NRC HEAF Phase II Information Sharing Workshop

Michael Cheok
Director Division Of Risk Analysis
Office of Nuclear Regulatory Research

April 18, 2018
Rockville, Maryland

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United States Nuclear Regulatory Commission
Protecting People and the Environment

Welcome

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- Welcome to the workshop
  - Participants at NRC Headquarters
  - Participants via Webinar
    - U.S
    - International
- Large amount of information to cover in 2 days
  - Encourage your participation

Expected Outcome

- Clear definition of the hazard
- Input to support Phase II testing
  - Realistic
  - Representative
- Input to support current stage of the Generic Issue Process

Thank You

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- Thank you for taking the time to support this important project
- Your experience and expertise are greatly valued as we move forward
- Improve safety
  – NRC Licensee
  – Larger Industrial Community

NRC HEAF Phase II Information Sharing Workshop – Introduction & Objectives

Mark Henry Salley P.E.
Chief Fire and External Hazards Analysis
Division of Risk Analysis
Office of Nuclear Regulatory Research
April 18, 2018
Rockville Maryland

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Welcome

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- Introduce Presenters
  - Room Introductions
  - Go To Meeting Webinar Introductions
    - U.S.
    - Foreign
    - Email Thomas.Aird@nrc.gov
  - Transcribe Workshop
    - Please identify yourself when you speak
  - Prepare a NUREG/CP at the end of workshop
    - Document what we learn next 2 days

Purpose

- Share what we have learned to date
- Solicit input from all stakeholders
- Discuss options moving forward
- Learn from each other
- Support OECD/NEA HEAF Project
  - Meeting next week
- Support NRC Generic Issue Program

Overview Day 1

- Review Phase I Full Scale Testing
- NRC Generic Issue Process
  - Aluminum HEAF Pre-GI-018
- Pilot Plants
- Definitions
- Small Scale Testing
- PRA Modeling Implications
- Industry Presentations
  - NFPA
  - EPRI
  - KEMA

Overview Day 2

- Discuss HEAF Phase II Test Plan
  - Comments Received
  - Proposed Comment Resolution
- NRC Request
  - Needs and Objectives
    - Test Parameters
    - Equipment Selection
- Public Comment
- Wrap-up

Path Forward

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- Revise Test Plans
  - Small Scale
  - Full Scale
- OECD/NEA Phase II Agreement
- Prepare for Testing
- Obtain Equipment
- Perform Testing
  - October 2018
  - Summer 2019

Develop Long Term, Risk-Informed, Defense-in-Depth Solution

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Safe Shutdown

Protect & Preserve Safe Shutdown

Rapid Detection & Mitigation

Circuit Protection, “HEAF Shields,”

Prevention

Safe Work Practices, Maintenance, Arc-Resistant Cabinets

NRC Safety Mission

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- NRC Mission Statement
  - "…to license and regulate the civilian use of radioactive materials in the United States to protect public health and safety, promote the common defense and security, and protect the environment."
- Secondary Benefit, - Openness & Collaboration
  - Share what we have learned with the larger engineering community to promote safety

Review of Phase I HEAF Research

Nicholas Melly
Mark Henry Salley P.E.
Office of Nuclear Regulatory Research
Division of Risk Analysis
April 18, 2018
Rockville , Maryland

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Purpose

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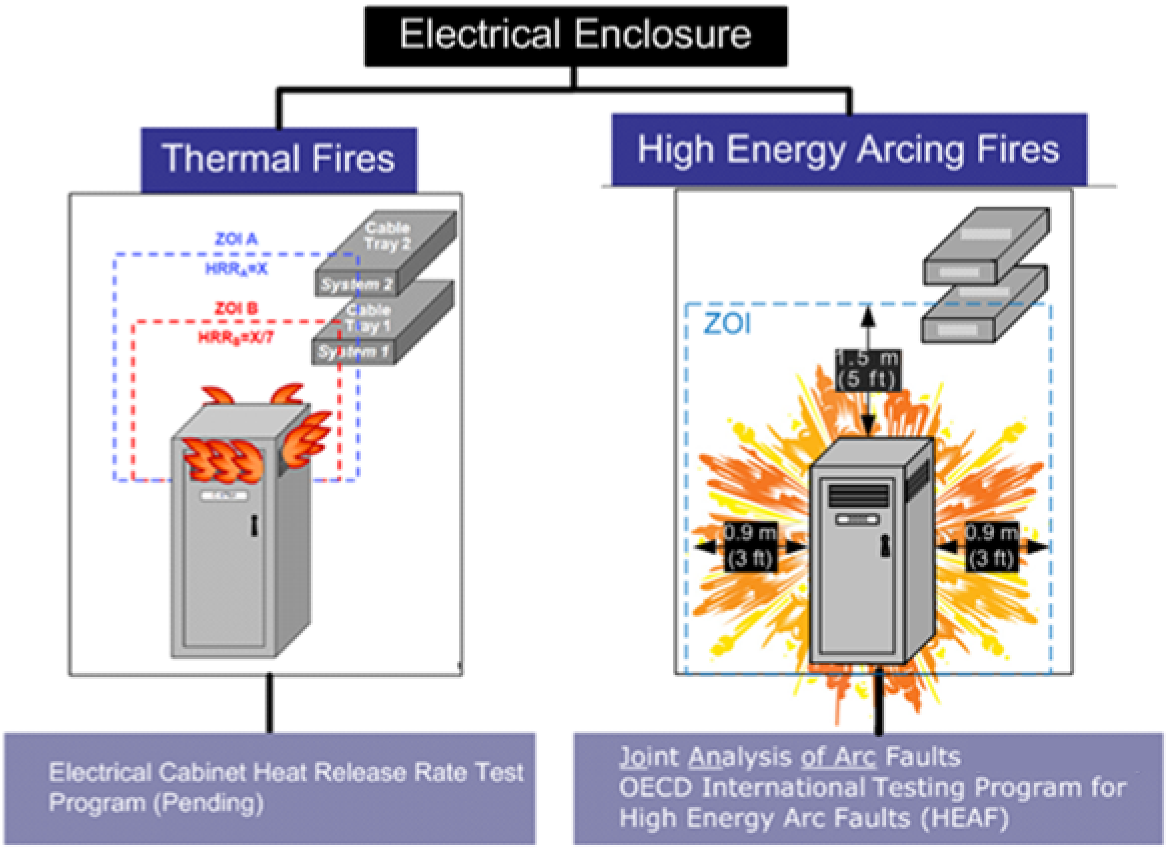
- Provide High Level Overview and Identify Reference Material on NRC Fire Research Program for:
  - Electrical Enclosure Fires
  - Arc Flash /Arc Blast Events
  - High Energy Arcing Faults (HEAF)
- Most current Information
  - Changes as Program Evolves

Initial Thoughts on Electrical Enclosures- Failure Modes



PRA Risk Significant Contribution

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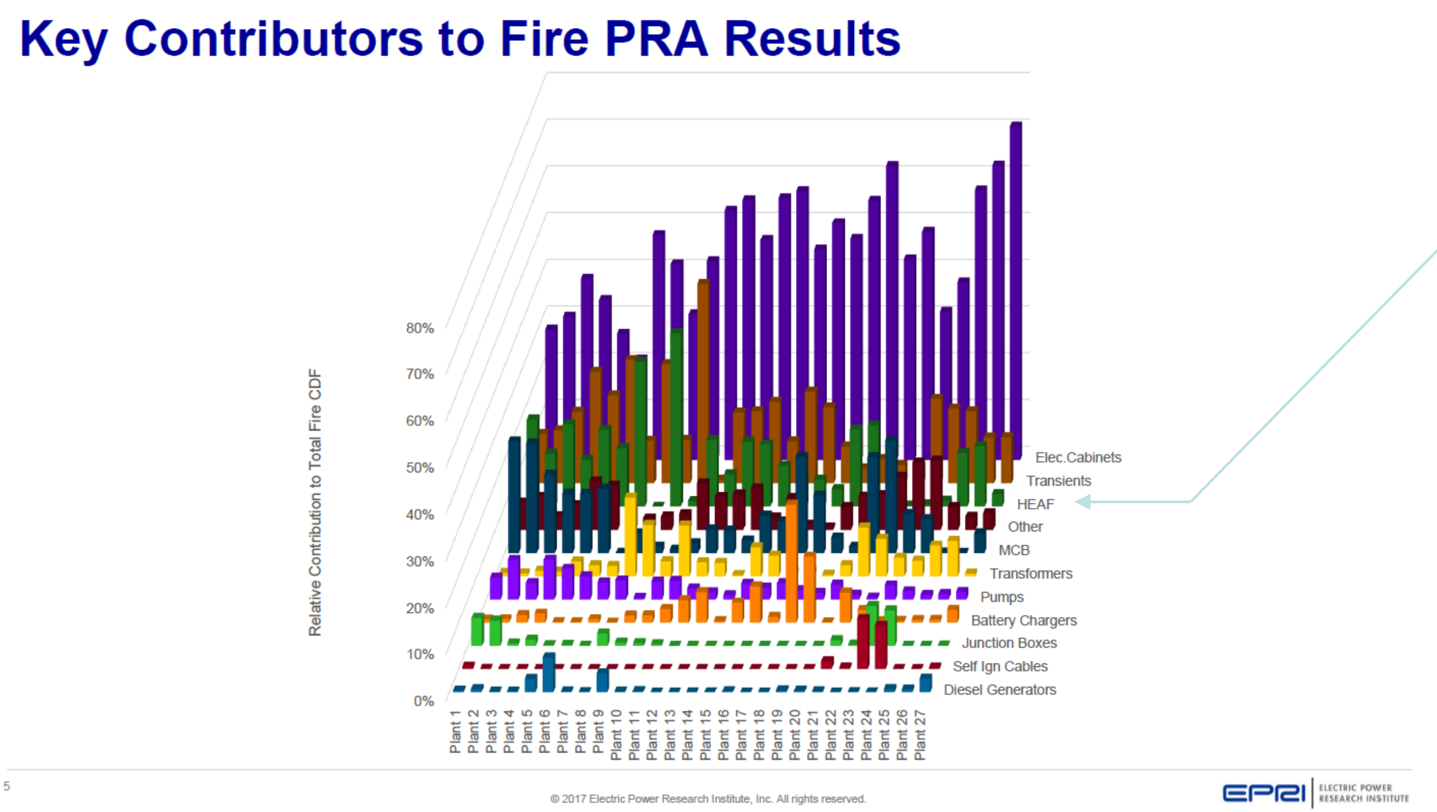
- Presentation by EPRI for the Regulatory Information Conference TH30 - Improving Realism in Fire PRA
  - March 15, 2018



NUREG/CR-6850
EPRI 1011989

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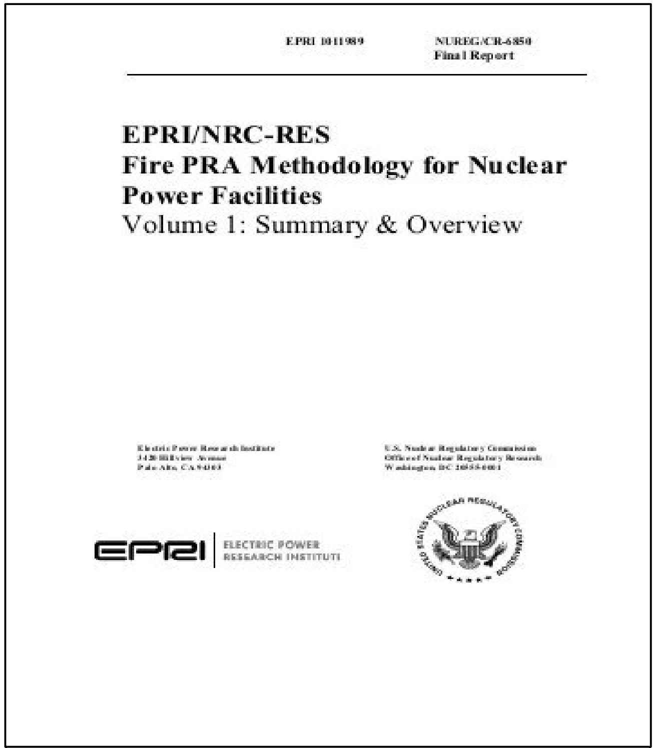
- Fire PRA Needs
  - Bin 15 Electrical Enclosure Fires
  - Bin 16 HEAF
- Lesson Learned
  - Bin 15 Too Broad
    - Low Voltage Controls considered same risk as Medium Voltage Switchgear
  - Create Realistic Divisions for Bin 16
    - Discussion later in workshop


EPRI 1011989 NUREG/CR-6850 Final Report

EPRI/NRC-RES
Fire PRA Methodology for Nuclear Power Facilities
Volume 1: Summary & Overview

https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6850/

Electrical Enclosure Fire Experiments (Bin 15)

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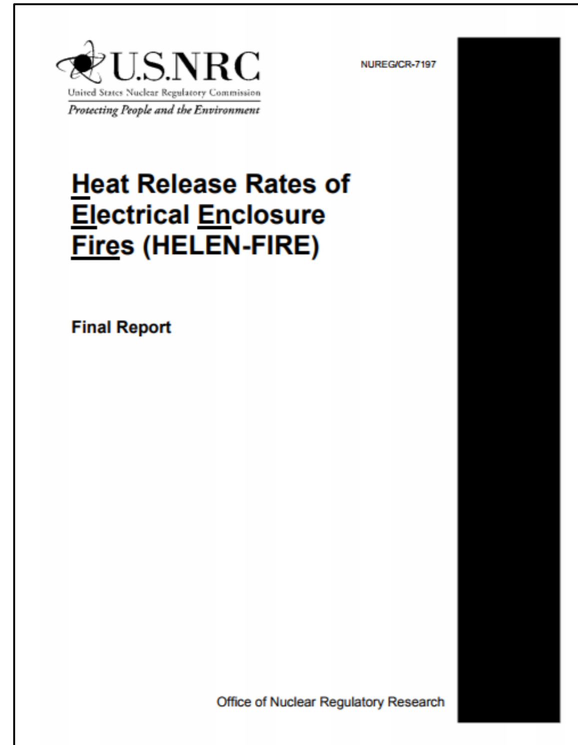
- Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE) NUREG/CR-7197
- 112 Full Scale Electrical Enclosure Fires
- Developed a Series of Heat Release Rate (HRR) Profiles
- Non- Energized
  - No electrical current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NUREG/CR-7197

Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE)

Final Report

Office of Nuclear Regulatory Research

https://www.nrc.gov/docs/ML1611/ML16110A037.pdf

Office of Nuclear Regulatory Research

Electrical Enclosure Fire Methodology

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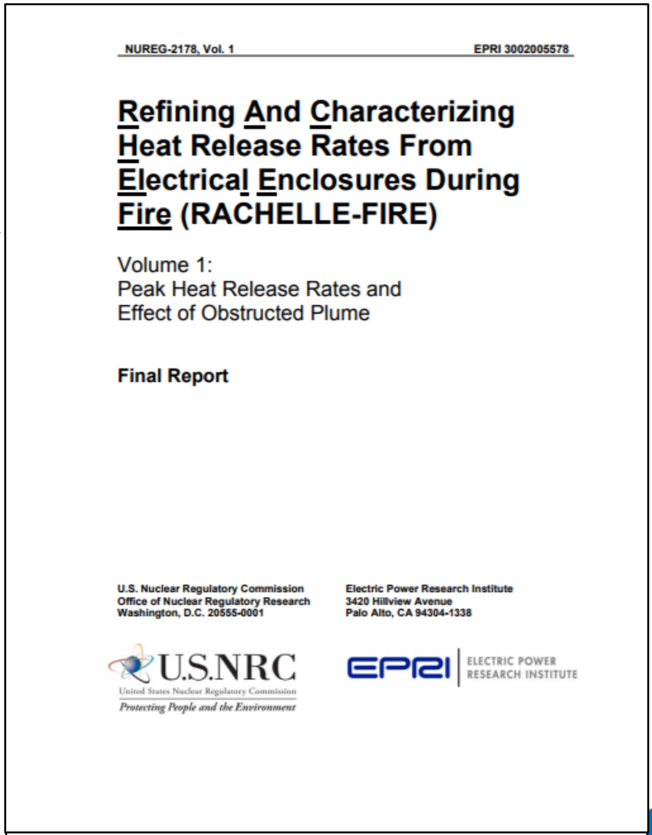
- Refining And Characterizing Heat Release Rates From Electrical Enclosures During Fire (RACHELLE-FIRE) — Volume 1: Peak Heat Release Rates and Effect of Obstructed Plume, Final Report (NUREG-2178, Volume 1, EPRI 3002005578)
- NRC/EPRI Working Group
- Classification of Electrical Enclosures (function, size, content, ventilation)
- Determined HRR probability distributions for corresponding categories
- Characterization of Fire Plumes
  - NIST Fire Dynamics Simulator (FDS)


NUREG-2178, Vol. 1 EPRI 3002005578

Refining And Characterizing Heat Release Rates From Electrical Enclosures During Fire (RACHELLE-FIRE)

Volume 1:
Peak Heat Release Rates and Effect of Obstructed Plume

Final Report

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555-0001

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304-1338

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2178/

HEAF Definition (Bin 16)

- Need for clear definitions
  - Subdivide Bin 16
    - Arc Flash (Bin 15)
    - Arc Blast
    - High Energy Arcing Fault
  - Electrical Enclosure Thermal Fire (Bin 15)
- NRC working with NFPA
  - Separate Discussion Later Today
  - Solicit Workshop Participants Input

Example of Recent Electrical Enclosure Arc Flash/Arc Blast Events

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Turkey Point; 2017

Brunswick; 2016

Example of Recent Electrical Enclosure HEAF Experience

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San Onofre; 2001

Onagawa; 2011

Example of Recent Bus Duct HEAF Experience

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Diablo Canyon Bus Duct (OpE)
2000

Zion Bus Duct (testing)
2016

Columbia Bus Duct (OpE)
2009

Operating Event History (OpE) - Duration

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- Operating Event history shows that breakers do not always work as expected (design vs. real world)
- HEAF events typically persist for timeframes much longer than design fault clearance times through the mechanism of breaker failures or other complicating factors

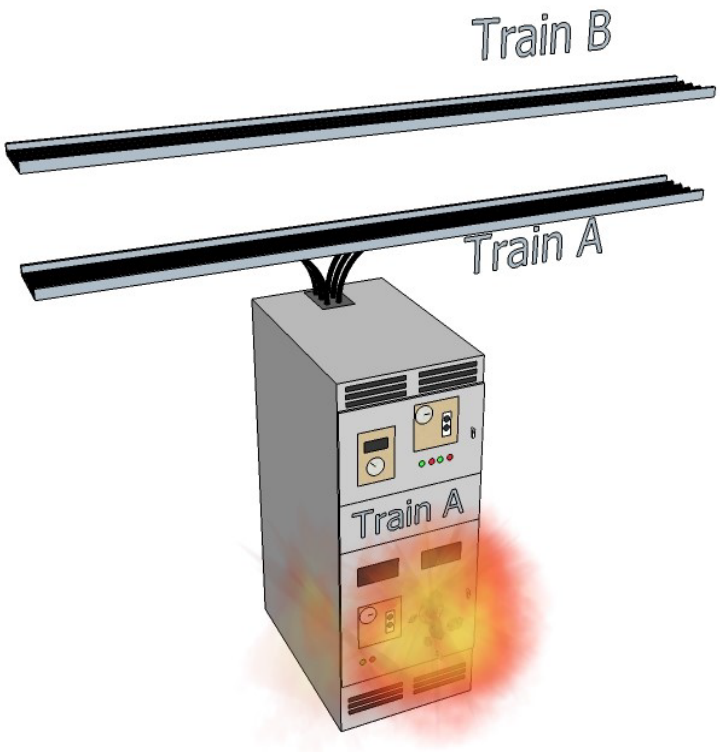
Event	Hold Time	Cause
Prairie Island; 08/03/2001	**>2 seconds**	Breaker Failure; Ionizing gas from the breaker was the initiator
Songs; 02/03/2001	**2.5 Seconds**	Breaker Failure; Ionizing gas from the breaker was the initiator
Robinson; 03/27/2010	**8-12 seconds**	Breaker Failure; Loss of DC Control Power
Diablo Canyon; 05/15/2000	**11 seconds**	Location; Voltage Decay
Columbia; 10/20/2009	**5 seconds**	Aging
Fort Calhoun; 06/07/2011	**Terminated by Operators >42 seconds**	Design Deficiency
Germany; 09/08/1989	**6 seconds**	Undetermined
Germany; 08/23/2004	**>2 seconds**	Overcurrent degradation
Germany; 05/30/1986	**8.5 seconds**	Undetermined

Safety Significance

- 10CFR 50 Appendix A "General Design Criteria (GDC)"
- GDC 3

  "Structures, systems, and components important to safety sha be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions."
- GDC 17

  "The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure."



Background of the HEAF Program

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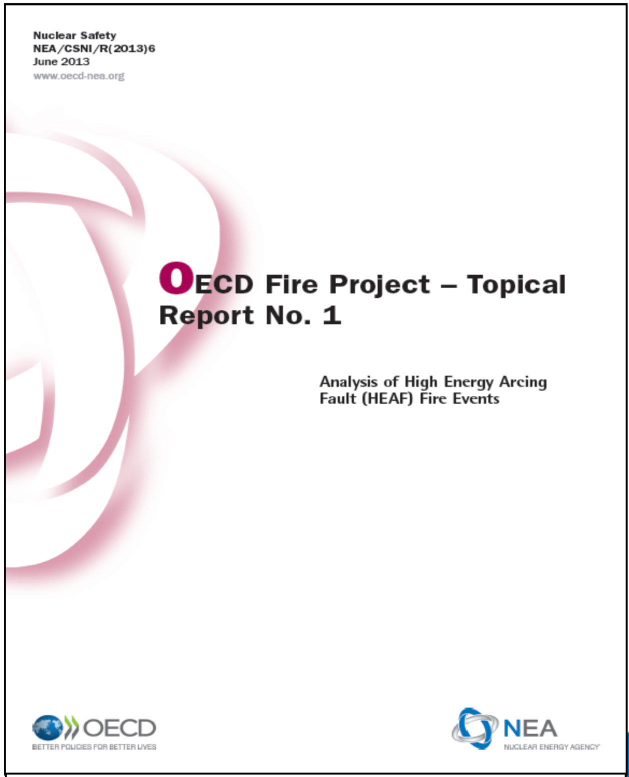
- OECD Fire Incident Records Exchange Project (FIRE)
  - *"Analysis of High Energy Arcing Fault (HEAF) Fire Events,"* NEA/CSNI/R(2013)6
  - 48 of 415 fire events collected represent HEAF-induced fire events (over 10%)
- International Partners
  - Canada, Finland, France Germany, Japan, Korea, Spain, U.S.


Nuclear Safety
NEA/CSNI/R(2013)6
June 2013
www.oecd-nea.org

OECD Fire Project – Topical Report No. 1

Analysis of High Energy Arcing Fault (HEAF) Fire Events

OECD BETTER POLICIES FOR BETTER LIVES
NEA NUCLEAR ENERGY AGENCY

https://www.oecd-nea.org/nsd/docs/2013/csni-r2013-6.pdf

Background of the HEAF Program

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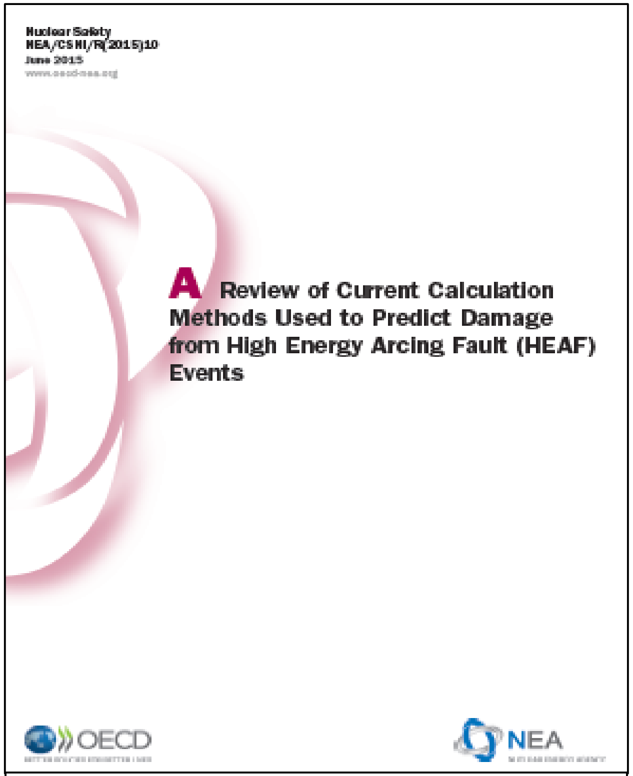
CSNI WGIAGE Task on High Energy Arcing Faults (2009 – 2013)

- Task Report "A Review of Current Calculation Methods Used to Predict Damage from High Energy Arcing Fault (HEAF) Events", NEA/CSNI/R(2015)10
  - Insights from operating experience with partly significant HEAF events
  - Literature study on methods for predicting HEAF consequences


Nuclear Safety
NEA/CSNI/R(2015)10
June 2015
www.oecd-nea.org

A Review of Current Calculation Methods Used to Predict Damage from High Energy Arcing Fault (HEAF) Events

OECD

NEA

http://www.oecd-nea.org/nsd/docs/2013/csni-r2015-10.pdf

Realistic Quantification of Hazard

- NRC testing has been, and will continue to be, informed by Operating Experience and NPP configurations:
  - LERs describe numerous three-phase arc faults with failure of an upstream breaker
  - Representative plant equipment used in testing
  - Voltage, current, arc duration within the bounds observed in LERs
  - Damage observed comports with LERs
- Input from Today's Workshop
- Draft Test Plans placed in Federal Register for Public Comment

U.S. OpE– Three Phase Faults

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- Three phase arcs generated at KEMA were initiated by means of a copper shorting wire 2.6 mm in diameter (10 AWG) as described in IEEE C37.20.7-2007 for low voltage equipment https://standards.ieee.org/findstds/standard/C37.20.7-2007.html
- Most HEAF event that we are aware of quickly progress to three phase faults. This is evident from a number of LERs:
  - The Kewaunee HEAF event (LER 87-009-00) involved a phase-to-ground fault, which “progressed to a phase-to-phase fault which accounted for the extensive bus damage.”
  - The Prairie Island HEAF event (LER 01-05-00) involved a “C-phase ground arcing event, which quickly involved all phases.”
  - The Zion HEAF event (LER 94-005-01) states that the “failure started as a single phase to ground fault which rapidly evolved into a three phase to ground fault.”

U.S. Operating Event History (OpE) Overpressurization

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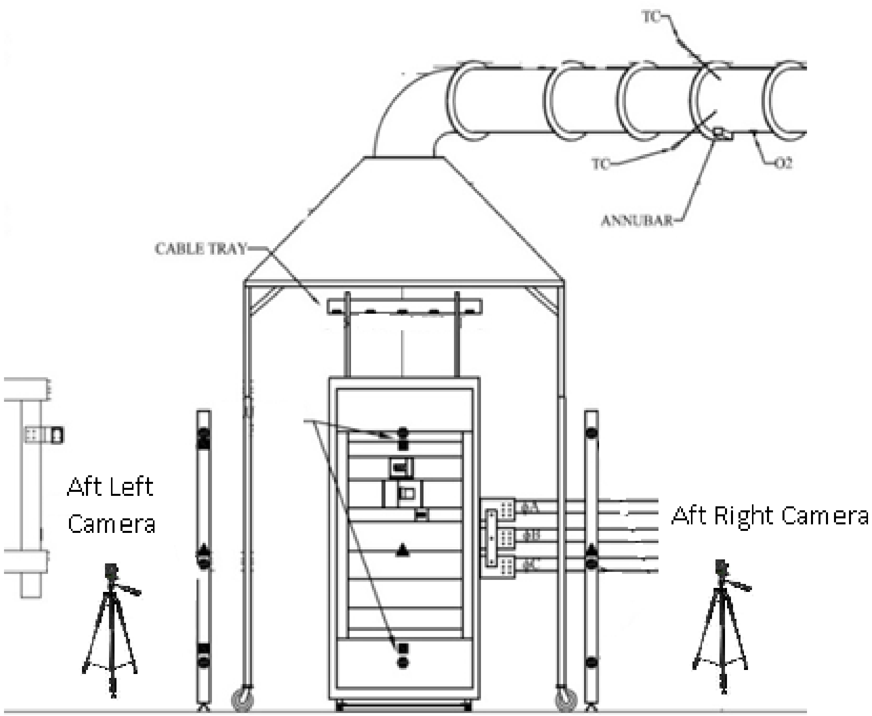
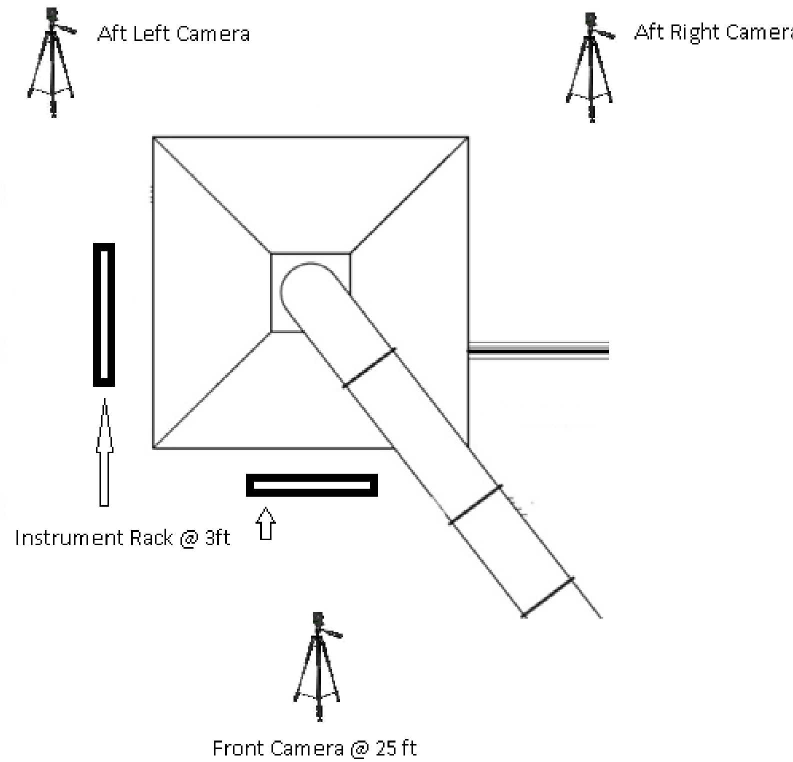
- Arc Flash and HEAF events can lead to overpressurization of compartments and challenge fire rated barriers even when circuit protection works as expected
  - Turkey Point Event-March 18, 2017
    - Fault Cleared in 35.8 cycles (or ~0.6 seconds)
    - The protective relays operated as expected
    - Fire Door D070-3, located 4.4m (14.5 ft.) away from the origin of the fault was damaged and the latch mechanism was deformed
    - Damage was caused by the over-pressurization of the room corresponding to the increase in pressure at the onset of the arc event
    - The damaged door defeated the 3 hour rated barrier between the 3A and 3B 4kV switchgear rooms
    - NRC Reactive Inspection Report May 12, 2017 (ML17132A258)

Phase I HEAF Testing

- 26 full-scale experiments carried out at KEMA high energy test facility between 2014-2016.





Phase I HEAF Testing

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Test #3: 480 V, 35 kA, 8 seconds
Copper Bus Bars

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Phase I HEAF Testing

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Test #15: 10 kV, 15 kA, 3 seconds
Oil-filled breaker (oil removed), copper bus bars

Phase I HEAF Testing

Test #23: 480 V, 40 kA, 7 seconds
Aluminum bus bars

Phase I HEAF Testing

Test #26: 4.16 kV, 26 kA, 3.5 seconds
Bus Duct, copper bus bars, aluminum housing

Phase I HEAF Testing Results

- Material Impact of Aluminum
  - Potentially much larger ZOI
  - Potentially greater likelihood of maintaining an arc at low voltages
  - Higher risk of fire propagation

Phase I HEAF Testing Results

- New Failure Mode: Conductive Products of Combustion
  - Conductive AL byproducts coated facility
  - Shorted out equipment and damaged electrical circuits
- Fort Calhoun HEAF event- June 7, 2011
  - Adjacent cabinets affected by HEAF bi-products

Test 23

Test 26

Phase I HEAF Testing Report

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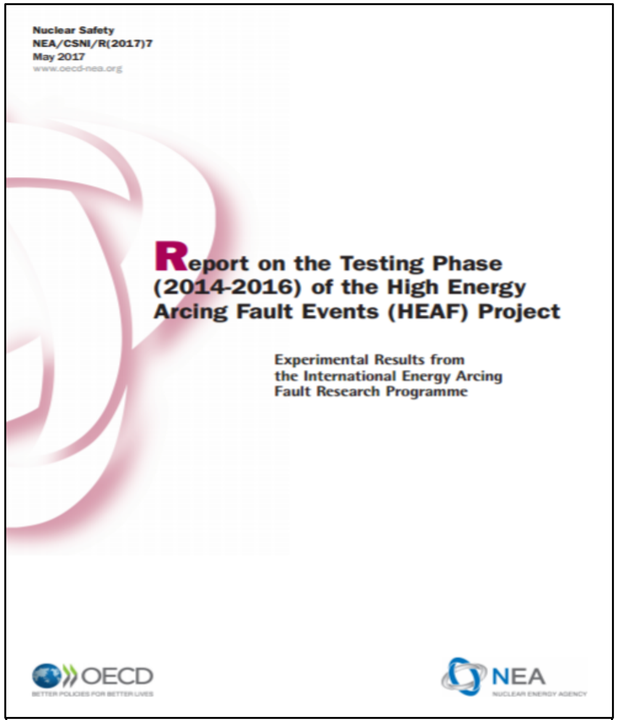
- *"Report on the Testing Phase (2014-2016) of the High Energy Arcing Fault Events (HEAF) Project: Experimental Results from the International Energy Arcing Fault Research Program,"* NEA/CSNI/R(2017)7


Nuclear Safety
NEA/CSNI/R(2017)7
May 2017
www.oecd-nea.org

Report on the Testing Phase (2014-2016) of the High Energy Arcing Fault Events (HEAF) Project

Experimental Results from the International Energy Arcing Fault Research Programme

OECD
NEA

https://www.oecd-nea.org/nsd/docs/2017/csni-r2017-7.pdf

Postulated HEAF Mitigation- "HEAF Shields"

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- Proposed shielding to limit the extent of damage from a HEAF events
  - objective is to minimize damage to risk-significant targets beyond the faulted switchgear and to prevent damage and ignition overhead cable trays:
  - In order for HEAF Shields to be Successful:
    - What is the Design Basis?
    - What is the Acceptance/Rating/Qualification Test Method?
    - How does the Installed HEAF Shield match what was Tested?
    - Why should this Engineered Feature be treated any different than: Fire Barriers (Walls/Floors), Fire Doors/Dampers Electrical Raceway Fire Barrier Systems, Penetration Seals, etc?

