Overview of USNRC Research Activities to Update PRA Treatment of High Energy Arcing Faults

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

SMiRT 26
50 Anniversary Berlin/Potsdam

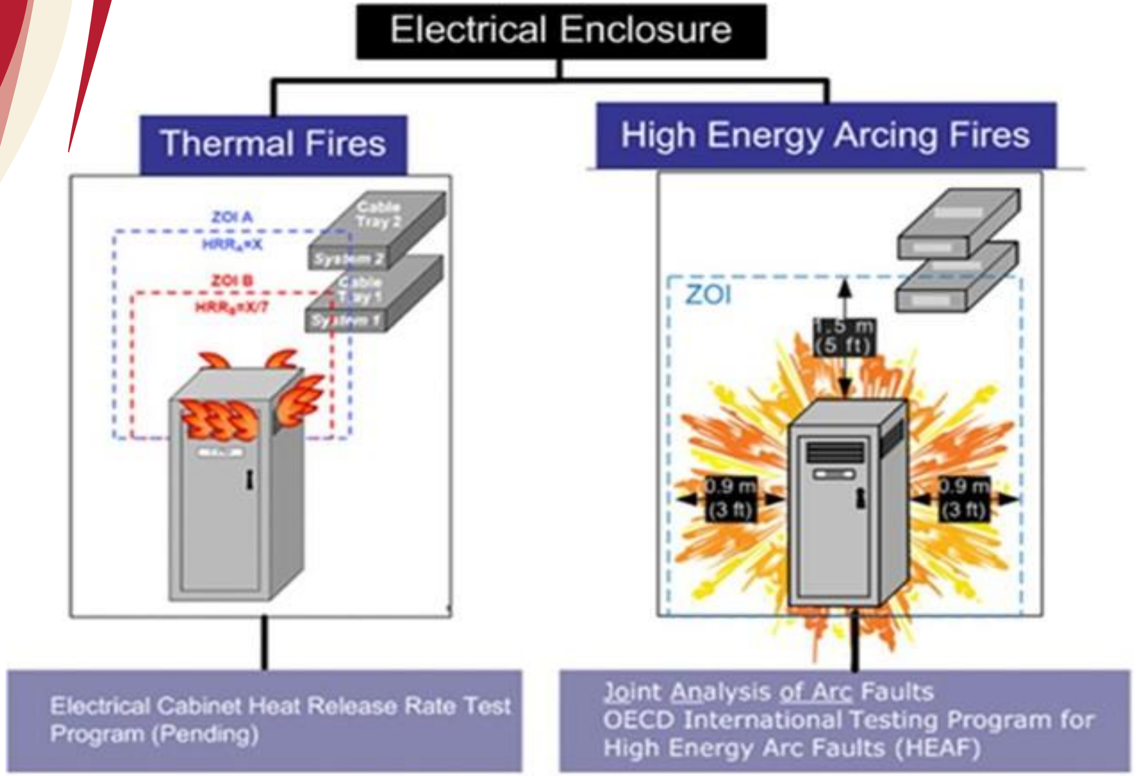
26th International Conference on Structural Mechanics in Reactor Technology (SMiRT 26)
17th International Post-Conference Seminar on
"FIRE SAFETY IN NUCLEAR POWER PLANTS AND INSTALLATIONS"

IASMiRT

HEAF **Background**

A High Energy Arcing Fault (HEAF) is a failure mechanism postulated for equipment at 440 V and higher

- Caused by poor or degraded electrical connections, foreign material ingress, misaligned breakers
- Rapid release of energy, including ionized gases, molten metal, and overpressures. Often accompanied by ensuing "classical" thermal fire



Regulatory **Context**

- **1980 — Appendix R**
  Prescriptive requirements for nuclear fire protection
- **2001 — NFPA-805**
  Performance-based standard for nuclear fire protection
- **2004 — NRC Endorses NFPA-805**
- **2005 — NUREG/CR-6850**
  Fire PRA Methodology
- **2006 — Reg Guide 1.205**
  Endorses NUREG/CR-6850
- **2010 — NUREG/CR-6850 Supplement 1**
  Includes bus ducts

Original HEAF **ZOI**

Documented in Appendix M of NUREG/CR-6850. Based largely on 2001 HEAF at San Onofre (pictured on right)

