Joint Analysis of Arc Faults (Joan of ARC) OECD International Testing Program for High Energy Arc Faults (HEAF)

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Office of Nuclear Regulatory Research

Fire Protection Information Forum

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

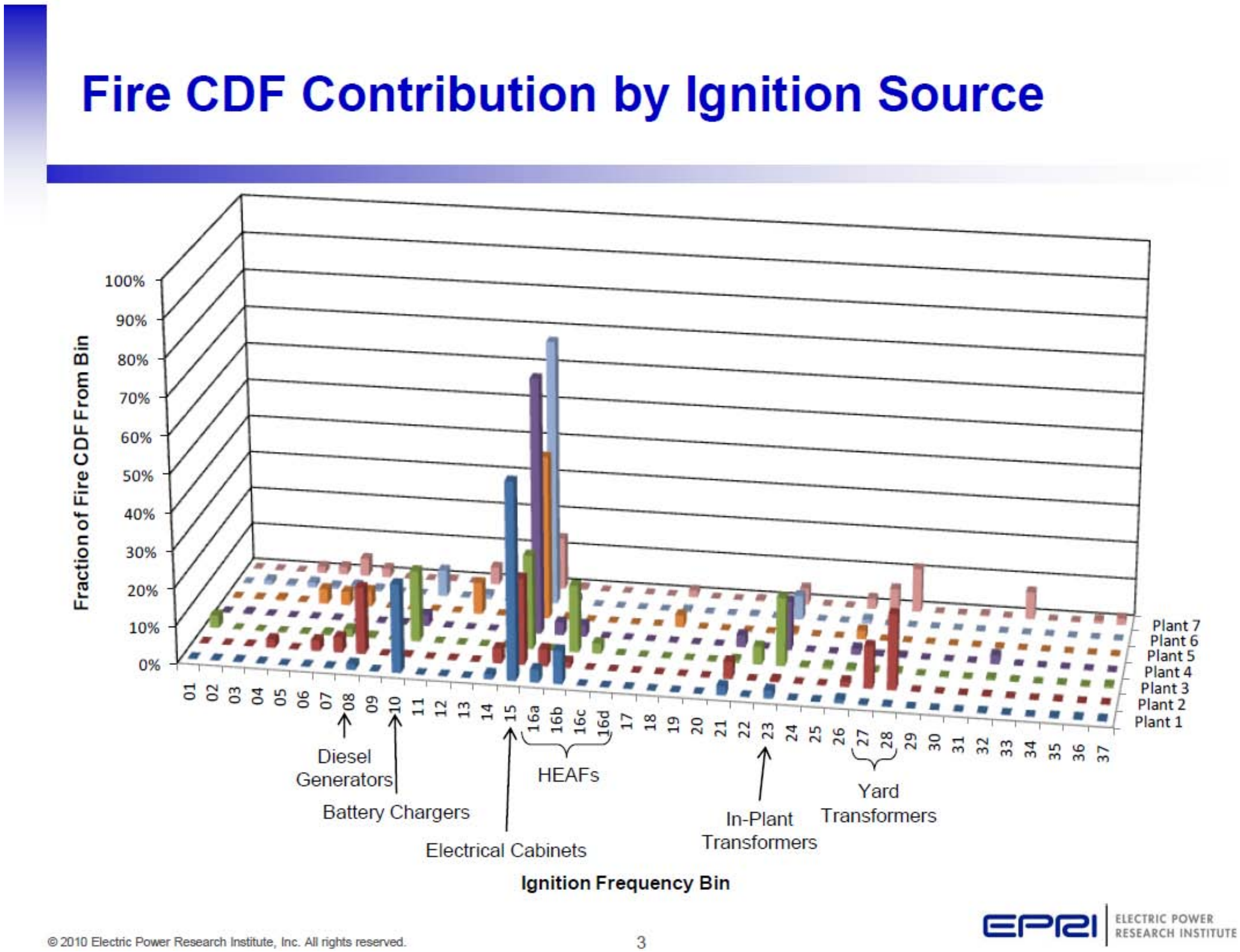
JOAN of ARC

- Need for testing & current fire PRA method
  - N. Melly
- Testing Plan
  - G. Taylor
- International Collaboration OECD
  - N. Melly
- US Collaboration
  - G. Taylor

Why Research?

- Massive unwanted electrical discharges, referred to as <u>H</u>igh <u>E</u>nergy <u>A</u>rcing <u>F</u>aults (HEAF), have occurred in nuclear power plant electrical components throughout the world
- Advance the state of the art for modeling HEAF in Fire PRA
- Can be a major risk driver for PRA analysis

Industry Challenges



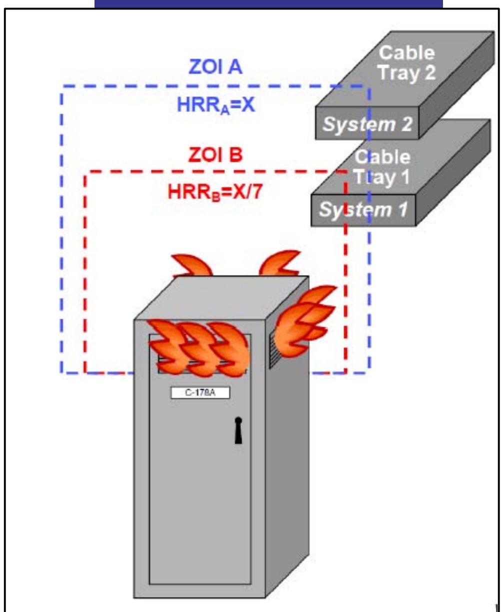
Industry Challenges

- There are currently no ideal way to deal with many HEAF risk driven scenarios
- Switchgear rooms are particularly vulnerable to this type of failure with cable trays routed directly above electrical cabinets
- Can be a major risk in a fire PRA

How Electrical Cabinets Fail

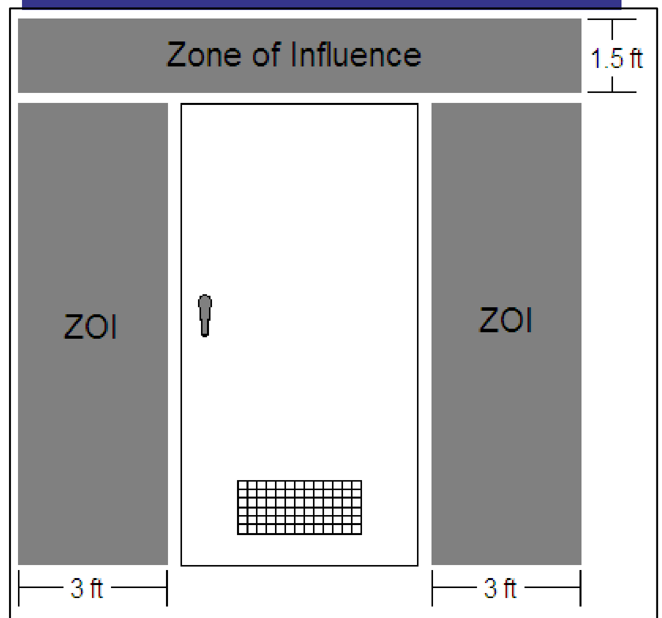
Electrical Cabinets

Thermal Fires



RES Electrical Cabinet Heat Release Rate Test Program planned for 2013 with NIST

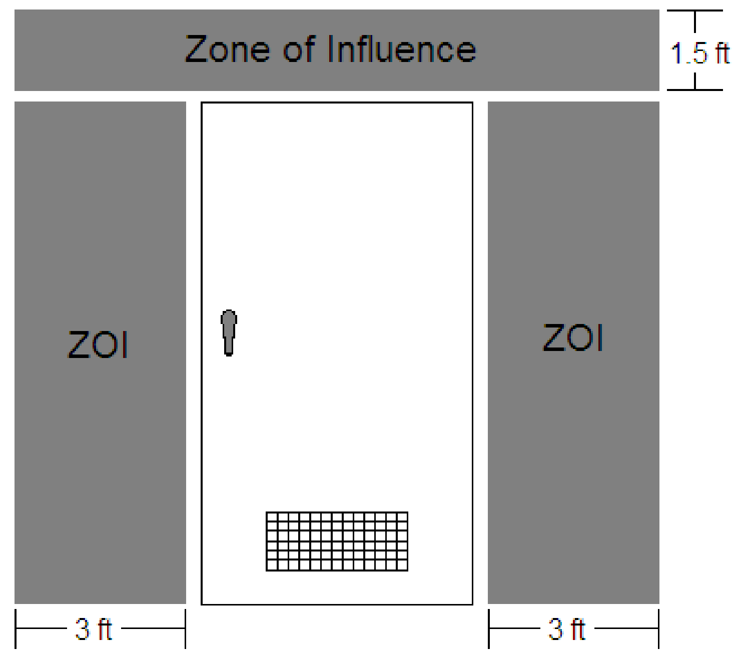
High Energy Arcing Fires



Joint Analysis of Arc Faults (Joan of ARC) OECD International Testing Program for High Energy Arc Faults (HEAF) 2013/2014

Current State-of-the-Art

- NUREG/CR-6850, Appendix M (2005)
- Method based on **one** well documented fire event at San Onofre in 2001 to define zone of influence (ZOI)
- Components within ZOI are assumed to fail or ignite
- This becomes the input to fire PRA model
- How do the Robinson and (Japan) events fit
- this model?



Recent HEAF Events

Definition

- High Energy Arc Faults (HEAF) are energetic or explosive electrical equipment faults characterized by a rapid release of energy in the form of heat, light, vaporized metal and pressure increase due to high current arcs between energized electrical conductors or between energized electrical components and neutral or ground. HEAF events may also result in projectiles being ejected from the electrical component or cabinet of origin and result in fire.

The energetic fault scenario consists of two distinct phases, each with its own damage characteristics and detection/suppression response and effectiveness.

- ***First phase:*** short, rapid release of electrical energy which may result in projectiles (from damaged electrical components or housing) and/or fire(s) involving the electrical device itself, as well as any external exposed combustibles, such as overhead exposed cable trays or nearby panels, that may be ignited during the energetic phase.
- ***Second phase, i.e., the ensuing fire(s):*** is treated similar to other postulated fires within the zone of influence.

Operational Experience

- As stated, NUREG/CR – 6850 heavily relied on the San Onofre HEAF in order to define HEAF behavior
- Interest in taking an expanded look industry wide in order to better characterize HEAF events over a wide range of circumstances
- This effort will also be expanded to cover international events through collaboration with the OECD member countries
- Table M-1 in Appendix M lists various suspected HEAF events and was populated through searching the EPRI database on “arc” or “blast”

Detailed Information Needed

- Relevant Information
  - Voltage
  - Power Level
  - Plant Location
  - Damage Zone (Pictures if available)
    - Blast Damage vs. Enduring Fire Damage
      - Can this be distinguished?
  - Event Duration/Method of extinguishment
  - Furthest extent of damage
    - Thermal (i.e. ensuing fire damage / smoke damage)
    - Physical (i.e. thrown cabinet door, shrapnel)
  - Root Cause Analysis (if available)

Operational Experience

- In order to more realistically classify the HEAF phenomenon we are looking to expand upon the information collected for the initial 6850 effort as well as those fires reported in table M-1 of Appendix M
- If you have any relevant plant fire events that fit the definition provided above please contact Nicholas.Melly@nrc.gov to discuss contributing information to Operating Experience Database

Experimental Program

- Large collaboration
  - NIST
  - SNL
  - High Power Testing Laboratory
  - International : OECD
  - National : EPRI

Test Plan

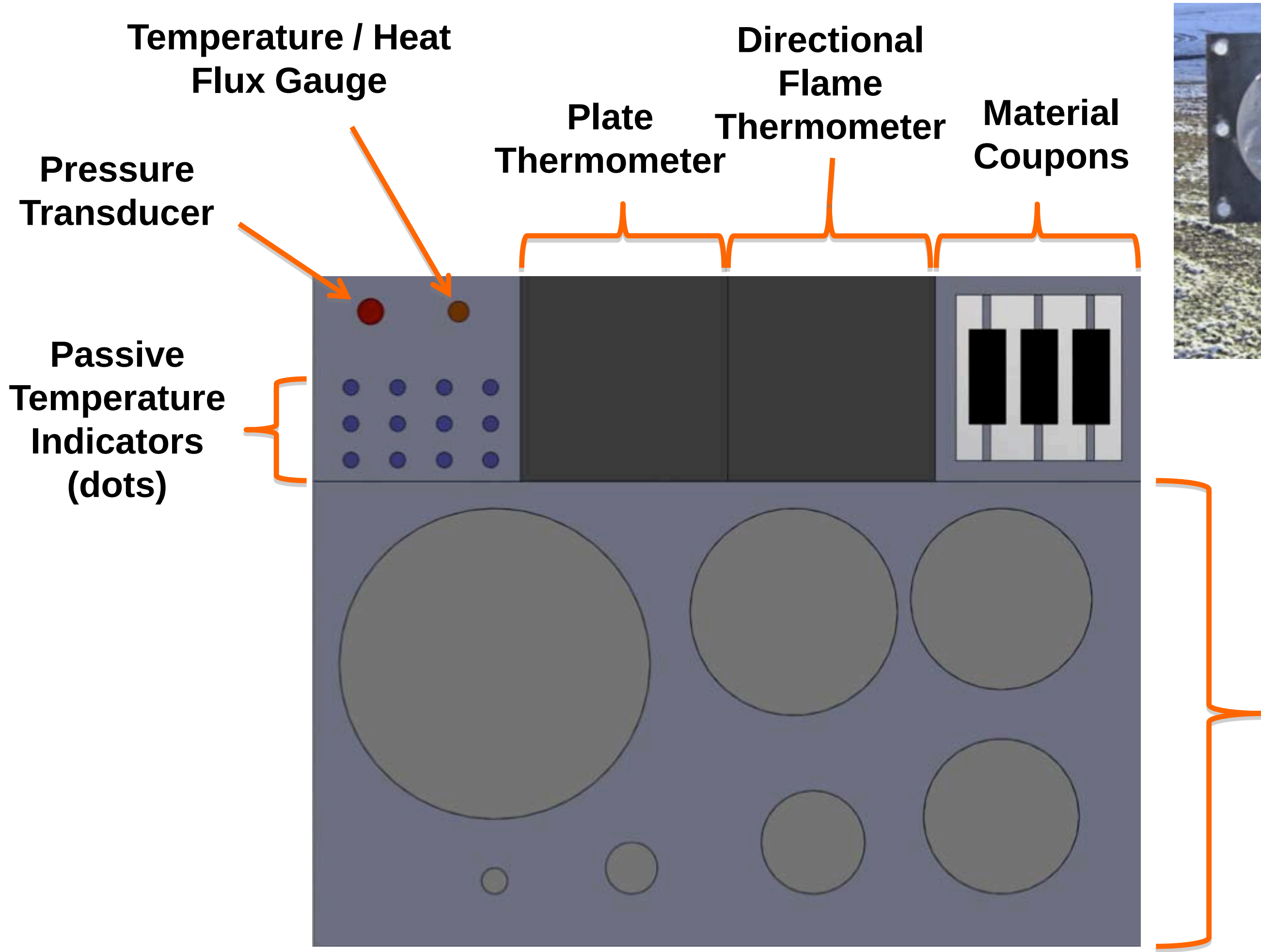
- Draft test plan has been developed
  - Specific components tested dependant on equipment procured or donated.
- Evaluate conditions that may influence failure characteristics
- Advance the understanding of physical dynamics of HEAFs
- Focus on obtaining data and information to advance zone of influence model
- Low and medium voltage switchgear along with bus bars are planned to be tested.

Instrumentation

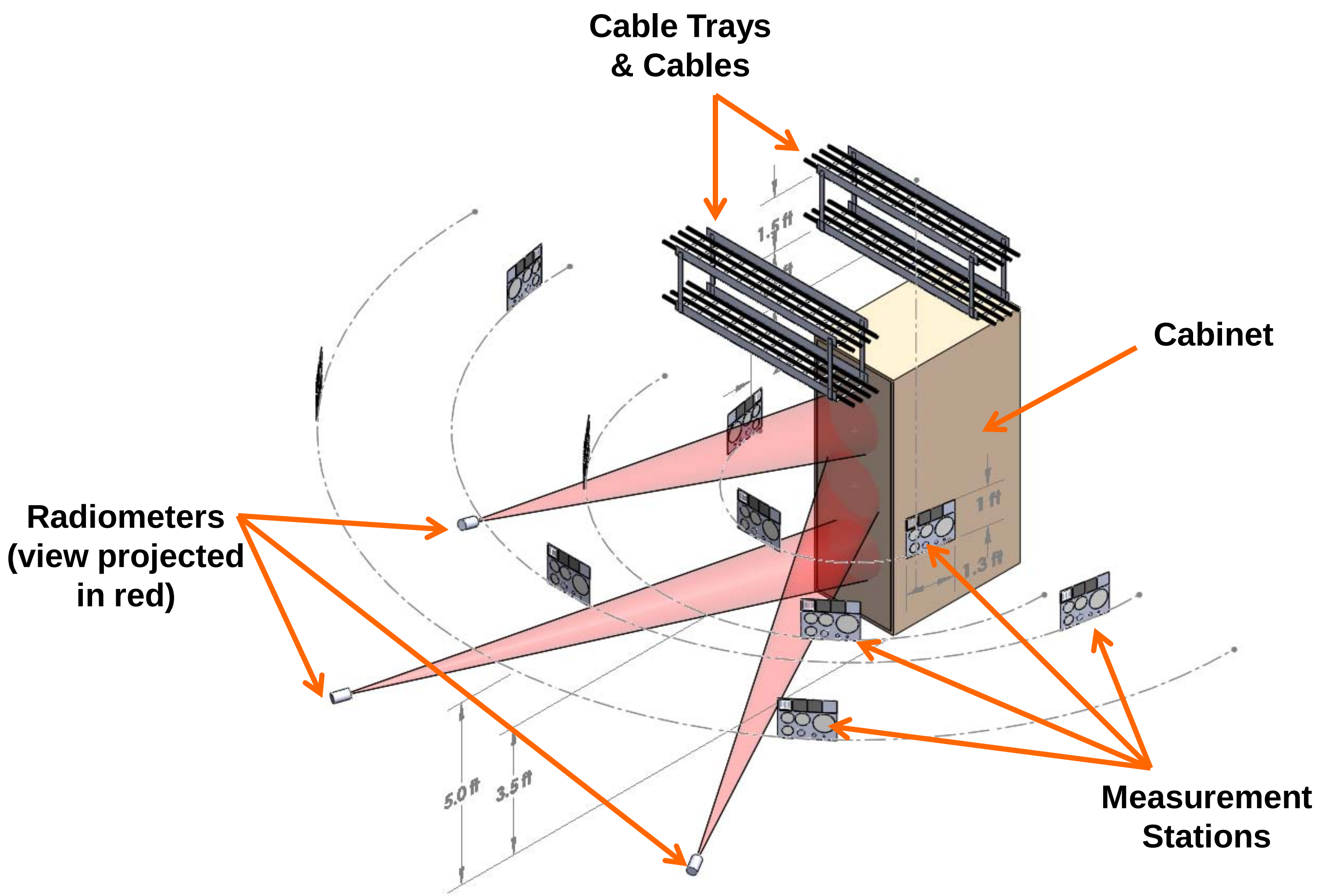
- Passive Gauges
  - Temperature: Lacquers, material coupons
  - Pressure: Bikini gauges
- Active Gauges
  - Temperature
    - Thin wall, fast response temperature and heat flux
    - Plate thermometers
    - Directional Flame Thermometers
    - Thermocouples
  - Pressure: Transducers
  - Incident Heat: Radiometers
  - Gas Sampling: O2, smoke density, flow meter

