VULNERABILITY OF NUCLEAR SAFETY SYSTEMS TO FIRE

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Fire Safety & Emergency Preparedness for the Nuclear Industry

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PRESENTATION OBJECTIVES

- Regulatory requirements for determining fire impact
- Safety related systems and mechanisms for damage
- Cable vulnerability
- Electrical Equipment Vulnerability
- Mechanical Systems
- Structures

REGULATORY REQUIREMENTS FOR REACTOR SAFETY

REGULATORY DOCUMENT

- IAEA NS-R-1 (Clause 4.6)
- IAEA NS-G-1.7 (Clause 2.1)
- CSA N293-12 (Clause 5.4.2)
- NFPA 805 – 2010 (Clause 1.5.1)

NUCLEAR SAFETY SYSTEMS

- Reactivity Control
- Inventory & Pressure Control / Maintaining Fission Boundary
- Decay Heat Removal
- Support Services
- Monitor Plant Parameters

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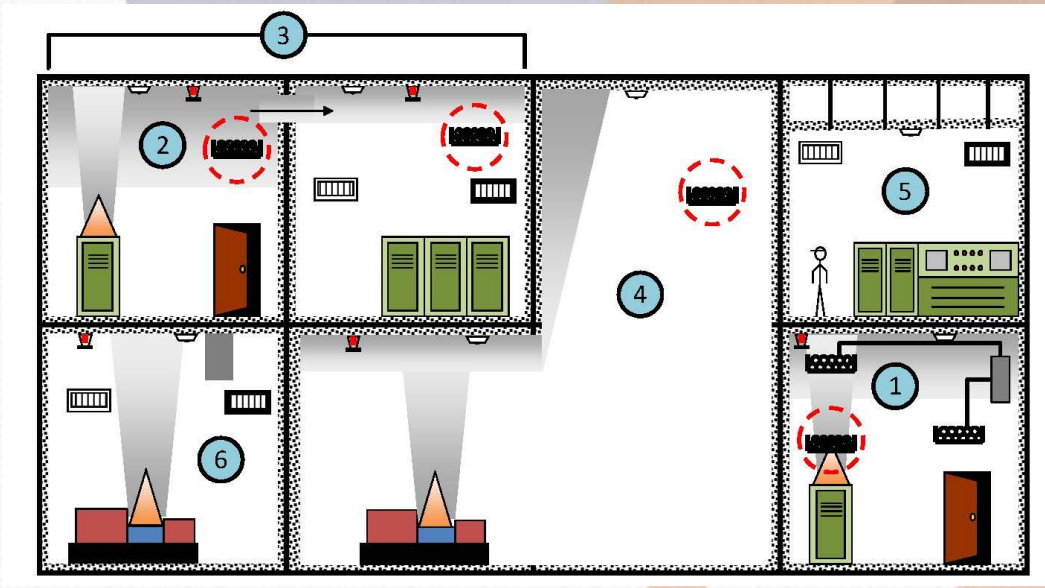
FIRE HAZARD ASSESSMENT

Fire Scenario Evaluations

- Source of Fire
- Target of Interest (NSS)

Do Fire Conditions Exceed Target Vulnerability Criteria?



NUREG 1934 – NPP Fire Modeling Application Guide

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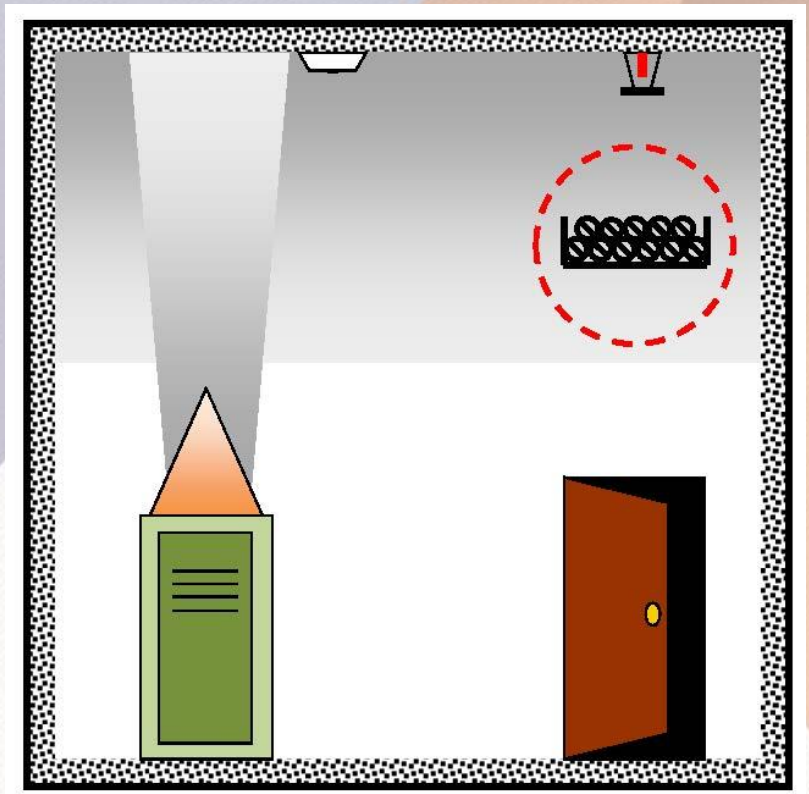
FIRE SCENARIO EVALUATION