Postulated HEAF Mitigation- Louvers / Solid Tops

Misconceptions:

- The force of the HEAF energy will be directed by vent louver
  - Energy will only travel in direction of the vents and will prevent significant energy/mechanical damage targets located above or away from the vent path
- Solid tops on switchgears always contain the HEAF and prevent damage to targets above

Aluminum HEAF Generic Issue

- Generic Issues Program Pre-GI-018
  - The NRC has performed a screening review as part of the GI process related to HEAF events involving aluminum components
  - The generic issue review panel (GIRP) determined that the seven screening criteria were met in accordance with management directive 6.4 (ML14245A048) and is in the process of finalization and release of the screening phase document
  - The staff has recommended a two phase approach to address the generic issue and identified both short term and long term actions
  - GIRP memo issued (ML16349A027)
  - Moving into next phase of Generic Issue Program
- Separate Presentation Later Today

Information Notice (IN) 2017-04

- *"High Energy Arc Faults in Electrical Equipment Containing Aluminum Components"*
  - OECD/NEA international test program insights
  - 6 U.S. operating experience events involving aluminum components

Plant	Date
Fort Calhoun	June 7, 2011
Columbia	August 5, 2009
Diablo Canyon	May 15, 2000
Zion	April 3, 1994
Shearon Harris	October 9, 1989
Kewaunee	July 10, 1987

  - Issued August 21, 2017

HEAF PIRT

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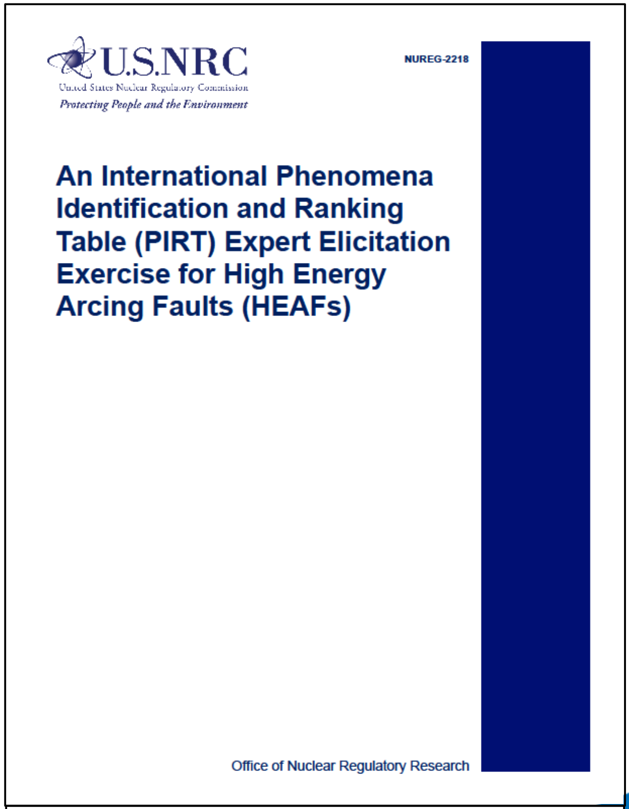
- International Phenomena Identification and Ranking Table (PIRT) exercise held in February 2017
- Early Insights:
  – Aluminum oxidation and byproducts
  – Pressure effects
  – Target characterization and sensitivity
  – Mitigating factors (“HEAF shields”)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NUREG-2218
An International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arcing Faults (HEAFs)
Office of Nuclear Regulatory Research

https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2218/

International Agreement Report

U.S.NRC
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- NUREG/IA-0470 Volume 1 "Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena"
- International Partnership with Japan Regulator
  - Secretariat of Nuclear Regulation Authority S/NRA/R

NUREG/IA-0470
Volume 1

International Agreement Report

Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena

Prepared by:
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Washington, DC 20555-0001

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Published by
U.S. Nuclear Regulatory Commission

https://www.nrc.gov/reading-rm/doc-collections/nuregs/agreement/ia0470/

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
- 64 comments received in total + 27 EPRI comments
- Separate Discussion Tomorrow

Conclusion

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- Electrical Enclosure Fires, Arc Flashes, Arc Blasts and HEAFs are not unique to Nuclear Power Plants
- However, they warrant special attention by the NRC and the Nuclear Industry due to their potential impact on Reactor Safety
- NRC would like to continue to work in collaboration with U.S. and International Partners

Generic Issues Program Overview

Office of Nuclear Regulatory Research
Division of Engineering
Regulatory Guidance and Generic Issues Branch

Thomas Boyce, Branch Chief
Stanley Gardocki, Senior Project Manager

April 2018

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Program Overview

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Purpose of Generic Issues Program

Fundamentals of the Generic Issues Program

- Stages of Generic Issues Program
- Process Overview
- Responsible Individuals and Groups
- Responsibilities of ACRS within the Generic Issues Program

Screening Criteria for Proposed Generic Issues

Documentation

- NUREG-0933
- Periodic Reports (semi-annual Generic Issue Management Control System)
- GI Dashboard

Origins of Generic Issues Program

December 1977- Section 210 of the Energy Reorganization Act of 1974 was amended by Congress directing the NRC Commission to:

- Develop a plan for specification and analysis of unresolved safety issues (USI) relating to nuclear facilities, and
- Take actions as necessary to implement corrective measures with respect to such issues

As a result, the NRC staff developed a Generic Issues Program that would identify important safety issues applicable to multiple nuclear facilities

Three Stages of Generic Issues Program

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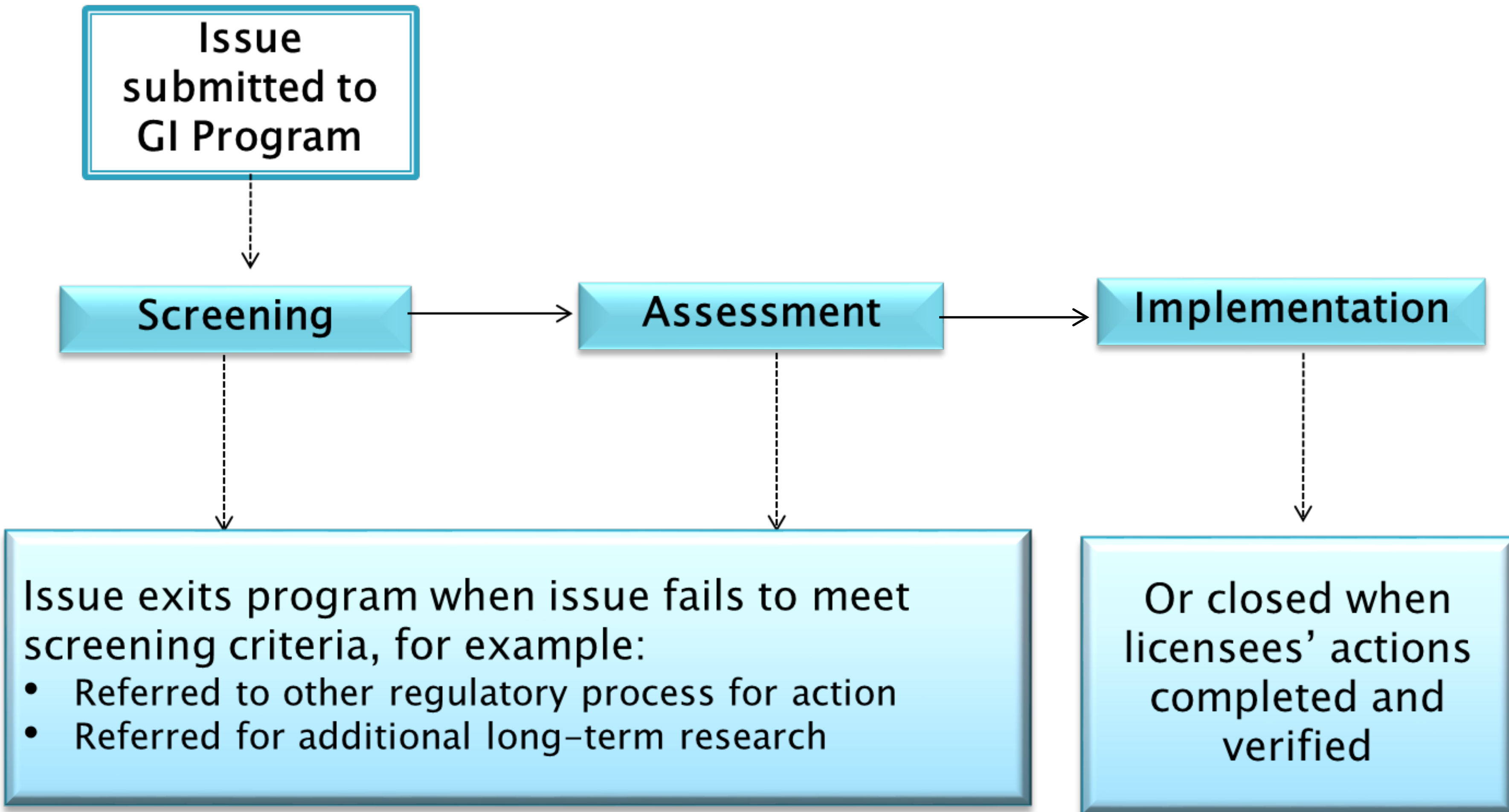

Responsible Program Individuals

Director of the Office of Nuclear Regulatory Research (RES)

- Provides overall management of the GI Program

The GI Program Manager (Chief of the Regulatory Guidance and Generic Issues Branch (RGGIB), RES/Division of Engineering)

- Responsible for program administration and daily program management. The GI Program Manager facilitates timely actions for the issue by the responsible organizations.

The Responsible Project Manager (RPM) (RGGIB staff member)

- Assigned the overall lead role for managing actions in the GI Program. The RPM facilitates progression of GIs, especially in the Screening and Assessment stages.

Responsible Program Groups/Panels

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Generic Issue Review Panel (GIRP):

- Composed of a chairman at the Senior Executive Service (SES) level, technical experts, the RPM, and a member of RES/DE line management. Responsible for evaluations performed during the screening and assessment stages. Provides recommendations whether a GI should proceed forward in the GI process.

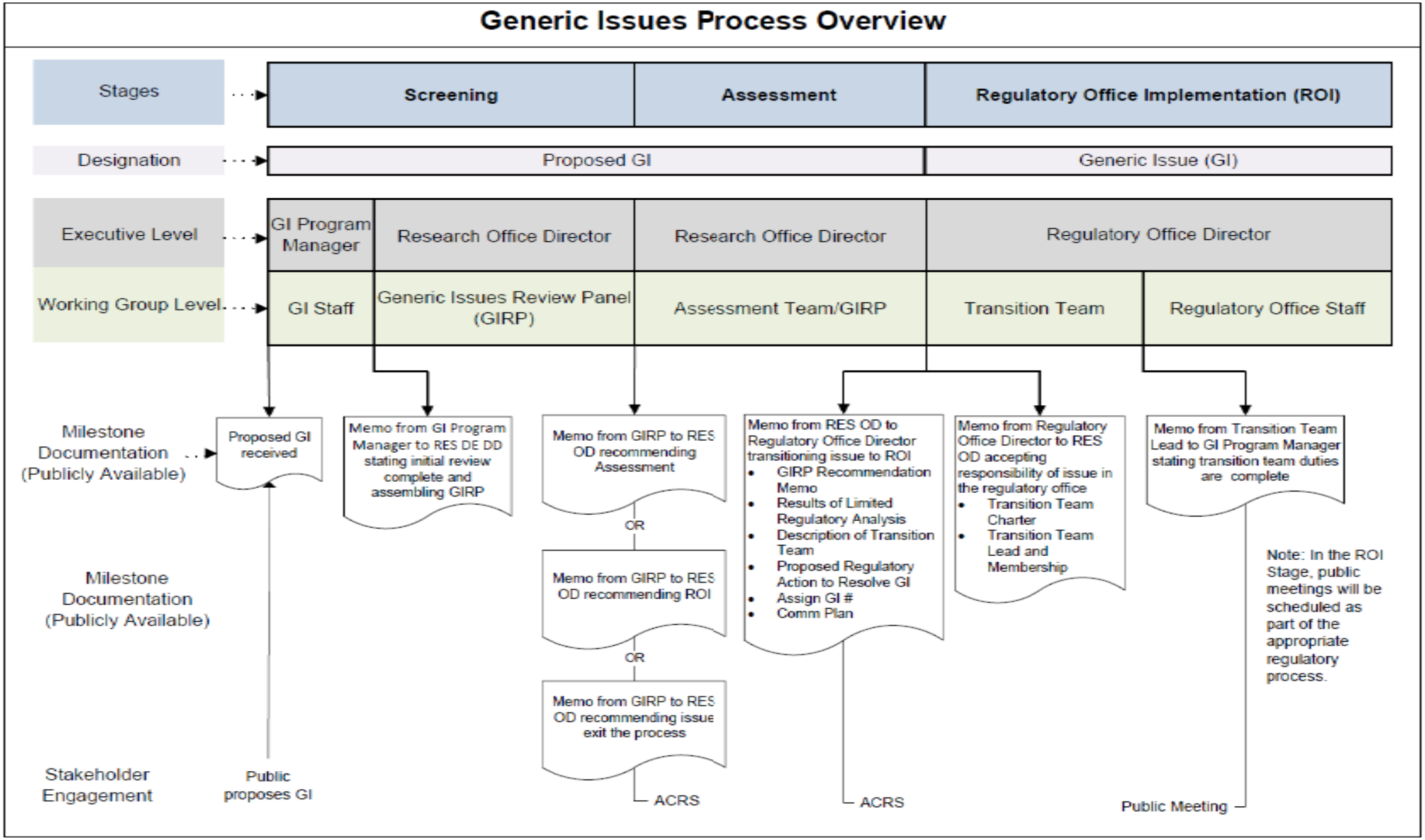
Assessment Team:

- Composed of the RPM and knowledgeable individuals of the issue. Provides technical support to assist the GIRP conclude whether the proposed GI should continue to Regulatory Office Implementation Stage.

Transition Team:

- Composed of a team lead at the SES level, the RPM, and knowledgeable individuals of the issue. Provides support until the transition team leader is satisfied that sufficient knowledge has been transferred to the receiving office staff

Process Overview



Screening Criteria for Proposed GIs

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The GI Program only addresses issues that meet all seven criteria:

1) The issue affects public health and safety, the common defense and security, or the environment.
2) The issue applies to two or more facilities, licensees, or holders of other regulatory approvals.
3) The issue is not being addressed using other regulatory programs and processes; not addressed by existing regulations, policies, or guidance.
4) The issue can be resolved by new or revised regulation, policy, or guidance.
5) The issue's risk or safety significance can be adequately determined in a timely manner (does not require long-term study).
6) The issue is well defined, discrete, and technical.
7) Resolution of the issue may involve review, analysis, or action by the affected licensees.

Screening Criteria can be found in:

Management Directive 6.4, "Generic Issues Program"

NUREG 0933

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NUREG-0933 provides the historical record of resolved generic safety issues.

It documents the screening analysis and disposition of all issues.

It is available on the NRC public website at https://www.nrc.gov/sr0933/

Resolution of Generic Safety Issues (Formerly entitled "A Prioritization of Generic Safety Issues") (NUREG-0933, Main Report with Supplements 1–34)

SEARCH GENERIC ISSUES

Matching all criteria:

Issue contains

Title contains

Related Licensee Events contains

Related Technical Area

Select options

Resolution Product Category

Select options

Facility Type

Select options

Search in

Select options

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EXPORT AND PRINT

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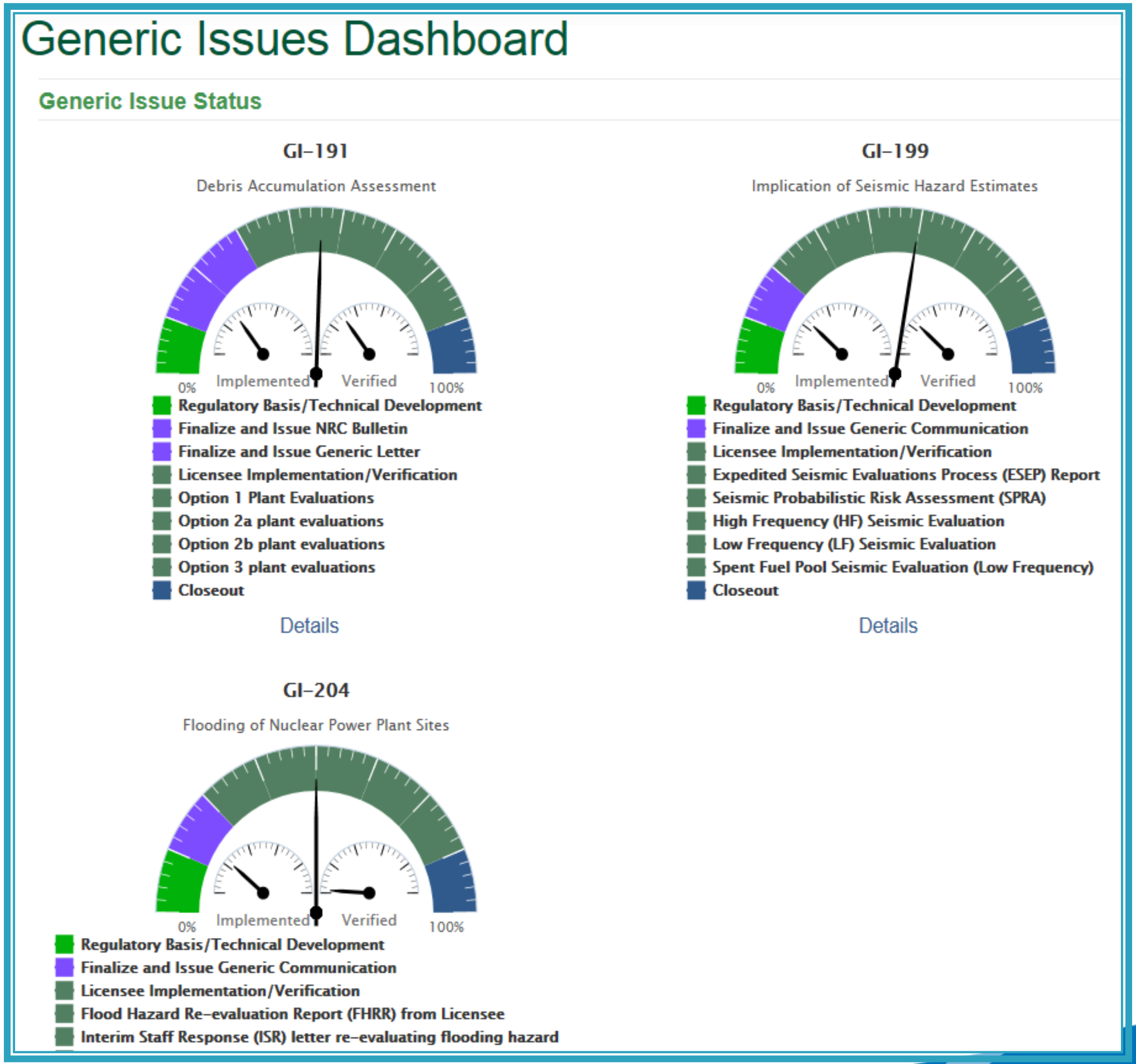
Generic Issue Dashboard



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The GI Dashboard provides on-line access to the detailed status of active generic issues in the Regulatory Office Implementation Stage.

GI Dashboard is available on the public NRC website: https://www.nrc.gov/about-nrc/regulatory/gen-issues/dashboard.html

((NRC Staff: GI Dashboard is also available on the internal NRC web page. It also provides status of generic issues that are in Screening and Assessment Stages. It can be found in the "Programs and Projects" section of the Research Web page: http://gid.nrc.gov/Static/SitePreview.html

Recent Proposed Generic Issues

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Recent Generic Issues: majority closed in Screening Stage **[bold still open]:**

- Pre GI-0001 - Multi-Unit Core Damage Events
- Pre GI-0002 - BWR Strainer Issues
- Pre GI-0003 - Fuel Pool Criticality Issue
- Pre GI-0004 - LOCA with Delayed LOOP
- Pre GI-0005 - Electromagnetic Pulse Attack
- Pre GI-0006 - Boron Precipitation following LOCA
- Pre GI-0007 - Core Uncovery after Discharge Leg LOCA
- Pre GI-0008 - BWR RHR Water Hammer
- **Pre GI-0009 - Flooding Following Upstream Dam Failure *[Currently open in the Regulatory Office Implementation Stage as GI-204]***
- Pre GI-0010 - Dispersal of Fuel Particles During LOCA
- Pre GI-0011 - Downstream Dam Failures
- Pre GI-0012 - Effects of Upstream Dam Failures on Fuel Facilities
- Pre GI-0013 - Effect of External Flooding on ISFSI
- Pre GI-0014 - Man-Made External Hazards
- Pre GI-0015 - Trapped Hydrogen and Oxygen Fire and Explosion During Fluid Transients
- Pre GI-0016 - Dependency on Electrical Power to Support Operation of AFW Turbine-Driven Pump
- Pre GI-0017 - Great Lakes Low Water Level
- **Pre GI-0018 - HEAF *[Currently open in the Assessment Stage]***
- Pre GI-0019 - Containment Penetrations short circuit protection
- **Pre GI-0020 – Inadequate Procedures for AOOs *[Currently open in the Screening Stage]***

References

- Management Directive 6.4, “Generic Issues Program” (ML14245A048), or on the web in the NRC Library in Document Collections
- RES Office Instruction TEC-002, Rev. 2, “Procedures for Processing Generic Issues” (ML11242A033)
- “NRR Office Instruction LIC-504, “Integrated Risk-Informed Decision-Making Process for Emergent Issues” (ML14035A143)
- NUREG-0933, “Resolution of Generic Safety Issues” <https://www.nrc.gov/sr0933/>

Generic Issue PRE-GI-018
High Energy Arc Faults Involving Aluminum

April 18, 2018

Office of Nuclear Regulatory Research /
Division of Engineering /
Regulatory Guidance and Generic Issue Branch
Stanley Gardocki / Senior Reactor Engineer

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PRE-GI-018 is in Assessment Stage

Issue submitted to GI Program

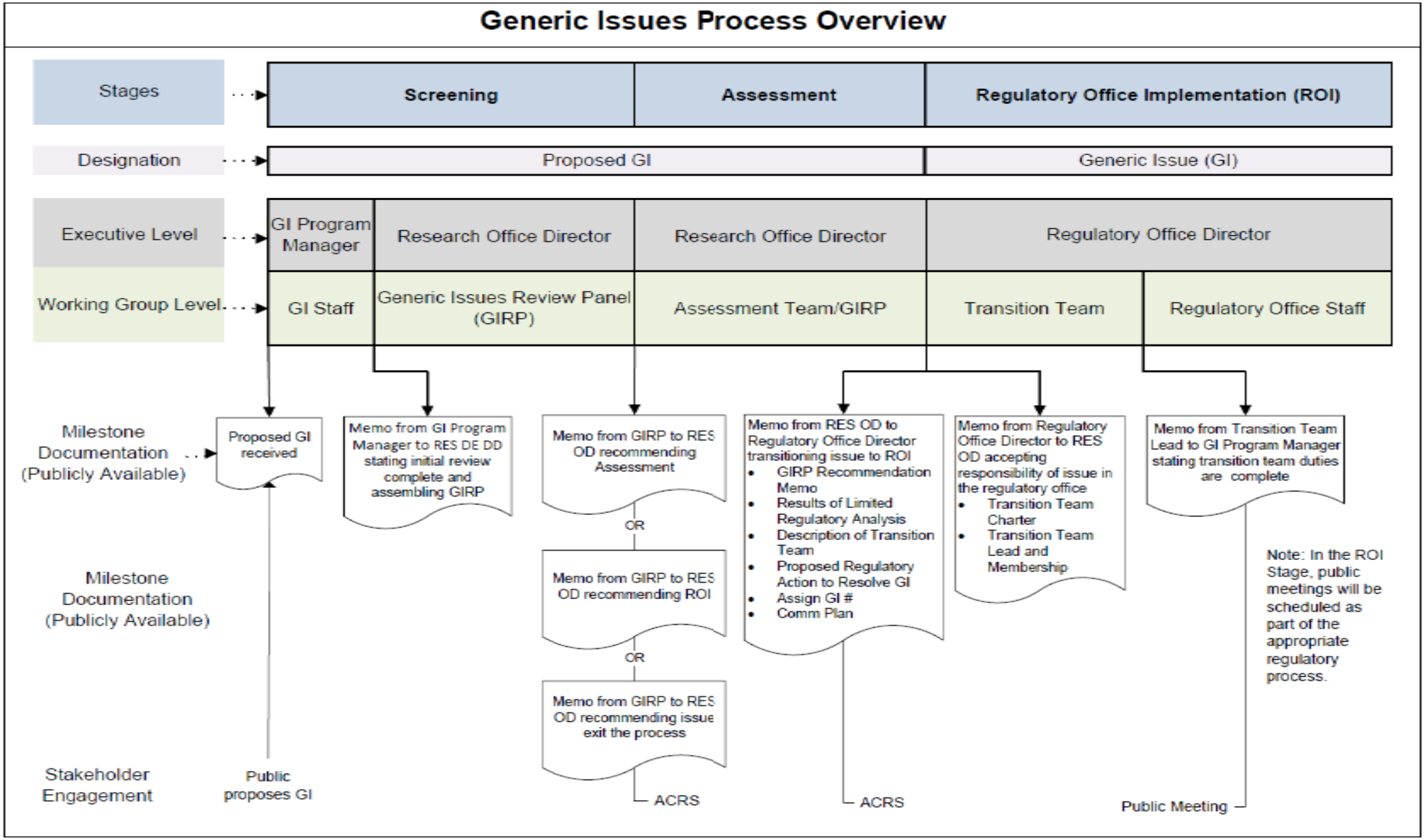
Screening → **Assessment** → **Implementation**

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

Process Overview



Screening Review - Complete

- The NRC formed a Generic Issues Review Panel (GIRP) and it completed a formal screening review on August 21, 2017
- The GIRP found it met all seven screening criteria in accordance with Management Directive 6.4, “Generic Issues Program”
- The GIRP recommended a phased approach during the assessment stage, involving both short term and long term actions to determine if it should proceed to next stage, Regulatory Implementation Stage (ROI)
- The screening report can be found in Agency Document Access Management System (ADAMS) under accession number ML16349A207

Short Term Actions

These actions occur during the Assessment Stage:

- Task 1) Determine the extent of condition
- Task 2) Develop an interim ZOI
- Task 3) Determine electrical fault characteristics
- Task 4) Develop a risk/safety determination
- Task 5) Develop a plan for future testing
- Task 6) Develop interim guidance
- Task 7) Perform additional focused HEAF testing
- Task 8) Determine if to proceed to ROI stage

Long Term Actions

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These actions commonly occur during the Regulatory Office Implementation (ROI) Stage:

- Task 1) Issue generic communications
  - Information Notice 2017-04 was issued August 21, 2017
  - Additional generic communications may be issued
- Task 2) Revise technical guidance
- Task 3) Assess risk through long-term performance monitoring

Long Term Actions: (Continued)

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- Phenomenon Identification and Ranking Table (PIRT) team to review OpE and testing results
- Identify the need for and specific type of future testing
- Perform additional focused HEAF testing specifically designed to quantify the ZOI for a HEAF involving aluminum components
- Develop revised guidance based upon tests performed on aluminum components
- Assess risk

Actions in progress or completed:

- NRC has received results of an informed Industry survey, conducted by NEI, on the extent of aluminum components currently installed in nuclear power plants
- NRC to invite personnel to potential joint industry/NRC expert elicitation process
- NRC to develop future test plans
- NRC scheduled workshop in April 2018 with Industry
- NRC staff to solicit candidates for plant assessment on the impact on risk

Actions in progress or completed: Continued

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- NRC and Industry will conduct testing to gather more experimental data
  - An experimental effort is being planned as a continuation of the OECD/NEA HEAF Experimental Project – Phase 2
- NRC to establish definitive zone of influence (ZOI) with the presence of aluminum
- NRC will calculate potential risk increase

Summary

- Summary
- Questions
- Comments

Pilot Plants
High Energy Arc Faults Involving Aluminum

Nick Melly
Office of Nuclear Regulatory Research
Division of Risk Analysis

April 18, 2018
Rockville, Maryland

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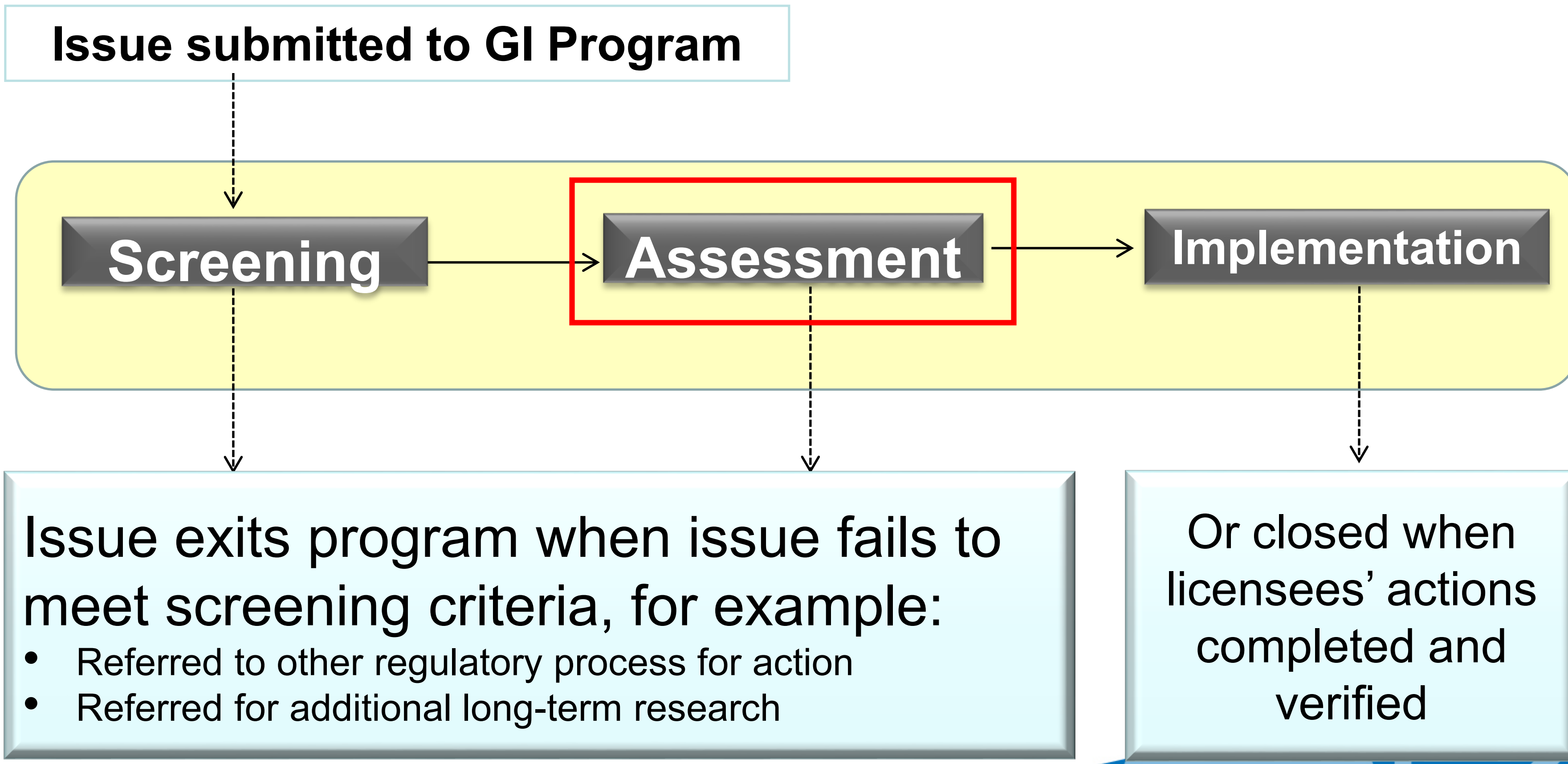
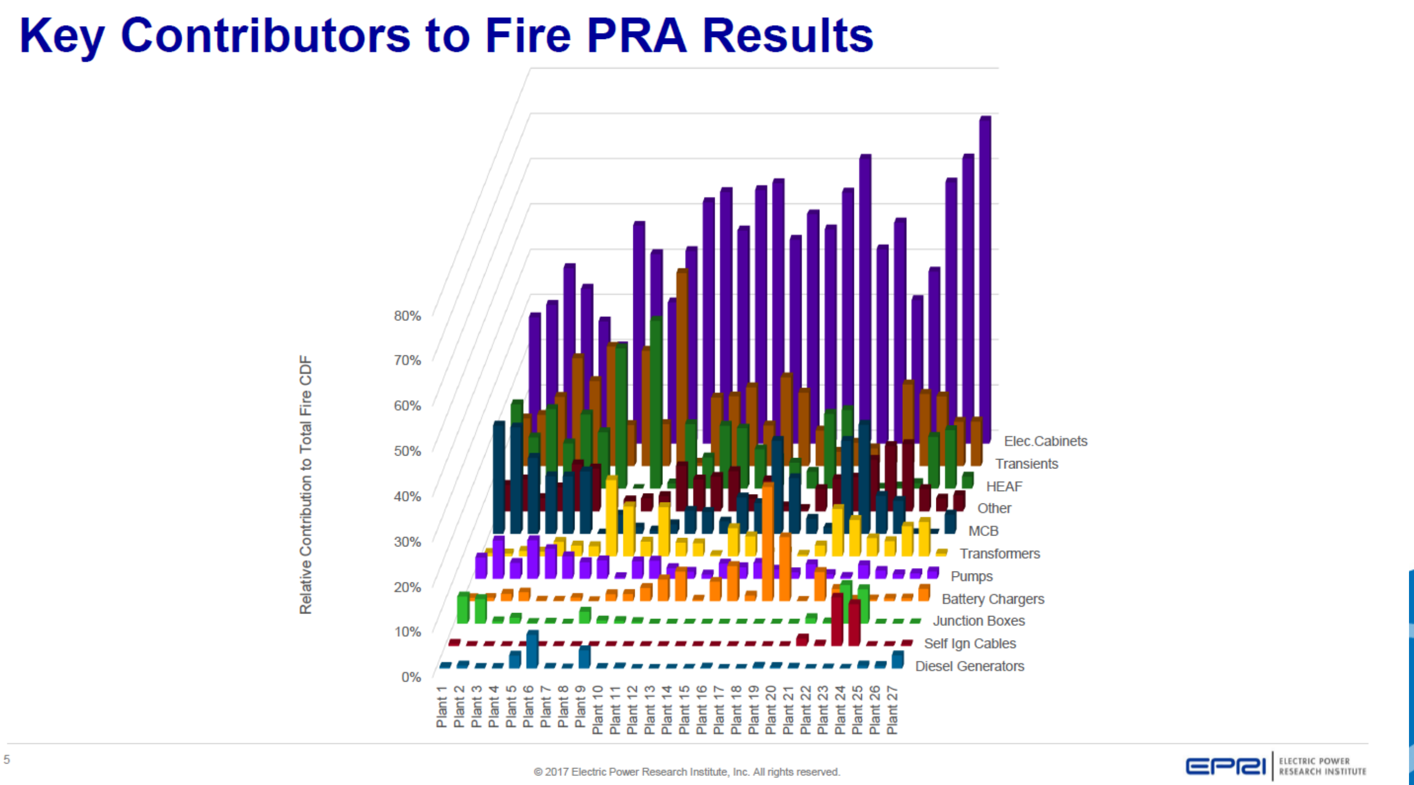
Assessment Stage Risk Analysis

Task 4: Develop a risk/safety determination

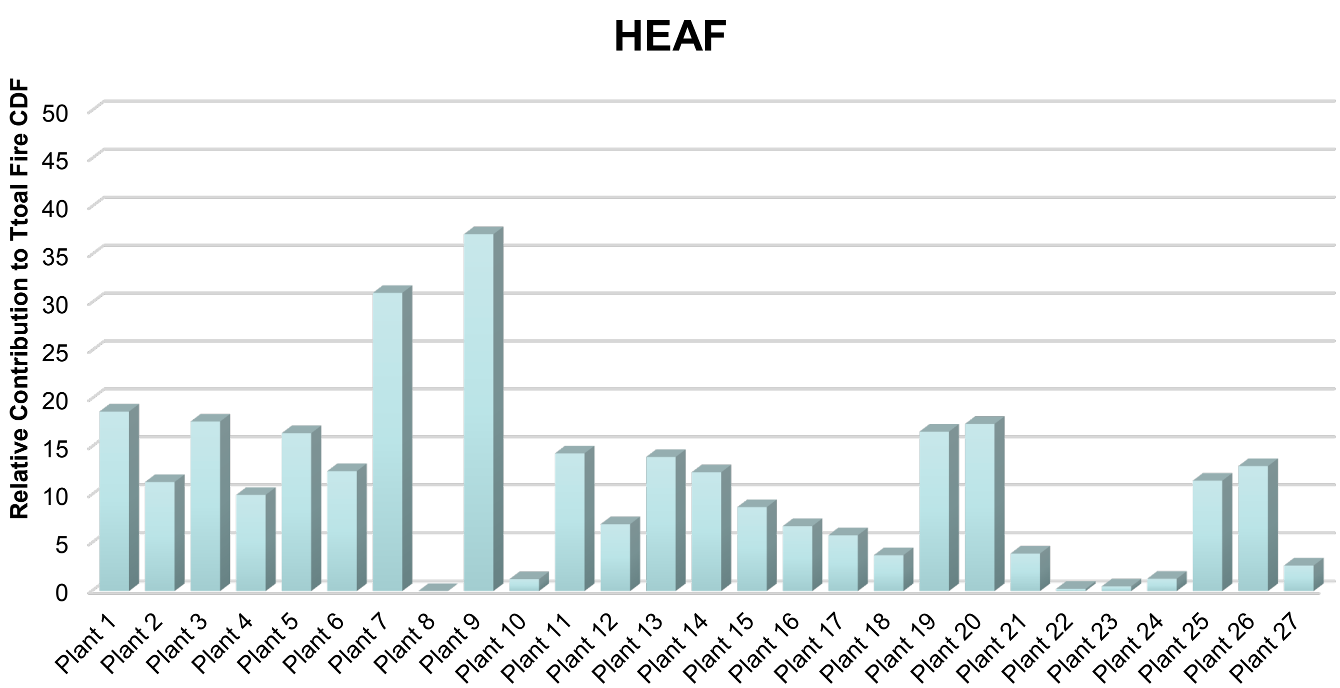


Plant Fire Risk Contribution

- Presentation by EPRI for the Regulatory Information Conference
  TH30 - Improving Realism in Fire PRA
  - March 15, 2018



HEAF Fire Risk Contribution



Preliminary Risk Assessment Assumptions

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- Performed using information from SPAR all hazards models
- All HEAF scenarios were assumed to have aluminum components
  - Potentially conservative, however a large number of plants did identify aluminum components as part of an informal NEI Survey. (ADAMS Accession No. ML17165A140)
- Hot Gas Layer (HGL) damage was used to evaluate the conditional core damage probability (CCDP) for each HEAF scenario
  - In lieu of performing plant walkdowns and evaluating what equipment would be damaged if a larger zone of influence (ZOI) was used for aluminum components
  - Conservative assumption which damages all components within the room

Initial Scoping Risk Assessment Assumptions (continued)

- No credit for automatic or manual suppression systems was used, non-suppression probability (NSP) values are set to 1.
- No evaluation was done to evaluate the potential impact on of a HEAF on the suppression systems.
- No evaluation of bus duct contribution
  - Scenarios were not provided

SPAR Model Results

COMPARTMENT	DESCRIPTION	Plant Fire CDF	HEAF ZOI as HGL CDF
1	B Switchgear Room	1.37E-05	**2.70E-05**
4	Turbine Building	2.47E-06	**7.12E-05**
5	A Switchgear Room	2.16E-06	**6.40E-05**
9	A Reactor Aux Building	1.38E-07	**2.07E-05**

	Total Plant Fire CDF	Increased HEAF ZOI CDF
SUM	3.06E-05	1.95E-04

Need for Pilot Plants

- Understand realistic risk associated with HEAF events involving aluminum.
- Leverage existing plant probabilistic risk assessment (PRA) models and use pilot plants
- Technical office instruction TEC-002," Procedure for Processing Generic Issues and Section 3 of NUREG/BR-0058, Rev. 4, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,"

Pilot Plant Features

- Volunteer pilot plants will be selected that have identified aluminum components
  – NEI Survey ADAMS Accession No. ML17165A140
- Pilot plants should have unique HEAF scenarios modeled within their PRA
- Identified ZOI used to model target damage following
  – NUREG/CR-6850, Appendix M
  – BUS DUCT (COUNTING) GUIDANCE FOR HIGH-ENERGY ARCING FAULTS (FAQ 07-0035)
  – Plants that mapped HEAF scenarios to HGL conditions are not ideal candidates for evaluation
- Plant walkdowns and NRC interaction will be decided on an as needed basis

Questions?