Measurement Station

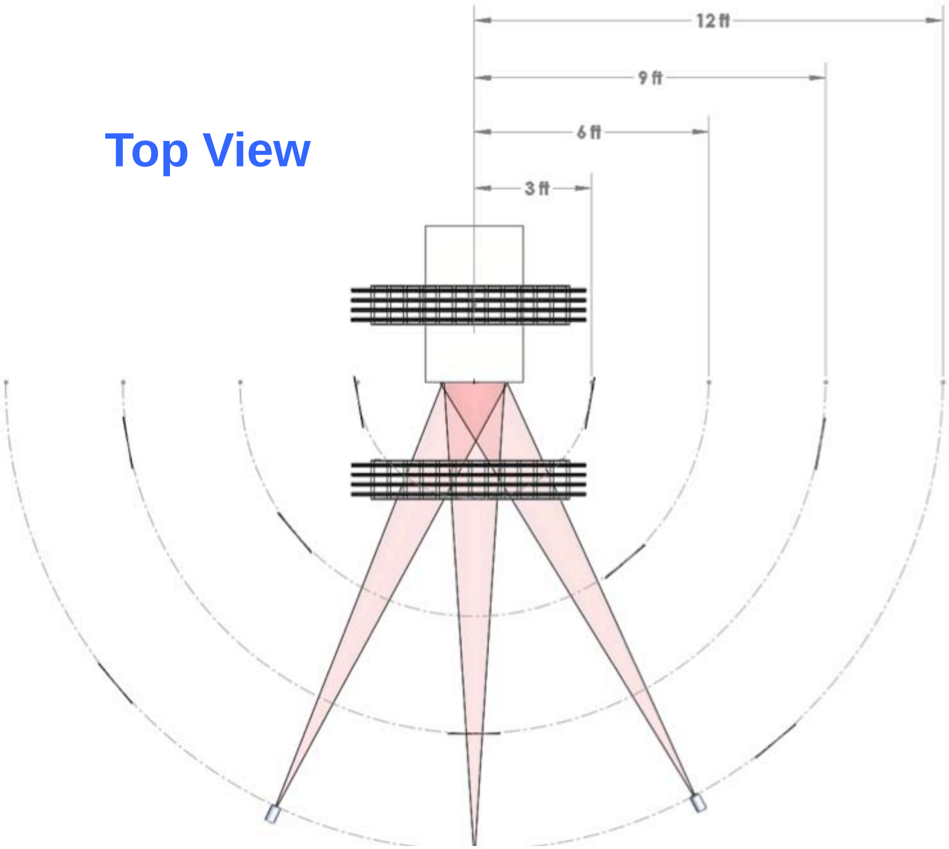
(Passive and Active Gauges)

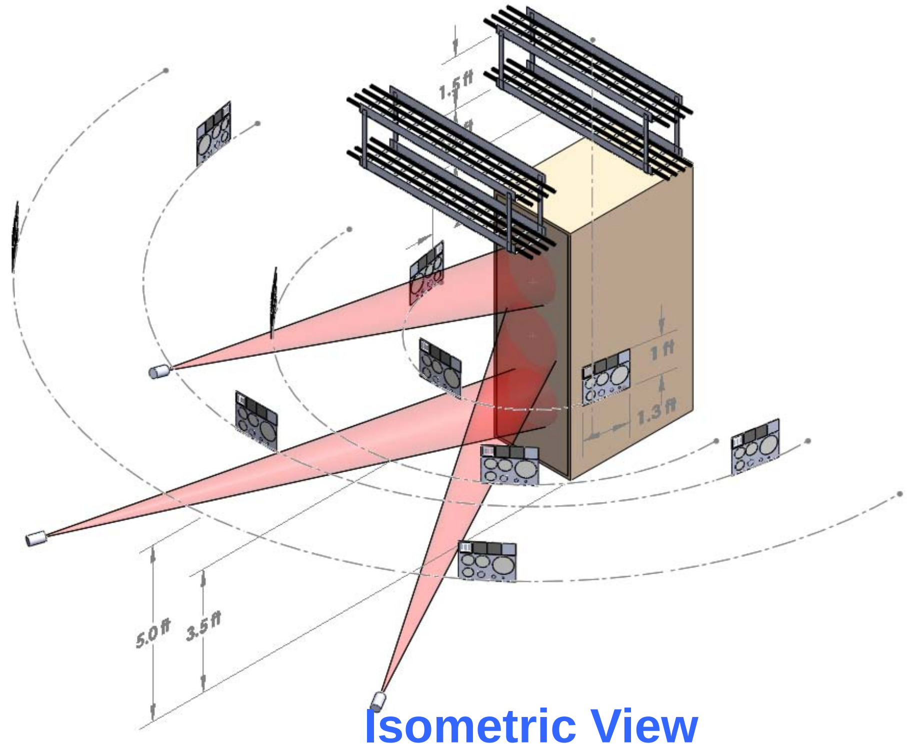


Theoretical Test Setup

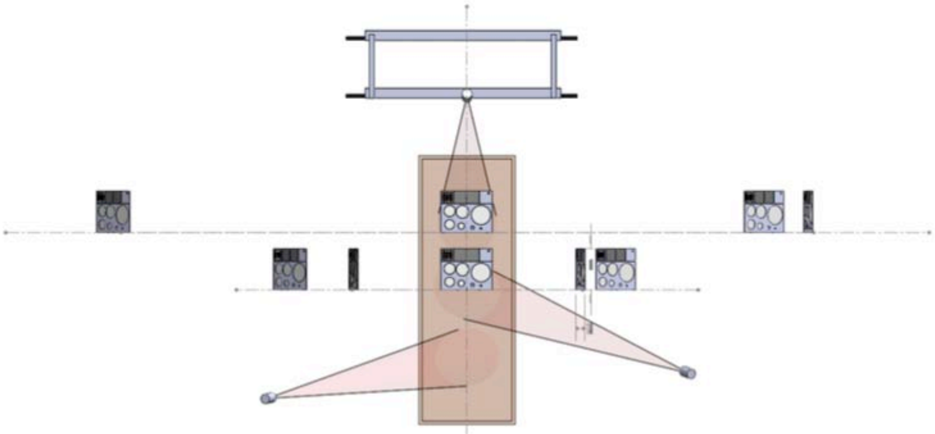


Top View

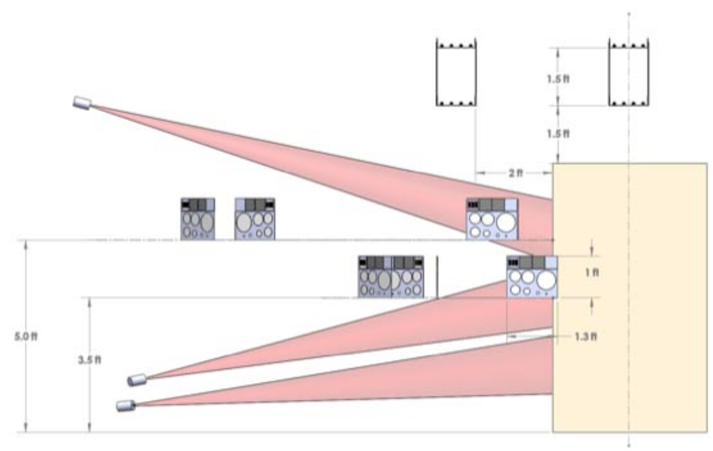




Isometric View



Front View



Side View

Initiating the Arc

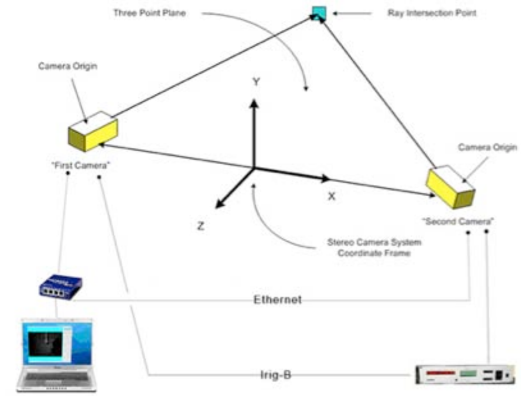
- IEEE Standard C37.20.7 – 2007 to be followed
  - For low voltage equipment: the arc shall be initiated by means of a metal wire 2.6 mm in diameter or 10 AWG
  - For medium voltage equipment: the arc shall be initiated by means of a metal wire 0.5 mm in diameter or 24 AWG
- Copper wire will be used for the tests

Data Acquisition

- Proper instrumentation will be needed to collect data:
  - Arc intensity and duration
  - Target damage as a result of the arc
  - Post-HEAF fire damage
- Pressure, temperature, and heat flux should be measured
- Electrical data will also be collected

Sensing & Imaging

- Photometric:
  - High-speed video capabilities – Employing 2D or 3D measurement techniques to track and quantify ejecta and leading edge of the fireball from multiple views
  - Open shutter image – Multiple views inside the cabinet to capture spatial extent of arching (if installation of Lexan window is allowed)
  - Photodiodes – Detectors using single point to capture initiation times of the arching (if installation of Lexan window is allowed)



Typical Digital Image Correlation system setup

Digital image correlation systems are used at Sandia to track objects moving at very high speeds

International Collaboration

- Collaborative project with the Organization for Economic Co-operation and Development (OECD/NEA)
- Members will jointly define an experimental test matrix, experimental conditions, and parameters to be investigated
- Our goal is to obtain International operation experience from additional sources related to non U.S. HEAF events

OECD Planned Donations

- The following countries have identified their interest in potentially donating equipment for testing
  - France
  - Germany
  - Korea
  - Japan
  - Spain

Planned Equipment Donation

Central Research Institute of Electric Power (CRIEPI), Japan Japan Nuclear Energy Safety Organisation (JNES), Japan	CRIEPI shall provide the following as Contributed Equipment: 1) Metal Clad Switchgear Cabinet (M/C); Type:VF-40 DM-BA (4 cabinets) Rated Voltage: 6,9 kV Rated Frequency: 50Hz Rated Short-Time Withstand Current: 40kA, 2s JNES shall be responsible for delivering the Contributed Equipment from Japan to NIST, USA
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Germany	1) 6.9 kV Switchgear (size: ~1.0m x 1.2m x 1.1m) 2) Transformer (size: ~1.5m x 1.8m x 1.0m ; weight ~6 t)
Korea Institute of Nuclear Safety (KINS), Korea (Republic of)	1) Class "M" Metal-Clad Medium Voltage Air Break Switchgear (GEC 480V) 2) Type DS Metal-enclosed Low Voltage Power Circuit Breaker Switchgear (DS 416, Westinghouse 480V) 3) Class E7 & E8 High Voltage Air Breaker Switchgear (GEC 6900V) 4) Procel-line Type CHP Magnetic Air Circuit Breakers (Westinghouse 6900V)
The Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France	7.2 kV switchgears (dry SF6-switchgears) (One or two)

Equipment Donation

- Equipment donation both internationally and domestically will be the key to the success of this effort
- More Equipment →More tests
- More tests → More Realistic Results
- More Realistic Results →Less uncertainty & Better Understanding of HEAF Phenomena

US involvement

- Any US utility interested in participating by providing equipment or valuable expertise is welcome to contact EPRI (Rick Wachowiak)
- Zion decommissioning activities
- Other sources for used equipment???

Summary

- HEAF events have occurred and are expected to occur in NPP and non-nuclear plants in the future
- Data from experimental testing will assist in better understanding the phenomena and developing more realistic tools to model the risk in fire PRAs
- Motive for experimental program is supported internationally by CSNI/IAGE HEAF TG work

Timeline		
2012	2013	2014
•Equipment Collection •Finalize Test Plan •Establish Lab Contracts •Establish OECD Contracts	•Perform actual Testing	•Document and Analyze Test Program •Update State-of-the-Art NUREG/CR – 6850 Appendix M

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Current Licensing Basis Issue Discussion

2012 NEI Fire Protection Information Forum

Daniel Frumkin, Team Leader
Division of Risk Assessment
U.S. NRC

Topics

- Circuits Licensing Basis
- NEI 00-01, Revision 3
- PORV, SRV and Other Scenarios
- Other Current Licensing Basis Topics

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Circuits Licensing Basis (1)

- The NRC staff is pursuing a generic letter, regarding fire-induced circuit failure licensing basis
- The details of the request are pre-decisional
- This is a follow-on of the draft GL that was included in SECY-06-0196
- The NRC staff has taken actions to resolve Commission concerns in SRM-SECY-06-0196

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Circuits Licensing Basis (2)

- Recent public meeting summaries
  - December 8, 2011 – ML120050208
  - January 31, 2012 – ML120481526
  - May 3, 2012 – ML121380184
- Industry concerns (from May 3 meeting):
  - Clarity of the CLB related to whether or not MSOs are included
  - Establishing a stable resolution process is seen as a necessary precursor to establishing a regulatory foot print

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Circuits Licensing Basis (3)

- The following points were provided in the meeting announcement for the May 3, 2012 pubic meeting (ML121040330)
  - *The NRC staff is committed to bringing stability to both the technical and regulatory side of the circuit failure issue.*
  - *Licensees maintaining a, "single spurious" plant specific licensing basis . . . that predates the [recent] circuit testing . . . will continue to be scrutinized by the NRC for safety.*
  - *A description of this analysis/evaluation should be included in each plant's licensing basis.*

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NEI 00-01, Revision 3

- The NRC staff provided comments in meeting summary May 3, 2012 (ML121380184)
- The NRC staff has additional comments on other sections of NEI 00-01, Revision 3
- NRC staff is awaiting more information regarding NEI 00-01, Revision 3
  - Application of shorting switch modification
- NEI 00-01, Revision 3, has not been endorsed by the NRC staff

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PORV, SRV and Other Scenarios (1)

- During May 3, 2012 public meeting (ML121380184), the NRC staff expressed concerns with manual actions to recover from spurious actuations that could affect RCS inventory.
  - Spurious PORV or SRV opening
- As quoted at a recent NFPA 805 meeting, "there are some control room fires that can not be recovered from with manual actions."
  - The NRC staff needs to understand how this applies to non-NFPA 805 plants

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PORV, SRV and Other Scenarios (2)

- Recent licensing actions and citations related to this subject involve numerous factors:
  - Operator manual actions – timing
  - Control room actions
  - Thermo-hydraulic plant response
  - Fire-induced cable failures
    - Spurious actuation
    - Cable short to ground (no spurious)

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Other Topics

- Procedure entry conditions, “T=0”
- Application of, “Adverse affect on safe shutdown”
  - Inspection Procedure 71111.05T, Enclosure 3 Discussion

Lessons Learned from Risk-Informed, Performance-Based Fire Protection (NFPA 805) Regulatory Reviews

Donnie Harrison, Chief
Probabilistic Risk Assessment Licensing Branch
Division of Risk Assessment
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission

Contents

- Background
- Pilot Applications Observations & Lessons Learned
- New Applications Observations & Lessons Learned
- Conclusions

Background

Problem Statement:

Fire protection regulation (10 CFR 50.48) was promulgated after most nuclear power plants already built

As a result,

- plant-specific fire protection licensing basis can include numerous exemptions or deviations from the deterministic requirements **AND**
- plant-specific fire protection licensing basis can be complex and ambiguous – open to interpretation

Background (continued)

2001

- Issued National Fire Protection Association (NFPA) Standard 805 "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," 2001 Edition

June 2004

- NRC promulgated a rule change to 10 CFR 50.48, "Fire Protection," adding a new section - 10 CFR 50.48(c) - that allows licensees to adopt NFPA 805 (2001 Edition), with some clarifications, as an alternative to the solely deterministic requirements of 10 CFR50.48(b)
- Rule relies upon combination of fire PRA and deterministic requirements
- About 50% of licensees indicated they would be voluntarily transitioning fire protection licensing basis to 10 CFR 50.48(c)

Background (continued)

Spring 2005

– Two licensees (Oconee and Harris) volunteered to pilot transition to 10 CFR 50.48(c)

September 2005

– NRC, in collaboration with the Electric Power Research Institute (EPRI), published NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Plants"

2005 – 2008

– Pilots developed fire PRAs and evaluated plants for transition
– NRC conducted a series of observation visits with pilots and evaluated industry guidance on making transition

Background (continued)

May 2006

- NRC issued Regulatory Guide 1.205, "Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants," that endorsed industry guidance (NEI 04-02, "Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c)," Revision 1)

May 2007

- NRC published NUREG-1824, "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications"

May 2008

- Both pilots submitted license amendment requests to implement 10 CFR 50.48(c)

May/December 2010

- Harris/Oconee license amendments approved with conditions

Pilots Lessons Learned

Pilot applications and regulatory approval demonstrated that it is possible to transition to a risk-informed, performance-based fire protection licensing basis

- Demonstrated risk-informed approach for broad-scope applications
- Demonstrated use of fire PRA to identify and disposition licensing issues
- Addressed exemptions and deviations
- Established clear licensing basis and change process

Pilots Lessons Learned (continued)

Transition license applications and regulatory reviews are more complex than originally estimated

- Significantly greater effort to collect information
  - Cable tracing and walk-downs
- Significantly more complex and detailed analyses
  - First-time integrated use of NUREG/CR-6850 and PRA Standard
  - Internal events PRA issues/simplifications can create fire PRA issues
- Significantly greater regulatory review effort and time
  - Much of the technical detail is in supporting analysis documentation and not directly in the license application
  - Requires significant knowledge of fire PRA methods

Pilots Lessons Learned
(continued)

Transition resulted in safety improvements

- Both licensees expended significant resources to evaluate and install modifications (and improve procedures) using risk insights
  - Moved at-risk safe shutdown cables
  - Installed 3-hour rated cables
  - Installed very early warning (incipient) fire detection in risk-critical electrical cabinets (alarms before flame occurs)
- Some fire-related modifications reduce overall plant risk
  - Installed alternate reactor coolant pump seal injection system significantly reduces plant risk, including from station blackout
  - Installing protected service water system significantly reduces plant risk, including from tornado and high energy line breaks
    - sole basis for risk acceptance of one pilot application, without self-approval

Pilots Lessons Learned (continued)

Frequently asked question (FAQ) process is effective in resolving regulatory and technical issues and brings regulatory stability to transition

- Recognized need to address regulatory and technical issues during pilot application development and review
  - August 2007 Issued Regulatory Issue Summary 2007-19, "Process for Communicating Clarifications of staff Positions Provided in Regulatory Guide 1.205 Concerning Issues Identified During the Pilot Application of National Fire Protection Association Standard 805"
  - Monthly public meetings with industry task force to discuss emerging issues and develop solutions
  - Regulator documents interim regulatory position on each issue
  - About 50 issues resolved using FAQ process
    - e.g., PRA modeling of the installed incipient detection system

Pilots Lessons Learned (continued)

Lessons learned during pilots captured by supplements and revisions to industry and regulatory guidance

- Fire PRA and methods/model clarifications and enhancements
  - Supplement to NUREG/CR-6850 issued in December 2010
- Licensee application and review clarifications and enhancements
  - NEI 04-02, "Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c)," Revision 2, issued April 2008
  - NEI 00-01, "Guidance for Post Fire Safe Shutdown Circuit Analysis," Revision 2, issued May 2009
  - Regulatory Guide 1.205, Revision 1, issued December 2009
  - Standard Review Plan Section 9.5.1.2 issued December 2009
- Developed templates for license application & safety evaluation
  - Identifies needed information and level of detail
  - Standardizes format and location of information

Early Applications Lessons Learned

10 license applications have been submitted since the completion of the pilots

Insights are based on the first 6 license application reviews

Recognized need for enhanced training for NFPA 805 reviewers so as to ensure common understanding of regulations, applications, and scope/approach to reviews

- Staff taking RES/EPRI NUREG/CR-6850 PRA Methodology training
- Developed NFPA 805 training for all staff and support contractors
- Established quality/consistency oversight role to ensure consistency among multiple, simultaneous application reviews
  - 1 senior staff for deterministic fire protection and 1 senior staff for fire PRA
- Established shadow reviewer role for early application reviews to enhance knowledge of new and less experienced staff
  - Prepares new staff for lead discipline reviewer role on future applications
  - Regulatory overhead expense

Early Applications Lessons Learned (continued)

License application and safety review templates provide consistent approach and presentation of information at a consistent level of detail

- Identifying additional clarifications for templates regarding specific information needed in license application

Use of an electronic document portal and performing site audit early in review allows regulator to review detailed supporting materials early in license application review

- Improves regulator understanding of licensee analyses/approach
- Focuses requests for additional information
- Should eliminate multiple rounds of questions
- Should reduce overall schedule of review

Early Applications Lessons Learned (continued)

Enhancements to fire PRA methods continue to be developed and used in NFPA 805 license applications

