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Proceedings of the Information-Sharing Workshop on High Energy Arcing Faults (HEAFS)

Office of Nuclear Regulatory Research

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Proceedings of the Information-Sharing Workshop on High Energy Arcing Faults (HEAFS)

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research, organized this *Information-Sharing Workshop on High Energy Arcing Faults (HEAFs).* The workshop took place April 18–19, 2018, at the NRC Headquarters' Professional Development Center, Building Three, 11601 Lansdown Street, Rockville, MD. The workshop had the following four objectives:

(1) Inform interested stakeholders about the status of PRE-GI-018 and related research.

(2) Review and resolve public comments received on the phase II draft test plan.

(3) Solicit and review information from industry partners regarding common equipment types and configurations to inform future testing.

(4) Provide an opportunity for public feedback on future testing.

The workshop was a Category 3 public meeting and open to the public for participation. The NRC broadcasted the meeting via webinar to encourage participation among interested parties for whom travel was not possible. The agency coordinated the workshop with the Electric Power Research Institute (EPRI) and the National Fire Protection Association (NFPA). The organizers advertised the workshop at recent nuclear industry information forums and during NRC public meetings related to fire protection. The workshop's technical topics focused on HEAF hazards and recently completed and ongoing research initiatives. The workshop also covered the NRC's Generic Issues (GI) program as it relates to the aluminum HEAF issue. This proceedings report documents the recommendations and insights from the session presentations and follow-on discussions.

FOREWORD

The U.S. Nuclear Regulatory Commission (NRC) values the technical views and inputs from all stakeholders in the development of agency research projects. The research on high energy arcing faults (HEAFs) is no different. The need for the research is driven by the analysis of the most recent U.S. and international nuclear power plant (NPP) fire event data and operating experience, which has identified HEAF events as a non-negligible fire hazard. This HEAF operational experience illustrates that significant damage may occur during the event. Experimental results have identified that the involvement of aluminum components during a HEAF may increase the hazard potential. Safe nuclear operation depends on engineers, operators, and probabilistic risk assessment (PRA) practitioners understanding the risk potential of a HEAF and preventing the event or protecting important safety systems, structures, and components from its effects.

This report documents the presentations and discussions conducted during a 2-day public workshop held in the spring of 2018. The NRC plans to use the information gained during the workshop to help finalize its test plans and inform the agency decision-making process. The staff also believes the workshop equally benefitted the participating stakeholders by providing them with the most current information available from the NRC on this matter.

This report continues to build upon previous U.S. and international HEAF work. This research will advance the understanding of this complex phenomenon and its impact on safety. I hope this work will ultimately be used to make a positive contribution to nuclear power plant fire safety.

Mark Henry Salley, P.E.
Chief, Fire and External Hazards Analysis Branch
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
June 26, 2018
Rockville, MD

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EXECUTIVE SUMMARY

PRIMARY AUDIENCE:

Generation facility staff, fire protection engineers, electrical engineers, and probabilistic risk assessment (PRA) practitioners who are responsible for fire protection programs, electrical equipment operation and maintenance, and associated duties involving the hazard assessment of fire and explosions caused by energetic electrical faults.

SECONDARY AUDIENCE:

Engineers, reviewers, utility managers, and other stakeholders who conduct, review, or manage protection programs and need to understand the U.S. Nuclear Regulatory Commission (NRC) research and planned research related to energetic electrical faults.

KEY RESEARCH QUESTION:

How can the NRC ensure that future research programs on the aluminum high energy arcing faults (HEAF) hazard accurately reflect plant conditions and will produce usable results?

RESEARCH OVERVIEW:

Energetic electrical faults can result in explosions, electrical arcing, fire, ionized gases, and smoke, prompting collateral damage to adjacent equipment and causing latent failures. The characteristics of these failures differ from those of the traditional fire protection hazard assessment, including the bypass of the fire ignition and growth stages; rapid propagation of the fire to other equipment and across vertical fire barriers; power system designs that are vulnerable to station blackout; failed fire-suppression attempts with dry chemicals and the need to use water; longer restoration time to recover; and unexpected challenges to operator response from event byproducts (smoke and conductive gases). These highly energetic events that have the potential to impact plant safety are commonly referred to as High Energy Arcing Faults (HEAFs).

NRC regulations, regulatory guidance, and defense-in-depth design philosophy exist to provide reasonable assurance of adequate protection to public health and safety from the consequences of fires that may occur in a nuclear facility. In the early 2000s, the NRC investigated the insights gained from fire incidents and began an international collaborative effort to better understand operating experience as it relates to fire safety. This collaboration resulted in a series of tests conducted in the United States between 2014 and 2017 to support revisions and improvement to existing fire risk methods. The results demonstrated a unique failure mode for electrical equipment that contained aluminum components, which displayed more damage than revealed in tests conducted on equipment that did not contain aluminum. These insights prompted the NRC and its international research partners to pursue additional testing.

The NRC issued Information Notice 2017-04, “High Energy Arcing Faults in Electrical Equipment Containing Aluminum Components,” dated August 21, 2017, to alert addressees of the test results and related operating experience. The NRC staff also proposed this potential safety issue as a generic issue (GI) (PRE-GI-018). In order to adequately assess PRE-GI-018, the NRC needed additional information and decided to hold a workshop to communicate this issue and obtain feedback and information from stakeholders.

The motivation for holding this workshop was to communicate the NRCs past and planned actions related to the HEAF hazard involving aluminum components. Additionally, the NRC sought feedback from stakeholders to support realistic and representative test conditions to ensure the efficient and effective use of NRC resources as the agency assesses the impact of HEAFs involving aluminum components. The workshop objectives were to (1) inform interested stakeholders about the status of PRE-GI-018 and related research, (2) review and resolve public comments received on the phase II draft test plan, (3) solicit and review information from industry partners regarding common equipment types and configurations to inform future testing, and (4) provide an opportunity for public feedback on future testing. In particular, the technical issues focused on the test parameters that influence the HEAF phenomena, and many discussions during the workshop focused on realistic and representative parameter ranges and nuclear power plant electrical system configurations.

The NRC staff from the Office of Nuclear Regulatory Research organized the workshop in collaboration with the Electric Power Research Institute (EPRI) and the National Fire Protection Association (NFPA). Staff from DNV GL, the National Institute of Standards and Technology (NIST), and Factory Mutual (FM) also provided feedback and direction for organization of the workshop. The NRC welcomed the public to attend and observe this Category 3 public meeting and posting workshop information on the agency's Public Meeting website. About 30 workshop registrants attended the workshop in person. In addition, approximately 33 individuals participated in the workshop via a webinar advertised on the NRC Public Meeting website.

KEY FINDINGS:

In the opening session, the NRC presented the expected outcomes of the workshop. Next, an introduction session welcomed the participants and identified the workshop purpose, objectives, and agenda and emphasized the NRC's safety mission. This was followed by a presentation that reviewed past agency efforts and research related to the HEAF hazard. Following this presentation, the NRC discussed the GI program and gave a presentation on the status of PRE-GI-018 related to the aluminum HEAF issue. Before concluding the morning sessions, presenters spoke about the development of HEAF definitions, small-scale testing, and risk assessment modeling implications. The afternoon sessions focused on research undertaken outside the NRC. This included presentations from the NFPA, EPRI, and DNV GL. The second day of the workshop included extensive discussion among the participants related to the parameters and test configurations that would support realistic and representative configurations to characterize the HEAF hazard and develop data to support the assessment of the HEAF hazard as it relates to the influence of aluminum components. Part of this discussion allowed for voluntary participation in ranking various parameters for their importance in influencing the HEAF phenomena. The NRC and partners could use results from this ranking to support test plan revisions and experimental configurations during future testing. The final sessions of the workshop revolved around the draft full-scale testing being pursued as an international initiative under the Nuclear Energy Agency (NEA) / Organisation for Economic Co-Operation and Development (OECD). The final session focused on a presentation of the draft test plan and resolution of comments received during the public comment period.

As a result of the workshop, the NRC identified several recommendations and follow-up actions, including the following:

- improvements to project tracking and task dependencies

- NRC expectations and schedule related to the pilot plant initiative to support the assessment stage of the GI program
- suggestion to perform a literature search to allow for better communication and basis for specific aspects of the proposed testing
- proposed changes to testing configurations and parameters
- follow-on interactions with stakeholders to communicate findings in a timely manner
- definitions of the hazard and associated frequencies that would support test result applicability to ensure consistent treatment of the hazard in a risk assessment

WHY IT MATTERS:

This report provides recommendations to assist the NRC staff and stakeholders in performing needed research and work to assess the impact of aluminum components on the HEAF hazard and the assessment of that hazard related to plant safety.

HOW TO APPLY RESULTS:

Engineers conducting research related to this topic should focus on Chapters 3–8 and 10. Users of this report are also encouraged to consult the reference material identified in Section 1.3 and included in the companion DVD.

LEARNING AND ENGAGEMENT OPPORTUNITIES:

Users of this report may be interested in the annual fire PRA training, Module III, “Fire Hazard Analysis,” sponsored jointly between EPRI and the NRC Office of Nuclear Regulatory Research. In addition, numerous commercial training opportunities are available related to the analysis of arc flash hazards for personnel safety.

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ABBREVIATIONS AND ACRONYMS

AC	alternating current
ADAMS	Agencywide Documents Access and Management System
AL	aluminum
AT	auxiliary transformer
AWG	American Wire Gauge
BSI	Brendan Stanton Inc.
CCDP	conditional core damage probability
CDF	core damage frequency
CFD	computational fluid dynamics
CFR	*Code of Federal Regulations*
CIGRE	International Council on Large Electric Systems
CSNI	Committee on the Safety of Nuclear Installations
DC	direct current
EELS	electron energy loss spectroscopy
ERFBS	electric raceway fire barrier systems
EPRI	Electric Power Reseach Institute
EDXA	energy dispersive x-ray analysis
FAQ	frequently asked question
GDC	general design criterion/criteria
GI	generic issue
GIRP	Generic Issue Review Panel
GSU	generator step-up
HEAF	high energy arcing fault
HGL	hot gas layer
HRR	heat release rate
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IN	information notice
ISO	International Organization for Standardization
KINS	Korea Institute of Nuclear Safety
LER	licensee event report
LV	low voltage
MOU	memorandum of understanding
MV	medium voltage
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NPP	nuclear power plant

NRC	U.S. Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
NSP	non-suppression probability
OECD	Orginisation for Economic Co-operation and Development
OpE or OPEX	operating experience
OSHA	Occupational Safety and Health Administration
PIRT	phenomena identification and ranking table
PRA	probabalistic risk assessment
RES	Office of Nucear Regulatory Research
ROI	Regulatory Office Implementation
RTPC	Research and Testing Planning Committee
SEM	scanning electron microscopy
S/NRA/R	Secretariat of Nuclear Regulation Authority (Japan)
SNL	Sandia National Laboratories
SPAR	standardized plant analysis risk
STL	short-circuit testing liason
SWRI	Southwest Reasearch Institute
T&D	transmission and distribution
TPP	test procedure and protocol
UCS	Union of Concerned Scientists
ZOI	zone of influence

1 INTRODUCTION

1.1 Background

The U.S. Nuclear Regulatory Commission (NRC) fire protection requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," (Ref. 1) and the supporting guidance address fire from energetic faults. For example, 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 3, "Fire Protection," requires that structures, systems, and components important to safety be designed and located to minimize, consistent with other safety requirements, the probability and effects of fires and explosions. The requirements in 10 CFR 50.48, "Fire Protection," state that each operating nuclear power plant must have a fire protection plan that satisfies General Design Criterion 3 of Appendix A to 10 CFR Part 50. Section 4.1.3.6, "Electrical Cabinets," of NRC Regulatory Guide 1.189, "Fire Protection for Operating Nuclear Power Plants," Revision 3, issued February 2018 (Ref. 2), states that electrical cabinets present an ignition source for fires and a potential for explosive electrical faults that can result in damage not only to the cabinet of origin, but also to equipment, cables, and other electrical cabinets in the vicinity of the cabinet of origin. Regulatory Guide 1.189 also states that fire protection systems and features provided for the general area containing the cabinet may not be adequate to prevent damage to adjacent equipment, cables, and cabinets following an energetic electrical fault; therefore, cabinets with voltages of 480 volts and above should have adequate spatial separation or substantial physical barriers to minimize the potential for an energetic electrical fault to damage adjacent equipment, cables, or cabinets important to safety.

Fire probabilistic risk assessments (PRAs) include methods to characterize the high energy arcing fault (HEAF) hazard, as documented in Electric Power Research Institute (EPRI) Technical Report (TR) 1011989/NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," issued September 2000 (Ref. 3). Volume 2 of NUREG/CR-6850 contains the guidance for electrical enclosures (Appendix M), and Supplement 1 (Ref. 4) contains guidance for bus ducts (Chapter 7). Both methods provide a bounding approach to quantifying the HEAF hazard; that is, they assume physical damage zones based on available operating experience that demonstrated extensive damage to surrounding equipment. Although the details of each method are documented in the reference identified above, the methods generally assume all components and systems within the physical damage zone are ignited and are unable to perform their intended design function. Accordingly, these methods were considered conservative and bounding for future arcing fault events.

Starting in the mid-2000s, the NRC began international collaboration to better understand the HEAF phenomena and advance the existing state of knowledge and fire PRA methods. This collaboration was facilitated through the Nuclear Energy Agency (NEA)/Organisation for Economic Co-operation and Development (OECD), of which the NRC is a member. Under an OECD FIRE data exchange project, member countries share operating experience related to fires occurring at nuclear facilities in 12 countries. As part of the analysis of this data, "a non-negligible number of reportable events with non-chemical explosions and rapid fires resulting from high energy arcing faults (HEAF)" was observed (Ref. 5). As a result of this observation and in alignment with the major goals of the NEA/OECD task to develop a correlation for predicting damage, establishing input data, and establishing boundary conditions for more detailed modeling, the member countries recommended performance of a series of experiments.

From 2014 to 2016, the NRC led an international experimental program, as documented in NEA/CSNI/R(2017)7, "Report on the Testing Phase of High Energy Arcing Fault Events (HEAF) Project," issued May 2017 (Ref. 6). This report documents 26 HEAF tests that were performed on a variety of donated electrical equipment. One significant finding from this work was that HEAFs involving aluminum components may result in greater damage and different failure modes than HEAFs that do not contain aluminum. Based on these findings, the international group recommended additional testing.

In 2016, based on the results from testing indicating that the current fire PRA methodology may not be bounding, the NRC staff proposed a potential safety concern related to HEAFs involving aluminum as an issue for the NRC's Generic Issue (GI) program. Following an initial review and a formal screening review, a Generic Issue Review Panel (GIRP) determined that the proposed issue met all seven screening criteria of the GI program and recommended that the issue be moved into the assessment stage of the GI program. As part of that assessment stage, a number of actions were identified that will be performed to assess the potential risk impact associated with HEAFs involving aluminum. These actions include, in part, additional testing.

These findings also prompted the NRC staff to reevaluate operating experience and identify any HEAF events that involved aluminum components. The staff documented the results of this effort in Information Notice (IN) 2017-04, "High Energy Arcing Faults in Electrical Equipment Containing Aluminum," issued August 2017 (Ref. 7). This IN summarizes the test results where damage states exceeded existing guidance and involved aluminum components. Additionally, the IN summarizes six HEAF events from operating experience that involved aluminum components and provides a qualitative description of those events.

Given the NRC's desire to understand the HEAF hazard involving aluminum and ensure adequate protection of public safety, external stakeholders have developed information to better understand and model the hazard. These initiatives include NRC Frequently Asked Question (FAQ)17--0013, "High Energy Arcing Fault (HEAF) Non-Suppression Probability (NSP)," dated March 21, 2017 (Ref. 8). EPRI has also developed two whitepapers (Refs. 9, 10) that provide an overview of nuclear power plant electrical distribution systems and characterize operating experience and testing.

In 2017, the NRC staff began formalizing an international agreement to perform a Phase II testing campaign to address knowledge gaps and further explore the impact aluminum plays in HEAF events. The NRC issued a draft test plan for public comment in the *Federal Register* on August 2, 2017. However, in order to ensure that U.S. interests are met and the program is performed in an efficient and effective manner, the NRC staff decided that additional stakeholder interactions and feedback were warranted. As such, it was suggested that an HEAF workshop be held as the forum for this interaction. The workshop took place April 18–19, 2018, at the NRC Headquarters' offices in Rockville, MD. This report documents that workshop, the discussions held, and the feedback received.

1.2 About This Report

This report is a collection of the materials presented at the 2-day workshop held April 18–19, 2018. The workshop transcripts (Refs. 11, 12) are available in the NRC's Agency-wide Documents Access and Management System (ADAMS) under Accession Nos. ML18114A817 and ML18114A818. The companion DVD also includes these transcripts.

In addition to the workshop materials and transcripts, the companion DVD includes a variety of documents related to the HEAF research program, including the following:

- test footage and data from Phase 1 testing
- FAQs, INs, and GI communications related to HEAF
- licensee event reports (LERs) from relevant HEAF events
- small- and large-scale draft test plans and comments

This report documents the material sequentially as it was presented during the workshop. For each session, this report includes a brief summary of any formal presentation, followed by documentation of discussion points, recommendations from those discussions, and any follow-up action items. Each chapter ends with the slide deck as presented, reproduced as embedded images.

2 WELCOME AND OPENING

2.1 <u>Workshop Opening</u>

Michael Cheok, Director of the Division of Risk Analysis in the NRC Office of Nuclear Regulatory Research, opened and welcomed everyone to the workshop. Mr. Cheok's key message was to encouraged participation to promote realistic and representative research that will support the NRC staff assessment of the proposed GI on aluminum HEAFs. Mr. Cheok thanked everyone for their time and dedication to this important effort and noted that the experience and expertise in the room are greatly valued as the NRC moves forward to ensure safety for NRC-licensed facilities, as well as the larger industrial community.

2.1.1 Discussion

No discussions from the participants occurred during or immediately after the opening. The Workshop Opening presentation is documented on pages 5–8 of the Day 1 transcript. No recommendations or follow-up actions were identified from this session.

2.1.2 Presentation Slides

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

NRC HEAF Phase II Information Sharing Public Workshop, April 18-19, 2018

3

Thank You

- 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 Public Workshop, April 18-19, 2018

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2.2 Workshop Introduction and Objectives

Mark Henry Salley, Chief of the Fire and External Hazards Analysis Branch in the Office of Nuclear Regulatory Research, welcomed the attendees and presented the workshop purpose and objectives, an outline of the agenda, and proposed path forward. Mr. Salley emphasized the need to develop a long-term, risk-informed, defense-in-depth solution to serve the NRC's mission and ensure public health and safety. Mr. Salley also noted that the openness and collaboration sought through the workshop will serve a much larger engineering community to promote safety.

2.2.1 Discussion

No discussions from the participants occurred during or immediately after the opening. The Workshop Introduction and Objectives presentation is documented on pages 13–18 of the Day 1 transcript. No recommendations or follow-up actions were identified from this session.

2.2.2 Presentation Slides

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

- 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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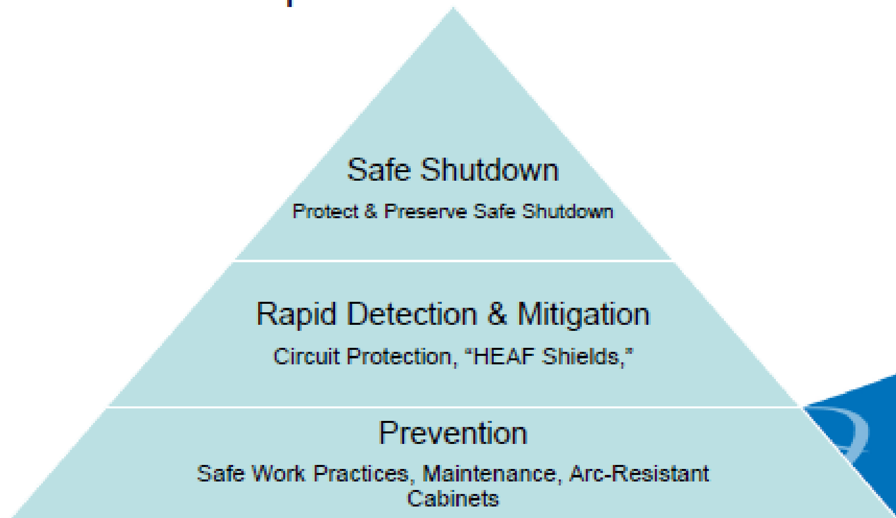

NRC Safety Mission

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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

3 REVIEW OF PHASE I HEAF RESEARCH

3.1 Review of Phase I HEAF Research

Nicholas Melly, Fire Protection Engineer in the Office of Nuclear Regulatory Research, and Mark Henry Salley presented a high-level review of the Phase 1 testing performed under the international agreement with NEA/OECD. The presentation addressed the types of fire hazards and their contribution to plant risk, referencing an EPRI skyline charge that EPRI presented at the NRC's Regulatory Information Conference in March 2018. The data indicate that, in general, HEAFs are the third largest contributor to plant fire risk as estimated by fire PRAs.

Mr. Melly communicated the basics of how fire PRAs partition fire ignition sources into different bins and explained the differences between Bin 15 fires that are associated with thermal electrical enclosure fires and Bin 16 HEAFs that are much different and more energetic that the classical thermal fire postulated in Bin 15. A key point of this discussion was the lessons learned from Bin 15, "electrical enclosure thermal fires" and how they would apply to Bin 16, "HEAFs." For Bin 15 fire ignition sources, the bin contains a broad range of fire ignition sources from low-voltage controls to medium-voltage switchgear. This broad range has resulted in difficulties quantifying the associated heat release rate (HRR) profile and detection and suppression assessments. Reviews of operating experience and test results have indicated that the HEAF hazard has varying levels of severity and, as such, Mr. Melly proposed that realistic divisions for Bin 16 be developed to improve fire PRA characterization of the HEAF hazard potential. To ensure continuity within the fire PRA definitions of the specific energetic fault, divisions are needed to ensure consistency in frequency estimation, hazard postulation, and hazard mitigation or fire suppression. Presentations on the draft set of definitions were discussed later in the day and can be found in Chapter **Error! Reference source not found.** of this report.

The presentation included several sets of slides containing photographs of energetic fault events or testing results. The photographs included events that would be classified as arc flashes, arc blasts, and HEAFs. Mr. Melly summarized the duration of several HEAF events, including both domestic and international operating experience. The duration of an energetic arcing event is a key parameter the influences its damage potential. The durations observed from operating experiences were much longer than would be expected for a typical electrical protection to clear a fault. This indicates that electrical protection does not always work as expected because of several failure mechanisms.

The presenters gave the background of the HEAF research program. Deliverables included several NEA/OECD technical reports related to operating experience exchange (NEA/OECD/R(2013)6) and a review of methods to estimate HEAF damage (NEA/OECD/R(2015)10) (Ref. 13).

Mr. Melly next presented an overview of the Phase I testing. This included information on the experimental configuration, videos of several HEAF tests with a comparison between testing involving aluminum and not, and a summary of the test report documented in NEA/OECD/R(2017)7.

The presenters briefly discussed mitigation measures, such as shields. Mitigation measures are intended to limit the extent of damage from HEAF events to plant targets that could impact the plant's ability to achieve safe and stable conditions. Although the intent of these measures is genuine, several questions were posed as to their design basis, acceptance/rating/qualification test method, and a general deviation from regulatory acceptance of classical fire-protective features such as fire barriers (walls and floors), fire doors and dampers, penetration seals, and electric raceway fire barrier systems. Additional photographs of testing results showed that existing assumptions on mitigation measure may not serve their intended purpose.