Fire Hazard
- Identify Source (NUREG 6850)
- Quantify Heat Release
  (NUREG 6850, SFPE Handbook)
- Calculate Fire Conditions
  (NUREG 1934, NUREG 1824, NUREG 1805)

Target
- Nuclear Safety Systems
- Vulnerability Criteria (NUREG 6850)
- Cables Most Vulnerable Item?



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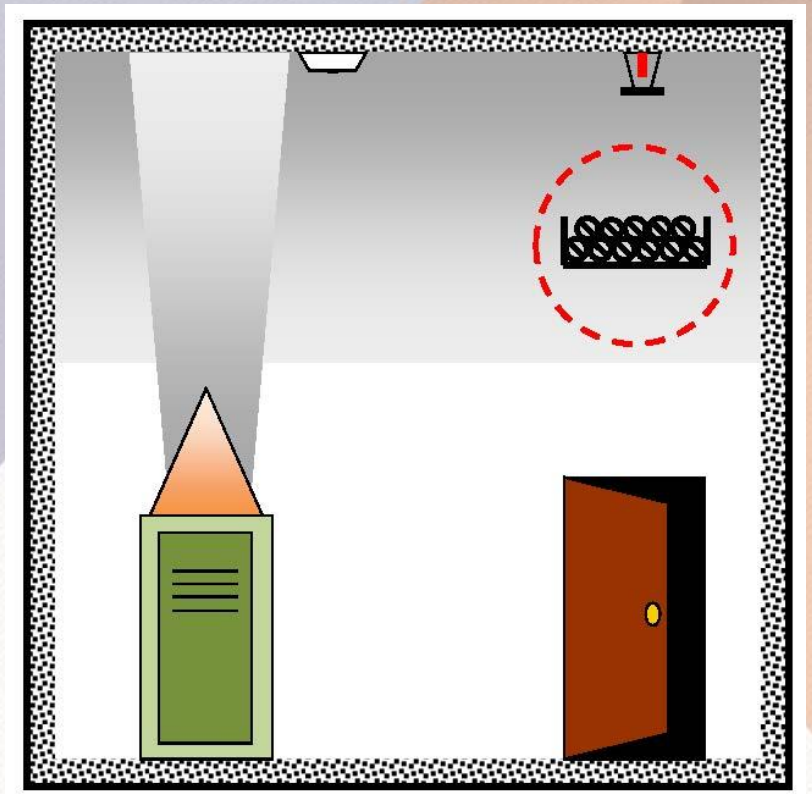
DAMAGE MECHANISM
THERMAL

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic [1]	6 kW/m^2	205 C
Thermoset [1]	11 kW/m^2	330 C

[1] NUREG 6850



Conservative Assessment

- Upper Layer Temperature > 330 C
- Thermoset Cable Fails

Does not consider duration of exposure and heating of cables.

