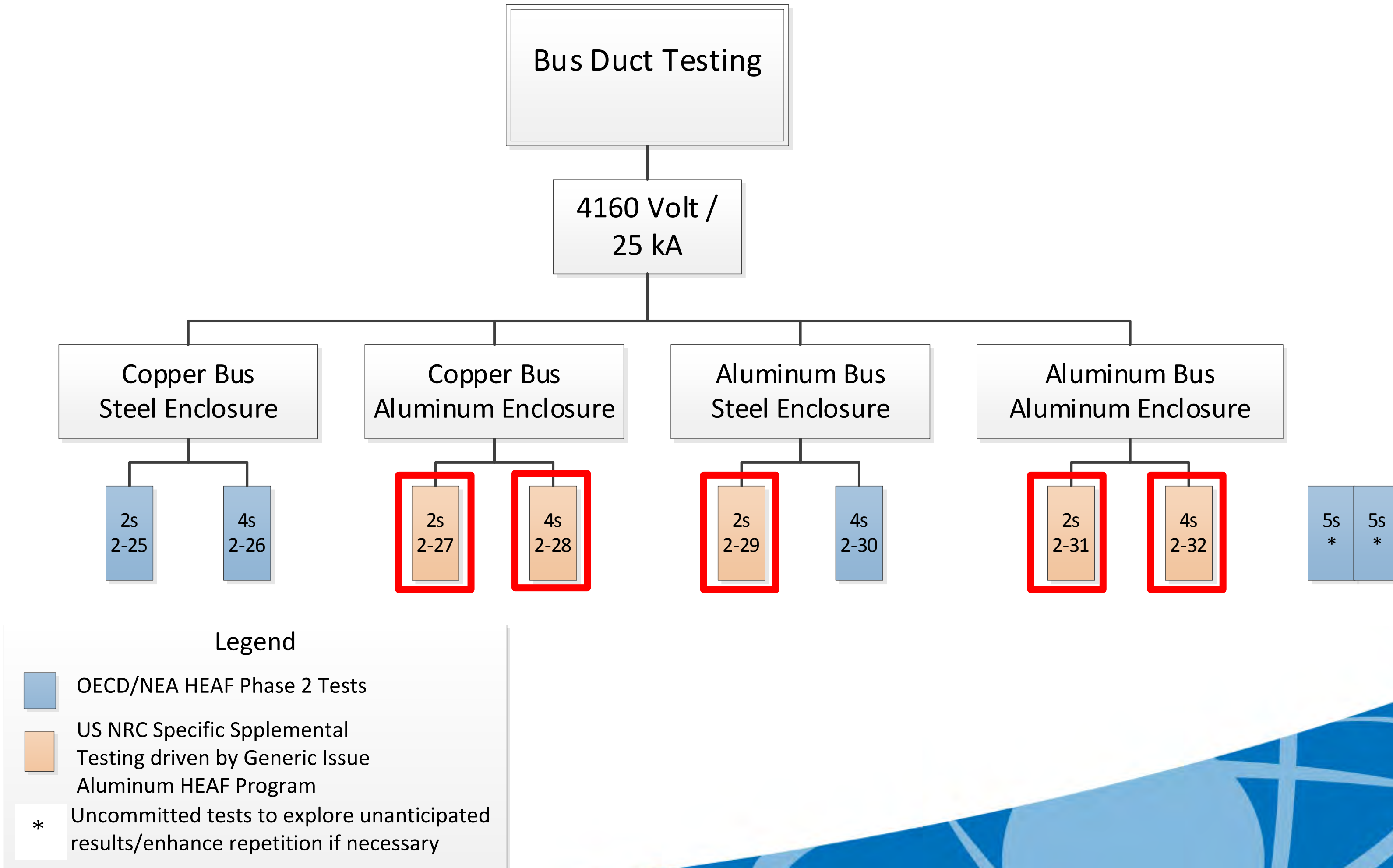

MV Bus Ducts

General Characteristics

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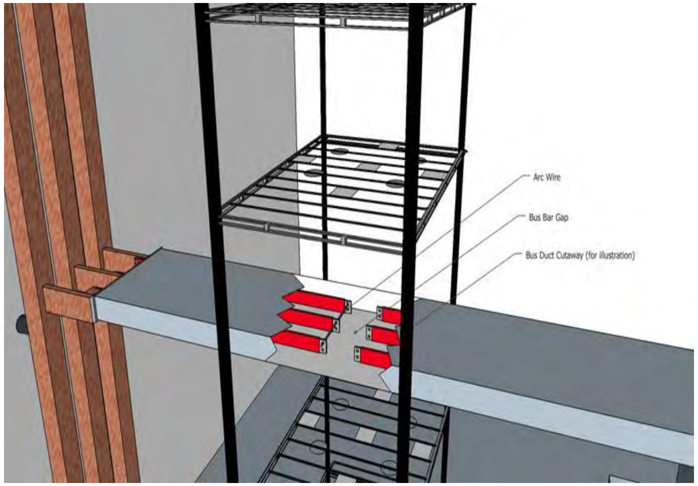
- Non-segregated phase bus duct
- Medium Voltage: 4.16kV
- 1200 – 2000A rated
- 31.5 – 63kA withstand
- IEEE C37.23
- Stabilize arc location
  - Gap at arc location?
  - Epoxy insulation?



