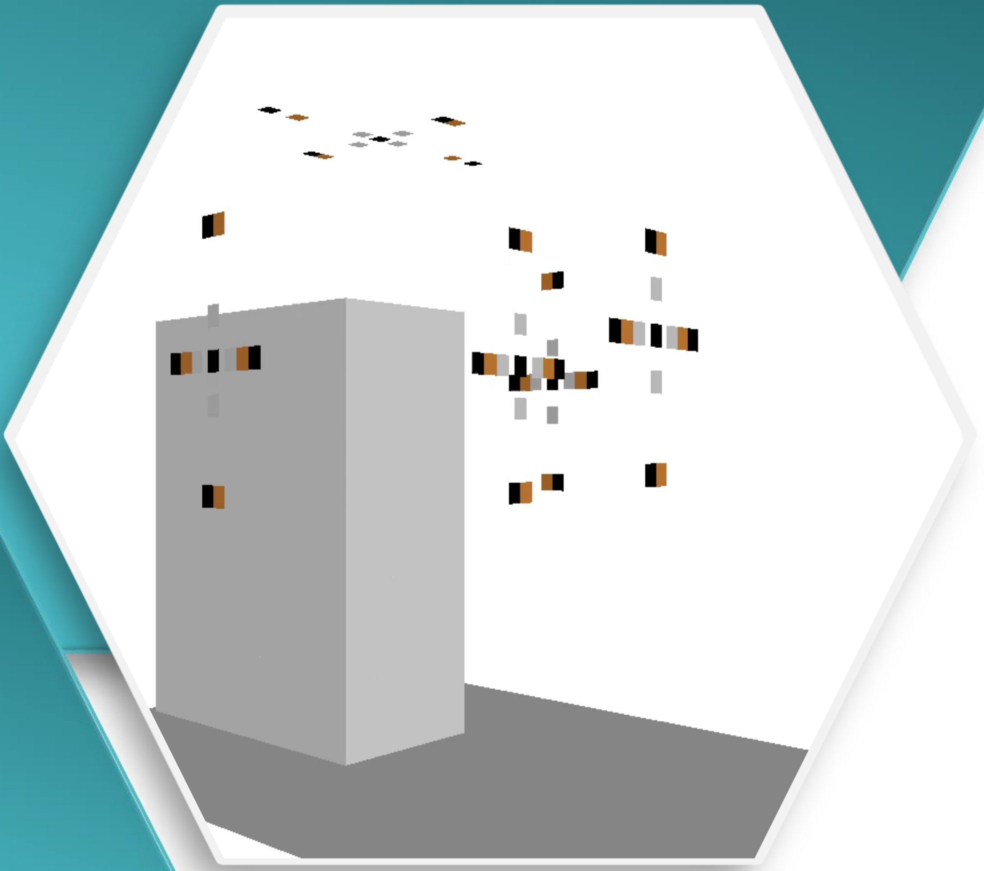


SMiRT 26
50 Anniversary Berlin/Potsdam
26th International Conference on Structural Mechanics in Reactor Technology (SMiRT 26)
17th International Post-Conference Seminar on
"FIRE SAFETY IN NUCLEAR POWER PLANTS AND INSTALLATIONS"
IASMiRT

Development of Improved High Energy Arcing Fault (HEAF) Target Damage Thresholds and Zone of Influence (ZOI) Models

Kevin Coyne, Gabriel Taylor, Kenneth Hamburger, Nicholas Melly, Kevin McGrattan, Mark Henry Salley

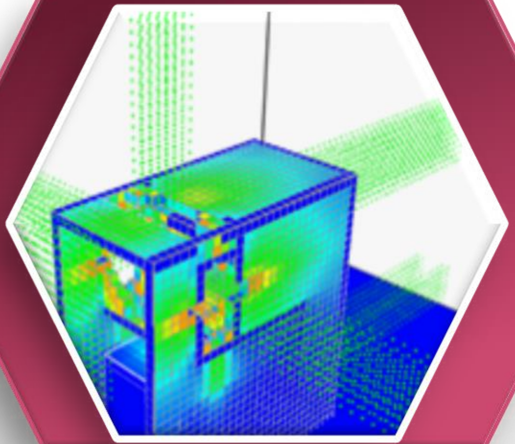
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