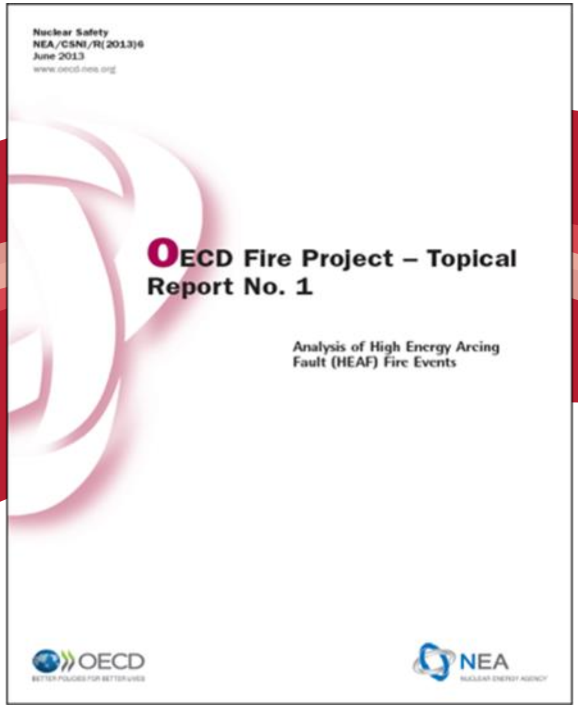
- ZOI was 3 feet (0.9 m) horizontally and 5 feet vertically (1.5 m)
- Insensitive to parameters affecting the severity of the HEAF (voltage, current, duration, geometry, materials, etc.) – “One-size-fits-all”

Original HEAF **ZOI**

Bus ducts addressed in NUREG/CR-6850 Supplement 1 as part of the “FAQ” process

- ZOI was sphere of 1.5 ft (0.45 m) radius, and a 30-degree right cone extending downward for 20 feet (6 m).
- Like switchgear, this model also neglected parameters affecting the severity of the HEAF (voltage, current, duration, geometry, materials, etc.) – “One-size-fits-all”

HEAF Research **Motivation**


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

NEA

"…to perform experiments for obtaining comprehensive scientific fire data on the HEAF phenomena known to occur in NPPs through carefully designed experiments…"

Phase I Test 23 – potential for increased ZOI where aluminum is involved

Research Activities **Overview**

The NRC developed a comprehensive project plan, consisting of five main tasks:

Development of a CFD Model
for predicting a wide variety of electrical and equipment configurations

Survey of the US Nuclear Fleet
to ensure that full-scale experiments are representative

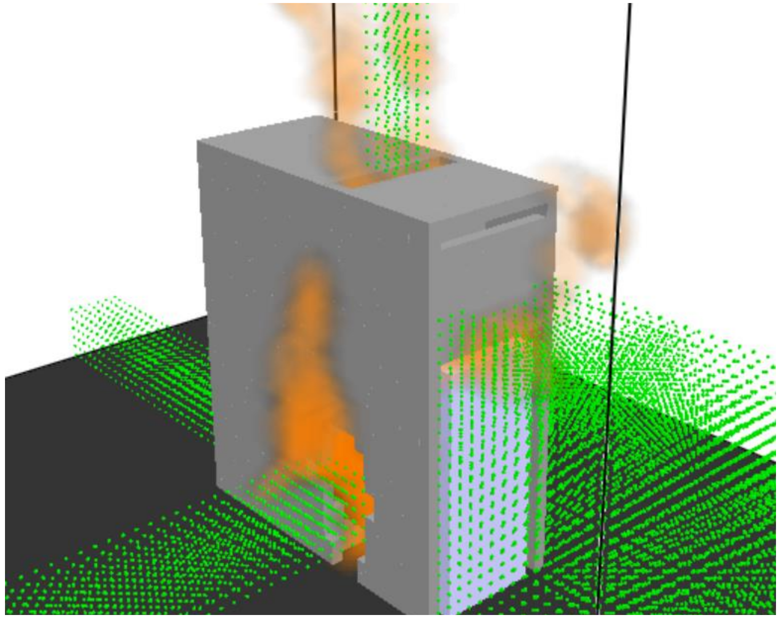
Physical Testing
to support the development and validation of the CFD model

Fragility Testing
to assess target damage from HEAF events

PRA Method Development
to improve the realism of the model and update fire ignition frequencies

Development of a **CFD Model**

Leverage experimental data and provide information for configurations that were not subject to full-scale testing. This provides a cost-effective and flexible approach.