MV Bus Ducts

Aluminum Components

- Enclosure
  - 11 gauge aluminum housing
- Conductor
  - ASTM B236
- Other design considerations?

Decrement Curve

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- Working with EPRI and KEMA to implement decrement curve
  - 6.9kV metal-clad switchgear
  - Requires new contract
  - Laboratory analysis & verification

Summary

- Continued focus on aluminum
- Equipment donations welcome
- Decrement curve
  - Implementation slow due to contracting process
  - Industry support could expedite this

High Energy Arcing Faults NRC-EPRI Working Group Charter

Mark Henry Salley, P.E.
Branch Chief
Office of Nuclear Regulatory Research
January 23, 2019

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
  - What can go wrong?
  - How likely is it?
  - What are the consequences?

Working Group Members

U.S.NRC
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Ken Fleischer (Fleischer Consultants)
Dane Lovelace (Jensen Hughes)
Shannon Lovvern (TVA)
Tom Short (EPRI)
Marko Randelovic/
Ashley Lindeman(EPRI)

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

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

Deliverables

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- Improved risk models
  - Frequency and binning
  - Zone of influence
- Risk to NPPs
  - Pilot plants
- Updated guidance
- Communication with stakeholders

NRC Priorities

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- Aluminum HEAF Generic Issue
  - Zone of influence
    - Physical/thermal damage
    - Effects of products of combustion cloud
- OECD/NEA Testing
  - Additional test data (primarily copper)
- NRC/EPRI Working Group
  - Develop realistic models
  - International OECD/NEA peer review
- Improve NUREG/CR-6850 Appendix M
  - Improve FAQ-07-0035 Bus Duct Guidance for HEAFs

The following 5 slides were presented by:

