Office of Nuclear Regulatory Research

High-Energy Arcing Faults Involving Aluminum: A Path to Resolution

Office of Nuclear Regulatory Research
Division of Risk Analysis
Fire and External Hazards Analysis Branch

Exhibit Overview

1) Background of HEAF Program
Brief overview of the origins of the NRC's HEAF Research Program.

2) Progress of the Joint Working Group
Updates on the progress of the NRC/Electric Power Research Institute (EPRI) working group, including hazard modeling and probabilistic risk assessment (PRA) methodology.

3) Technical and Regulatory Paths to Resolution
Next steps in the research and regulatory approach and incorporation of enterprise risk management strategies.

4) Live Q&A Session
NRC staff will be available to answer questions or take comments during a live Q&A session.

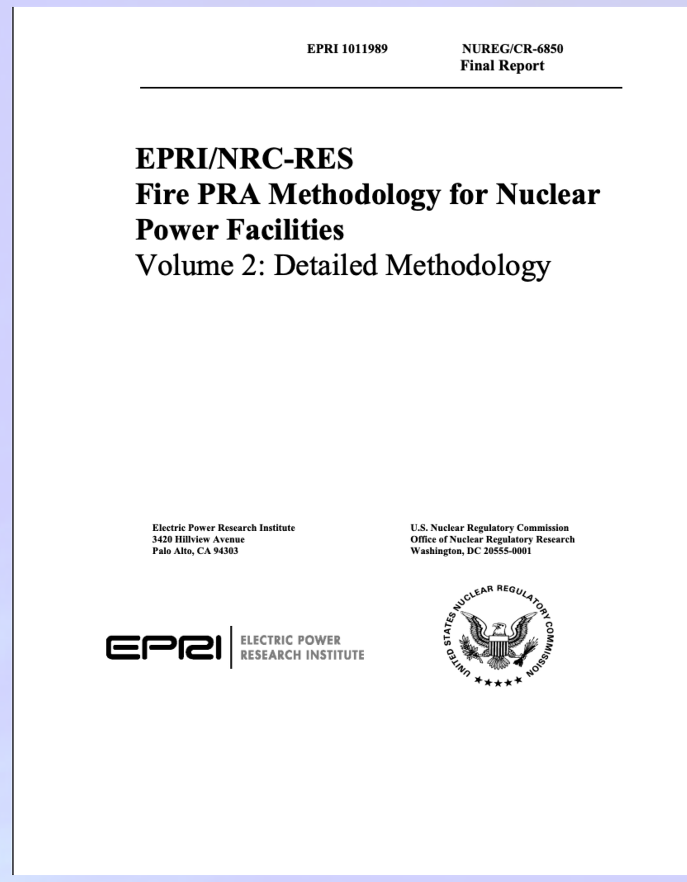
What Is a HEAF?

- Sustained discharge of electric current across a gap between two conductors with different voltages.
- Typically observed in switching equipment with voltages of 440 volts and higher and bus ducts.
- Generates significant heat, light, and pressure, which have the potential to damage surrounding equipment.

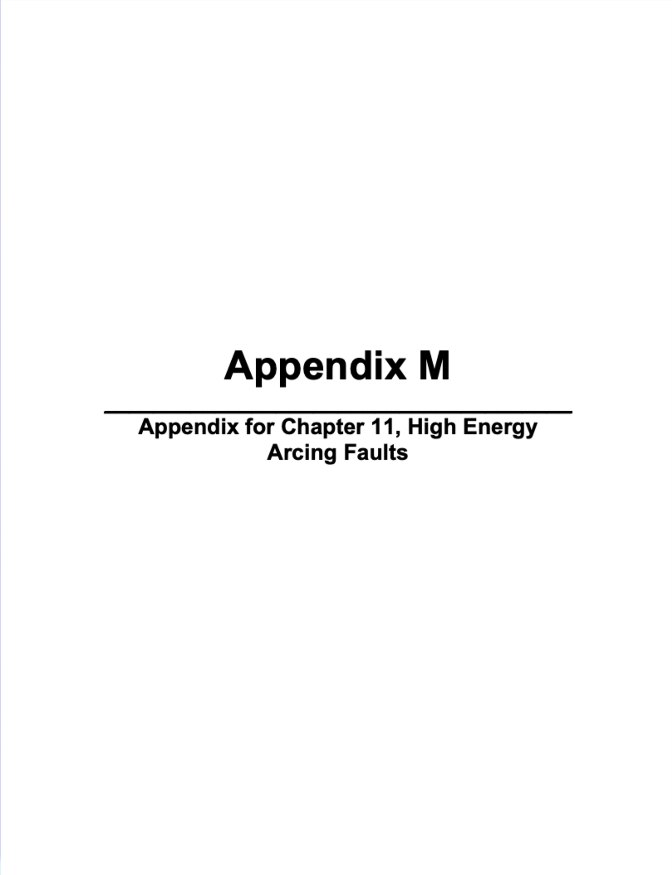
A. Upper right: Damage to a bus duct caused by a HEAF at Columbia in 2009.
B. Lower left: Damage to an electrical enclosure caused by a HEAF at Prairie Island in 2001.
C. Lower right: Damage to a bus duct caused by a HEAF at Diablo Canyon in 2000.