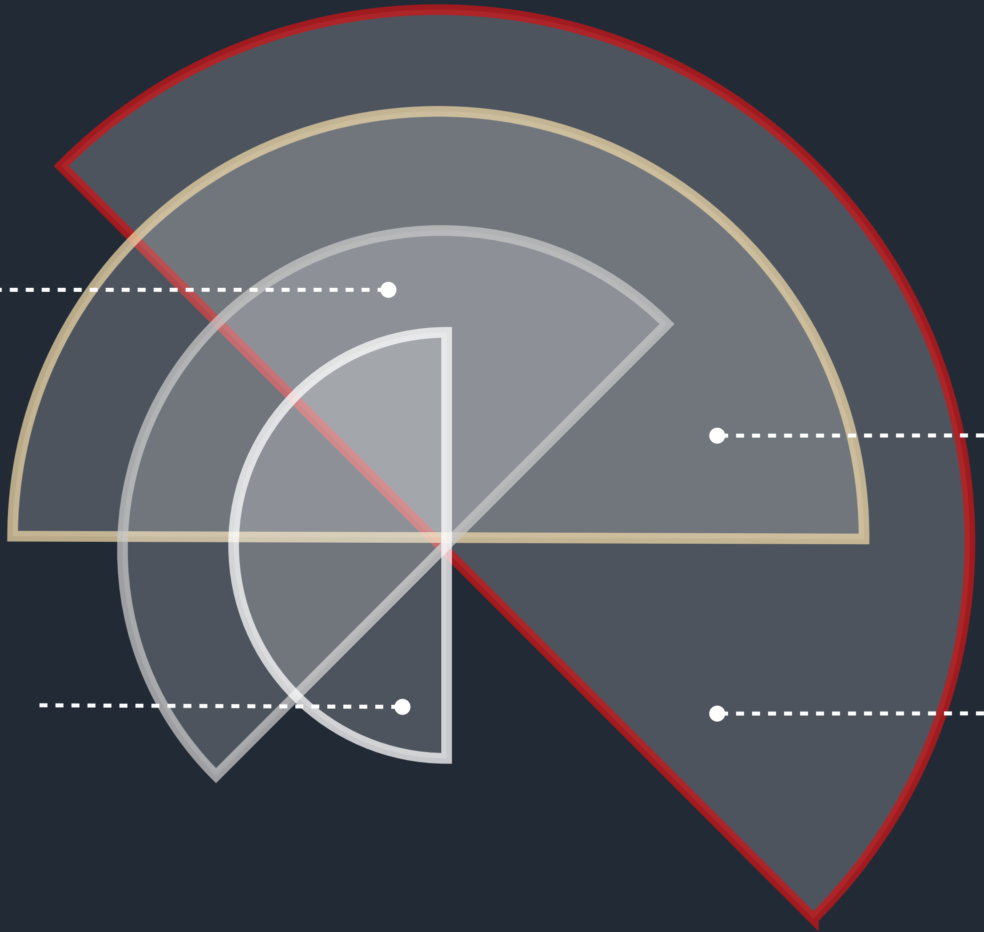
Low Voltage Switchgear
Bus bar material (aluminum, copper), arc duration, arc location, arc energy
34 FDS simulations

Medium Voltage Switchgear
Bus bar material (aluminum, copper), arc duration, arc location, arc energy
42 FDS simulations

Non-segregated Bus Ducts
Duct material (aluminum, steel), bus bar material (aluminum, copper) arc duration, duct geometry, arc energy
57 FDS simulations

Survey of US **Nuclear Fleet**

Conducted by the Electric Power Research Institute (3002020692)



Bus Bar Insulation

MV bus bars primarily insulated; LV bus bars are usually not

SAT Fault Clearing Times

50% of units had SAT FCTs of 2 seconds or less

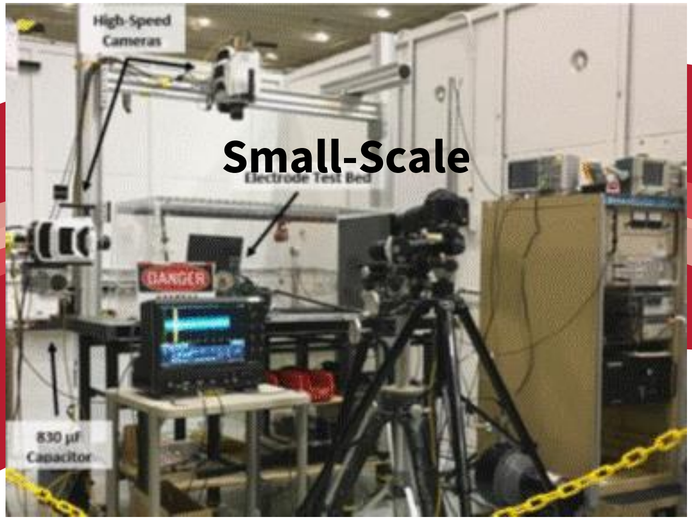
Switchgear Style

83% of switchgear use horizontal draw-out style; the remainder use vertical-lift style