Victoria K Anderson

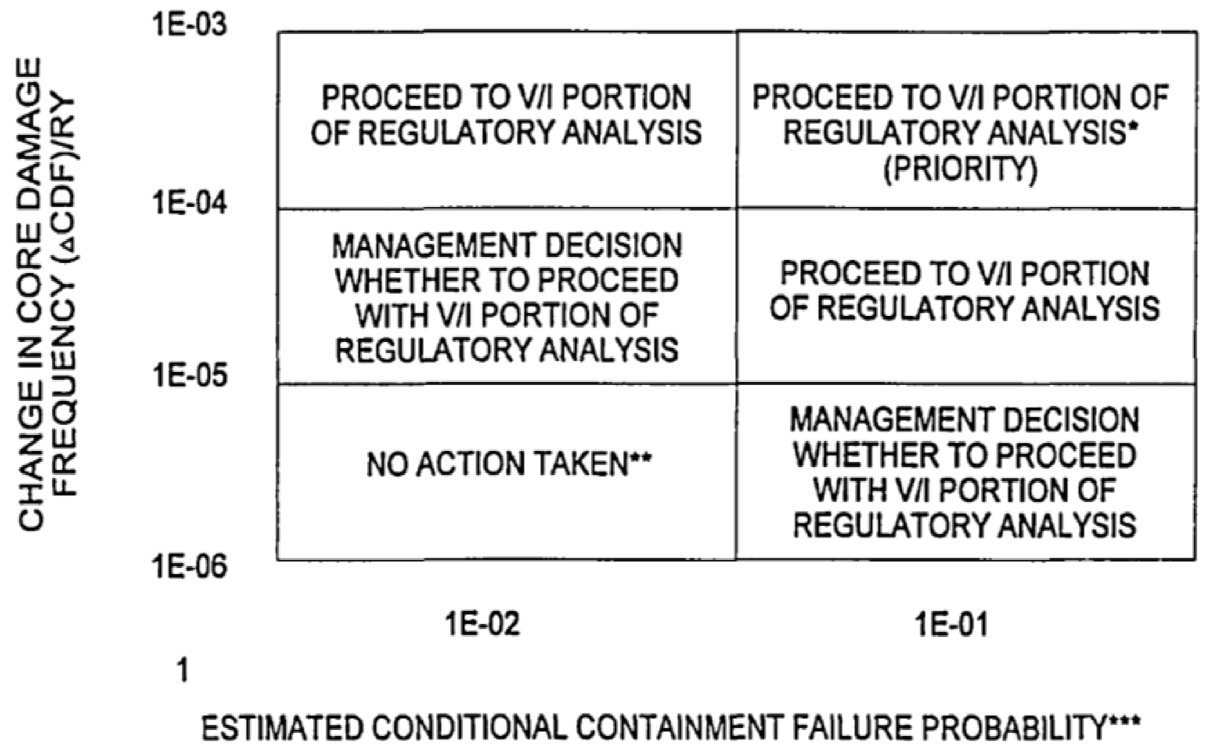
Technical Advisor

Risk and Technical Services

Nuclear Energy Institute

HEAF Aluminum Pre-GI

- Decisions regarding a Generic Issue are designed to be risk-informed

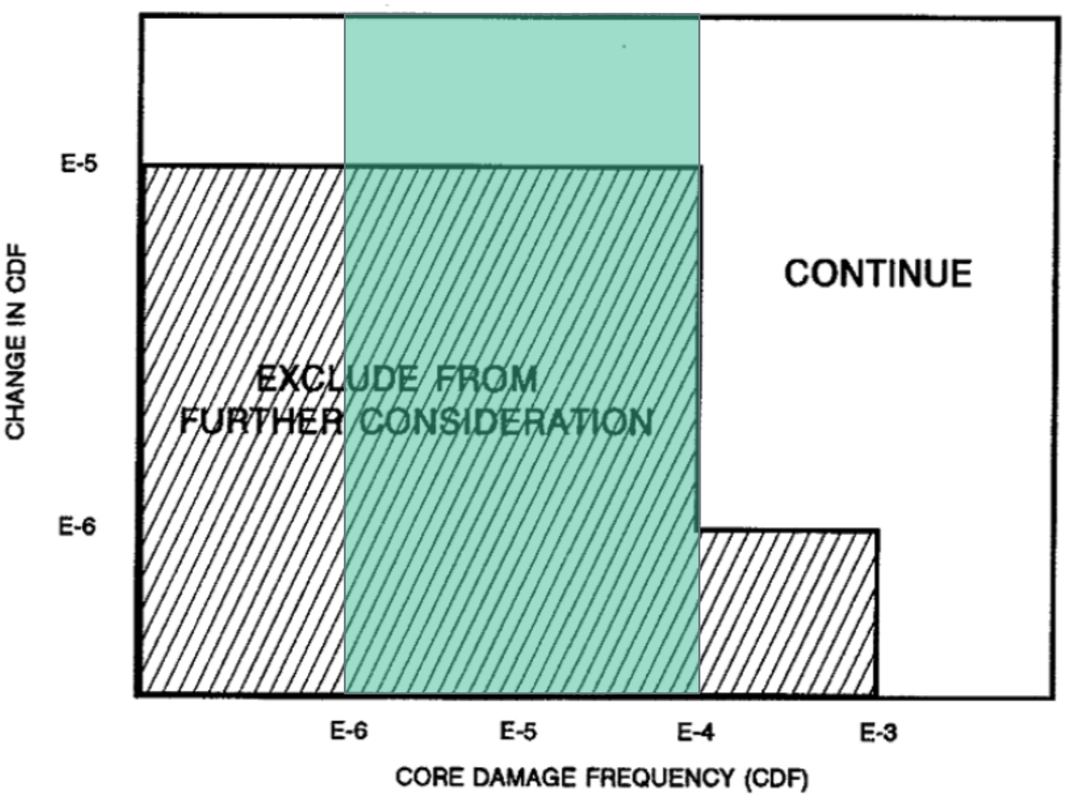


Specifically: $\Delta CDF_{HEAF\ Al} = CDF(HEAF\ Al) - CDF(HEAF\ Baseline)$

HEAF Aluminum Pre-GI

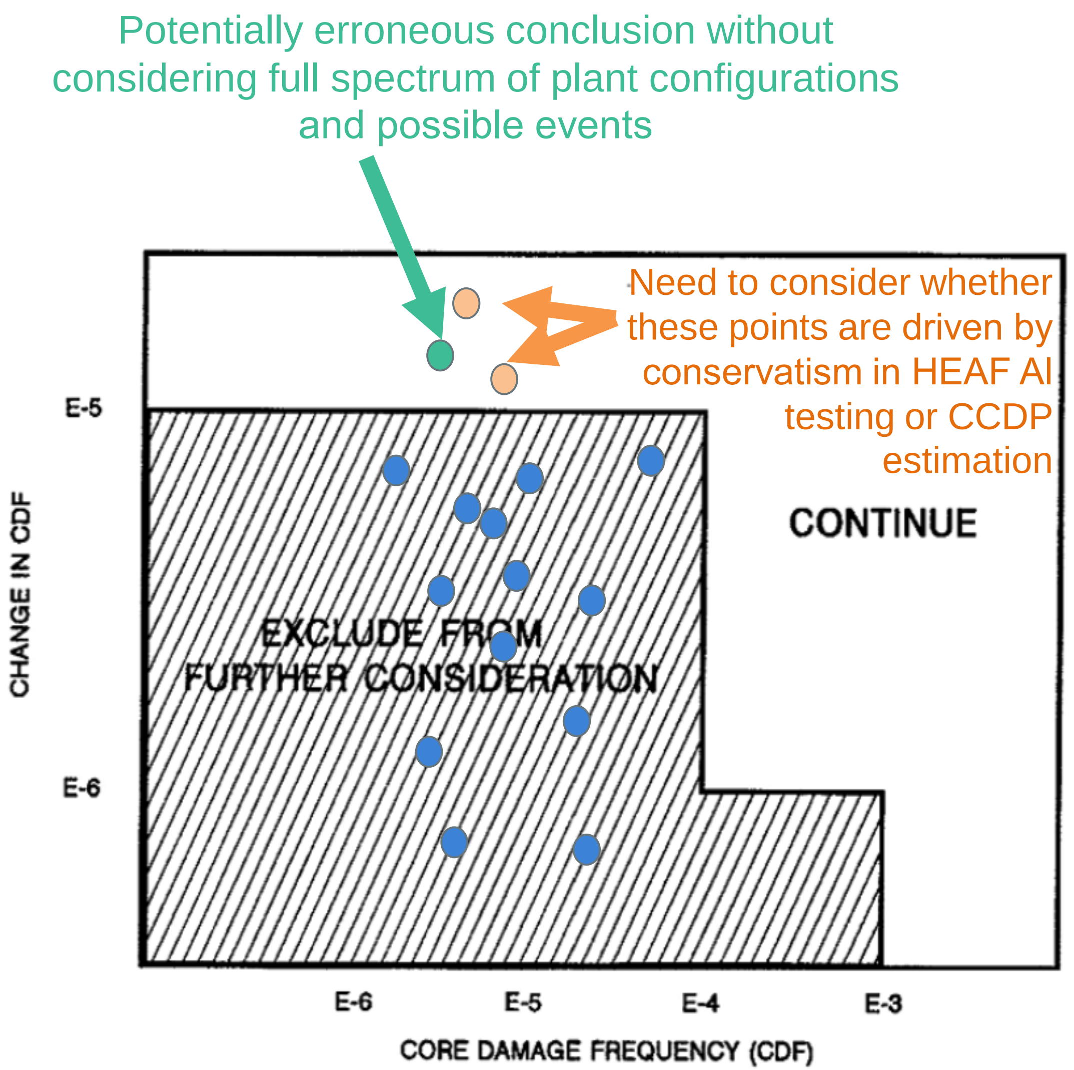
- Past Generic Issues were dispositioned according to ΔCDF versus CDF changes
  - Likely the case for this pre-GI
- Decisions based on conservative assumptions could result in inappropriate decisions
- A single fire PRA assessment without realistic assessment of the baseline risk, and event-specific initiating event frequencies and consequences, will lead to inaccurate assessments

Most Fire PRA CDF(HEAF Baseline) results found in green region



HEAF Aluminum Pre GI

- Decisions based on conservative assumptions could result in industry-wide assessment that does not apply to vast majority of plants, i.e.:
  - Assumption Al is always present
  - HEAF Al is always more energetic
  - HEAF Al always increases CCDP
  - HEAF Al based on the worst case fire scenario applies to all plants



HEAF Aluminum Pre-GI

- Comparison with previous GI on new seismic hazard information
  - Seismic PRAs not available to the extent fire PRAs currently are
  - Even with limited risk-informed approach, high variability in decision making impact
- Resolution of the issue requires better realism in assessment AND in resolution of pre-GI
  - Assuming a one-size fits all would waste resources
  - Crediting realistic HEAF Al impacts, protections against feeding HEAF, existence of Al is critical
  - Imperative to accurately assess baseline
  - Most plants may not require action

Industry Priorities for HEAF Evaluations

- Understanding and evaluating data from previous tests and OE
- Achieve consensus on technical approach for frequency and zone of influence work
- Complete additional testing to resolve any identified gaps
- Complete realistic evaluation of plants using testing data and OE

Timeline needs to support execution of these steps in order

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High Energy Arcing Fault (HEAF)