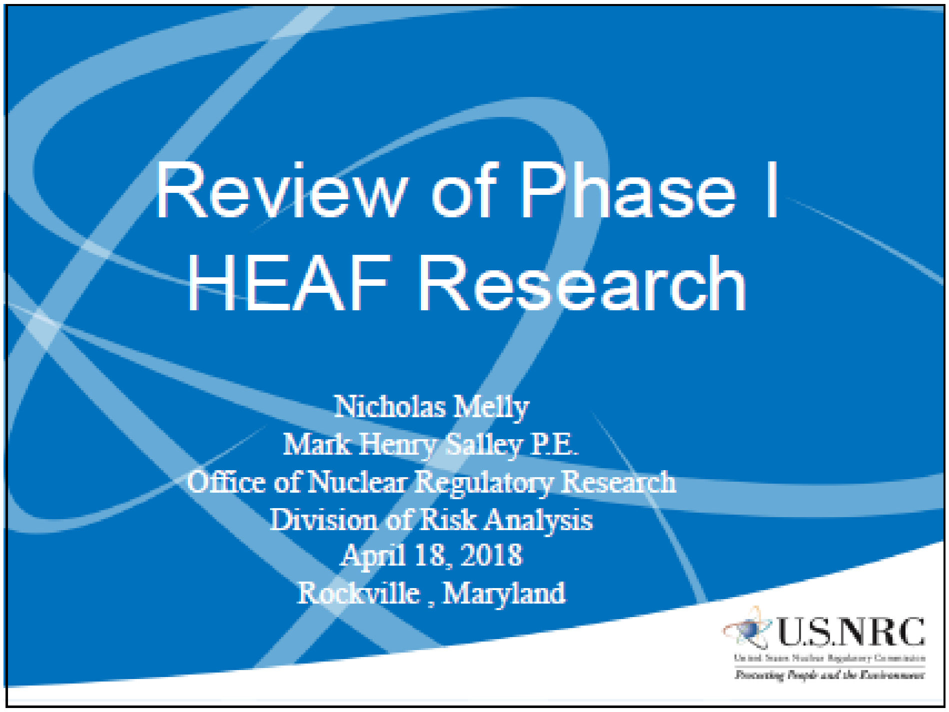
Mr. Melly briefly discussed PRE-GI-018, which was covered in more detail later in the day (see Chapter **Error! Reference source not found.** of this report), and IN 2017-04, which informed addressees of operating experience and test results pertaining to the magnitude of arc fault hazards in electrical equipment containing aluminum.

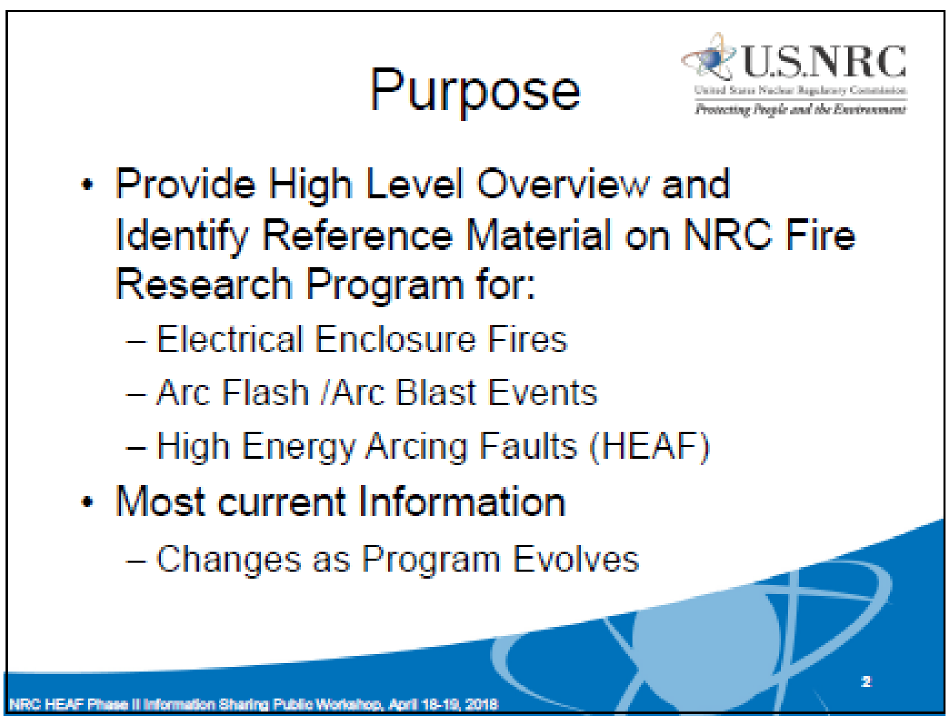
The final portion of Mr. Melly's presentation covered recently completed research. In January 2018, the NRC issued NUREG-2218, "An International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arcing Faults (HEAFs)," (Ref. 14) which documented a PIRT to better understand the parameters that influence the HEAF phenomena. Conclusions from this work included the need to focus HEAF research to support fire PRA applications, characterize target fragility, understand mitigation measures that support the defense-in-depth safety philosophy, understand the characteristics of the ensuing fire, and characterize the HEAF source term and pressure effects. Lastly, Mr. Melly summarized the International Agreement Report (Ref. 15), which documents a series of testing the Secretariat of the Nuclear Regulation Authority (S/NRA/R) performed.

3.1.1 Discussion

Following a presentation on the Phase I HEAF testing, Stephen Turner asked if the conductivity of the HEAF-generated aerosol was evaluated. Mr. Melly and Mr. Cielo confirmed that there was no post-test evaluation of that byproduct. The Review of Phase I HEAF Research presentation is documented on pages 19–58 of the Day 1 transcript. No recommendations or follow-up actions were identified from this session.

3.1.2 Presentation Slides





Initial Thoughts on Electrical Enclosures- Failure Modes

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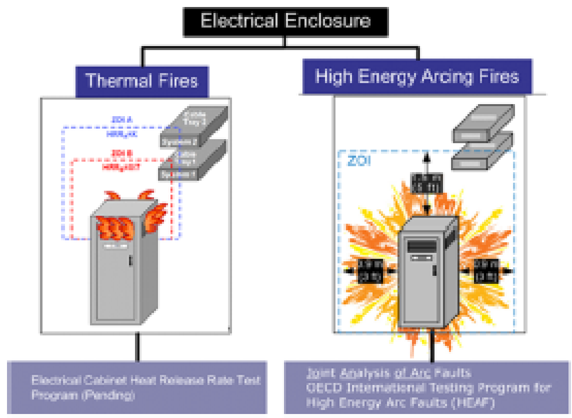
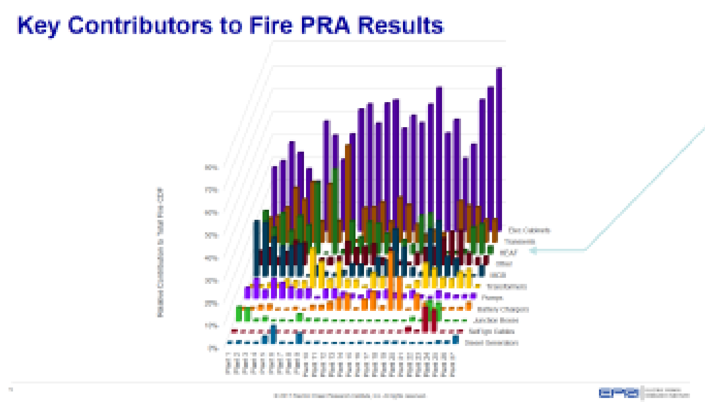


PRA Risk Significant Contribution

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

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



3rd highest contributor

NUREG/CR-6850
EPRI 1011989

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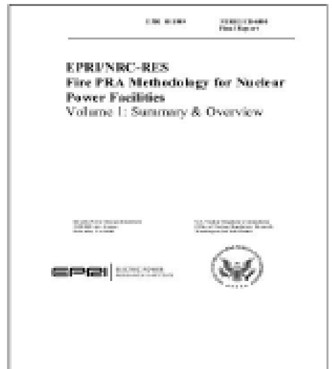
- Fire PRA Needs
  - Bin 15 Electrical Enclosure Fires
  - Bin 16 HEAF
- Lesson Learned
  - Bin 15 Too Broad
    - Low Voltage Controls considered same risk as Medium Voltage Switchgear
  - Create Realistic Divisions for Bin 16
    - Discussion later in workshop



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

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Electrical Enclosure Fire Experiments (Bin 15)

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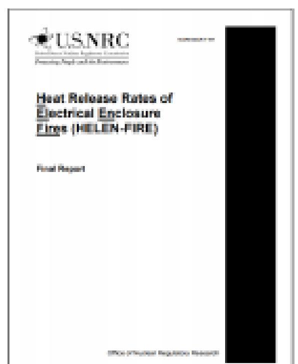
- Heat Release Rates of Electrical Enclosure Fires (HELEN-FIRE) NUREG/CR-7197
- 112 Full Scale Electrical Enclosure Fires
- Developed a Series of Heat Release Rate (HRR) Profiles
- Non- Energized
  - No electrical current



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

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Electrical Enclosure Fire Methodology

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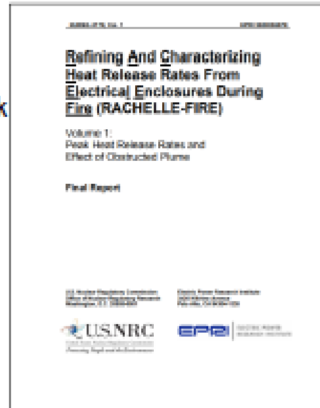
- Refining And Characterizing Heat Release Rates From Electrical Enclosures During Fire (RACHELLE-FIRE) — Volume 1: Peak Heat Release Rates and Effect of Obstructed Plume, Final Report (NUREG-2178, Volume 1, EPRI 3002005578)
- NRC/EPRI Working Group
- Classification of Electrical Enclosures (function,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


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

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

HEAF Definition (Bin 16)

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- 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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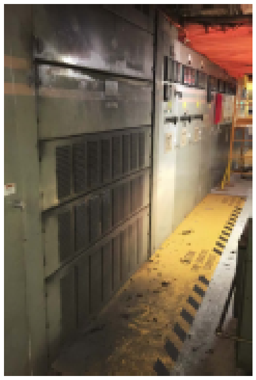
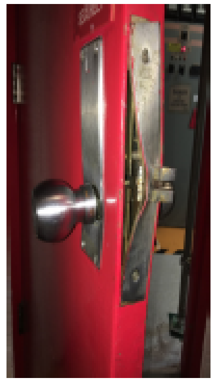

Turkey Point; 2017

Brunswick; 2016

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Example of Recent Electrical Enclosure HEAF Experience

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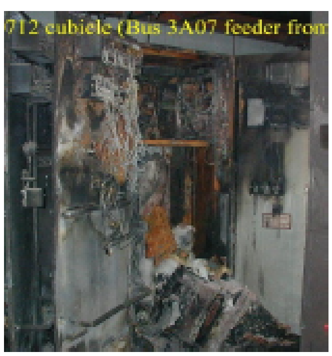
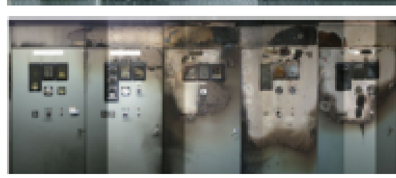


San Onofre; 2001

Onagawa; 2011

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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

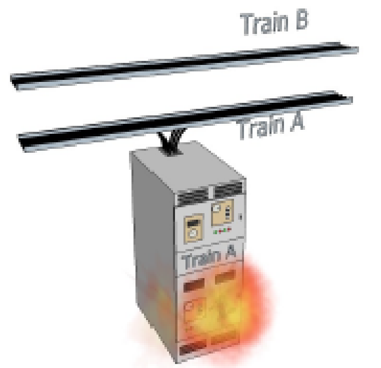
Event		Hold Time	Cause
Prairie Island;	08/03/2001	>2 seconds	Breaker Failure; Ionizing gas from the breaker was the initiator
Songs;	02/03/2001	2.5 Seconds	Breaker Failure; Ionizing gas from the breaker was the initiator
Robinson;	03/27/2010	8-12 seconds	Breaker Failure; Loss of DC Control Power
Diablo 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

- 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.

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

Background of the HEAF Program

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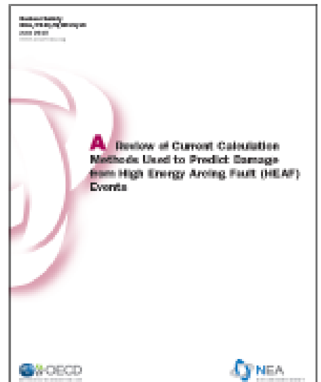
CSNI WGIAGE Task on High Energy Arcing Faults (2009 – 2013)

- 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



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

Realistic Quantification of Hazard

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- 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

- 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."

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U.S. Operating Event History (OpE) Overpressurization

- 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)

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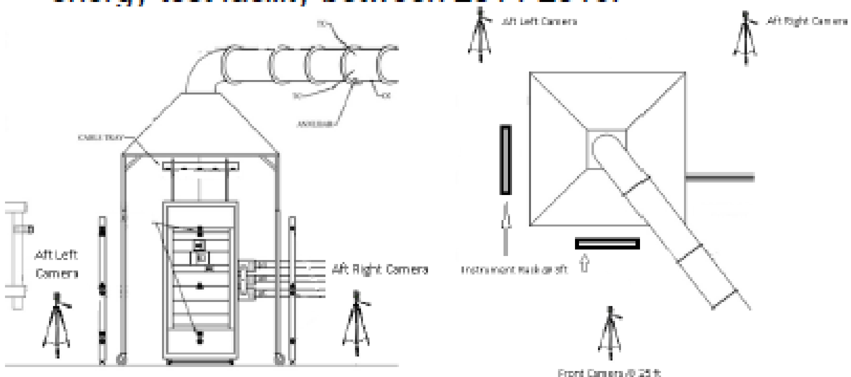
Phase I HEAF Testing

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



Phase I HEAF Testing

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

Phase I HEAF Testing

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

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Phase I HEAF Testing

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

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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

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- 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

U.S.NRC
United States Nuclear Regulatory Commission
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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

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

Postulated HEAF Mitigation- "HEAF Shields"

- 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?

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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

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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

- 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")

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

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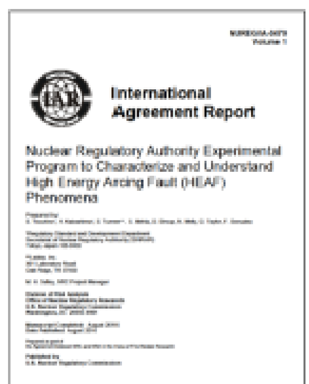
International Agreement Report

- 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



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

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Phase II Draft Test Plan

- 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

- 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

4 THE GENEREIC ISSUE PROCESS AND PILOT PLANTS

4.1 The Generic Issue Process

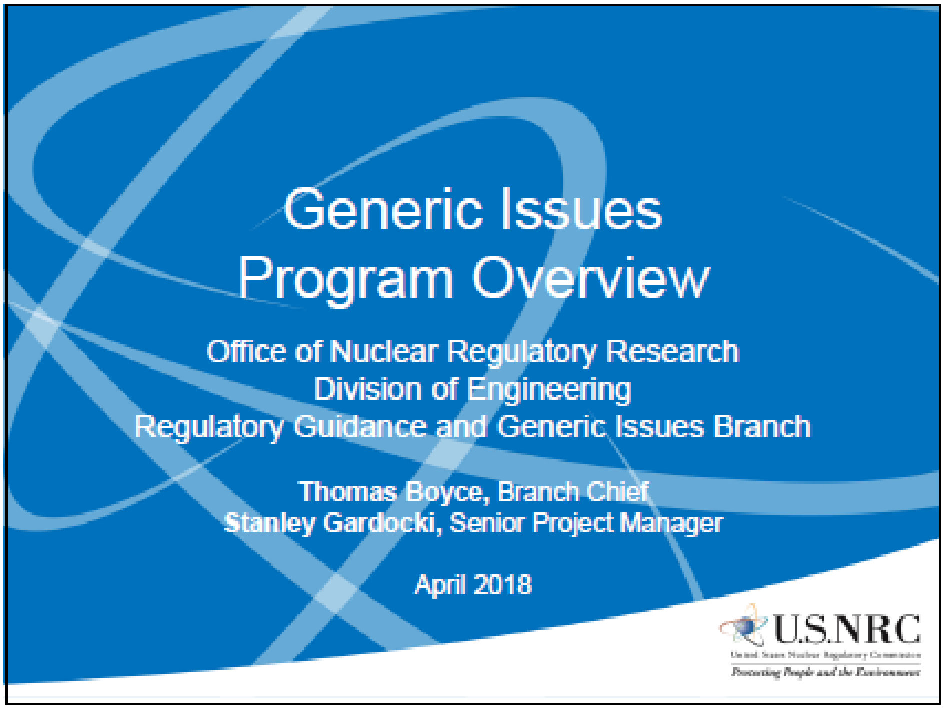
Thomas Boyce, Chief of the Regulatory Guidance and Generic Issues Branch in the Office of Nuclear Regulatory Research, provided an overview of the GI program. The presentation included a discussion of the origins and purpose of the GI program, the program's three stages (screening, assessment, and implementation), and the roles and responsibilities of various NRC staff members. Mr. Boyce clarified that a proposed GI does not become a GI until both the screening and assessment stages have been completed and the issue is transitioned to the appropriate regulatory office for implementation. Mr. Boyce closed his presentation by identifying resources for additional information, including NUREG-0933, "Resolution of Generic Safety Issues," (Ref. 16) and the GI dashboard on the NRC's public website.

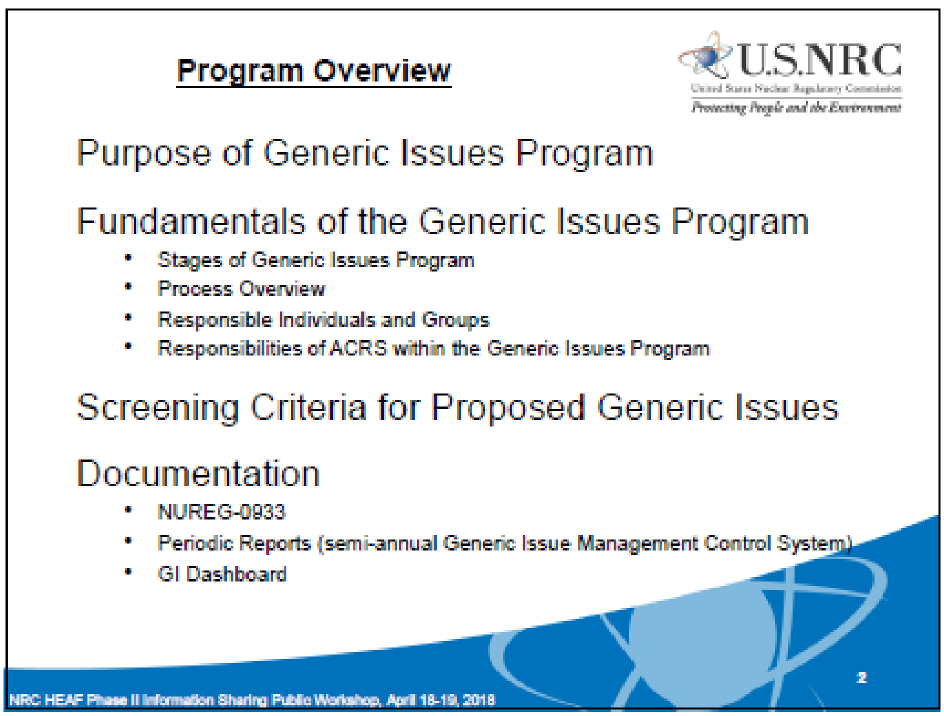
4.1.1 Discussion

During this presentation, the attendees asked several questions. Beth Wetzel asked whether the limited regulatory analysis would go out for public comment. Mr. Boyce answered that the process allows for the memorandum to be made publicly available but not for public comment. The public would have an opportunity to comment during the development process for the regulatory action selected to address the GI. A second attendee asked where the backfit process fits into the GI process. Mr. Boyce indicated that if a pre-GI moves past the assessment stage and the transition team decides that action is warranted, the backfit process would occur at the appropriate point in the development process for the regulatory action selected to address the GI.

The Generic Issue Process presentation is documented on pages 58–80 of the Day 1 transcript. No recommendations or follow-up actions were identified from this session.

4.1.2 Presentation Slides





Origins of Generic Issues Program

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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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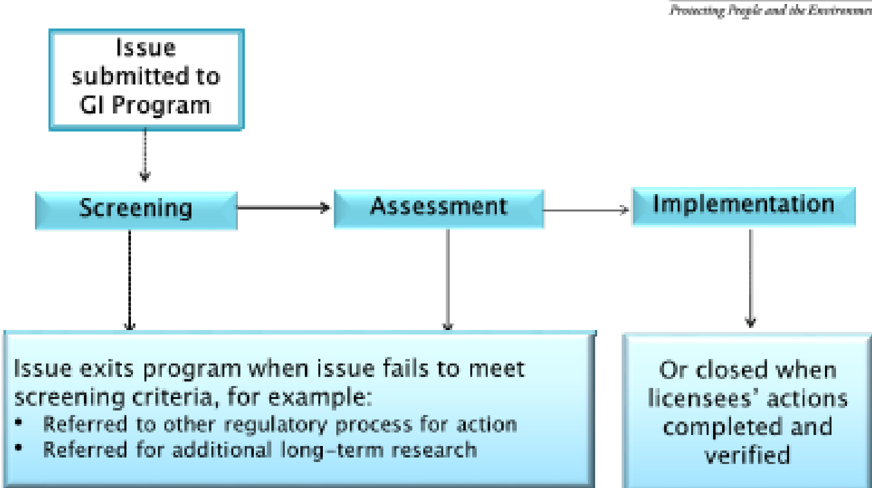

Responsible Program Individuals

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.

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Responsible Program Groups/Panels

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

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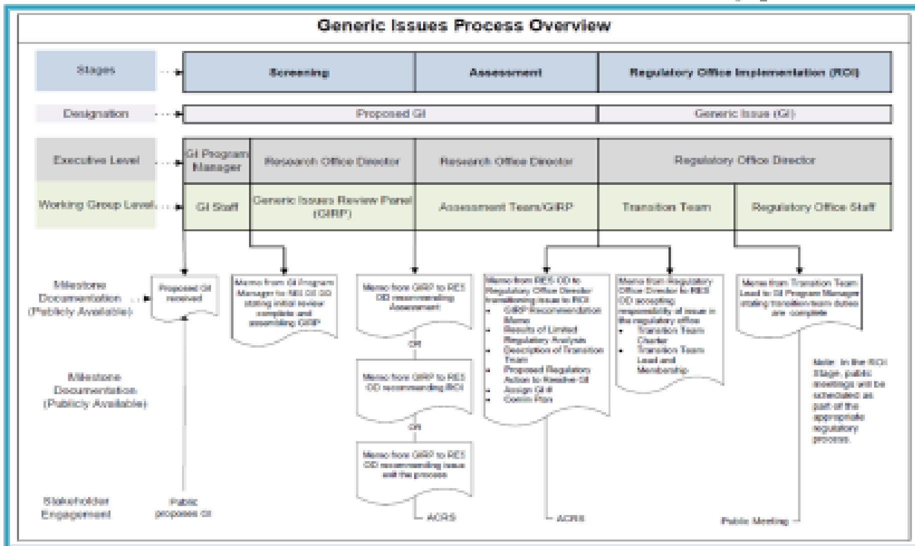
Process Overview



Screening Criteria for Proposed GIs

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

TABLE OF CONTENTS — EXPORT AND PRINT

Generic Issue Dashboard

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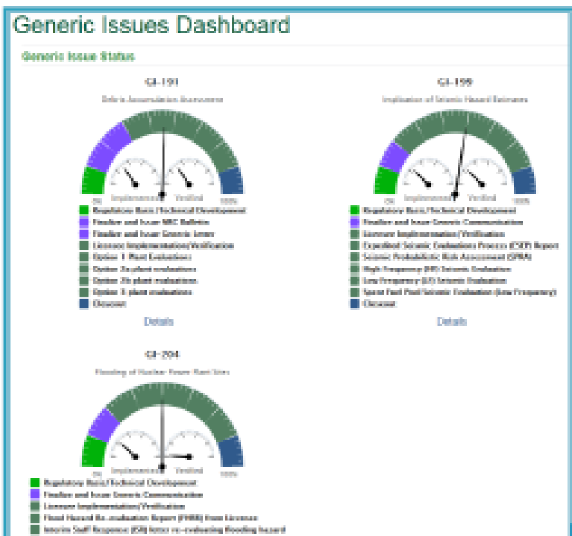

The GI Dashboard provides on-line access to the detailed status of active generic issues in the Regulatory Office Implementation Stage.