Arc Flash/Blast HEAF Definitions

Kenn Miller
Office of Nuclear Regulatory Research
Division of Engineering

April 18, 2018
Rockville , Maryland

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Purpose

- Collectively develop/document clear definitions to insure common understanding:
  - Arc/Electric Arc
  - Arc Flash
  - Arc Blast
  - High Energy Arcing Fault (HEAF)
  - Electrical Enclosure Thermal Fire

Purpose (Cont.)

- Proposed Arc Fault Severity Classifications:
  - Arc Fault Class 1 (Arc Flash)
  - Arc Fault Class 2 (Arc/Blast/HEAF)
  - Arc Fault Class 3 (Arc Blast/HEAF)
- Proposed definitions and collect input to finalize
- Build on established definitions for development, execution and documentation of research

Arc/Electric Arc

- **Arc/Electric Arc** – An arc is a high-temperature luminous electric discharge across a gap or through a medium such as charred insulation.
  – Based on NFPA 921 definition 3.3.8

Arc Flash

- **Arc Flash** – An arc flash is a release of energy caused by an electric arc characterized by a rapid release of thermal energy due to the vaporization and ionization of materials by the arc.
  - Developed from NFPA 70E definition of Arc Flash Hazard
  - When electrical protective systems work as designed, the arcing event is typically limited to an arc flash on the order of cycles rather than seconds depending upon breaker set points
  - Arc Flash events typically are associated with self-extinguishing fire events

Arc Blast

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- **Arc Blast** – An arc blast is a rapid release of thermal, mechanical and acoustical energy) caused by the rapid heating and vaporization and ionization of materials resulting from a sufficiently energetic arc flash. Arc Blasts are more energetic than Arc Flash events depending on the electrical characteristics of the system during the initiation of the event; such as the phase angle, current, and voltage characteristics.
  - Developed from NFPA 70E definition of Arc Flash Hazard
  - Arc blasts can cause room over-pressurization effects and have the potential to lead to missile damage effects from thrown equipment or enclosure material
  - All arc blasts are associated with arc flashes, but not all arc flashes lead to arc blasts
  - Arc Blast events can still occur when electrical protective systems work as designed

High Energy Arching Fault (HEAF)

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- **High Energy Arcing Fault (HEAF)** – A high energy arcing fault is a type of arc flash that persists for an extended duration (duration indicative of a level of circuit protection failure and/or protection design flaw)
  - High Energy Arcing Faults are typically associated with events contingent with a failure (or lack) of circuit protection or adequate circuit protection coordination
  - All high energy arcing faults are associated with arc flashes, but not all arc flashes are high energy arcing faults
  - High energy arcing faults may produce varied levels of arc blasts

Arc Fault Class 1 (Arc Flash)

- **Arc Fault Class 1 (Arc Flash) –** Damage is contained in within the general confines of the component of origin.
  - These events are associated with minor damage and minimal bus bar degradation from melting/vaporization.

Arc Fault Class 2 (Arc Blast/HEAF)

- **Arc Fault Class 2 (Arc Blast/HEAF) –** Damage is contained in within the general confines of the component of origin. However, arc blast effects have the potential to damage surrounding equipment through pressure rise effects (i.e. severe equipment deformation, thrown doors, degraded fire barriers).
  - Typically do not create ensuing fires
  - Typically associated with designed electrical coordination and breaker performance
  - Pressure effects are highly dependent on room configuration and electrical characteristics of the event

Arc Fault Class 3 (Arc Blast/HEAF)

- **Arc Fault Class 3 (Arc Blast/HEAF) –** Damage includes the component of origin as well as spread to surrounding equipment within the fire zone. This damage includes pressure rise effects (i.e. severe equipment deformation, thrown doors, degraded fire barriers) which potentially can effect equipment in other fire zone(s).
  - These events are typically contingent with ensuing fire conditions
  - Typically indicative of a level of circuit protection failure and/or design flaw allowing for extended duration arc events
  - Pressure effects are highly dependent on room configuration and electrical characteristics of the event

Arc Fault Classifications

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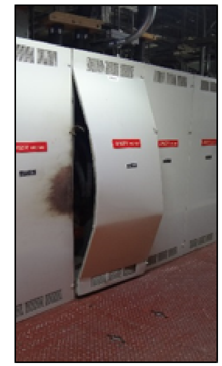
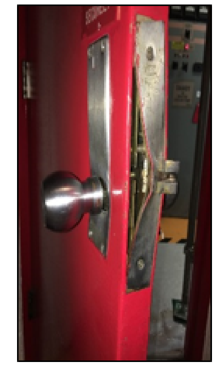
Protective System Performance (Duration)

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	   	

Electrical Enclosure Thermal fire

- **Electrical Enclosure Thermal fire** – A "thermal" fire is an electrical enclosure fire in which electrical energy does not significantly contribute to the heat release rate of the fire; rather, the heat release rate (HRR) is determined solely by the chemical energy released by combustion of cabinet's contents and classical fire dynamics.
  - This does not preclude a fire ignited by electricity, as long as the electricity does not significantly contribute to the ensuing heat release rate.

Small-scale testing

Gabriel Taylor, P.E.
Office of Nuclear Regulatory Research
Division of Risk Analysis

April 18, 2018

Rockville, MD

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Why small scale?

What do we expect to learn?

- Arc ejecta characteristics
  - Particle size distribution
  - Rates of production
  - Particle composition
  - Particle trajectory
- Mass loss of conductors
- Net energy contribution

How is it being accomplished?

- Sandia National Laboratories (SNL) lightning simulator
- Single phase to ground arcing between two vertical bus bars
- Particle collection and post test analysis
- High speed videography

Testing apparatus

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Experimental Variables

- Voltage
  - 0.48kV, 4.16kV, 6.9kV, 10kV
- Current
  - 0.35kA to 29kA
- Duration
  - 4 to 8 ms
  - 100 ms may be possible
- Bus bar material
  - Copper
  - Aluminum

Test Matrix

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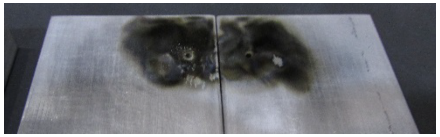
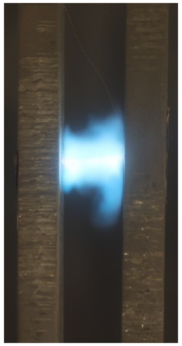
Table 1. HEAF Test Matrix and Experimental Parameters

Test	DC Current [A]	AC Voltage [V]				AC Scaled Current [kA]							Target Arc-Duration [ms]		Bus Bar Material		AC/DC	
	300	480	4160	6900	10,000	0.35	1.4	3.0	5.0	7.2	12.0	20.0	29.0	4	8	Al	Cu	AC	DC
1		x				x									x	x		x	
2		x				x									x		x	x	
3		x					x							x		x		x	
4		x					x							x			x	x	
5			x					x							x	x		x	
6			x					x							x		x	x	
7			x								x			x		x		x	
8			x								x			x			x		
9				x					x						x	x		x	
10				x					x						x		x	x	
11				x								x		x		x		x	
12				x								x		x			x		
13					x					x					x	x		x	
14					x					x					x		x	x	
15					x								x	x		x		x	
16					x								x	x			x		
17	x														x	x			x
18	x														x	x			x
19	x														x		x		x
20	x														x		x		x

Measurements

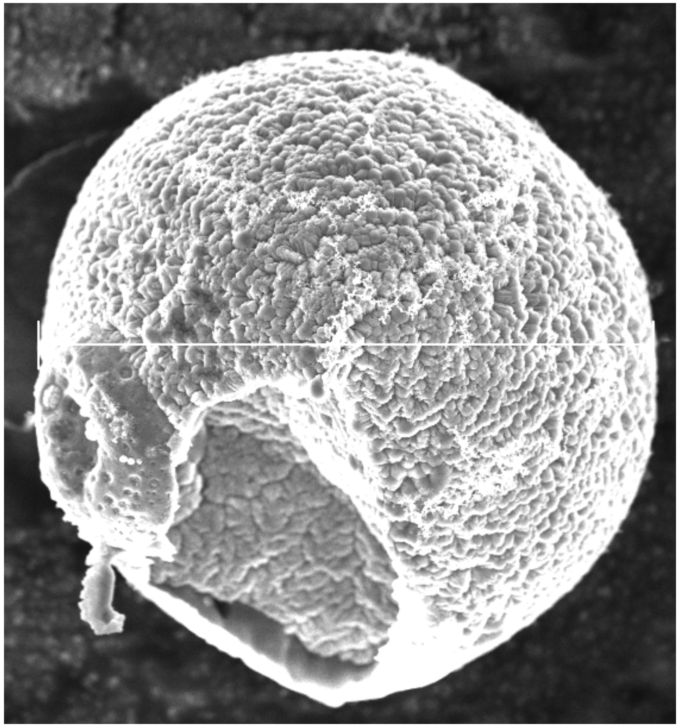
- Videography
  - High-speed infrared (IR) imaging
  - Trajectory
- Particle collection
  - Aerogel plates (99.999% SiO_2)
  - Carbon tape
- Particle Analysis
  - Energy dispersive x-ray analysis (EDXA)
  - Electron energy loss spectroscopy (EELS)
  - Scanning electron microscopy (SEM)
  - Raman spectroscopy
  - X-ray photoelectron spectroscopy

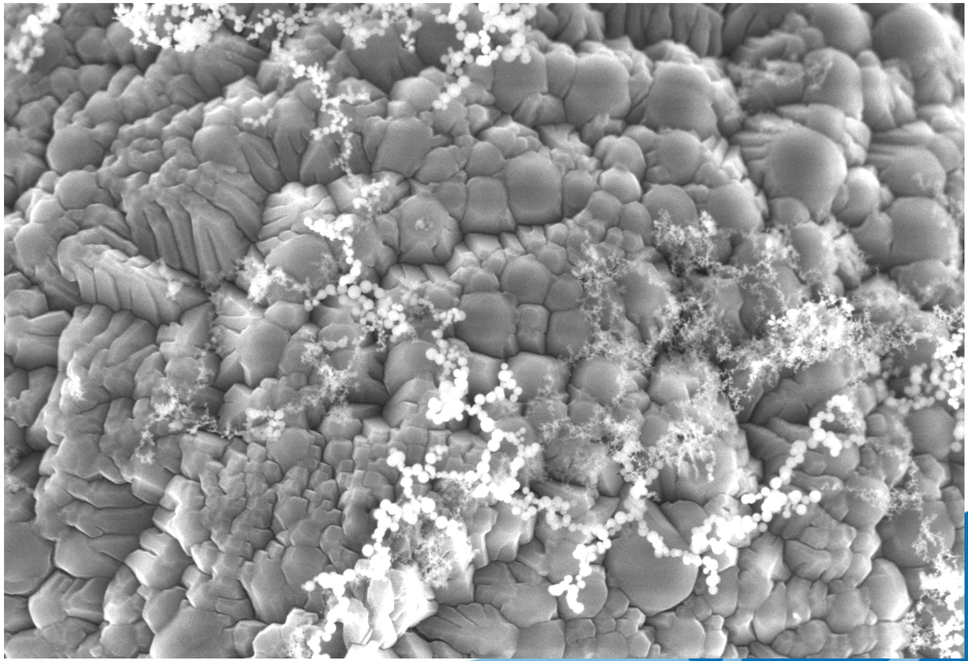




Scanning Electron Microscopy

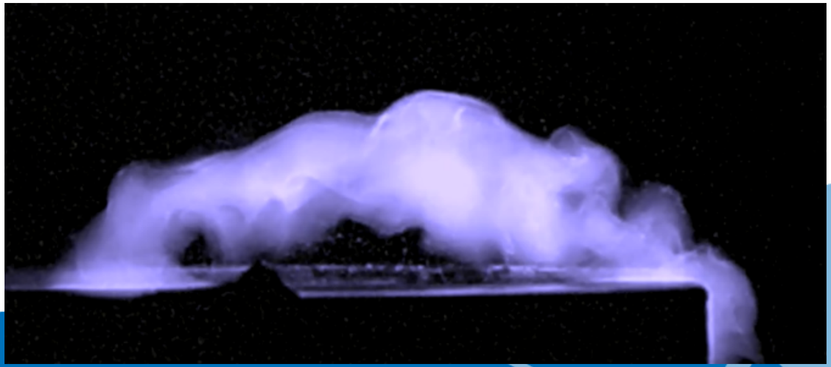
Collected via aerogel substrate
or
carbon microscopy tape





Modeling of Aluminum contribution

- Information will be used to support development of a fundamental energy balance modeling technique to account for contribution of aluminum
  - Collaboration with the University of Maryland, College Park



Small-scale benefits and limitations

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Advantages

- Measurement proximity to arc
- Cost
- Measurement
- Control of variables

Limitations

- Duration
- Single Phase

Federal Register

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- Draft test plan issued for public comment
- www.regulations.gov
  - Docket ID #: NRC-2018-0040
- Comment period closed April 4, 2018
  - April 2: Magnetic field monitoring / effect of insulated bus / parameter significance
  - April 3: NEI sent a request to extend for additional 45 days
- Any comments sent to Gabriel.Taylor@nrc.gov by May 4, 2018 will be placed into ADAMS and assessed by the NRC/SNL team.
- Testing planned to start June 25th

Test Matrix

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Table 1. HEAF Test Matrix and Experimental Parameters

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1		x				x									x	x		x	
2		x				x									x		x	x	
3		x					x							x		x		x	
4		x					x							x			x	x	
5			x					x							x	x		x	
6			x					x							x		x	x	
7			x								x			x		x		x	
8			x								x			x			x		
9				x					x						x	x		x	
10				x					x						x		x	x	
11				x								x		x		x		x	
12				x								x		x			x		
13					x					x					x	x		x	
14					x					x					x		x	x	
15					x								x	x		x		x	
16					x								x	x			x		
17	x														x	x			x
18	x														x	x			x
19	x														x		x		x
20	x														x		x		x

Questions?

PRA Modeling Implications

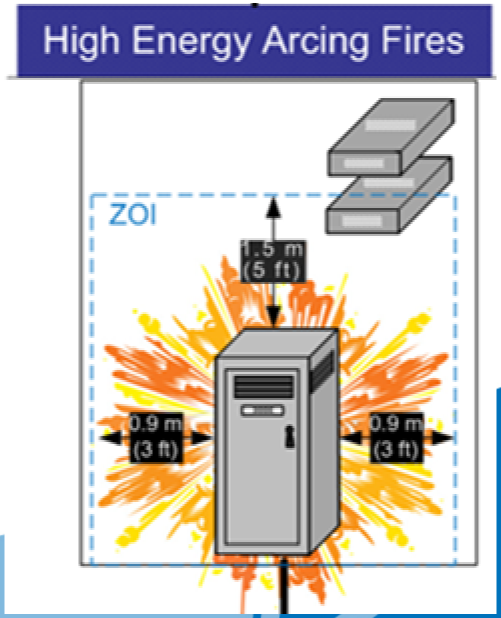
Gabriel Taylor, P.E.
Office of Nuclear Regulatory Research
Division of Risk Analysis

April 18, 2018

Rockville, MD

Existing Models
NUREG/CR-6850, EPRI 1011989

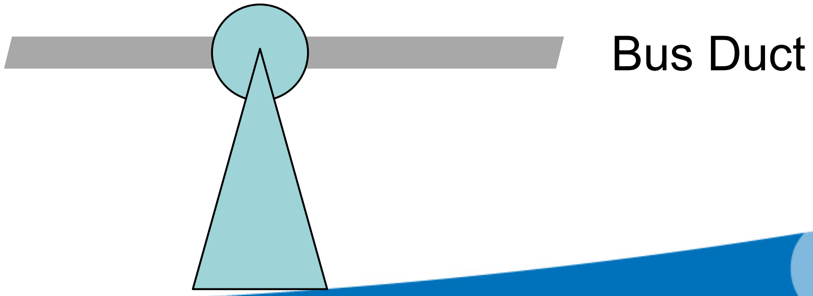
- Electrical enclosure HEAF event
  - Assume functional failure and physical damage
    - Zone of Influence (ZOI)
      - 1.5m (5 ft) vertical
      - 0.9m (3 ft) horizontal
  - Enduring fire
    - Modeled constant with detailed fire modeling procedure (Appendix E and G)



Existing Models

NUREG/CR-6850, EPRI 1011989

- Segmented Bus Duct HEAF Event
  - Functional failure and physical damage
    - 0.46m (1.5 ft) sphere at fault location
    - 30° downward cone (15° from vertical) up to max diameter of 6.1m (20 ft), i.e., 11.3m (37 ft) below fault



Modeling Approach

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- Bounding (Current models)
  - Enclosure, bus ducts
- Bounding by Categories
  - By power, energy, voltage, fault current, protection scheme, material, safety class
- Dynamic ZOI
  - Scenario dependent source
  - Target fragility

$$E = kVI\left(\frac{t}{D^p}\right)$$

$$E = k_1 \cdot t \cdot \left(\frac{k_2}{D}\right)^x \cdot 10^{[k_3 + k_4 \cdot \log(I) + k_5 \cdot G]}$$

Bounding ZOI (Current Model)

- Assumes worst case damage for all HEAF
  - i.e., one size fits all
  - Damage and ignition of components within ZOI
  - Peak HRR
- Least amount of information needed to determine ZOI
- Least realistic for majority of cases
- Simple
- Lowest cost

Refined Bounding ZOI

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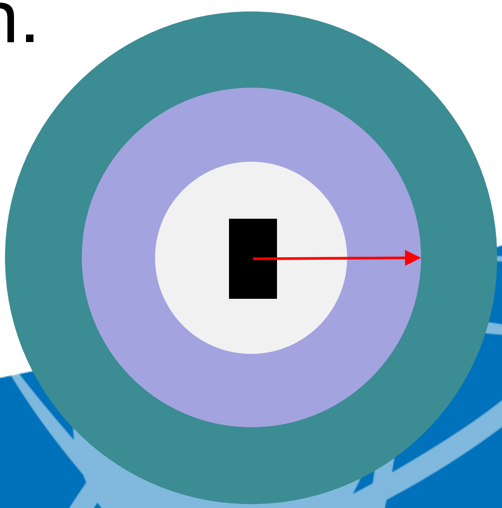
- Subdivides equipment by HEAF damaged potential
  - Equipment type
  - Energy/Power potential
  - Protection scheme
  - Size, Material, Design, etc.
- More realistic
- Requires more information to apply
- More costly for development and application

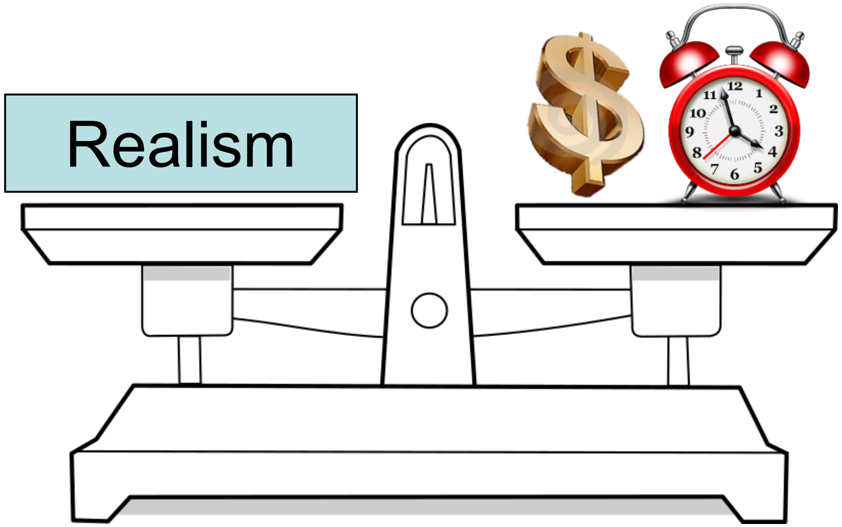
Dynamic ZOI

- Requires detailed information on power system
- Correlation from experiments and theory to model source term and incident flux as a function of distance
- Requires knowledge of fire PRA target fragility to high heat flux short duration.
- Potential to provide most realistic results
- Complex
- Most costly



What do we need?

- Reasonably accurate model to assess risk impact of HEAFs on plant safety



IEEE/NFPA Arc Flash Collaborative Research Project

Presented to the Nuclear Regulatory Commission HEAF Workshop

Mark W. Earley, P.E.
Chief Electrical Engineer
National Fire Protection Association
Wei-Jen Lee, PhD, PE, IEEE Fellow
University of Texas at Arlington

IT'S A BIG WORLD. LET'S PROTECT IT TOGETHER.™

IEEE/NFPA Arc Flash Collaborative Research Project

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Mark W. Earley, P.E.
Chief Electrical Engineer
National Fire Protection Association
Wei-Jen Lee, PhD, PE, IEEE Fellow
University of Texas at Arlington

Who we are

- The National Fire Protection Association (NFPA) is a global nonprofit organization, established in 1896, devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards.
- The world's leading advocate of fire prevention and an authoritative source on public safety, NFPA develops, publishes, and disseminates more than 300 consensus codes and standards intended to minimize the possibility and effects of fire and other risks.
- NFPA membership totals more than 50,000 individuals around the world.

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The National Electrical Code®

- Providing safety from hazards arising from the of electricity since 1897.
- First committee meeting held in 1896.
  - IEEE representatives were present
  - NFPA has been the sponsor since 1911

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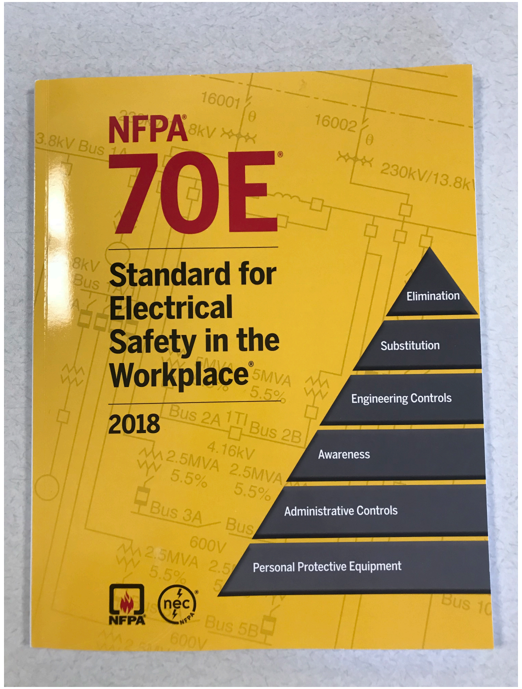
OSHA

- First electrical safety standard recognized by OSHA was the 1971 National Electrical Code®.
- OSHA with IEEE member support asked NFPA to consolidate electrical safety rules that affected workers into a new stand alone document that did not include all of the installation rules.
- The result was NFPA70E®-Electrical Safety Requirement for Employee Workplaces (later renamed “Electrical Safety in the Workplace®”)

NFPA70E®-Electrical Safety in the Workplace®

- Evolved into 4 parts (eventually reduced to three parts)
- As arc flash phenomena was introduced into NFPA70E, IEEE formed a new working group to provide a method to quantify the phenomena. This working group developed IEEE 1584



Arc Flash Research

- There were some differences of opinion between members of the IEEE committee and the NFPA committee on how to determine the hazard and how to protect workers

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Arc Flash Research

- Both Committees became concerned about the technical basis for arc flash analysis
- Both committees decided to separately pursue arc flash research projects
- Each committee recognized that a considerable amount of money would be needed to do a proper job
- NFPA would pursue project through the Fire Protection Research Foundation

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Arc Flash Research

- Both organizations were likely to seek support from the same sponsors
- It was unlikely that any sponsor would support both projects
- It was unlikely that either organization would receive enough contributions necessary to complete research
- Sue Vogel approached Mark Earley about collaboration

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Arc Flash Research

- The whole would be greater than the sum of the parts
- A partnership of the two organizations would be a powerful combination
- For both organizations, it was all about protecting people
- We recognized the conflicting viewpoints of committee members
- Asked Michael Callanan, Executive Director of NJATC (now the Electrical Training Alliance) to chair RTPC

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RTPC

- Members were told “Check your guns at the door!”
- RTPC membership represented various constituencies from IEEE and NFPA committees
- Developed a research plan, which formed the basis of the research project
- We had strong consensus for the research plan

 |

The Research and Testing Planning Committee Members

- Mike Callanan, Chair
- Daleep Mohla, Vice Chair
- Allen Bingham
- Jim Cawley
- David Dini
- Dan Doan
- Paul Dobrowski
- Mike Doherty
- Dick Doughty
- Carl Fredericks
- George Gregory
- Ray Jones
- Mike Lang
- Bruce McClung
- David Pace
- Vince Saporita
- David Wallis
- Craig Wellman
- Kathy Wilmer
- Jim White

Project Goal

- Primary objective was to work together collaboratively so that we could obtain the maximum synergies of our diverse constituencies with the goal of protecting people.

IEEE-NFPA Collaboration Project Sponsors

- **Platinum**
  - Bruce Power
  - Cooper Bussmann/Eaton
  - Ferraz Shawmut (Mersen)
  - Square D/Schneider Electric
  - Underwriters Laboratories
- **Gold**
  - Hydro One
  - Procter & Gamble, Inc
- **Silver**
  - ArcFlashForum.com
  - Arc Wear
  - Brainfiller.com
- **Silver (cont'd)**
  - Cadick Corporation
  - DCM Electrical Consulting Services
  - Duke Energy Foundation
  - e-Hazard
  - Inter-National Electrical Testing Association
  - McSquared Electrical Consulting, LLC
  - NFPA
  - Powell Electric
  - Salisbury
  - SKM System Analysis, Inc.

Historical Perspective

- Formation of Collaboration (2003-2006)
  - Circumstances (Challenges to the status quo)
  - Goals
  - **RTPC**
  - Fundraising
- Initial Research period (2007-2008)
  - Gammon's Research and PK's Work
- Testing period and initial model (2008-2012)
  - Lee and His team's Work
- Model handoff & refinements (2013-2016)
  - Lee and P1584 Task Group's Work

Priorities: IEEE/NFPA Test Procedures and Protocols (TPP) Ad Hoc Committee 2/2/2006 Report

- TPP recommended
  - Hiring of a Test Program Project Manager
  - Contracting with a Research Manager
  - Establishment of a Test Program Advisory Committee (TPAC).
- List of Tests
  - Over 2000 test set-ups that were integrated from RTPC task groups
  - LV & MV AC tests and DC tests
  - Tests with protective devices that were omitted in the RTPC Report
- Cost projections - $6.5M
  - 500 laboratory testing days at $5000 per day $2.5M
  - Personnel costs including travel $1.7M
  - Equipment costs $0.7M
- Other
  - Test program 2-1/2 years - complete by 2009
  - Engineering based model by 2012
  - Program to get used equipment

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Appendix B - Summary of Programs and Testing Priorities

Total estimated cost	Program 6 cost in $1,000's	Program 5 cost in $1,000's	Program 4 cost in $1,000's	Program 3 cost in $1,000's	Program 2 cost in $1,000's	Program 1 cost in $1,000's
Fund Raising costs	83	83	83	83	83	83
Lab costs	2599	2429	2067	1905	1488	1488
Equipment costs	700	450	160	80	80	80
Personnel costs	1703	1478	1198	832	568	503
Escalation at 10%	508	444	351	290	222	215
Contingencies at 15%	839	733	579	478	366	355
Totals	6433	5617	4437	3668	2808	2725
Say	$6.5 million	$5.5 million	$4.5 million	$3.5 million	$3 million	$2.5 million
Number of lab days	520	486	413	381	298	298
Tests and lab cost comments	As recommended by RTPC plus limited testing of protective devices.	Where needed equipment is not donated, skip the tests. Drop test boxes for MV motor starters.	Where needed equipment is not donated, skip the testing. Drop protective device testing.	Reduced instrument checkout time due to reduced amount of instrumentation. Drop Panel Gutter test box tests and 1000 V tests LV MCC.		
Equipment cost comments		Cut budget for used equipment purchase in half.	Drop TG#5 toxicity (gas chromatograph and dosimeter) testing. Eliminate purchase of used equipment.	Drop TG#6 optical and ionizing radiation testing. Drop independent portable DAS.		
Personnel cost comments		Reduce RM time. Reduce TPA and specialist time.	Drop physicist. Solicit volunteer.	Cut time and travel. Solicit volunteers.	Drop literature search. Drop RM.	Drop TPA and TA

 |

Summary of the Tests

Voltage kV	Current kA	Gap Mm (Inch)	Number of Tests	Enclosure (H x W x D) mm x mm x mm (in x in x in)
0.208	2.5 - 20	6.35 (0.25) – 19.05 (0.75)	67	355.6 x 304.8 x 203.2 (14 x12 x 8) 203.2 x 152.4 x 152.4 (8 x 6 x 6)
0.24	20 - 41	12.7 (0.50) – 25.4 (1.0)	25	355.6 x 304.8 x 203.2 (14 x12 x 8)
0.3	20 - 60	25.4 (1.0) – 38.1 (1.5)	24	355.6 x 304.8 x 203.2 (14 x12 x 8)
0.311	17 - 26	6.35 (0.25) – 12.7 (0.5)	11	355.6 x 304.8 x 203.2 (14 x12 x 8)
0.48	0.5 – 80.2	10 (0.4) – 50.8 (2.0)	369	508 x 508 x 508 (20 x 20 x 20)
0.575	40	25.4 (1.0) – 38.1 (1.5)	21	508 x 508 x 508 (20 x 20 x 20)
0.60	0.5 - 37	12.7 (0.5) – 101.6 (4.0)	375	508 x 508 x 508 (20 x 20 x 20)
2.7	0.5 – 33	38.1 (1.5) – 114.3 (4.5)	293	660.4 x 660.4 x 660.4 (26 x 26 x 26)
2.97	37 – 40	38.1 (1.5)	32	660.4 x 660.4 x 660.4 (26 x 26 x 26) 914.4 x 914.4 x 914.4 (36 x 36 x 36)
3.90	60 – 65	38.1 (1.5)	18	660.4 x 660.4 x 660.4 (26 x 26 x 26) 914.4 x 914.4 x 914.4 (36 x 36 x 36)
4.16	20 - 63	38.1 (1.5) – 76.2 (3.0)	184	660.4 x 660.4 x 660.4 (26 x 26 x 26)
14.3	0.5 - 42	76.2 (3.0) – 152.4 (6.0)	274	914.4 x 914.4 x 914.4(36 x 36 x 36)
0.253 (1-Ph)	5.0 - 23	6.35 (0.25) – 19.05 (0.75)	41	Faraday Cage
12	2.3 – 9.1	254 (10)	136	Real Equipment
0.6	1.6 - 33		22	Real Equipment

Publications during Project

- **“Arc Flash Visible Light Intensity as Viewed from Human Eyes”,** Shiuan-Hau Rau, Zhenyuan Zhang, Wei-Jen Lee, and David A. Dini, “ IEEE Transactions on Industry Applications. September/October **2017**
- **“3D Magnetohydrodynamic Modeling of DC Arc in Power System”,** Shiuan-Hau Rau, Zhenyuan Zhang, and Wei-Jen Lee, IEEE Transactions on Industry Applications. Volume: 52, No. 6, November/December 2016
- **“DC Arc Model Based on 3D DC Arc Simulation”,** Shiuan-Hau Rau, Wei-Jen Lee, IEEE Transactions on Industry Applications. November/December 2016.
- **“Arc Flash Pressure Measurement System Design”,** Zhenyuan Zhang, Shiuan-Hau Rau, Wei-Jen Lee, Tammy Gammon, and Ben Johnson, IEEE Transactions on Industry Applications. November/December **2016**
- **“Arc Flash Light Intensity Measurement System Design”,** Wei-Jen Lee, Zhenyuan Zhang, Shiuan-Hau Rau, Tammy Gammon, Ben Johnson, and James Beyreis, IEEE Transactions on Industry Applications. September/October **2015**.
- **“Grounding and Isolation of Sensitive Measurement Equipment for Arc Flash Testing at High Power Lab”,** Zhenyuan Zhang, Wei-Jen Lee, and David A. Dini, IEEE Transactions on Industry Applications. November/December **2015**.
- **“‘Arc Flash’ Hazards, Incident Energy, PPE Ratings and Thermal Burn Injury – A Deeper Look,”** Tammy Gammon, Wei-Jen Lee, Zhenyuan Zhang, Ben Johnson. IEEE Transactions on Industry Applications. September/October **2015.**
- **“Electrical Safety, Electrical Hazards & the 2018 NFPA 70E: Time to Update Annex K?”,** Tammy Gammon, Wei-Jen Lee, Zhenyuan Zhang, and Ben Johnson, IEEE Transactions on Industry Applications. July/August **2015**.
- **"Arc Flash and Electrical Safety,"** Wei-Jen Lee, Tammy Gammon, Zhenyuan Zhang, Ben Johnson, James Beyreis. 2013 Protective Relay Engineers Conference.