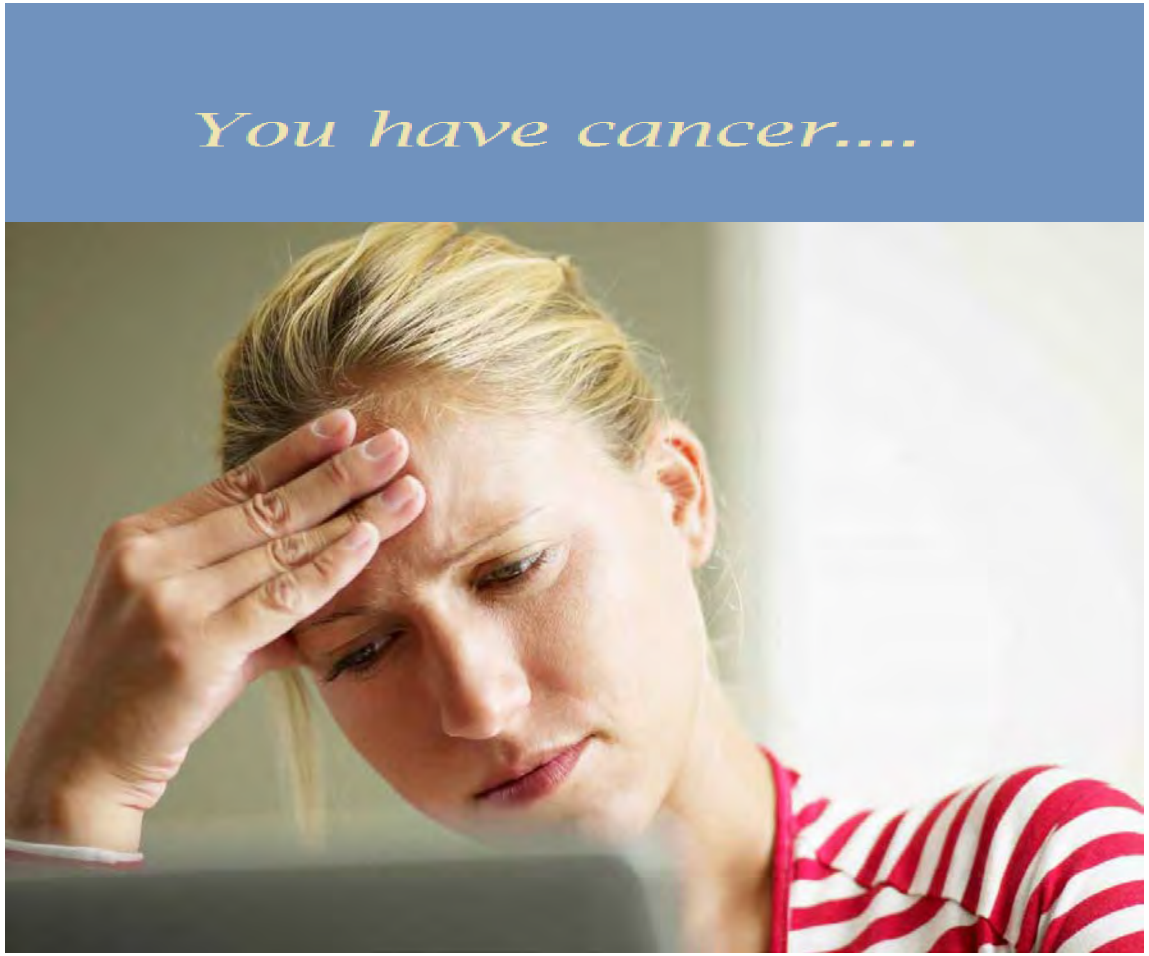
Technical Considerations for Understanding Risk