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://ipld.nrc.gov/Static/SitePreview.html

Recent Proposed Generic Issues

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]***

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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/>

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4.2 Aluminum HEAF PRE-GI-018

Stanley Gardocki, Senior Reactor Engineer in the Office of Nuclear Regulatory Research, presented on the topic of Generic Issue PRE-GI-018, High Energy Arc Faults Involving Aluminum. The presentation provided an overview of the GI stages, a summary of completed actions, a list of short- and long-term actions, and the status of progress associated with these actions. PRE-GI-018 is currently in the assessment stage of the process, having met all seven screening criteria of the screening process. The GIRP recommended a phased approach, whereby both short- and long-term actions were identified as possible requirements to perform the assessment. Mr. Gardocki reported that the NRC received an informal survey from the Nuclear Energy Institute (NEI) on the extent of aluminum components currently installed in nuclear power plants. The NRC will invite experts to support a joint industry/NRC expert elicitation process, possibly through the EPRI memorandum of understanding (MOU), to develop interim guidance to support performance of focused-scope risk assessments for a select number of pilot plants containing aluminum components susceptible to HEAFs. Lastly, Mr. Gardocki indicated that a complete assessment of aluminum-involved HEAF phenomena would require additional testing and refinements to the methods used to assess risk. Presentations and discussion on future testing was the focus of Day 2 of the workshop.

4.2.1 Discussion

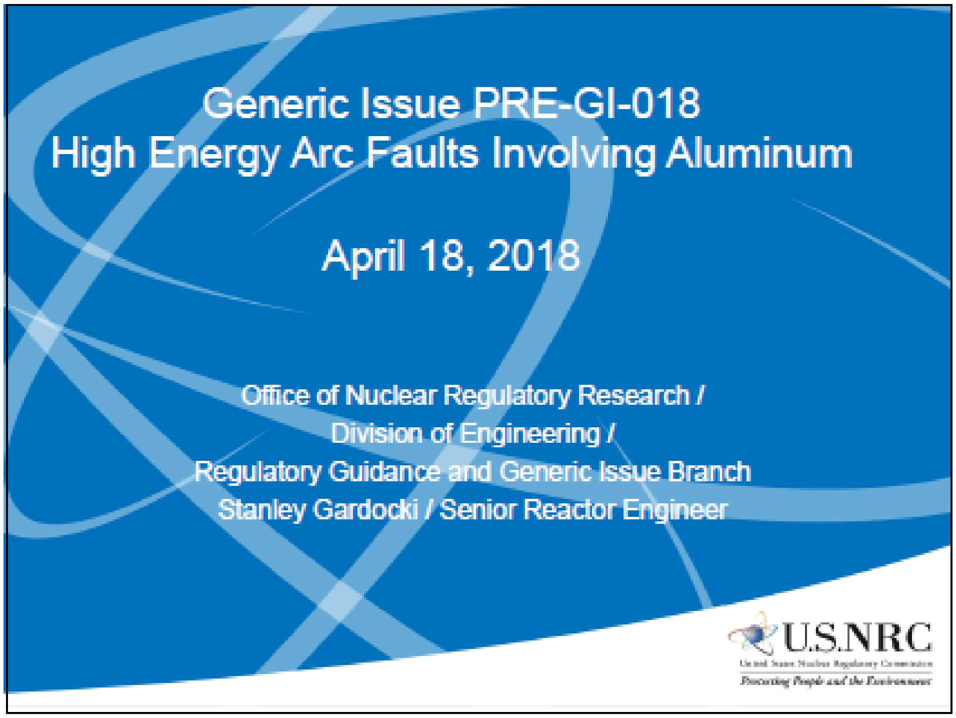
During this presentation, the attendees asked several questions, summarized as follows with responses:

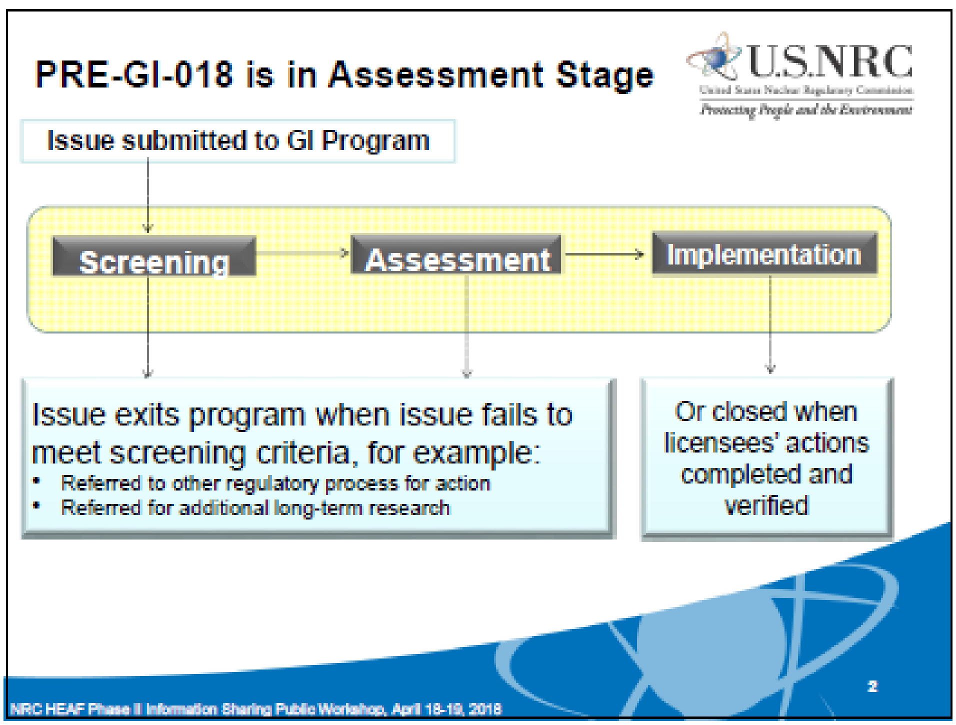
- With regard to the international review of plant equipment, what was the level of rigor and detail of that assessment, whether they do or do not have aluminum?
    - It varied from country to country. Finland did have some aluminum, while Germany indicated that only one of its plants had aluminum, and it was shut down.
    - Other participants indicated that the use of aluminum in new installation is increasing globally. This is happening for a variety of components, including transformers, distribution equipment, and cables for a variety of facility and distribution types.
- With regard to the probabilities and frequencies, what does it mean that the NRC will calculate potential risk increase?
    - As part of the GIRP process, the assessment team will have to assess the increase in risk to the plant from the aluminum HEAF hazard. This assessment includes reevaluation of the frequency of occurrence (based on the definitions being revised to better characterize the HEAF hazard) and the probabilities of damage for a specific plant (based on revised HEAF hazard assessment).
- Is PRE-GI-018 only being approached strictly from a fire PRA perspective or is the NRC questioning the Class 1E traditional separation criteria acceptability?
    - The GI includes plants licensed with either deterministic or performance-based fire protection programs. The NRC is focusing the initial effort on the performance-based side because the information from that effort can directly

support resolution for deterministic plants. The separation criteria will be evaluated once more information and data are collected.

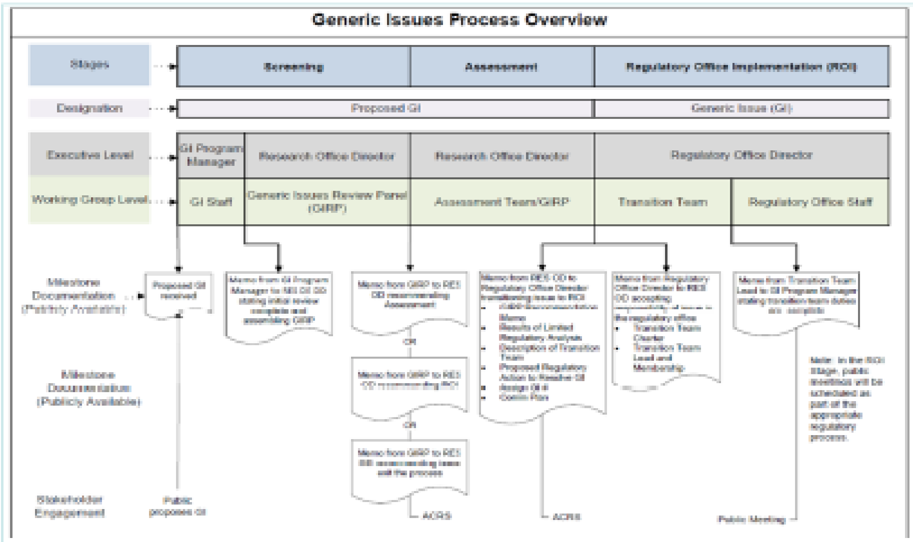
The Aluminum HEAF PRE-GI-018 presentation is documented on pages 81–106 of the Day 1 transcript.

4.2.2 Presentation Slides





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

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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

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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

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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

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Actions in progress or completed:

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- 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

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Actions in progress or completed: Continued

- 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

4.3 Pilot Plants

Nicholas Melly presented on the need for pilot plants to support PRE-GI-018 during the assessment stage. Mr. Melly presented EPRI data on the key contributions to fire risk by ignition source from 27 different plants. The data indicate that, according to current risk assessment techniques, HEAFs are the third highest contributor to plant risk. Next, Mr. Melly showed that in preliminary risk assessments using available information and assumptions, an expanded HEAF impact from aluminum would increase plant risk. The analysis contained both conservative and non-conservative assumptions because of the lack of detailed scenario information. However, without plant-specific information, there is a limit to the amount of realism that such an analysis could produce. Therefore, to provide improved estimates, the GIRP identified the need to perform focused-scope fire PRA assessments at a select number of pilot plants. Mr. Melly asked the attendees to identify volunteer plants that have aluminum to support the GIRP assessment. In addition, those plants selected should have unique HEAF scenarios modeled within their PRA. Plants that mapped HEAF scenarios to hot gas layer damage states are not ideal candidates for this evaluation.

4.3.1 Discussion

During this presentation, the attendees asked several questions, summarized as follows with responses:

- How many plants are needed for the pilot?
    - An actual number has not yet been determined. The initial thoughts were three, but it would ultimately depend on the differences between scenarios among the plants.
- Will the pilot effort be done with HEAF ignition frequencies corrected or just adjusting the zones of influence without adjusting the frequencies?
    - If new HEAF frequencies are developed that have been vetted through a regulatory process, such as the NRC FAQ process or a joint research effort between EPRI and the NRC Office of Nuclear Regulatory Research with NRC acceptance, then they will be used. It makes sense to use all available information and methods at the time of the assessment. It is ultimately an issue of timing.
    - Along these lines, it is also important to have continuity throughout the risk assessment process so that the frequencies match the hazard being assessed or modeled.
- It would be important to understand any latent sources of conservatism in the pilot results before further decisions are made related to the GI treatment.
    - Mr. Melly agreed with this statement.
- What is the schedule for performing these pilot plant assessments?

- Typically, the assessment stage should be completed within a 2-year period. Given that the NRC is approximately 6 months into this stage, the assessment stage is expected to be completed in the next 18 months.

- What is the benefit to a plant for volunteering to be a pilot?

  - Without pilots, the program will have to resort to using the conservative analysis that was presented earlier, the results of which look very unappealing. This may cause the NRC to make decisions that are resource intensive for both the agency and the industry and that may not improve risk as much as expected.

- The interim zone of influence (ZOI) and the other HEAF-related fire PRA modeling improvements, such as frequency, should dovetail together to support the pilot plant assessment. If the NRC agrees with that, some confusion remains as to the schedule and how these tasks outlined in the GI screening letter fit together.

  - Mr. Melly agreed with this statement.

- It is also important to show some logical linking between the GI milestones and how they are related and scheduled together.

  - Mr. Melly agreed with this statement.

- Current PRA results are constrained by methods acceptable to the authority with jurisdiction. Would methods the GI assessment team proposes impose the same constraints? For licensees to commit to the pilot plants, there needs to be some level of assurance that constraints on acceptable methods will not drive the results.

  - The GI assessment will likely be performed much like a sensitivity study, rather than something that is going to inform plant changes. If any changes to existing acceptable methods were an outcome of the GI assessment stage, then the assessment team would make a recommendation for the Regulatory Office to consider when that office is resolving the GI.

- There are several nuances to what and how current HEAFs vs. classical fires are modeled, and it will be important for industry to identify pilot plants that have the right modeling and insights to help provide the best information.

  - Mr. Melly agreed with this statement.

- Adding conservatism will show unrealistic results and will make finding pilot plants difficult. If the NRC proposes something that is at least in the ballpark, then the likelihood of licensees volunteering for a pilot plant and collecting meaningful data will increase.

  - The NRC staff envisions the pilot plant focused-scope risk assessment to be a collaborative effort in order to better understand the risk and instill realism into the process with the expert elicitation.

The Pilot Plants presentation is documented on pages 106–133 of the Day 1 transcript.

4.3.1.1 Recommendations

- It would be helpful for project tracking and status of the GI program to have a schedule of when specific actions are expected to be completed and any relationship between the individual action items (i.e., dependencies).

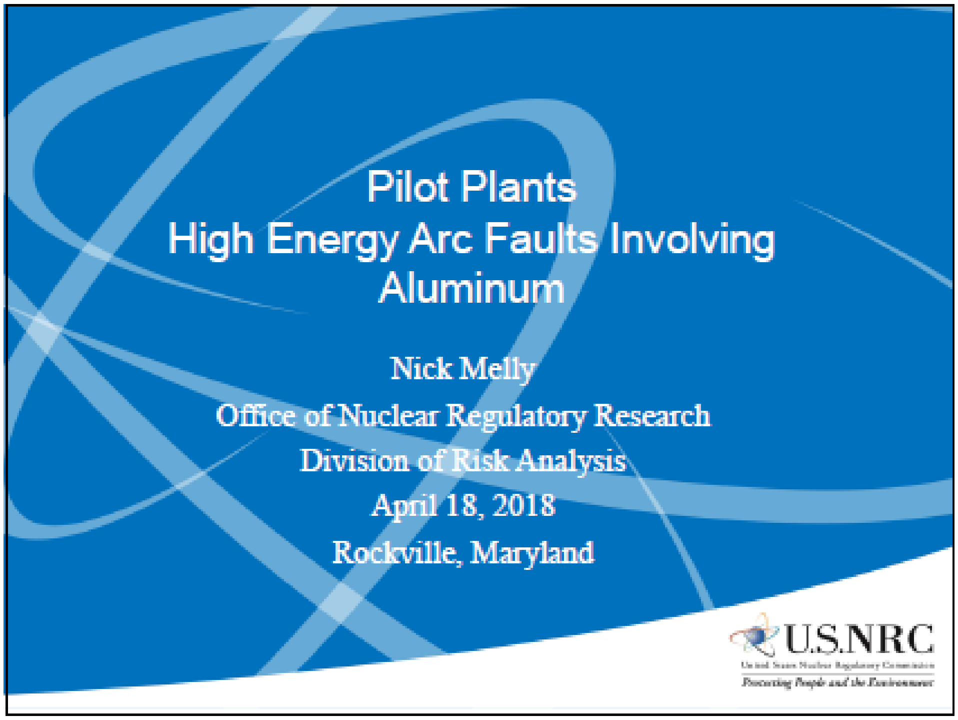
- In order for EPRI or NEI to better support the pilot plant initiative, they would need to understand the NRC's expectations for a pilot plant. A timeline or schedule would also be useful.

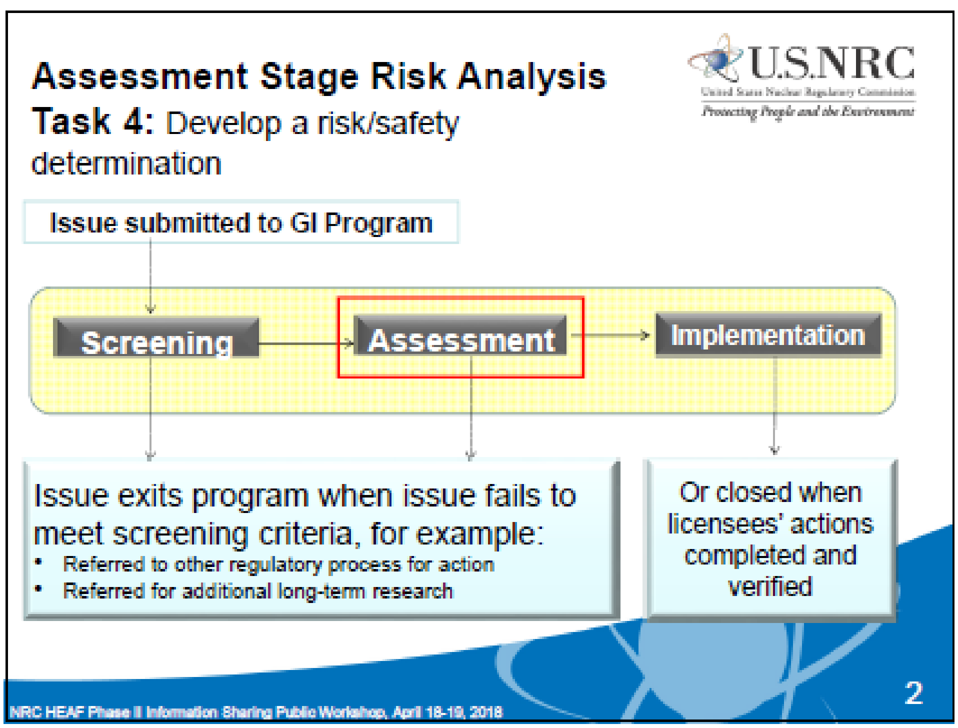
- In addition to better characterize the HEAF ZOI, associated HEAF frequency, binning, and suppression modeling improvements are needed to ensure a consistent risk assessment methodology.

4.3.1.2 Follow-up Actions

- Develop a tentative schedule for PRE-GI-018 action items.
- Show dependencies between and among action items.
- Develop a charter for the pilot plant focused-scope HEAF assessment.
- Develop revised HEAF binning (definitions) and frequency estimates.

4.3.2 Presentation Slides

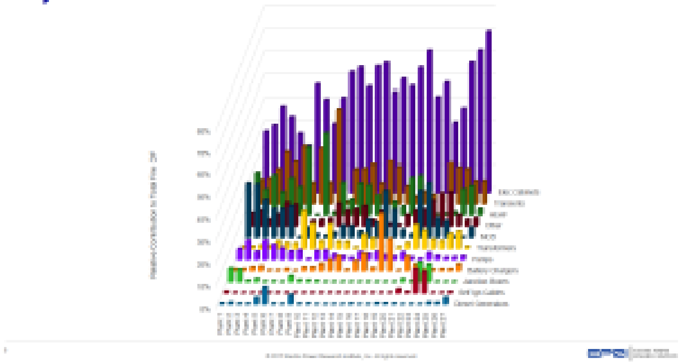




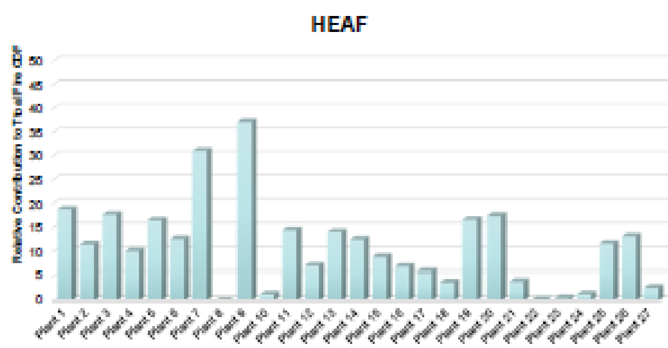
Plant Fire Risk Contribution

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

Key Contributors to Fire PRA Results



HEAF Fire Risk Contribution



Preliminary Risk Assessment Assumptions

- 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

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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

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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

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Questions?

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5 DEFINING THE HAZARD

5.1 Definitions of Energetic Electrical Faults

Kenn Miller, Team Leader in the Office of Nuclear Regulatory Research, gave a presentation on definitions of energetic electrical faults. The purpose of documenting clear definitions is to ensure a common understanding of the various types of energetic electrical faults and to ensure a consistent assessment of those energetic electrical faults that pose a substantial risk to plant safety. The proposed definitions evolved from established definitions from consensus standards. Mr. Miller proposed three severity classes for arc faults:

(1) Class 1: Arc Flash

Damage is contained within the general confines of the component of origin.

(2) Class 2: Arc Flash/Blast/HEAF

Damage is contained 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).

(3) Class 3: Arc Blast/HEAF

Damage includes the component of origin as well as the 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 affect equipment in other fire zone(s).

5.1.1 Discussion

During this presentation, the attendees asked several questions, summarized as follows with responses:

- The definitions do not make reference to the minimum voltage level or power level to be classified as a HEAF hazard. A voltage of 120 volts or lower will not have enough energy to cause the types of damage discussed.
  - Mr. Miller agreed with this statement.
- A tremendous amount of research was done on the threshold for a sustained arc. So instead of testing to the lower end, it may be worthwhile to perform a literature search to inform the agency’s judgment.
  - Mr. Miller agreed with this statement.
- Typically, faults lasting for several seconds occur because there are several protection failures. This should be referred to as “multiple circuit failure protection.”
  - Mr. Miller agreed with this statement.

The Definitions of Energetic Electrical Faults presentation is documented on pages 139–163 of the Day 1 transcript.

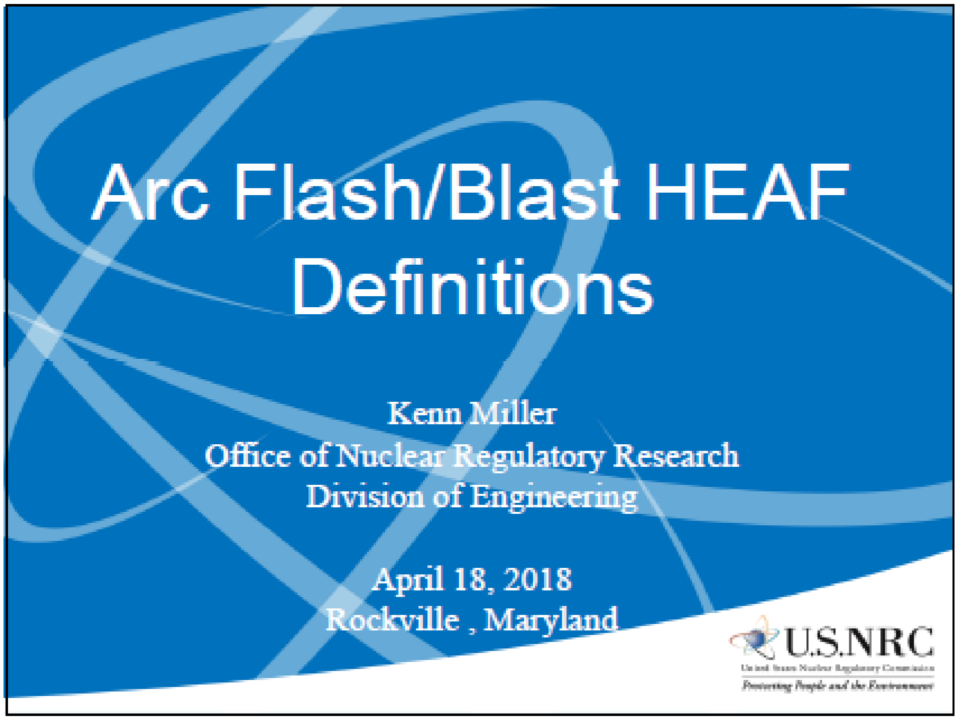
5.1.1.1 Recommendations

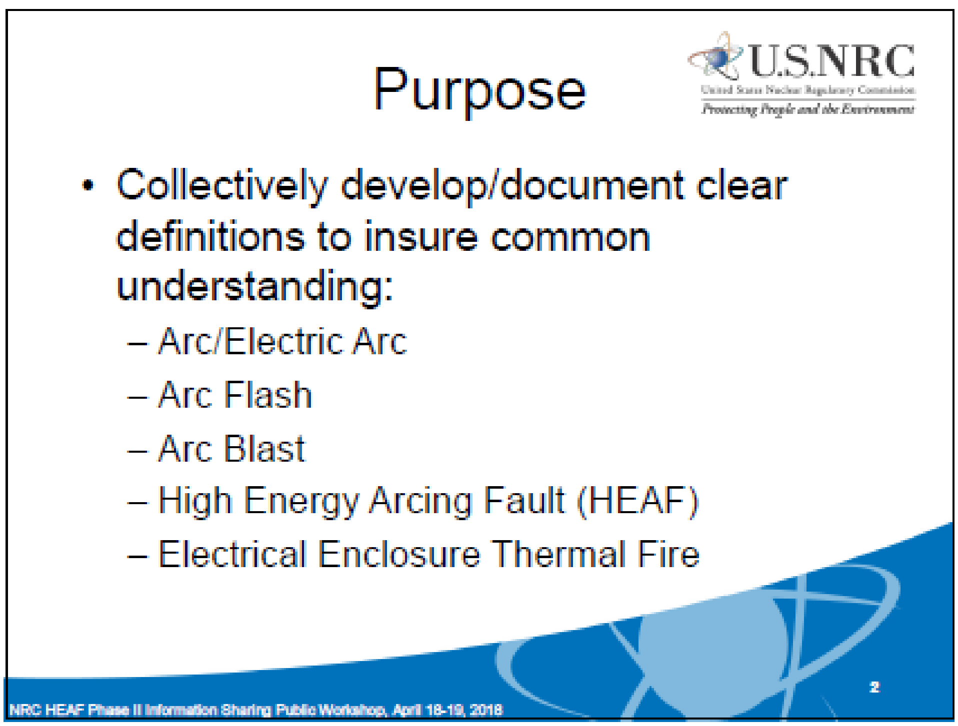
- Perform literature search.
- Tie EPRI into the discussion between the NRC and National Fire Protection Association (NFPA) members on the definitions.