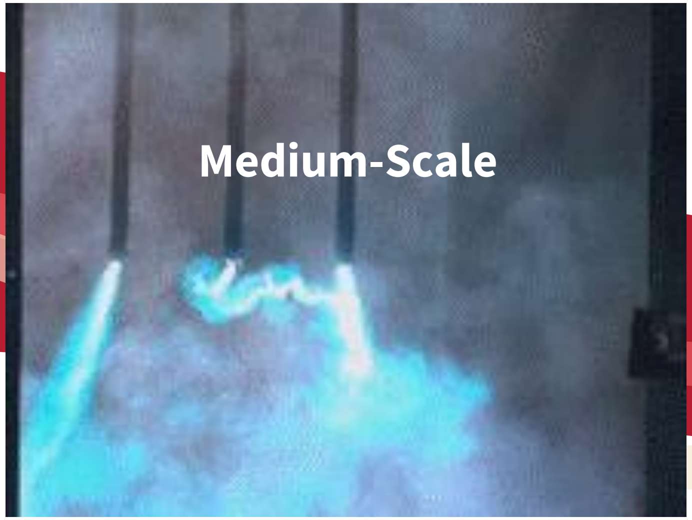
Presence of Aluminum

Typically located in the main bus bars and primary cable compartment

Physical **Testing**



Aluminum/copper particle size distributions, rates of particle production, particle morphology, and oxidation



Direct observation of the arc, enclosure breach, material loss, arc spectral emissions

Enclosure breach, event progression, pressure rise, thermal/visual imaging. Served as benchmark cases for CFD model.