Kelli Voelsing
RSM Program Manager

NRC Public Meeting
January 23, 2019

Assuming the worst case

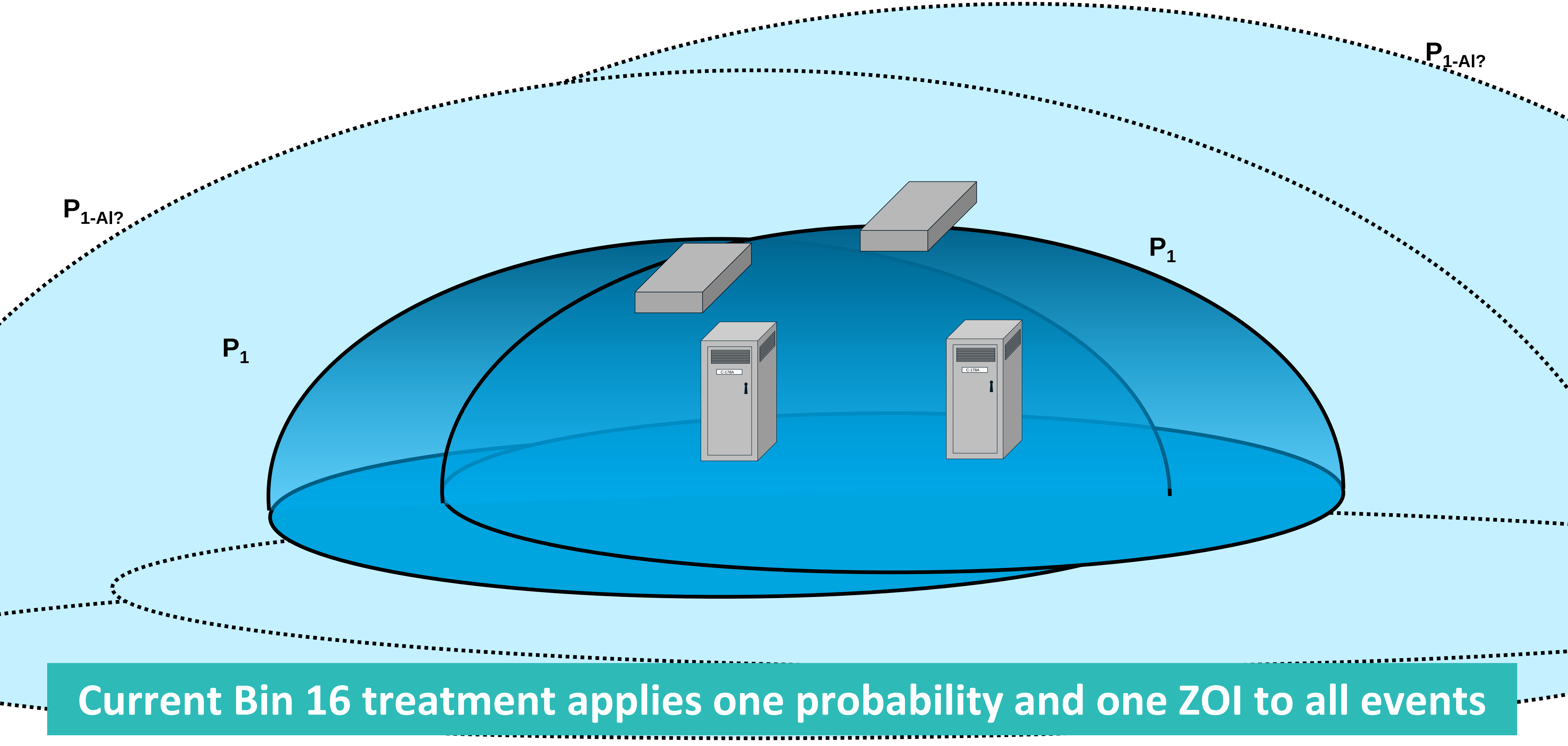
- Invasive surgery to remove the malignancy
- Poisonous chemotherapy with damaging side-effects
- Risks and sickness from radiation therapy



- Location/size
- Type of Cancer
- Stage
- Genetic Markers
- Targeted therapies on the market
- Other treatments supporting quality of life

Not all cancers, and not all arcing faults, are the same

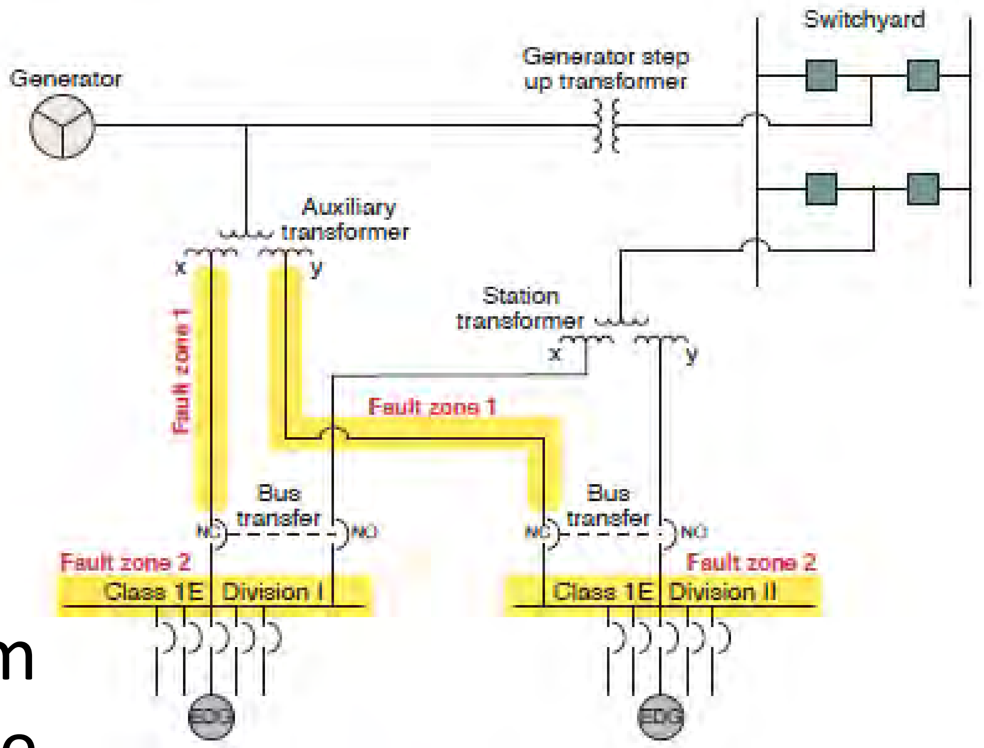
Current Bin 16 Treatment in NUREG/CR-6850 (1011989)