5.1.1.2 Follow-up Actions

- Conduct a literature search.
- Refine the definitions based on feedback from 2- and 3-second time durations of switchgear and breakers, respectively.
- Include EPRI in future collaboration on refinements to the definitions.

5.1.2 Presentation Slides





Purpose (Cont.)

- Proposed Arc Fault Severity Classifications:
  - Arc Fault Class 1 (Arc Flash)
  - Arc Fault Class 2 (Arc Flash/Blast/HEAF)
  - Arc Fault Class 3 (Arc Blast/HEAF)
- Propose 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

- **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 Informative Annex K/K4
  - 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)

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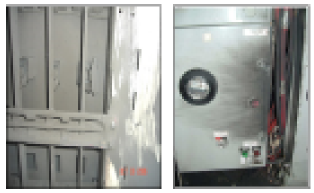
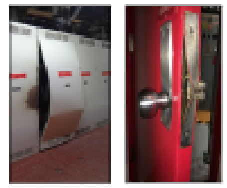
Protective System Performance (Duration)	Arc Severity Classifications	Arc Fault Class 1 (Arc Flash)	Arc Fault Class 2 (Arc Blast/HEAF)
	Arc duration limited by proper electrical protection design		
		Arc Fault Class 3 (HEAF)	
	Arc duration persists for an extended duration indicative of a level of circuit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

Electrical Enclosure Thermal fire

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- **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.

6 SMALL-SCALE TESTING AND PROBABILISTIC RISK ASSESSMENT MODELING IMPLICATIONS

6.1 Small-Scale Testing at Sandia National Laboratories

Gabriel Taylor of the Office of Nuclear Regulatory Research delivered a presentation on the small-scale testing being performed at Sandia National Laboratories (SNL). Mr. Taylor explained the reason for pursuing small-scale testing, including to minimize experimental variation, take measurements close to the arc, and characterize the particulate size near the arc where the exothermic reaction occurs for aluminum. Mr. Taylor identified the expectations of this testing and the means for accomplishing them, both experimentally and post analytically. Mr. Taylor gave an overview of the test matrix and the variety of parameters SNL was testing to understand their impact. He discussed the public comment period for the draft test plan (see Appendix D), which closed on April 4, 2018. Mr. Taylor indicated that he would add any comments received via e-mail (Gabriel.Taylor@nrc.gov) by May 4, 2018, to the agency document management system, and that the NRC/SNL team would review the comments for incorporation, as appropriate.

6.1.1 Discussion

During this presentation, the attendees asked several questions, summarized as follows with responses:

- Given the short duration of these experiments, they are more similar to direct current (DC) rather than alternating current (AC).
  - Mr. Taylor agreed with this statement. The limitation of the arc duration does not allow for a true sinusoidal current profile.
- How is the change of current being made?
  - The laboratory is using a motor generator in conjunction with inductors and capacitors to achieve the desired current and duration.
- The test matrix appears to be missing some information. Tests 8, 12, and 16 do not indicate whether they are AC or DC.
  - Mr. Taylor agreed that this is an error.
- The NRC questioned the need to perform the DC tests given the limitation on available current to 300 amperes.
  - Feedback from the attendees indicated that it was worthwhile to explore DC arcing, given the lack of the zero crossing point and research that indicates that DC arcing events can be severe.
- Will the testing be able evaluate isophase voltages (approximately 22kV)?
  - The NRC staff is unsure of SNL's capabilities and will confer with the laboratory.

- Will the testing be phase to phase or phase to ground?
  - The voltage across the bus bars will be the phase-to-phase voltage.
- Will 480V testing bound the 600V testing?
  - The 480V will not bound the 600V tests. The purpose of these tests is to evaluate particulate size, and testing at 480 volts will provide some data at the low-voltage level. A voltage of 480 is more common than a voltage of 600 in U.S. nuclear power plant facilities.
- Can the test results be extrapolated or interpolated to gain information on configurations (voltage) not tested?
  - The NRC staff is unsure of SNL's capabilities and will confer with the laboratory.
- Arc voltage is more important than system voltage. Bus spacing has a first-order effect on arc voltage. The focus should be on the parameter variation on gap spacing rather than system voltage.
  - The team will consider changing the three levels of medium voltage to a single medium voltage (system voltage) and vary the bus spacing.

The Small-Scale Testing at SNL presentation is documented on pages 164–-191 of the Day 1 transcript.

6.1.1.1 Recommendations

- Consider changing system voltage to bus bar spacing as a parameter of importance for the medium-voltage tests.

6.1.1.2 Follow-up Actions

- Determine whether SNL can perform at isophase bus voltages and, if so, whether it is worth including in this effort.
- Determine the possibilities for the extrapolation or interpolation of test results.
- If needed, perform a public webinar to communicate the results of the small-scale testing.

6.1.2 Presentation Slides

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

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- 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

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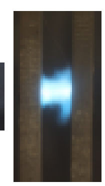
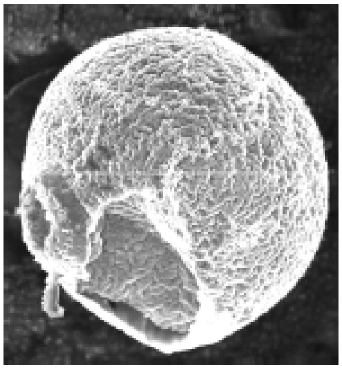
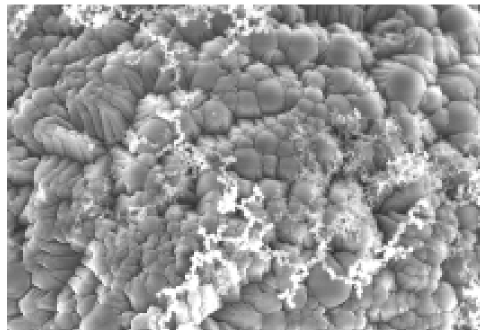
- Videography
  - High-speed infrared (IR) imaging
  - Trajectory
- Particle collection
  - Aerogel plates (99.999% SiO_2)
  - Carbon tape
- Particle Analysis
  - Energy dispersive x-ray analysis (EDXA)
  - Electron energy loss spectroscopy (EELS)
  - Scanning electron microscopy (SEM)
  - Raman spectroscopy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



Scanning Electron Microscopy

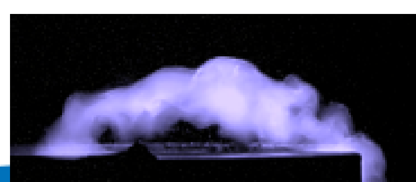
Collected via aerogel substrate
or
carbon microscopy tape





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

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	
	380	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

Questions?

6.2 Probabilistic Risk Assessment Modeling Implications

Gabriel Taylor of the Office of Nuclear Regulatory Research gave a presentation on PRA modeling implications. Mr. Taylor provided an overview of the current methods to quantify the HEAF hazard, documented in EPRI TR-1011989 and NUREG/CR-6850, Volume 2, and its Supplement 1. Mr. Taylor next provided an overview of three modeling approaches to improve realism and characterize the aluminum HEAF hazard. The first method is an update to the existing "bounding" model, whereby new data are used to update the existing method to ensure the model bounds all potential HEAF hazards. The second proposed approach would be an evolution of the bounding approach, whereby different categories could be devised by, for example, power, energy, voltage equipment type, or material, and then a specific method used to bound the individual categories. The third proposal would be to devise a dynamic model by using scenario-dependent source information (current, voltage, bus bar gaps) to characterize the source term, and then evaluating target damage on a scenario-dependent case. In this last case, the physical damage zone is dependent on the source and target characterization. Mr. Taylor provided information on the advantages and disadvantages of the various approaches, along with qualitative cost differences. He indicated that the choice of an adequate approach must be a balance between realism and cost and time.

6.2.1 Discussion

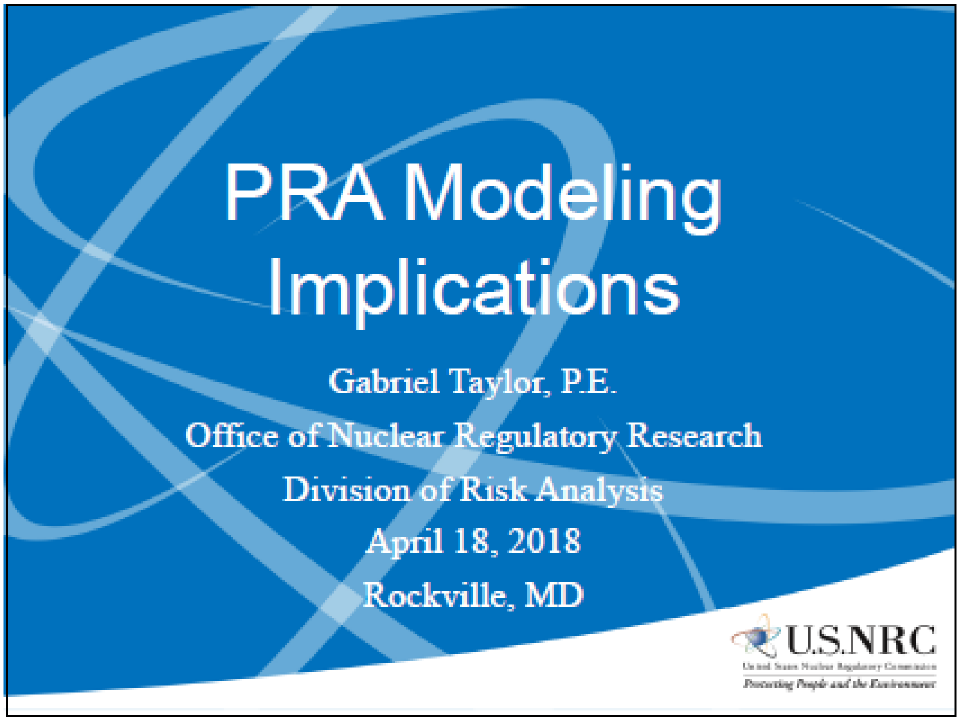
During this presentation, the attendees made several comments, summarized as follows:

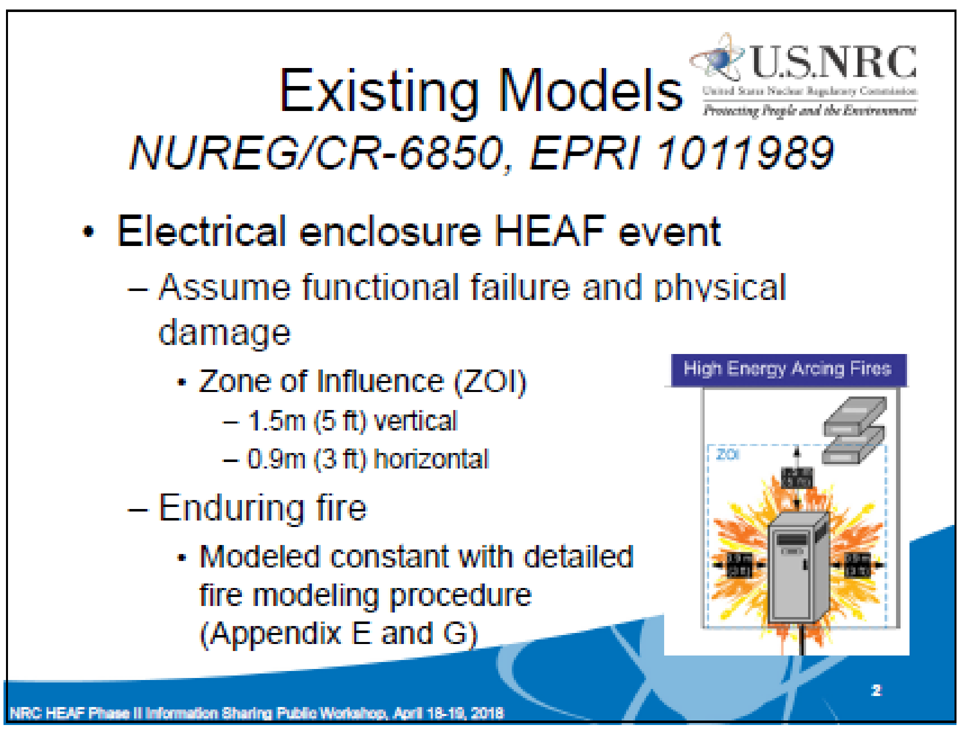
- There appears to be two schools of thought on the modeling of these arcing events: (1) those that use Institute of Electrical and Electronics Engineers (IEEE) 1584, "IEEE Guide for Performing Arc-Flash Hazard Calculations," (Ref. 17) to protect people and (2) those that use computational fluid dynamics (CFD) models. Japan has been performing CFD studies, and those appear to be matching up with the data fairly well; however, the durations appear to be short. Fluent has been used without the plasma physics model and is coming up with some good results. Although the NRC is not advocating to require licensees to use CFD to support licensing, those tools are available to support this research and possibly confirm experiments and fill gaps.

- Much of the discussion has focused on the modeling of the source term, but there are also models that look at the result with respect to the target. There is a need to tie them together.

The PRA Modeling Implications presentation is documented on pages 191–206 of the Day 1 transcript. No recommendations or follow-up actions were identified from this session.

6.2.2 Presentation Slides

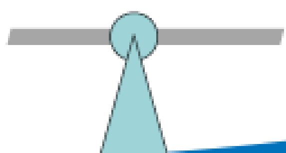




Existing Models

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

- 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

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

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

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

- 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

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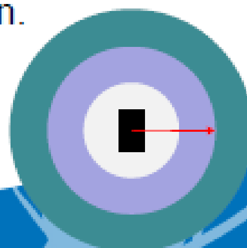
- Requires detailed information on power system
- Correlation from experiments and theory to model source term and incident flux as a function of distance
- Requires knowledge of fire PRA target fragility to high heat flux short duration.
- Potential to provide most realistic results
- Complex
- Most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



What do we need?

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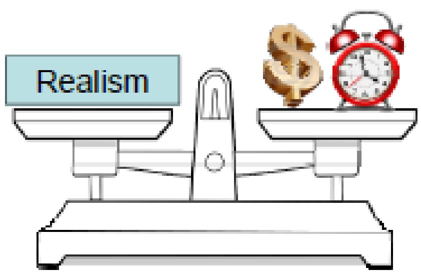
- Reasonably accurate model to assess risk impact of HEAFs on plant safety



7 NATIONAL FIRE PROTECTION ASSOCIATION PERSPECTIVE

7.1 Perspective from the National Fire Protection Association

Mark Earley, Chief Electrical Engineer at NFPA, gave a presentation on the IEEE/NFPA Arc Flash Collaborative Research Project. The presentation provided an overview of NFPA, Federal electrical safety requirements, and formulation of the joint IEEE/NFPA Arc Flash Collaborative Research Project. Mr. Earley identified the project's goals, membership, and sponsorship and gave an historical perspective of the project. The next phase of NFPA research will focus on a comprehensive DC arc flash model. This model will focus on parameters such as power source configuration, voltage and current ranges, bus gaps, and materials. Mr. Earley identified the research approach to developing hypotheses and models, followed by performing scouting tests to provide preliminary validation of the models.

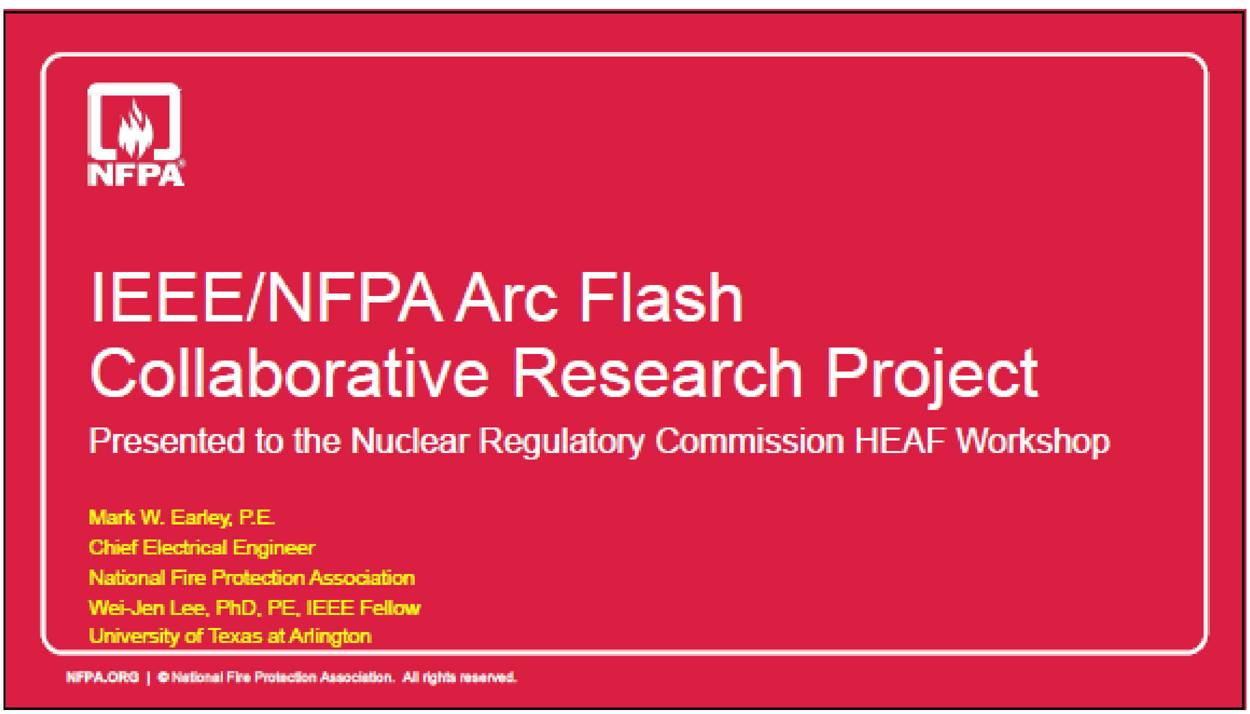
7.1.1 Discussion

During this presentation, attendees asked several questions, summarized as follows with responses:

- Everyone is here today because it has been noted that aluminum is problematic for a HEAF event. Given the large number of arcing experiments that the IEEE/NFPA cooperative has performed, the IEEE standard does not make a distinction between copper and aluminum. Please provide some background on why this is. Were there any differences in the team's tests?
    - Mr. Earley noted that most of the tests were actually conducted with copper, which does splatter as well. Those in the fuse and circuit breaker industry are well aware of the aluminum issue and its implications.

The NFPA Perspective presentation is documented on pages 206–226 of the Day 1 transcript.

7.1.2 Presentation Slides



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®")

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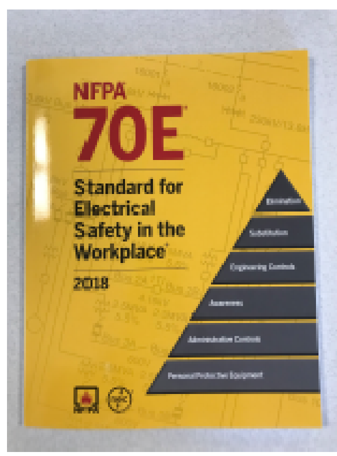
NFPA70E®-Electrical Safety in the Workplace®

- 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

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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.

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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

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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

	Program 6	Program 5	Program 4	Program 3	Program 2	Program 1
Total estimated cost	cost in $1,000's	cost in $1,000's	cost in $1,000's	cost in $1,000's	cost in $1,000's	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	368	356
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 TGHS toxicity (gas chromatograph and dosimeter) testing. Eliminate purchase of used equipment.	Drop TGHS 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

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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

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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.

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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.*

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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**

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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

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Factors to be Considered

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

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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.

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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?

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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

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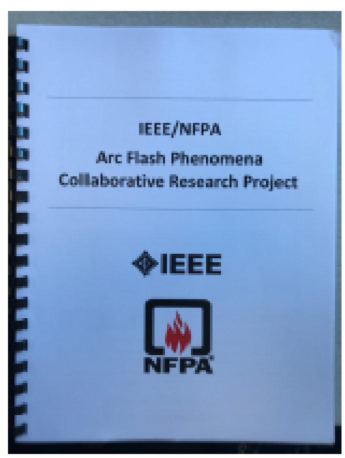
Deliverables and Accomplishments

- 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.

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8 ELECTRIC POWER RESEARCH INSTITUTE PERSPECTIVE

8.1 Perspective from the Electric Power Research Institute

Ashley Lindeman of EPRI provided a presentation on EPRI's perspective on HEAFs. Ms. Lindeman started by referencing the following EPRI white papers that were issued in 2017:

- EPRI 3002011922, "Characterization of Testing and Event Experience for High-Energy Arcing Fault Events" (Ref. 9)

- EPRI 3002011923, "Nuclear Station Electrical Distribution Systems and High-Energy Arcing Fault Events" (Ref. 10)

The EPRI work characterized the electrical distribution system into seven categories and provided a qualitative assessment of the impact and consequences given a HEAF. The team identified one vulnerability, the "unit-connected" design, in which a generator-fed electrical fault could progress for an extended duration as the generator coasts down. Ms. Lindeman summarized the operating experience from U.S. HEAFs and suggested that HEAF-initiating frequencies and HEAF ZOIs should be refined as suggested by the operating experience. Ms. Lindeman also presented the statistics of the operating experience. This included identifying that more than 90 percent of HEAFs occur in non-safety related equipment, and less than 15 percent of HEAFs occur in low-voltage equipment (less than 1,000 volts). Ms. Lindeman also provided EPRI perspectives on the testing. These views included variations between low-voltage and medium-voltage equipment, variation on the amount of energy from aluminum tests, and threshold for aluminum involvement. Ms. Lindeman's final topic involved the treatment of HEAF in fire PRAs. EPRI suggested that HEAF ignition frequencies be refined and scenarios be defined. Ms. Lindeman summarized the importance of HEAF events to both safety and economic consideration, the importance of optimizing overcurrent protection, and the need for proper maintenance to help prevent these events.

8.1.1 Discussion

During this presentation, the attendees had several questions, summarized as follows with responses:

- Did the database discriminate between events that involved aluminum and those that did not?

    - The team did not consider that at this time. However, it may be something to consider when EPRI works with the NRC to refine the HEAF frequencies.

- The presentation indicated that HEAF events in the United States represent approximately 2 percent of fires. Is this 2 percent relative to all fires or challenging fires?

    - The 2-percent figure is relative to all fires that contribute to fire frequency; that is, all fires classified as challenging or potentially challenging.