ZOI **Development**

Comprised of three major research activities

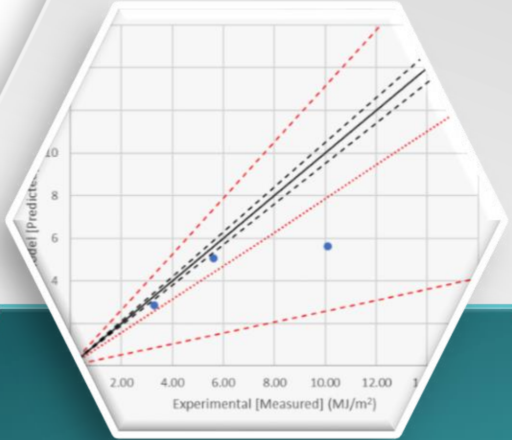
Updated Fragility Modeling

Physical testing and operating experience to develop fragilities for electrical cables



CFD Simulations

FDS development and application to large matrix of configurations



Confirmatory ZOI Analysis

Independent confirmation using modified IEEE arc flash model

Cable Fragility Experiments

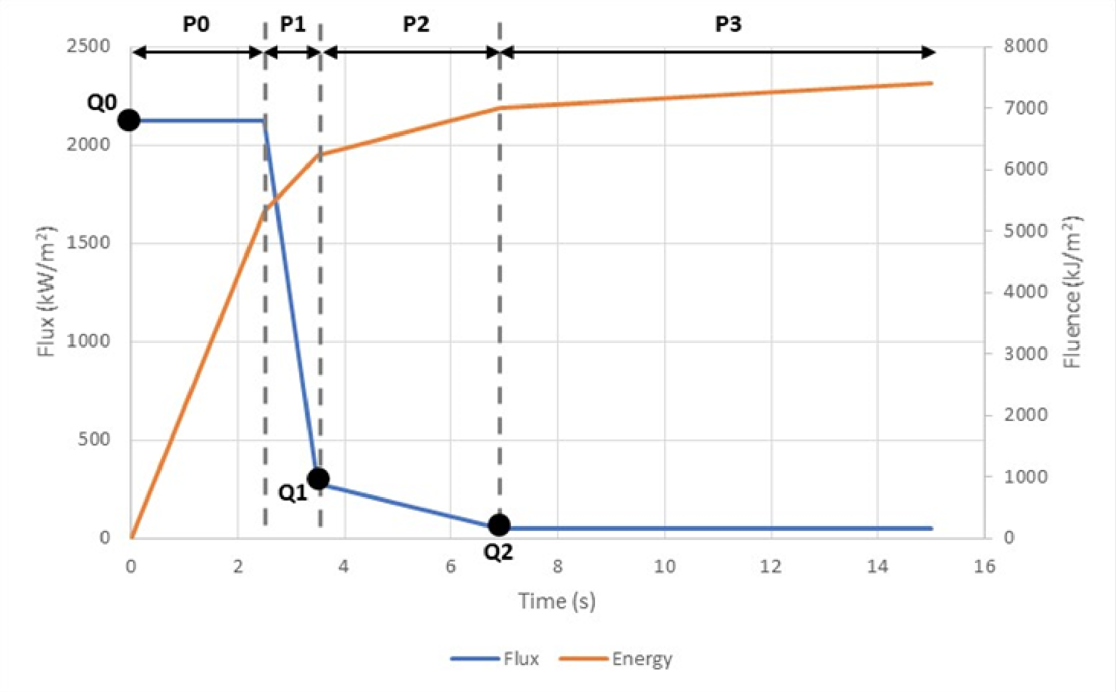
SNL Solar Furnace Facility

Heliostat and parabolic reflector, generating up to 6 MW/m^2 over a 5 cm circle

Varied heat flux, duration, cable material, and exposure profile

Objective was to develop metrics for evaluating cable failure and quantify threshold criteria