Publications during Project

- **"Redeveloping the 2018 NFPA 70E Annex K and Contemplating Beyond,"** Tammy Gammon, Wei-Jen Lee, Zhenyuan Zhang, Ben Johnson, James Beyreis. 2015 ESW.
- **"Electrical Safety, Electrical Hazards & the 2018 NFPA 70E, Time to Update Annex K?"** Tammy Gammon, Wei-Jen Lee, Zhenyuan Zhang, Ben Johnson. IEEE Transactions on Industry Applications. July/August 2015..
- **"Addressing Arc Flash Problems in Low Voltage Switchboards: A Case Study in Arc Fault Protection,"** Bruce Land, Tammy Gammon. 2014 ICPS.
- "**IEEE / NFPA Collaboration on Arc Flash Phenomena Research Project,**" Wei-Jen Lee, Tammy Gammon, Zhenyuan Zhang, Ben Johnson, Sue Vogel. 2012 PES Trans. & Distrib. Expo.
- **"Comparative Study of Arc Modeling and Arc Flash Incident Energy Exposures"** Ravel Ammerman, Tammy Gammon, P. K. Sen, John Nelson. **2008** PCIC.
- **"IEEE 1584-2002 Arc Modeling Debate,"** Tammy Gammon, John Matthews. 2008 *IAS Magazine.*
- **"Modeling High-Current Electrical Arcs: A Volt-Ampere Characteristic Perspective for AC and DC Systems,"** Ravel Ammerman, P. K. Sen. ***2007*** *North American Power Symposium.*
- **"Arc Flash Hazard Incident Energy Calculations a Historical Perspective and Comparative Study of the Standards: IEEE 1584 and NFPA 70E,"** Ravel Ammerman, P. K. Sen, John Nelson. **2007** *PCIC.*

DC Work To Date

- **Bruce Power Test Results**
- **IEEE papers documenting research into DC arcs.**
  - **"3D Magnetohydrodynamic Modeling of DC Arc in Power System",** Shiuan-Hau Rau, Zhenyuan Zhang, and Wei-Jen Lee, IEEE Transactions on Industry Applications. Nov/Dec **2016**
  - **"DC Arc Model Based on 3D DC Arc Simulation",** Shiuan-Hau Rau, Wei-Jen Lee, IEEE Transactions on Industry Applications. Volume: 52, No. 6, November/December **2016**.
  - **"A Review of Commonly Used DC Arc Models,"** Tammy Gammon, Wei-Jen Lee, Zhenyuan Zhang, Ben Johnson. **2014** PPIC.
  - **"DC Arc Models and Incident Energy Calculations"** Ravel Ammerman, Tammy Gammon, P. K. Sen, John Nelson, **2009** PCIC
- **Theoretical DC Simulation Model Development**

Steering Committee Members -2018

• Mark Earley	NFPA
• Mike Lang	Mersen
• John Kovacik	Underwriters Lab
• Sam Sciacca	IEEE-SA
• Alan Manche	Schneider-Electric
• Daleep Mohla	DCM Consulting
• Tom Domitrovich	Eaton
• Jim Phillips	Brainfiller
• Wei-Jen Lee	University of Texas at Arlington

Moving Forward for a Comprehensive DC Arc Flash Model Development

 |

Factors to be Considered

- Source (Rectifier, Battery, PV, and etc.)
- Voltage and Current Ranges
- Configurations (In-line or parallel)
- Gaps
- Materials

Hypothesis and Proposed Approaches

- Hypothesis
  - Incident energy is proportional to the arc energy during the arc flash event
  - It is possible to establish the relationship and use AC arc flash model for DC incident energy and arcing current estimation
- Scouting Test
  - Based upon the input from steering committee, design a 3-4 days scouting test.
  - If possible, it will be great to run both AC and DC arc flash test with the identical configurations.

Proposed Approaches

- Preliminary Study
  - According to the test configurations, perform computer simulations to obtain estimated arcing current, arcing voltage, and arc energy
  - Comparison among DC, AC and computer simulation results
  - Does the hypothesis hold and computer simulation yield reasonable results?
  - Can we establish the relationship between DC arc flash test results and its AC counterpart?

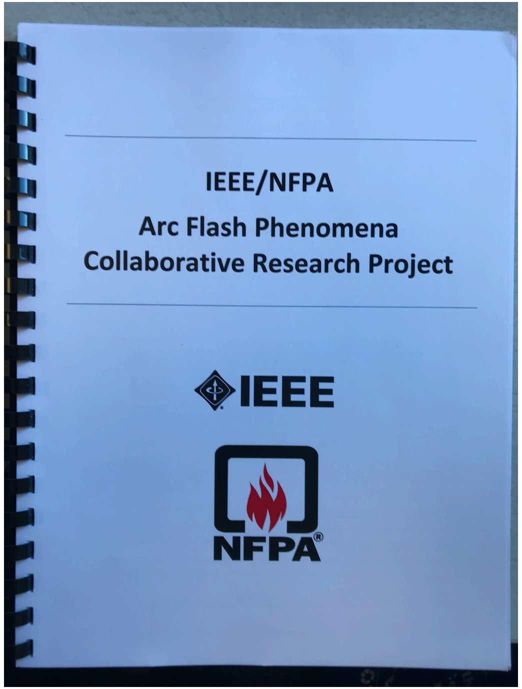
 |

Proposed Approaches

- Based Upon the Findings of the Preliminary Study
  - If the Preliminary Study shows positive results
    - Design additional DC laboratory testing
    - Perform DC simulations
    - Establish the relationship and use AC arc flash model for DC incident energy and arcing current estimation
    - Develop DC incident energy and arcing current estimation models
  - If the Preliminary Study is unable to establish the link to the AC arc flash model

Deliverables and Accomplishments

- 10 AC Models integrated into 1
  - 5 electrode test configurations
  - LV and MV AC
- Tests and report on arc sustainability at 208V
- Tests and report on arc flash in real equipment
- Development of Instrumentation for
  - Thermal
  - Light
  - Pressure
  - Sound
  - Portable Instrumentation Unit
- Several IEEE Papers



Conclusion

- The mission of the collaboration was to develop ONE model that ensures worker safety that can be consistently used across the electrical industry.
- We have a working ac model.
- We need to explore the lower boundary
- The next step is correlation of the dc model with the ac model.

 |

EPRI Perspective

High Energy Arcing Faults

Ashley Lindeman
Senior Technical Leader

HEAF Information Sharing Workshop
April 18, 2018

White Papers on HEAF

- 3002011922 – Characterization of Testing and Event Experience for High-Energy Arcing Fault Events
- 3002011923 – Nuclear Station Electrical Distribution Systems and High-Energy Arcing Fault Events

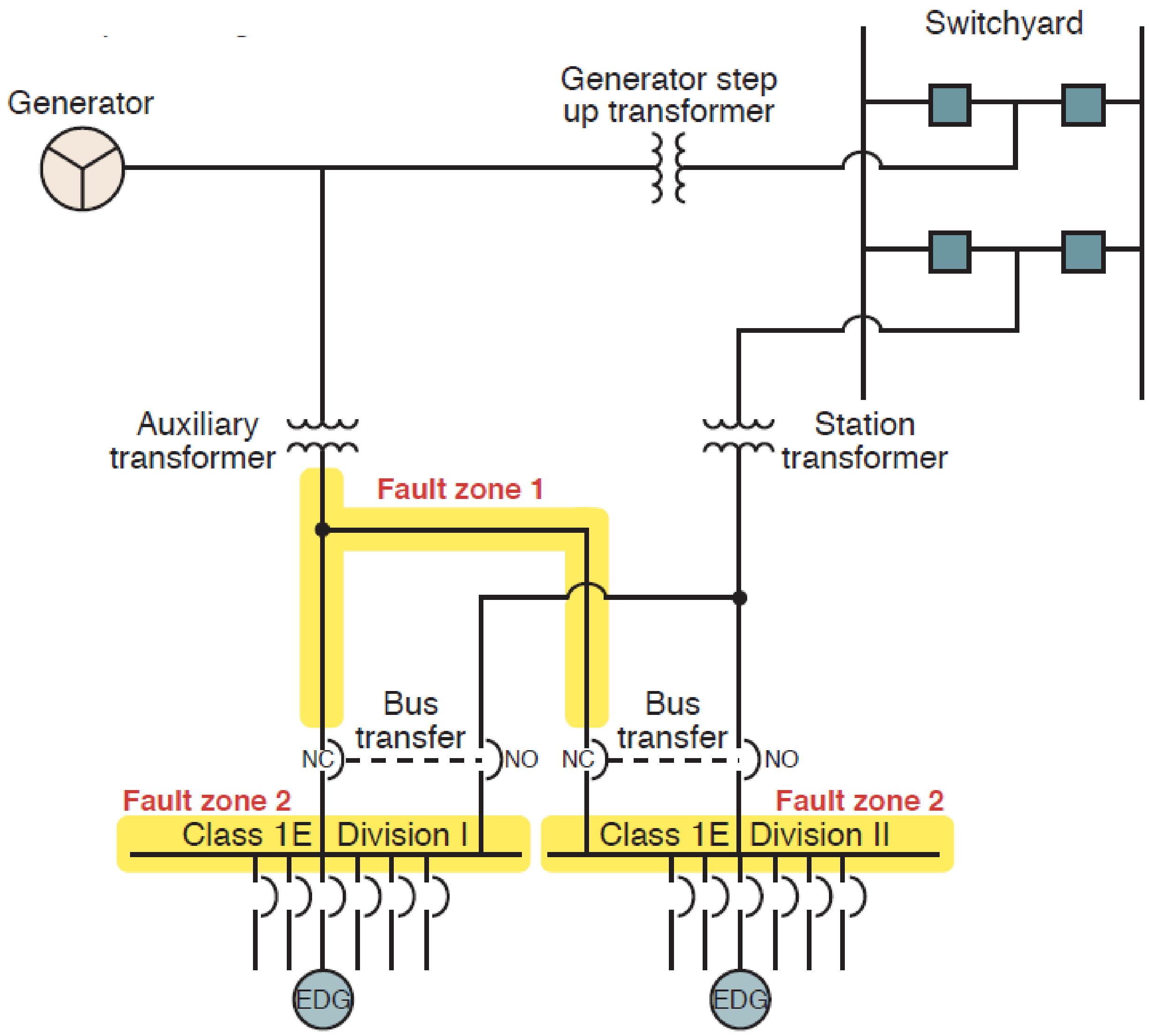
White papers are publicly available at epri.com

Electrical System Distribution System Configurations

- Identified 7 common EDS configurations and relative generator-fed HEAF risk
  - Ranked designs most vulnerable to least vulnerable
  - Reviewed 19 U.S. NPP sites
    - 14 of 19 sites have low risk (designs 5 through 7)

Unit-Connected Designs

- Power system downstream of the main generator is worthy of special attention
- Refers to the operational configuration of the (1) main generator, (2) GSU transformer, (3) generator output switchyard breakers, (4) AT, and (5) associated buses and connections, with no generator circuit breaker and no thus backup circuit breaker(s) to isolate a generator-fed fault if the (1) AT secondary side breaker failed to open (that is, is stuck) or is slow to open or (2) a fault exists between the generator and GSU transformer, or anywhere in the auxiliary transformer to the first low-voltage side circuit breakers.



Unit-Connected Designs

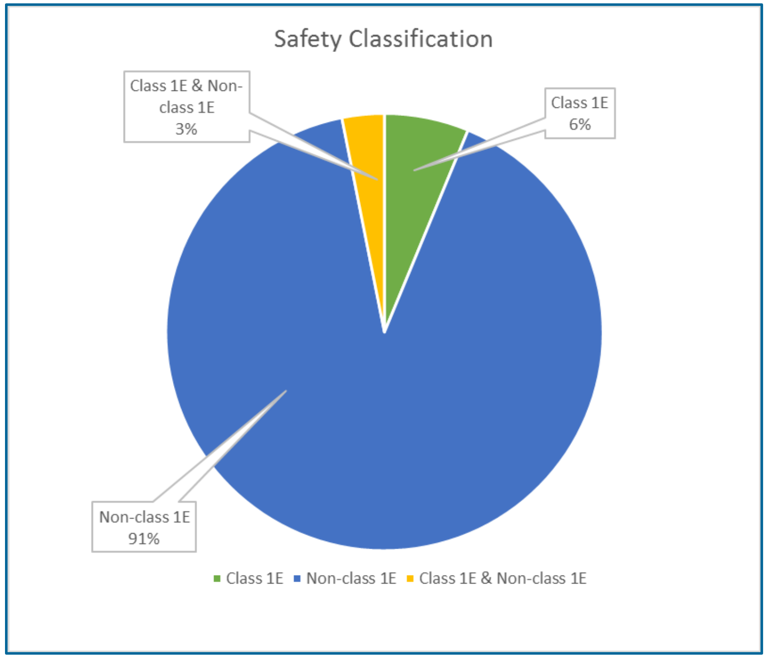
- OPEX has revealed that a main generator can feed a HEAF for several seconds following a unit trip if a fault originates in the unit-connected design
  - Some plant have a generator breaker that can isolate the energy source (main generator) from the fault during generator coast-down before the voltage collapses
- The events impacted only non-Class 1E equipment in non-Class 1E locations in the medium-voltage range
  - Post-event fire occurred in all instances
  - In 8 of 9 events damage was observed outside equipment of origin
  - Events caused significant damage and were challenging

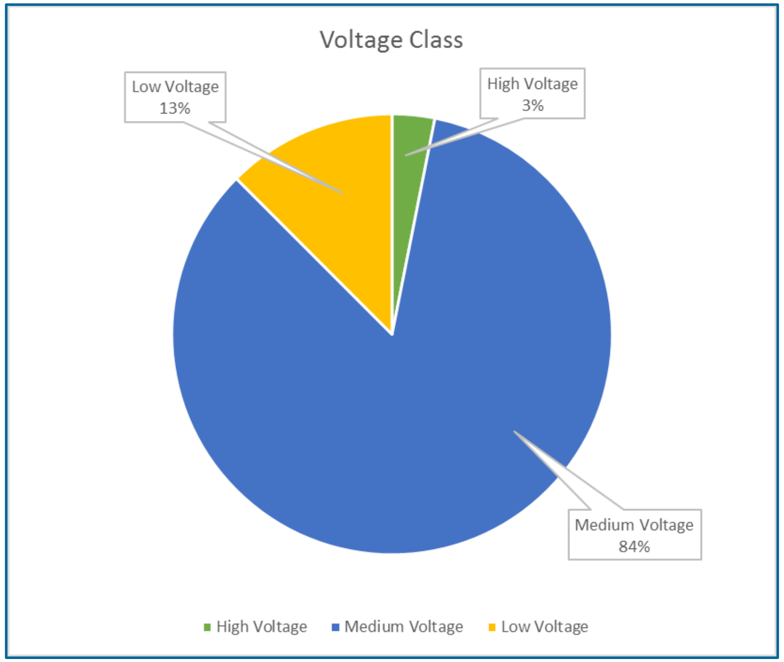
EPRI Characterization of Testing and Experience

- Performed detailed review of HEAF events at U.S. NPPs
  - 1980 through 2017
- Event review indicates:
  - HEAF events represent ~2% of fires within the U.S. NPP fleet
  - Wide variety in severity of events
    - Not all HEAFs result in post-event fire
    - Most HEAF events damage only the equipment suffering failure
  - Several notable influence factors
  - Metrics indicate refinements to both “HEAF frequencies” and “HEAF zones of influence” are appropriate and defensible based on objective data

Key Influence Factors

- Greater than 90% of documented HEAFs occurred on non-safety related equipment
- Less than 15% of HEAFs occurred at equipment operating at less than 1,000 volts





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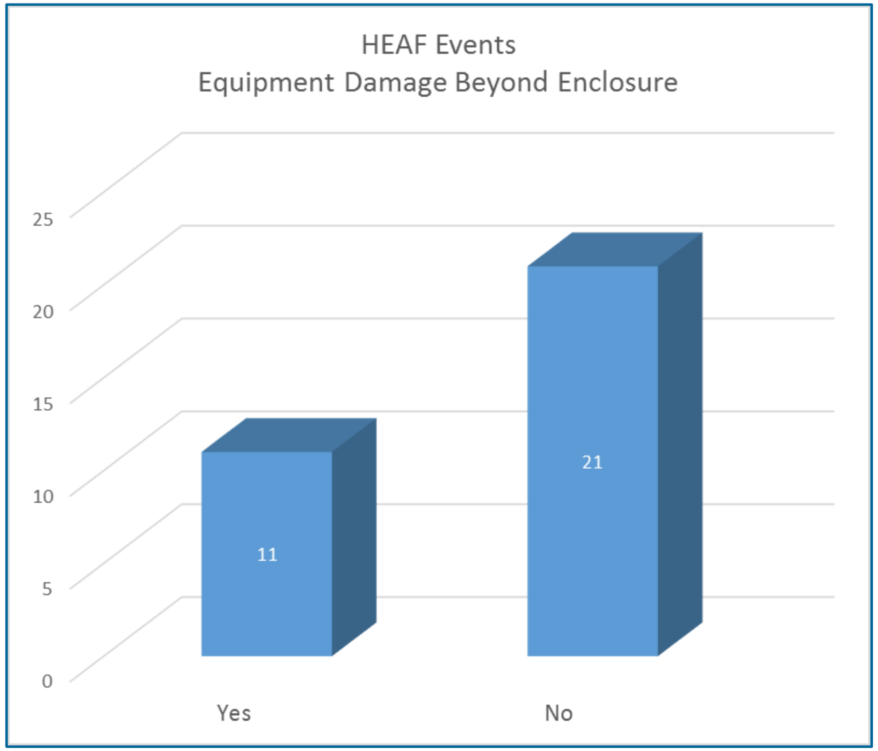
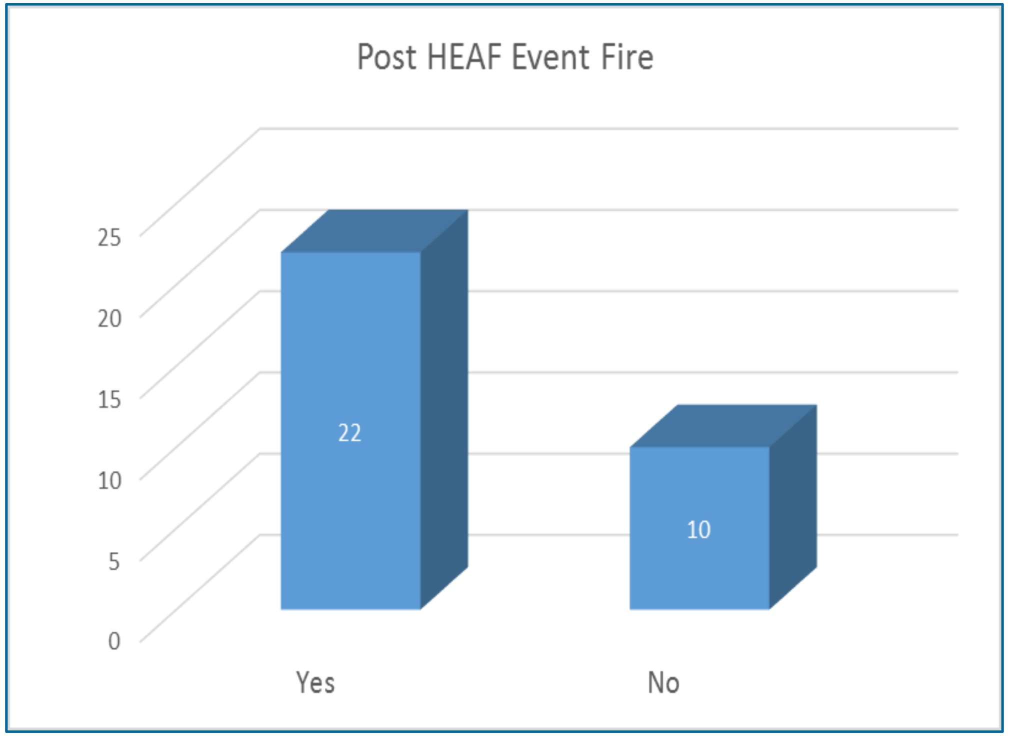
Key Influence Factors

- 2/3 of HEAF events did not impact equipment beyond equipment of origin
- About 2/3 of HEAF events resulted in a post-event fire





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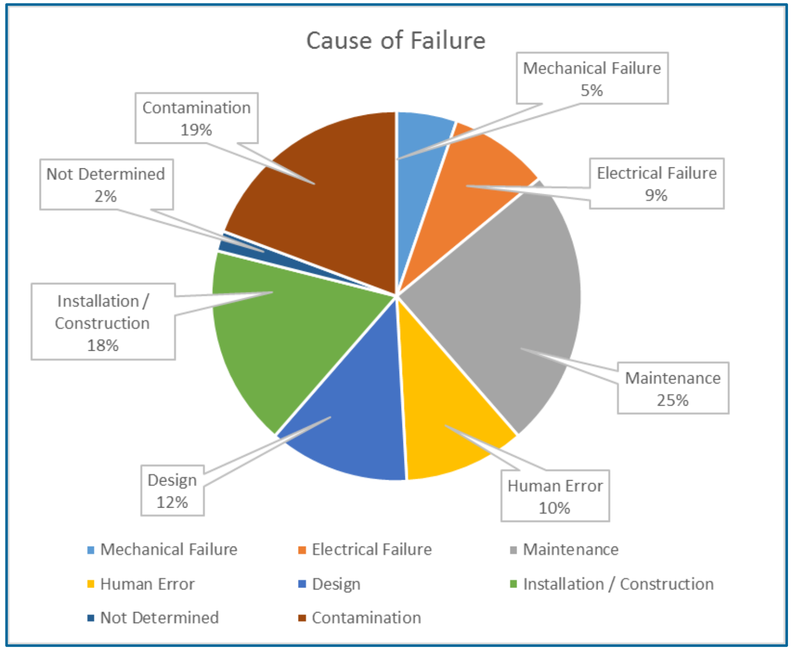
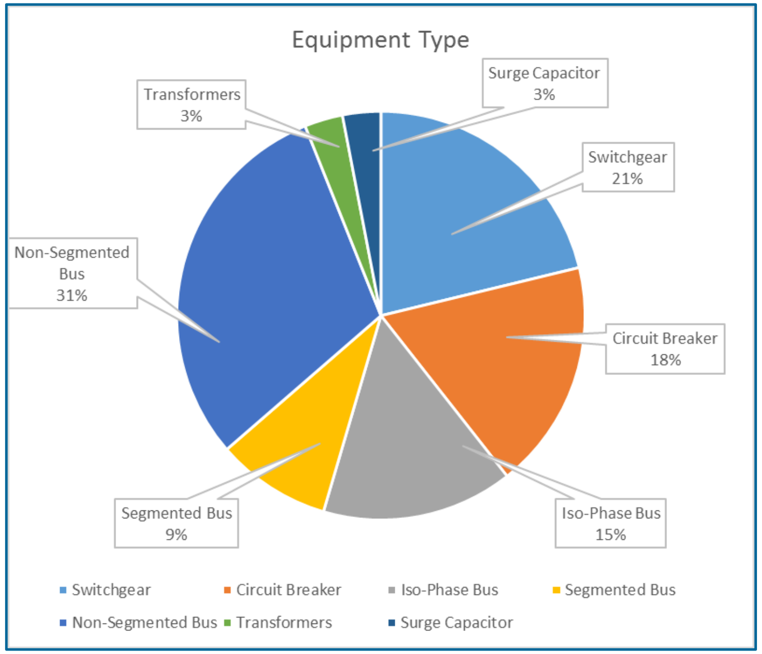
Key Influence Factors

- Contrary to conventional wisdom, no one equipment type is a dominant source of HEAF events
- 65% (or more) of HEAFs involved preventable shortcomings (human error, maintenance, design, installation/construction)





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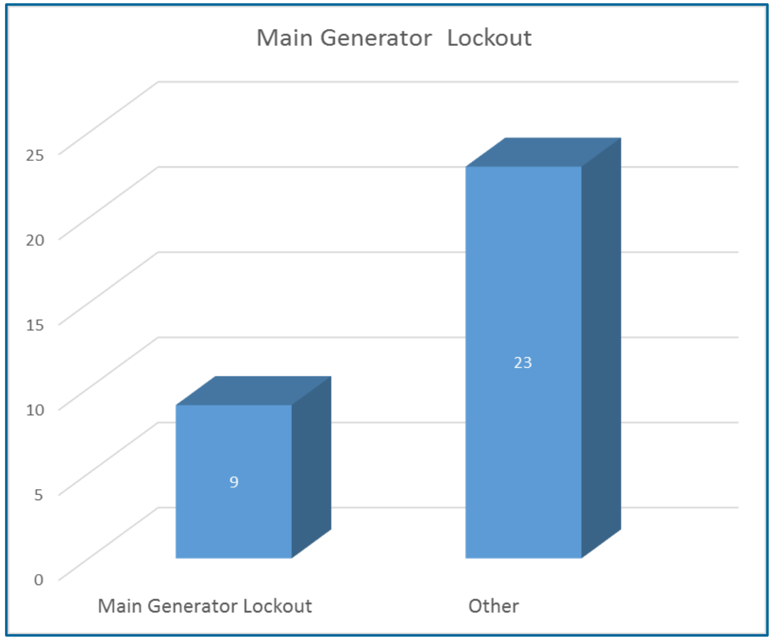
Key Influence Factors

- Nearly 1/3 of HEAF events are associated with "Unit Connected" designs
  - Main generator is not immediately isolated from faulted equipment
  - Fault allowed to persist for extended time while generator coasts down and excitation field decays



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Characterization of HEAF Events

- Experimental insights
  - Tests assumed that overcurrent protection is absent or failed
    - In the absence of protection, electrical faults may persist for several seconds, resulting in violent energy release
  - Testing characterized the most severe consequences for extended-duration three-phase faults
  - OPEX confirms that most HEAF events will be interrupted by overcurrent protection and thus the fault energies would be lower

Characterization of HEAF Events - Experimental Insights

- Low-voltage testing
  - Arcs did not always sustain
  - Tests with durations shorter than 2 seconds did not result in fires
  - The threshold arc energy to ignite cables was ~28 MJ
- Medium-voltage testing
  - Energy threshold higher than low-voltage
  - Once initiated, arcs sustained themselves for a longer time
  - Variety of damage observed
    - External ruptures
    - Breaches between compartments

Involvement of Aluminum

- NUREG/IA-0470 and NEA/CSNI/R(2017)7 highlight aluminum oxidation phenomena as a significant contributor to total energy released for test in which reaction present
  - In the most severe NUREG/IA-0470 test, the researchers estimated the energy release from the oxidation was 2.6 times the energy release by the arc
  - The estimated ratio of oxidation to arc energy varies between 0.34 – 2.6, so scenarios with high oxidation were less common
- Aluminum oxidation phenomena not considered in standards such as IEEE 1584, IEEE C37.20.7-2007, NFPA 70E
  - May not have included aluminum electrodes, test of shorter duration (<0.5s) result in less melting of conductors
- The threshold at which the aluminum oxidation occurs is undefined
  - Phenomena not observed in all tests with aluminum components
  - Aluminum oxidation observed in test conditions imposing severe arcing methods (i.e., extended duration faults beyond the rating of switchgear and breakers)

Fire PRA Treatment

- Refine HEAF ignition frequencies / scenario definition
  – Update ignition frequencies for Bins16.a, 16.b, 16.1, and 16.2
  – Create new bins or sub-divide existing ignition frequency bins based on new data analysis:
    - Sub-groups
    - Split fractions
  – Data supports numerous sub-groups
    - Safety-related vs. non-safety related
    - Low voltage vs. medium/high voltage (existing)
    - Damage limited to enclosure vs. consequential damage
    - Post-event fire vs. no fire
    - Design vulnerabilities (e.g., unit-connected designs, protection schemes)

Fire PRA Treatment

- Sensitivity of Fire PRA results to aluminum oxidation
  - Sensitivity of CDF and LERF will be plant and configuration dependent
  - Plants with safety-related switchgear in separate rooms will show lower impact
- Sample sensitivity study was conducted
  - Sample plant had safety-related switchgear in separate rooms
  - Impact was minimal
    - Assumed aluminum oxidation failure mode rendered all equipment in room non-functional
    - Current fire modelling of switchgear rooms most always involves a HGL
    - HGL typically impacts all (or most) equipment in the room
    - HGL and aluminum failures produce similar functional impact for the room
    - Plant configurations with multiple trains of equipment in same room was not included in sample sensitivity study

Summary

- HEAFs are both a safety and economic consideration
  - Severe HEAF event could easily keep a plant off-line for months
- Testing highlights the importance of optimizing overcurrent protection such that HEAF events are rapidly detected and cleared
- Proper maintenance is prevention
  - Strong PM and test program is important element in preventing HEAF events
  - 3002011923 identifies several preventative maintenance, refurbishment, testing, and walkdowns to ensure proper operation of equipment / electrical distribution system

Together…Shaping the Future of Electricity

EPRI ELECTRIC POWER RESEARCH INSTITUTE

DNV·GL

ENERGY

Physical Testing & Failure Rates

NRC HEAF Phase II Information Sharing Workshop, April 18 & 19

Bas Verhoeven
Director Global Business Development and Innovation - KEMA Laboratories

KEMA Laboratories

SAFER, SMARTER, GREENER

Table of content

- **Introduction KEMA Laboratories**
- **Certification, the global approach**
- **Statistics on failure rate during type testing**
- **Summary and takeaways**

Disclaimer: All photographs/pictures used by KEMA Laboratories in this presentation are for illustrative purposes solely. The pictures/photographs do not in any way relate to the (failure of) component, products and/or manufacturer shown on the pictures/photographs.

KEMA Laboratories

DNV·GL

Introduction in KEMA Laboratories

DNV GL, A global quality assurance and risk management company

OUR PURPOSE

TO SAFEGUARD LIFE, PROPERTY AND THE ENVIRONMENT

KEMA Laboratories

Industry consolidation

DNV·GL

DNV

KEMA Laboratories

GL Group

KEMA

NOBLE DENTON

GARRAD HASSAN

ADVANTICA

Global reach – local competence

150+ years

100+ countries

100,000+ customers

12,500 employees

KEMA Laboratories

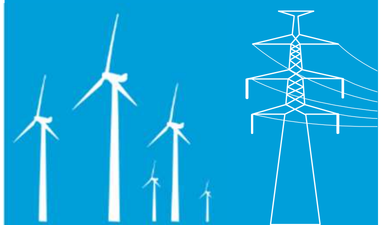
DNV·GL

Our vision: global impact for a safe and sustainable future

MARITIME

OIL & GAS

ENERGY



BUSINESS ASSURANCE

DIGITAL SOLUTIONS

TECHNOLOGY & RESEARCH

KEMA Laboratories

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High Power Laboratory – Operating Principle

KEMA Laboratories

Power rating of KEMA Laboratories

Location	Generators	Can be grouped	Max. Power	Accreditation
Arnhem, NL	6 x 2,500 MVA	Yes	15,000 MVA	ISO/IEC 17025 by RvA
Chalfont, US	1 x 2,250 MVA 1 x 1,000 MVA	No	2,250 MVA	ISO/IEC 17025 by A2LA
Prague, CZ	2 x 2,500 MVA	Yes	5,000 MVA	ISO/IEC 17025 by CAI

Required power for testing depends on components and type of test:

- Power Transformers, high power
- Circuit breakers, medium power (synthetic testing)
- (Internal) Arc, low to medium power

KEMA Laboratories

KEMA Laboratories – Beyond the Standards

Commercial Grade Dedication

- KEMA Laboratories are accredited by A2LA in accordance with international standard ISO/ IEC 17025:2005. Our quality program, our accreditation and the NRC's endorsement of NEI14-05 simplifies the commercial grade dedication process.

  - "NRC's Expectations…
    - Licensees and vendors must follow their commercial grade dedication process when using the International Laboratory Accreditation Cooperation (ILAC) accreditation alternative for procurement of commercial calibration and testing services.
    - Licensees and vendors may use the alternative method in lieu of performing a commercial grade survey as part of the dedication process."

  U.S. NRC, Safety Evaluation Report (SER), NRC conditions and expectations.

KEMA Laboratories

Certification, the Global Approach

Risk mitigation through equipment certification

Equipment certification

- **Ensures performance criteria are met**
- **Ensures highest level of service reliability**
- **Minimizes liability issues**

Best practice in certification

- **Independent laboratory (STL) outside country of equipment manufacturer**

- Quality starts early in the process and must be written in the specifications.
- FAT and SAT to check quality with initially type tested object.