- Identified as an issue during early industry fire PRA peer reviews in determining appropriateness of new methods
  - Industry established a Fire PRA methods task force (expert panels) to review "unreviewed analysis methods (UAMs)"
    - Regulatory staff member was involved with review panels to ensure regulatory awareness and early identification of acceptability or issues related to new methods
    - Panel determination sent to industry task force who sends it to rest of industry (including peer review teams) and submits it to the regulator
    - Regulator sends a letter back to industry to establish the regulatory position on the acceptability of new methods for risk-informed applications
    - Expect acceptable methods to be eventually incorporated into guidance documents (e.g., NUREG/CR-6850)

Early Applications Lessons Learned (continued)

4 new methods have been through this process

- All have been changed to be found appropriate for use
  - Panel often turned into a development effort instead of a review effort
- 1 method accepted by regulator with no clarification
- 1 method accepted by regulator with minor clarification
- 1 method accepted by regulator, but with modification to ensure correct input data are used
- 1 method rejected by the regulator (identified dissent during panel)

- Use of UAMs in NFPA 805 license applications prior to, or while under, review by industry fire PRA task force panel creates uncertainty in regulatory acceptability of application
  - Applications using UAMs need to address acceptability by providing an analysis using accepted methods
    - Provides assurance that application review can progress regardless of outcome of panel review and regulatory acceptance of UAM

Early Applications Lessons Learned (continued)

Staff have observed 3 Fire PRA peer reviews

Fire PRA Peer Review observations provide insights supporting staff reviews

- Overall observation is that a very expert team is needed to adequately perform these peer reviews
  - Different peer reviews can have different findings for similar plants
    - Inherent in approach, expertise of peer reviewers, scope of peer review
- Some peer reviews against Standard do not address RG 1.200
- Many peer reviews performed prior to Fire PRAs completed
  - Requires follow-on peer reviews
  - Can impact licensee application submittal schedules
- Early peer reviews may not have adequately addressed UAMs
  - Especially likely prior to creation of UAM bin in peer review guidance
- Documentation findings need to be fixed

Early Applications Lessons Learned **(continued)**

PRA Peer Reviews are intended to obviate the need for an **in-depth** staff review of the **base** PRA

- Does not eliminate staff review of the base PRA
  - Specific issues and complexities can drive staff into more detailed reviews of the base PRA
- NRC typical focus is on:
  - Licensee’s resolution of peer review findings (both internal and fire PRA findings) as they impact the specific application
  - Risk impacts for the specific application
- NFPA 805 applications typically build an NFPA 805 PRA without a base Fire PRA
  - Whole Fire PRA becomes in scope for the staff review

Conclusions

- Two pilot license application approvals represent a significant milestone for industry and regulator
  - Both pilots proposed significant safety enhancements, demonstrating how risk insights can be used to improve fire safety (and overall plant safety) at nuclear power plants
  - Numerous lessons learned were incorporated into supplemented/revised guidance documents and development of license application and safety evaluation templates
- Lessons continue to be learned
- Achievements
  - Improved license applications
  - More efficient and effective regulatory reviews
  - Improved regulatory clarity and regulatory stability
  - Enhanced understanding of fire risk and improved plant safety

Thank You!

Questions?

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Plenary Seven: Fire Protection Research and Development

Mark Henry Salley P.E. Branch Chief
Office of Nuclear Regulatory Research

Fire Protection Information Forum

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Today's Presentations

- Fire Events Data Base Project
  - Rick Wachowiak (EPRI)
- CHRISTIFIRE
  - Dr. Kevin McGrattan (NIST)
- Fire Modeling Activities
  - Dr. Francisco Joglar (Kleinsorg Group)
  - Dr. Kevin McGrattan (NIST)

Today's Presentation continued

- Latest Electrical Cable Performance Testing under Fire Conditions, PIRT. Expert Elicitation
  - Gabriel Taylor (NRC-RES)
  - Harry Barrett (NRC-NRR)
  - Robert Daley (NRC-RIII)
  - Andy Ratchford (RDS)
  - Dan Funk (Kleinsorg Group)

Today's Presentation continued

- Future updates to NUREG/CR-6850 (EPRI1011989)
  - Nicholas Melly (NRC-RES)
  - Rick Wachowiak (EPRI)
- Metal –Clad Switchgear Fire at ONAGAWA NPP in Japan
  - Susumu Tsuchino

NRC Fire Research Other Key Activities

- Low-Power Shutdown NUREG/CR-7114
- Very Early Warning Fire Detection Systems (VEWFDS) NUREG/CR-XXXX
- Fire Protection Compensatory Measures NUREG/CR-XXXX
- Shipping Cask Seal Performance NUREG/CR-7115
- Smoke Effects on Electronic Equipment NUREG/CR-7123

Fire PRA Training

- Five Different Classes:
  - Fire PRA
  - Electrical Circuits
  - Fire Analysis
  - Fire Human Reliability Analysis (HRA)
  - Advanced Fire Modeling
- NRC Sponsored Two Weeks in 2012
  - Bethesda Maryland
  - July 16 – 20
  - September 24 – 28
  - Over 200 attendees, 7 Different Countries
  - http://www.nrc.gov/public-involve/conference-symposia/epri-fire-pra-course/epri-fire-pra-course-info.html

Fire PRA Training (continued)

- Video taped the 2012 sessions;
  - Hope to produce an updated:

    Method for Applying Risk Analysis to Fire Scenarios (MARIAFIRES – 2008) NUREG/CP-0194 (EPRI1020621)
- EPRI will sponsor two weeks in 2013
- NRC will sponsor two weeks in 2014

Research Knowledge Management Activities

- NUREG/KM-0001 Three Mile Island
  - Fall 2012
- NUREG/KM-0002 Browns Ferry Fire (Formerly NUREG/BR-0361)
  - Winter 2012
- NUREG/KM-0003 Fire Protection and Fire Research Knowledge Management Digest (Formerly NUREG/BR-00465)
  - Spring 2013

Research Collaboration

- Always Looking for Best Partnerships:
  - National Institute Standards & Technology
  - Sandia National Laboratories
  - Brookhaven National Laboratories
  - Idaho National Laboratories
  - University of Maryland
  - OECD
- EPRI

NRC/RES- ERPI MOU

- Memorandum of Understanding on Research between NRC(RES) and EPRI
  - Separate Addendum specifically for Fire Research
- Some of the Most Successful Fire Research Projects were Performed under the MOU:
  - Fire PRA NUREG/CR-6850 (EPRI1011989) 2005
  - Fire Model V&V NUREG-1824 (EPRI1011999) 2007
  - MARIAFIRES NUREG/CP-0194 (EPRI1020621) 2010
  - Fire HRA NUREG-1921(EPRI1023001) 2012
  - Fire Model Application Guide NUREG-1934 (EPRI1023259) 2012
  - Electrical PIRT NUREG/CR-7XXX (EPRI1026424)

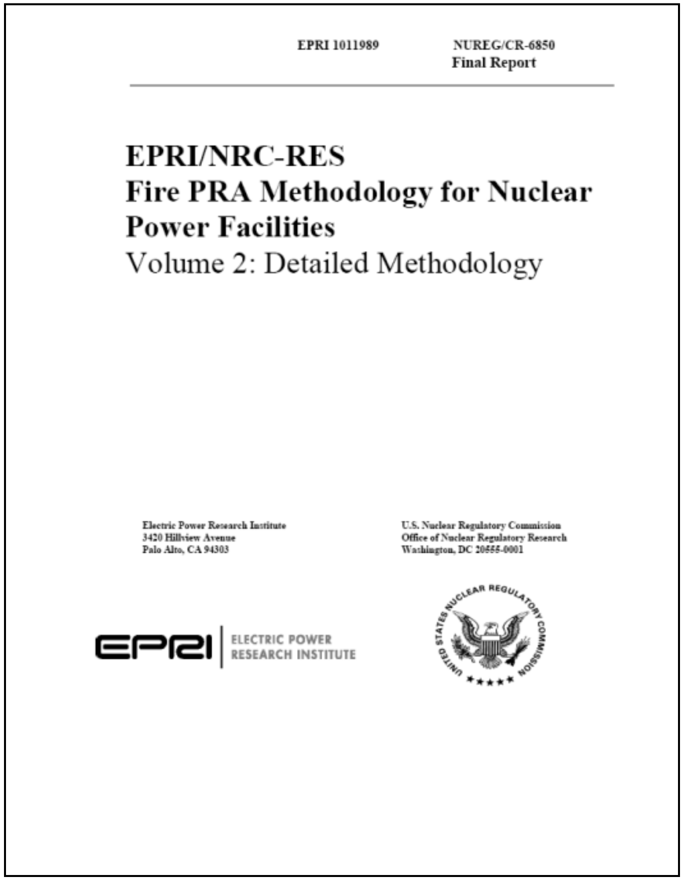
CHRISTIFIRE Phase 2
Cable Heat Release, Ignition and Spread in Tray Installations

Kevin McGrattan, NIST

Fire Protection Information Forum

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

Current Guidance for Modeling Cables


EPRI 1011989

NUREG/CR-6850
Final Report

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

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94303

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Problems going from "bench" to full-scale

Table R-1
Bench Scale HRR Values Under a Heat Flux of 60 kW/m^2, q_{bs} [R-4]

Material	Bench Scale HRR [kW/m^2]
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
PE/PVC	395
PE/PVC	359
PE/PVC	312
PE/PVC	589
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218

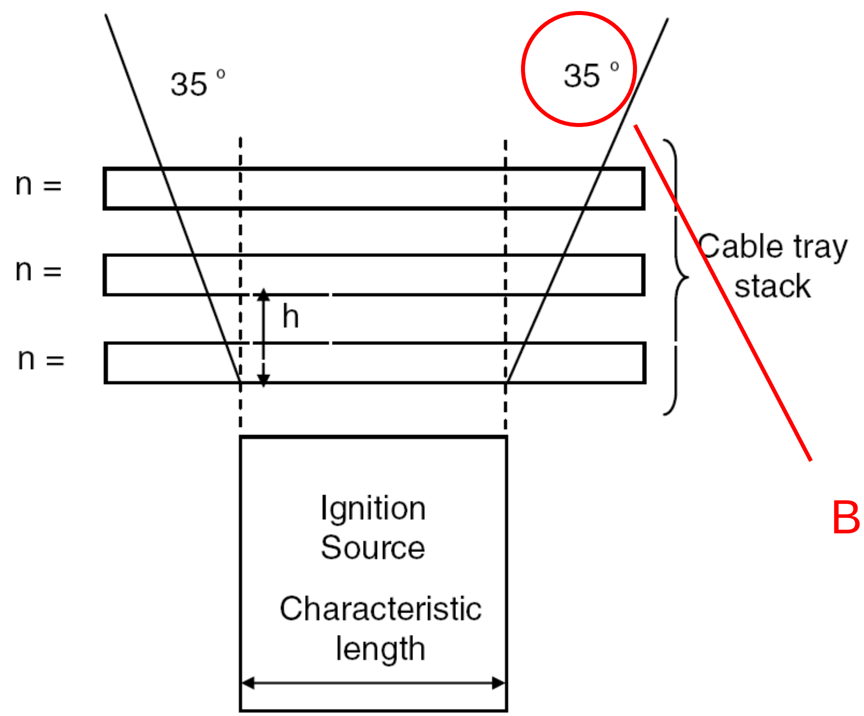
Which HRR to Use?

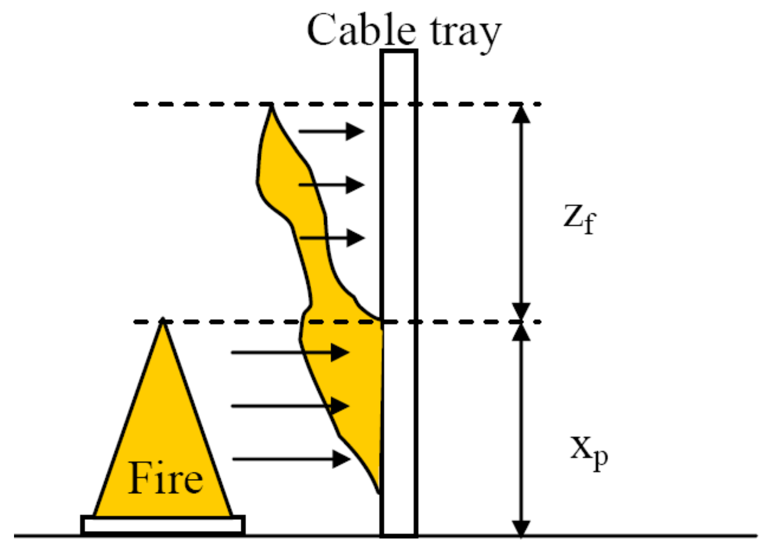
Similar guidance/info in NUREG-1805 (FDTs)

Current Guidance on Flame Spread

$$v = \frac{4\left(\dot{q}''_f\right)^2 \delta_f}{\pi (k\rho c)\left(T_{ig} - T_{amb}\right)^2}$$

Vague or ill-defined parameters





Based on only one experiment

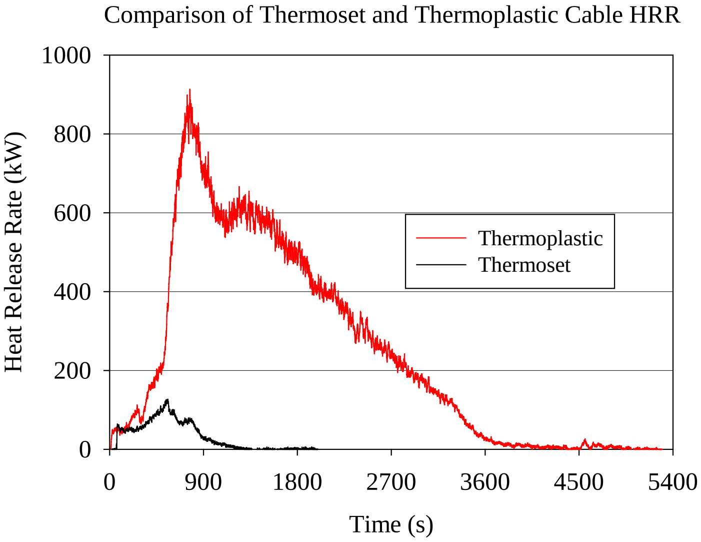
CHRISTIFIRE Phase 1

Micro-Calorimeter

Cone Calorimeter

Panel Calorimeter

Full-Scale Calorimeter



U.S.NRC
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NUREG/CR-7010, Vol. 1

Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE) Phase 1: Horizontal Trays

Office of Nuclear Regulatory Research

Results of Phase 1

Burning rates for thermoplastic and thermoset cables that simplify the methodology in NUREG/CR-6850

Validation of empirical fire spread rates in Appendix R of 6850

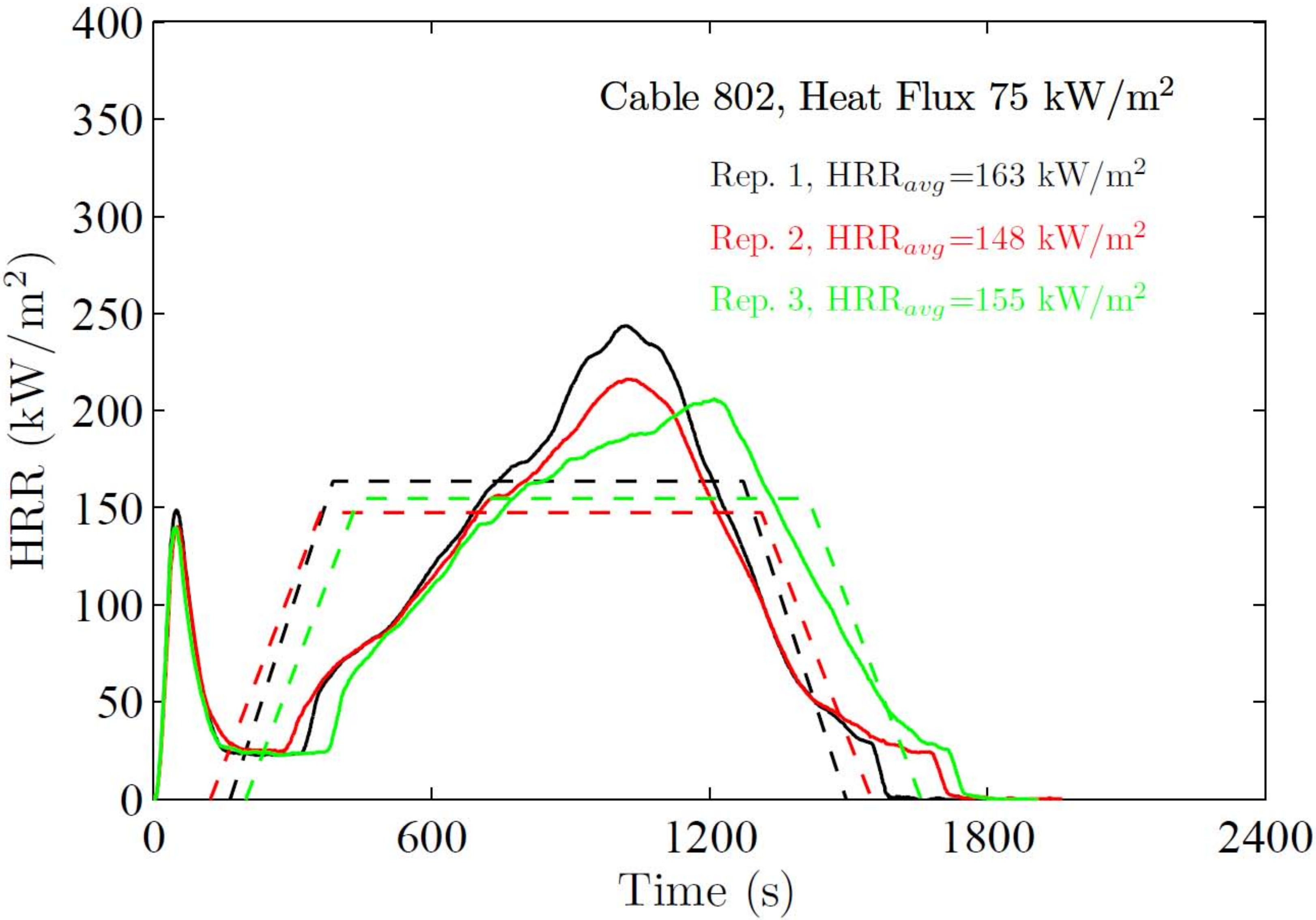
A simple flame spread algorithm for ladder back, horizontal cable trays – FLASH-CAT (Flame Spread over Horizontal Cable Trays)

Cables used in CHRISTIFIRE Phases 1 and 2

Phase 2 Cone Calorimetry

Figure 4-45. Additional photographs of Cable 819.

