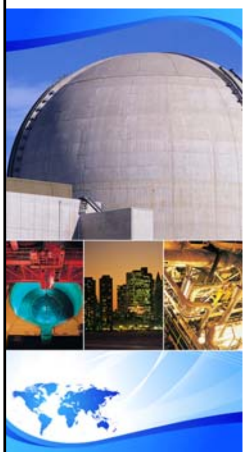

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 1: Plant Partitioning

Joint RES/EPRI Fire PRA Workshop
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Plant Partitioning
Scope

The following topics are covered:

- Task 1: Plant Partitioning Analysis
  - Define Global Analysis Boundary
  - Partition into physical analysis units or Compartments
  - Problem sets from the Sample Problem

Support Task A: Plant Walkdowns
Just a Quick Note….

- You *cannot* complete a Fire PRA without walkdowns
- Expect to conduct a number of walkdowns, especially for key areas (e.g., those analyzed in detail)
- Walkdowns can have many objectives and support many tasks:
  - Partitioning features, equipment/cable mapping, fire ignition source counting, fire scenario definitions, fire modeling, detection and suppression features, recovery actions HRA
- Walkdowns are generally a team activity so coordinate them to optimize personnel time and resources

Plant Partitioning
General Comment/Observation

- The recommended practice for Task 1 has changed little from prior methods.
  - That means you can likely benefit from a previous analysis
    - e.g., your IPEEE fire analysis
    - However: watch out for new equipment/cables, new initiators when screening\
- May need to work closely with the cable routing experts to ensure coordination among the plant partitioning schemes.

Task 1: Plant Partitioning
Key Definitions: Compartment vs. Fire Area/Zone

- We talk mainly about Fire Compartments which are defined in the context of the Fire PRA only
  - Defining Fire Compartments is necessary for analysis management
  - Also known as Physical Analysis Units
- Fire Areas are defined in the context of your regulatory compliance fire protection program
- Fire Zones are generally defined in the context of fire protection features (e.g., detection, suppression, hazards)
  - Fire zones have no direct meaning to the Fire PRA context and we avoid using this term
- Physical Analysis Unit is another term coined lately

Task 1: Plant Partitioning
Task Objectives and Output

- There are two main objectives to Task 1:
  1. Define the Global Analysis Boundary
     - The maximum physical extent of the plant that will be considered in the Fire PRA
  2. Divide the areas within the Global Analysis Boundary into analysis Compartments (Physical Analysis Units)
     - The basic physical units that will be analyzed and for which risk results will be reported
- Task output is the definition of these two aspects of the analysis

Task 1: Plant Partitioning
Task Input

- No real input from any other task is required (it is, after all, Task 1)
  - You may also find yourself iterating back to this task later in the analysis – that is fine, just be careful to track any changes
- What do you need to support this Task?
  - Layout drawings that identify major structures, walls, openings
    - Drawings that identify Fire Areas are especially helpful
  - Plan <u>and</u> elevation drawings are helpful
  - You *will* need to do a walkdown to support/verify decisions

Task 1: Plant Partitioning
Task Breakdown in Steps

- Task 1 is defined in terms of the following steps:

Step 1: Selection of Global Plant Analysis Boundary

Step 2: Plant Partitioning

Step 3: Compartment Information Gathering and Characterization

Step 4: Documentation

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary

- We want a *Liberal* definition of the global analysis boundary
  - It's OK to include obviously unimportant areas, we'll drop them quickly, but better to do this formally
- Encompass all areas of the plant associated with both normal and emergency reactor operating and support systems, as well as power production
- Sister Units should be included unless they are physically and functionally separated
  - No shared areas, no shared systems, no shared components and associated cables, no conjoined areas (e.g., shared walls)

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary

- Begin with your protected area: everything within the protected area should be included in the Global Analysis Boundary
  - In most cases that will capture all risk-important locations
- If necessary, expand the boundary to include any other locations that house equipment or cables identified in Tasks 2 or 3
  - This is the Task 2/3 link mentioned before!
  - Example: If your offsite power related equipment is outside the protected area, you need to expand Global Analysis Boundary to capture it

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary

- *Problem Set 01-01*

- By the end of the analysis, you need to provide a fire risk disposition for all locations within the global analysis boundary
  - That may be anything from screened out qualitatively to a detailed risk quantification result

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- We divide the Global Analysis Boundary into smaller pieces (compartments) for the purpose of tracking and reporting risk results

- A compartment can be many things, but when it comes down to it, a compartment is:

A well-defined volume within the plant … that is expected to substantially contain the adverse effects of fires within the compartment.