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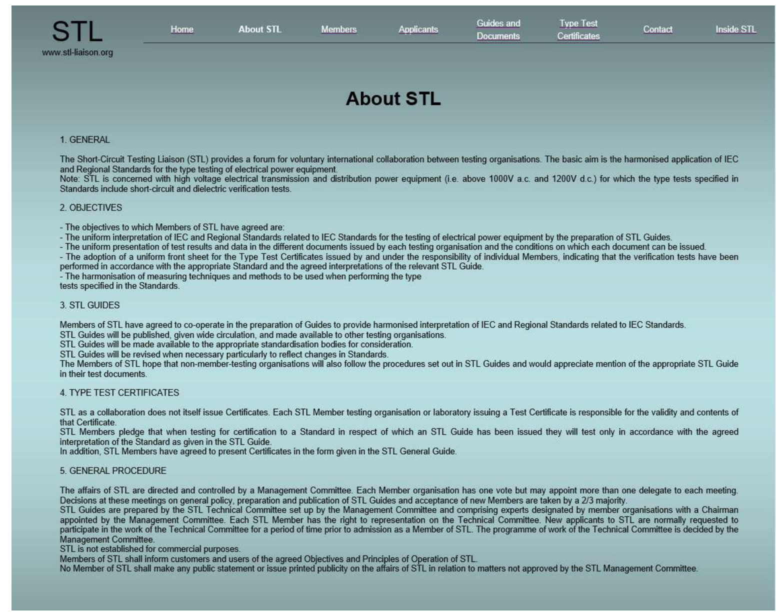
Short Circuit Test Liaison (STL)

- **GENERAL**

The Short-Circuit Testing Liaison (STL) provides a forum for voluntary international collaboration between testing organizations.

The basic aim is the harmonized application of IEC and Regional Standards for the type testing of electrical power equipment.

Note: STL is concerned with high voltage electrical transmission and distribution power equipment (i.e. above $1000V_{ac}$ and $1200V_{dc}$) for which the type tests specified in Standards include short-circuit and dielectric verification tests.



STL
www.stl-liaison.org

Home | About STL | Members | Applicants | Guides and Documents | Type Test Certificates | Contact | Inside STL

About STL

1. GENERAL

The Short-Circuit Testing Liaison (STL) provides a forum for voluntary international collaboration between testing organisations. The basic aim is the harmonised application of IEC and Regional Standards for the type testing of electrical power equipment.
Note: STL is concerned with high voltage electrical transmission and distribution power equipment (i.e. above 1000V a.c. and 1200V d.c.) for which the type tests specified in Standards include short-circuit and dielectric verification tests.

2. OBJECTIVES

- The objectives to which Members of STL have agreed are:
- The uniform interpretation of IEC and Regional Standards related to IEC Standards for the testing of electrical power equipment by the preparation of STL Guides.
- The uniform presentation of test results and data in the different documents issued by each testing organisation and the conditions on which each document can be issued.
- The adoption of a uniform front sheet for the Type Test Certificates issued by and under the responsibility of individual Members, indicating that the verification tests have been performed in accordance with the appropriate Standard and the agreed interpretations of the relevant STL Guide.
- The harmonisation of measuring techniques and methods to be used when performing the type tests specified in the Standards.

3. STL GUIDES

Members of STL have agreed to co-operate in the preparation of Guides to provide harmonised interpretation of IEC and Regional Standards related to IEC Standards.
STL Guides will be published, given wide circulation, and made available to other testing organisations.
STL Guides will be made available to the appropriate standardisation bodies for consideration.
STL Guides will be revised when necessary particularly to reflect changes in Standards.
The Members of STL hope that non-member-testing organisations will also follow the procedures set out in STL Guides and would appreciate mention of the appropriate STL Guide in their test documents.

4. TYPE TEST CERTIFICATES

STL as a collaboration does not itself issue Certificates. Each STL Member testing organisation or laboratory issuing a Test Certificate is responsible for the validity and contents of that Certificate.
STL Members pledge that when testing for certification to a Standard in respect of which an STL Guide has been issued they will test only in accordance with the agreed interpretation of the Standard as given in the STL Guide.
In addition, STL Members have agreed to present Certificates in the form given in the STL General Guide.

5. GENERAL PROCEDURE

The affairs of STL are directed and controlled by a Management Committee. Each Member organisation has one vote but may appoint more than one delegate to each meeting. Decisions at these meetings on general policy, preparation and publication of STL Guides and acceptance of new Members are taken by a 2/3 majority.
STL Guides are prepared by the STL Technical Committee set up by the Management Committee and comprising experts designated by member organisations with a Chairman appointed by the Management Committee. Each STL Member has the right to representation on the Technical Committee. New applicants to STL are normally requested to participate in the work of the Technical Committee for a period of time prior to admission as a Member of STL. The programme of work of the Technical Committee is decided by the Management Committee.
STL is not established for commercial purposes.
Members of STL shall inform customers and users of the agreed Objectives and Principles of Operation of STL.
No Member of STL shall make any public statement or issue printed publicity on the affairs of STL in relation to matters not approved by the STL Management Committee.

www.Stl-liaison.org

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STL Members

STL
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Mem

Organisations concerned with testing high voltage electrical power equipment shall be eli
testing at 500 MVA, 3 phase as a minimum. Each organisation shall be widely recogi
interests and that it can actively participate in the work of STL.
There shall be only one member or applicant per country or group of countries.

Members of STL are:

Intertek (ASTA), UK	CESI, Italy
JSTC, Japan	KEMA, The Netherlands
SATS, Norway	STLNA, USA

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STLNA

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STLNA Member Laboratories

All laboratories accredited according to ISO/IEC 17025

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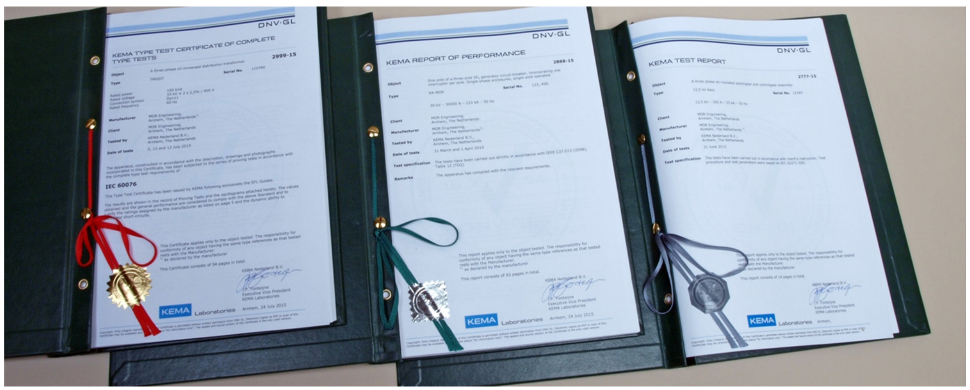
Eaton Corporation 200 Westinghouse Circle Horseheads NY 14845 USA	Telephone: +1 607 259 3041 Telefax: +1 607 796 3364 E-Mail: Jean-MarcTorres@Eaton.com Contact: J. Torres

Certification – how the majority of the world sees it …

- Independent type test and certification of the functional performance of a T&D component based on an international accepted standard. Standards normally have a section of clauses for Type or Design Tests. Other sections are for production tests; Routine and Sample.
- Utilities require a Certificate upfront at tendering process and/or during delivery to ensure that the component has proven that it meets the functional requirements.



Certification = Mitigation of risk by levelling the procurement playing field

- Note; liability of the component tested (certified) remains at the manufacturer and is not transferred to the certifying body.

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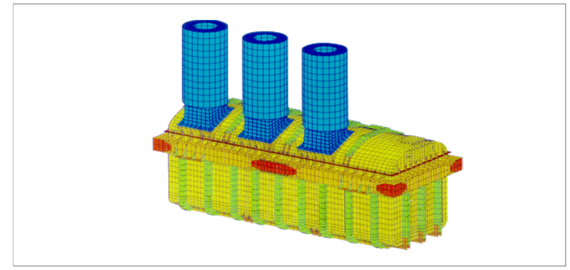
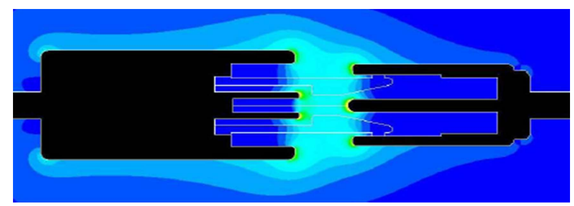
Can computer modelling replace testing?

Models are well accepted in the design phase of equipment for the calculation of stresses for example electrical, mechanical, pressure, thermal etc.

CIGRE has investigated the possibility to replace testing by modelling and concluded that withstand of stresses cannot be predicted by models.

The CIGRE survey showed that, from all LPT having failed in service due to a short circuit, one third passed a design review successfully. None underwent a real test.





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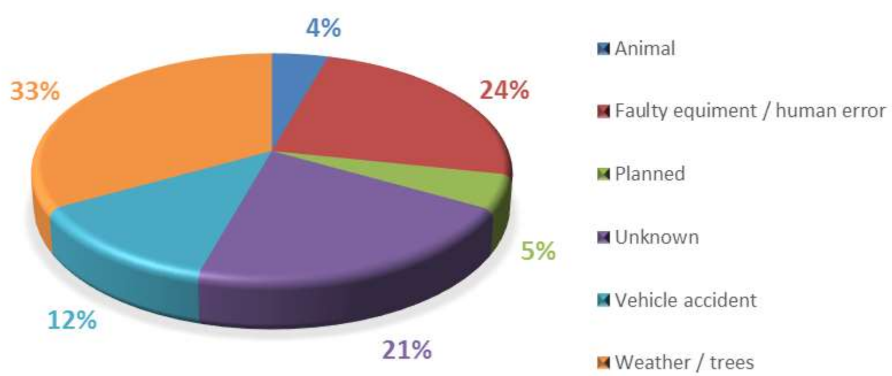
Power System Reliability and Failures

Equipment failures causes blackouts

USA 2016 (n = 3.879)



Most avoidable outages are equipment related

Source: Eaton Corporation, Blackout Tracker USA Annual Report 2016

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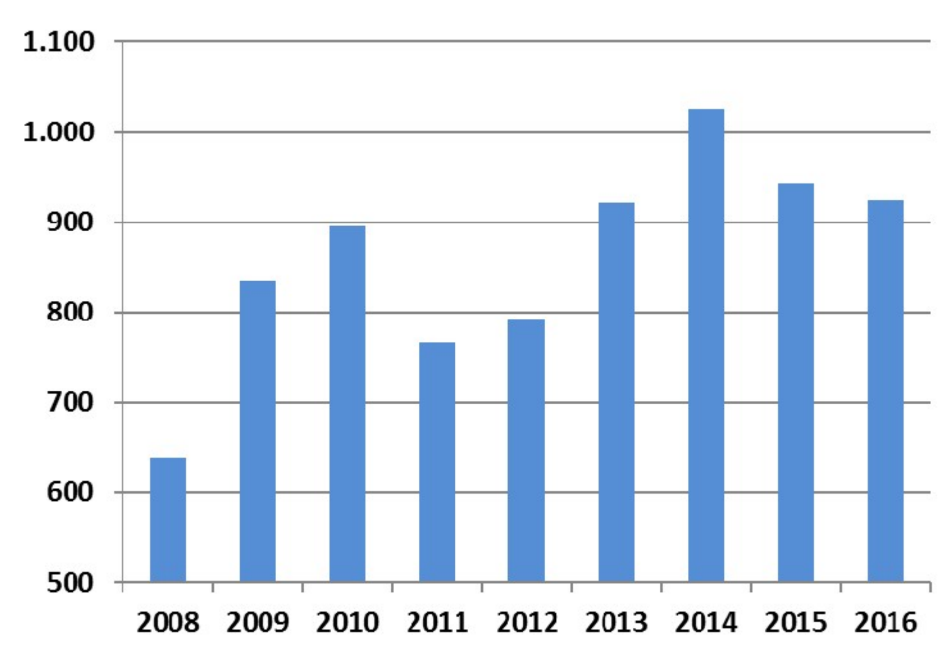
Number of outages increase over the years

Interconnection of power networks improves network performance but increases short circuit current level.

Increase of switching actions for dealing with all network conditions and occurring events.

Networks have higher loading profile with more dynamics.

Number of outages in Equipment failure / human (Eaton Corp.)



Source: Eaton Corporation, Blackout Tracker USA Annual Reports

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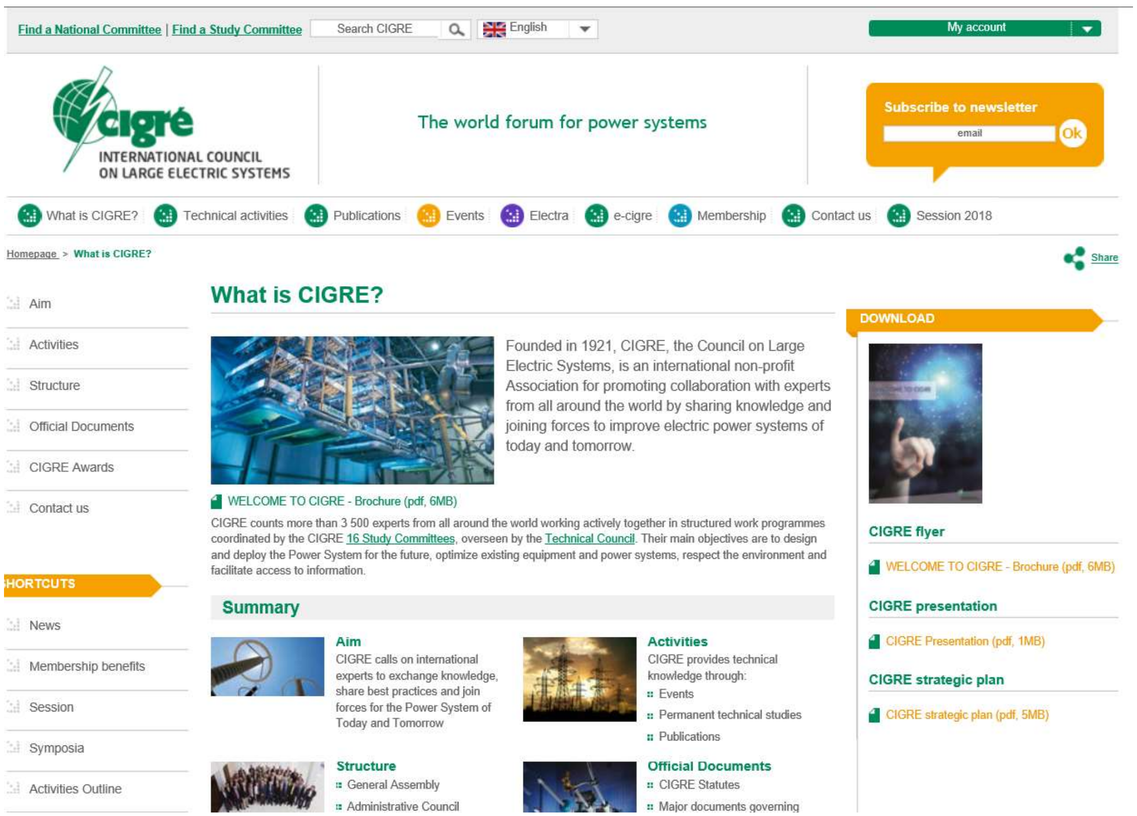
Cigre Organization



Founded in 1921, CIGRE, the Council on Large Electric Systems, is an international non-profit Association for promoting collaboration with experts from all around the world by sharing knowledge and joining forces to improve electric power systems of today and tomorrow.

www.cigre.org

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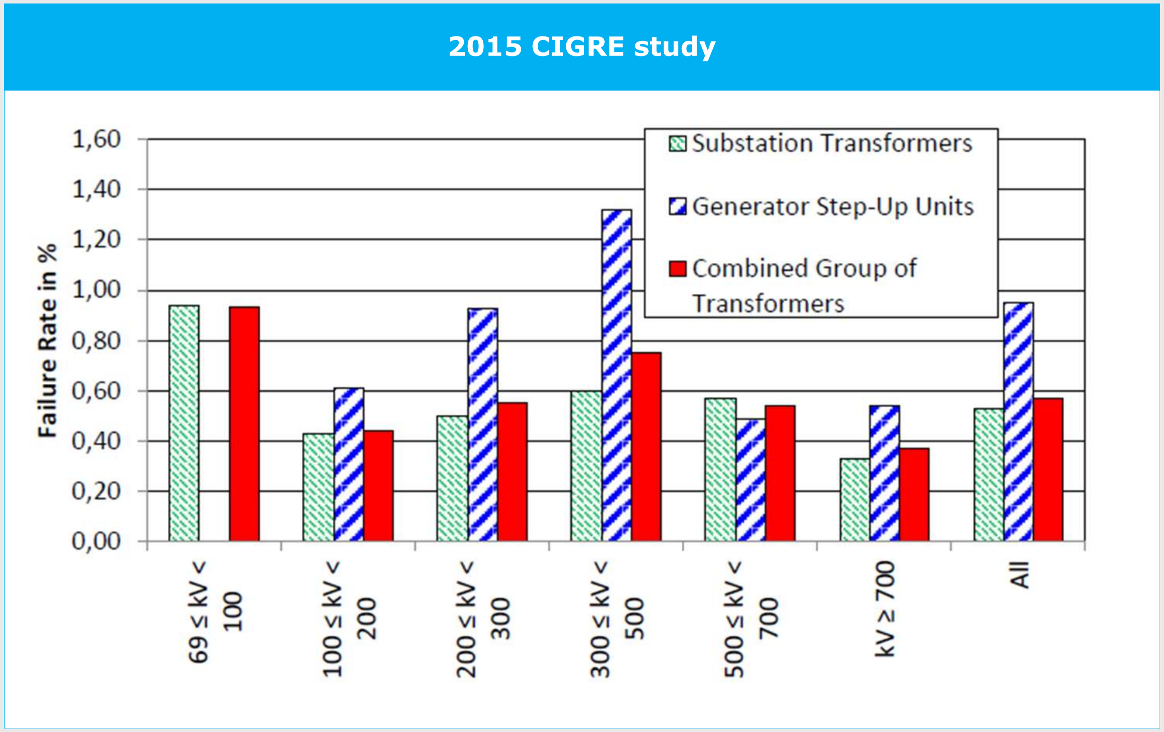
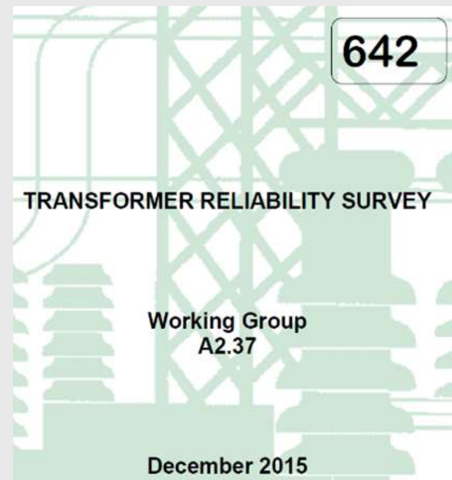
Large Power Transformers



1 out of 200 transformers runs into a major failure per year



Available for free at https://e-cigre.org/publication/642-transformer-reliability-survey

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Large Power Transformers

2015 CIGRE study

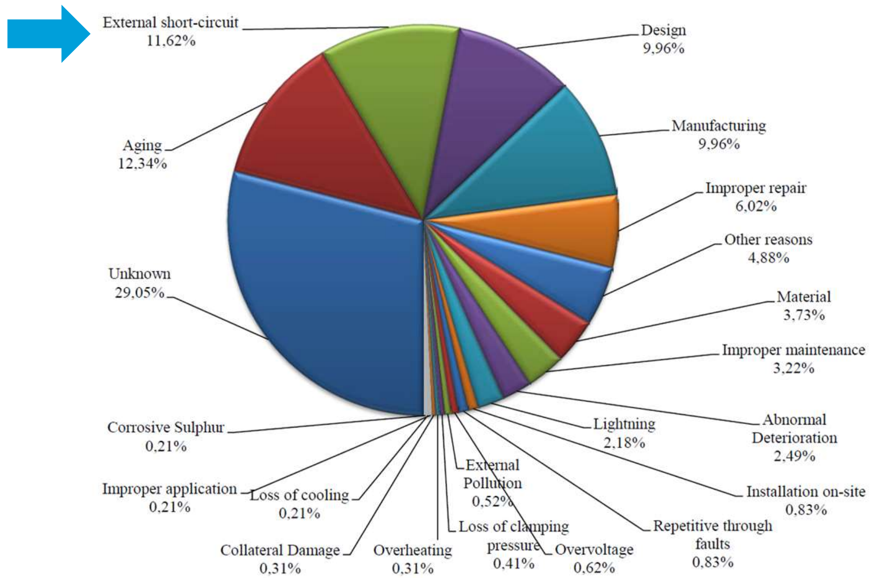
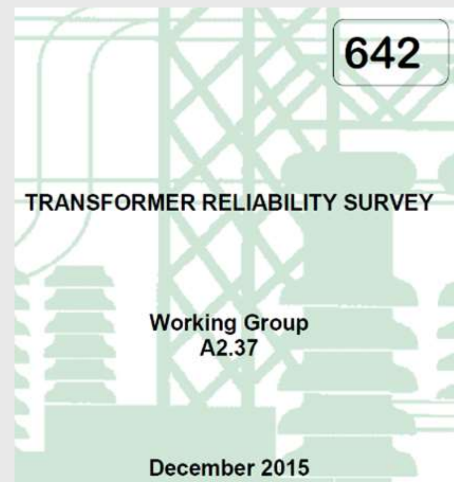


Figure 9: Failure cause analysis based on 964 MAJOR failures

11,62% of failures are caused by external short-circuit



EPRI (USA) database of > 20.000 power transformers (start 2006)

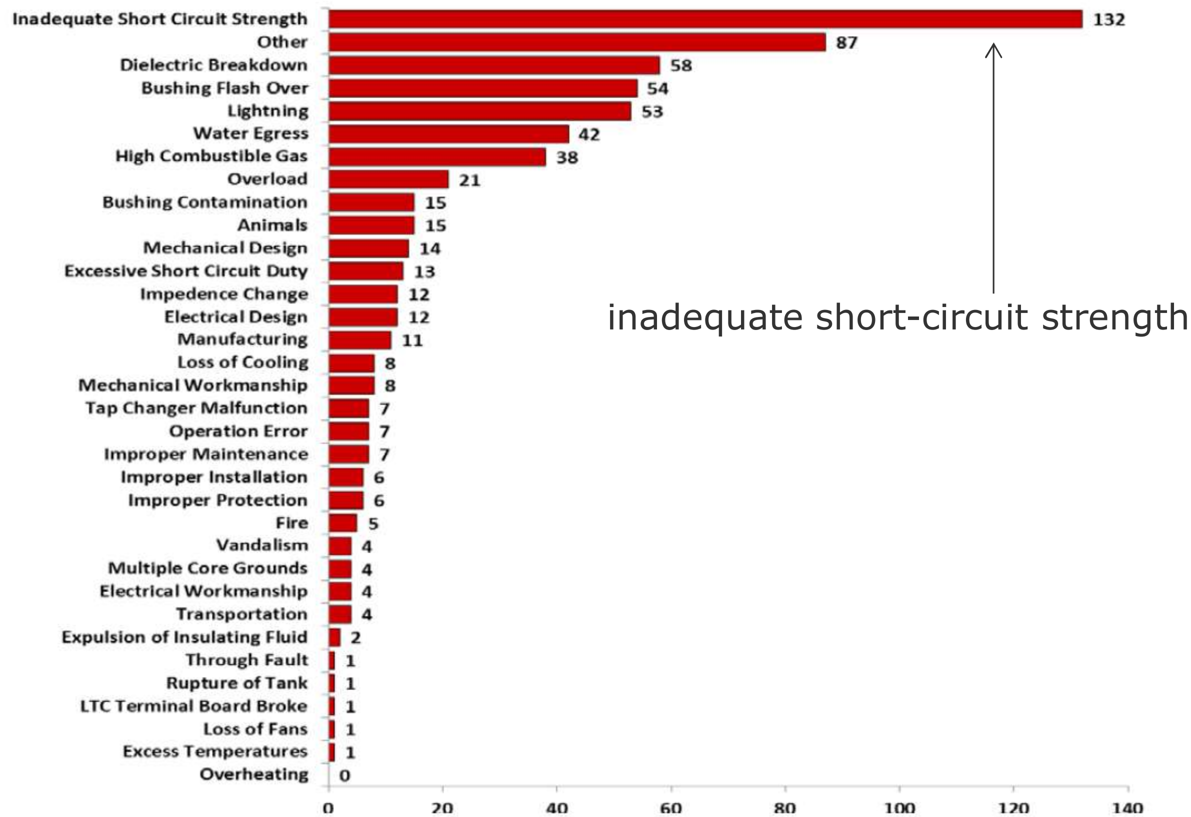


FIGURE 28: ANALYSIS OF FAILURE CAUSE (654 OF 1863 RECORDS HAVE FAILURE CAUSE IDENTIFIED)

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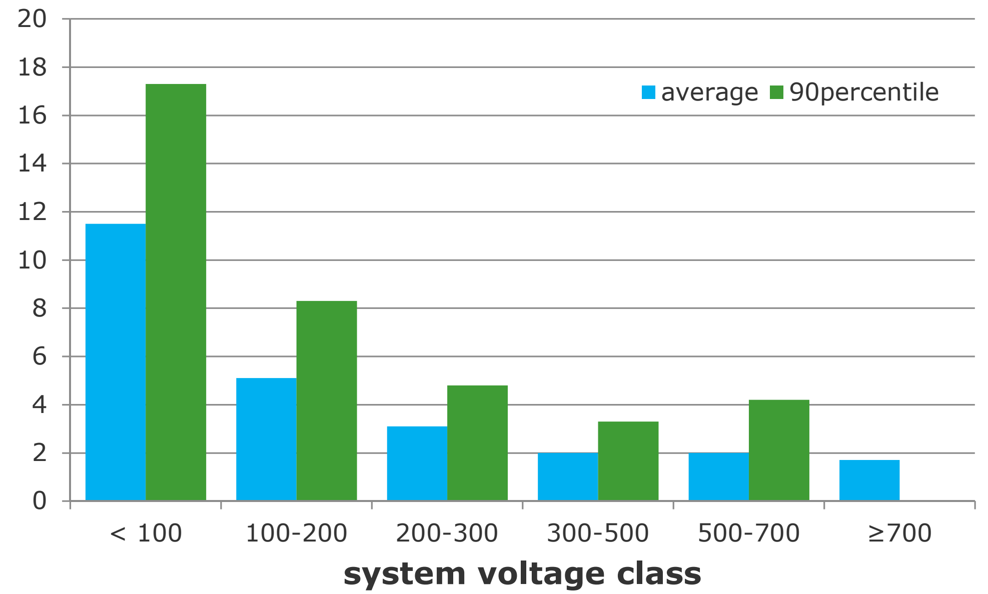
How Often do Faults Occur?

CIGRE 13.08 Study:
- 900.000 circuit breaker years
- 70.000 km overhead lines

Wide regional variations:

- **Global average: 1.7 faults per year on an overhead line**
- **90th percentile: 3.3 faults per year on an overhead line**
- **Lower voltage systems suffer more faults**
- **90% of faults happen in overhead lines or cable**

Number of faults per 100 km overhead line per year



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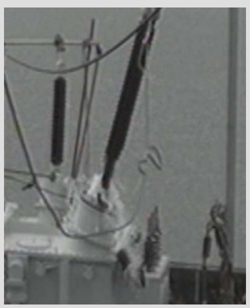
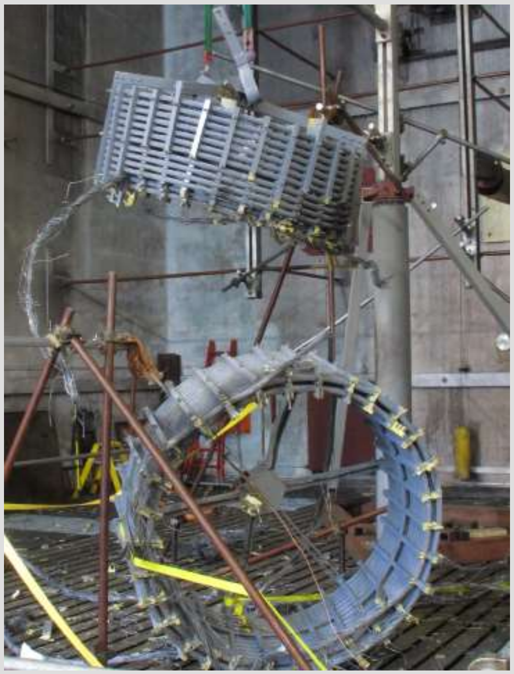
Statistics on Failure Rate during Type Testing

Around 25% of test-objects initially fail to pass type-tests


Line trap

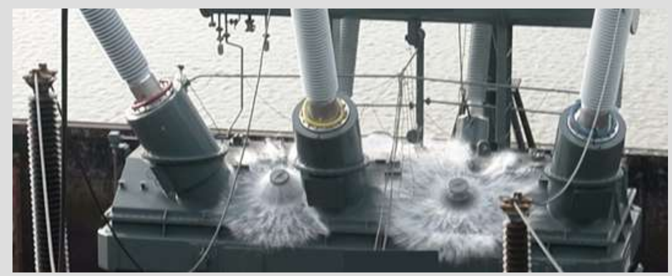

Broken bushing


Line trap


Disconnector


Switchgear panel


Distribution transformer


Oil spill

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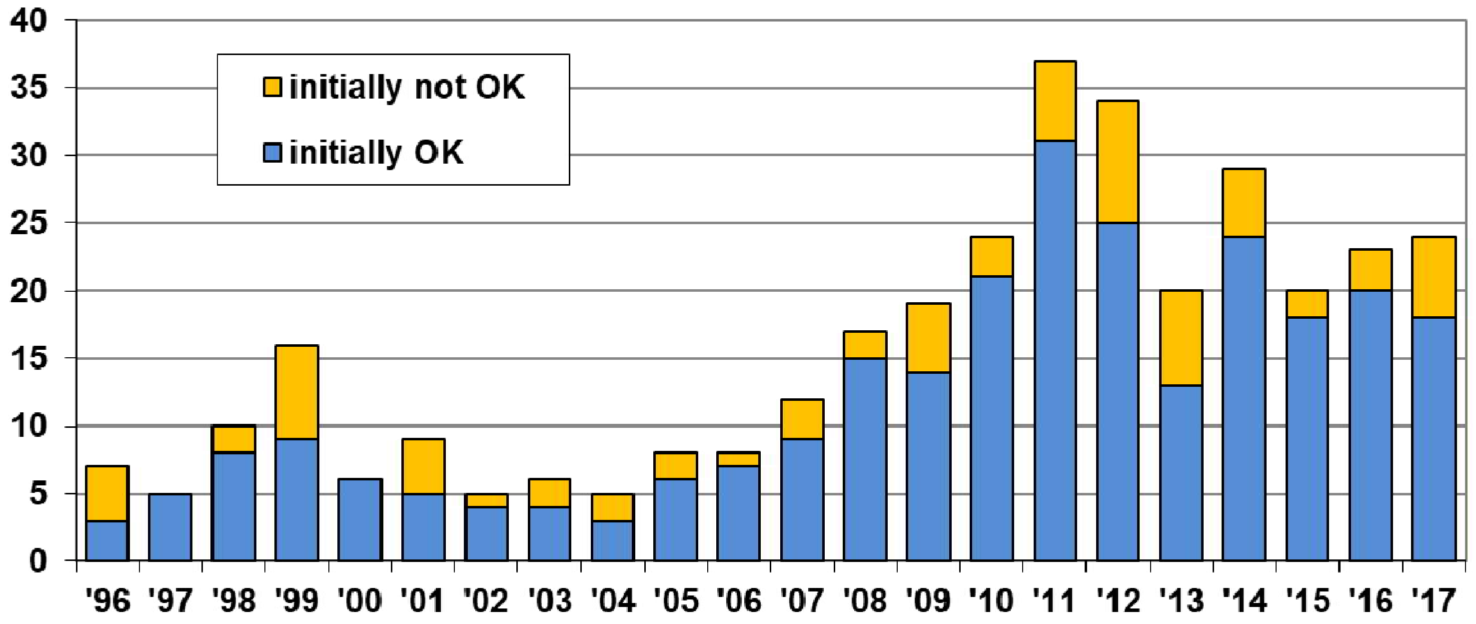
Initial failure rate large power transformers > 20 MVA

Number of large power transformers tested over the years (KEMA Laboratories) n=344



Average 22%

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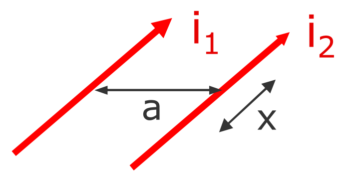
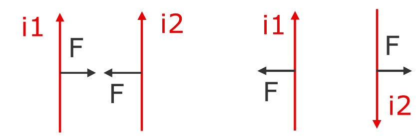
Forces between conductors

- Axial and radial force arises because current carrying conductors are inside a magnetic field

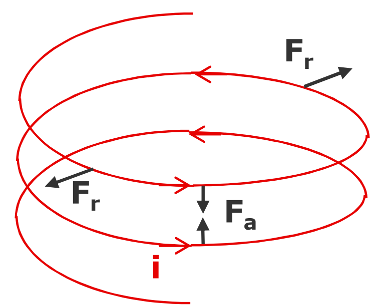
Lorentz-force: $\frac{F}{x} = \frac{\mu}{2\pi}\frac{i_1 i_2}{a}$



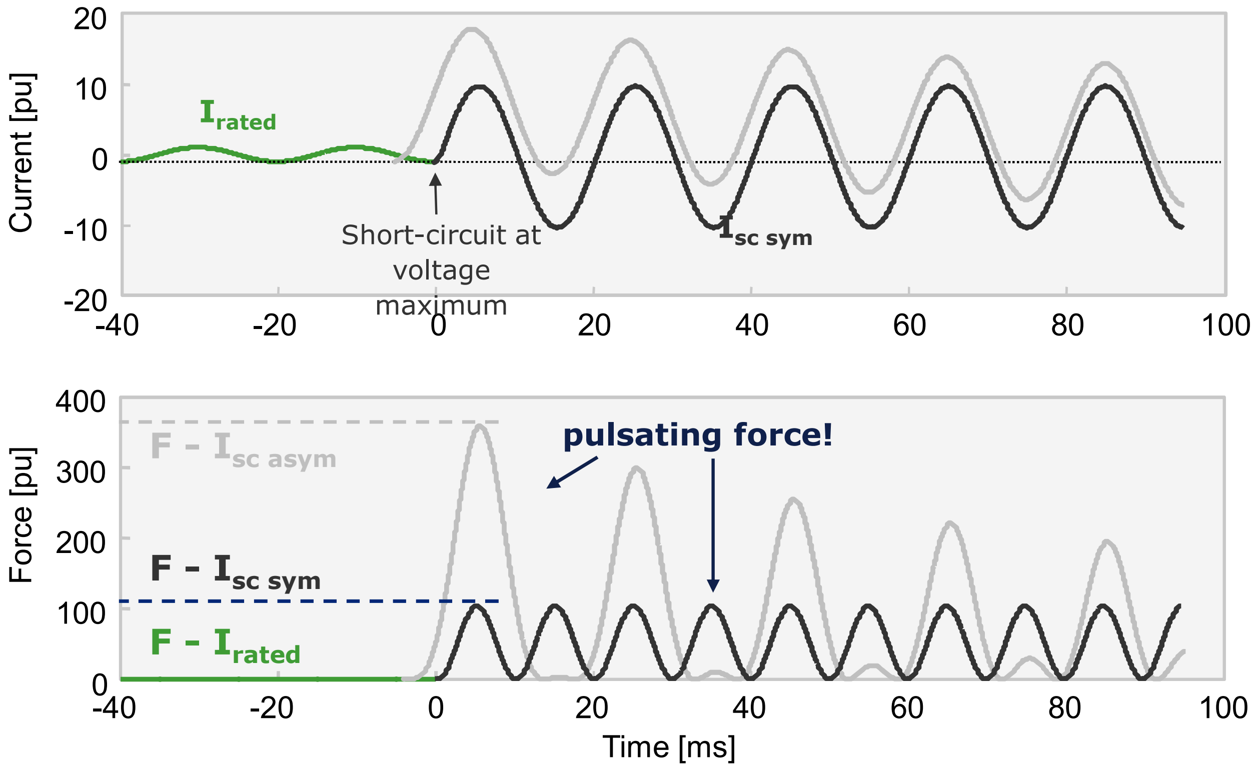


- Equal polarity: attraction
- Opposite polarity: repulsion

- For windings $i_2 = i_1$, so forces depend quadratically on current amplitude(!)