Method for determining average heat release rate

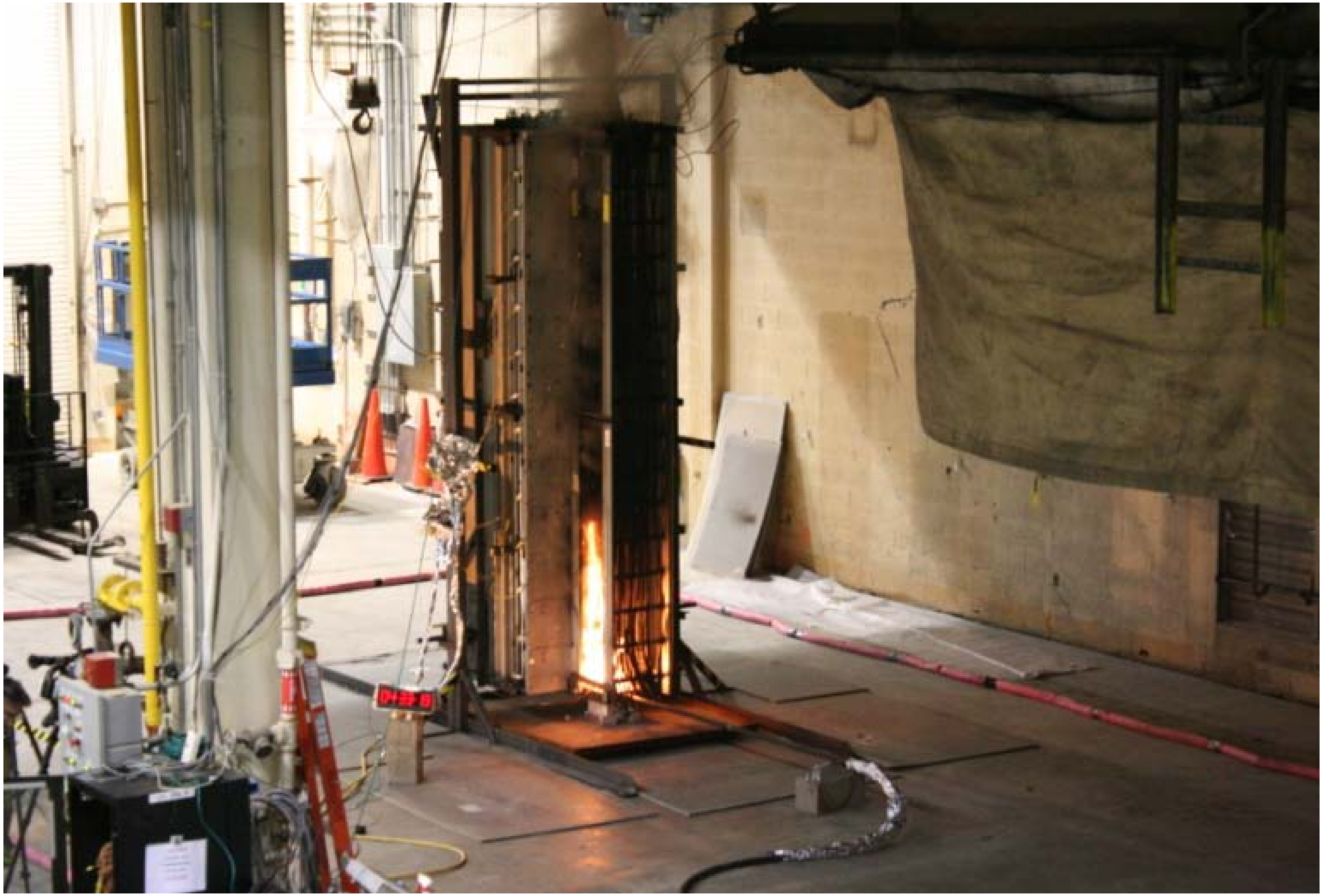


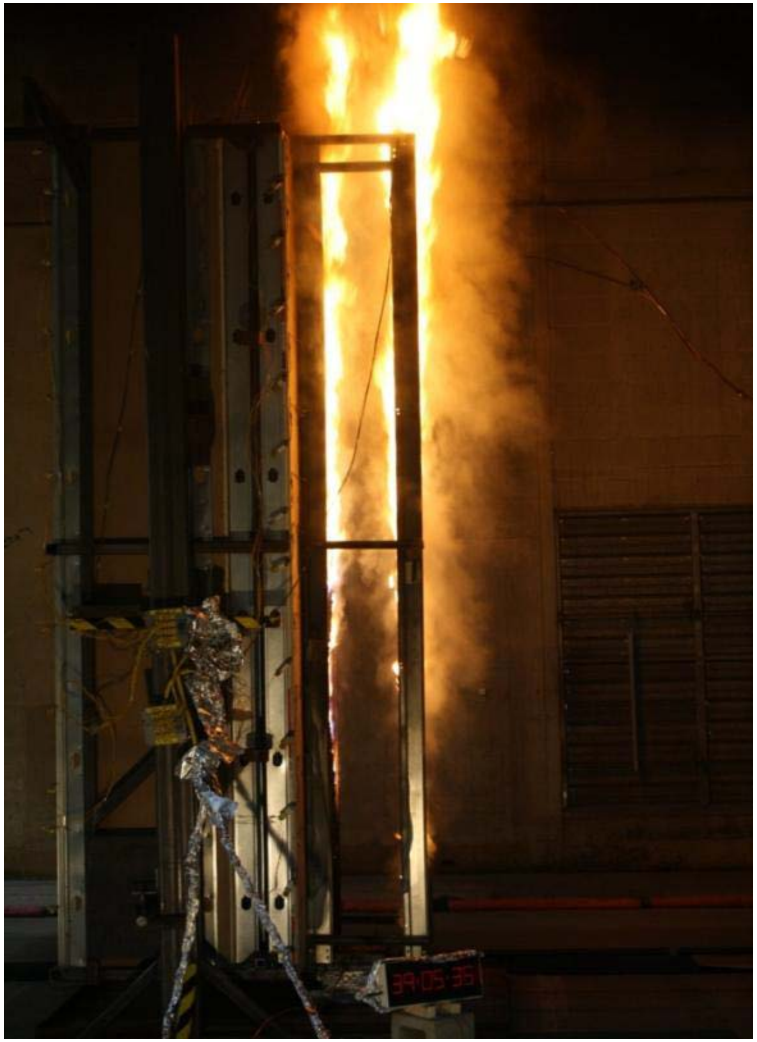
Summary of Cone Calorimeter Experiments

Table 4-2. Average heat release rates and residue fractions for TS and TP cables.

Class	Average Residue Fraction	Average Heat Release Rate (kW/m^2)	
		50	**75**
TP	0.17	179	238
TS	0.38	117	153

Vertical cable fire spread



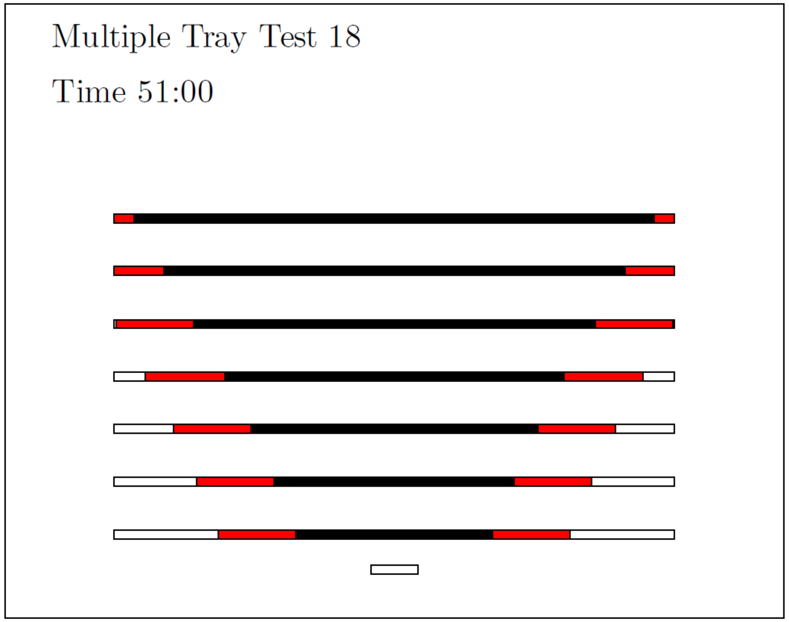


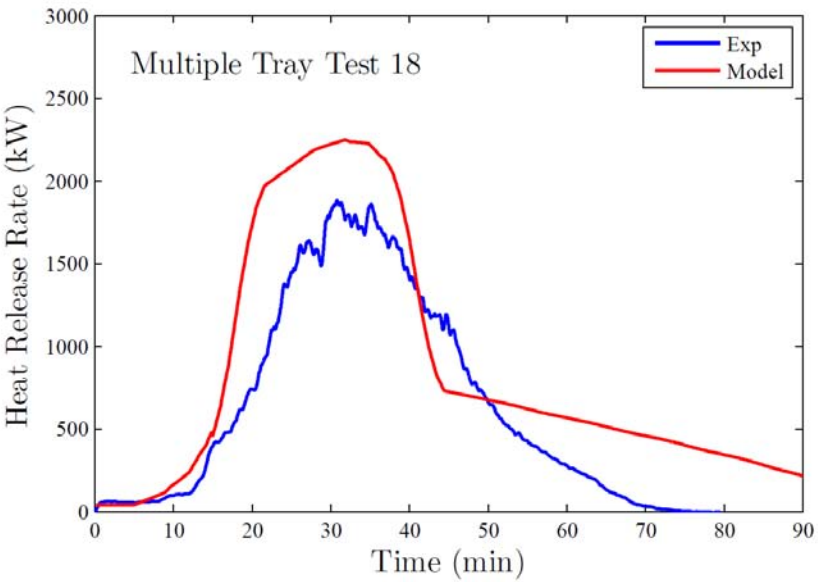
Hallway Tests


35·06·58

FLASH-CAT

Flame Spread over Horizontal Cable Trays





Required Data

- Cable mass/length
- Non-metal mass fraction

Ignition

- 5-4-3-2-1 minute rule

Upward Spread

- 35° spread angle

Burning Rate

- 250 kW/m² for thermoplastics
- 150 kW/m² for thermosets

Lateral Spread

- 3.2 m/h for thermoplastics
- 1.1 m/h for thermosets

Heat of Combustion

- 16 MJ/kg for all

The spread rate of a fire can be estimated from:

$$v \propto \frac{(\dot{q}_{\mathrm{f}}'')^2 \, \delta_{\mathrm{f}}}{\pi \, (k\rho c) \left(T_{\mathrm{ign}} - T_{\infty}\right)^2}$$

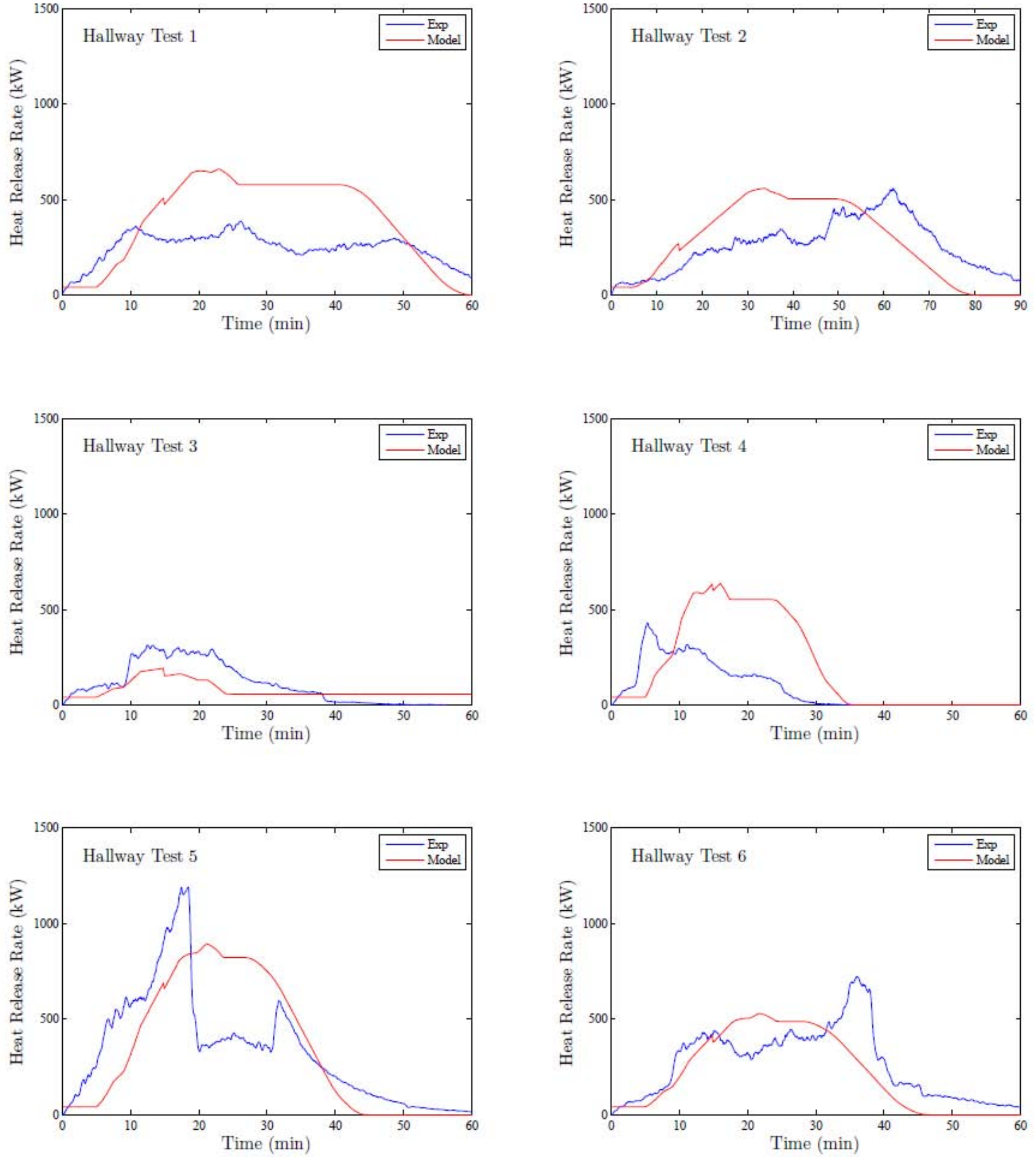
If the cables are located within the Hot Gas Layer (HGL), the spread rate could increase by a factor of 10.

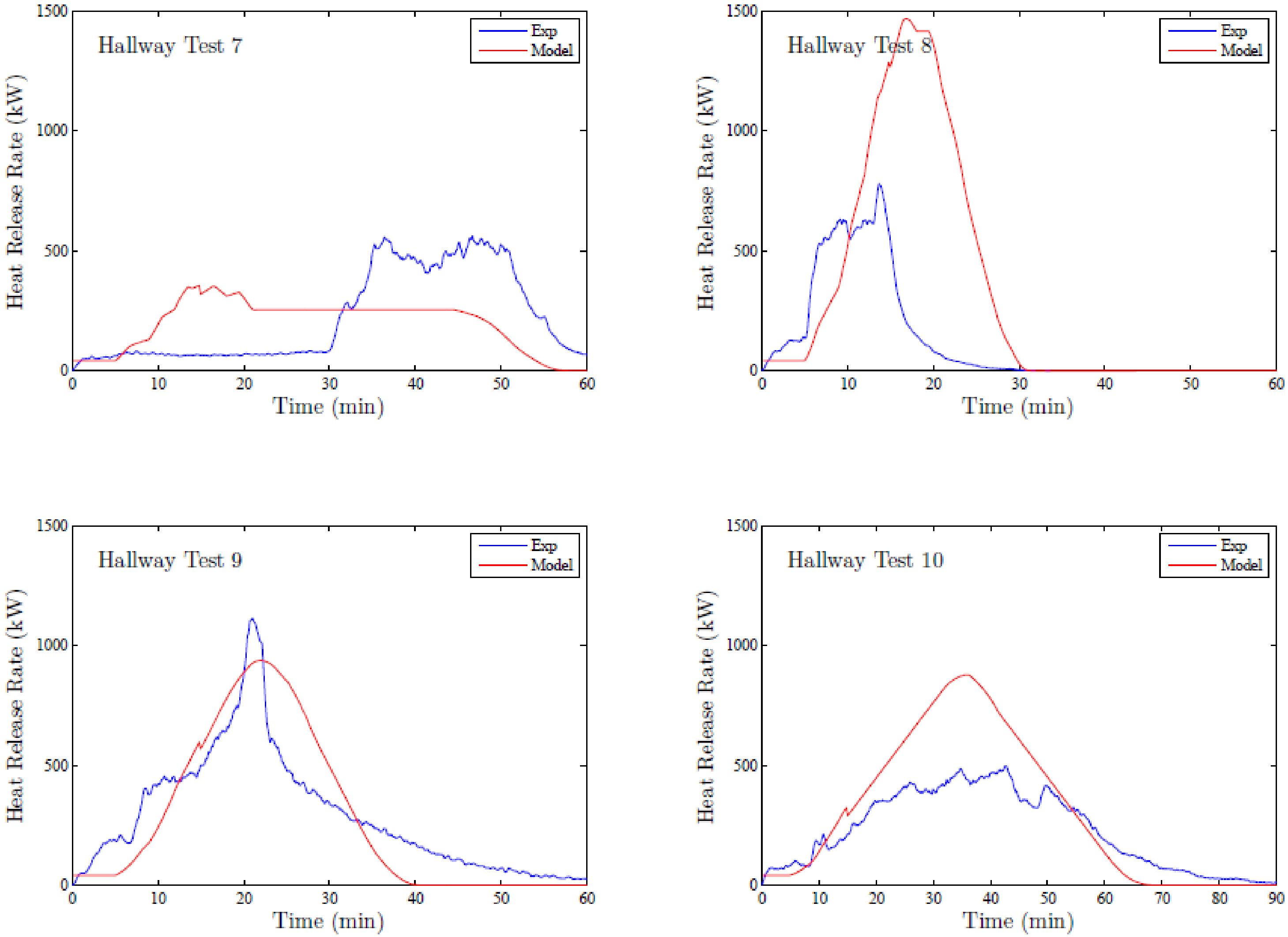
$$\frac{v_2}{v_1} = \left(\frac{T_{\mathrm{ign}} - T_{\infty}}{T_{\mathrm{ign}} - T_{\mathrm{HGL}}}\right)^2 = \left(\frac{400 - 20}{400 - 280}\right)^2 \cong 10$$

FLASH-CAT

Flame Spread over Horizontal Cable Trays

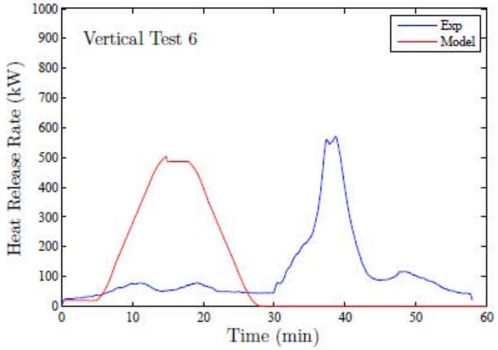
Results of Hallway Experiments

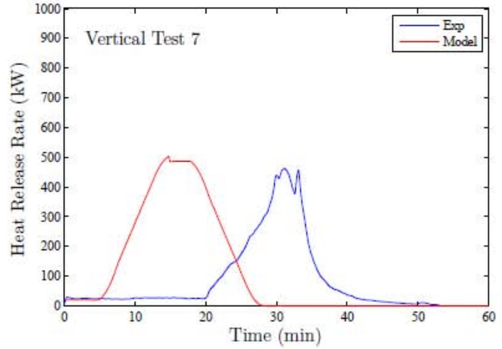


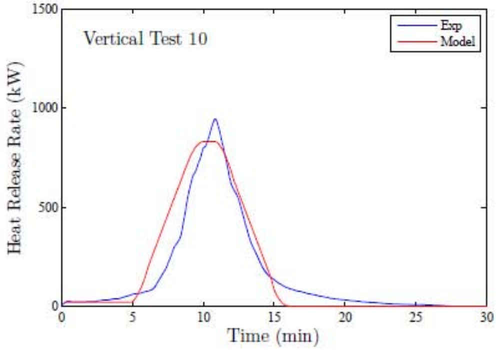

Hallway Test 7
Hallway Test 8
Hallway Test 9
Hallway Test 10
Exp
Model
Heat Release Rate (kW)
Time (min)
0
500
1000
1500
10
20
30
40
50
60
70
80
90

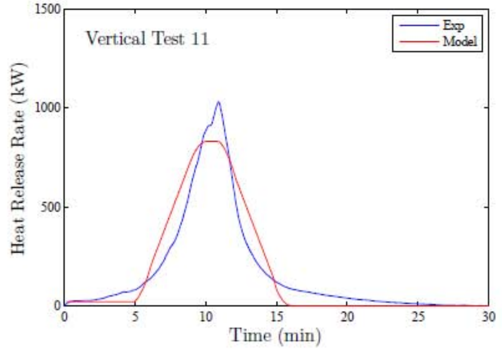
FLASH-CAT

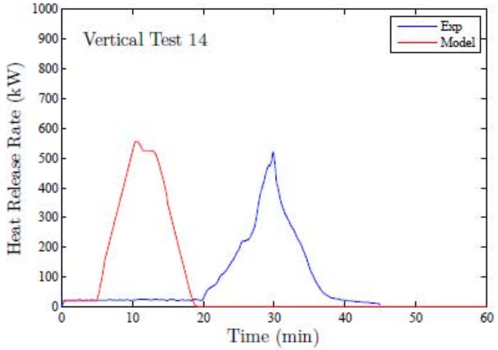
Vertical Tray Results

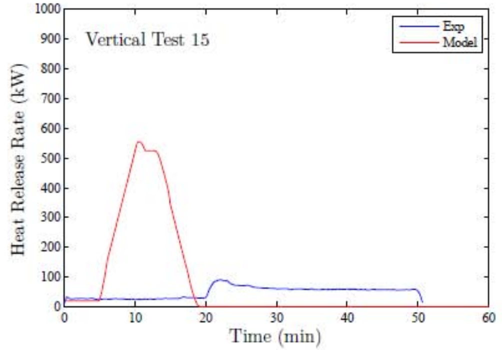












Results of CHRISTIFIRE Phase 2

Average heat release rates for thermoplastic and thermoset cables are consistent with Phase 1 experiments and FLASH-CAT modeling.