Existing HEAF Models

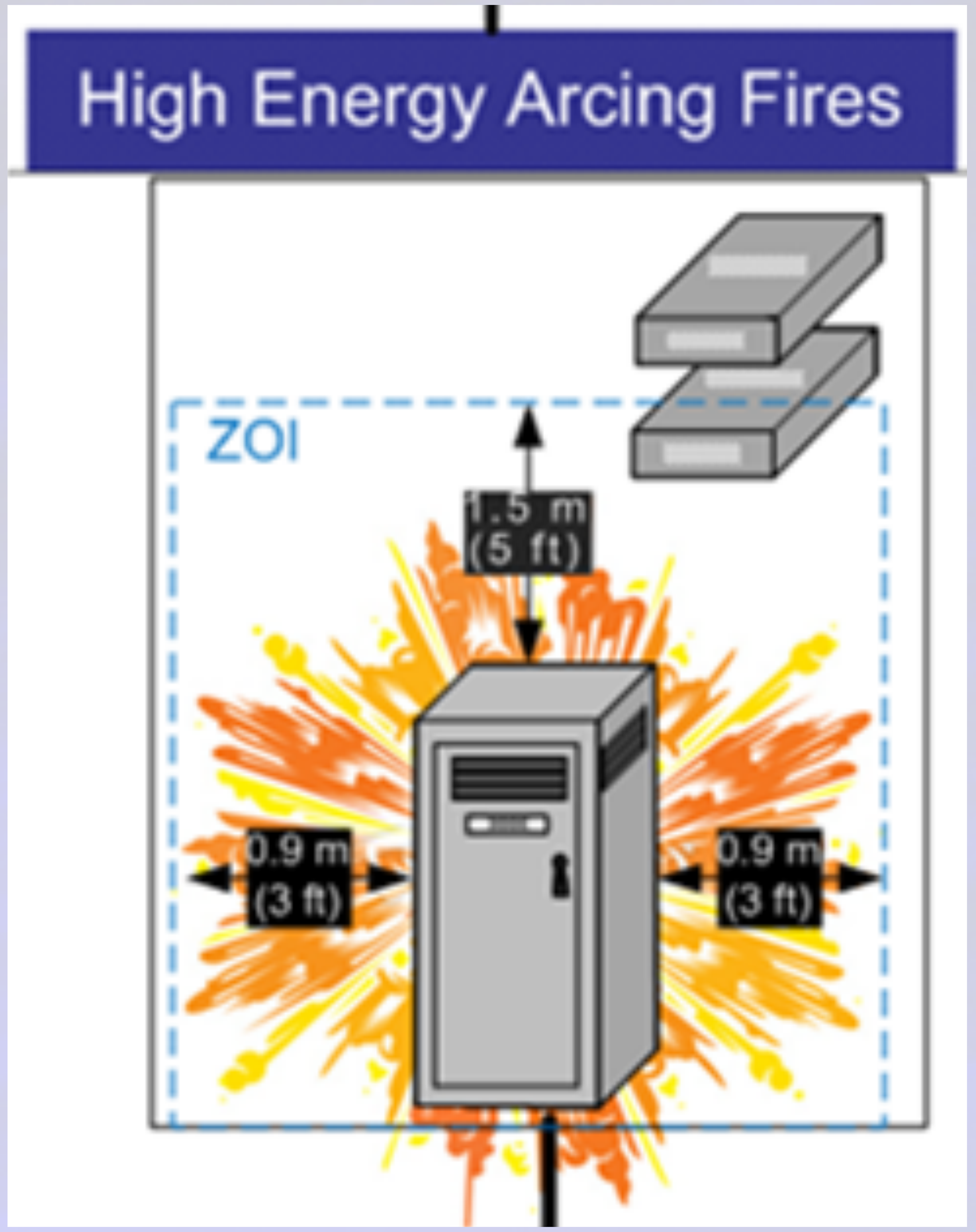
The original hazard model for HEAFs, documented in Appendix M to NUREG/CR-6850, was based largely on the 2001 event at the San Onofre Nuclear Generating Station.


EPRI 1011989 NUREG/CR-6850 Final Report

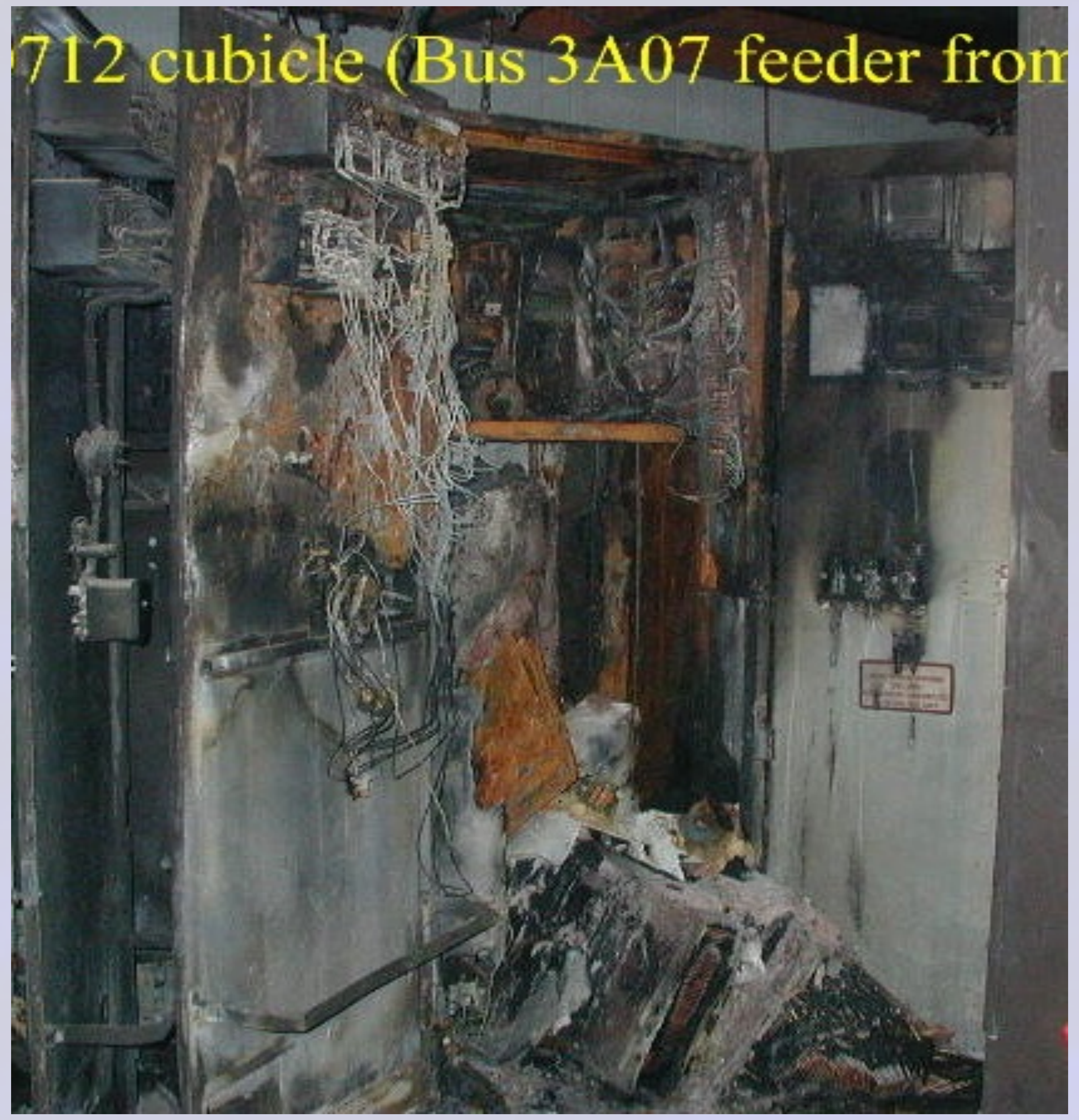
EPRI/NRC-RES
Fire PRA Methodology for Nuclear Power Facilities
Volume 2: Detailed Methodology


Appendix M

Appendix for Chapter 11, High Energy Arcing Faults



Idealized graphic depicting the current zone of influence (ZOI) for a HEAF in an electrical enclosure.