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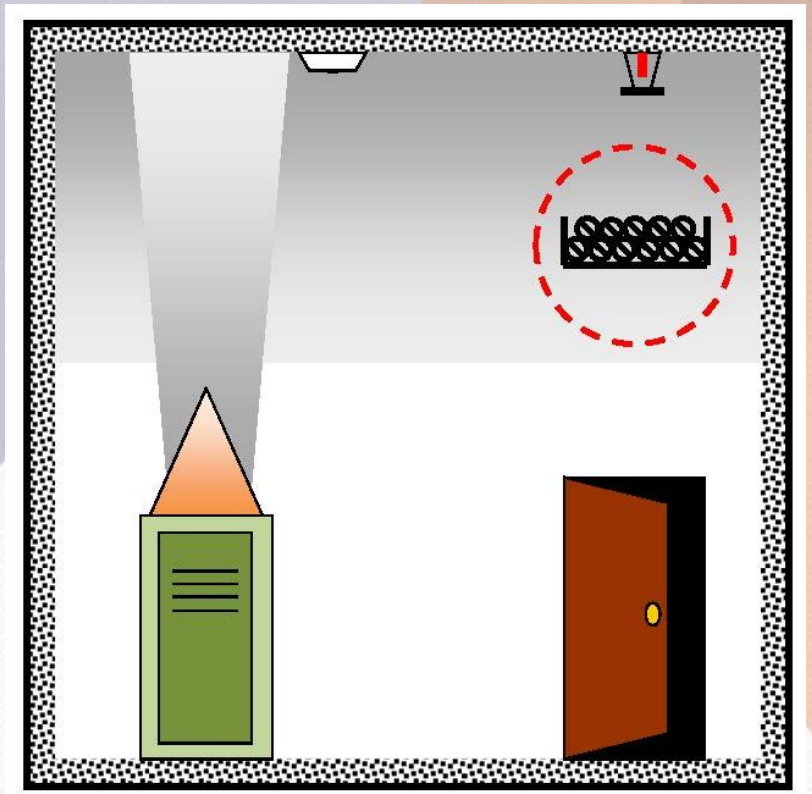
DAMAGE MECHANISM THERMAL

External Heat Flux (kW/m^2)	Thermoplastic Time to Failure (min)	Thermoset Time to Failure (min)
6	19	No Damage
11	4	19
14	2	12
16	1	6
20	<1	1

[1] NUREG 6850



- Duration of exposure important
- Fire conditions change with time

Vulnerability Criteria should consider duration of exposure

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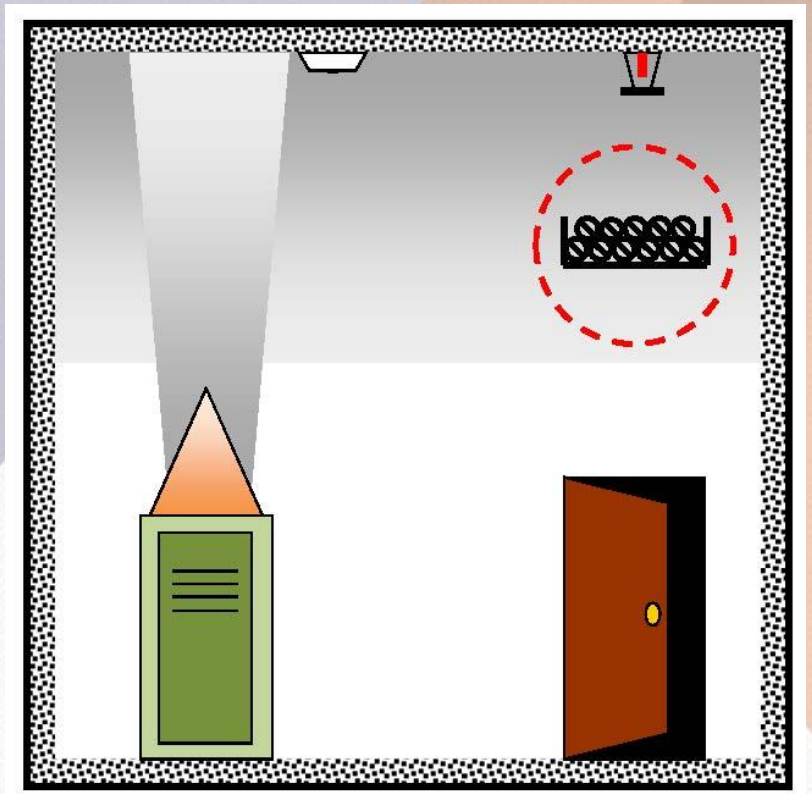
DAMAGE MECHANISM THERMAL

Exposure Temperature (C)	Thermoplastic (min)	Thermoset (min)
220	30	No Damage
275	10	No Damage
345	4	20
370	2	10
430	1	5

[1] NUREG 6850



Improved Assessment

- Link of Fire Environment change with time to target response
- THIEF - Calculation of thermal response of cable to determine failure

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DAMAGE MECHANISM
THERMAL

FAILURE MODES

- Ground Faults – conductor to ground
- Hot Shorts – conductor to conductor
- Open Circuits

CONSEQUENCES

- Inoperability – loss of power, control or information
- Spurious Actuations

NUREG/CR-6834 *Circuit Analysis – Failure Mode and Likelihood Analysis*

EPRI Report 1006961 *Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of an Expert Elicitation*

NEI 00-01 – Guidance for Post-Fire Safe Shutdown Analysis

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FIRE DAMAGE TO SAFETY RELATED EQUIPMENT (1985)