Solar Furnace Testing Methodology



Test 1-22 (7 MJ/m^2): Surface damage to jacket only

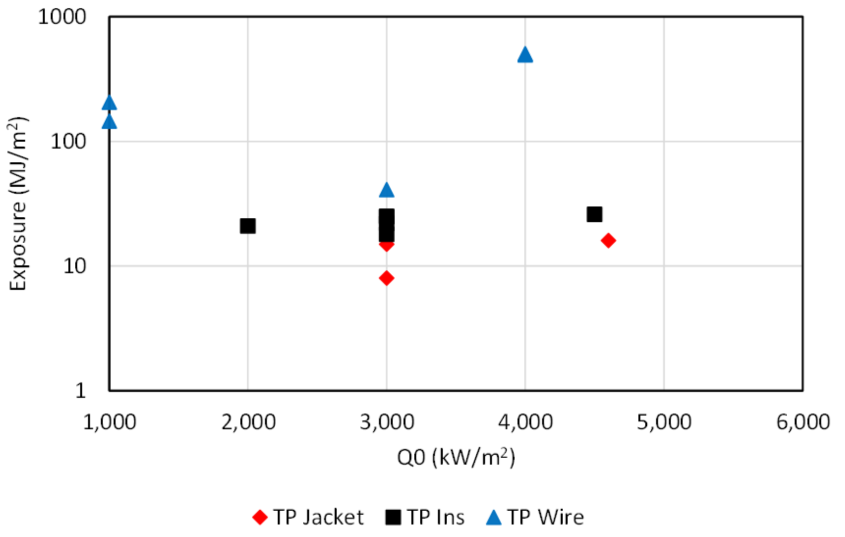
Test 1-32 (24 MJ/m^2): Sub-jacket shielding visible

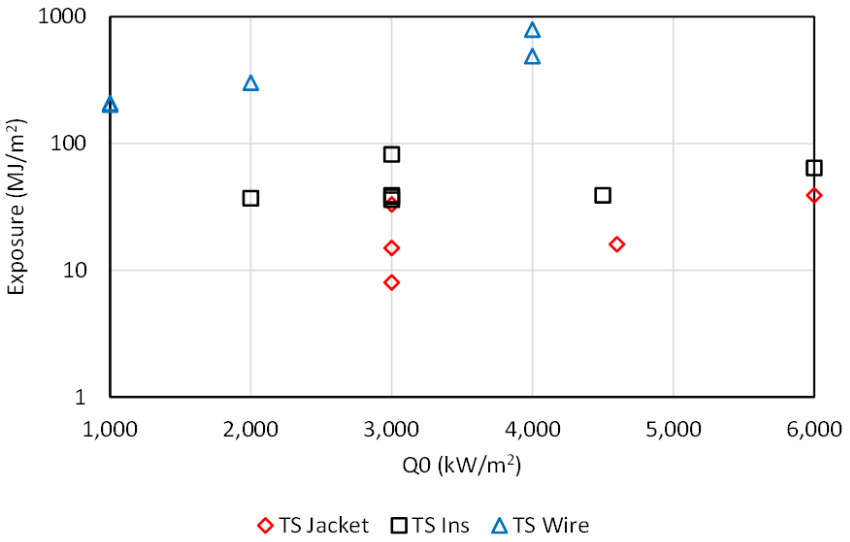
Test 1-09 (206 MJ/m^2): Cable insulation and bare wire exposed

Solar Furnace Testing Results

Total of 38 tests conducted, and categorized by damage extent: jacket damage, insulation exposure, conducting wire exposure

Results for initial heat fluxes of >1 MW/m^2 are shown (upper plot thermoplastic, lower plot thermoset)





Fragility Working Group

Process for data analysis and consensus building

1

Proposal Development

Two teams developed proposals to address the specific technical issues

2

Weekly Meetings

Proposals presented to full working group and resource experts for feedback

3

Consensus

Technical evaluators and integrators caucused to reach agreement on path forward for each issue