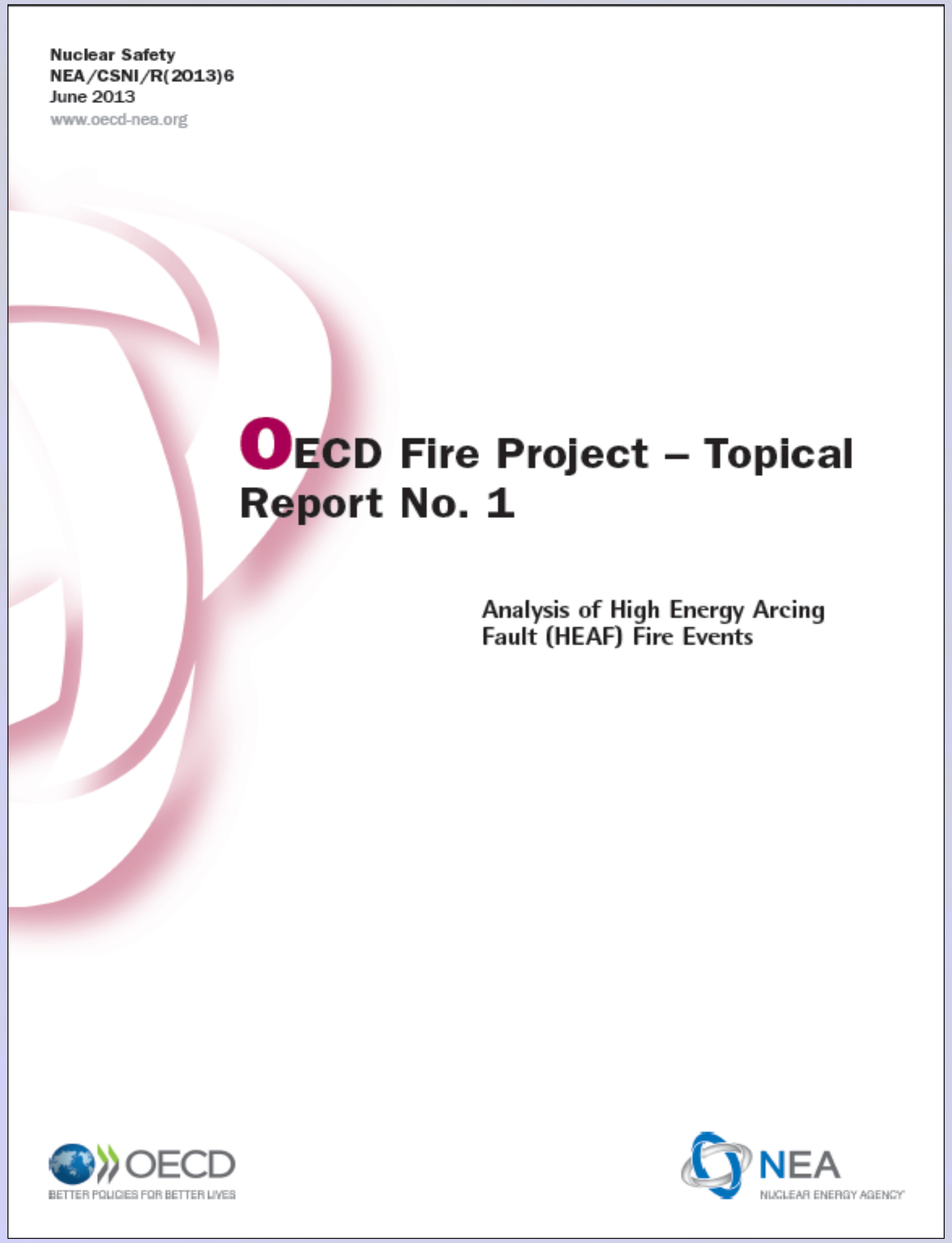


Damage caused by the 2001 San Onofre. HEAF event, upon which the current model is based.

HEAFs Reexamined

OECD/NEA International Fire Incident Records Exchange (FIRE) Program

- HEAFs often associated with complicated shutdowns.
- Hazard model in use had few supporting data.
- Better technical basis needed.


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

OECD Fire Project – Topical Report No. 1

Analysis of High Energy Arcing Fault (HEAF) Fire Events

OECD BETTER POLICIES FOR BETTER LIVES
NEA NUCLEAR ENERGY AGENCY

EXECUTIVE SUMMARY

Operating experience from nuclear installations has shown a non-negligible number of reportable events with non-chemical explosions and rapid fires resulting from high energy arcing faults (HEAF) in high voltage equipment such as circuit breakers and switchgears. Such electric arcs have led in some events to partly significant consequences to the environment of these components exceeding typical fire effects. Investigations of this type of events have indicated failures of fire barriers and their elements as well as of fire protection features due to pressure build-up in electric cabinets, transformers and/or compartments.

Left: The cover of NEA/CSNI/R(2013)6—OECD Fire Project Topical Report No. 1. Report available at https://www.oecd-nea.org/jcms/pl_19310/oecd-fire-project-topical-report-no-1-analysis-of-high-energy-arcing-faults-heaf.

Above: An excerpt from the executive summary highlighting key conclusions of the report.

Confirmatory Research – Phase I

Damage from a 480-volt test at 35 kA for 8 seconds, copper conductors. Energy release largely in agreement with existing models.