- The slides identify a wide variety and severity of events, stating, "Not all HEAFs result in post-event fire. Most HEAF events only damage the equipment suffering the failure." Would the cable be thermoplastic or thermoset?

- The results did not have that level of clarity.

- With regard to Slide 15, "Fire PRA Treatment," could the NRC work with EPRI to support the GI and meet the need of the pilot programs so that the GI can reach the assessment stage of the GI program?
  - Yes, however, it is unclear whether it would be EPRI or NEI.

- Was the plant status considered during the assessment of the operating experience?
  - Yes, most of the events occurred at power.

- With regard to the categorization by safety class (Class IE vs non-Class IE), could this distinction be from normal loading as opposed to safety classification?
  - The team discussed this but believes it has more to do with care and maintenance and some operational practices.

- Did you evaluate differences between insulated and non-insulated buses?
  - No. The licensee event report data were not ideal, but a subsequent analysis should try to drill down into more detailed information from the events to clarify the driver of these events.

- Did the review of the events reveal any new insights or information related to event duration that has not already been identified in NRC documents such as IN 2017-04 or the draft test plan?
  - This study focused less on the event review of duration but rather on how the protection schemes differed and whether there were failures in the protection.

The EPRI Perspective presentation is documented on pages 226–251 of the Day 1 transcript.

8.1.1.1 Follow-up Actions

- EPRI or NEI will support the NRC GI pilot plant assessment.

8.1.2 Presentation Slides

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

EPRI Perspective

High Energy Arcing Faults

Ashley Lindeman
Senior Technical Leader

HEAF Information Sharing Workshop
April 18, 2018

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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

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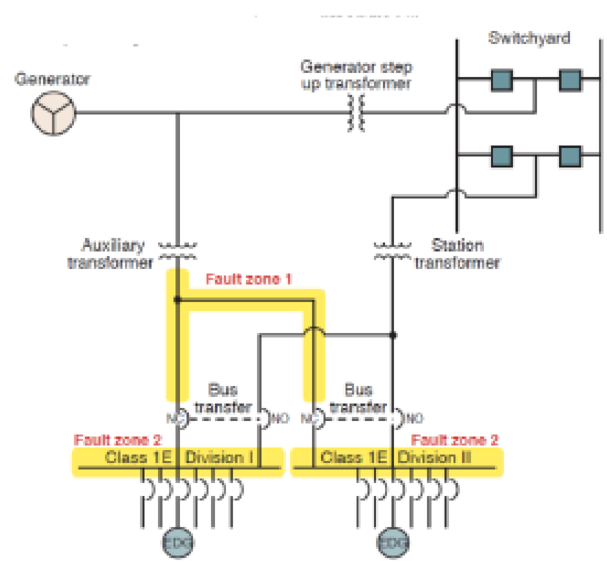
EPRI | ELECTRIC POWER RESEARCH INSTITUTE

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

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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

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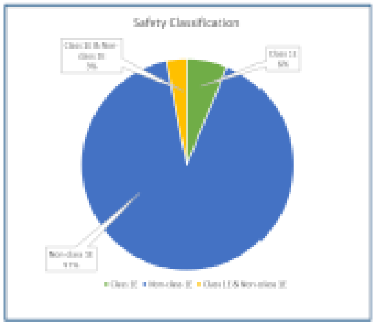
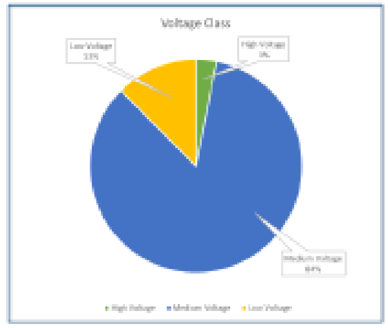
Key Influence Factors

- 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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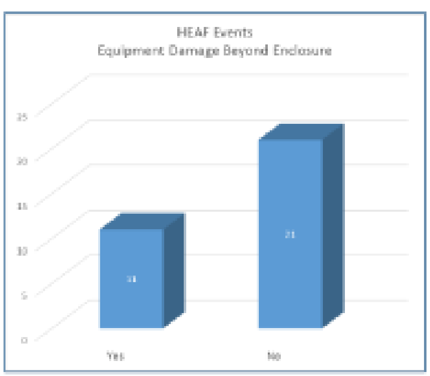
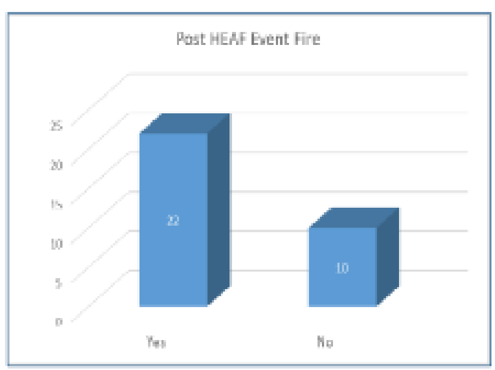
Key Influence Factors

- 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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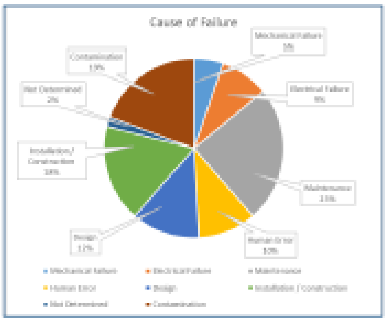
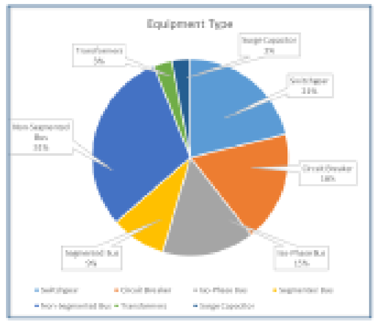
Key Influence Factors

- 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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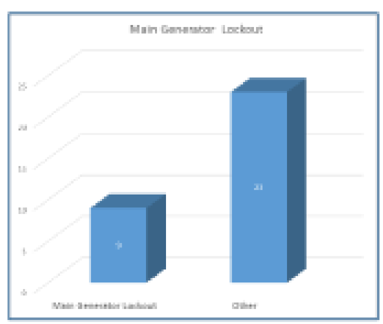
Key Influence Factors

- 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

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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

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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

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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

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Together…Shaping the Future of Electricity

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9 PHYSICAL TESTING AND FAILURE RATES

9.1 Physical Testing and Failure Rates

Bas Verhoeven, Director of Global Business Development and Innovation at DNV GL, gave a presentation on physical testing and failure rates. Mr. Verhoeven provided a high-level overview of the testing laboratories, including the KEMA facility in Pennsylvania, where the Phase II testing is planned to occur. Mr. Verhoeven then discussed certification as a risk mitigation measure. This included discussion of certification groups, protocol, and relationship to computer modeling as a surrogate to testing. The next topic covered was related to power system reliability and failures. The discussion identified causes of equipment failure, trending of equipment outages, failure modes of equipment, and failure rates. The final topic Mr. Verhoeven covered was related to statistics on the failure rate during type testing. Roughly 25 percent of test objects initially failed type tests. The presentation included statistics by equipment classification and type, along with theory of operation and failure. A key point is that although a significant amount of research and testing has been performed, the knowledge from these efforts has gone into improving the business line rather than ensuring adequate equipment operating margin.

9.1.1 Discussion

During this presentation, attendees asked several questions, summarized as follows with responses:

- Is the high failure rate because the standard requires testing at 100 percent of the component's rating, whereas in reality, the component may only be running at, for example, 60 percent?
    - IEEE, the International Electrotechnical Commission, and the American Society for Testing and Materials standards require testing transmission and distribution components at their maximum rating as assigned by the manufacturer. While in service, these components normally have a lower loading; however, the components can be loaded by the utility up to the maximum rating; thus, the test requirements in the standards are realistic.
- How many different cables are within each year's dataset?
    - The total dataset is 900 samples, so there are always at least 10 to 50 samples per year.

The Physical Testing and Failure Rates presentation is documented on pages 253–300 of the Day 1 transcript. No recommendations or follow-up actions were identified from this session.

9.1.2 Presentation Slides

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.

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Introduction in KEMA Laboratories

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DNV GL, A global quality assurance and risk management company

OUR PURPOSE

TO SAFEGUARD
LIFE, PROPERTY
AND THE ENVIRONMENT

KEMA Laboratories

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Industry consolidation

DNV
GL Group
KEMA
NOBLE DENTON
GARRAD HASSAN
ADVANTICA

KEMA Laboratories

Global reach – local competence

150+ years	100+ countries	100,000+ customers	12,500 employees

KEMA Laboratories

Our vision: global impact for a safe and sustainable future

MARITIME	OIL & GAS	ENERGY	BUSINESS ASSURANCE	DIGITAL SOLUTIONS

TECHNOLOGY & RESEARCH

KEMA Laboratories

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

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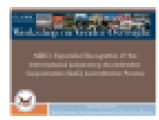
KEMA Laboratories – Beyond the Standards

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.



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Certification, the Global Approach

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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.

www.Stl-liaison.org

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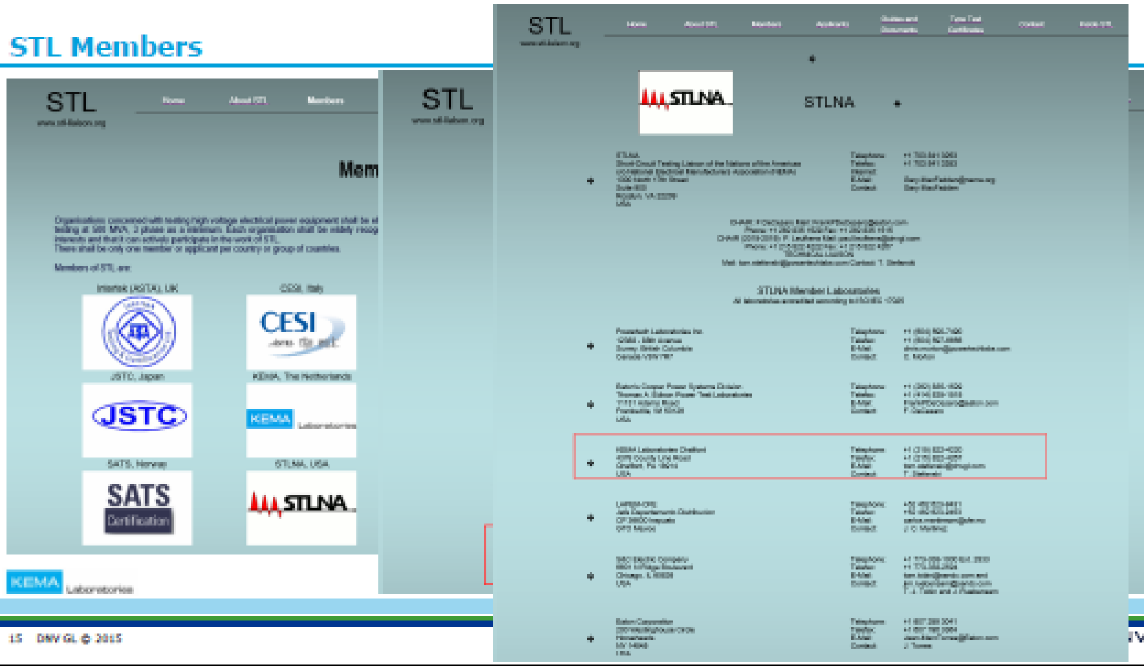
STL Members



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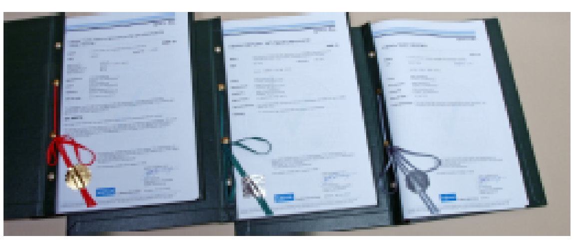
Certification – how the majority of the world sees it …

- 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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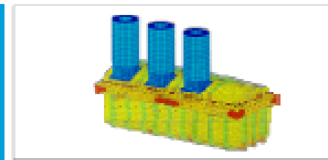
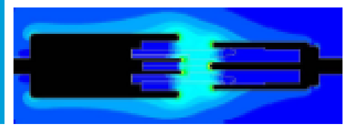
Can computer modelling replace testing?

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

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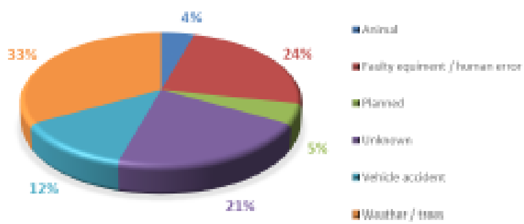
Equipment failures causes blackouts

USA 2016 (n = 3.879)



Most avoidable outages are equipment related

Source: Eaton Corporation, Blackout Tracker USA Annual Report 2016

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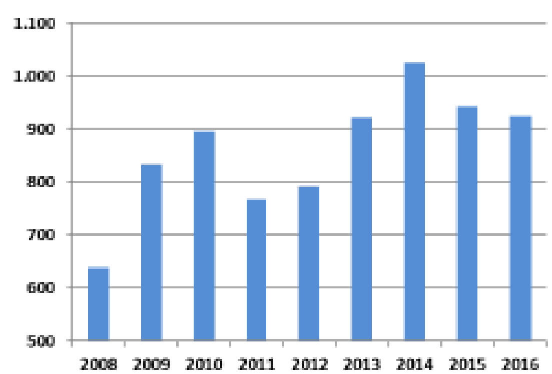
Number of outages increase over the years

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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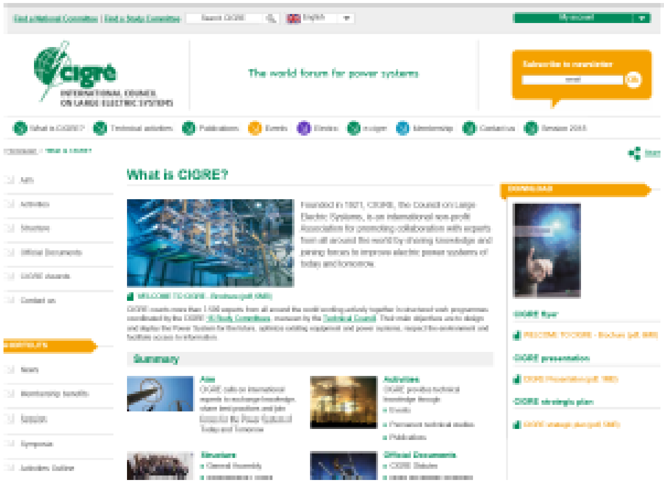
Cigre Organization



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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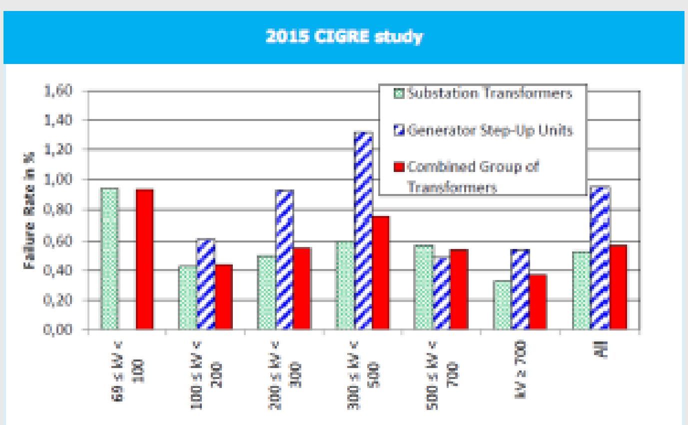
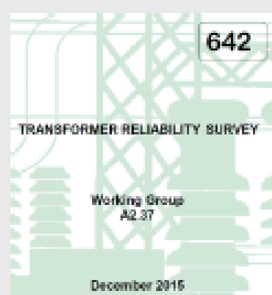
Large Power Transformers



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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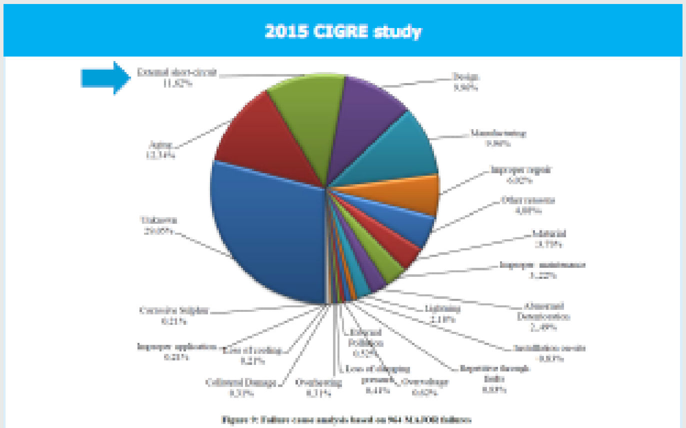
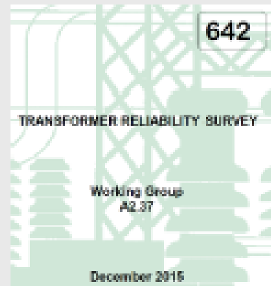
Large Power Transformers



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



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

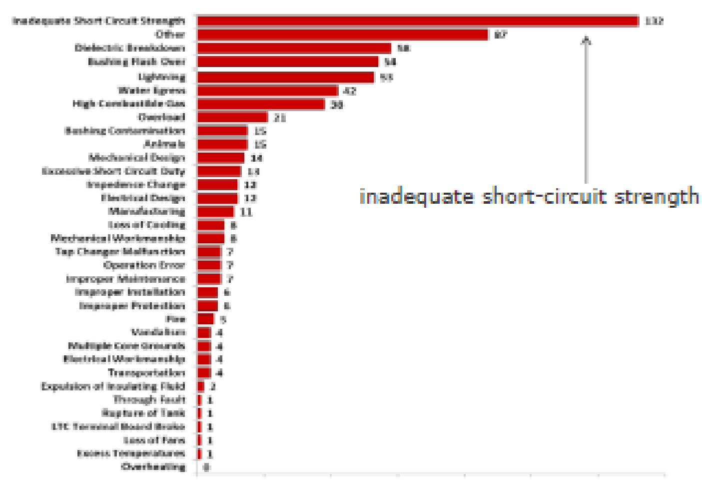

FIGURE 23: ANALYSIS OF FAILURE CAUSE (654 OF 1563 RECORDS HAVE FAILURE CAUSE IDENTIFIED)

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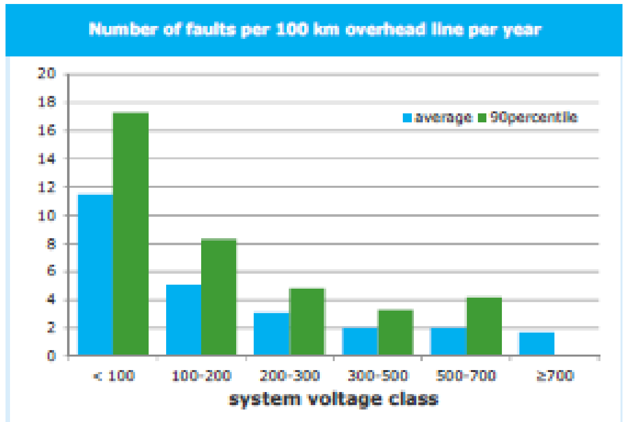
How Often do Faults Occur?

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



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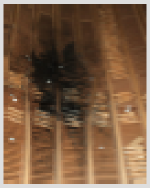
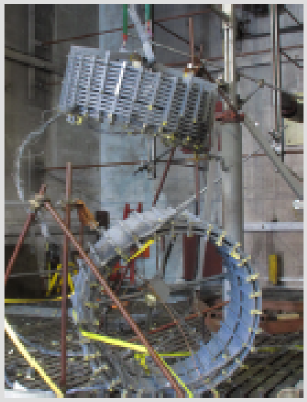
Statistics on Failure Rate during Type Testing

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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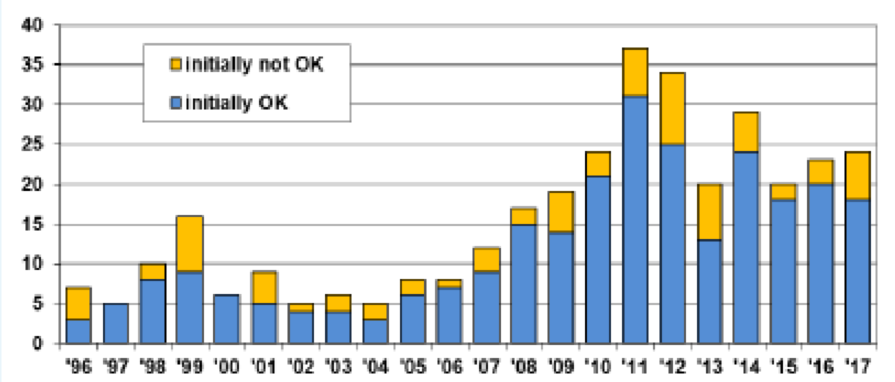
Initial failure rate large power transformers > 20 MVA

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



Average 22%

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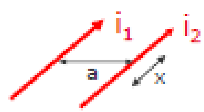
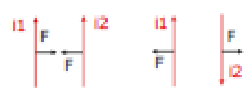
Forces between conductors

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

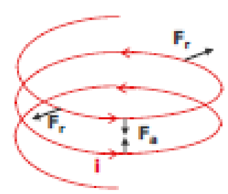
Lorentz-force: $\frac{F}{x} = \frac{\mu}{2\pi} \frac{i_1 i_2}{a}$



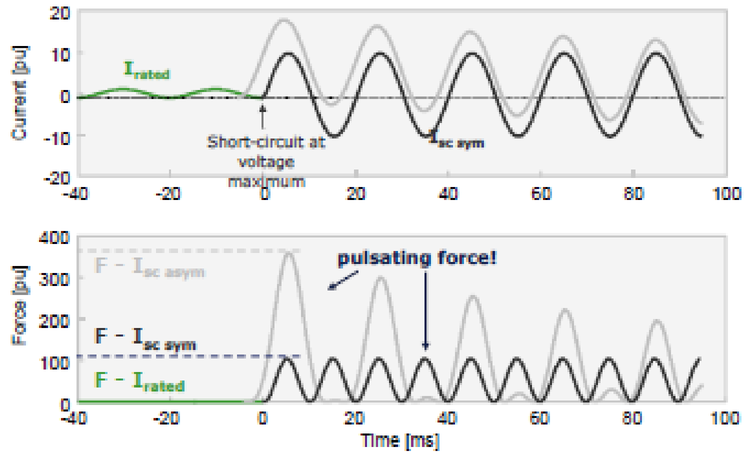


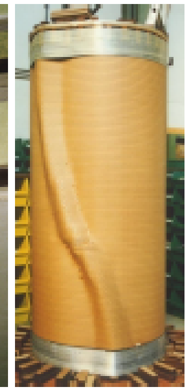
- Equal polarity: attraction
- Opposite polarity: repulsion

- 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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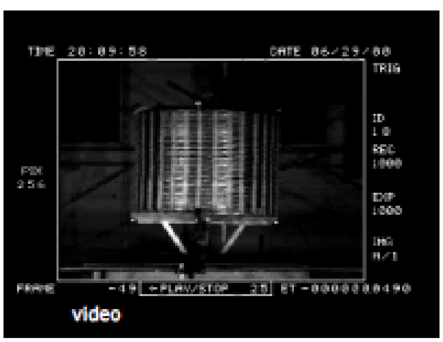
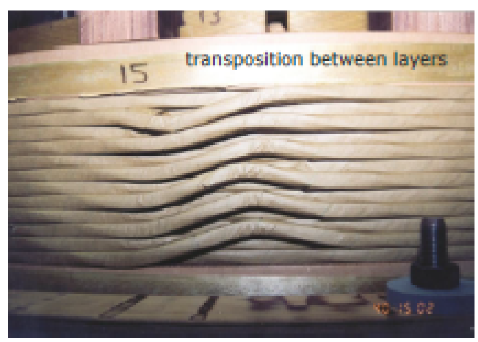
Short-circuit forces on a winding



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

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

[T]he code defines a procedure to demonstrate the mechanical capability of a transformer to withstand short-[c]ircuit stresses. The prescribed tests are not designed to verify thermal performance. Conformance to [s]hort-circuit thermal requirements shall be by calculation in accordance with Clause 7 of IEEE Std [C]57.12.00-2015.