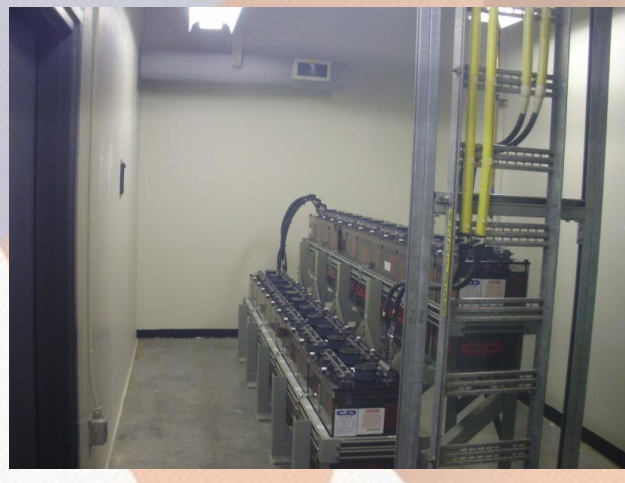
Sensitivity Level – High

- Recorders
- Logic Equipment
- Meters
- Solid State Relays
- Electro Mechanical Relays

FIRE DAMAGE TO SAFETY RELATED EQUIPMENT (1985)

Sensitivity Level – Med. High

- Hand Switches
- Battery Chargers/Inverters
- Motor Control Centers
- Switchgear
- Batteries
- Temperature Switches



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FIRE DAMAGE TO SAFETY RELATED EQUIPMENT (1985)

Sensitivity Level – Med. Low

- Distribution Panels
- Solenoid Valves
- Control Transformers
- Motors
- Position/Limit Switches
- Terminal Blocks

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DAMAGE MECHANISM NON-THERMAL

Non-Thermal Fire Products

- Smoke (particulate)
- Relative Humidity
- Particulate and Relative Humidity
- Corrosive Vapors

Damage Mechanism

- Circuit Bridging
- Long Term Corrosion

Vulnerability Factors

- Coated v Bare Circuit Boards
- Mechanical Enclosures
- Functional Circuit Type
- Etc.

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NUREG/CR-7123 - A Literature Review of the Effects of Smoke from Fire on Electrical Equipment

DAMAGE MECHANISM NON-THERMAL

Conclusions

- Although there are 4 modes of failure due to smoke, Circuit Bridging is the only risk significant failure mode.
- Current fire models and data are insufficient at this time to directly assess the risk contribution of circuit bridging faults.

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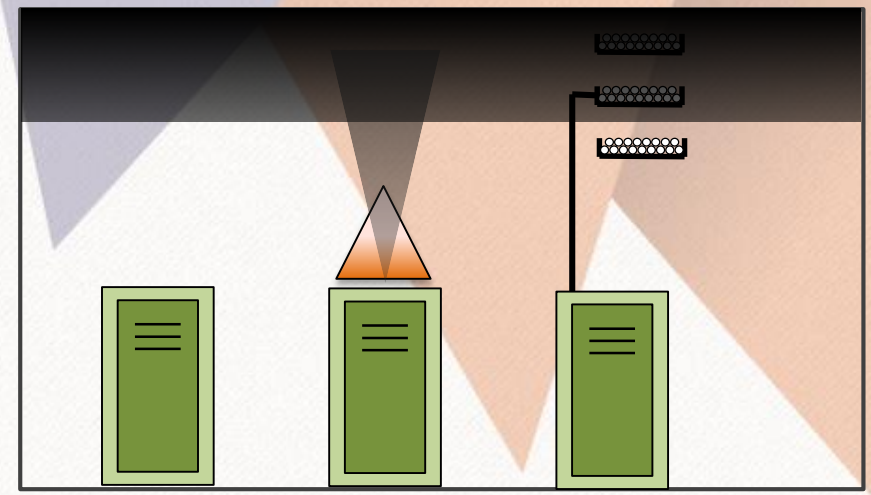
THE VULNERABLE CABLE ASSUMPTION

- Equipment & Cable Configuration
  (cables feed from above or below)
- Fire in Adjacent Space
- Fires Conditions:
  - Low Temperature
  - Large Smoke Production