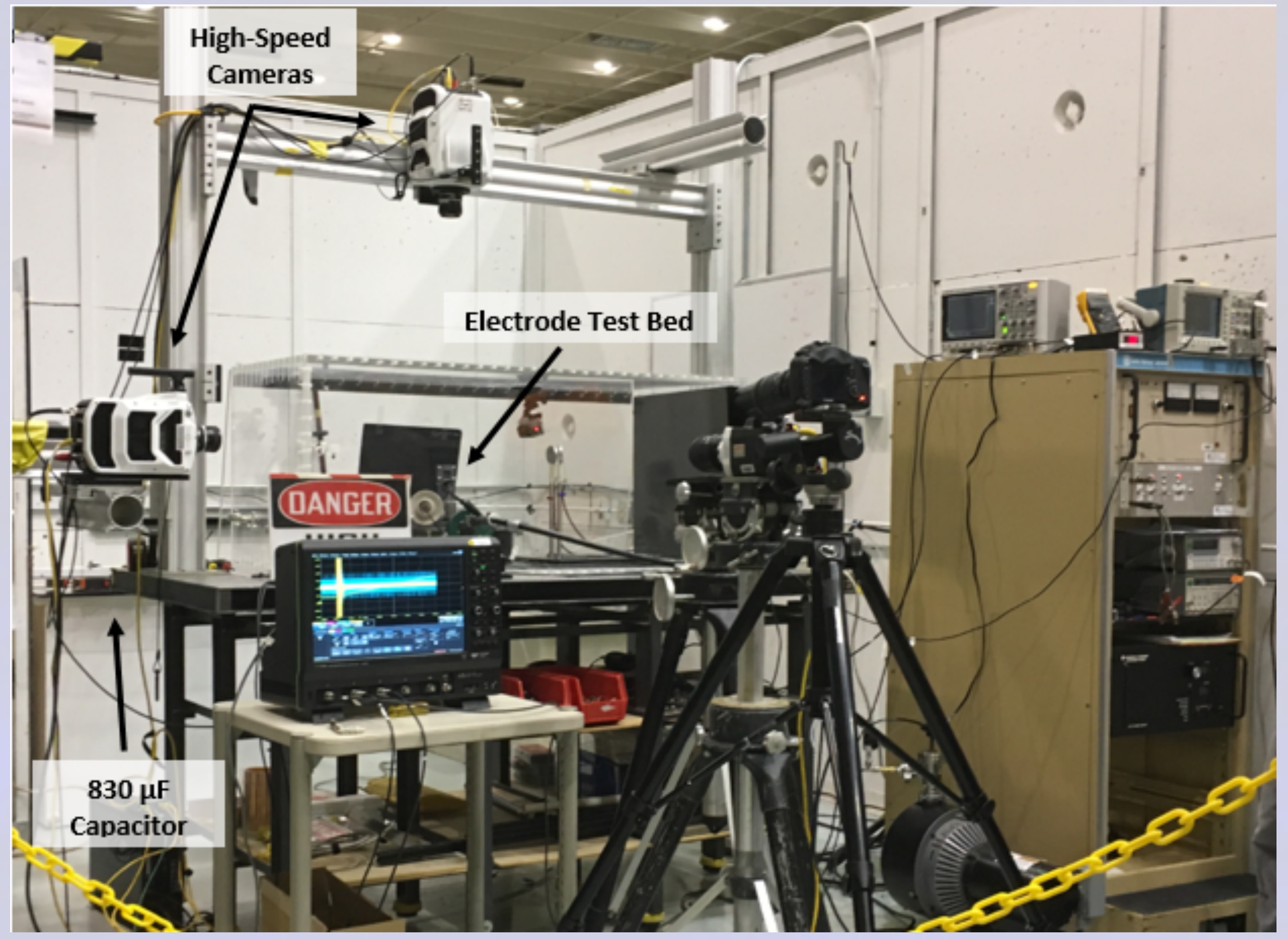
Damage from a 600-volt test at 40 kA for 7 seconds, aluminum conductors. Energy release exceeds existing models.

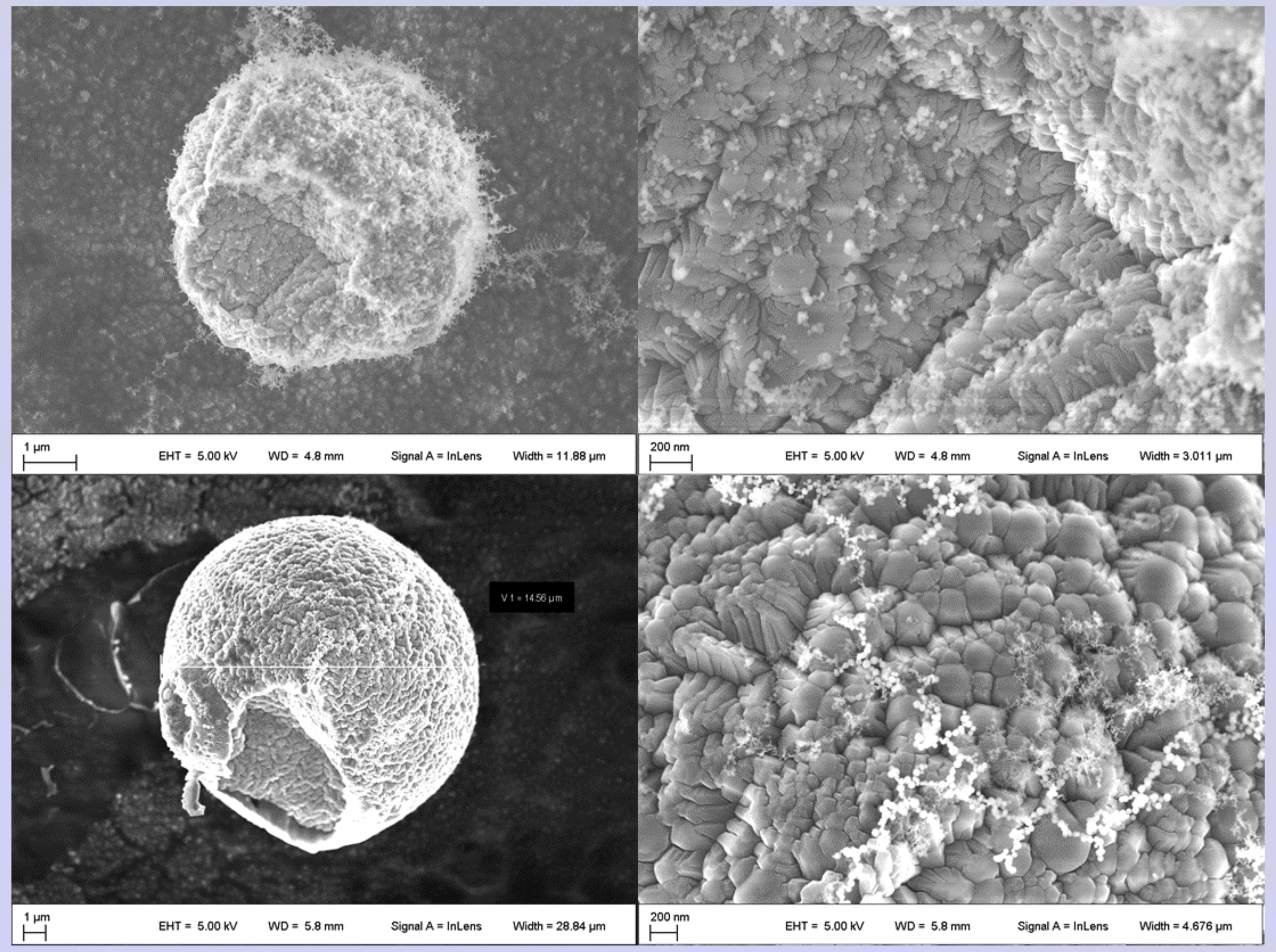
Damage from a 4160-volt test at 27 kA for 4 seconds, copper conductors with aluminum housing. Aluminum oxidation effects observed.