Fire spread rates are roughly a factor of 10 greater for multiple vertical trays or horizontal trays close to ceilings (or within the hot gas layer).

Fire Model Applications Guidelines (NUREG 1934) Overview

NEI Fire Protection Information Forum
September 2012, Austin TX

Kevin McGrattan, NIST
Mark Henry Salley, NRC/RES

Francisco Joglar, KGRS
Rick Wachowiak, EPRI

Purpose of Report

- Replaces EPRI Fire Model User’s Guide from 2001 with updated information on fire models, results of 2007 V&V study, model validity ranges, uncertainty analysis, more realistic examples
- Serves as the text book for NRC/EPRI Fire PRA Advanced Modeling course
- Provides a consistent framework for reporting the results of fire modeling

Public Comments

Two Rounds of Public Comments

– Reviewers wanted specific advice on selection of fire scenarios and model inputs like HRR, often to the point of going beyond just "guidance"
– Fire modeling examples pushed models beyond their range of validation, *i.e.* we didn't practice what we preached.

Fire Modeling Process

1) Define objective(s)
2) Describe fire scenario(s)
3) Select fire model(s)
4) Calculate fire-generated conditions
5) Conduct sensitivity and uncertainty analyses
6) Document the analysis

Model Applicability

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON DC 20555-0001

ACRSR-2219

October 25, 2006

Mr. Luis Reyes
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington DC 20555-0001

SUBJECT: DRAFT FINAL NUREG-1824, "VERIFICATION AND VALIDATION OF SELECTED FIRE MODELS FOR NUCLEAR POWER PLANT APPLICATIONS"

Dear Mr. Reyes:

During the 536th meeting of the Advisory Committee on Reactor Safeguards, October 4-6, 2006, we met with representatives of the NRC staff, Electric Power Research Institute (EPRI), and the National Institute of Standards and Technology (NIST) to discuss the draft final NUREG-1824 (EPRI 1011999), "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications." Our Subcommittee on Reliability and Probabilistic Risk Assessment (PRA) also reviewed this matter during its meeting on September 21, 2006. During our review, we had the benefit of the documents referenced.

CONCLUSION AND RECOMMENDATIONS

1. The report provides a systematic evaluation of the predictive capability of five commonly used compartment fire models. It should be published.
2. The user's guide to be developed by the staff should include:
   a. Estimates of the ranges of normalized parameters to be expected in nuclear plant applications.
   b. Quantitative estimates of the uncertainties associated with each model's predictions, preferably in the form of probability distributions.

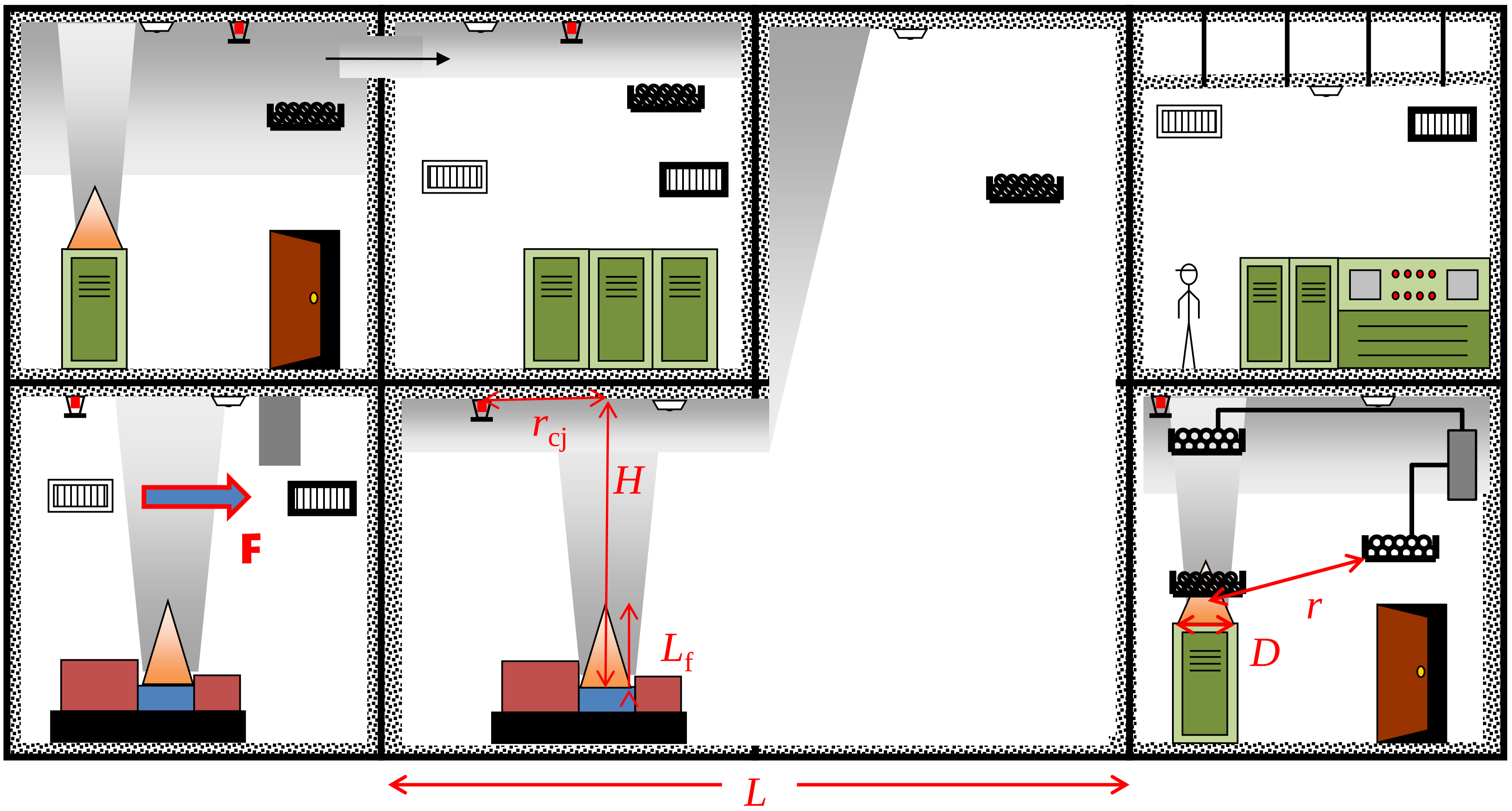
BACKGROUND

Fire models are used in a number of safety evaluations, including fire risk analysis; demonstrating compliance with, and exemptions to, the regulatory requirements for fire protection in 10 CFR Part 50, Appendix R; the significance determination process of the Reactor Oversight Process; and establishing the risk-informed, performance-based voluntary

ACRS Review:

A user will have to determine whether the results of the verification and validation study are applicable to the situation to be analyzed. This is done using "normalized parameters" ... that allow users to compare results from scenarios of different scales by normalizing physical characteristics of the scenario. These normalized parameters are traditionally used in fire modeling applications and are included in the NUREG report. The user's guide should provide estimates of the ranges of normalized parameters to be expected in nuclear plant applications. These estimates would allow a determination of whether risk-significant fires fall within or outside the parameter ranges covered by the verification and validation process.

Typical fire scenarios and Important parameters



What to do if the scenario is out of the validation range?

1. Sensitivity Analysis – Perform a calculation for a similar scenario that is more severe yet in range.

2. Reference other validation studies performed by model developers or others (i.e. universities, professional societies)

Summary of NUREG-1824 V&V Study

NUREG-1824 EPRI 1011999
Final Report

Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications

Volume 1:
Main Report

U.S. Nuclear Regulatory Commission
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Washington, DC 20555-0001

Electric Power Research Institute
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U.S.NRC

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Table 3-1: Results of the Validation & Verification of the Selected Fire Models for Nuclear Power Plant Fire Modeling Applications

Parameter[5]		Fire Model				
		FDT[s]	FIVE-Rev1	CFAST	MAGIC	FDS
Hot gas layer temperature ("upper layer temperature")	Room of Origin	YELLOW+	YELLOW+	GREEN	GREEN	GREEN
	Adjacent Room	N/A	N/A	YELLOW	YELLOW+	GREEN
Hot gas layer height ("layer interface height")		N/A	N/A	GREEN	GREEN	GREEN
Ceiling jet temperature ("target/gas temperature")		N/A	YELLOW+[2]	YELLOW+	GREEN	GREEN
Plume temperature		YELLOW–	YELLOW+[2]	N/A	GREEN	YELLOW
Flame height[3]		GREEN	GREEN	GREEN	GREEN	YELLOW[1]
Oxygen concentration		N/A	N/A	GREEN	YELLOW	GREEN
Smoke concentration		N/A	N/A	YELLOW	YELLOW	YELLOW
Room pressure[4]		N/A	N/A	GREEN	GREEN	GREEN
Target temperature		N/A	N/A	YELLOW	YELLOW	YELLOW
Radiant heat flux		YELLOW	YELLOW	YELLOW	YELLOW	YELLOW
Total heat flux		N/A	N/A	YELLOW	YELLOW	YELLOW
Wall temperature		N/A	N/A	YELLOW	YELLOW	YELLOW

ACRS Review of NUREG-1824

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ACRSR-2219

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Fire models are used in a number of safety evaluations, including fire risk analysis; demonstrating compliance with, and exemptions to, the regulatory requirements for fire protection in 10 CFR Part 50, Appendix R; the significance determination process of the Reactor Oversight Process; and establishing the risk-informed, performance-based voluntary

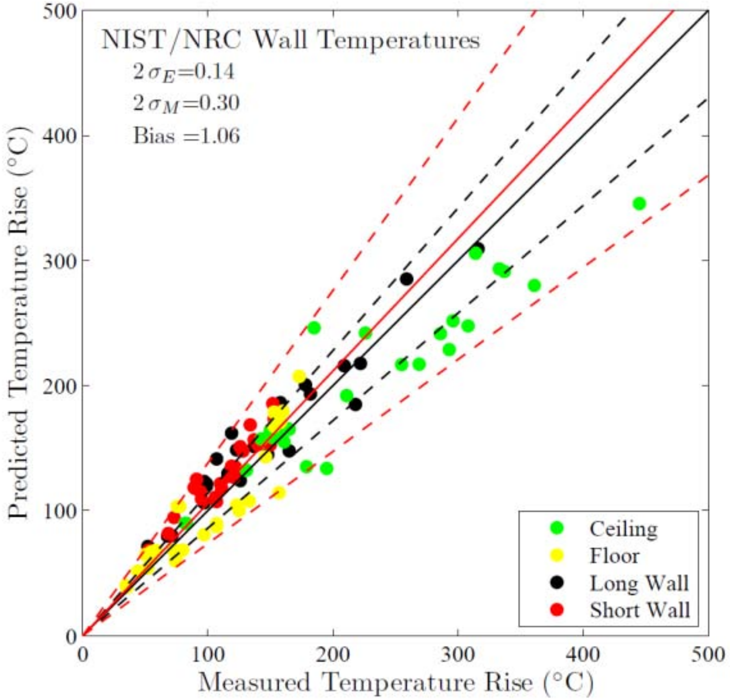
The user's guide should also provide probability distributions for the model predictions due to the intrinsic model uncertainty, i.e., the uncertainty associated with the model's physical and mathematical assumptions. These distributions should not include the uncertainties in the heat release rate since the latter will be an input specified by the user. The color designations provide no quantitative estimate of the intrinsic uncertainty. This uncertainty is an important input in risk-informed applications. Even in non-risk-informed applications, a quantitative assessment of the tendency of a model to over- or under-predict would be valuable. The staff told us that such quantitative estimates will be provided in the user's guide. We look forward to reviewing this document.

Improved Model Uncertainty Metrics

Table 4-1. Results of the V&V study, NUREG-1824 (EPRI 1011999).

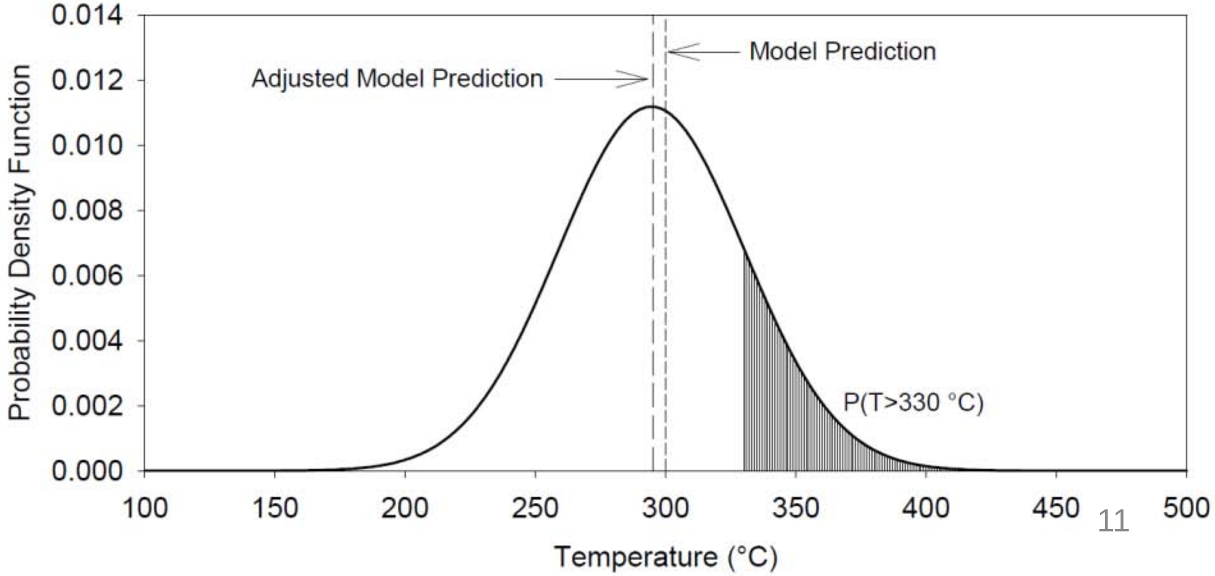
Output Quantity	FDTs		FIVE		CFAST		MAGIC		FDS		Exp
	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	δ	$\tilde{\sigma}_M$	$\tilde{\sigma}_E$
HGL Temperature Rise*	1.44	0.25	1.56	0.32	1.06	0.12	1.01	0.07	1.03	0.07	0.07
HGL Depth*	N/A		N/A		1.04	0.14	1.12	0.21	0.99	0.07	0.07
Ceiling Jet Temp. Rise	N/A		1.84	0.29	1.15	0.24	1.01	0.08	1.04	0.08	0.08
Plume Temperature Rise	0.73	0.24	0.94	0.49	1.25	0.28	1.01	0.07	1.15	0.11	0.07
Flame Height**	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.
Oxygen Concentration	N/A		N/A		0.91	0.15	0.90	0.18	1.08	0.14	0.05
Smoke Concentration	N/A		N/A		2.65	0.63	2.06	0.53	2.70	0.55	0.17
Room Pressure Rise	N/A		N/A		1.13	0.37	0.94	0.39	0.95	0.51	0.20
Target Temperature Rise	N/A		N/A		1.00	0.27	1.19	0.27	1.02	0.13	0.07
Radiant Heat Flux	2.02	0.59	1.42	0.55	1.32	0.54	1.07	0.36	1.10	0.17	0.10
Total Heat Flux	N/A		N/A		0.81	0.47	1.18	0.35	0.85	0.22	0.10
Wall Temperature Rise	N/A		N/A		1.25	0.48	1.38	0.45	1.13	0.20	0.07
Wall Heat Flux	N/A		N/A		1.05	0.43	1.09	0.34	1.04	0.21	0.10

I.D. indicates insufficient data for the statistical analysis.
N/A indicates that the model does not have an algorithm to compute the given Output Quantity.
Underlined values indicate that the data failed a normality test because of the relatively small sample size.
* The algorithm used to compute the layer temperature and depth for the model FDS is described in NUREG-1824.
** All of the models except FDS use the Heskestad Flame Height Correlation (Heskestad, *SFPE Handbook*). These models were shown to be in qualitative agreement with the experimental observations, but there was not enough data to further quantify this assessment.

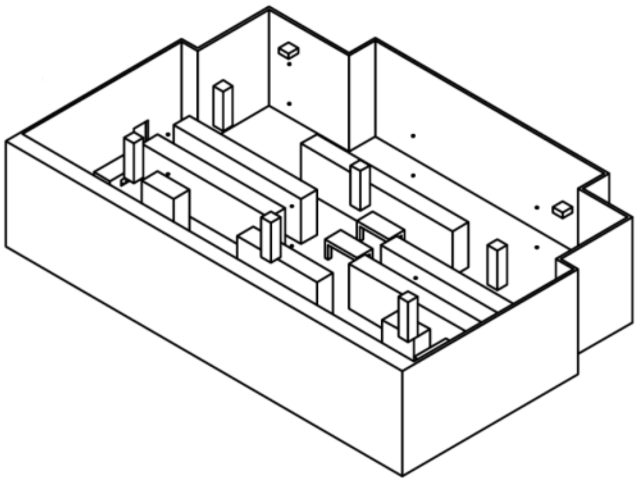


(Left) Typical results from a validation study. The black lines indicate the experimental uncertainty and the red lines indicate the model uncertainty.

(Below) Given a model prediction of 300 °C, what is the probability that the actual temperature might exceed 330 °C, the failure temperature of the given target?



How Model Uncertainty is Applied



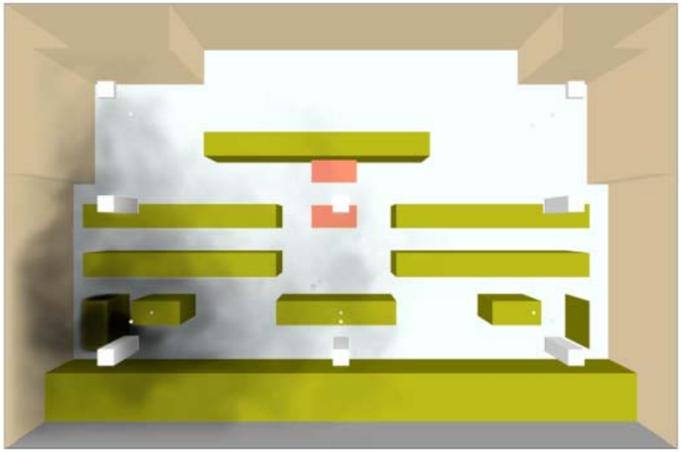
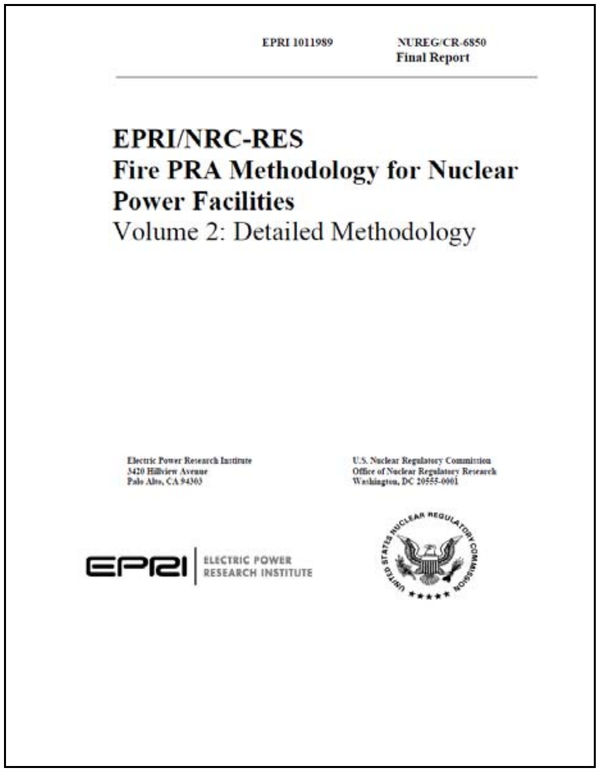


Table A-4. Summary of the model predictions of the MCR scenario.