Current Bin 16 treatment applies one probability and one ZOI to all events

Examples of Differentiating Factors in Arcing Fault Events

- Energy – Medium Voltage or Low Voltage
- Location – potentially affecting safety significant equipment
- SSC – Switchgear, Motor Control Center, Isophase/Non-seg bus duct
- Source of fault – Breaker-side or load-side
- Electrical configuration – e.g., “Unit-connected*” and protection scheme
- Material – Presence and location of aluminum
- Operational issues – Cleanliness, maintenance, human performance



* Plant electrical system design found in fossil and nuclear plants that do not employ a generator breaker that can isolate the energy source (main generator) from the fault during generator coast-down as the voltage collapses

Elements of HEAF Working Group Charter

To improve understanding of risk from electrical arcing fault hazards in nuclear power plants (NPPs)

1. Improved risk models – supported by all available information (e.g., testing, data, OE, expert engineering judgement)
   - Realistic representation of **frequency** of events represented in Bin 16
   - Appropriate modeling of various **zones of influence** (ZOI) for events included in Bin 16

2. Risk to NPPs - Evaluation of potential increase in **risk of actual plants** considering impact of frequency and ZOI work as well as-built, as-operated plant
3. **Updated guidance** – Enhanced fidelity and realism for modeling arcing fault events in Fire PRA
4. Communication with stakeholders

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Early Insights Related to "Frequency Work"

- Limited data – Total population in Bin 16 from 1964-2017 is 28 events
  - Includes a wide variety of equipment
  - Data includes arcing flash/blast events (at least 10) and HEAF events
  - Data includes events with and without post-event fire and damage
  - With only 28 events, creating multiple sub-bins of 0-1 events makes it difficult to break down further and retain statistically useful information
- Within Bin 16 there are useful insights about the which events occur under which conditions
  - Medium Voltage (MV) SSCs - 84% of the Bin 16 events that were "damaging" occurred in MV equipment
  - Low Voltage (LV) SSCs - Only 2 damaging events occurred in LV equipment. In both cases, there was insufficient energy to trip the protection features. This prolonged the event, but there is no indication of a HEAF, and the "damage" term was related to post-event fire, not the HEAF
  - Of the events with external damage, 7 out of 11 were in buses (isophase/non-seg buses) that are less likely to impact safety – significant equipment based on plant configuration

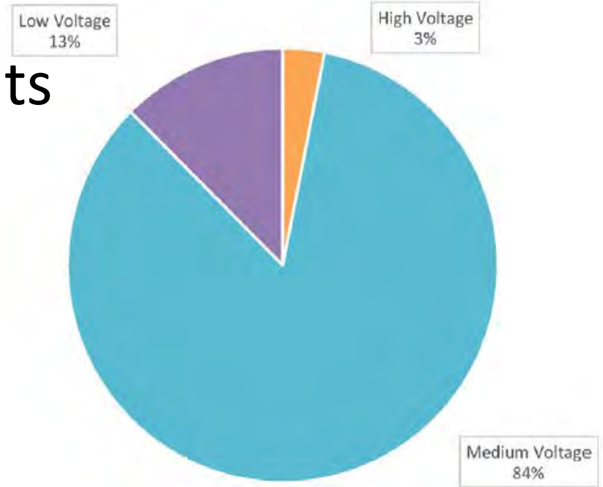


Figure 8 – Categorization of damage extent

Early Insights Related to "ZOI Work"

- Limited data – Fragility of SSCs versus contact with the by-product
  - Current ZOI used for Bin 16 is based on a SONGS event (Appendix M).
  - Small scale nor large scale test results on HEAF by-product characterization are not available
- Significant useful insights about the which events occur under which conditions
  - Al_2O_3 is an excellent insulator material with very low conductivity
  - In most conditions Al oxidizes to Al_2O_3 very rapidly
  - Presence of Al_2O_3 white dust may not cause failure
  - The arc travels away from the source. Cable trays are not likely to be located directly in front/back of switchgear cabinets.
  - Bus ducts likely have a downward directed conical ZOI when not constrained by barriers (e.g., floor)
  - Arc flash and arc blast events have negligent ZOIs