Confirmatory Research—Focus on Aluminum

Experiments at three scales:

- Small-scale testing to investigate aluminum oxidation and morphology.
- Medium-scale "open-box" testing to investigate the temperature and spectral emissions of the arc column.
- Large-scale testing to investigate enclosure breach and energy distribution.





A. Upper left: Small-scale test apparatus at Sandia National Laboratories.
B. Upper right: Posttest photo of "open-box" test 4 at KEMA Laboratories.
C. Lower left: Small-scale microscopy results of aluminum particulate morphology and oxidation.
D. Lower right: Enclosure breach during full-scale testing at KEMA Laboratories, medium-voltage with aluminum conductors.

Joint NRC/EPRI Working Group

Working Group Goal Statements:

- Characterize the primary factors that influence the occurrence and severity of arcing fault events (arc flash, arc blast, or HEAF).
- Develop tools and methods to assess the risk posed by arcing fault events based on experimental data, operating experience, and engineering judgment.
- Analyze the plant impact of, and quantify the change in risk from, arcing fault events involving copper and aluminum.

Major Working Group Tasks:

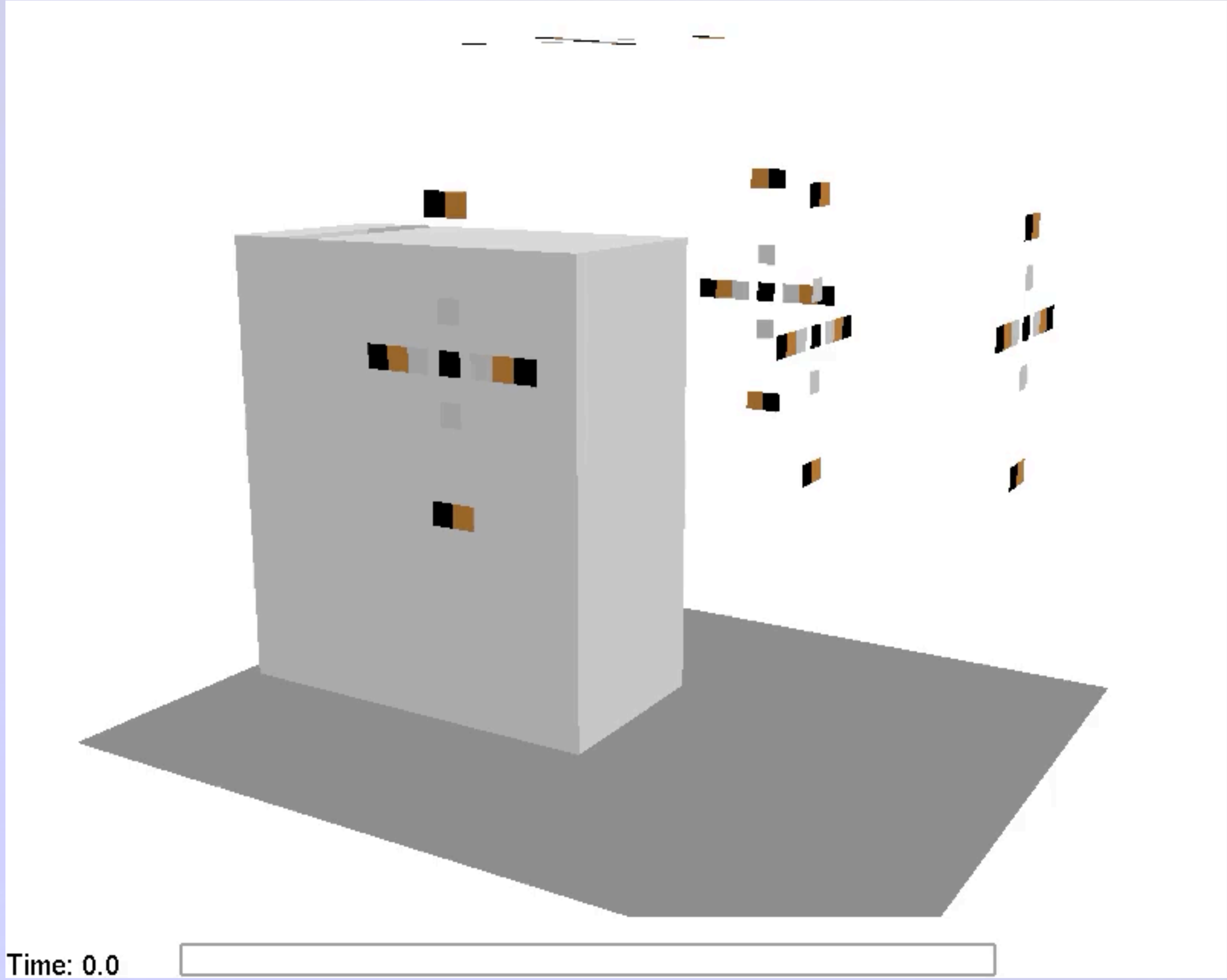
- EPRI survey of U.S. nuclear fleet.
- Hazard modeling and validation.
- Updated PRA guidance.
- Target fragility testing and characterization.