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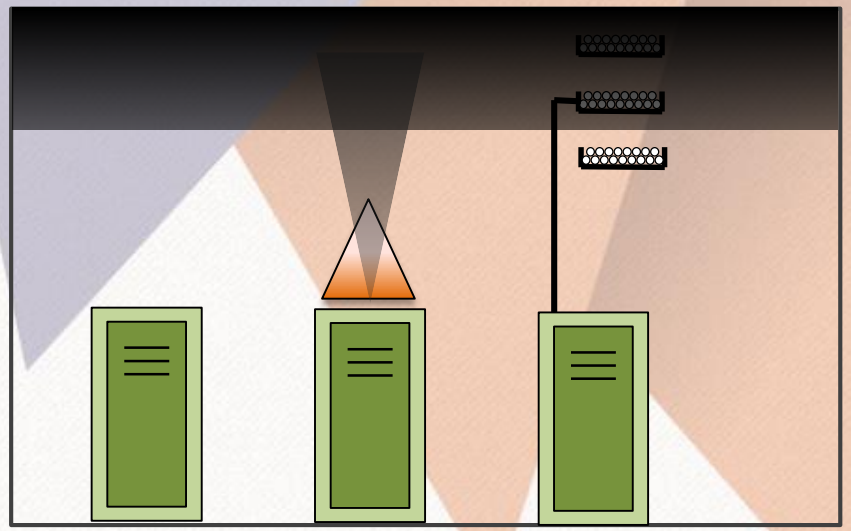
THE VULNERABLE CABLE ASSUMPTION

OPEX (OPerating EXperience)

Fire Hazard Analysis / Fire Safe Shutdown Assessment (Single Unit Plants)

- Compartment Fire Scenarios - 40
- Temperature < 200 C - 15
- Smoke Layer < 2 m - 8

Conclusion – 20% of rooms modeled have conditions where Smoke has damage potential to Nuclear Equipment in the "High" and "Med High" sensitivity categories.



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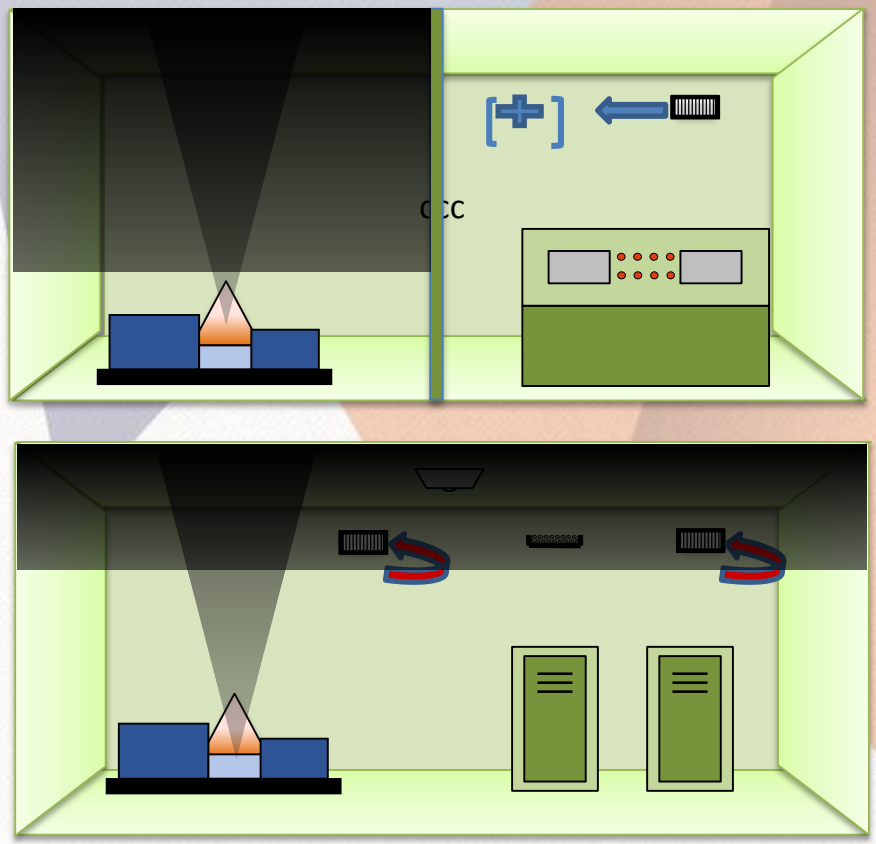
VULNERABILITY TO SMOKE DAMAGE

Recommendations

1. FHA needs to identify nuclear safety equipment with vulnerability to smoke damage
2. FHA needs to demonstrate smoke conditions in room with this equipment
3. Plant Operators require emergency procedures & actions where fire or smoke expose NSS
4. Since we cannot Predict potential impact we should Protect sensitive equipment by detection and smoke management



QUESTIONS

Vulnerability of Nuclear Safety Systems to Fire

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