Model	Bias Factor, δ	Standard Deviation, $\tilde{\sigma}_M$	Ventilation	Predicted Value	Critical Value	Probability of Exceeding
Temperature (°C), Initial Value = 20 °C						
FIVE (FPA)	1.56	0.32	Purge	70	95	0.000
CFAST	1.06	0.12		60	95	0.000
FDS	1.03	0.07		48	95	0.000
CFAST	1.06	0.12	No Vent.	82	95	0.009
FDS	1.03	0.07		70	95	0.000
Heat Flux (kW/m^2)						
FIVE	1.42	0.55	Purge	0.4	1	0.000
CFAST	0.81	0.47		0.1	1	0.000
FDS	0.85	0.22		0.2	1	0.000
CFAST	0.81	0.47	No Vent.	0.6	1	0.228
FDS	0.85	0.22		0.4	1	0.000
Optical Density (m^{-1})						
CFAST	2.65	0.63	Purge	6.5	3	0.362
FDS	2.7	0.55		0.5	3	0.000
CFAST	2.65	0.63	No Vent.	47	3	0.906
FDS	2.7	0.55		31	3	0.909

Parameter Uncertainty Propagation


EPRI 1011989

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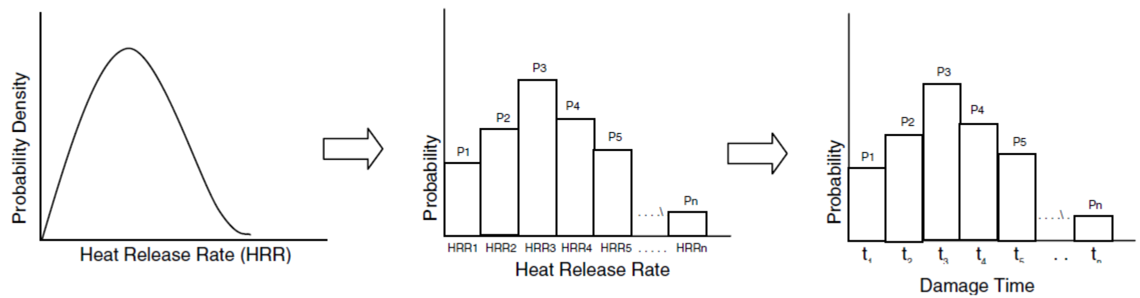
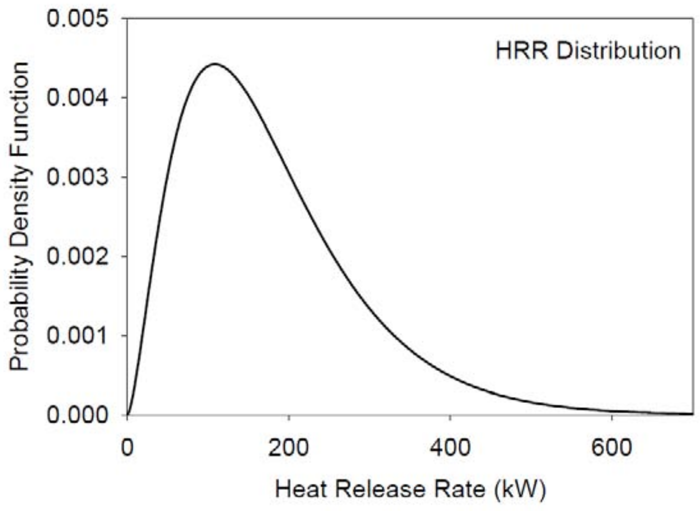
E
APPENDIX FOR CHAPTERS 8 AND 11, SEVERITY FACTORS



Currently, NUREG/CR-6850 contains a simple method for propagating parameter uncertainty. Several examples have been added to the Fire Model User's Guide.

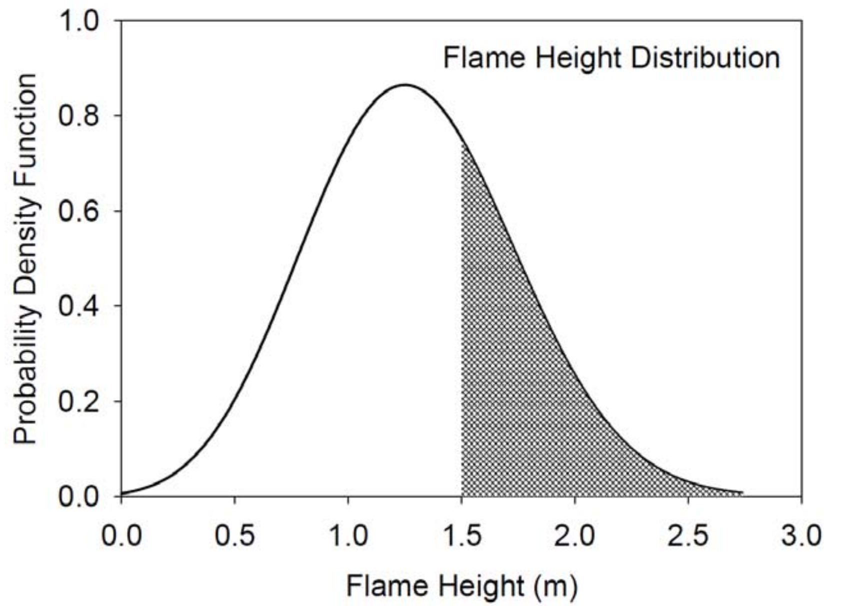
Model Input Parameter Distribution



Model: Flame Height Correlation

$$L_f = 0.235\,\dot{Q}^{2/5} - 1.02\,D$$

Model Output Distribution

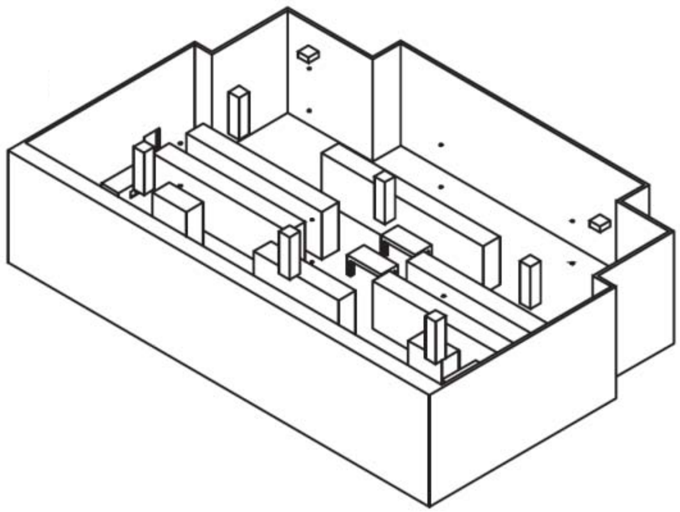


Question: What is the probability that the flames from a particular type of cabinet fire will reach a target 1.5 m above the cabinet?

Appendices

- Eight example applications, each documented in an individual appendix
  - Based on typical fire scenarios in NPP's
  - Serve as a template for consistency in the analysis and documentation of fire modeling calculations
  - Consider the fire modeling requirements of NFPA 805
  - Cover the routinely used capabilities of the fire models

A. Cabinet Fire in the Main Control Room



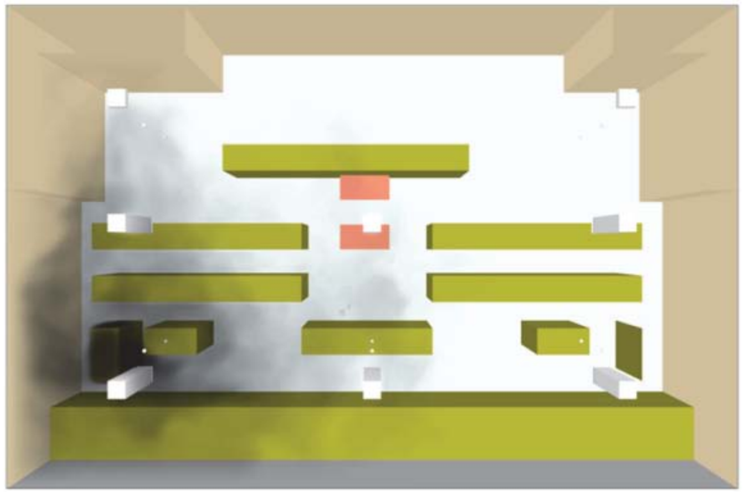
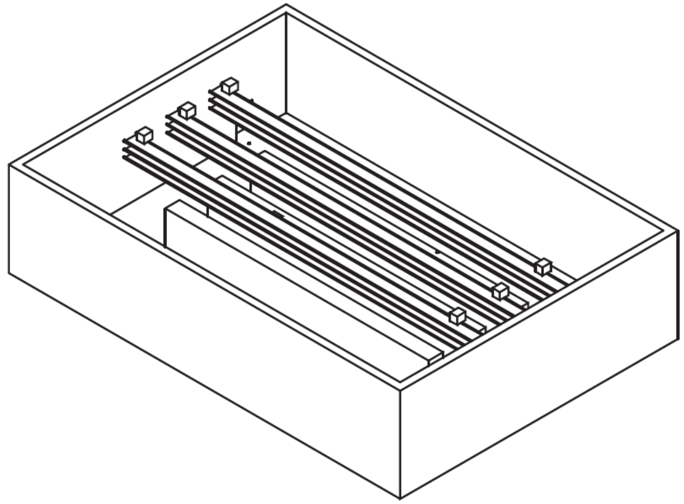


Figure A-11. FDS/Smokeview rendering of the MCR, as viewed from above.

B. Cabinet Fire in a Switchgear Room



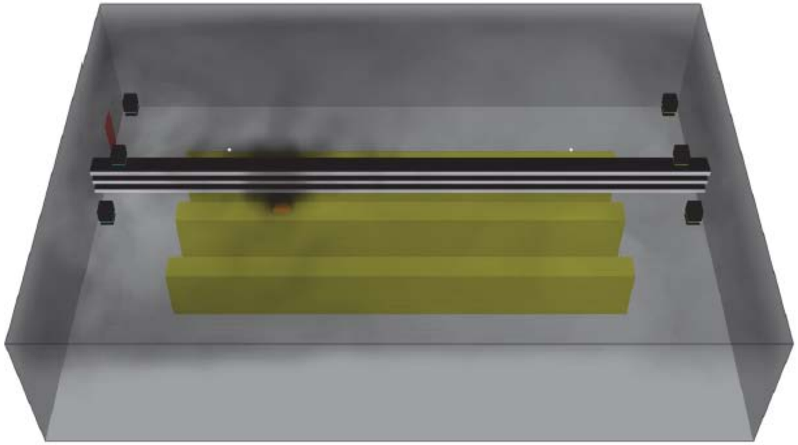
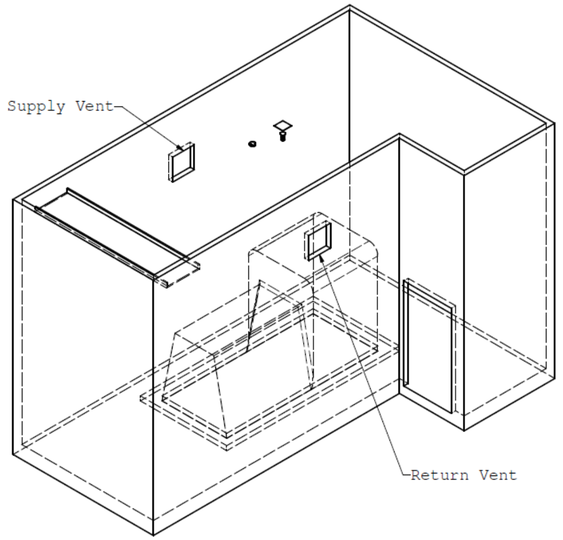
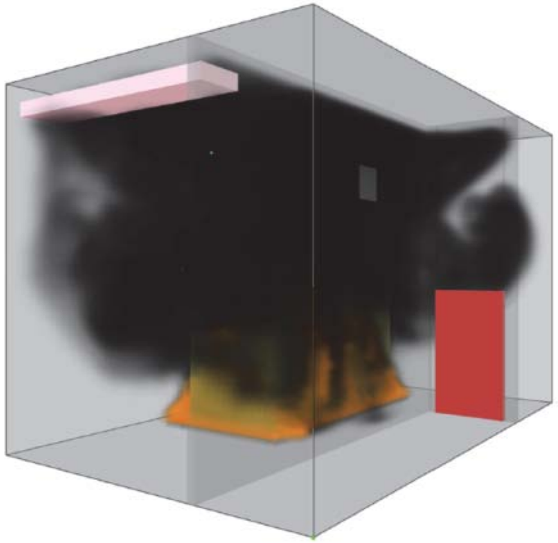


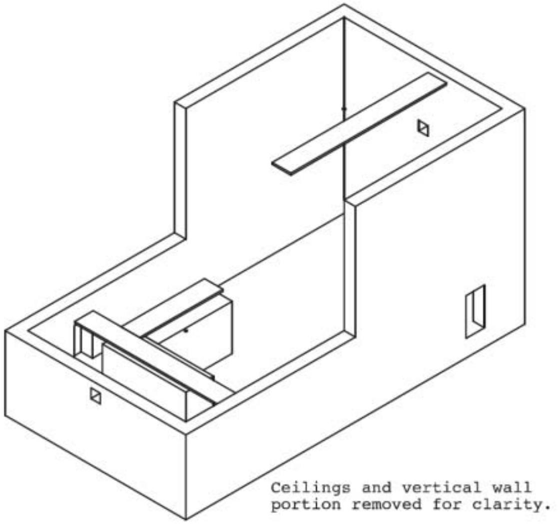
Figure B-10. FDS/Smokeview rendering of the switchgear room.

C. Lube Oil Fire in a Pump Room

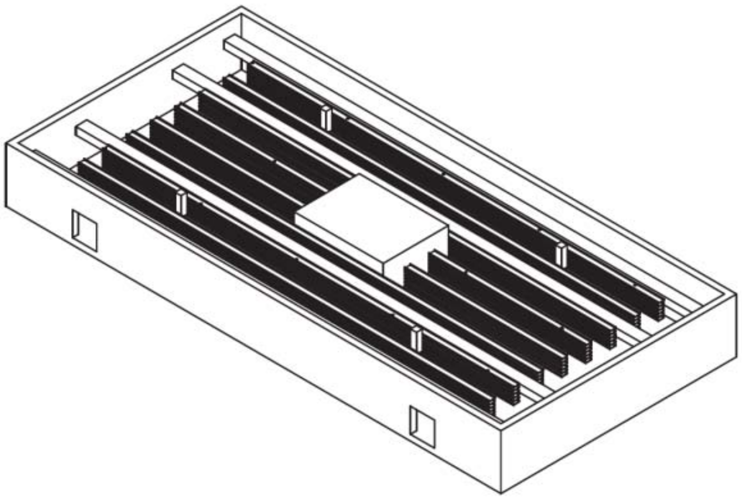


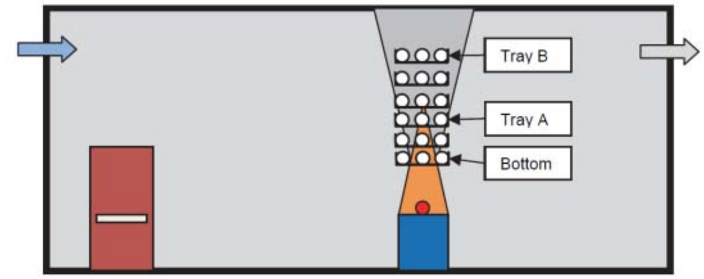


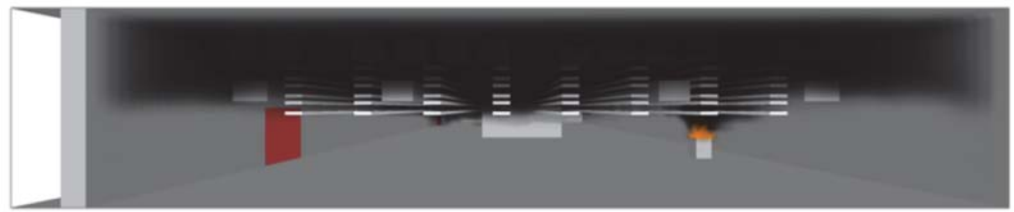
D. Motor Control Fire in a Switchgear Room



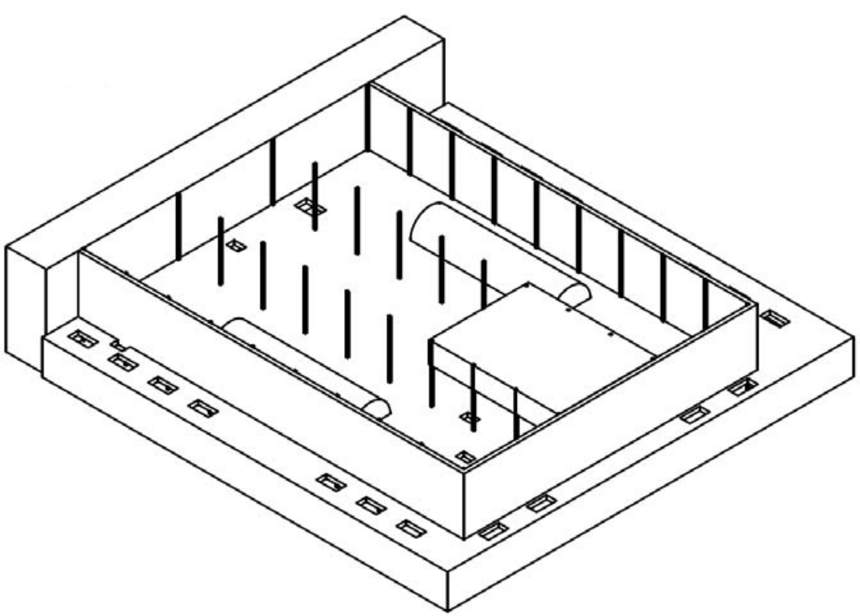
E. Transient Fire in a Cable Spreading Room