EPRI Survey

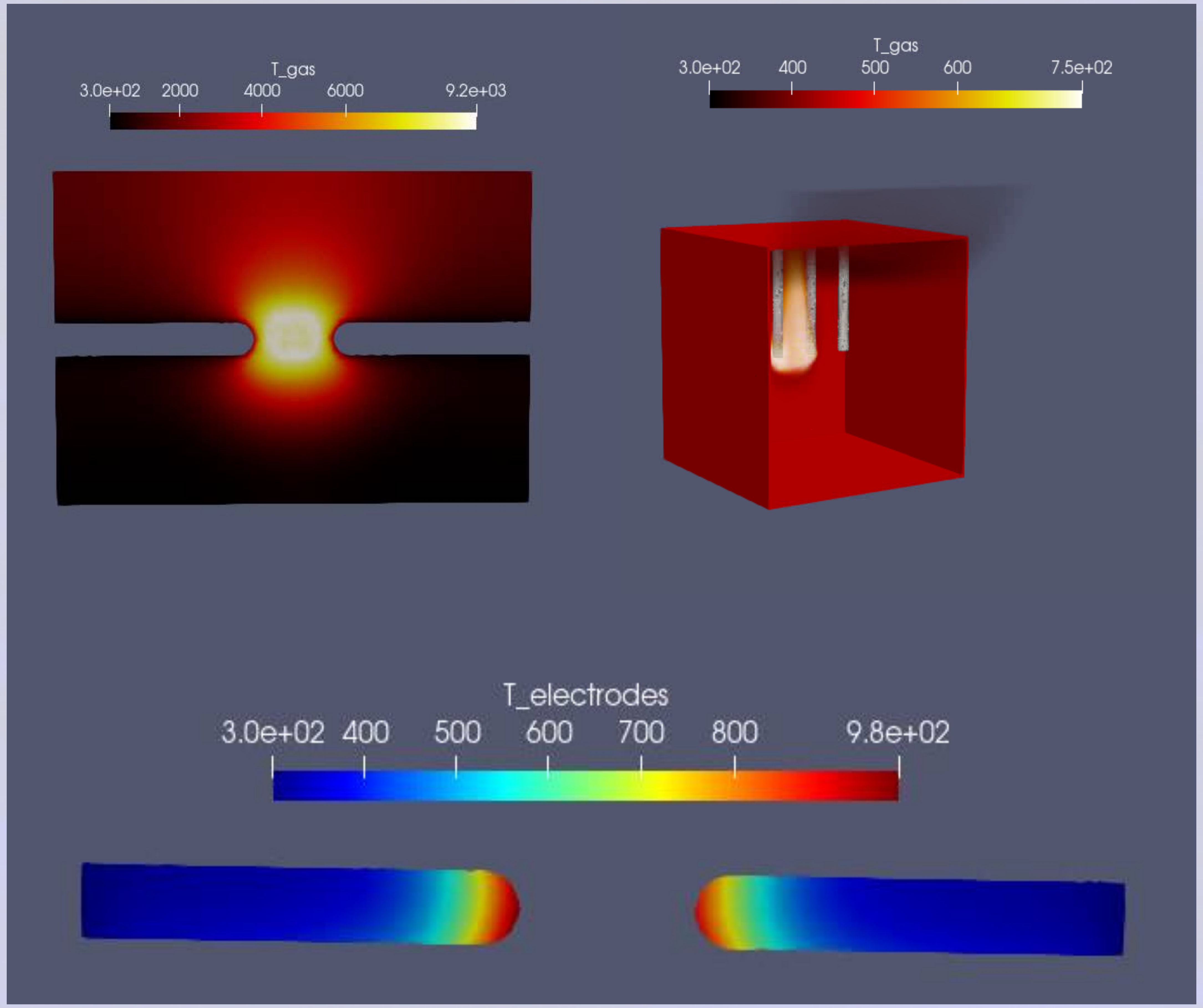
Types of Information Collected:

- General plant information.
- The number of plants with aluminum in equipment susceptible to HEAFs.
- Types of equipment containing aluminum, including medium-voltage switchgear, low-voltage switchgear, load centers, nonsegregated bus ducts, and isophase bus ducts.
- Information on equipment containing aluminum, including manufacturer, model, voltage, enclosure material, location of aluminum, and bus bar insulation.
- Electrical design information, including unit auxiliary transformer lineup and fault clearing times.

Multiphysics Modeling



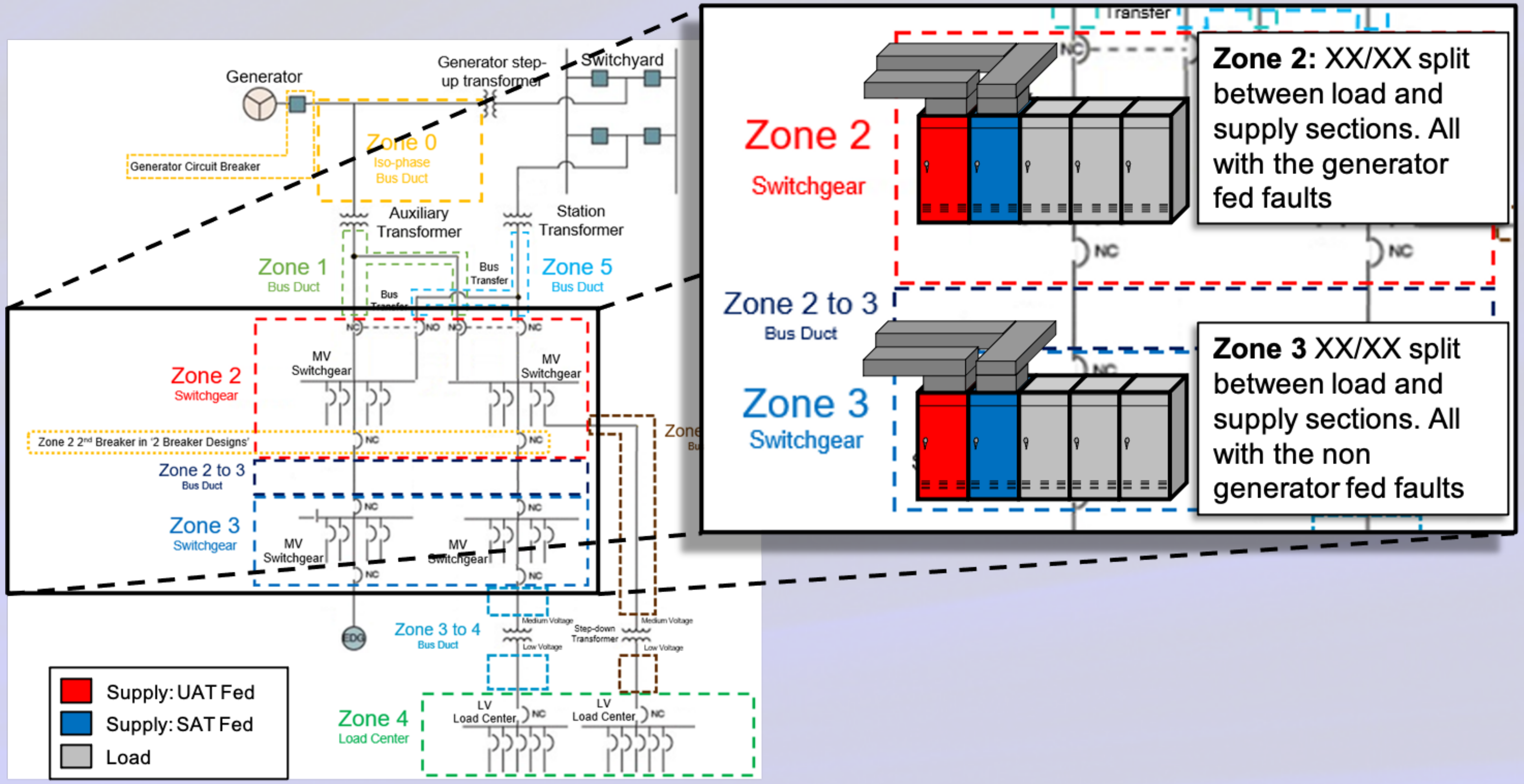
A simulation of test 2-24 (medium-voltage switchgear with aluminum bus bars) performed in the Fire Dynamics Simulator.