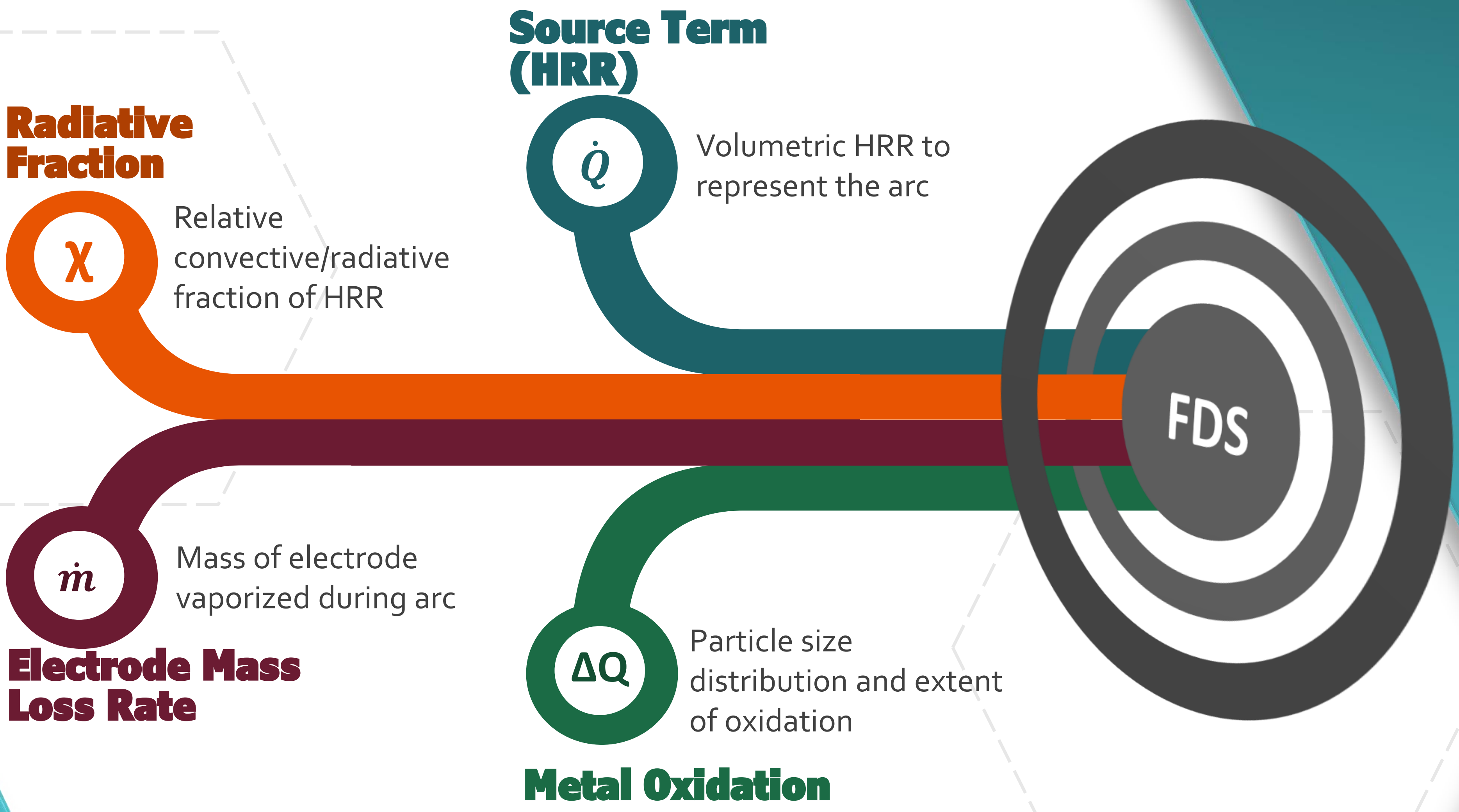
Fragility Working Group Conclusions

The threshold for electrical failure/damage of thermoplastic jacketed cables is 15 MJ/m^2 and the threshold for thermoset jacketed cables is 30 MJ/m^2

Sustained ignition is assumed for cables within the enclosure of origin (e.g. internal cables and components within switchgear and load centers)

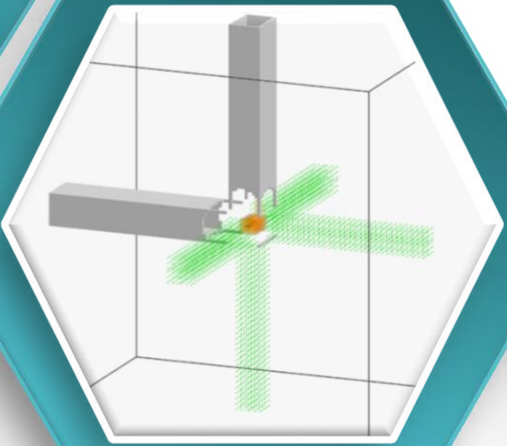
1 hour (or greater) rated Electrical Fire Raceway Barrier System (ERFBS) will prevent ignition inside the enclosure of origin, and damage in the ZOI