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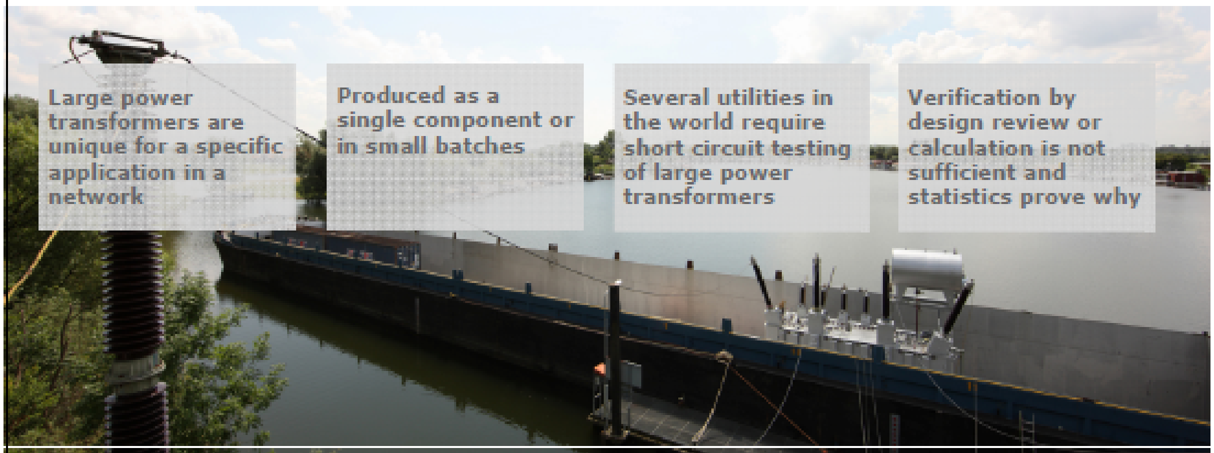
Large power transformers



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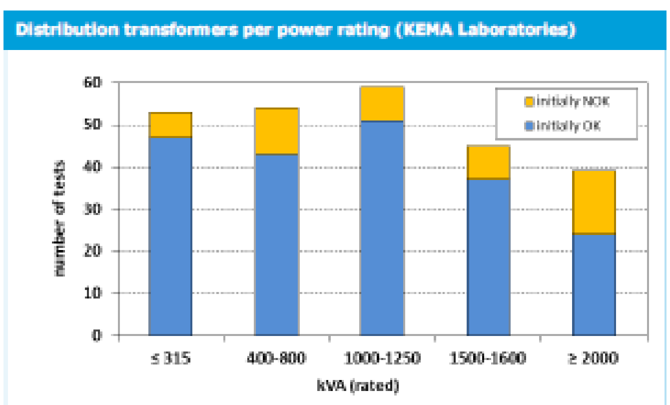
Initial failure rate distribution transformers



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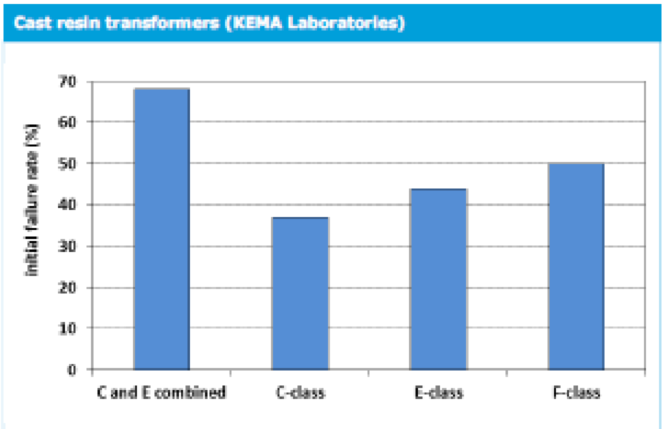
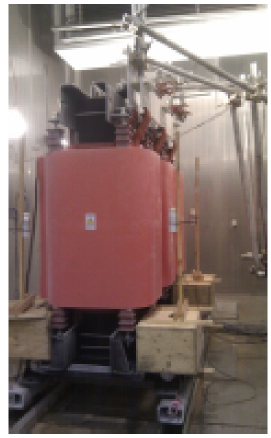
Initial failure rate cast resin transformers





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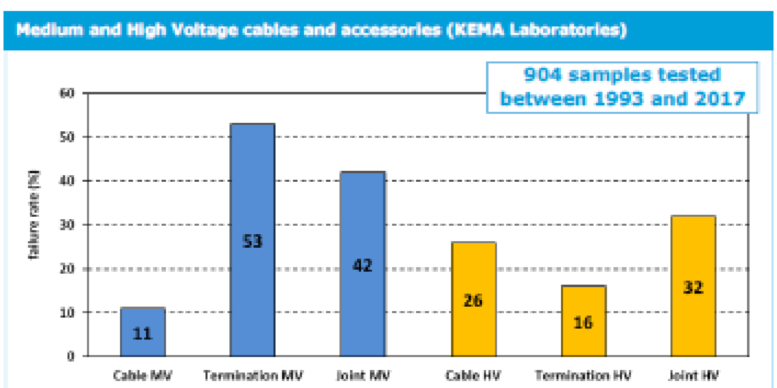
Initial failure rate cable and accessories



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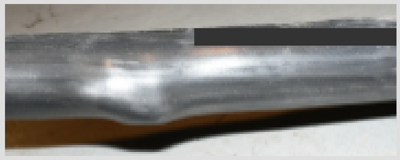
Examples of cable accessory failures

Mechanical deformation



Tracking and erosion insulator shed

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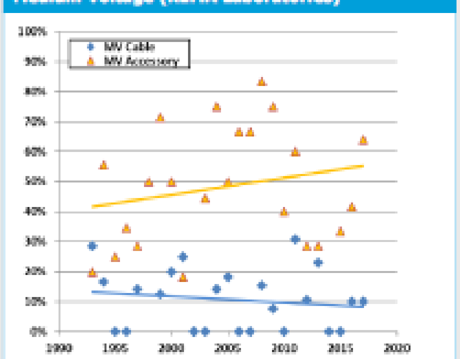
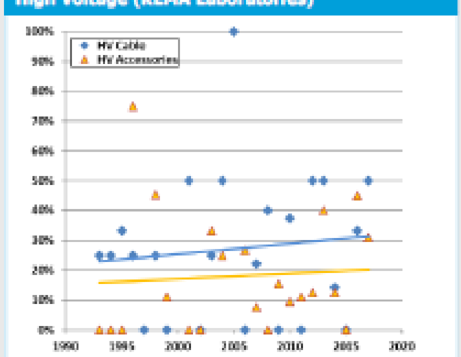
Initial failure rate cables and accessories

Medium Voltage (KEMA Laboratories)



High Voltage (KEMA Laboratories)



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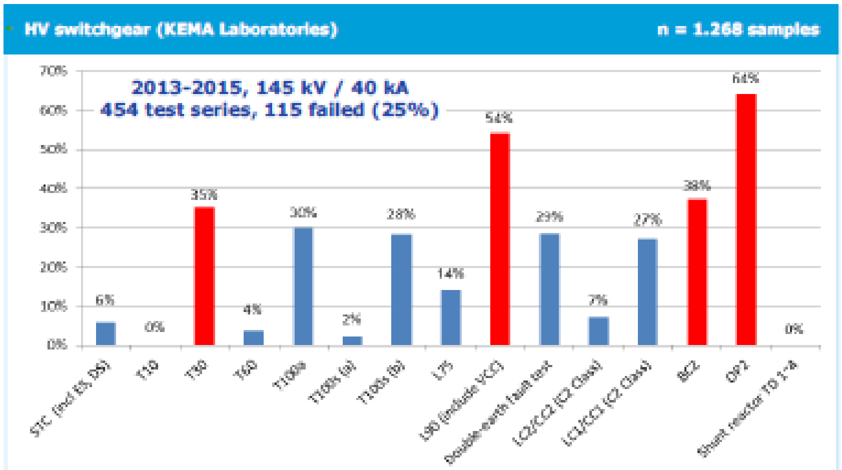
Initial failure rate circuit breakers – PRELIMANARY RESULTS



- 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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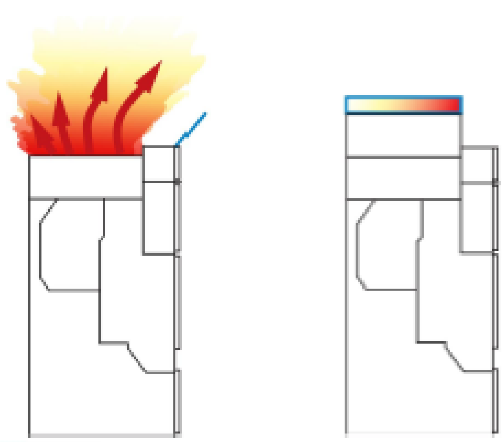
Internal arc test on MV switchgear

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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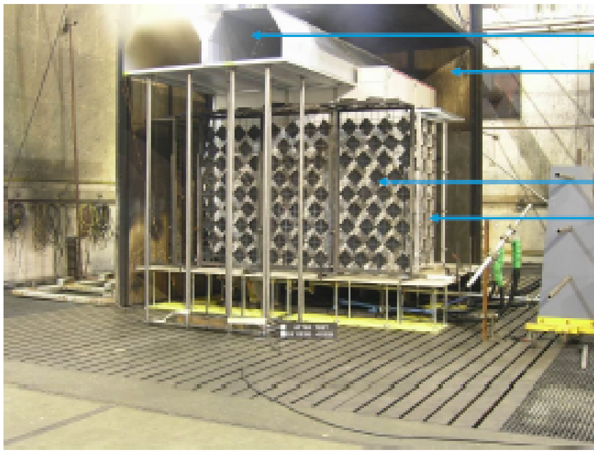
Carrying out the test

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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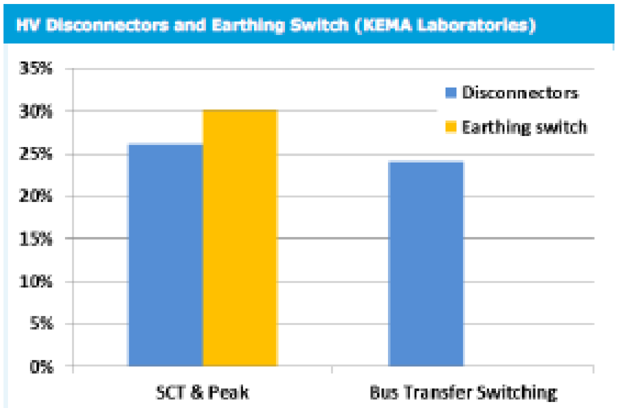
Initial failure rate HV disconnector and earthing switch



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Initial failure for power arc on insulator strings

Successful tests	109
Failures	57
Failure rate	34%

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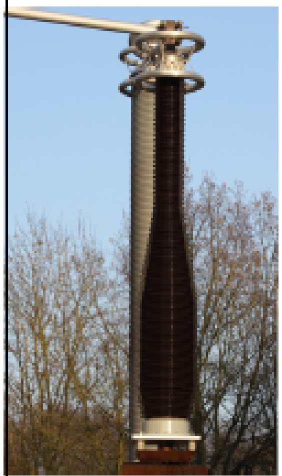
Takeaways



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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10 TEST PARAMETER AND EQUIPMENT SELECTION

10.1 Test Parameter and Equipment Selection

Gabriel Taylor, Senior Fire Protection Engineer, and Kenn Miller, Team Leader, both in the Office of Nuclear Regulatory Research, led a presentation on NRC test parameter and equipment selection. The objective of the session was to solicit discussion and feedback from the audience on the NRC's Phase II test program, understand the range of operating (fault) conditions, and identify equipment configurations and types for inclusion in the test program. Mr. Taylor gave a high-level overview of "High Energy Arcing Fault (HEAF) Research, Needs and Objectives," dated March 23, 2018 (ADAMS Accession No. ML18081B300). The presenters communicated the goals and objectives of the NRC project and identified the parameters that the NRC believes influence the HEAF phenomena. Following the overview, the presenters discussed each parameter, including the data used to support the choice of test parameter range. After this discussion, the audience gave feedback, including whether they agreed on the selection of test parameters, as summarized in Section 10.1.1 . The presentation concluded with a discussion of equipment selection and bus bar test configurations. Mr. Taylor presented the proposed equipment to be supplied through an international agreement. This includes medium-voltage Magneblast breakers and switchgear from Korea and low- and medium-voltage switchgear from Germany. After the discussion on the test parameters, Nicholas Melly summarized the international PIRT documented in NUREG-2218.

10.1.1 Discussion

During this presentation, attendees asked questions and provided comments and feedback, summarized as follows with responses:

- Normally, low-voltage fault currents are much higher than identified in the tables in the presentation.
    - Presently, the selection of fault currents for medium- and low-voltage tests is based on infinite bus calculations. The team took this approach because the NRC does not have the information needed to perform detailed studies of the plant-specific bolted fault currents. It should be noted that although the infinite bus (zero source impedance) assumption adds conservatism, the analysis does not account for motor contributions, a non-conservative assumption. Therefore, while these data have limitations, they should be considered a reasonable estimate of expected fault currents. In addition, the proposed fault currents of the test program are arcing fault currents. The bolted fault currents from the study were converted to arcing fault currents using the approach presented in IEEE 1584.
    - Several attendees suggested that the proposed fault currents are likely realistic. Nuclear plants are somewhat unique, in that their step-down transformers between medium and low voltage are typically small, from 750kVA up to the maximum of 2.5MVA, most are in the 1MVA range.
    - One utility identified that its low-voltage fault current was in the range of 16kA or 18kA and typically feed off of a 1MVA transformer.

- What is the population of aluminum components in the plants? Is it both in 480V and 4,160V, or is it primarily in one application as opposed to another? This may be important when considering risk and the influence of separation among components.
    - Based on the NEI informal survey (ADAMS Accession No. ML17165A140), the team is not able to determine the population by voltage level.
- The NEI survey is anonymous, and the individuals in the room do not represent all U.S. plants. Is there another effort to gather that information from the industry to ensure the testing is done correctly with regard to that configuration?
    - The NRC would like to leverage the experts at the workshop, as well as industry support groups such as EPRI and NEI, to assist the program by providing information representative of plant configurations.
    - Mr. Salley communicated the opportunity for stakeholders to provide input or actual equipment to the testing program to ensure realism.
- When will the international agreement be signed and the tests locked down from further input?
    - The current schedule is to have the agreement signed by the end of the summer 2018.
- The low-voltage tests identify testing to either 4 or 8 seconds. What is the derivation of the 8-second figure?
    - International operating experience has a low-voltage HEAF event that lasted for 8.5 seconds. One U.S. low-voltage event that was discussed earlier also lasted longer than 8 seconds.
- Extensive discussion identified that although time-delay protection could clear a fault in 1 to 15 seconds, the proposed currents for the test program would not correlate to the high end of that range. Rather, the more realistic durations for low voltage would be in the 2- to 4-second range. Testing at 2 seconds would be a good lower end because it has ties to equipment ratings, and an upper level of 4 seconds would be consistent with some of the coordination studies that the workshop participants mentioned.
    - A change of fault current from 4 to 8 seconds to 2 to 4 seconds will be proposed.
- The testing should occur in the 1- to 2-second range, as the equipment is rated for this range.
    - Although such a test would provide some information, it is not the type of information that the program is trying to obtain because those shorter durations would not appear as a HEAF event. Those events would typically be characterized as a non-HEAF event (Bin 15 fire) if the event met certain screening requirements to be included in the PRA ignition frequency.
- Compared to the HRR profiles of traditional fires, does the energy release of a HEAF vary over the duration or is it essentially constant?

- For the most part, the energy is constant; however, test 23 in the Phase I program resulted in an observation of increased energy. The typical behavior observed during testing may be a result of the characteristics of the electrical power feed into the fault from the test facility. The team has used a constant energy source via super excitation, whereas this may not be the case, for example, in a generator-fed fault where the generator trips and the energy decreases with time. Another aspect is the energy received at a target. The time it takes the arc event to breach the electrical enclosure, whether a door or panel opening or the arc burning through the enclosure, has an impact on the temporal profile for the energy received.

- Testing at medium voltage should represent the current decrement curves when the fault is being fed from a generator.

    - The laboratory can produce steady currents or follow a current profile (with some limitations). To be realistic, the NRC would need information such as decrement curves from high-speed digital recorders (or similar) to evaluate whether testing could match those characteristics.

- Is there any proposal to test the electrical equipment within a larger room enclosure to understand the pressure effects?

    - The focus thus far has been to record the pressure within the electrical enclosure and try to extrapolate room pressure. It is uncertain at this time whether that will be possible. It may be possible to construct a test room at the test laboratory, but that decision will be weighed in terms of the costs and benefits.

- Is it possible to demonstrate the switchgear's compliance with IEEE C37.20.7, "IEEE Guide for Testing Switchgear" (Ref. 18) (i.e., that it does not damage anything beyond the enclosure) and thereby certify that the switchgear is healthy for testing?

    - This may be possible for the low-voltage tests but expensive for the medium-voltage tests. It would also be cost prohibitive if the equipment tested is not all of the same design. In general, it is unclear as to what would be gained from performing these tests. The referenced IEEE document provides a qualification process for arc-resistant equipment, and it is unclear that this was a requirement or procurement specification of the plant when it was licensed. Additionally, if the test used equipment representative of the plant equipment and it failed, what would that imply for the equipment in the field? In general, the comment appears to be off topic for the purpose of these tests.

- IEEE has performed a number of tests with durations from 0.5 to 1 second. This information should be reviewed to understand the results and help communicate that the focus of this work is the large energy releases that are being observed in plants, but the data are not there to support a realistic modeling tool.

    - Mr. Taylor agreed with this statement.

- Is it possible to characterize the generation source, such as a black box model or impedance model?

- Many configuration changes are available with the test laboratory's generators, reactors, and other supply equipment to meet a wide range of power system configurations. The team will document the configurations tested; however, it is more important to understand the generation facilities sources so that the test power supply can be configured to match.

- If the NRC is seeking voluntary information from the industry, how will the NRC ensure that any information provided is representative of the overall industry and not a non-representative best case?

  - NRC experts, such as the electrical engineers in Mr. Miller's group or regional staff who have experience inspecting this equipment at various sites, would vet the information received. If EPRI and NEI participate in the information review, experts from those organizations would also review and check the information.

- With regard to the discussion on wye or delta connected testing power sources, there are a variety of configurations in the field and it may make sense to test a combination of the two. However, the preference was not that strong, and it was felt that a more important aspect of the testing would be to test in the configuration that allowed the laboratory to meet the current, duration, and voltage specifications of the testing. The international PIRT ranked the system connection configuration as a low importance.

- Regarding the discussion on the grounding configuration, the audience identified several grounding configurations from solid grounds on the low-voltage systems to high-resistance grounding and grounding transformers on the medium-voltage systems. The discussion concluded with the point that grounding should not affect the testing. It will affect the duration of actual events and the associated protection scheme. For testing, the tests will be initiated phase to phase, and grounding has little to do with those types of failures.

  - The biggest testing concern with grounding configuration is the thermal effects on the generators because those cannot be damaged and the laboratory will not allow testing in a configuration that will damage or potentially damage its infrastructure.

  - The discussion concluded that variations of the grounding configuration are not warranted.

- EPRI provided information on a sample of medium-voltage transformer winding configurations for the unit auxiliary transformer. Based on a sample of 28 units, the following population was noted:

  - Delta primary to Wye secondary (Δ-Y): 20 units
  - Delta primary to Delta secondary (Δ-Δ): 6 units
  - Wye primary to Wye secondary (Y-Y): 2 units

  Therefore, the predominant of the secondary side of the unit auxiliary transformer is a Wye-connected configuration.

- Should the phase-to-ground fault that does not transition to a phase-to-phase fault be considered in frequency space? Although it may be a lower likelihood that the phase-to-ground fault remains a phase-to-ground fault, the phase-to-ground fault would limit the current.

- That is something that should be kept in mind if the team performs a more thorough review of the operating experience. From the information that is currently available, the commenter's distinction cannot be made.

- With regard to the discussion on the placement of arcing wire, the most recent issuance of IEEE 1584 describes a definite distinction between the energy that was emitted from an arc created on a vertical versus horizontal section of bus. Should this be considered when deciding where to place the arcing wire?
  - Mr. Earley of NFPA responded that it is true that the results from the vertical and horizontal test yielded different results. The horizontal configuration was more severe.
  - Although testing guides such as IEEE C37.20.7 identify placing the arcing wire far from the incoming power source, OECD Phase I test results indicate that the arc can move to other locations within the enclosure.
  - It was also recommended that the arc should not be placed in a location where it is unlikely to occur, such as documented in the IA report where some of the bus insulation was removed to support a sustained arc.
    - The original configuration of the equipment should be kept; where changes are required, those changes and the rational for the change should be documented.

- The participants discussed the arcing wire characteristics.
  - IEEE C37.20.7 identifies two types of acing wire. The purpose of the arcing wire is to provide sufficient material to initiate and sustain the arc plasma. Low-voltage systems use a 10-American Wire Gauge (AWG) type K stranded conductor, while a medium-voltage system uses a 24-AWG. The NRC has requested clarification on the specification of the arcing wire from IEEE. The IEEE guide wire sizes will be used unless justification for other sizes is identified.

- The participants discussed bus duct testing.
  - One plant was identified as having non-segregated bus ducts with bus bar insulation made of Norrell. Other participants identified that there was a mix of insulated and non-insulated bus bars within bus ducts.
  - The ventilation of bus ducts also differs from bottom ventilated to top-hat ventilated.
  - The end treatment of the tested bus ducts will also be important.
    - The end treatment for the Phase 1 testing did not last long and, from industry testing the supporting insulators along with the insulated bus, seems to have stabilized the arc in one location. As testing progresses,

the team wants to make the testing as realistic as possible while still being able to predict arc location such that active measurements at those locations can be made. Whether connecting a bus duct to an electrical enclosure, using insulation, or making physical breaks in the conductor, the team is trying to balance realism with testing practicality.

- Is the intent to simulate a segmented bus duct failing at a joint or is it to be applied to both segmented and non-segmented bus duct failures? The current fire PRA modeling approach is different.
  - The focus was on segmented bus ducts failing at a bolted connection. The team is trying to stay consistent with the current modeling technique in Supplement 1 to NUREG/CR-6850 and EPRI 1011989.

- Do cameras provide information needed to assess the severity of the HEAF event or is their role to help market the badness of HEAF events?
  - The cameras can help identify where shrapnel is ejected. There were some limitations with the initial cameras that were used, and the team is working with the national laboratories to obtain valuable information from these recordings. The other aspect is thermal imaging. The camera that was previously used was limited by its dynamic range. For Phase II testing, the team is looking at other products that allow for a wider dynamic range to capture more information.

- Will different alloys of aluminum be tested?
  - Currently, the team does not know the population of aluminum alloy in the plants. We have provided some information on this aspect in the small-scale test plan, but it appears that there is not much difference in the aluminum used for electrical applications.

- Do atmospheric conditions influence the HEAF phenomena?
  - The testing performed during Phase I has a significant variation of atmospheric conditions, but the team did not observe that as being a driving factor. It may be more important from a frequency (or arc initiation) standpoint, but once the arc is initiated, the atmospheric conditions likely do not influence the HEAF results.

- Will the coupons located on the instrument racks have unique identifier such that they are identifiable after the test and if they were to come lose and fall off of the rack?
  - Each coupon will have a unique identifier.

- With regard to donated and procured equipment, it is vitally important to have the equipment vendor manuals, factory test reports, and everything that is related to the equipment.
  - Mr. Taylor agreed with this statement.

- Regarding the discussion on equipment selection, the participants identified the following as common types of equipment:

- GE Magna-Blast
- Westinghouse DB-50
- ITE k-line

- If equipment is donated to the testing program, will it be tested to rated voltage or to the voltages specified in the testing plan, which may be greater than the rating of the equipment?