Simulated results from the SIERRA modeling framework showing local temperatures at the electrodes.

Updated PRA Methodology

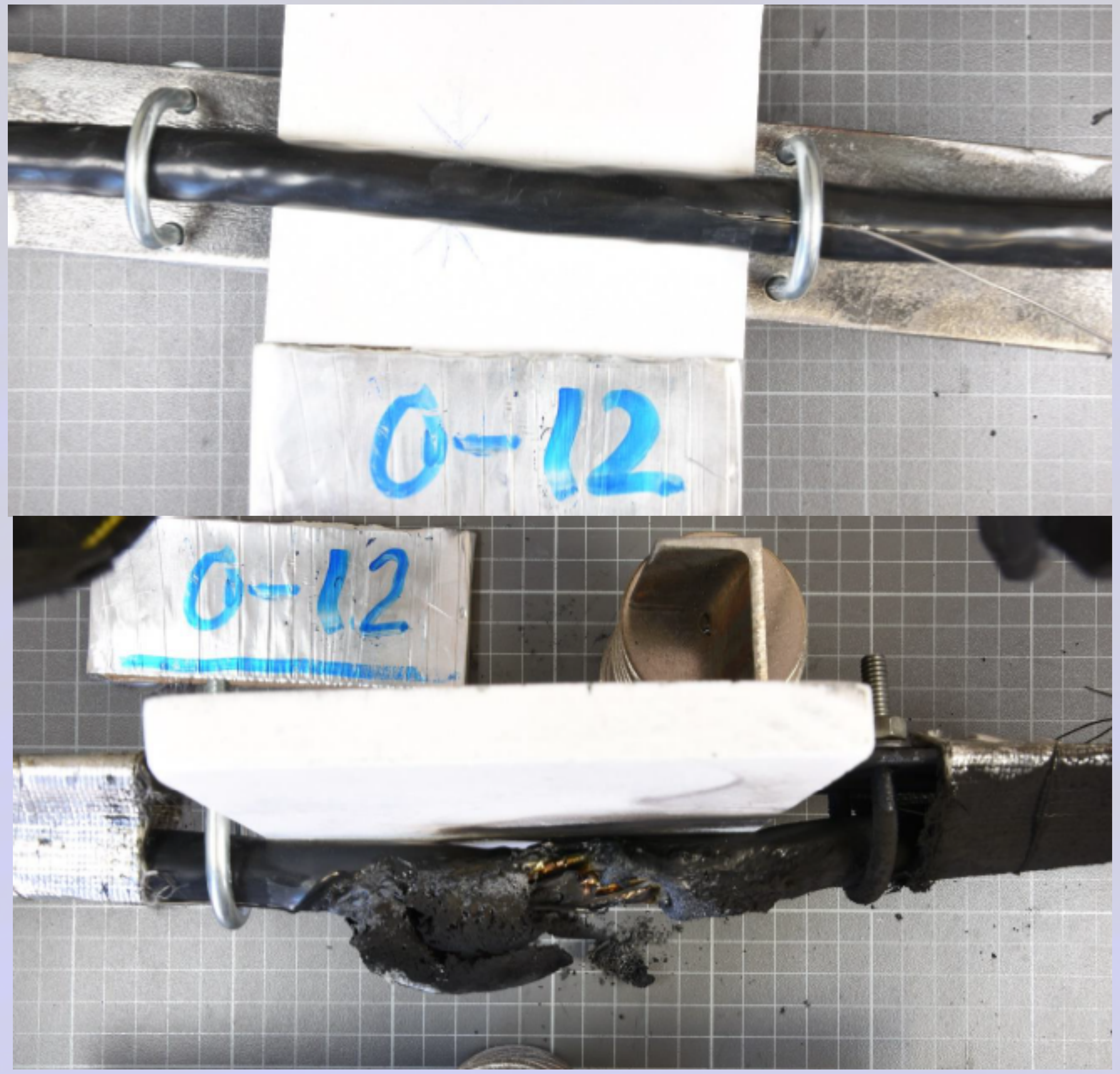
- Aimed at improving the realism and fidelity of the hazard model.
- Includes an evaluation of U.S. operating experience, updated fire ignition frequencies, and updated nonsuppression probabilities.
- Also incorporates the configuration of plant electrical distribution systems.