FDS Inputs



Radiative Fraction
χ
Relative convective/radiative fraction of HRR
Source Term (HRR)
$\dot{Q}$
Volumetric HRR to represent the arc
FDS
Electrode Mass Loss Rate
$\dot{m}$
Mass of electrode vaporized during arc
Metal Oxidation
ΔQ
Particle size distribution and extent of oxidation

Heat Release Rate Development



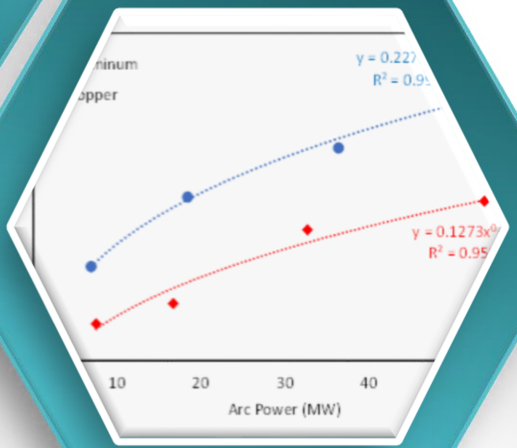
Volumetric HRR Definition

FDS does not include models for electrical/magnetic fields, dissociation of molecules at high temperatures, or formation of plasma

Total arc energy can be accounted for using arc voltage, current, and duration

A volume was defined in FDS to approximate the arcing region with the same total arc energy

Radiative Fraction & Electrode Mass Loss

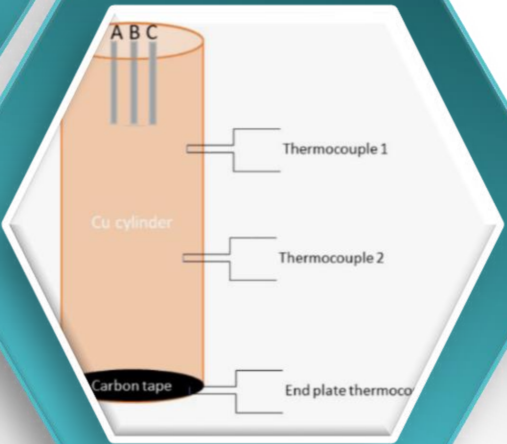


Data from Literature

Cressault developed radiative fraction correlations for electrical arcs as a function of electrode material (aluminum, copper) and arc power

Stanback developed electrode mass loss rate correlations as a function of electrode material (aluminum, copper) and arc current

Metal Oxidation



Experimental Data

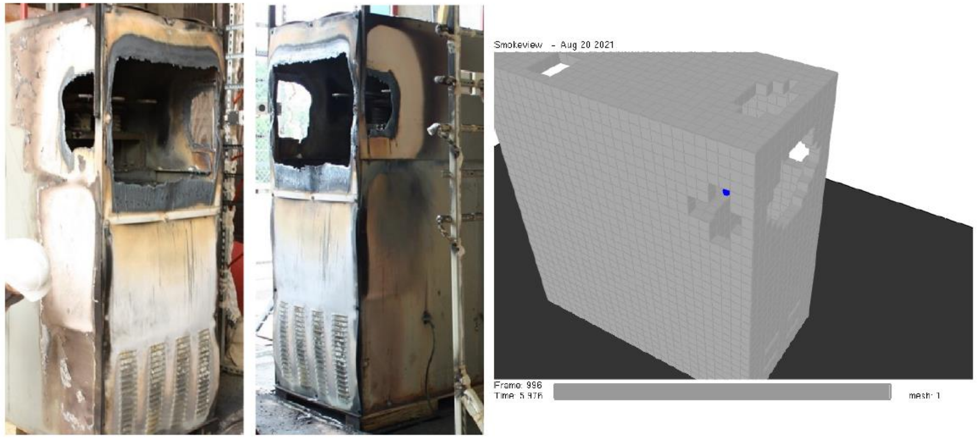
SNL conducted experiments in a closed calorimeter with scaled current densities