Relationship between current and force in a transformer



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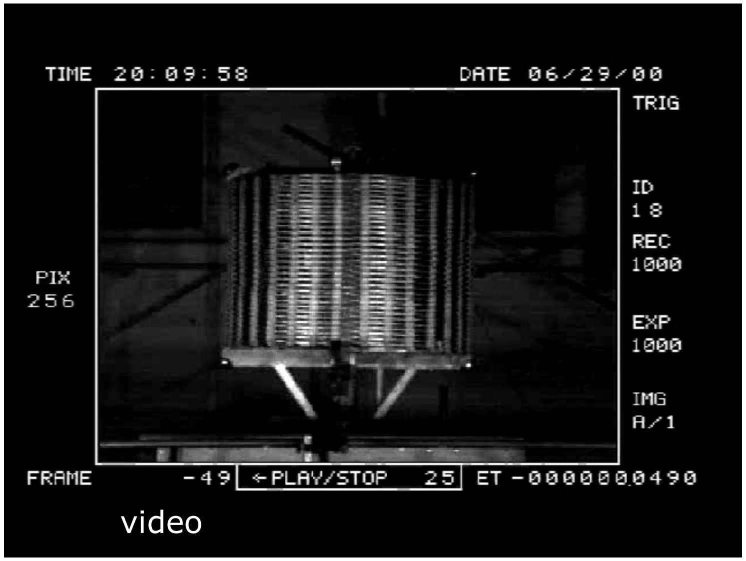
Short-circuit forces on a winding



Vibrations caused by dynamic stresses

Pulsating forces at 100 Hz cause severe
stresses to windings of transformers and reactors

Axial & radial forces on reactor are huge,
especially at transposition between layers

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Can design review replace short-circuit testing?

- Calculation methods are only based on static forces and do not cover all parts of the transformer. Following aspects are not/cannot be addressed fully:
  - cross overs of turns (inside the winding)
  - transpositions of parallel conductors (inside the winding)
  - exit leads of the windings (fixation to prevent movement and friction (wear of insulation) of exit lead)
  - support of cleats and leads
  - connections to OLTC
  - support of leads to bushings
  - stability of the radial support of windings (for example spacers used during winding the coil (untreated, dried, dried and oil impregnated)
  - effect of varying densities of the different windings due to axial compressing forces
  - dynamic pressure build up and movement of the oil

Types of failures in the laboratory prove that calculation/modelling are inadequate

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IEC 60076 and IEEE Std C57.12.90

– 12 – 60076-5 © IEC:2006

4.2 Ability to withstand the dynamic effects of short circuit

4.2.1 General

If required by the purchaser, the ability to withstand the dynamic effects of short circuit shall be demonstrated either

– by tests, or
– by calculation and design and manufacture considerations.

The choice of method of demonstration to be used shall be subject to agreement between the

- IEC allows the ability to withstand the dynamic effects of short circuit to be tested or calculated.

- **The revised versions of IEEE and IEC standards only allow testing, no calculations anymore. To be published 2019**

- Short circuit tests do not harm or age a transformer. (In normal applications, a transformer sees 10 to 15 short-circuits per year with 80 % or more currents.)

IEEE Std C57.12.90-2015
IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

The code defines a procedure to demonstrate the mechanical capability of a transformer to withstand short-ircuit stresses. The prescribed tests are not designed to verify thermal performance. Conformance to hort-circuit thermal requirements shall be by calculation in accordance with Clause 7 of IEEE Std C57.12.00-2015.

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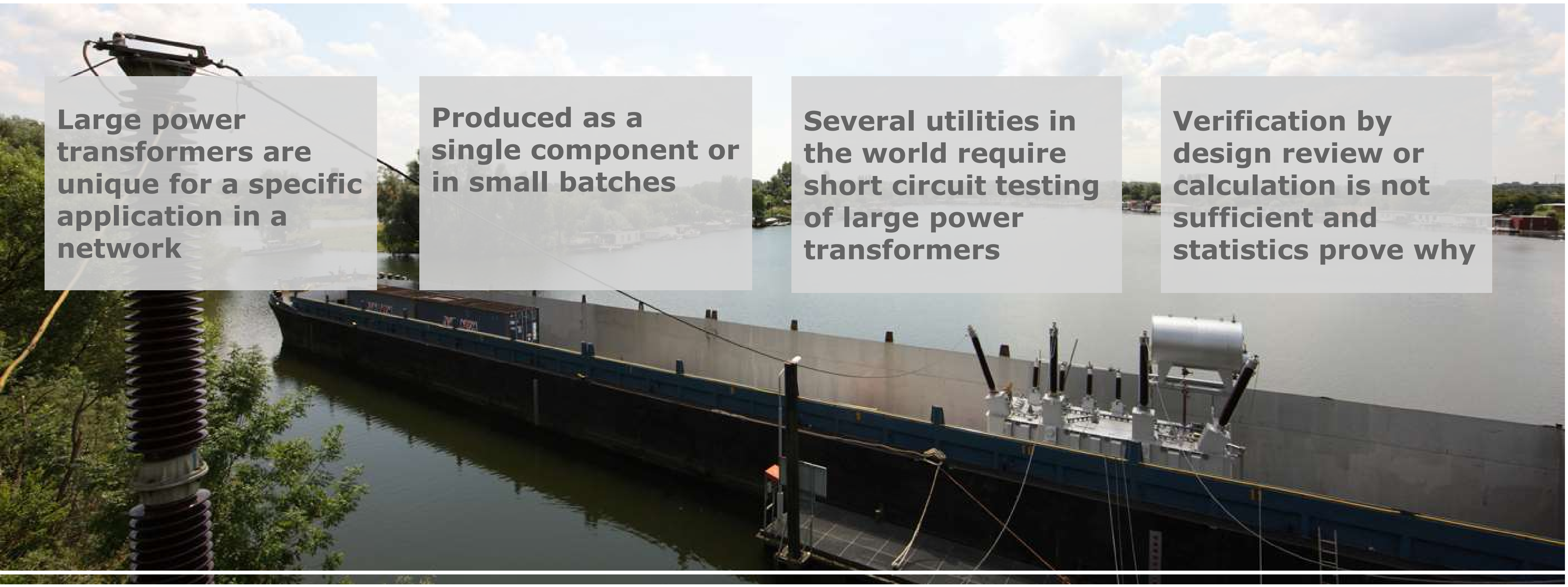
Large power transformers



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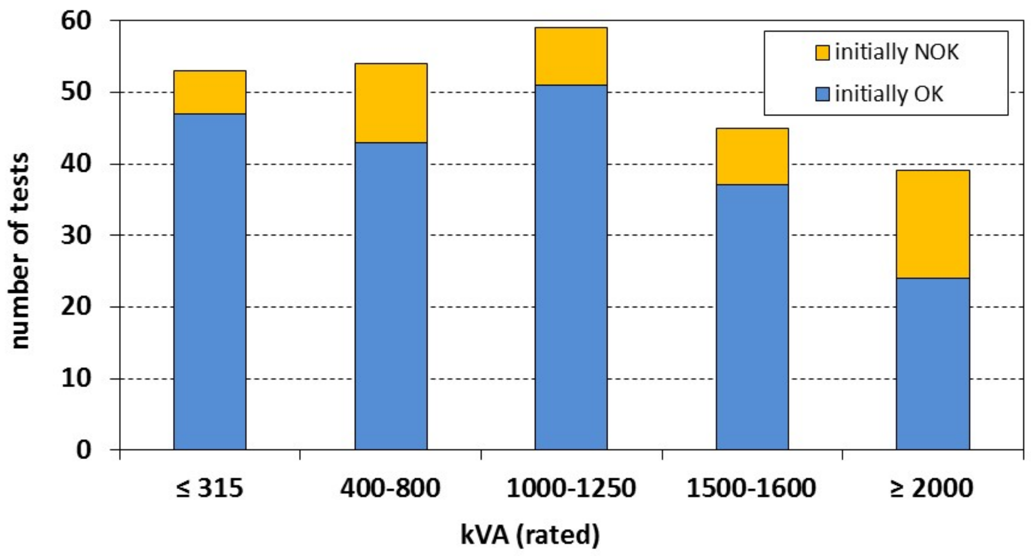
Initial failure rate distribution transformers

Distribution transformers per power rating (KEMA Laboratories)



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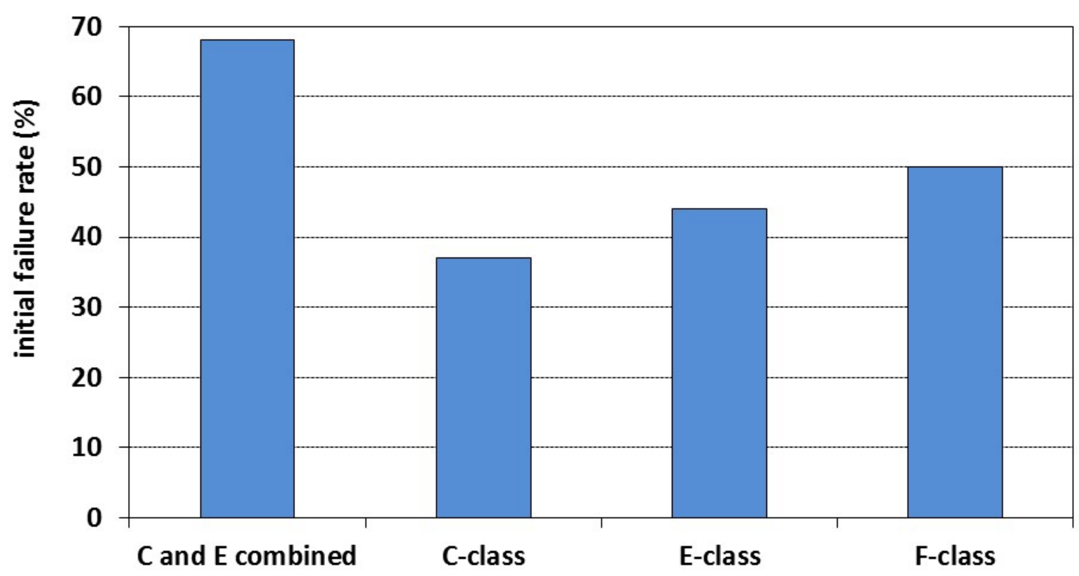
Initial failure rate cast resin transformers

Cast resin transformers (KEMA Laboratories)



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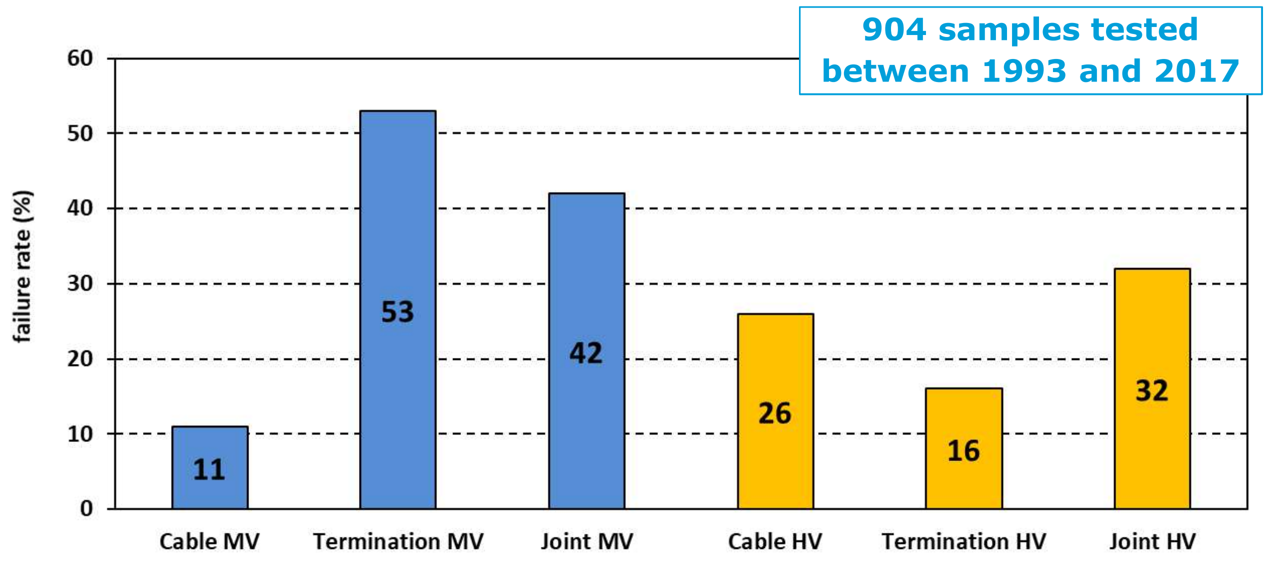
Initial failure rate cable and accessories

Medium and High Voltage cables and accessories (KEMA Laboratories)



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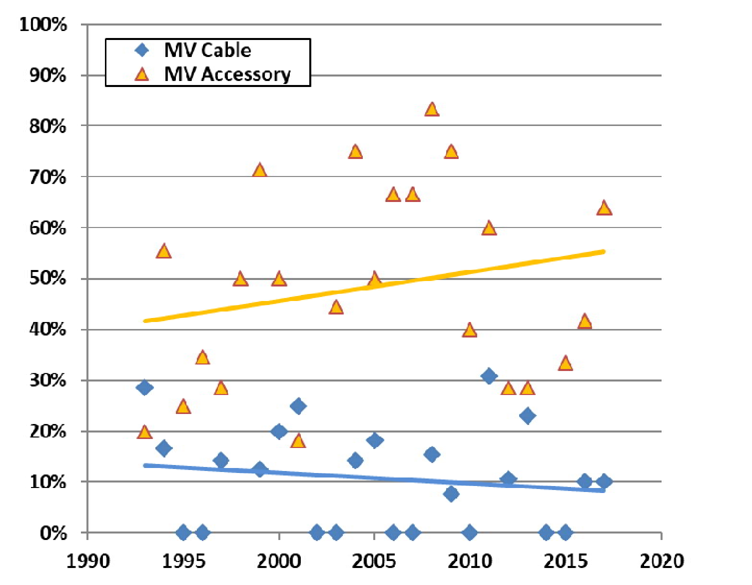
Examples of cable accessory failures

Mechanical deformation

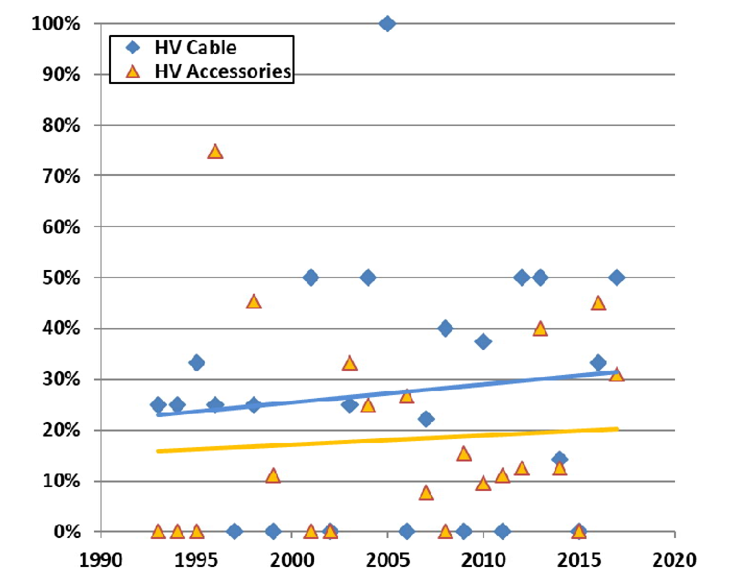
Tracking and erosion insulator shed

Initial failure rate cables and accessories

Medium Voltage (KEMA Laboratories)



High Voltage (KEMA Laboratories)



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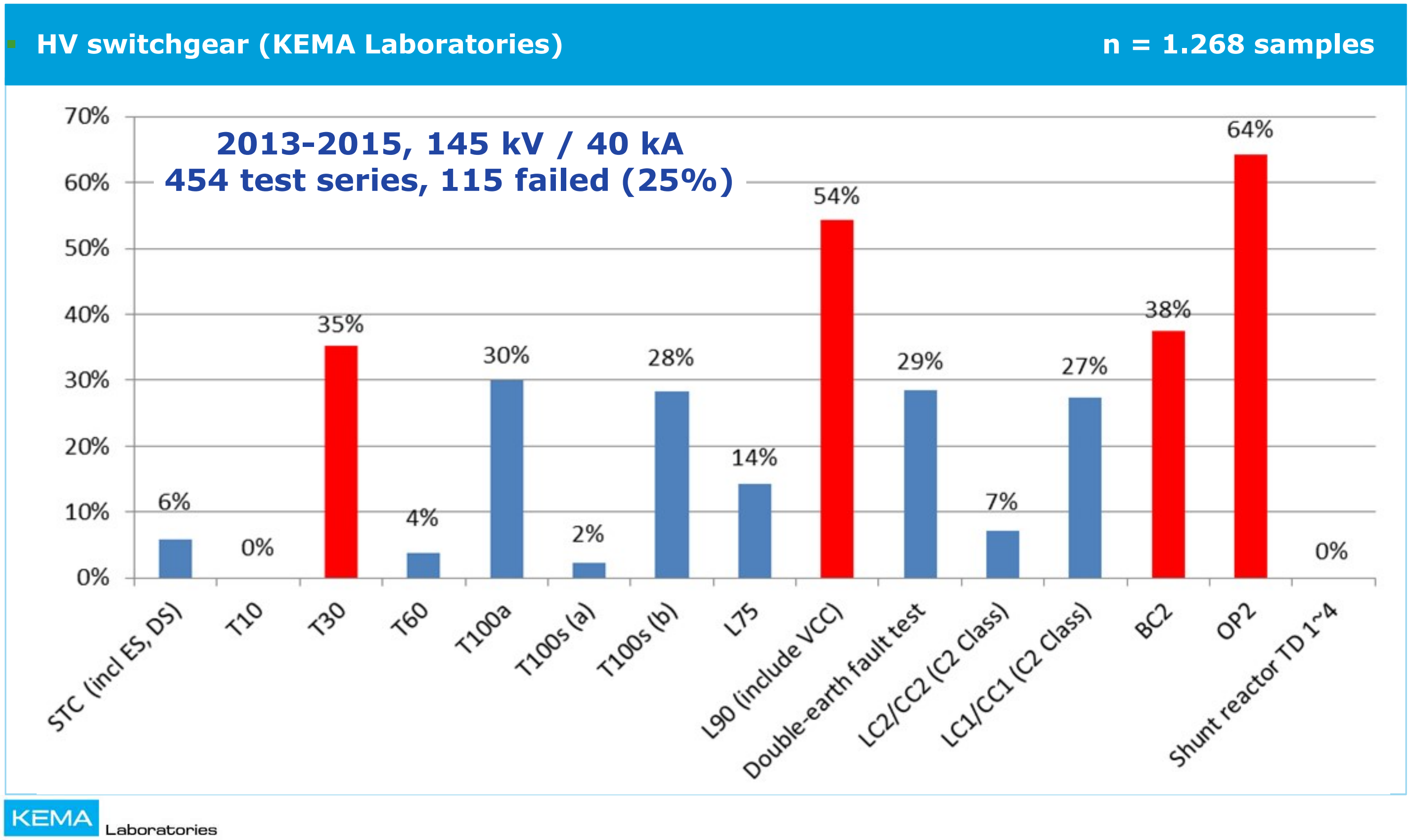
Initial failure rate circuit breakers – PRELIMANARY RESULTS



- Failure rate (72.5 – 800 kV) is 28%
- Issues: population size, few poor designs shall not dominate, ..
- More work is needed

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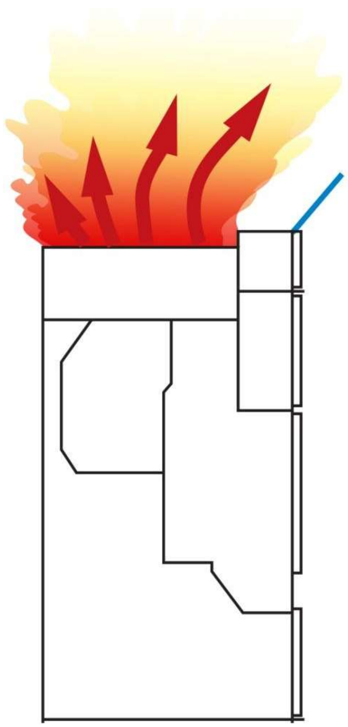
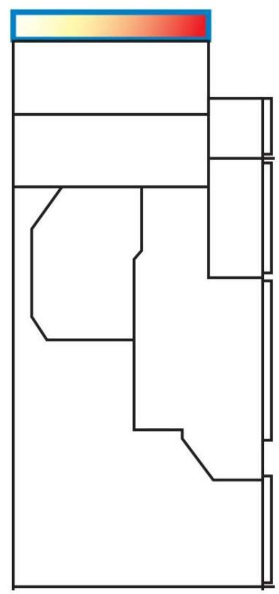
Internal arc test on MV switchgear

Deflector plate



Diversion channel



Internal arc test on low and medium voltage switchgear is important for **safety of workers**.

High attention internationally due to (serious) injuries to workers and potential liability for utilities.

IEEE and IEC for test on internal arc protection wide used.

Statistical data from KEMA not yet available. Indication, is again a 25% initial failure rate.

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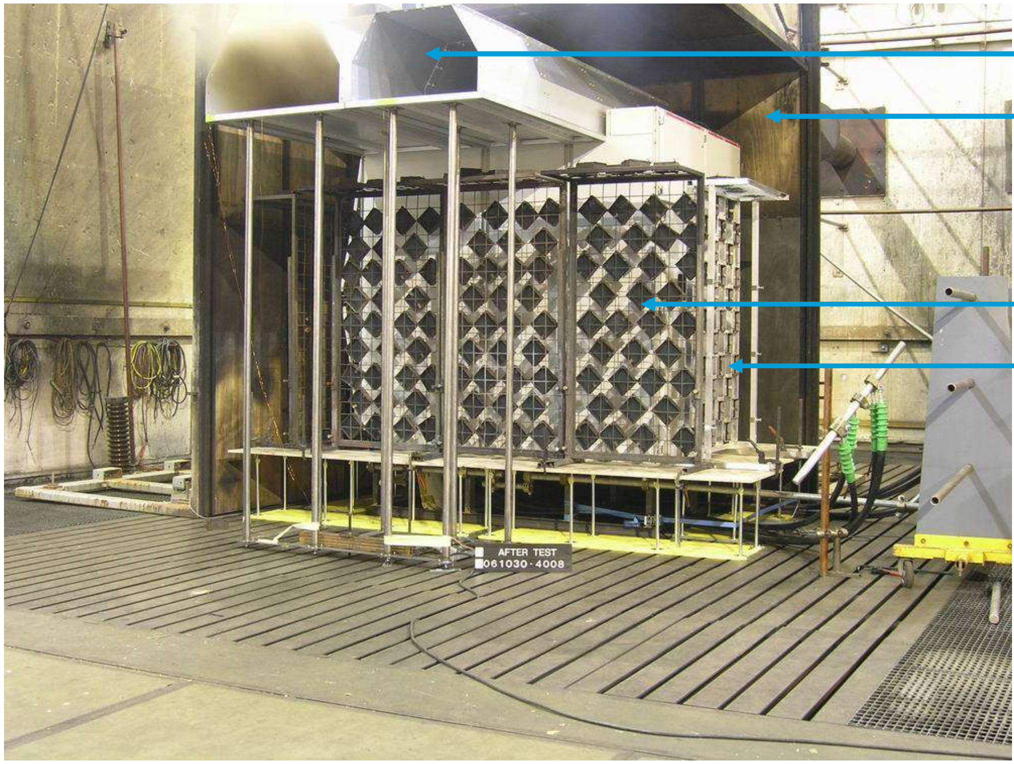
Carrying out the test

Cotton indicators mimic worker's clothing



exhaust

room simulation

front indicators

lateral indicators

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Successful 63 kA test

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Failed

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Passed

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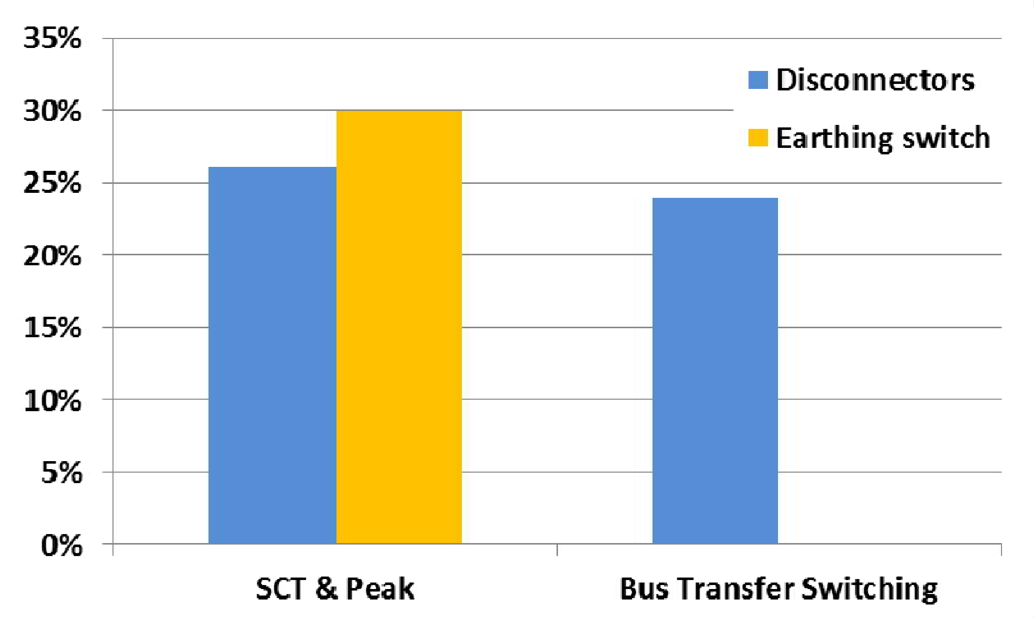
Initial failure rate HV disconnector and earthing switch

HV Disconnectors and Earthing Switch (KEMA Laboratories)



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Initial failure for power arc on insulator strings

Successful tests	109
Failures	57
Failure rate	34%

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Takeaways

Initial failure rate of type testing is 25% for all T&D components. Failure rate stays stable over the years, despite better materials, knowledge, modelling and production techniques. Business tendencies that drive this are:

- Build more compactly
- Reduce usage of materials
- Market competition and price pressure

Statistics and experience in testing shows that nothing can replace physical testing. Modelling and calculation is an important designer tool not a conclusive verification tool

Physical testing to a certain pre-defined standard or to a specific customer situation, is the only true test

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Disclaimer: All photograph's/pictures used by KEMA Laboratories in this presentation are for illustrative purposes only. The pictures/photographs do not in any way relate to the (failure of) component, products and/or manufacturer shown on the pictures/photographs.

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SAFER, SMARTER, GREENER

KEMA Laboratories

Review of Phase II Draft Test Plan
High Energy Arc Faults Involving Aluminum

Nick Melly
Office of Nuclear Regulatory Research
Division of Risk Analysis
April 19, 2018
Rockville, Maryland

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

Objectives

- Phenomena Identification and Ranking Table (PIRT) Result
- Experimental variables
- Measurement
- Phase 2 OECD Members
- Test Structure
- Experimental Approach
- Phase 2 Timeline

PIRT Phenomena of High Importance

- Cabinet-to-cabinet fire spread and secondary arcs in cabinet lineups
- Thermal damage criteria and target sensitivity for short, high heat exposures
- Likelihood and severity of secondary fires
- Performance of “HEAF shields”
- Likelihood and severity of damage from arc ejecta on electronic equipment
- Metal oxidation
- Arc electrical characterization

HEAF Phase 2
Focused Variable changes

- Arc current
  - Arc current was identified as a primary impact to total energy released
  - Two currents will be selected for both low and medium voltage enclosures; this current will be selected based upon feedback from needs and objectives document of typical system electrical line-ups and fault capacities (focus of later discussion)
- Arc Duration
  - Arc duration was identified as a primary impact to total energy released
  - Two durations will be selected for both low and medium voltage enclosures; the durations will be selected to make 1 to 1 comparisons between tests; nominally 2, 4 and 8 seconds
  - Bus ducts- 1,3,5 seconds
  - These values correspond with the KEMA electrical capabilities (focus of later discussion)

HEAF Phase 2
Focused Variable changes

- Material Property
  - Electrical Enclosure Conductor Material
    - Aluminum vs. Copper
  - Bus Ducts
    - Aluminum Enclosure; Copper Conductor
    - Aluminum Enclosure; Aluminum Conductor
    - Steel Enclosure; Copper Conductor
    - Steel Enclosure; Aluminum Conductor

HEAF Phase 2
Focused Variable changes

Potential Variable	**Potential Values**
Equipment Type	Cabinet, Bus Duct
Bus bar material	Aluminum, Copper
Bus duct material	Steel, Aluminum
Voltage	480 V, 4160V, 6900 V (workshop discussion)
Current	I_1, I_2 (workshop discussion)
Frequency	60 Hz
Power configuration	Delta, Wye (workshop discussion)
Equipment grounding	Grounded, Ungrounded (Floating)
Arc duration	100 ms to 8s (workshop discussion)
Arc Energy	Dependent on other variables
Arc location	(workshop discussion)
Bus bar insulation	Insulated, Uninsulated
Bus bar spacing (arc length)	(workshop discussion)
Bus bar size	(workshop discussion)
Bus bar thickness	(workshop discussion)
Enclosure thickness	(workshop discussion)

HEAF Phase 2 Measurement

- Measured Parameters
  - Temperature and Heat Flux
    - Both parameters will be modeled at multiple distances away from the arc point
    - Will aid in a dynamic ZOI creation
  - 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)
  - 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 (to be tested for damage and electrical continuity)
  - Byproduct Testing
    - Conductivity measurements for aluminum deposited on surfaces
    - Spectroscopy
  - Heat Release Rate (HRR) will not be measured during experiments based on lessons learned in phase 1 testing

HEAF Phase 2 Measurement

Measurement	Device
Temperature	Thermocouple (TC), Plate Thermometer (PT), IR imaging
Heat flux (time-varying)	Plate Thermometer (PT)
Heat flux (average)	Plate Thermometer (PT), Thermal Capacitance Slug (T_{cap} Slug)
Incident energy	Slug calorimeter (slug)
Cabinet internal pressure	Piezoelectric pressure transducer
Compartment internal pressure	Piezoelectric pressure transducer
Arc plume / fire dimensions	Videography, IR filter videography, IR imaging
Surface deposit analysis	Energy dispersive spectroscopy, electron backscatter diffraction

OECD –Phase II HEAF Expected Members

- **Belgium-**
  - The Federal Agency for Nuclear Control (FANC)
- **Canada-**
  - Canadian Nuclear Safety Commission (CNSC)
- **Czech Republic**
  - State Office for Nuclear Safety (SÚJB)
- **France**
  - The Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
- **France**
  - Electricité de France (EDF)
- **Germany**
  - Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH
- **Korea** (Republic of)
  - Institute of Nuclear Safety (KINS)
- **Japan**
  - Central Research Institute of Electric Power (CRIEPI)
- **Japan**
  - Japan Nuclear Regulatory Authority (NRA)
- **Netherlands**
  - The Authority for Nuclear Safety and Radiation Protection (ANVS)
- **Spain**
  - Consejo de Seguridad Nuclear (CSN)
- **USA**
  - United States Nuclear Regulatory Commission (USNRC)