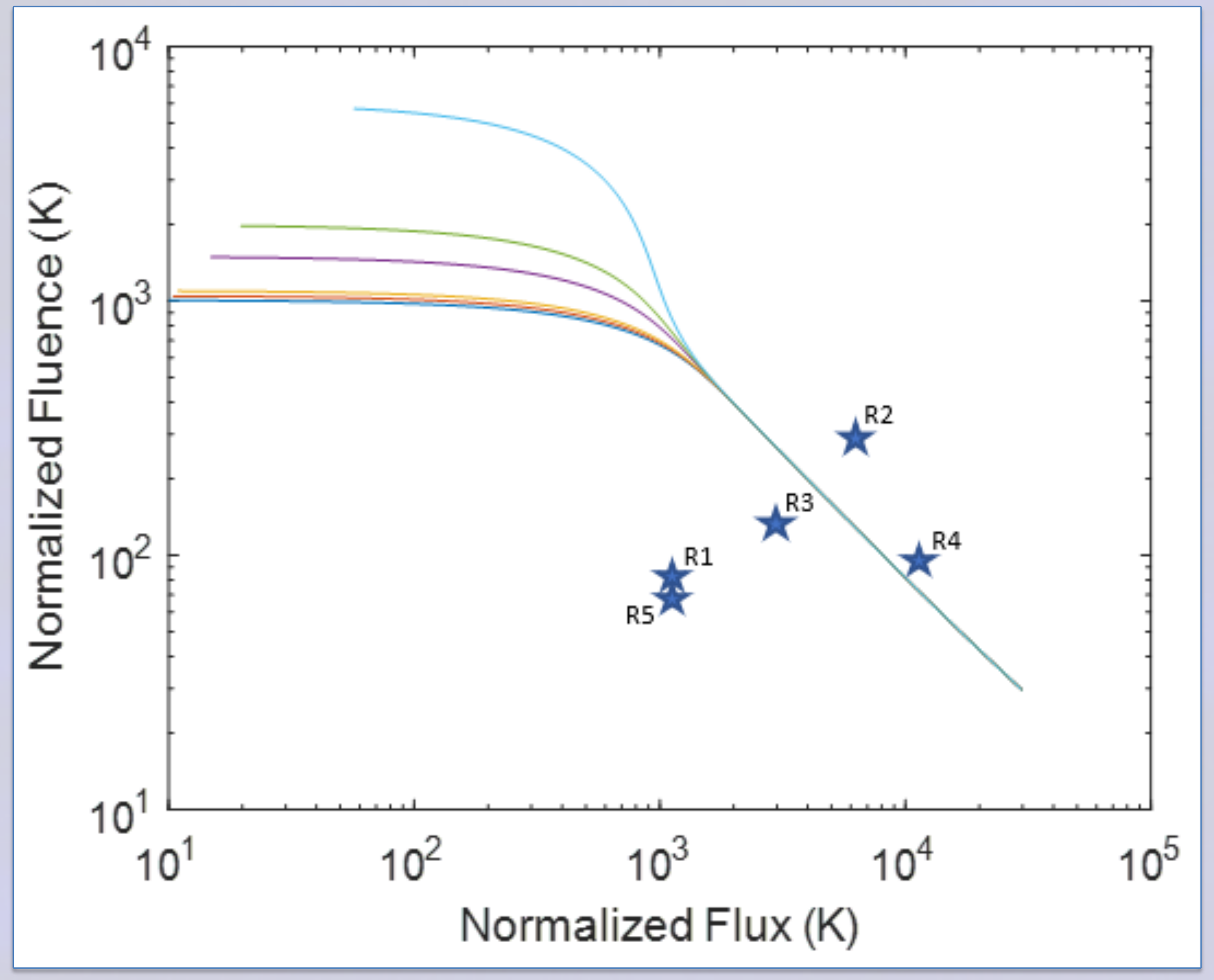


Sample analysis of a plant electrical distribution system for updated PRA methodology.

Target Fragility Testing

The response of common PRA targets is being tested for HEAF-like exposures at Sandia National Laboratories' Solar Furnace test facility.





Left: Reflective surface at Sandia National Laboratories' Solar Furnace test facility.

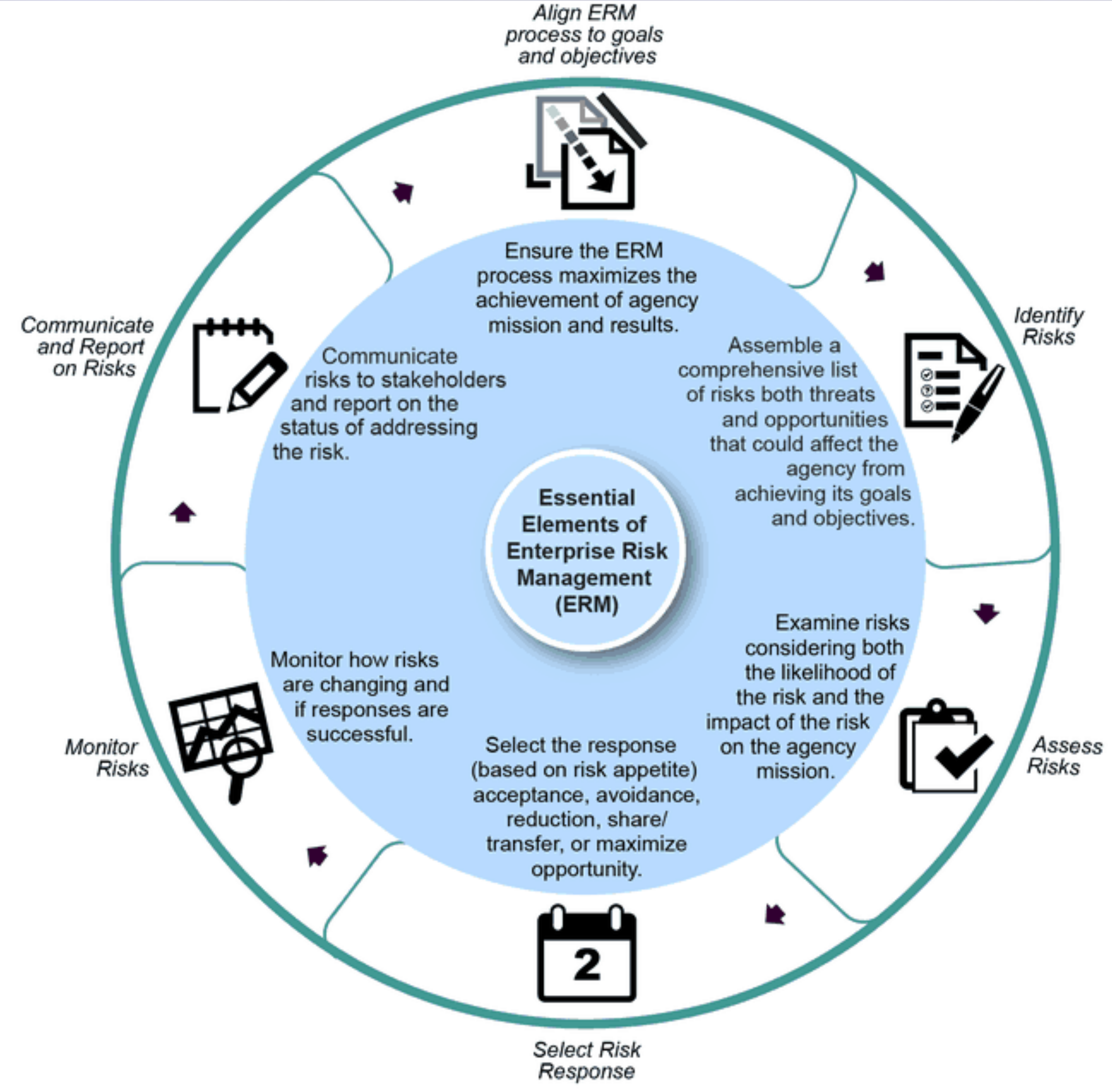
Above: Pre- and post-test cable samples showing damage caused by thermal exposure.

Right: Sample fragility model based on critical target parameters.

This damage model can be coupled with the hazard and PRA models to comprehensively and realistically assess the risk of HEAFs.

Regulatory Treatment

- The NRC is pursuing an enterprise risk management approach to achieve timely resolution of the aluminum HEAF issue.
- This approach will apply an NRC screening method using EPRI insights to bin plants of interest for further evaluation.
- The screening method will consider factors such as the fidelity of the fire PRA model, the conditional core damage probability of aluminum HEAF, and the change in core damage frequency.
- The screening method will also take into account EPRI best practices and potential mitigation using Diverse and Flexible Coping Strategies (FLEX) equipment as appropriate.



Source: GAO. | GAO-17-63

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HEAF Web Site

https://www.nrc.gov/about-nrc/regulatory/research/fire-research/heaf-research.html