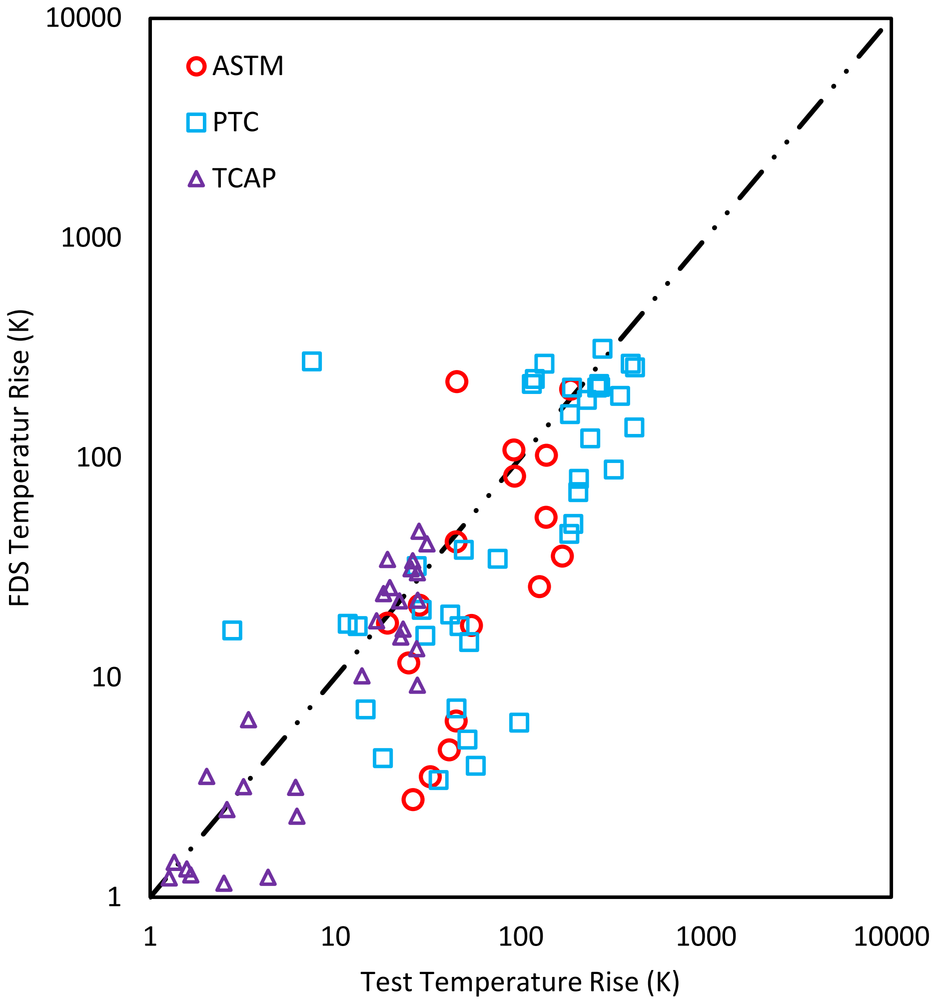
Experiments determined vapor fraction of lost electrode and extent of particle oxidation

Nozzles defined in FDS to emit metal particles with defined oxidation rates at each conductor in the arc volume

FDS Validation

Full-scale experiments used for model validation; unbiased FDS predictions plotted against experimental temperatures for MV switchgear shown at right





Processing the FDS Run Matrix

Scripted Automation

A matrix of FDS simulations was created to vary the important inputs: energy profile, geometric configuration, electrode material, housing material, and arc initiation location

In total, 130+ simulations were run

A Python script, FDS template, and parameter file were used to programmatically swap the relevant variables in and out and reduce the chance of human error