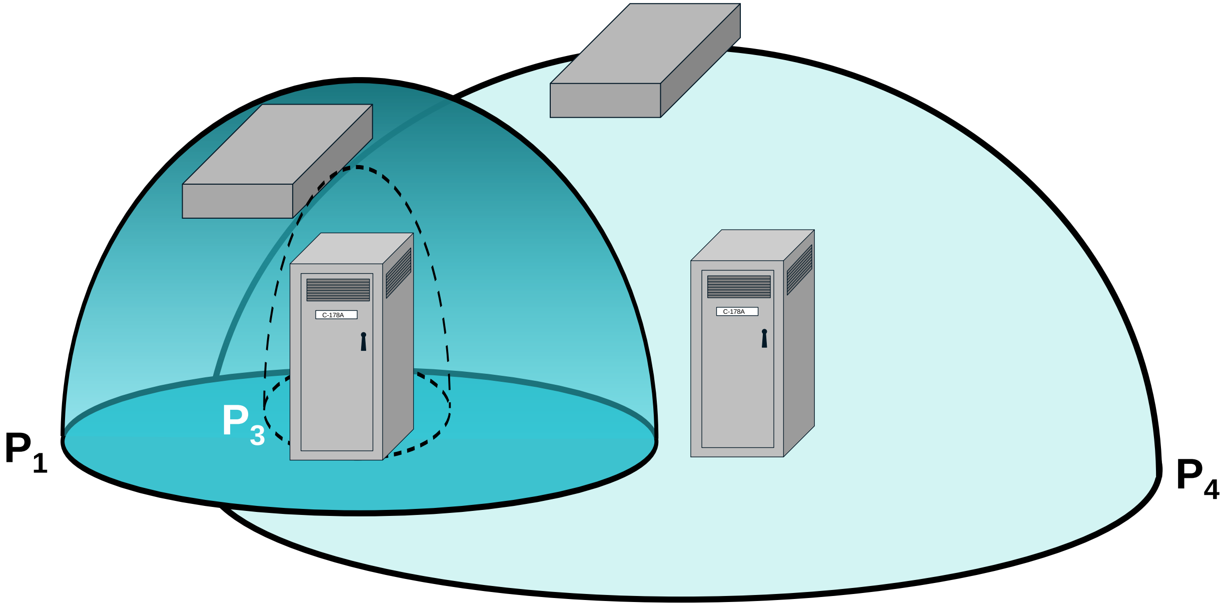
Early Insights on Plant Risk

- "Average" plant risk is an elusive concept
  - A review of all units in the US shows that ~70% of plants are NOT susceptible to a long-duration generator fed fault on the safety related bus (i.e. do not have the "unit connected" design).
  - Even when long-duration generator fed faults can occur the following factors must be considered
    - Voltage will decay rapidly as the generator spins down
    - Presence or absence of Al, proximity to fault location
    - Equipment in the ZOI
  - It is not rare to have aluminum in bus ducts (isophase and non-seg) due to weight/cost
    - Risk is depending on SSCs within the ZOI
    - This is generally a low contributor to risk in most plant fire PRAs – outside/non-safety related equipment is impacted

Test Considerations

- Breaker initiated versus switchgear initiated faults
  - OE shows that the frequency is for these is different.
  - Breaker-side initiated faults may not be able to persist long enough to impact Al with high energy
  - Consequences may be different
- Data for evaluating “damage”
  - Target selection to assure results are representative of plant equipment
  - Actual location and data collection to assess impact on operation
  - OE does not suggest large-scale deposition of by-products and damage outside the cubicle
  - Clarity on what conductivity/material is being measured is required
- Representative conditions that can lead to longer durations for the 4-second and 8-second faults
  - MV - Generator wind-down voltage curve for decay of voltage during spin down
  - LV - Not enough energy to trip the protection scheme

Refined Bin 16 Treatment in Supplemental NUREG/CR-6850 (1011989) Guidance



All arcing fault events are not the same - Risk should consider probability of various event types and associated ZOIs

Together…Shaping the Future of Electricity

High Energy Arcing Faults Involving Aluminum Closing Remarks

Michael Franovich
Division Director
Office of Nuclear Reactor Regulation
January 23, 2019

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

Closing Remarks

- Thank you
- Transparency, public involvement, and clear communication
- Realistic assessment of the hazard
- Risk-Informed Resolution