HEAF Phase 2
Test Structure-Enclosures

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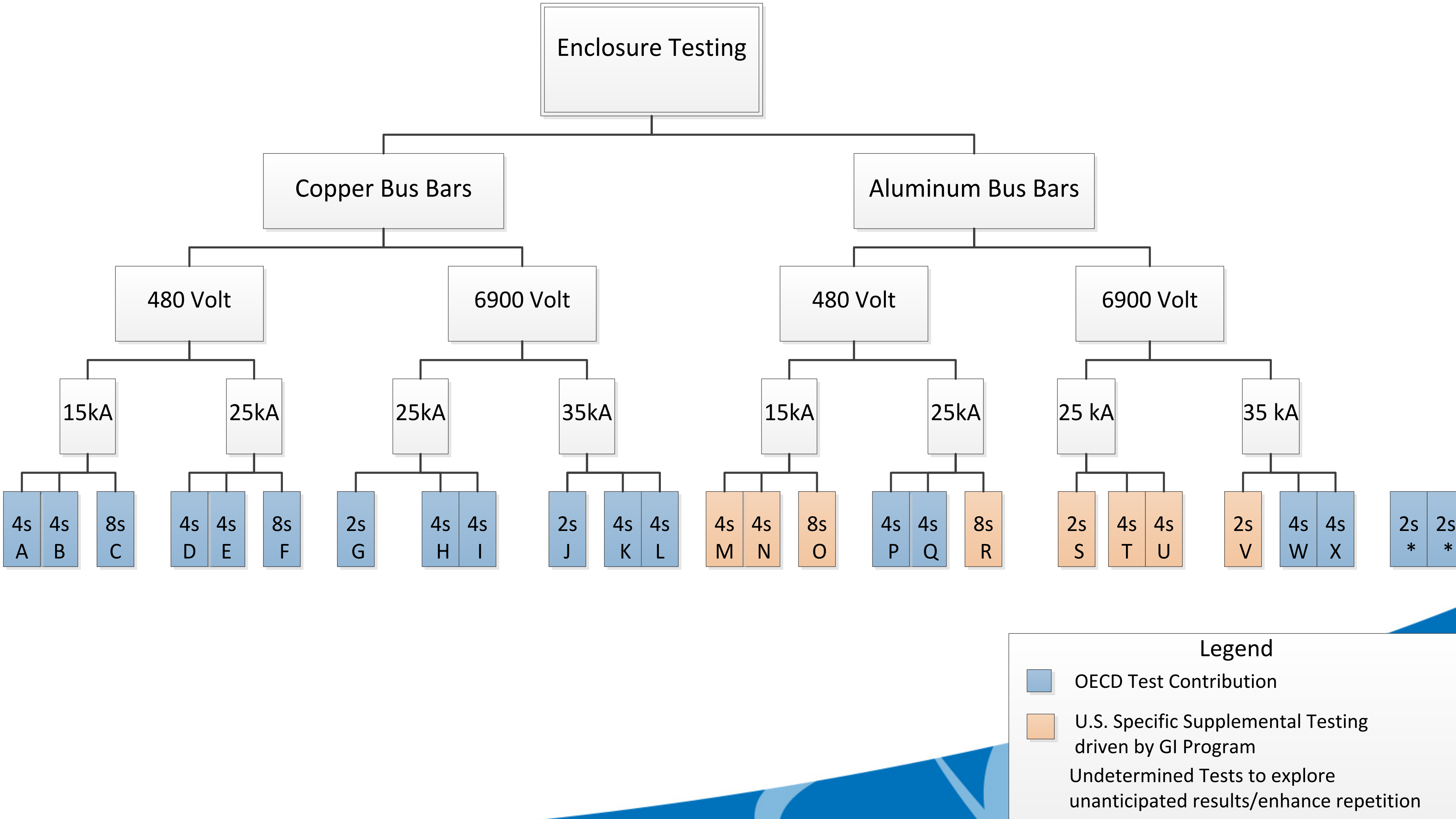
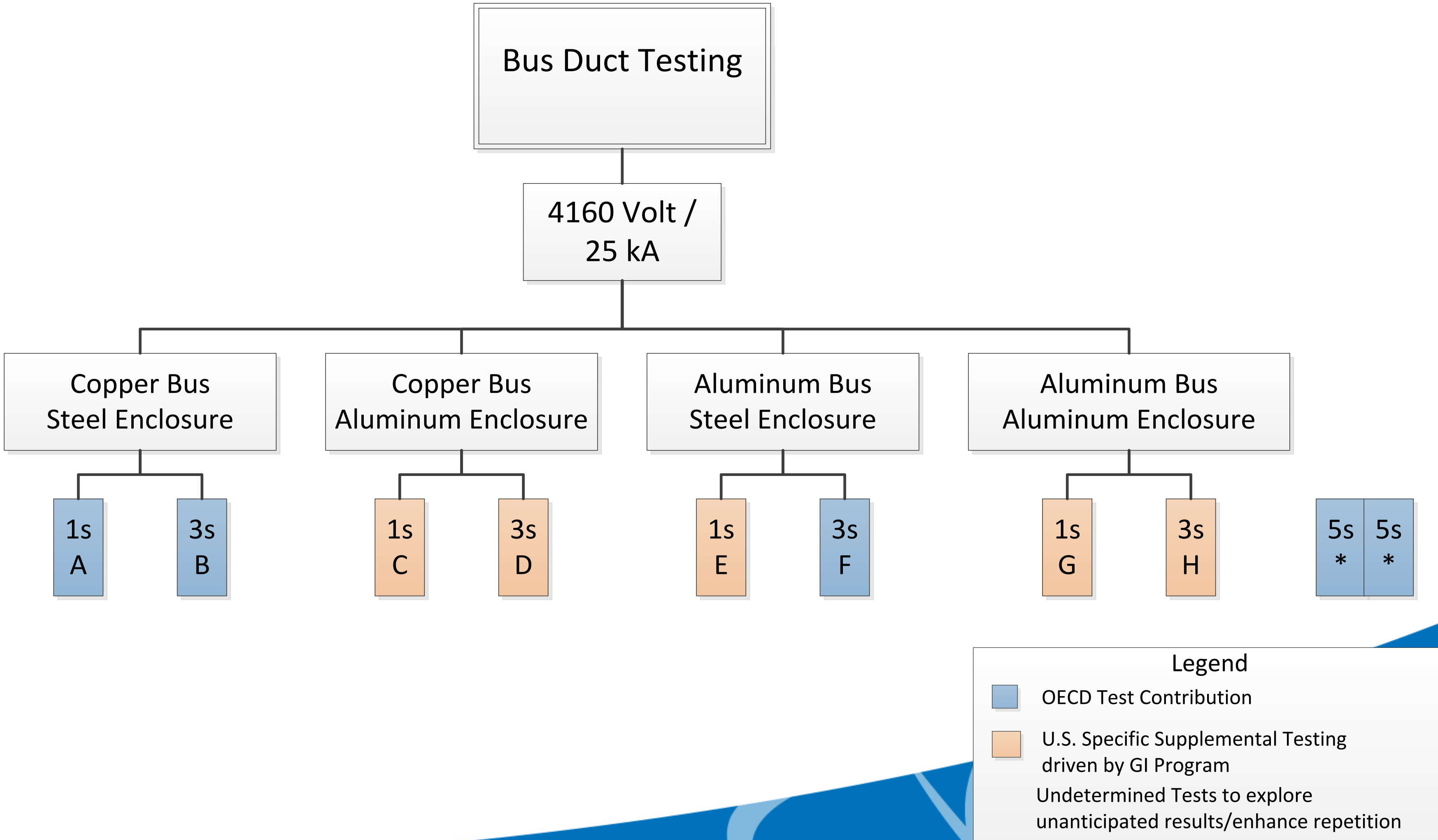


HEAF Phase 2
Test Structure- Bus Ducts

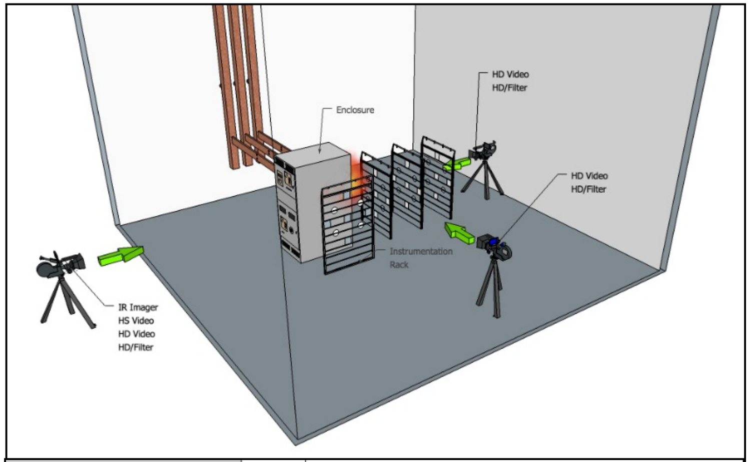


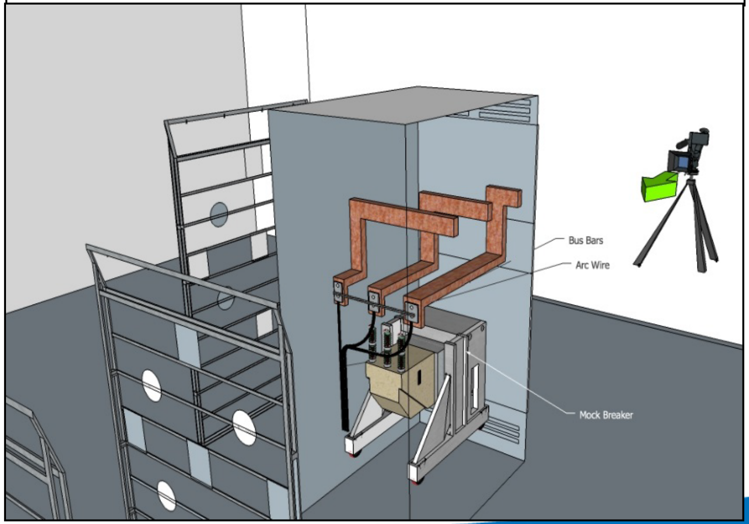
HEAF Phase 2 Experimental Approach

- Limit Test variables to understand the importance of specific variables on the severity of the HEAFs
  - create a dynamic model based on scenario specific factors
- Repeatable arc location and plasma ejection direction
  - repeatable tests using the same enclosure configurations
- Instrumentation will be the primary means of data collection at multiple distances from the HEAF origin
  - No cable trays or external combustibles will be used
- No testing to be performed will subject any equipment to conditions that exceed equipment ratings.

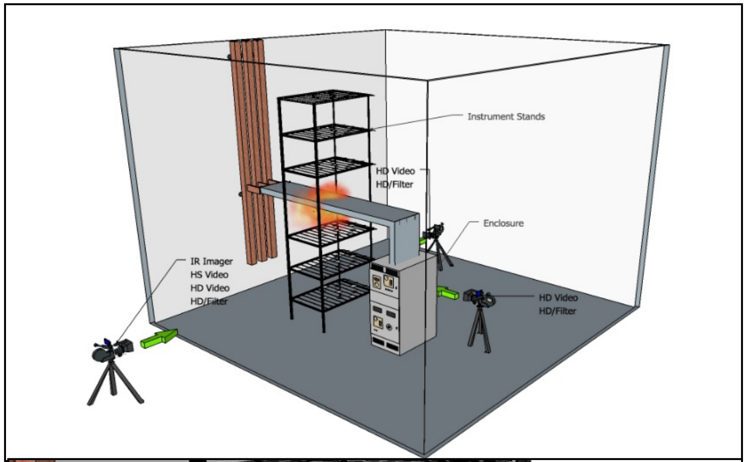
HEAF Phase 2 Experimental Approach

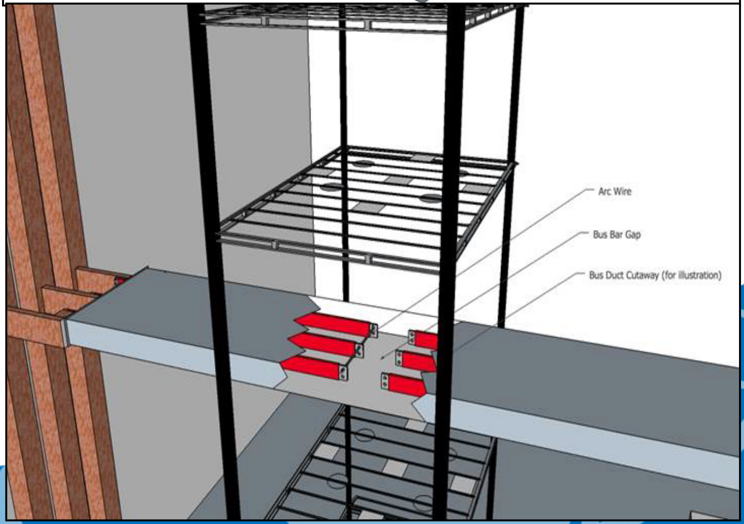
Enclosures





Bus Ducts





Timeline of NRC Phase II actions

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

Questions?

Review of Phase II Draft Test Plan Comments High Energy Arc Faults Involving Aluminum

Nick Melly
Office of Nuclear Regulatory Research
Division of Risk Analysis
April 19, 2018
Rockville, Maryland

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Phase II Draft Test Plan

- Official Public Comment Period
  - Organisation for Economic Co-operation and Development (OECD) and Nuclear Energy Agency (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
  - Additional comments received from EPRI on January 12, 2018
- 91 comments received in total
  - International and U.S. Industry

Industry Comment Categories

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- Generator capabilities and applicability for HEAF testing
- Protective relaying and the duration of testing
- Equipment ratings/Equipment selection
- Test conditions
  - Equipment setup, combustible load, cable trays
- Test Parameters
  - Voltage, current, grounding scheme
- Comparisons to IEEE Guide for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear IEEE C37.20-2007

Generator capabilities and applicability for HEAF testing

- The 2,250 MVA limitation on KEMA Laboratories' generator is the maximum available generator power, not the power delivered to the equipment.
- KEMA is equipped with current and power-limiting components, allowing precise adjustment of delivered power to any level within that rating.
- 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 what the tested enclosure actually sees

Equipment ratings and Equipment selection

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- No testing will be performed on equipment with conditions that exceed the equipment ratings
- The magnitude of the fault conditions for the apparent power of a three-phase electrical system is given by SQU(3)*Voltage*Current
- At the selected test parameters the apparent power rating is within the industry average e based on a review of available plant information

Phase II Apparent Power Range			
		Votage (V)	
		4160	6900
Current (A)	25,000	180 MVA	300 MVA
	35,000	252 MVA	418 MVA

Industry Sample Averages		
Votage (V)		
4160	6900	13800
320 MVA	430 MVA	690 MVA

Protective relaying and the duration of testing

- Majority of arcing fault events are quickly terminated by protective devices; however such events are not the subject of this test program
  - These are typically encompassed in the NUREG/CR-6850 bin 15 frequency as ignition sources for electrical enclosure fires *not HEAF or *not fires i.e. self extinguished
- This test program is designed to evaluate the impact of "bin 16" events; i.e. arcing faults that are not quickly interrupted by circuit protection schemes
- The frequency of HEAF events is a current area of work previously discussed and will be captured though a joint EPRI/NRC program

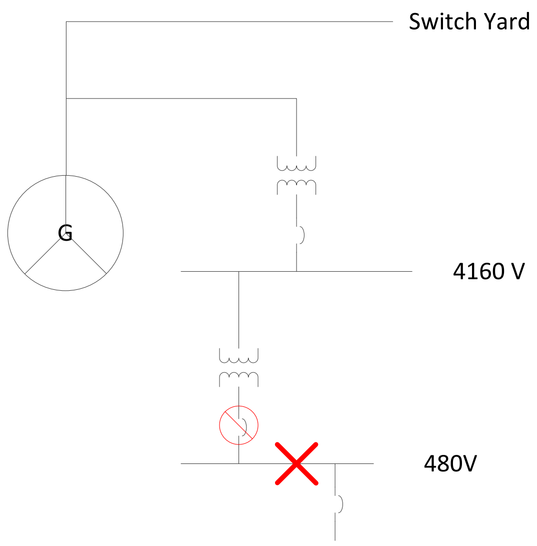
Protective relaying and the duration of testing

- Duration of tests is based on operating experience of bin 16 events
- Plant specific circuit protection schemes will be an area of discussion for the joint EPRI/NRC HEAF project to begin in Q4 of 2018

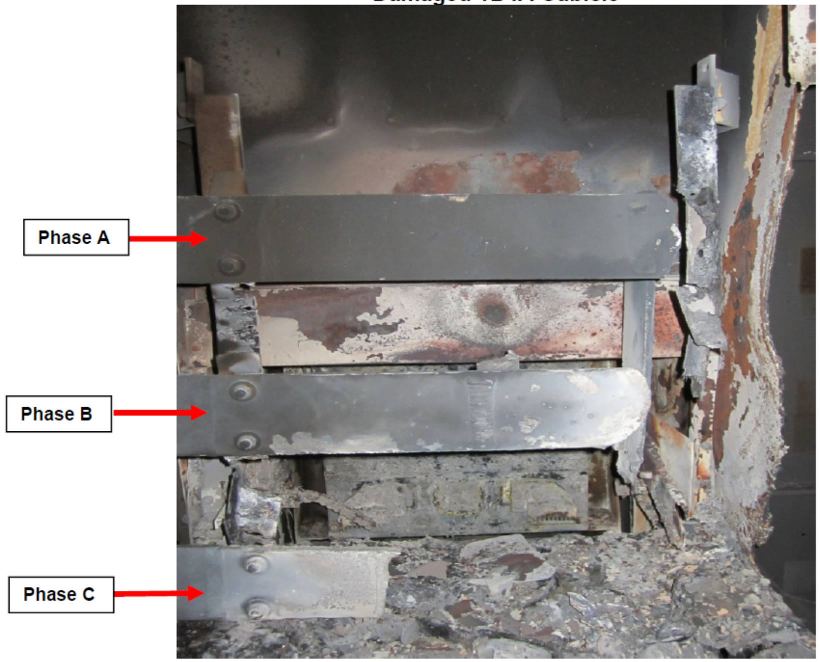
Plant Name	Date	Arc Duration
Robinson	03/27/2010	8 s to 10 s
Diablo Canyon	05/15/2000	11 s
Prairie Island	08/03/2001	>2 s
San Onofre	02/03/2001	>2 s
Fort Calhoun	06/07/2011	42 s(required operator intervention)

Protective relaying and the duration of testing
(Low Voltage)

- Several low voltage events have exhibited the ability to hold in for extended durations from both U.S. OpE and International experience
  - Fort Calhoun- 42 seconds (interrupted by control room action)
  - German" Event 17" - 8.5 seconds; Analysis of High Energy Arcing Fault (HEAF) Fire Events," NEA/CSNI/R(2013)6



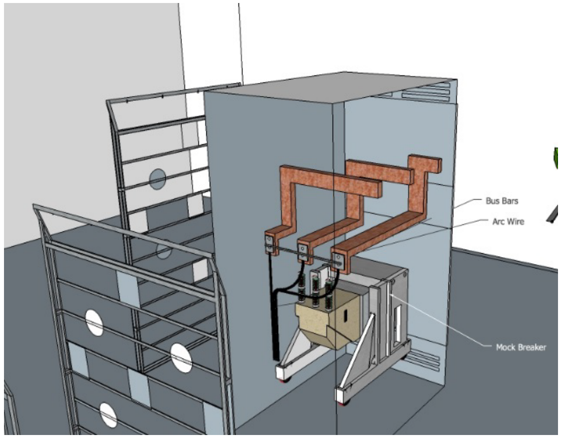
Damaged 1B4A Cubicle

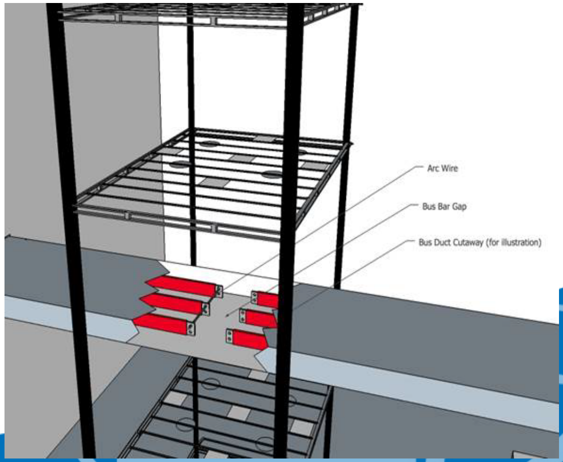


Test conditions

Equipment setup, combustible load, cable trays

- The test program has been modified to include circuit breakers in all electrical enclosures
- No cable trays will be used in this test program
  - Tests will focus on data collection systems arranged around the enclosure to collect relevant information
- All internal combustible load arrangements will be documented
  - size, orientation, mass, cable jacket material, cable insulation material





Comparisons to IEEE Guide for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear – IEEE C37.20-2007

- The NRC tests do not intend to replicate the IEEE guide.
- The NRC is NOT attempting to qualify arc resistant equipment per the guide but attempting to obtain information to aid in the development of advancing the HEAF methodology for use in the context for NPP PRA use in a dynamic manner
- The guide will be followed for the extent practicable for the needs of this research
- Wire Size #10 AWG (Class K Stranded) vs #24 AWG
- Arc Location, Arc initiation phase angle

Test Parameters

(Topics to be discussed collaboratively in the next session)

- Duration
- Voltage
- Current
- Grounding Configuration
- X/R
- Bus spacing
- Enclosure configuration
- Arc Location
- Arc initiation phase angle

Questions?

NRC Test Parameters and Equipment

Gabriel Taylor, P.E.
Division of Risk Assessment

Kenn Miller
Division of Engineering

Office of Nuclear Regulatory Research

April 19, 2018

Rockville, MD

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Session Objective

- Solicit discussion and feedback for Phase II test parameters
- Understand range of operating conditions
- Identify equipment configurations and types for testing

Needs and Objectives

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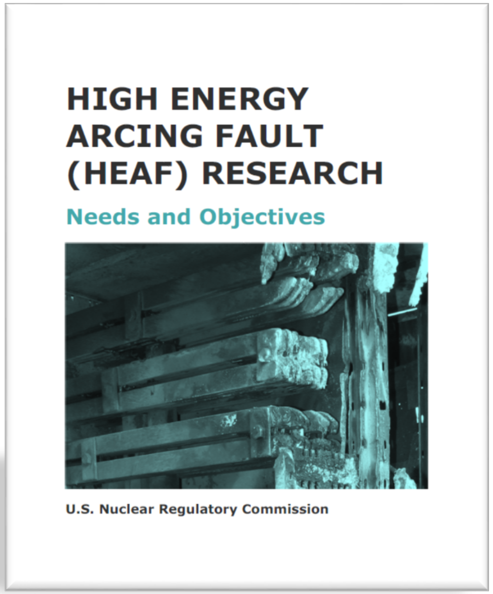
- Provides high level overview of hazard, data, and models
- Identifies research goals and objectives
- Identifies informational needs to ensure testing representative of event potential


HIGH ENERGY ARCING FAULT (HEAF) RESEARCH

Needs and Objectives

U.S. Nuclear Regulatory Commission

The Hazard

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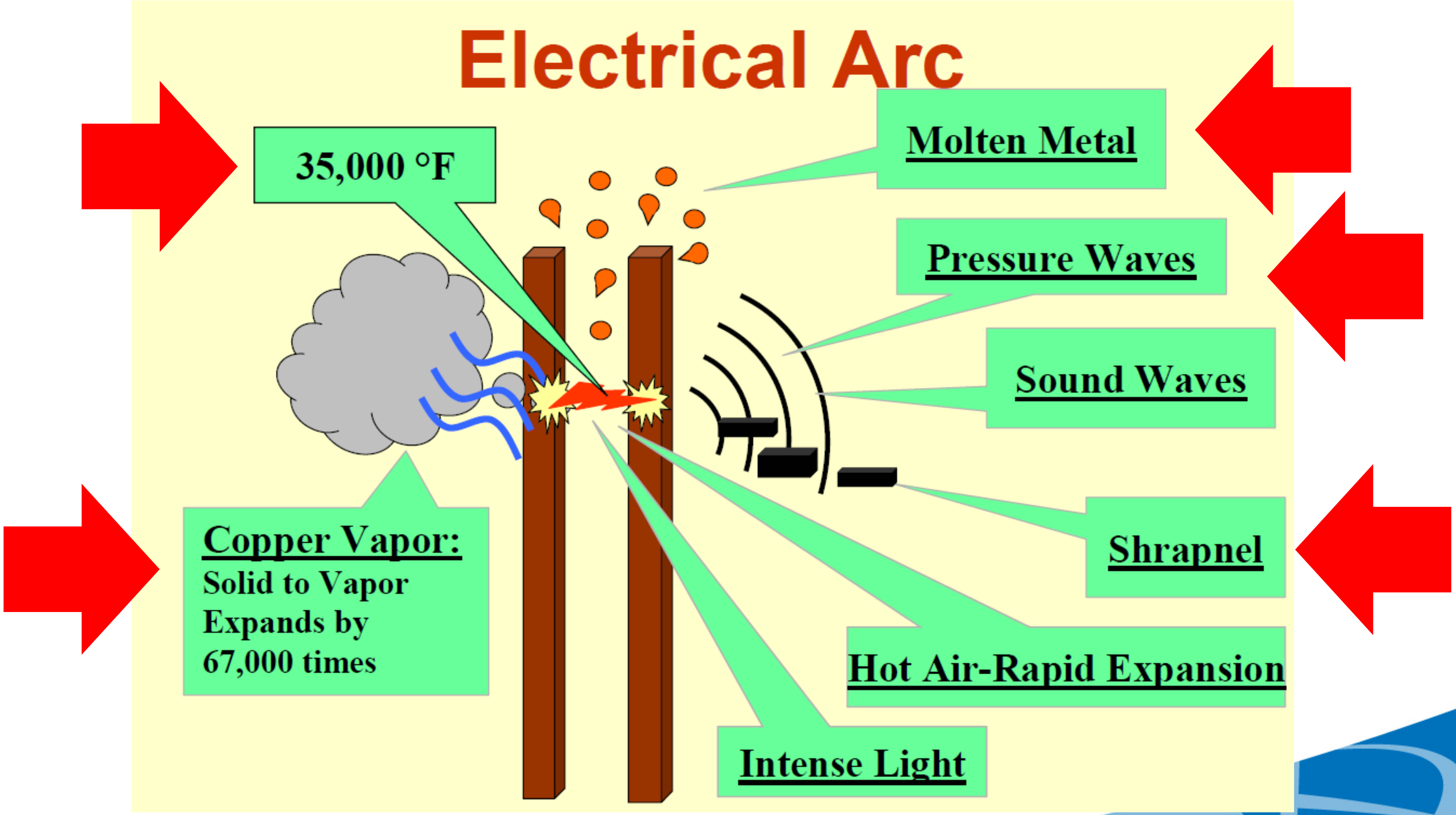

Ref. UAW Electrical Safety in the Workplace

Goals

- Provide data to refine and improve HEAF damage estimation methodology
  - Refine existing model
  - Modify refined model to account for Aluminum

Objective

In order to reach the stated goal the following objectives have been determined to be important

- *Identification of realistic test conditions, based on:*
  - *typical nuclear power plant electrical distribution system design and protection*
  - *operating experience*
- *Optimize test parameter variants*
- *Development and application of measurement devices*
- *Collect measurement data to characterize HEAF environment*
- *Analyze data to determine extent of damage and understand extent of hazard*
- *Revise existing models*

Test Parameters

- Duration
- Voltage
- Current
- Grounding Configuration
- X/R
- Bus spacing
- Enclosure configuration
- Arc Location
- Arc initiation phase angle

Thermal Energy

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- Thermal energy released from HEAF will be a function of primary parameters
  - Arc voltage (V_{arc})
  - Arc current (I_{arc})
  - Duration of arc (t)
  - Heat transfer efficiency (k)

Electrical Enclosure Test Matrix

Test #	Type		Material		Voltage (kV)			Current (kA)			Duration (seconds)						Gap (mm)	Energy (J/cm^2)
	Cabinet	Bus Duct	Cu	Al	0.48	4.16	6.9	15	25	35	1	2	3	4	5	8		
A	X		X		X			X						X				
B	X		X		X			X						X				
C	X		X		X			X								X		
D	X		X		X				X					X				
E	X		X		X				X					X				
F	X		X		X				X							X		
M	X			X	X			X						X				
N	X			X	X			X						X				
O	X			X	X			X								X		
P	X			X	X				X					X				
Q	X			X	X				X					X				
R	X			X	X				X							X		
G	X		X			X[1]			X			X						
H	X		X			X[1]			X					X				
I	X		X				X		X					X				
J	X		X			X[1]				X		X						
K	X		X			X[1]				X				X				
L	X		X				X			X				X				
S	X			X			X		X			X						
T	X			X			X		X					X				
U	X			X			X		X					X				
V	X			X			X			X		X						
W	X			X			X			X				X				
X	X			X			X			X				X				
Sp1	X																	
Sp2	X																	

Bus Duct Test Matrix

Test #	Bus Material		Duct Material		Voltage (kV)	Current (kA)	Duration (seconds)			Gap (mm)	Energy (J/cm^2)
	Cu	Al	Steel	Al	4.16	25	1	3	5		
BD_A	X		X		X	X	X				
BD_B	X		X		X	X		X			
BD_C	X			X	X	X	X				
BD_D	X			X	X	X		X			
BD_E		X	X		X	X	X				
BD_F		X	X		X	X		X			
BD_G		X		X	X	X	X				
BD_H		X		X	X	X		X			
Sp1					X				X		
Sp2					X				X		

Test Parameters

- Arcing Time (Duration)
  - Electrical protection clearing times for primary and secondary protection
    - Worst case bolted fault conditions may not produce bounding incident energy
    - Should also evaluate clearing times for arc conditions with limiting source
    - With and without considering failure of 1st upstream circuit protection

Proposed Testing Arc Durations

- Electrical Enclosures
  - Low Voltage
    - 4 and 8 seconds
  - Medium Voltage
    - 2 and 4 seconds
- Bus Bar Duct
  - Medium Voltage
    - 1, 3, 5 seconds

Durations from Operating Experience

Plant Name	Date	Arc Duration (seconds)
Robinson	03/2010	8 – 10
Diablo Canyon	05/2000	11
Prairie Island	08/2001	>2
San Onofre	02/2001	>2
Fort Calhoun	06/2011	42

Why long durations?

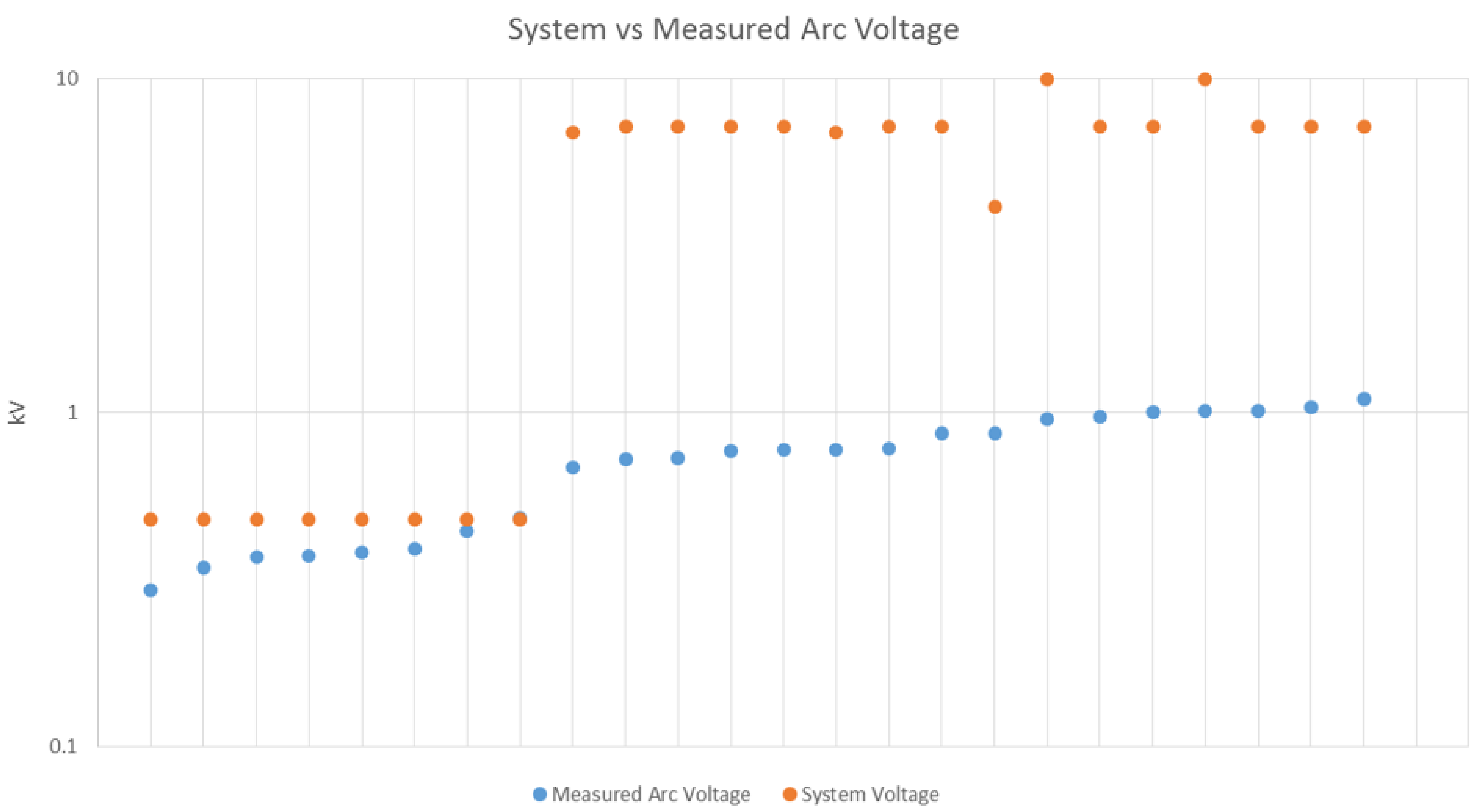
- Short arc flashes lack sufficient energy to cause thermal damage to other equipment
- Total energy (thermal source term) dependent on duration
- Long durations and their damage footprint are showing up in operating experience
  - Arc flash vs HEAF

Discussion

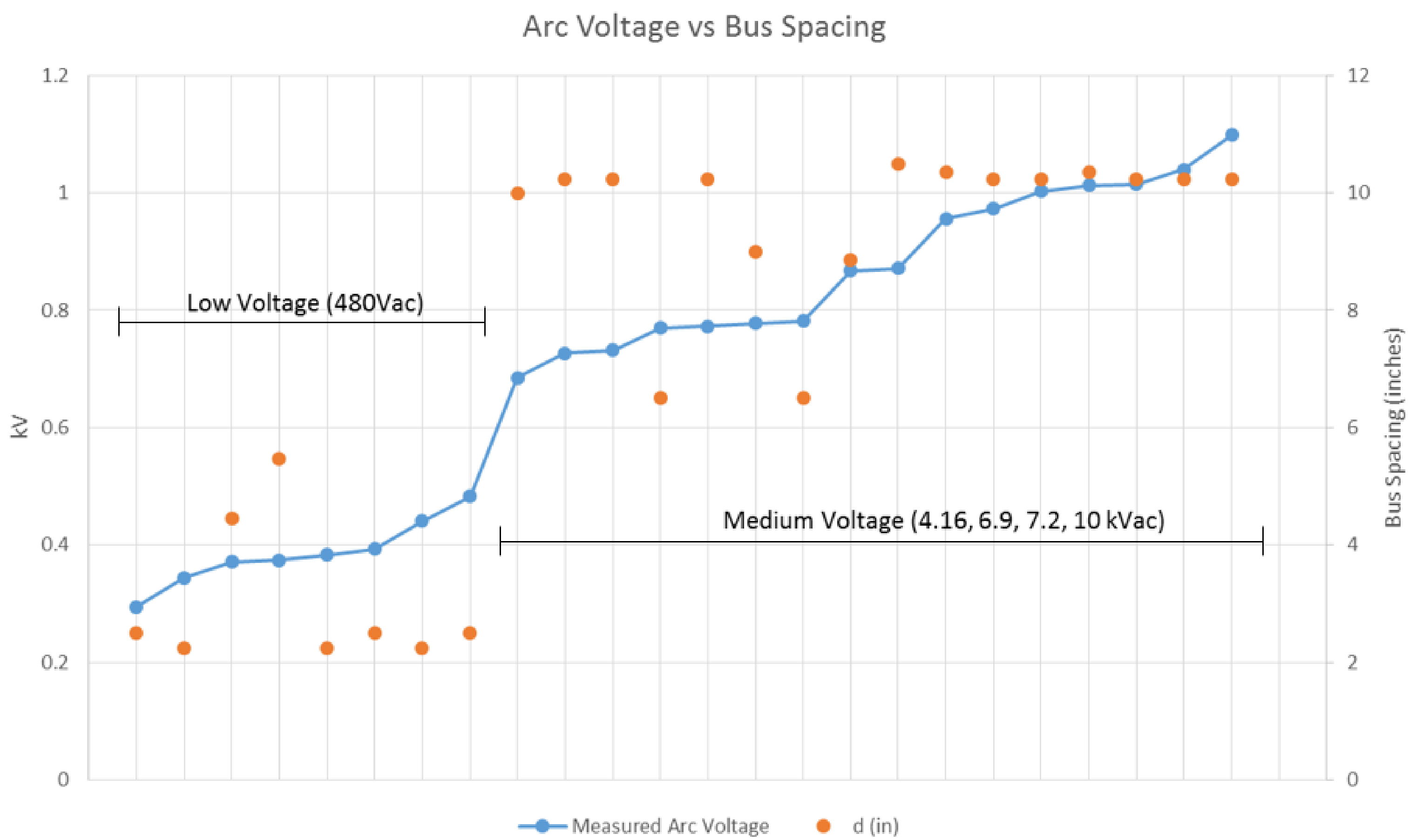
Test Parameters (cont.)