  - The equipment will NOT be tested at voltages in excess of its rating. For example, although the test plan specifies 6.9kV for medium voltage, if the team receives a set of equipment that is only rated for 5 kV, then that equipment would be tested at 4.16kV.

- Will the testing include cable as targets?

  - Yes, there will be cable coupons located on the instrument measuring racks. Initially, the team planned to use cable trays for the testing, but after much thought that was dropped because of several limitations. The first difficulty of having full cable trays was defining a representative cable type and configuration, given the vast range of configurations found in the plant. Secondly, the cable trays block some of the HEAF effluent and incident energy to the active measurements devices. Because the team plans on developing a model to predict (validate) incident energies, having cables in the way did not serve this interest.

- Will the program evaluate differences in equipment design between indoor and outdoor offerings?

  - No, the focus of this effort is indoor equipment that poses a fire-related hazard to safe shutdown.

- After the presentations and discussion from the morning session and a presentation on the results from NUREG-2218, the participants reviewed the parameters and ranked their importance to influencing the HEAF phenomena. The participants discussed each parameter to clarify the meaning of the parameter. Following that discussion, the parameter was ranked either high, medium, or low with respect to its importance to the HEAF phenomena, as presented in Table 10-1. Not everyone in attendance voted, and not everyone voted for each issue. The table also includes votes received through the webinar.

Table 10-1 Summary of Parameter Ranking from Workshop Participants

Parameter	Importance Ranking High/Medium/Low	Comment
Duration	High (consensus)	
Voltage	High (consensus)	Arc voltage not system
Current	High (consensus)	
Arc Location (orientation)	5 High 2 Medium 3 Low	More examination of the IEEE testing configuration
Grounding Configuration	Low (consensus)	Important to frequency

Parameter	Importance Ranking High/Medium/Low	Comment
Delta vs. Wye	Low (consensus)	Experience that arc voltage has not shown a difference
Current Decay	5 High 6 Medium 3 Low	Plant information necessary for decay behavior
Enclosure Thickness	3 Medium 9 Low	
Bus Insulation (enclosure)	Low (consensus)	
Bus Insulation (non-segmented bus)	9 High 1 Medium	
Circuit Characteristics	2 High 7 Medium	Potentially included in earlier parameters, however needed for modeling
Bus Gap	11 High 1 Low	Linked to arc voltage; Low because of phase-to-phase interaction and other arc strike locations within the enclosure
DC Offset	6 Medium 3 Low	
Ventilation (enclosure)	9 High 1 Medium	
Ventilation (bus duct)	3 Medium 7 Low	
Aluminum Alloy	1 High 8 Low	State of knowledge—High rank outlier
Measurement Separation Interval	High (consensus)	Target locations and positions
Atm. Conditions	1 Medium 10 Low	Important to frequency and initiation of event; unknown to consequence
Ventilation (oxygen availability; aluminum)	8 High 3 Medium	
Ventilation (oxygen availability; copper)	2 Medium 10 Low	

The Test Parameter and Equipment Selection presentation is documented on pages 7–227 of the Day 2 transcript.

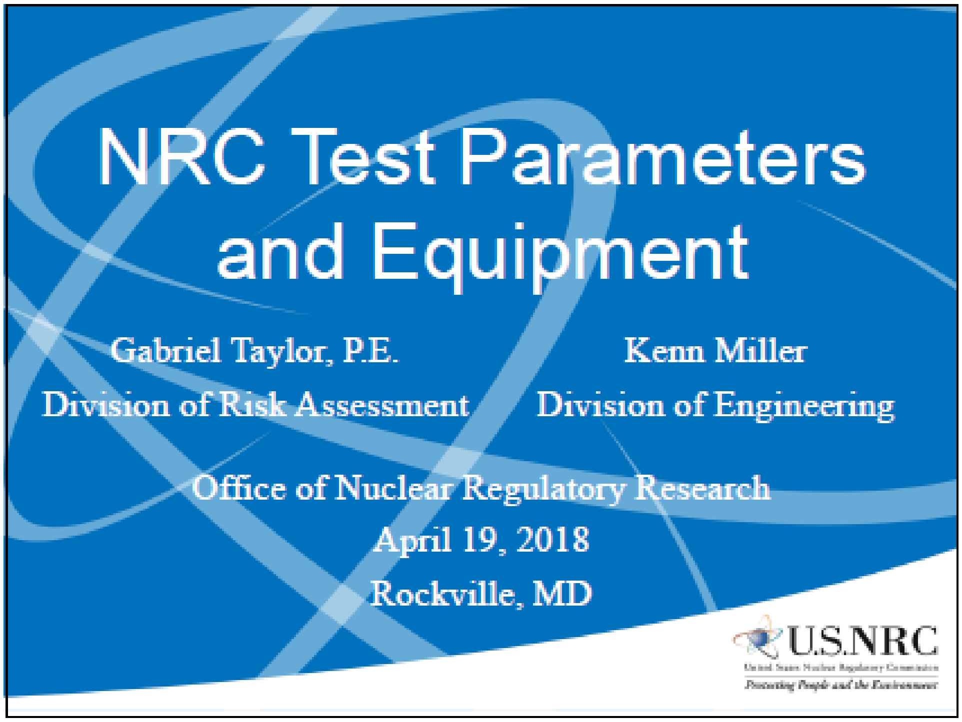
10.1.1.1 Recommendations

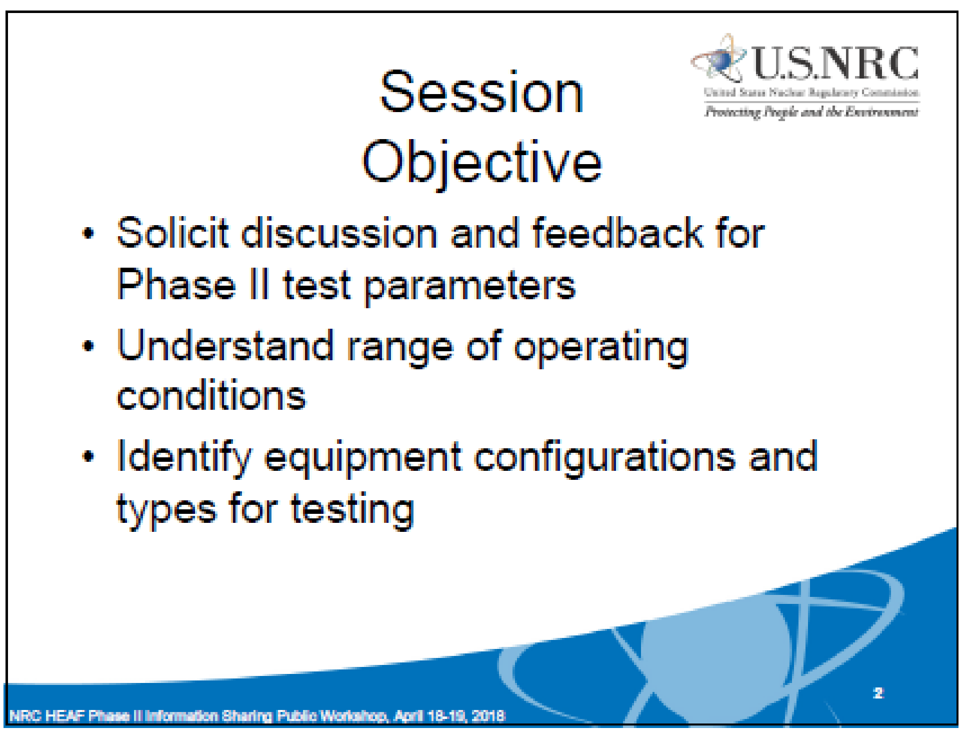
- Consider reducing the number of low-voltage tests, given the presentation by EPRI, which indicated that less than 15 percent of the events are in the low-voltage class, while the draft test plan has 50 percent of the tests at low voltage.
- Change the range of the low-voltage durations to 2 to 4 seconds.
- Review the IEEE literature on short-duration testing to support the basis of need for longer duration tests.
- Split the bus duct tests into insulated / non-insulated.

10.1.1.2 Follow-up Actions

- Prepare generator-fed fault decrement curves from high-speed digital recorders (EPRI).
- Develop the station power source characteristics to support the testing of power supply configurations (EPRI).
- Conduct follow-on interactions with stakeholders or EPRI, as needed.

10.1.2 Presentation Slides





Needs and Objectives

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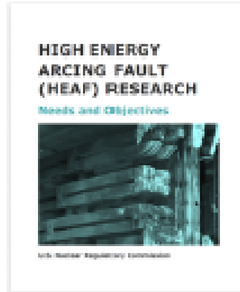
- Provides high level overview of hazard, data, and models
- Identifies research goals and objectives
- Identifies informational needs to ensure testing representative of event potential



The Hazard

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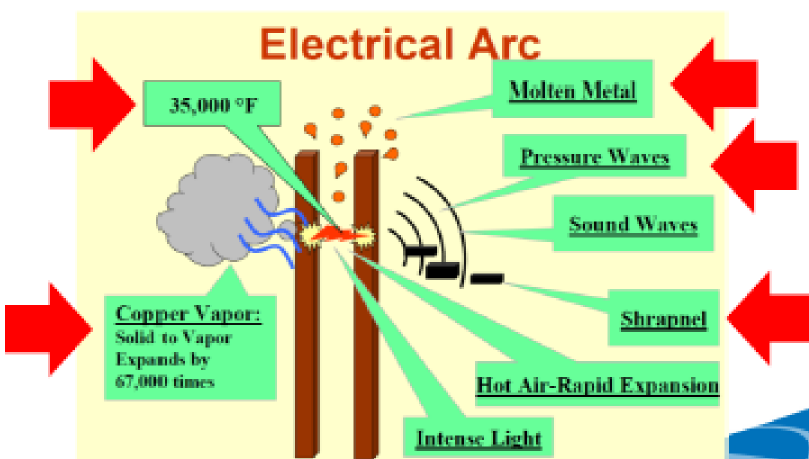

Ref. UAW Electrical Safety in the Workplace

Goals

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

Objective

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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

- 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

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Test #	Type		Material		Voltage (kV)			Current (kA)			Duration (seconds)						Gap (mm)	Energy (J/cm²)
	Cabinet	Bus Duct	Cu	Al	0.48	4.16	6.9	15	25	35	1	2	3	4	5	6		
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

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Test #	Bus Material		Duct Material		Voltage (kV)	Current (kA)	Duration (seconds)			Gap (mm)	Energy (J/cm²)
	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?

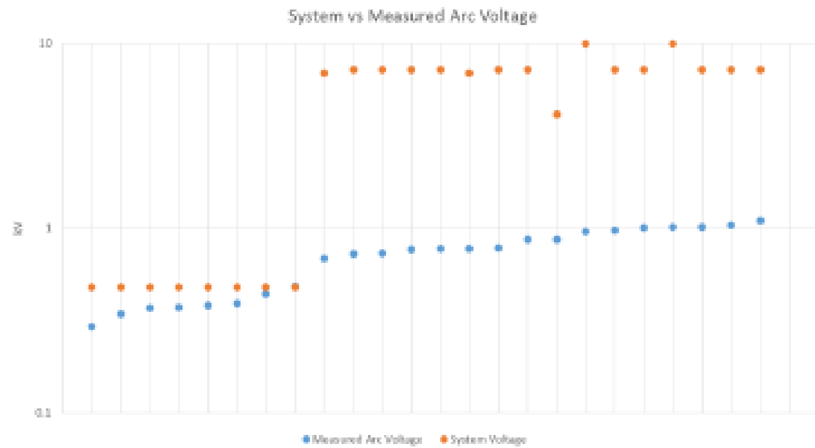
- Short arc flashes lack sufficient energy to cause thermal damage to other equipment
- Total energy (thermal source term) dependent on duration
- Long durations and their damage footprint are showing up in operating experience
  - Arc flash vs HEAF

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)



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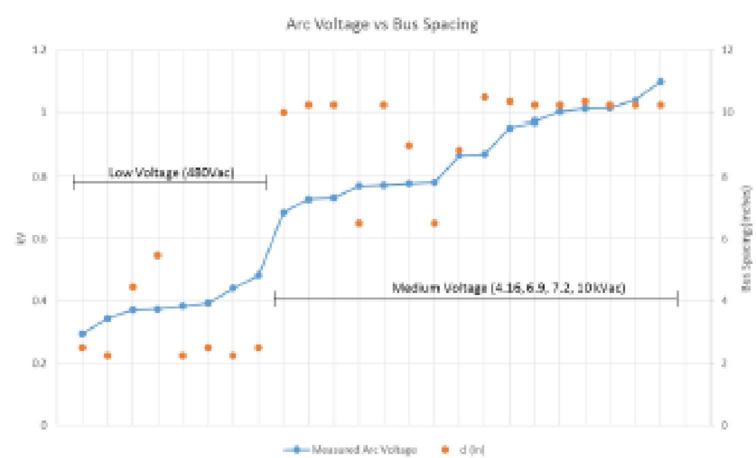
Enclosure Bus Bar Spacing for Phase 1



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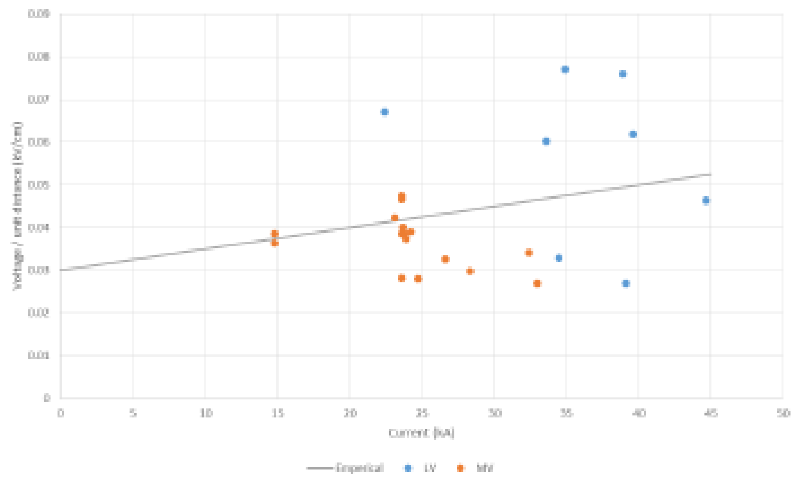
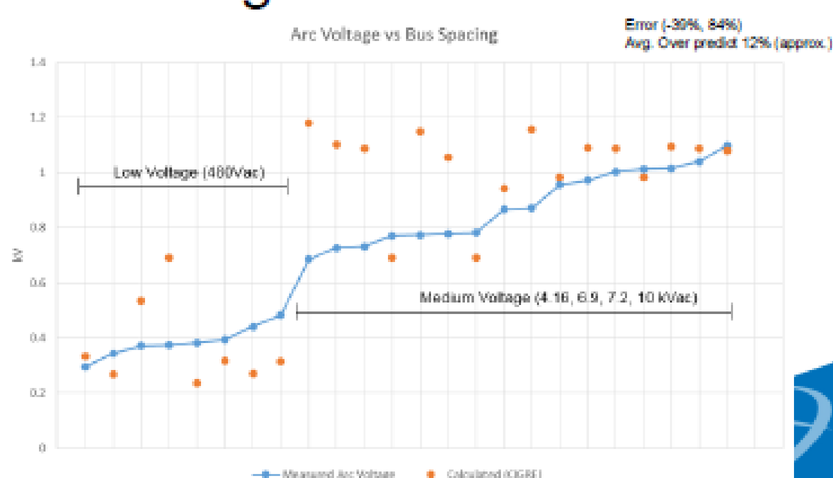
Arc voltage vs bus bar spacing (phase 1 results)



Bus Spacing versus Arc Voltage for Phase 1 results



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

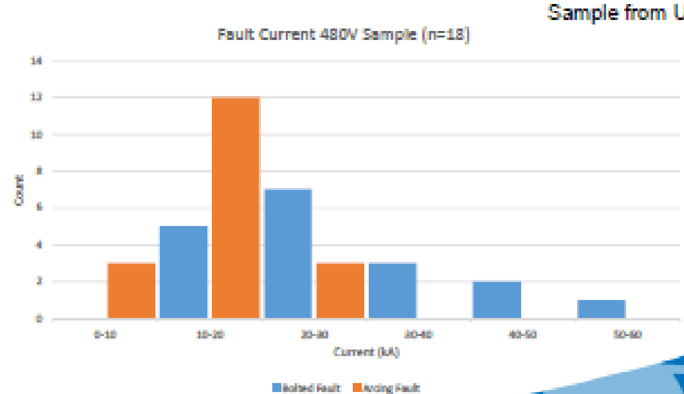
Proposed test fault current levels

- 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

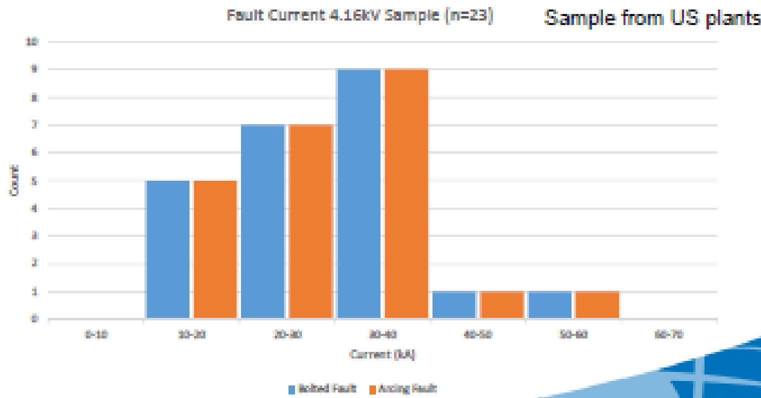


Test Levels: 15kA and 25kA

Medium Voltage 4.16kVac

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

Sample from US plants

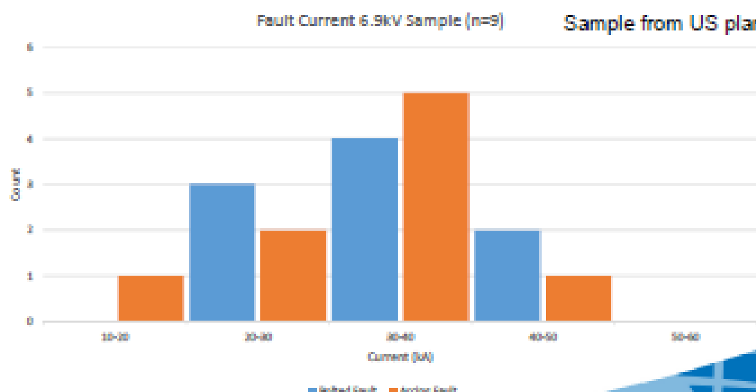


Test Levels: 25kA and 35kA

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

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

Grounding

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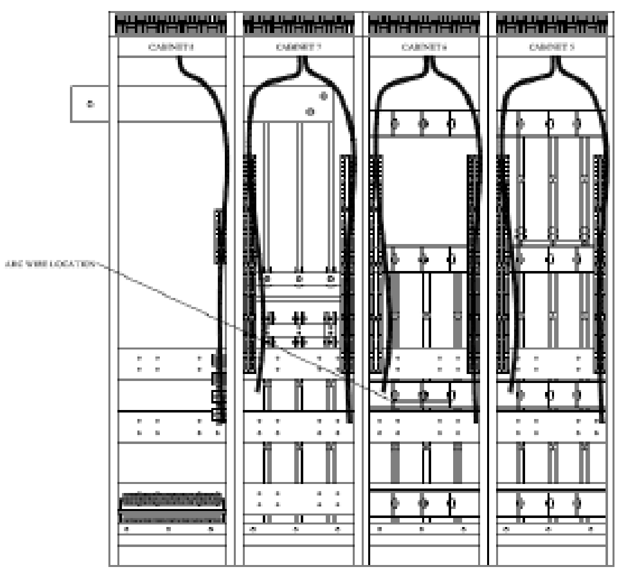
- Wye connected system grounding
  - Solid
  - Resistive
  - Reactive
  - Ungrounded



REAR VIEW
(WITH PANELS REMOVED)

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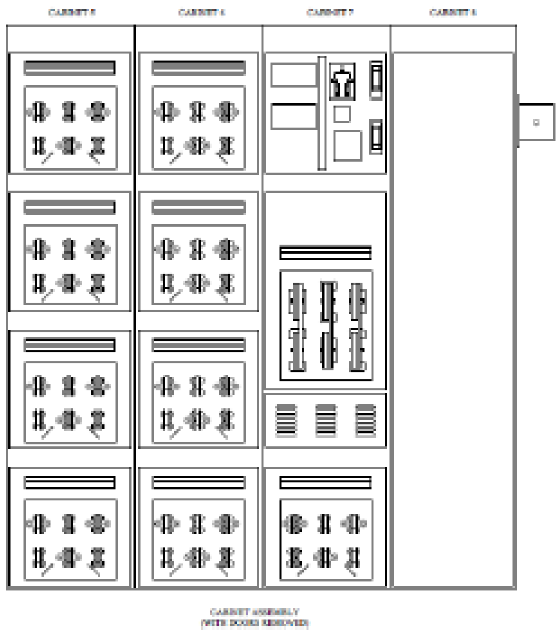
Arc Location LV Switchgear - Back



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Arc Location LV Switchgear - Front

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Arc Location MV MC Switchgear - Side

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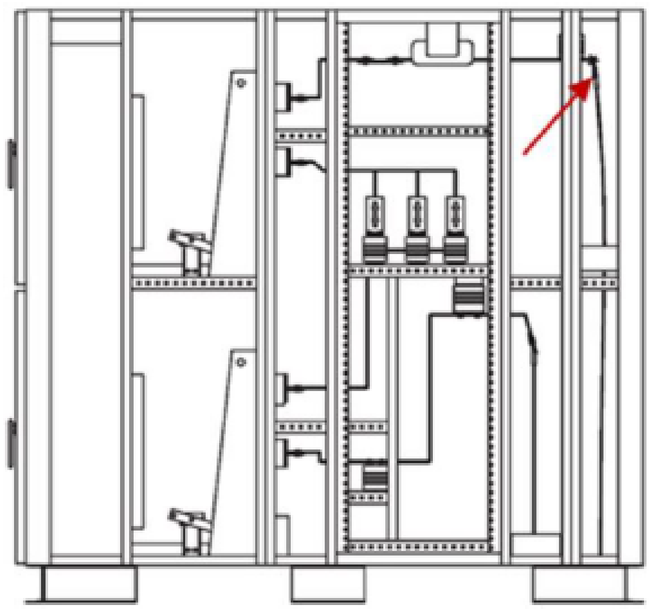

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Arc Location MV MC Switchgear - Side

Bus Bar Spacing

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- 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)

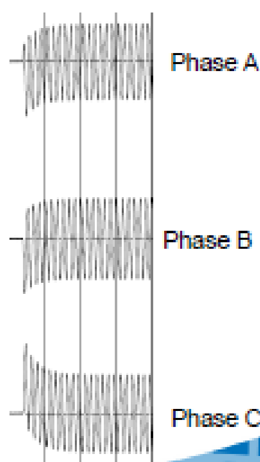
Bus Insulation

- 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
  - ?

11 DRAFT TEST PLAN AND COMMENT RESOLUTION

11.1 Review of Phase II Draft Test Plan and Comment Resolution

Nicholas Melly, Fire Protection Engineer in the Office of Nuclear Regulatory Research, presented a review of Phase II draft test plan HEAFs involving aluminum. Because the morning session covered a majority of the information, Mr. Melly focused his presentation on the information not already covered. Mr. Melly presented the experimental variables, measurements, OECD member countries, test structure, experimental approach, and timeline. He also presented comments on the draft test plan.

11.1.1 Discussion

During these presentations, attendees asked several questions, summarized as follows with responses:

- The small-scale testing is not integrated into the schedule; the expectation was that it was going to be a predecessor.
    - The small-scale testing is separate from the OECD program. It will be conducted before the full-scale OECD testing.
- How will all of this work be documented?
    - The current plan is to have seven or eight reports that document this work.
        - The NRC will document the workshop in a NUREG/CP.
        - A NUREG/CR report will document the small-scale testing at SNL.
        - An OECD report will document the OECD-sponsored tests, as was done in Phase I.
        - A NUREG will document the NRC tests and provide an analysis of all tests performed.
        - A NUREG or joint report with EPRI will document an improved HEAF methodology.
        - Researchers in Japan have performed a number of tests, and, through an MOU, the NRC plans on working with them to publish two more NUREG/IA reports to document this work.
        - A NUREG report will document the analysis of photographic and video information.
- Will the documentation of the enclosure include any aluminum piece other than the conductors?
    - The report will document aluminum pieces or parts that could become involved in the HEAF.