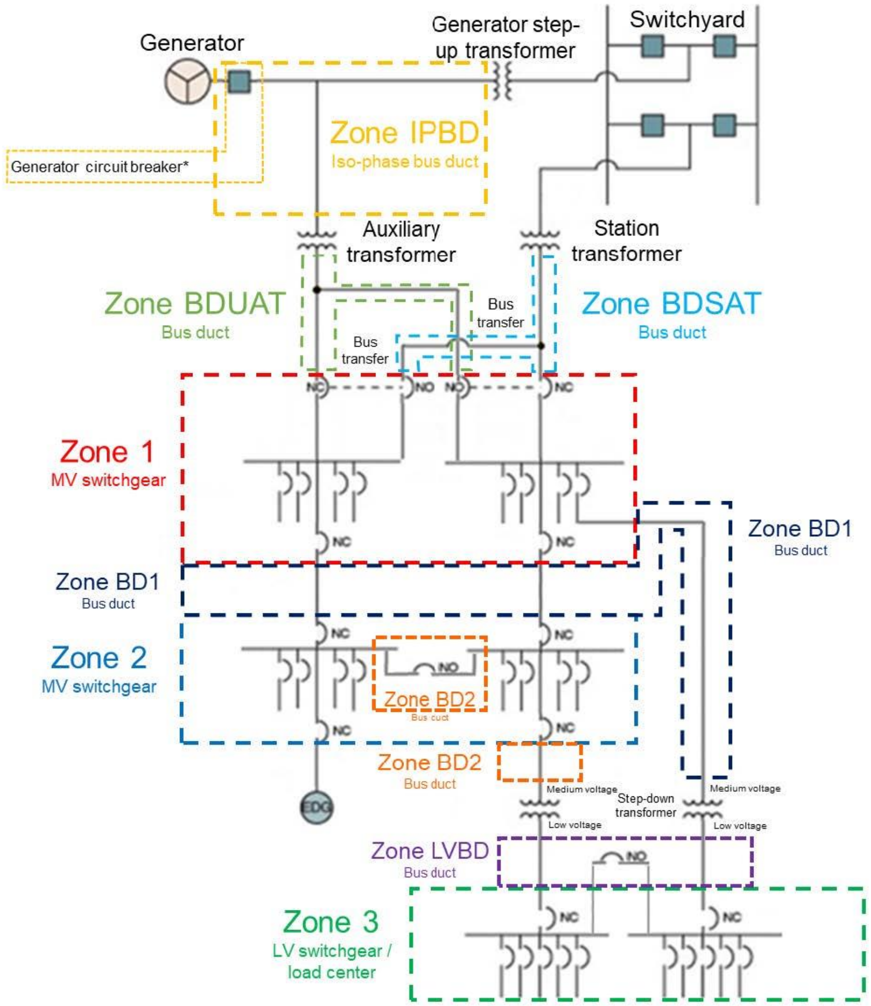
Fragility **Testing**

The need for defining fragility criteria with respect to HEAFs was a key conclusion of the 2017 Phenomena Identification and Ranking Table (PIRT).

Physical Testing
Conducted at SNL's Solar Furnace facility to simulate the effects of a short duration, high heat flux exposure

Engineering Analysis
Data analysis, operating experience review, and consensus building to establish fragility criteria

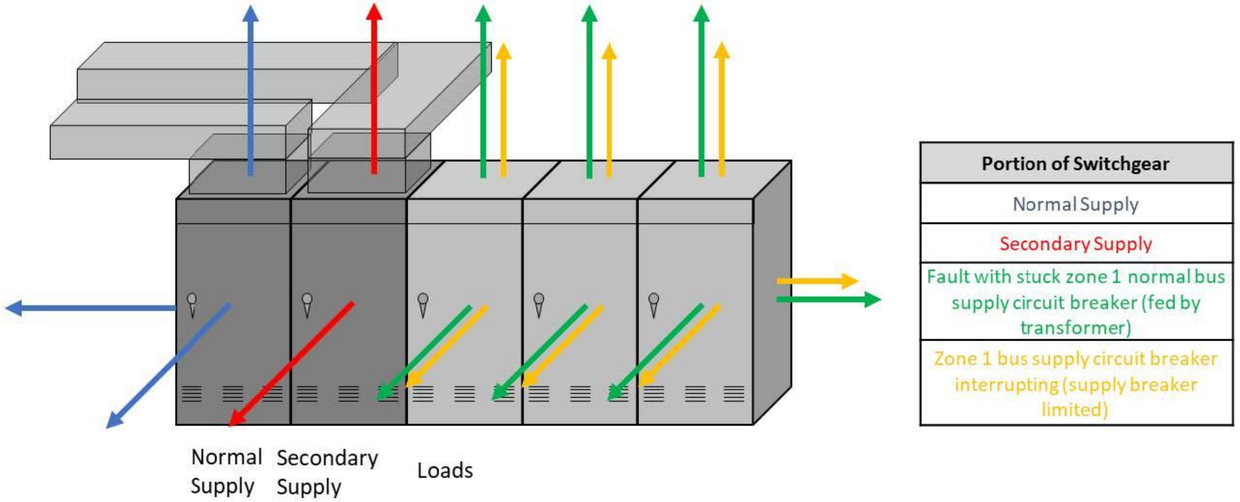
PRA Method **Development**



Fault Zone Analysis
Location of fault within plant EDS determines maximum fault duration and provides credit for circuit protection features

Generator-Fed Faults & GCB
Accounts for potential generator-fed fault and provides credit for generator circuit breakers