- Voltage level
  - Low voltage
    - 480Vac
  - Medium Voltage
    - 6.9kVac
      - Exception
        - » if donated equipment is not rated for 6.9kV then it will be tested to its rated voltage (i.e., 4.16kV, 2.4kV, etc.)

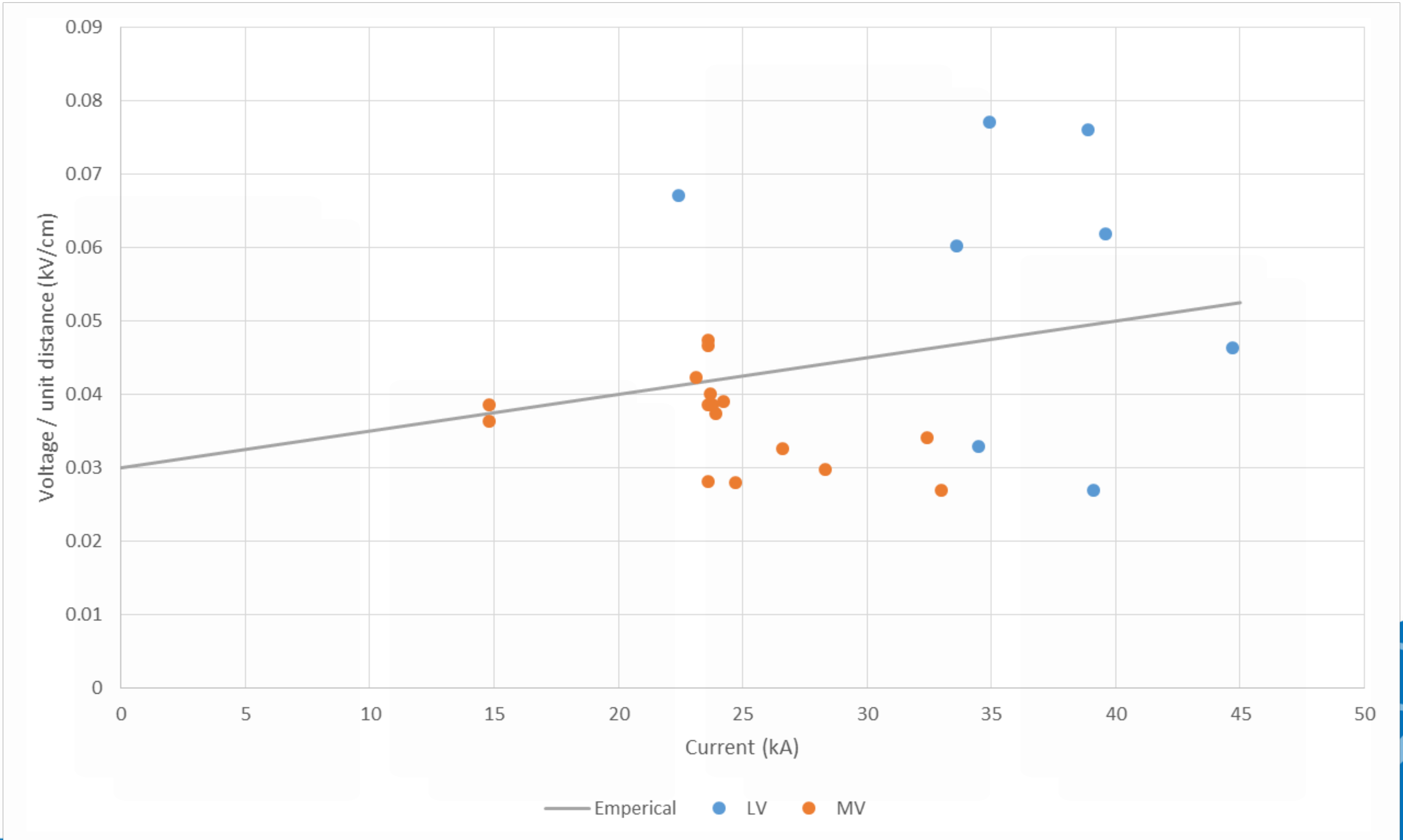
System voltage versus Arc voltage (Phase 1)



Enclosure
Bus Bar Spacing for Phase 1

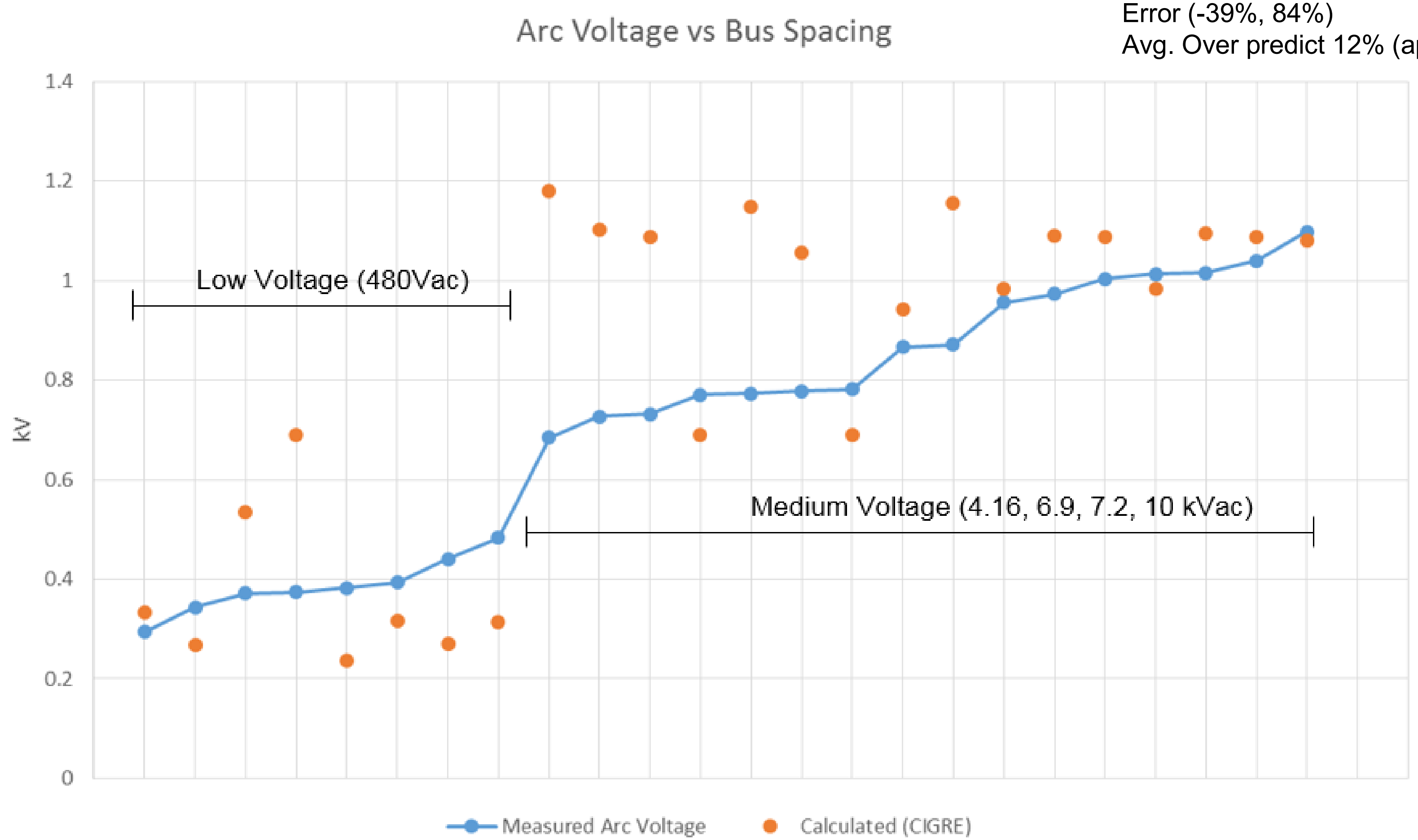


Arc voltage vs bus bar spacing (phase 1 results)



Bus Spacing versus Arc Voltage for Phase 1 results

Error (-39%, 84%)
Avg. Over predict 12% (approx.)



Discussion

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Test Parameters (cont.)

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- Current
  - Bolted fault current
    - A short circuit or electrical contact between two conductors at different potentials in which the impedance or resistance between the conductors is essentially zero
  - Arcing fault current
    - A fault current flowing through an electrical arc plasma

Ref. IEEE 1584

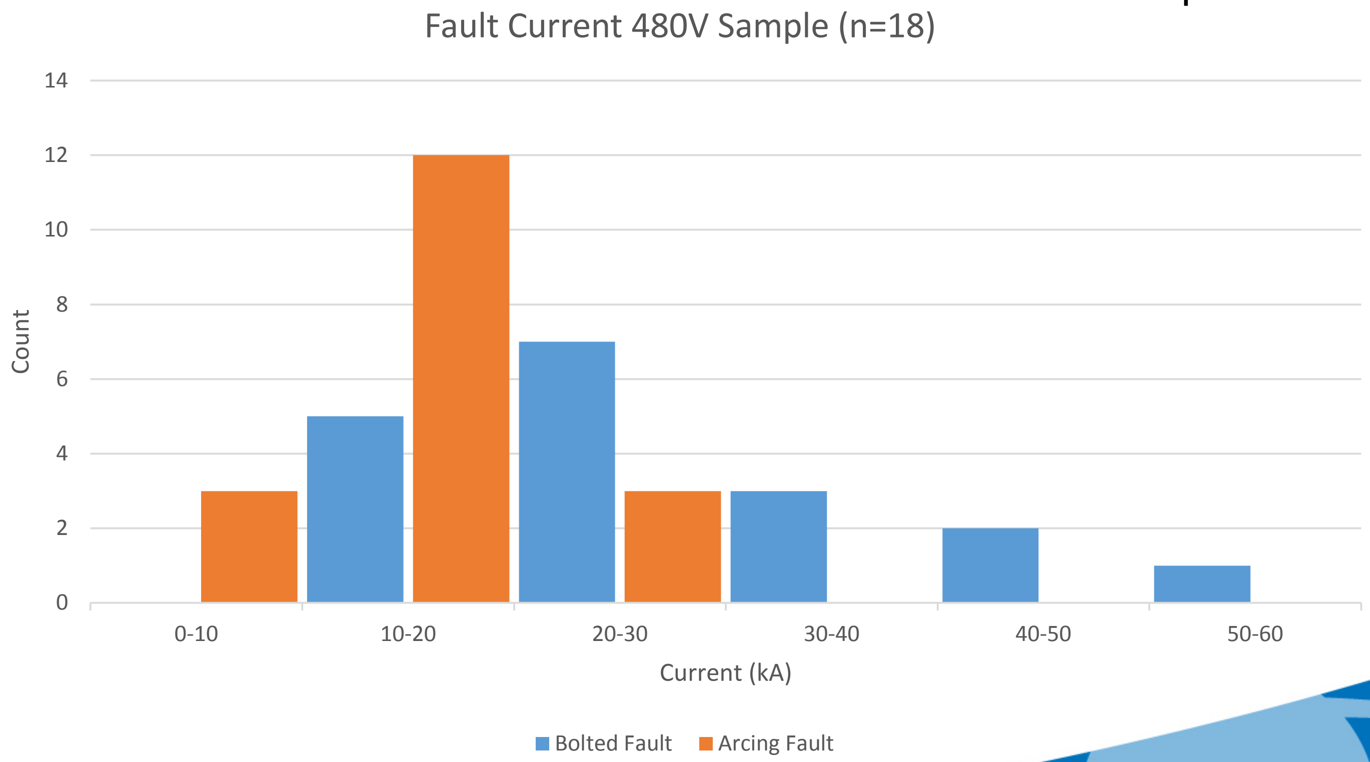
Proposed test fault current levels

- 480Vac – Low voltage
  - 15kA
  - 25kA
- 6.9kVac – Medium Voltage
  - 25kA
  - 35kA

Low voltage 460-480 Vac

Fault Current	Mean (kA)	Median (kA)
Bolted	27.3	24.6
Arcing	14.4	13.3

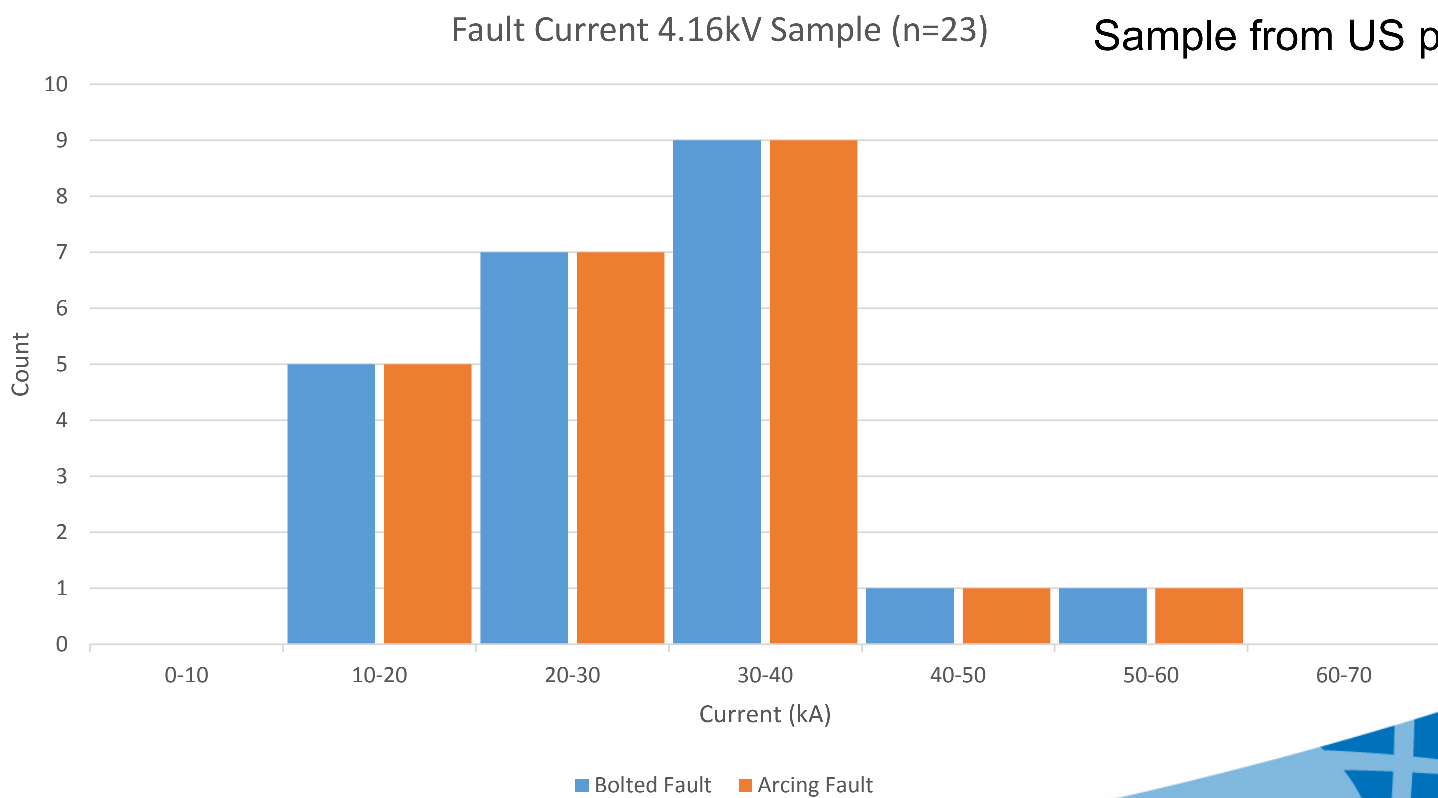
Sample from US plants



Test Levels: 15kA and 25kA

Medium Voltage 4.16kVac

Fault Current	Mean (kA)	Median (kA)
Bolted	31.0	30.8
Arcing	29.5	29.3

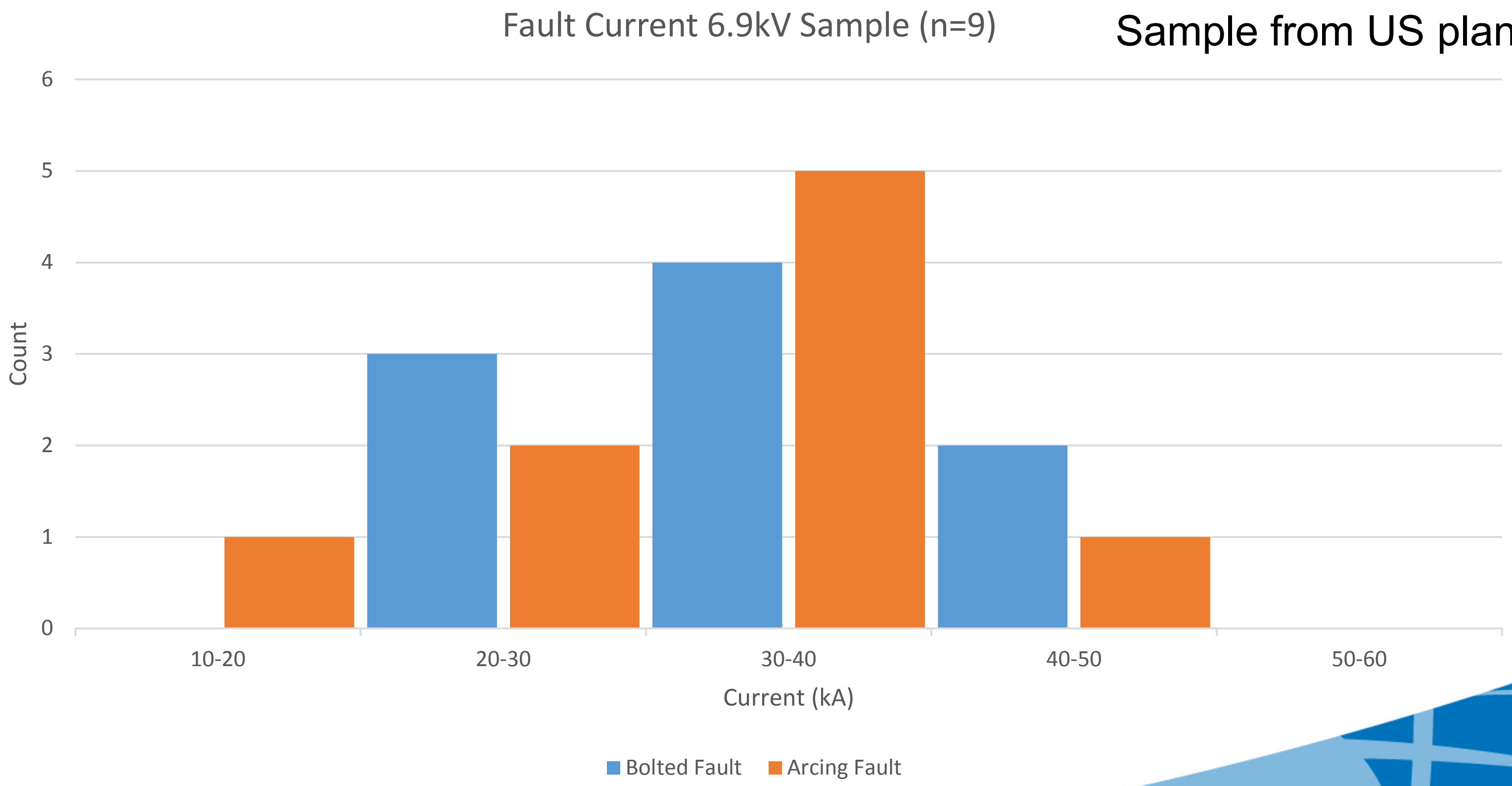


Sample from US plants

Test Levels: 25kA and 35kA

Medium Voltage 6.9kVac

Fault Current	Mean (kA)	Median (kA)
Bolted	32.8	33.6
Arcing	31.2	31.9



Sample from US plants

Test Levels: 25kA and 35kA

Discussion

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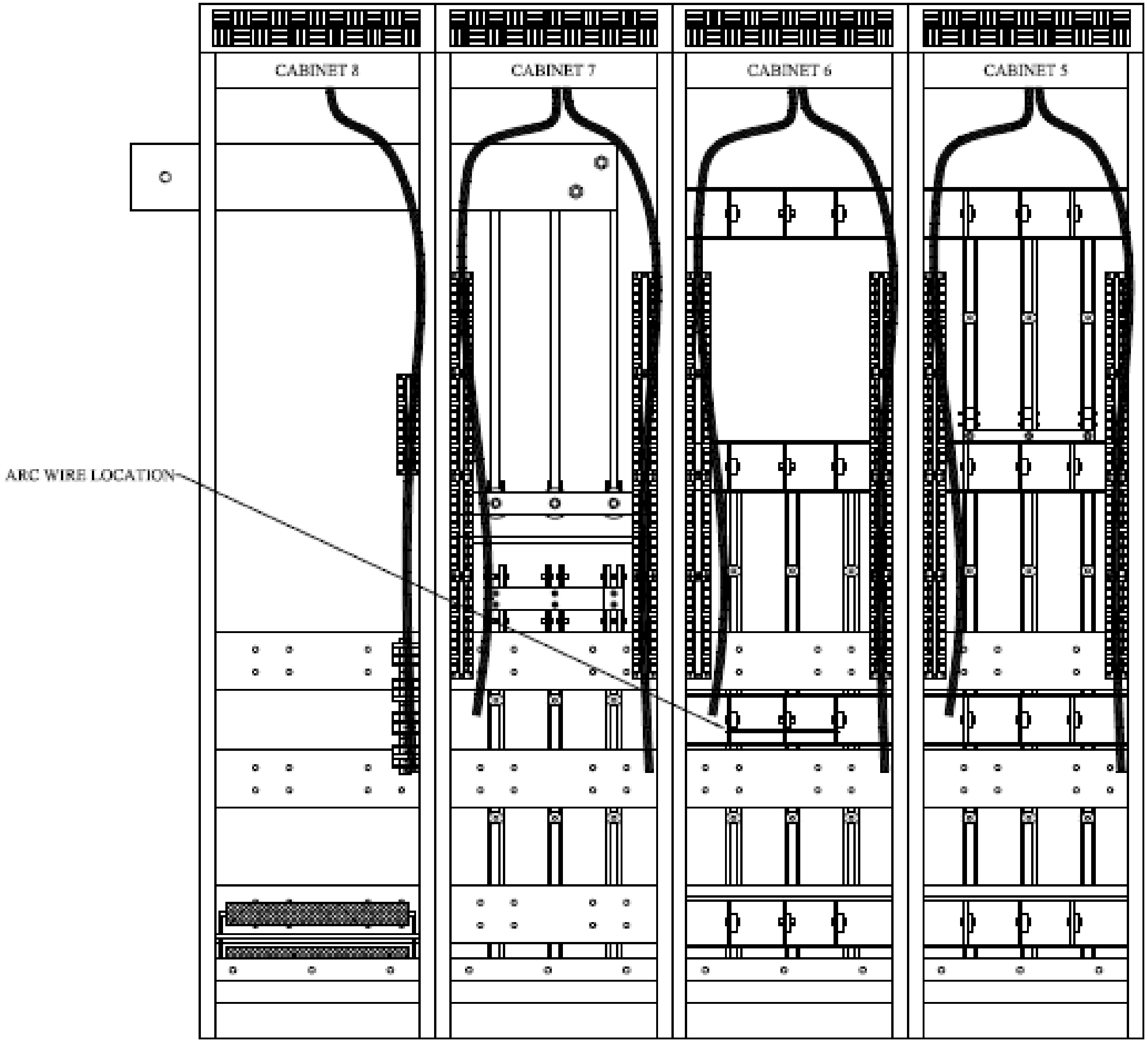
System connection

- Wye vs Delta
  - Majority of past testing has been performed in Delta configuration
  - Wye connections are available at KEMA

Grounding

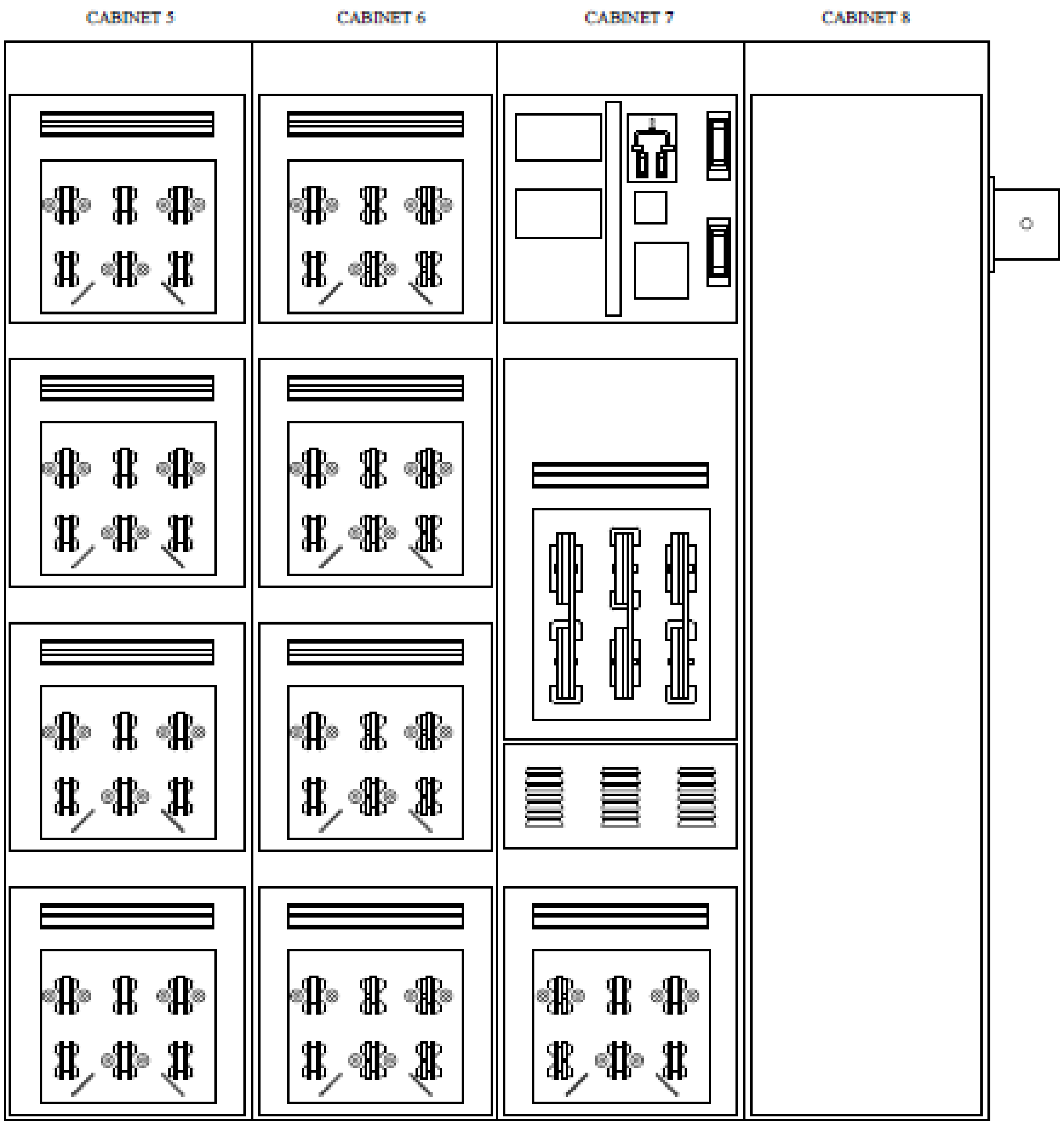
- Wye connected system grounding
  - Solid
  - Resistive
  - Reactive
  - Ungrounded

Arc Location LV Switchgear - Back



REAR VIEW
(WITH PANELS REMOVED)

Arc Location LV Switchgear - Front



CABINET ASSEMBLY
(WITH DOORS REMOVED)

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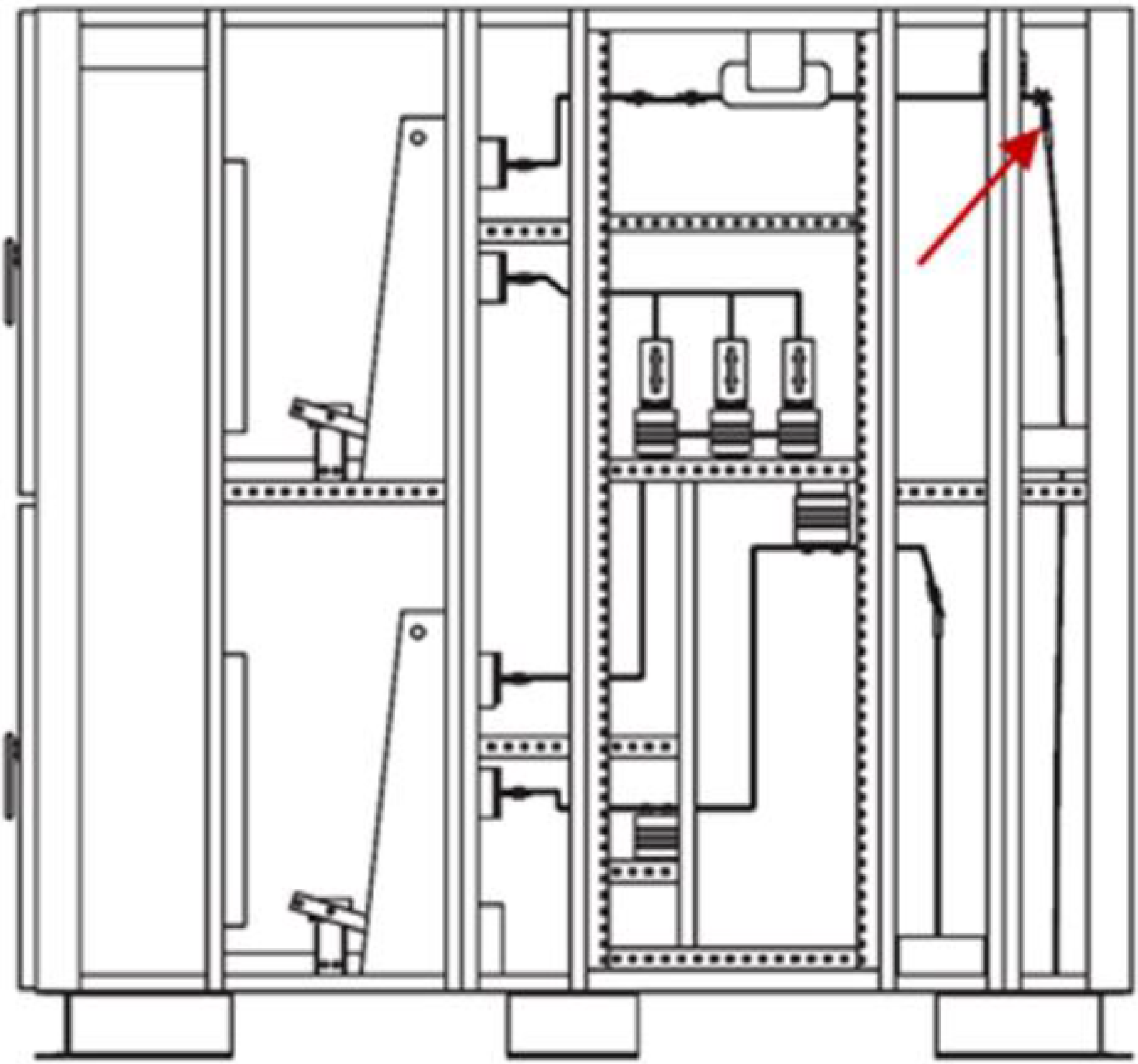
Arc Location MV MC Switchgear - Side



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Arc Location MV MC Switchgear - Side

Bus Bar Spacing

- Standards don't specify requirement,
  - manufacture determines spacing to ensure equipment will pass performance tests
- Typical spacing

Class	IEEE 1584	Web
15kV switchgear	152 mm (6.0 in)	152 mm (6.0 in)
5kV switchgear	104 mm (4.1 in)	89 mm (3.5 in)
LV switchgear	32 mm (1.3 in)	25 mm (1 in)

Bus Insulation

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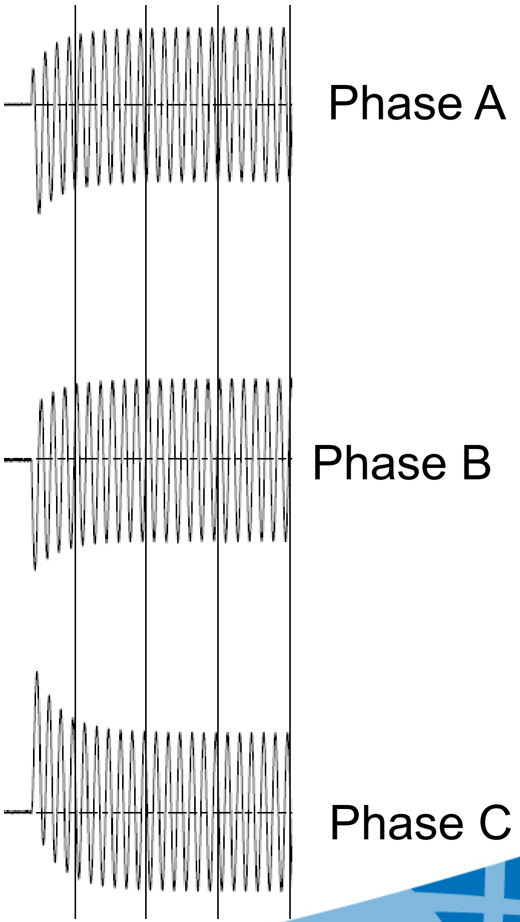
- Insulating material used to cover primary voltage conductors except where that conductor is a cable or wire. Bus joint insulation is excluded from this category and is treated separately.
- The primary functions of bus insulation are to impede arc movement and to allow closer spacing of conductors than would be possible with bare conductors.
- Bus insulation may also serve a secondary function as an element of the bus support insulation system

IEEE C37.20.2

Pressure influences

- Arc Power
- DC time constant
- Asymmetric current
- Volume
- Area of opening



Equipment

- Germany and Korea plan on donating equipment to program
- All other equipment will be procured
- Input is requested to ensure applicability

- **US Utility Donation?**

Planned Equipment Donation

Equipment Procurement Medium Voltage

- Magne Blast AM
- Allis Chalmers MA-250
- Westinghouse DB-50
- ITE 5KH-350
- ABB

Equipment Procurement Low Voltage

- Westinghouse DS-5
- General Electric AKD-10

Enclosure Thickness

- Electrical Enclosures
  - Enclosure
    - Steel, min. thickness MSG No. 14 (1.9mm)
  - Partition between each primary circuits
    - Steel, min. thickness MSG No. 11 (3mm)
  - Aluminum thickness based on equivalent strength and deflection
- Annex B of IEEE C37.20.1 & 20.2 have enclosure requirements

IEEE C37.20.1, *Standard for Metal Enclosed Low-Voltage Power Circuit Breaker Switchgear*
IEEE C37.20.2, *Standard for Metal-Clad Switchgear*

Enclosure Ventilation

- Important variable for pressure
- Any specific concerns

Bus Duct Tests

- Configuration
  - Al Bus / Al Duct
  - Al Bus / Steel Duct
  - Cu Bus / Al Duct
  - Cu Bus / Steel Duct
- Bus bars Config.
  - Square hollow
  - Rectangular
  - Circular
- Size / Rating
  - 1600A
  - 3200A
  - ?