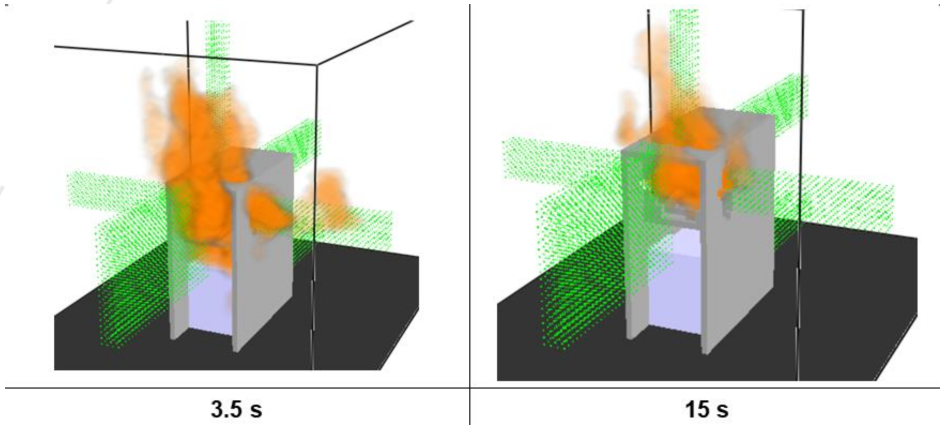
FDS Results & Conclusions

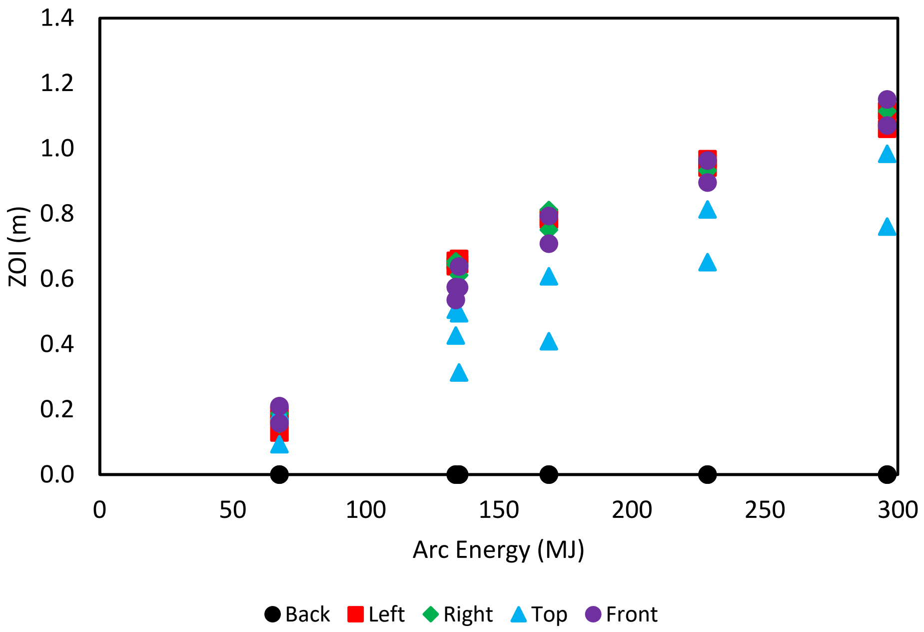
FDS simulations allowed the determination of the distances where 15 MJ/m^2 and 30 MJ/m^2 would be exceeded.

Sample results shown for medium-voltage switchgear with arc initiated at the main bus bars and a 15 MJ/m^2 fragility threshold

Dominant factor in ZOI is total arc energy. Switchgear are sensitive to arc initiation location and geometry. Bus ducts are sensitive to housing material (aluminum vs. steel)

Results not sensitive to electrode composition (aluminum vs. copper)





Confirmatory ZOI Analysis

Using a modified model based on IEEE guide 1584-2018

Base Model

Base model developed to estimate incident energy at various distances from an arc flash for personnel safety

Current & Voltage

Base model uses bolted fault current, modified to use arc current. Arc voltage obtained from CIGRE-602 model

Enclosure Breach

Base model does not assume a barrier between source and target. Modified model incorporates a time to breach before target receives energy

Decay Current

Arc energy profile developed for generator-fed faults during coast down following a trip

Modified IEEE & FDS Models Compared

Modified IEEE model results are generally within 20 cm of FDS results.

Considering vastly different nature of the models (empirical vs. CFD) the ZOIs are in fairly good agreement and provide confidence in the results

	IEEE Max ZOI	FDS Max ZOI
MV Switchgear (15 MJ/m2)	1.6 m	1.3 m
MV Switchgear (30 MJ/m2)	1.06 m	0.97 m
NSBD Aluminum (15 MJ/m2)	1.2 m	1.41 m
NSBD Aluminum (30 MJ/m2)	0.77 m	0.95 m
NSBD Steel (15 MJ/m2)	1.18 m	1.33 m
NSBD Steel (30 MJ/m2)	0.76 m	0.89 m

THANK YOU!

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