PRA Method **Development**



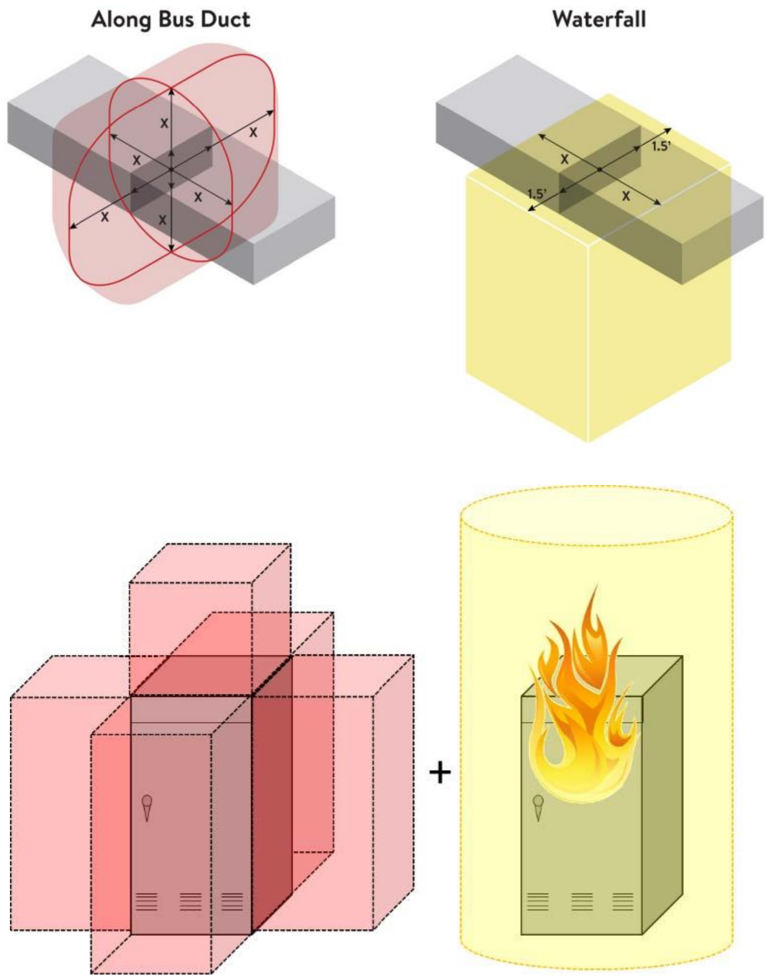
Zone 1 - 30 MJ/m² target fragility				Default ZOI dimensions (inclusive of horizontal and vertical-lift circuit breakers)				ZOI dimensions for vertical-lift style circuit breakers			
Fault location	Power source and duration	Arc Energy (MJ)	End State	Left/Right (feet)	Front (feet)	Back (feet)	Top (feet)	Left/Right (feet)	Front (feet)	Back (feet)	Top (feet)
Normal supply (0.57) and Secondary supply (0.28)	UAT - Generator fed	132	GF-30	1.5	1	2*	1	1	1	None	1
	SAT - 0 to 2.00 s	68	SAT2-30	0.5	None	1*	None	None	None	None	None
	SAT - 2.01 to 3.00 s	101	SAT3-30	1	0.5	1.5*	0.5	0.5	0.5	None	0.5
	SAT - 3.01 to 4.00 s	135	SAT4-30	1.5	1	2*	1	1	1	None	1
	SAT $\geq$ 4.01 s	169	SATMAX-30	2	2	2.5*	1	1.5	2	None	1
Loads: Supply breaker limited (.14)	4 seconds or less (generic)	135	SBL4-30	1.5	1	2*	1	1	1	None	1
	2 seconds or less	68	SBL2-30	0.5	None	1*	None	None	None	None	None
	2.01 to 3 seconds	101	SBL3-30	1	0.5	1.5*	0.5	0.5	0.5	None	0.5
Loads (0.01)	UAT - 0 to 0.5 s + GF	132	GF-30	1.5	1	2*	1	1	1	2**	1
	UAT - 0.51 to 2 s + GF	199	UAT2-30	2	1.5	2.5*	1.5	1.5	1.5	2.5**	1.5
	UAT - 2.01 to 3 s + GF	233	UAT3-30	2.5	2	3*	2	2	2	3**	2
	UAT - $\geq$ 3 s + GF	300	UATMAX-30	3	2.5	3.5*	2.5	2.5	2.5	3.5**	2.5
	SAT - 0 to 2.00 s	68	SAT2-30	0.5	None	1*	None	None	None	1**	None
	SAT - 2.01 to 3.00 s	101	SAT3-30	1	0.5	1.5*	0.5	0.5	0.5	1.5**	0.5
	SAT - 3.01 to 4.00 s	135	SAT4-30	1.5	1	2*	1	1	1	2**	1
	SAT $\geq$ 4.01 s	169	SATMAX-30	2	2	2.5*	1	1.5	2	2.5**	1

Supply vs. Load Configuration
Additional specificity based on the function of the switchgear within the lineup (breaker set points)

Direction-Specific ZOIs
ZOIs are formulated for each face of the enclosure (left/right, front, back, and top)

Breaker Style Refinements
Additional refinements for horizontal draw-out or vertical lift breakers due to mass and position of the breaker

PRA Method **Development**



Revised NSBD ZOI Geometry
Testing and operating experience leveraged to redefine the "waterfall" portion of the ZOI

Additonal Guidance
-Ensuing fire modeling guidance
-Updated HEAF frequencies and bins
-Updated non-suppression probabilities

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