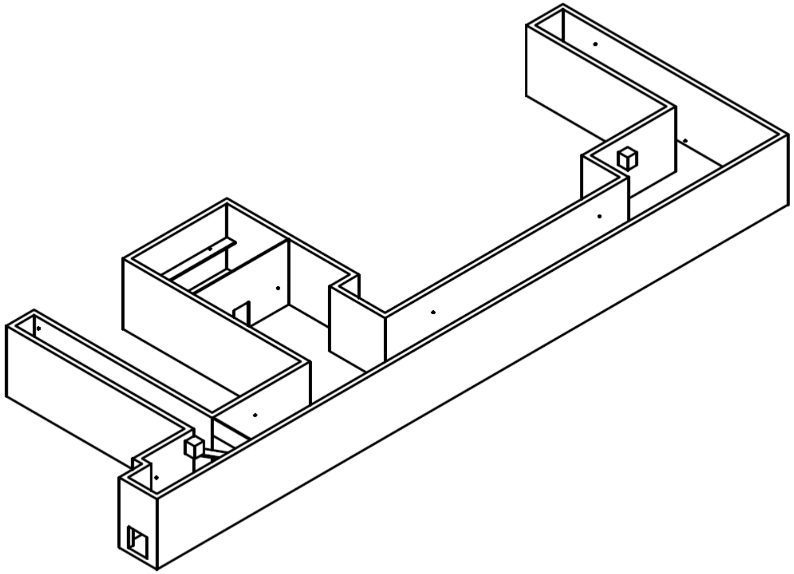


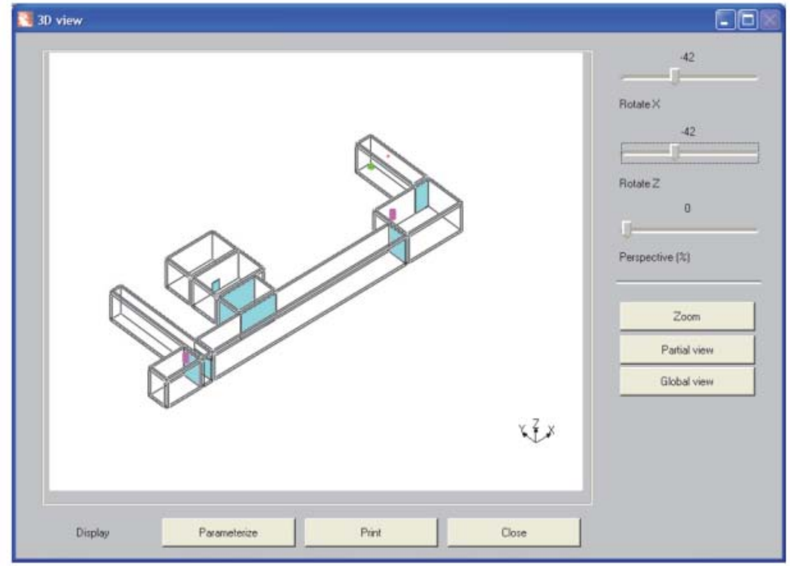


F. Lube Oil Fire in a Turbine Building

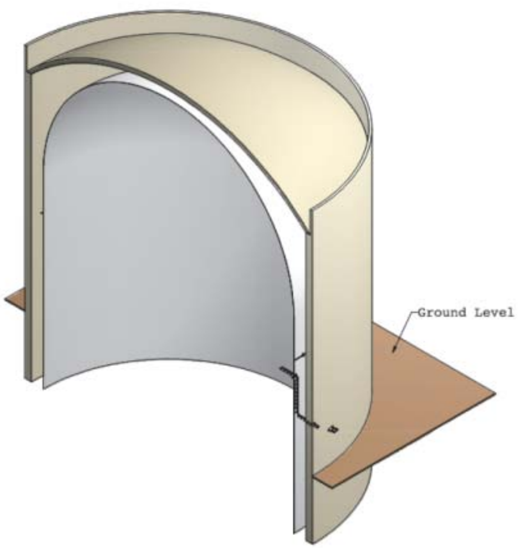


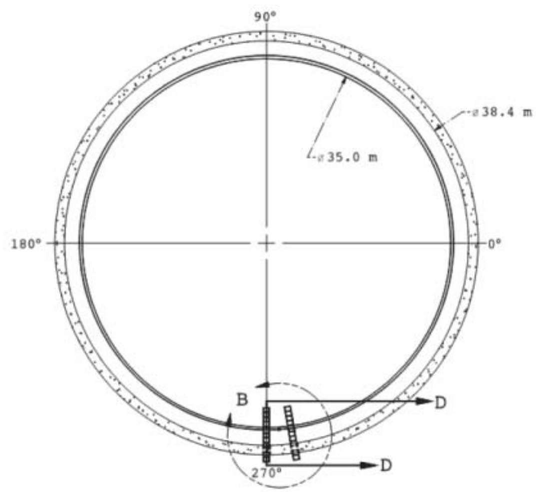
G. Transient Fire in a Multi-Compartment Corridor

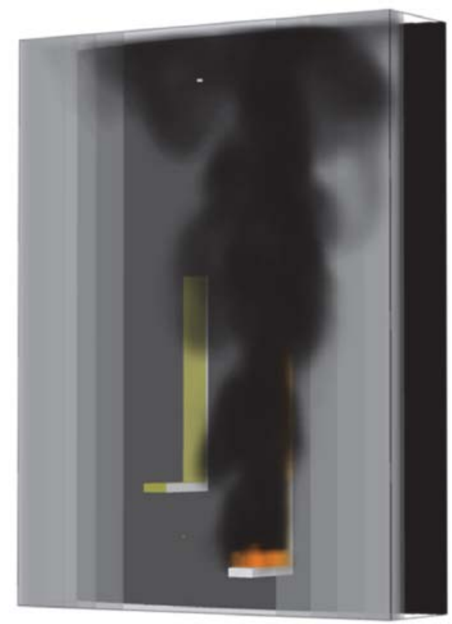




H. Cable Tray Fire in the Annulus







What is Next!

- Update of NUREG 1805
- Update of FIVE REV 1
- Update NUREG 1824, Fire Modeling V&V
- New module on Detailed Fire Modeling as part of the joint EPRI/NRC Fire PRA trainings

Latest Electrical Cable Performance Testing under Fire Conditions, PIRT and Expert Elicitation

Gabriel Taylor, Harry Barrett, Robert Daley
Andy Ratchford, Daniel Funk

Cable Coating Testing

Gabriel Taylor

Fire Protection Information Forum

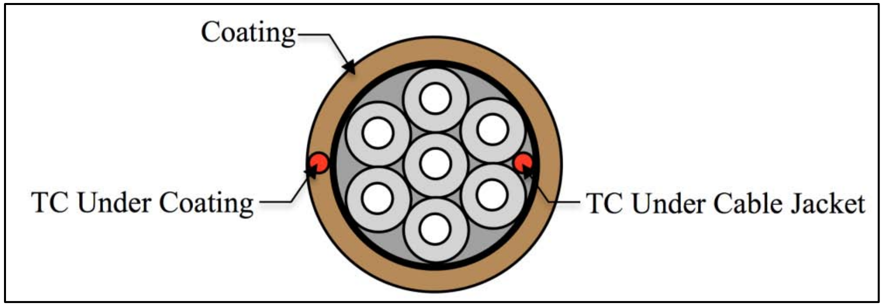
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Purpose

- Limited data to support method provided in Appendix Q of EPRI 1011989 (NUREG/CR-6850)
- Literature search provide little added insights to improve method.
- Testing was conducted to evaluate the effect of cable coating to delay time to damage and time to ignition.
- Future testing will evaluate cable tray covers, solid bottom, etc.

Coatings Tested

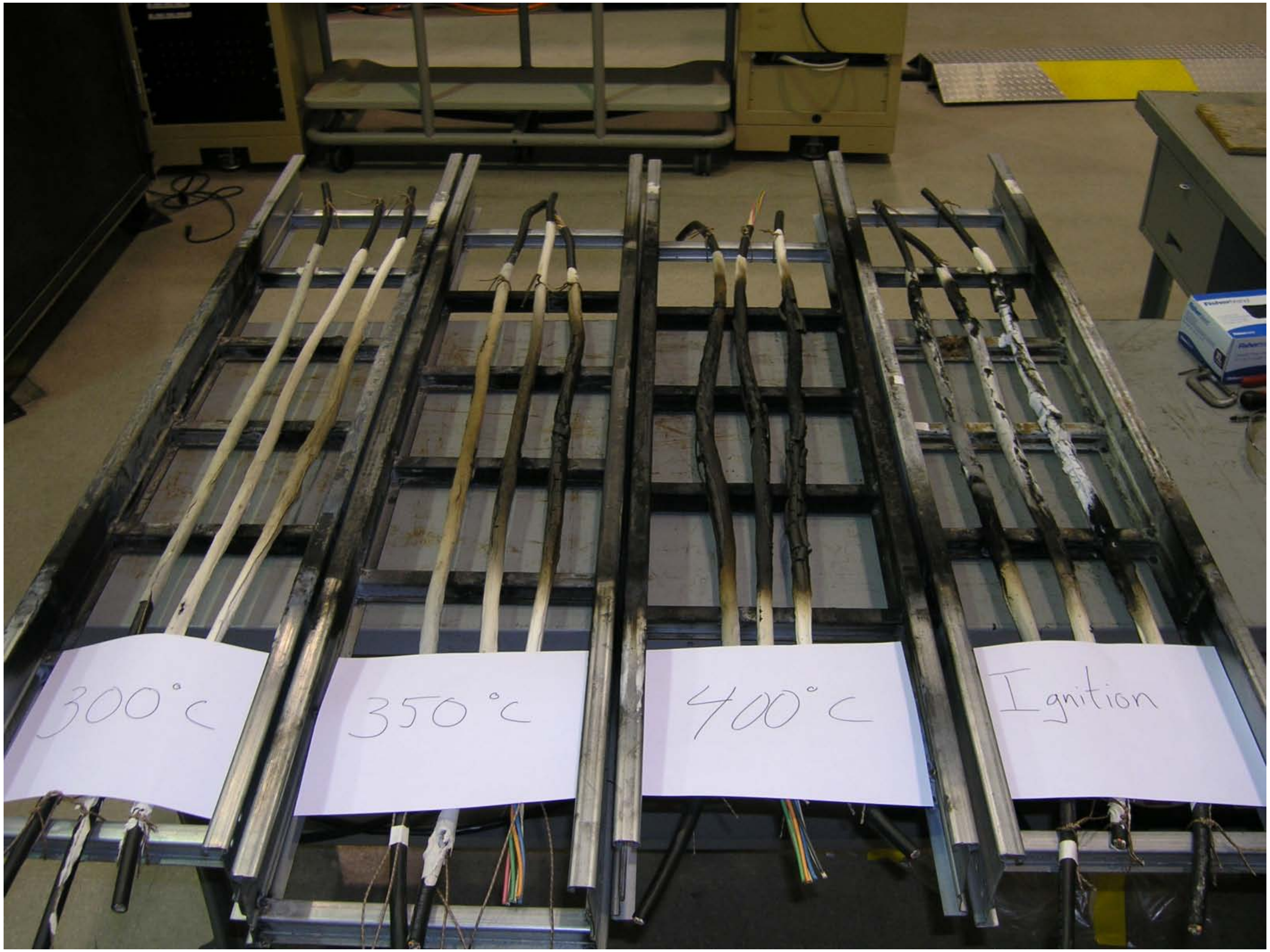
- Three different cable coatings were tested,
  - Carboline Intumastic 285
  - Flamemastic F-77
  - Vimasco 3i
- Coatings containing asbestos were NOT tested.
- There is no nationally recognized test standard to qualify cable coatings
- Coatings were applied and cured per vendor recommendations
- Tests were conducted at Sandia National Laboratories



Testing

- Small scale radiant exposure - Penlight
- Uncoated and coated cables tested to evaluate differences in time to damage, time to ignition
- Thermoset and Thermoplastic cables evaluated
- Time to damage measured using surrogate circuits and insulation resistance measurement
- Time to ignition did not use any pilot ignition source or follow any standard test method.

Testing (cont.)



Results

- Delay in time to damage varied by coating type and cable configuration
- Some coatings samples failed earlier than uncoated samples
- Bundled coated assemblies performed better than single coated assemblies.
- Delay in ignition showed similar trends to delay in time to damage.

Conclusion

- Testing program provides some value, but results should be used with caution.
- Performance of aged cable coatings is a concern. Currently uncertain of a method to determine coating performance for visibly degraded coatings
- NUREG/CR to document results.

Insights

- There should be a nationally recognized test standard for qualifying cable coatings
- Thermally Induced Electrical Failure (THIEF) 1-dimensional heat conduction model could be adapted to predict the time to damage of coated cables

Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE)

Gabriel Taylor

Fire Protection Information Forum

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

NUREG-2128

- Data analysis report
- 3 major test programs evaluated
- Graphical analysis approach
- Ground Fault Equivalent Failure Mode Documented
- No advanced statistical methods used to manipulate data

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NUREG-2128

Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE)

A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011

Draft Report for Comment

Office of Nuclear Regulatory Research

Purpose / Objective

- To support electrical expert Phenomena Identification and Ranking Table (PIRT) panel to make informed decisions
- Provide factual and systematic evaluation of test data to identify specific parameter effects on:
  - spurious operation
  - duration of spurious operations

Graphical Analysis

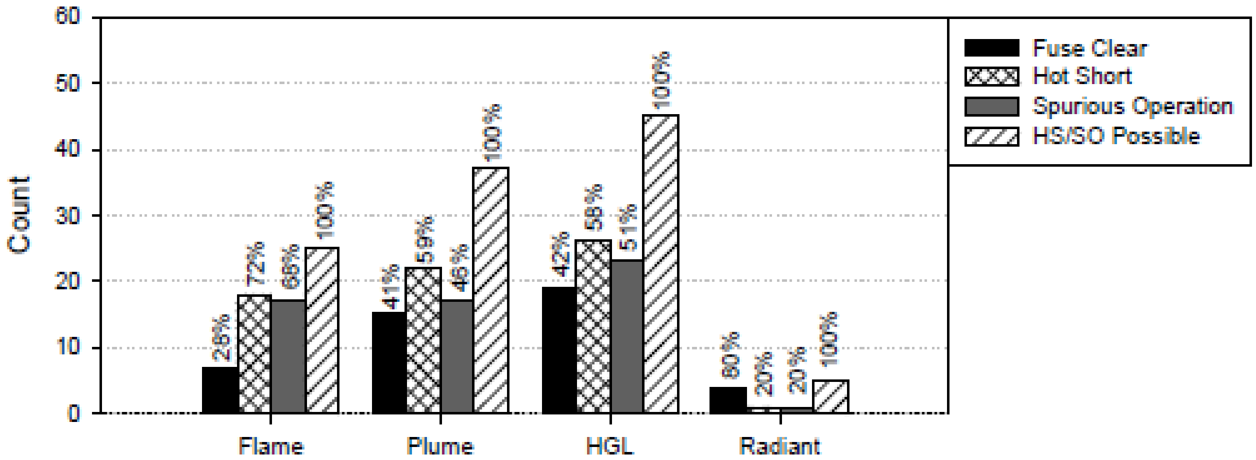


Figure 2-5. Thermal exposure conditions, global approach, ac tests

Spurious Operation / Hot Short Evaluation

Duration of Spurious Operations

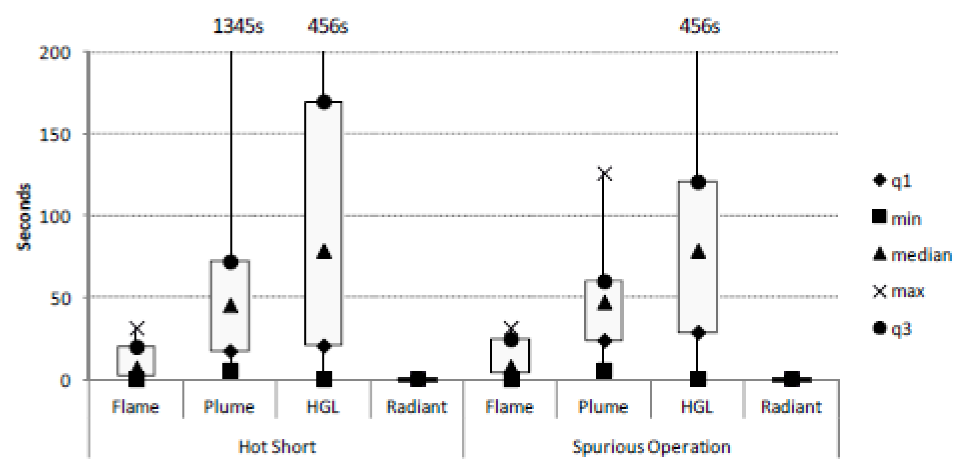
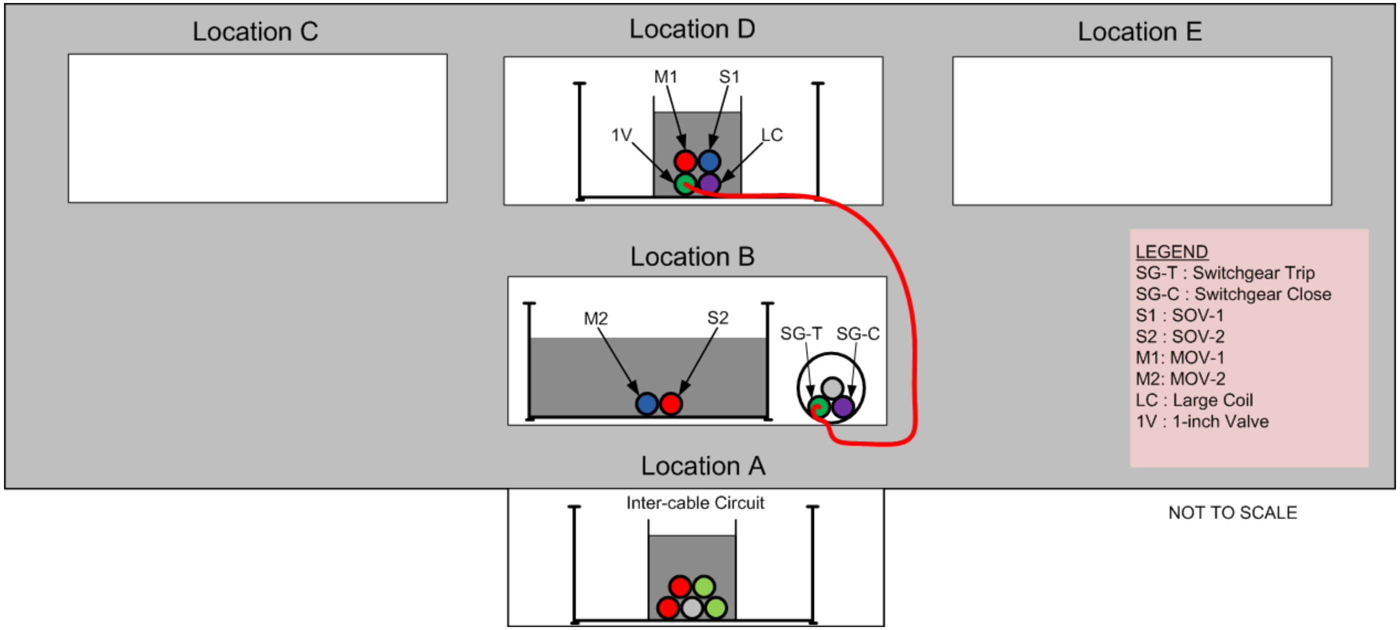


Figure 2-6. Thermal exposure conditions box plot, duration, ac tests

Ground Fault Equivalent Hot Short (GFEHS)

- Review of DESIREE-FIRE data showed that GFEHS occurred during testing.



Project Status

- Report issued draft in June 2012
- 45-day public comment period noticed in Federal Register
  - 77 FR 37717, June 2012
- 2 comment submissions were received
- Final report expected to be issued late 2012 / early 2013

Conclusion

- NUREG-2128 (ELECTRA-FIRE), provides consolidated information to
  - support PIRT work
  - identify potential areas for future research
  - Identify relative effect of parameter on spurious operation likelihood and duration

Electrical Expert Phenomena Identification and Ranking Table (PIRT) Exercise

Gabriel Taylor, Harry Barrett, Robert Daley
Andy Ratchford, Daniel Funk

Fire Protection Information Forum

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

Presentation Outline

- Overview of Project
- Results of PIRT
- Future Research
- Technical Recommendations
- Industry Perspectives
- NRC Perspectives

CAUTION

- Statements contained in the presentation do NOT constitute regulatory position or requirements.
- These slides are meant to provide preliminary information on current research efforts in the area of fire-induced electrical cable/circuit failures
- This information is a summary of technical recommendations made by a panel of experts equally represented by the NRC-RES and EPRI.