- When does the NRC expect to complete the small-scale report?

    - The NRC will issue a draft final report no later than September 30, 2018. The report will go through a review and publication process. The report should be available to the public around the end of 2018. If stakeholders are interested, the NRC could hold a public webinar to announce the results once the reports have been approved internally.

- Does the NRC expect the majority of the test equipment to be donated, or will the agency procure the test equipment? Ideally, it may be preferred to identify a specific line of equipment and then contact the manufacturer to understand whether the enclosure could contain either aluminum or copper bus and then make the design specifications available to support such a change.

    - Currently, only two countries from the international program are expected to donate equipment. The NRC will accept donations that support the intent and objectives of the program from U.S. utilities or vendors. Donations are needed primarily in the area of bus duct testing. However, if, for example, six Vendor A switchgears were donated and they are representative of U.S. fleet equipment, then the NRC could procure more equipment like that and then use resources to perform additional testing or other activities, as needed.

- EPRI provided a summary of the high-speed digital recorder event that would support generator test setup. In summary, for the first 26 cycles, the voltage drops from 22kV down to 17kV and then holds steady. This steady state may be because the exciter switchgear breaker is still closed and actually exciting the rotor. Afterward, there is another 20-percent drop to about 50 percent of the original system voltage. Then, it is assumed that the breaker opens and the voltage slowly decays from there as would be expected. This decay lasts to about the 6-second point, when the arc finally extinguishes. EPRI may be able to compile this information into a short whitepaper.

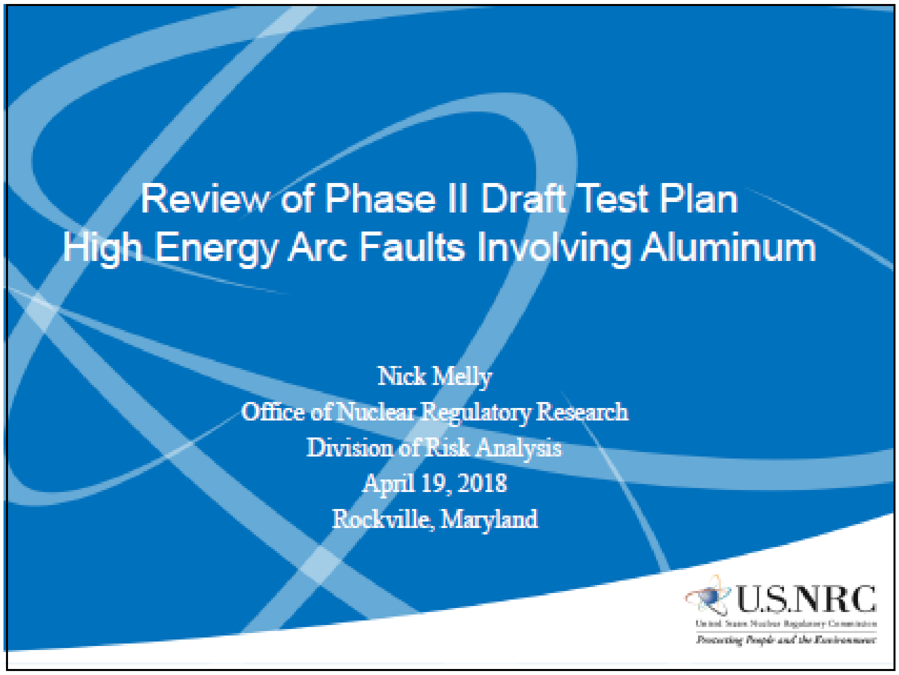
    - That information would be beneficial.

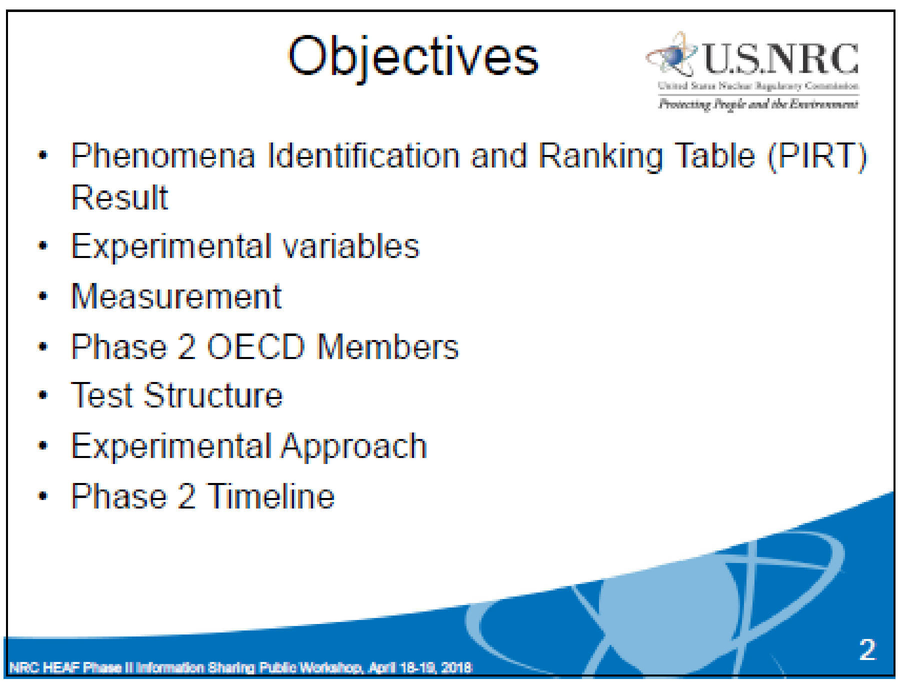
The Review of Phase II Draft Test Plan and Comment Resolution presentations are documented on pages 227–288 of the Day 2 transcript.

11.1.1.1 Follow-up Actions

- Prepare a white paper on the generator decrement curve from high-speed digital event recorder. (EPRI)

11.1.2 Presentation Slides





PIRT Phenomena of High Importance

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- 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

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- 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

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- 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

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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

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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

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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)

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HEAF Phase 2 Test Structure-Enclosures

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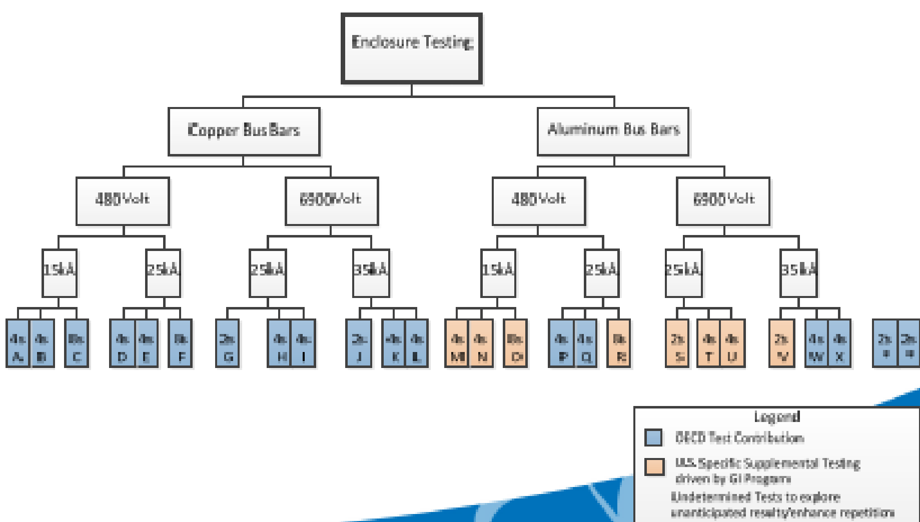
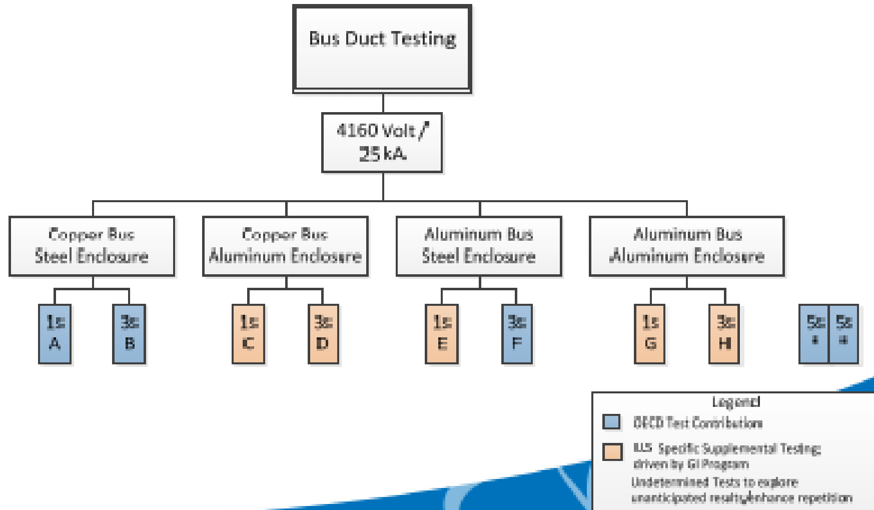


HEAF Phase 2
Test Structure- Bus Ducts



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

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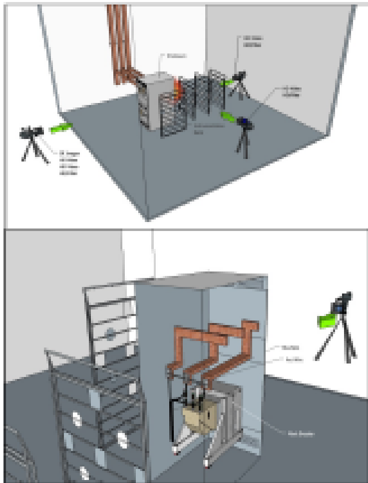
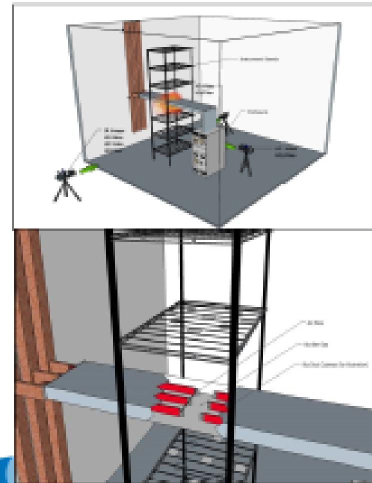
Enclosures



Bus Ducts



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Timeline of NRC Phase II actions

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- Public Comment Period Closes.. September 2, 2017 (Completed)
- OECD Comment Period.. August 31 / September 15, 2017 (Completed)
- OECD HEAF Meeting.. October 12, 2017 (Completed)
- 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

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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

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- 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

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Generator capabilities and applicability for HEAF testing

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- 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

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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		
Voltage (V)		
4160	6900	13800
320 MVA	430 MVA	690 MVA

5

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Protective relaying and the duration of testing

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- 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

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Protective relaying and the duration of testing

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- 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)

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Protective relaying and the duration of testing

(Low Voltage)

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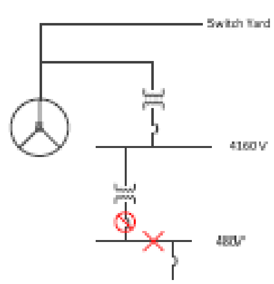
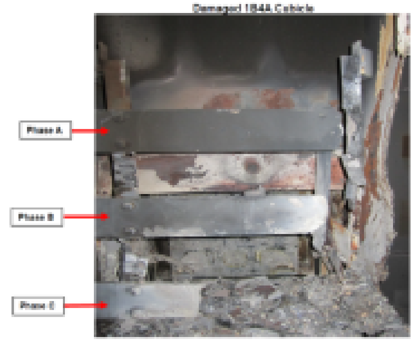
- Several low voltage events have exhibited the ability to hold in for extended durations from both U.S. OpE and International experience
  - Fort Calhoun- 42 seconds (interrupted by control room action)
  - German" Event 17" - 8.5 seconds; Analysis of High Energy Arcing Fault (HEAF) Fire Events," NEA/CSNI/R(2013)6



Damaged 1B4A Cubicle



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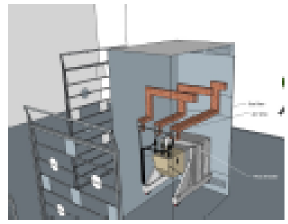
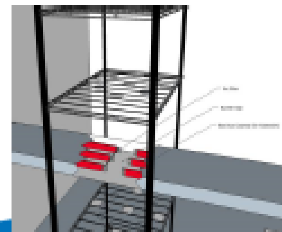
Test conditions

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





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

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- The NRC tests do not intend to replicate the IEEE guide.
- The NRC is <u>NOT</u> 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

10

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Test Parameters

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(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

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Questions?

12 WORKSHOP WRAPUP, SUMMARY OF RECOMMENDATIONS, AND FOLLOW-UP

12.1 Conclusion of Workshop

The workshop concluded with remarks from Mark Henry Salley, Chief of the Fire and External Hazards Analysis Branch, and Michael Cheok, Director of the Division of Risk Analysis in the Office of Nuclear Regulatory Research.

Mr. Salley thanked everyone for attending and providing valuable feedback and recommendations that will undoubtable improve the quality and results of this work. He reminded the attendees of the importance of performing the pilot plant focused-scope aluminum HEAF risk analysis. That effort is needed to support the GI program during the assessment stage for PRE-GI-018, and the NRC requests support from utilities and EPRI, through its MOU on fire risk, to accomplish this task.

Mr. Cheok thanked everyone in attendance and those on the webinar for spending the 2 days supporting this important work for the NRC and public safety. Interactions like this workshop provide an opportunity for participants to learn more about NRC processes and allows the NRC to better understand the comments and questions that it receives. Mr. Cheok also reminded the attendees that the Office of Nuclear Reactor Regulation is prominent in the GI process. Mr. Cheok's counterpart, Mike Franovich, Director of Division of Risk Assessment in the Office of Nuclear Reactor Regulation, followed the workshop via the webinar. Staff from both offices will work together to move this issue through the GI process.

12.2 Summary of Recommendations

The discussions held during the workshop resulted in several recommendations that were viewed as adding value to the program. Table 12-1 summarizes those recommendations.

Table 12-1 Summary of Workshop Recommendations

#	Description	Chapter
R1	It would be helpful for project tracking and status of the GI program to have a schedule of when specific actions are expected to be completed and any relationship between the individual actions items (i.e., dependencies).	4
R2	In order for EPRI or NEI to better support the pilot plant initiative, they would need to understand the NRC's expectations for a pilot plant. A timeline would also be useful.	4
R3	In addition to better characterization of the HEAF ZOI, associated HEAF frequency, binning, and suppression modeling improvements are needed to ensure a consistent risk assessment methodology.	4
R4	Perform a literature search.	5
R5	Tie EPRI into the discussion between NRC and NFPA members on the definitions.	5
R6	Consider changing system voltage to bus bar spacing as a parameter of importance for the medium-voltage tests.	6
R7	Consider reducing the number of low-voltage tests, given the presentation by EPRI indicating that less than 15 percent of the events are in the low-voltage class, while the draft test plan has 50 percent of the tests at low voltage.	10
R8	Change low-voltage durations to be within the range of 2 to 4 seconds	10
R9	Review IEEE literature on short-duration testing to support the basis of need for longer duration tests.	10
R10	Split the bus duct tests into insulated / non-insulated	10

12.3 Summary of Follow-Up Actions

The discussions held during the workshop identified several follow-up actions that were viewed as adding value to the program. Table 12-2 summarizes those actions.

Table 12-2 Summary of Follow-up Actions

#	Description	Responding Organizations	Chapter
A1	Develop a tentative schedule for PRE-GI-018 action items.	NRC	4
A2	Show dependencies between and among action items.	NRC	4
A3	Develop a charter for the pilot plant focused-scope HEAF assessment.	NRC	4
A4	Develop revised HEAF binning (definitions) and frequency estimates.	NRC / EPRI	4
A5	Conduct a literature search.	NRC	5
A6	Refine the definitions based on feedback from 2- and 3-second time durations of switchgear and breakers, respectively.	NRC	5
A7	Include EPRI in future collaboration on refinements to the definitions.	NRC / EPRI / NFPA	5
A8	Can the laboratory perform at isophase bus voltages? If so, is it worth including in this effort?	NRC / SNL	6
A9	What abilities are there for extrapolation or interoperation of test results?	NRC	6
A10	If needed, perform a public webinar to communicate the results from the small-scale testing.	NRC	6
A11	EPRI or NEI to support the NRC GI pilot plant assessment.	NRC / EPRI / NEI	8
A12	Prepare generator-fed fault decrement curves from high-speed digital recorders.	EPRI	10 & 11
A13	Develop the station power source characteristics to support the testing of power supply configurations.	EPRI	10
A14	Conduct follow-on interactions with stakeholders or EPRI, as needed.	NRC	10

13 REFERENCES

[1] 10 C.F.R. Part 50, "Domestic Licensing of Production and Utilization Facilities."

[2] Regulatory Guide 1.189, "Fire Protection for Nuclear Power Plants," Revision 3, U.S. Nuclear Regulatory Commission (NRC), Washington, DC, February 2018.

[3] EPRI TR-1011989 and NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities: Volume 2, Detailed Methodology." Electric Power Research Institute (EPRI), Palo Alto, CA, and NRC Office of Nuclear Regulatory Research, Washington, DC, September 2005.

[4] Supplement 1 to NUREG/CR-6850 and EPRI 1011989, "Fire Probabilistic Risk Assessment Methods Enhancements," EPRI, Palo Alto, CA, and NRC, Washington, DC, December 2009.

[5] NEA/CSNI/R(2013)6, "OECD Fire Project—Topical Report No. 1 Analysis of High Energy Arcing Fault (HEAF) Fire Events," Nuclear Energy Agency, Paris, France, June 2013.

[6] NEA/CSNI/R(2017)7, "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," Nuclear Energy Agency, Paris, France, May 2017.

[7] Information Notice 2017-04, "High Energy Arcing Faults In Electrical Equipment Containing Aluminum Components," NRC, Washington, DC, August 2017.

[8] FAQ 17-0013, "High Energy Arcing Fault (HEAF) Non-Suppression Probability (NSP)," NRC, Washington, DC, March 21, 2017.

[9] EPRI 3002011922, "Characterization of Testing and Event Experience for High-Energy Arcing Fault Events," Electric Power Research Institute, December 2017.

[10] EPRI 3002011923, "Nuclear Station Electrical Distribution Systems and High-Energy Arcing Fault Events," Electric Power Research Institute, December 2017.

[11] "HEAF Information Sharing Workshop Transcript, Day 1," ADAMS Accession No, ML18114A817.

[12] "HEAF Information Sharing Workshop Transcript, Day 2," ADAMS Accession No, ML18114A818.

[13] NEA/CSNI/R(2015)10, "A Review of Current Calculation Methods Used to Predict Damage from High Energy Arcing Fault (HEAF) Events," Nuclear Energy Agency, Paris, France, June 2015.

[14] NUREG-2218, "An International Phenomena Identification and Ranking Table (PIRT) Expert Elicitation Exercise for High Energy Arcing Faults (HEAFs)," NRC, Washington, DC, January 2018.

[15] NUREG/IA-0470, “Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena,” S/NRA/R, Tokyo, Japan, and NRC, Washington, DC, August 2016.

[16] NUREG-0933, “Resolution of Generic Safety Issues,” NRC, Washington, DC, December 2011.

[17] IEEE 1584, “IEEE Guide for Performing Arc Flash Hazard Calculations,” IEEE, September 2001.

[18] IEEE C37.20.7, “IEEE Guide for Testing Switchgear Rated Up to 52 kV for Internal Arcing Faults,” IEEE, January 2017.

APPENDIX A DRAFT LARGE-SCALE TEST PLAN AND COMMENTS

The citation information for the "High Energy Arcing Faults in Electrical Equipment, Phase 2, Draft Test Plan" as published in the *Federal Register* is as follows:

Date of Publication: August 2, 2017
Comment Period Close: September 1, 2017
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Page: 36006–36007 (2 pages)
Agency/Docket Number: NRC-2017-0168
Document Number: 2017-16233

The draft test plan is accessible on the companion DVD at the following file address:
/Reports & Documents/NRC Phase 2 Materials/Large Scale Testing/Draft Test Plan.pdf

The draft test plan is also accessible in the Agencywide Documents Access and Management System (ADAMS) at ADAMS Accession No. ML17201Q551 (https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML17201Q551).

The comments and their dispositions are accessible on the companion DVD at the following file address:
/Reports & Documents/NRC Phase 2 Materials/Large Scale Testing/Comments and Dispositions.pdf

The draft test plan is also accessible in the Agencywide Documents Access and Management System (ADAMS) at ADAMS Accession No. ML18233A469 (https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18233A469).

APPENDIX B REVISED LARGE-SCALE TEST PLAN

The revised large-scale test plan is detailed below. This final test plan incorporates public comments.

The final test plan is accessible on the companion DVD at the following file address:
/Reports & Documents/NRC Phase 2 Materials/Large Scale Testing/Revised Test Plan.pdf

APPENDIX C NEEDS AND OBJECTIVES

The workshop organizers disseminated “High Energy Arcing Fault (HEAF) Research, Needs and Objectives,” dated March 23, 2018, before the workshop for discussion at the event.

The document is accessible on the companion DVD at the following file address:
/April 2018 Workshop/Needs & Objectives.pdf

The document is also accessible in the Agencywide Documents Access and Management System (ADAMS) at ADAMS Accession No. ML18081B300 (https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18081B300).

APPENDIX D DRAFT SCMALL-SCALE TEST PLAN AND COMMENTS

The citation information for the "Aluminum High Energy Arc Fault (HEAF) Particle Size Characterization Test Plan—DRAFT," dated February 5, 2018 (draft small-scale test plan) as published in the *Federal Register* is as follows:

Date of Publication: March 5, 2018
Comment Period Close: April 4, 2018
Document Citation: 83 FR 9344
Page: 9344–9345 (2 pages)
Agency/Docket Number: NRC-2018-0040
Document Number: 2018-04341

The draft small-scale test plan is accessible on the companion DVD at the following file address:
/Reports & Documents/NRC Phase 2 Materials/Small Scale Testing/Draft Test Plan.pdf

The draft test plan is also accessible in the Agencywide Documents Access and Management System (ADAMS) at ADAMS Accession No. ML18036A448 (https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18036A448).

The comments received on this draft test plan and their resolution are available on the companion DVD in the following folder:
/Reports & Documents/NRC Phase 2 Materials/Small Scale Testing/

The draft small-scale test plan comments and their resolution are also accessible in ADAMS at ADAMS Accession No. ML18163A423 (https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML18163A423).

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10. SUPPLEMENTARY NOTES

M. Salley, NRC Project Manager

11. ABSTRACT (200 words or less)

The U.S. Nuclear Regulatory Commission (NRC) organized the *Information-Sharing Workshop on High Energy Arcing Faults (HEAFs).* The workshop took place April 18–19, 2018, at the NRC Headquarters in Rockville, MD. The NRC coordinated the workshop with the Electric Power Research Institute (EPRI) and the National Fire Protection Association (NFPA) and advertised it at recent nuclear industry information forums and during recent NRC public meetings related to fire protection. The workshop technical topics focused on HEAF hazards and recently completed and ongoing research initiatives. The workshop also included discussion about the NRC's generic issues program as it relates the aluminum HEAF issue. The objectives of the workshop were to (1) inform interested stakeholders about the status of PRE-GI-018 and related research, (2) review and resolve public comments received on the Phase II draft test plan, (3) solicit and review information from industry partners on common equipment types and configurations to inform future testing, and (4) provide an opportunity for public feedback on future testing. This report documents the recommendations and insights given during session presentations and the discussions that followed.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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arc flash
high energy arcing fault (HEAF)
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fire safety

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