PIRT Objective

- Phenomena Identification and Ranking Table (PIRT) panel
  - Identifies influencing parameters and ranks parameters
  - Focused on Fire-Induced spurious operation and duration of spurious operations
- Rankings include
  - Parameter Applicability
  - Research Ease
  - Parameter Importance
  - State of Knowledge

PIRT Panel Members

EXPERTS

NRC Sponsored

Harold Barrett, NRC/NRR
Robert Daley, NRC/Region 3
Steven Nowlen, SNL
Gabriel Taylor, NRC/RES

EPRI Sponsored

David Crane, Pyrolico Corp.
Daniel Funk, KGRS
Thomas Gorman, PPL
Andy Ratchford, RDS

Sponsors

Mark Henry Salley, NRC/RES
Rick Wachowiak, EPRI

Moderator

Mano Subudhi, BNL

Project Schedule Outline

- FIRST PIRT MEETING (November 16-18, 2010)
  - Developed PIRT Process – Figures of Merit, Cable Fire Related Definitions, XCEL Scoring Sheets
  - Indentified Influencing Parameters for all Circuit Types
- SECOND PIRT MEETING (January 20-22, 2011)
  - Evaluated Panel Scores for all Circuit Types
  - Determined that because of lack of sufficient test data only Control Circuits will be considered for the PIRT process. Power circuits – will be considered for certain open or unresolved cable fire related issues. Instrument Circuits – Panel will suggest future testing
- THIRD PIRT MEETING (February 16-18, 2011)
  - Determined that for Control Circuits All Test Data Analysis is needed
  - Formulated the analysis procedures for addressing all influencing parameters
  - Developed preliminary ranking tables
- FOURTH PIRT MEETING (May 11-13, 2011)
  - Discussed Both ac/dc test data analysis (Preliminary)
  - Discussed Power Circuit and Instrument Circuit Issues
- FIFTH PIRT MEETING (September 27-29, 2011)
  - Evaluated Both ac/dc test data analysis - Control Circuit Influencing Parameters
  - Discussed Power Circuit and Instrument Circuit Issues – Developed scope and resolutions
  - Re-evaluated Consensus Scores for Control Circuits and PIRT Ranking Tables
- SIXTH PIRT MEETING (November 29 - December 1, 2011)
  - Finalized parameter ranking
  - Developed probability table and circuit configurations for PRA expert elicitation panel to consider

Figures-of-Merit

- Spurious Operation
  - After fire-induced cable damage has occurred to an appropriate conductor in an electrical circuit resulting in a hot short(s), a spurious operation(s) of the component occurs…
- Duration
  - Duration is the amount of time during which the fire-induced hot short transfers voltage or current to an appropriate conductor of a specific component or device that then can cause the component to move or travel in the undesired direction.

How were parameters ranked?

- Parameter Applicability
  - How common is it?
- Research Ease
  - How easy would it be to research?
- Parameter Importance
  - How important based on figure-of-merit?
- State of Knowledge
  - How much do we know about the parameters effect?

Ranking Tables

Identification	Influencing Parameter	Parameter Applicability	Research Ease	Effect of Parameters on the Likelihood - INTRA-CABLE HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge	Effect of Parameters on the Likelihood - INTER-CABLE HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge	Effect of Parameters on the Likelihood - INTER-CABLE GROUND FAULT EQUIVALENT HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge	Effect of Parameters on the DURATION - HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge
1	**Conductor Count**			**L**			**L**			**NA**			**L**		
	a. 1/C	M	NA		NA	NA		L	M					L	M
	b. 2-6/C	H	H		L	M		L	M					L	M
	c. 7-9/C	H	H		L	H		L	H					L	H
	d. 10-15/C	H	H		L	M		L	M					L	M
	e. >15/C	H	H		L	L		L	L					L	L

Parameters Ranked as HIGH

- Spurious Operation
  - Cable Routing/Raceway: Panel Wiring
  - Cable Raceway Fill: Bundles
  - Conductor Insulation Type: Inter-cable
  - Cable Grounding Configuration: drain/shield
  - Armor: Grounded vs Ungrounded circuit
  - Cable Wiring Configuration: Source/Target/Ground
  - Grounded vs. Ungrounded circuits: Inter-cable

Parameters Ranked as HIGH

- Duration
  - Fire Exposure Conditions
  - Cable Routing/Raceway: panel wiring
  - Cable Raceway Fill: bundles
  - Time-Current Characteristics: fuse/breaker size
  - Cable Wiring Configuration: Source/Target/Ground
  - Latching vs. Non-latching

Define Terms

- Incredible
  - signifies the PIRT panel's conclusion that the event cannot occur
  - In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring, and there are no apparent credible engineering principles or technical argument to support its happening during a fire.
  - Probabilistic numbers assigned to these types of phenomena would have little meaning

Define Terms (2)

- Implausible
  - Supports the PIRT panels conclusion that the happening, while theoretically possible, would require the convergence of a combination of factors that are so unlikely to occur that the likelihood of the phenomenon can be considered statistically insignificant.
  - Panel could not find any evidence of the phenomenon ever occurring during fire tests or real world fires

Future Research Recommendations

- Control configurations as identified in PIRT tables
- Instrumentation signal failure modes
- Surrogate ground path – likelihood
- Current Transformers
- Panel wiring
- Trunk cables

Insights, Summary & Conclusion

- 50/50 split of RES/EPRI representatives worked well
- Concensus approach to acquiring expert judgment has pros and cons
- Results of PIRT provide valuable information for deterministic and PRA applications
- Formed basis for PRA expert elicitation work

Where's the report???

- Internal Review and Publication process
- Expected to be published in November timeframe.
- Volume 2 – PRA Expert Elicitation Results

BNL-NUREG-98204-2012 Final Report

Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE)

Volume 1:
Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555-0001

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

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

EPRI ELECTRIC POWER RESEARCH INSTITUTE

NRC PIRT Perspectives

Harold Barrett, NRR; Robert Dale, Region III

Fire Protection Information Forum

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PRA expert elicitation

Gabriel Taylor

Fire Protection Information Forum

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Objective

- Use expert judgment to develop best-estimates for the conditional probability (or likelihood) of these phenomena representing the current NPP design and cable configurations and for the duration so those phenomena where the length of its persistence could affect the circuit function of the component or device being considered.
- Results to be used to revise, directly replace, or create new fire PRA likelihood tables

Tentative Schedule

- January 2012
  - Introductory meeting held
- May 2012
  - 1st workshop held
- October 2012
  - 2nd workshop
- December/January
  - 3rd workshop
- Summer 2013
  - Report publication

Method

- Commission interest in standardizing methods used to acquire expert judgment
- Conference call held in March to discuss viable approaches
- SSHAC Level 2 with modifications selected
- SSHAC = senior seismic hazard analysis committee

SSHAC goal

- to represent the center, the body, and the range that the larger informed technical community would have if they were to conduct the study

Level 2

- Technical Integrator (TI) interact with experts to identify issues and interpretations
- TI team consists of 2 BNL staff, 1 NRC, and 1 EPRI sponsored member
- 3 types of experts
  - Resource, proponent, evaluator
- Added two level 3 components
  - Workshops, and participatory peer-review panel (PPRP)

Current status

- Proponent experts are developing their proposals to present and defend at the next workshop in October.

Future Fire PRA Methods Updates to NUREG/CR-6850 (EPRI 101989)

Presentors: Nick Melly & Rick Wachowiak

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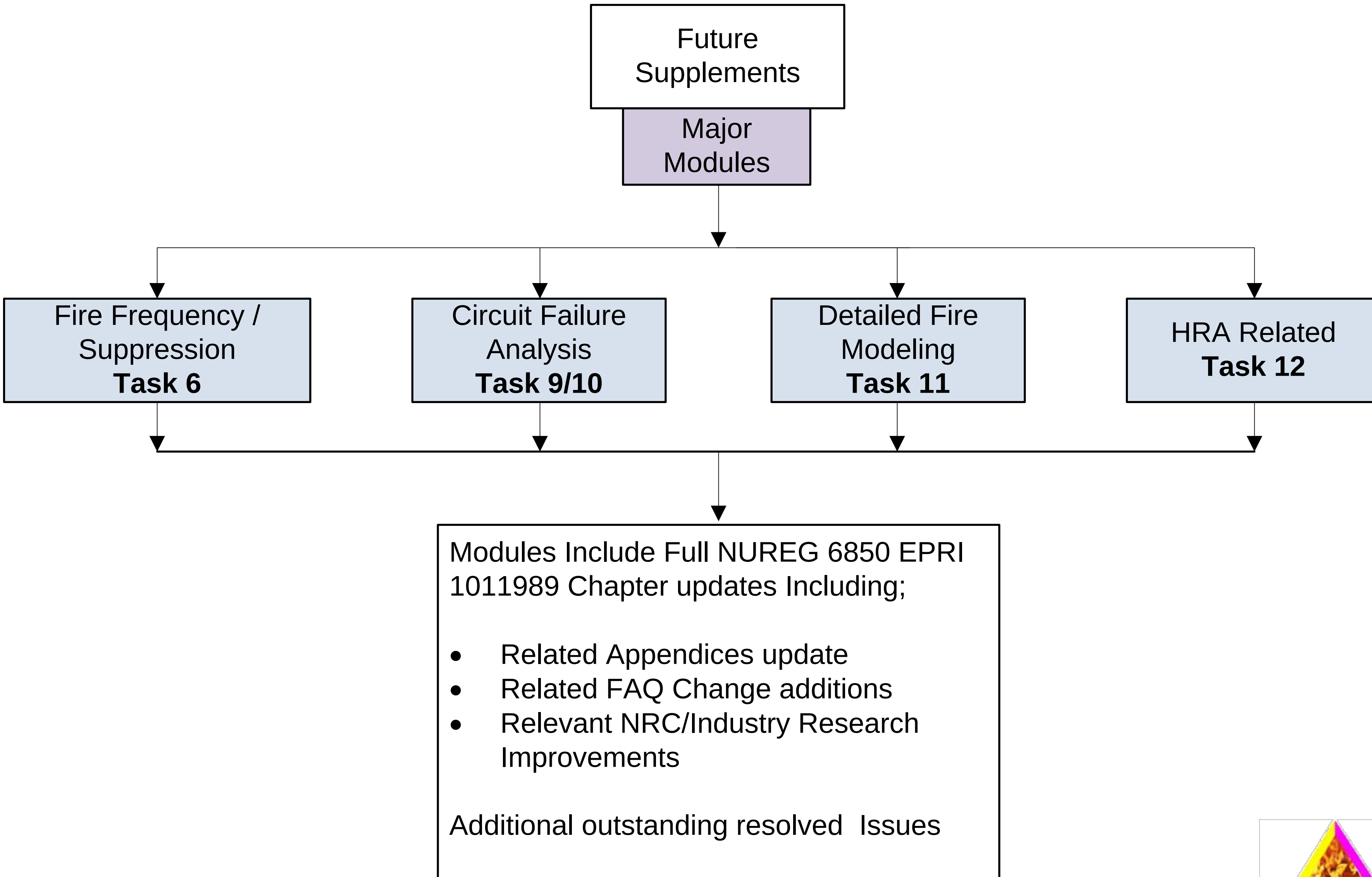
Maintain State of the Art Knowledge

- NUREG/CR-6850 EPRI1011989 written in 2003; published in 2005.
- NUREG/CR-6850 EPRI1011989 acknowledges that the development of methods would continue
- Volume 1, Page xi states:
  - *The methods documented in this report represent the current state-of-the-art in fire PRA practice. Certain aspects of PRA continue to evolve and likely will see additional developments in the near future. Such developments should be easily captured within the overall analysis framework described here. It is important to emphasize that while specific aspects of the analysis process will likely evolve, the overall analysis framework represents a stable and well-proven platform and should not be subject to fundamental changes in the foreseeable future.*
- Practical applications and continued efforts have improved the state of knowledge in the area of Fire PRA as expected by the authors

Maintain State of the Art Knowledge



Fire Frequency & Suppression Module

Fire Frequency / Suppression Related Task 6

- **Unrelated Task Changes**
  - As needed
- **Directly Affected Appendices**
  1) Appendix C
  2) Appendix P
- **Relevant FAQ Impact**
  1) FAQ 06-0016
  2) FAQ 06-0017
  3) FAQ 06-0018
  4) FAQ 07-0031
  5) FAQ 07-0035
  6) FAQ 08-0042
  7) FAQ 08-0048
  8) FAQ 12-0064 (Pending)
- **Current Research Effort Impact**
  1) EPRI Fire Events Database (FEDB)
  2) EPRI/NRC Joint Frequency & Suppression Analysis (Ongoing)
  3) Unreviewed Analysis Method (UAM)
     - -Frequencies for Cable Fires Initiated by Welding and Cutting
     - -Clarification for Transient Fires

Circuit Failure Module

Circuit Failure Analysis Related Task 9/10

<u>Unrelated Task Changes</u>

As needed

<u>Affected Appendices</u>

1) Appendix I
2) Appendix J
3) Appendix K
4) Appendix M

<u>Relevant FAQ Impact</u>

1) FAQ 08-0047
1) FAQ 08-0051

<u>Current Research Effort Impact</u>

1) Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE)
   -Volume 1:Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire Induced Electrical Circuit Failure
   -Volume 2: Expert Elicitation Panel (Ongoing)
3) Kerite Analysis in Thermal Environment of FIRE (KATE-Fire) NUREG-7102
4) <u>Jo</u>int <u>An</u>alysis <u>of Arc</u> Faults (Joan of ARC) OECD International Testing Program for High Energy Arc Fault (HEAF)

Detailed Fire Modeling Module

Detailed Fire Modeling Task 11

Unrelated Task Changes

As needed

Affected Appendices

1) Appendix E
2) Appendix G
3) Appendix L
4) Appendix M
5) Appendix N
6) Appendix O
7) Appendix P
8) Appendix Q
10) Appendix R
11) Appendix S
12) Appendix T
13) Appendix A
14) Appendix B

Relevant FAQ Impact

1) FAQ 08-0042
2) FAQ 08-0044
3) FAQ 08-0043
4) FAQ 08-0046
5) FAQ 08-0049
6) FAQ 08-0050
7) FAQ 08-0050

Current Research Effort Impact

1)Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE) NUREG/CR-7010
2) Kerite Analysis in Thermal Environment of FIRE (KATE-Fire) NUREG-7102
3) Nuclear Power Plant Fire Modeling Application Guide NUREG-1934
4) Joint Analysis of Arc Faults (Joan of ARC) OECD International Testing Program for High Energy Arc Fault (HEAF) (ongoing)
5) Cabinet Heat Release Rate Testing Program (ongoing)
6) Unreviewed Analysis Method (UAM)
 -Alignment Factor for Pump Oil Fires

EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities (NUREG/CR-6850, EPRI TR-1011989)

File	Description
Volume 1	Summary & Overview
Volume 2	Detailed Methodology
Errata, Volume 1 & 2	List of Acronyms
Supplement 1	Fire Probabilistic Risk Assessment Methods Enhancements

Page Last Reviewed/Updated Thursday, March 29, 2012

Supplement 2	Task 6- Fire Frequency Method Enhancements
Supplement 3	Task 9 & 10 – Circuit Failure Analysis
Supplement 4	Task 11- Detailed Fire Modeling

Page Last Reviewed/Updated Thursday, …

Additional Supplements as needed

Page Last Reviewed/Updated Thursday, …

Supplement 1	Fire Probabilistic Risk Assessment Methods Enhancements
Updated Document	(Proposed Updated version encompassing Supplemental Changes / Clarifications / Additions)

Page Last Reviewed/Updated Thursday, …

Page Last Reviewed/Updated Thursday, March 29, 2012

Conclusions

- These modular updates are being proposed to be performed in collaboration under the EPRI/NRC MOU
- NUREG/CR-6850 EPRI1011989 will continue to evolve and mature in response to industry experience and ongoing research
- The Modular approach presented here is aimed at capturing significant gains in the state of knowledge through recent and ongoing research activities and issuing them in a timely manner.

Harold Barrett, PE

Senior Fire Protection Engineer

Fire Protection Branch

Division of Risk Assessment

Office of Nuclear Reactor Regulation

NFPA 805 NRR Regulatory Perspectives

NEI Fire Protection Information Forum

Sheraton Austin Hotel

Austin, Texas

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

Topics for Discussion

United States Nuclear Regulatory Commission
Protecting People and the Environment

- The Positives, Negatives and Challenges of NFPA 805
- NFPA 805 Program Status
- Pre-submittal meetings with the NRC staff
- Acceptance Review
- Site Audits
- Licensee Information Portals
- Request for Additional Information
- Summary

The Positives

- NFPA 805 transition is a pretty good scrub of the Fire Protection Program
- Several licensees have made commitments to install significant risk reduction modifications
- In the end, all NFPA 805 licensees will have a good map to understand where their plant fire risk is

The Negatives

- The process requires more work (and time) than planned
- Calculated risk numbers came out higher than anticipated
- Significantly higher costs than planned
  - Higher Licensee costs to perform required analyses
  - Higher NRC staff costs to review the application

The Challenges

- Unreviewed Analysis Methods or UAMs
  - – Methods review being performed “real-time”
  - – Fire PRA re-work
  - – Schedule delays
- “AHJ Issues”
  - – Resistance from industry to NRC staff’s need for acceptance of Fire PRA methods
  - – Belief that methods acceptance has been delegated to Peer Reviews

Program Status

LAR Submittals	LAR Review Status
1. D. C. Cook 1 & 2	Issued 2nd Round of RAIs & SE Development
2. Duane Arnold	Issued 2nd Round of RAIs & SE Development
3. Callaway	Awaiting RAI Responses & SE Development
4. Fort Calhoun	Reviewing RAI Responses & SE Development
5. Waterford 3	Awaiting RAI Responses & SE Development
6. V. C. Summer 1	Awaiting RAI Responses & SE Development
7. ANO 2	Pending
8. Cooper	Preparing for Site Audit
9. Nine Mile Point 1	Preparing for Site Audit
10. Turkey Point 3 & 4	Performing Acceptance Review
ANO 1	Delayed
Beaver Valley 1 & 2	Delayed

Pre-Submittal Meetings with the NRC Staff

- If there are any areas of uncertainty with respect to what level of detail the licensee plans to present in their NFPA 805 LAR, the staff encourages the use of a pre-submittal meeting
- The use of examples and potential draft sections/pages would be good

Acceptance Review

- Acceptance Review Process
  - Receive LAR – start clock when it hits ADAMS
  - Staff has 60 working days (3 calendar months)
  - We try to get initial review done in 30 days
  - Process has 3 outcomes
    - Acceptable
    - Unacceptable with the opportunity to supplement
    - Unacceptable
  - Process allows licensee 13 calendar days to supplement

Acceptance Review

- Acceptance Review Process – continued
  - We have allowed licensees to use the remaining portion of the 60 days plus the 13 days to submit supplemental information
  - One important point about the acceptance review process is that you only get one chance to supplement once the staff issues the unacceptable with opportunity to supplement letter

Acceptance Review

- Acceptance Review Results
  - One licensee had a clean acceptance review (no supplements)
  - Some general Acceptance Review issues:
    - Completeness of analysis
    - Peer review nomenclature
    - UAMs

Acceptance Review

- Acceptance Review Results - continued
  - Specific Acceptance Review issues:
    - Negative recovery action risk
    - Modifications not fully described or scope established
    - Using a global VFDR to represent all VFDRs in a given fire area (Main Control Room and/or Cable Spreading Room)

NFPA 805 Site Audits

- The staff brings questions about the LAR and/or the plant
- Presentations, interviews and plant tours help answer and/or refine questions
- Audit team condenses questions into draft RAIs by the exit meeting when they are shared with the licensee
- PM should forward electronic version of draft RAIs to licensee shortly after audit

NFPA 805 Site Audits

- Plant simulator tours
  - Allows staff to review control room layout without bothering operating crew
- Availability of Subject Matter Experts
  - Some audits have suffered from one or more key SMEs being pulled by multiple NRC team members (fire modeling, Fire PRA, etc.)

Licensee Information Portals

- Timing
  - By the completion of the Acceptance Review
- Usability
  - Slowness
  - Roadmap
- Document Change Management
  - Draft RAI responses need version control
- Portal is used for information only
  - Only <u>docketed</u> info can be used in SE

Request for Additional Information (RAIs)

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- First "Round" is generated from the site audit questions
- Additional RAIs are a combination
  - clarifications to existing RAIs and
  - new RAIs as a result of additional staff review
- Some RAIs have required significant time to respond (up to 180 days)

Summary

- In general, NFPA 805 has improved FPPs
- Some licensees are significantly improving risk
- Acceptance Reviews have found several issues
- NFPA 805 Site Audits generate Draft RAIs
- While they can be quite useful, Information Portals also have some issues that should be managed
- RAIs are an integral part of the NFPA 805 LAR review process