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- This task is often subjective – judgment *is* required
- Ideally: Compartments = Rooms
  - Locations that are fully defined by physical partitioning features such as walls, floors, and ceilings
- But the ideal is not the only solution - other features and elements may be credited in partitioning
  - That's where judgment comes into play!
  - What will you credit as a Partitioning Feature?

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- A good starting point is your Fire Areas, but you are *by no means limited* to equating Fire Compartments to Fire Areas
  - A Fire Area may be partitioned to two or more Compartments
  - You may combine two or more Fire Areas into a single Compartment
- In the end: { ∑ Compartments } = { Global Analysis Bnd. }
  - No omissions
  - No overlap!

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- So what can you credit as a partitioning feature:
  - Bottom line: anything you can justify – see text for examples
    - You do need to justify your decisions with the exception of structural elements maintained as rated fire barriers
  - In the end, your partitioning decisions should not affect the risk results, but . .
  - Don't go crazy – there are disadvantages to over-partitioning
  - General guideline: try to minimize the need to develop and analyze multi-compartment scenarios

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- It is not recommended to partition based on:
  - Radiant energy shields
  - Beam pockets
  - Equipment obstructions (e.g., pipes)
  - (per Fire PRA Standard: Raceway or other localized fire barriers *cannot be credited* in partitioning)
- Spatial separation credited as partitioning scheme requires justification.

- *Problem Set 01-02*

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- Final Point: You need a system to identify/name your Fire Compartments
  - Something both consistent and logical – but whatever works for your application and plant
  - Often makes sense to use Fire Area designations in naming schemes
    - Example: Fire Area 42 might become Fire Compartments 42A, 42B…
  - Use your naming scheme consistently throughout the Fire PRA
    - Documentation, equipment/cable routing database, etc.

Task 1: Plant Partitioning
Compartment Information Gathering and

- Later tasks need certain information about each compartment. They include, but are not limited to the following:
  - Compartment boundary characteristics
  - Ventilation features, and connections
  - Fire protection features
  - Identification of all adjacent compartments
  - Access routes to the fire compartment

Task 1: Plant Partitioning
Compartment Information Gathering and

- A thorough plant walkdown is needed to confirm and gather information about each fire compartment.
- Initially it is not expected that all information pieces to be collected and documented.
- As work on fire PRA progresses, additional information, as needed, is collected and documented
- This task, similar to other later tasks, is expected to be revisited and compartment definitions modified as additional information is obtained.

Task 1: Plant Partitioning
Summary

- Plant Partitioning is the first step of fire PRA.
- Done in three steps
  1. Define global plant analysis boundaries to include all those area that will be addressed by the fire PRA
  2. Define fire compartments in such a way that all the areas identified in the preceding step are covered, there are no overlaps and there is a balance between size and number of compartments selected
  3. Confirm the selected compartments through a walkdown and record important information that will be used later.

Workshop Problems for Task 1: Plant Boundary Definition and Partitioning

Workshop Problem Set 01-01

Step 1 - Selection of Global Plant Analysis Boundary: Using the information provided in Tab 1.4 identify the Global Plant Analysis Boundaries in terms of plant areas shown on Drawing #A-01. Make a complete list of plant areas shown on Drawing #A-01 in the matrix provided below. Specify whether or not the area should be included within the Global Plant Analysis Boundaries. Provide the basis of your decision.

Plant Area	Included?	Basis

Plant Area	Included?	Basis

Workshop Problem Set 01-02

Step 2: Plant Partitioning: Using the drawings provided in Tab 1.4, identify a set of compartments that you will consider for the fire PRA. In the following matrix:

(1) List the "compartments"

(2) Give each compartment an identification number,

(3) Identify the associated plant area for each compartment from the Solution Statement for Problem Set 01-01.

Compartment ID #	Compartment Descriptor	Plant Area	Comments

Compartment ID #	Compartment Descriptor	Plant Area	Comments

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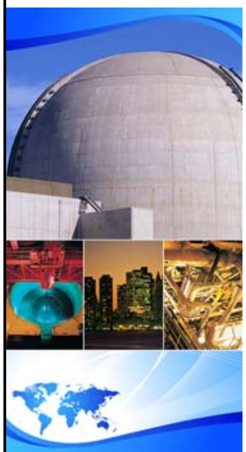

Module III

Task 6: Fire Ignition Frequency

Joint RES/EPRI Fire PRA Workshop
June 2009
Palo Alto, CA

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FIRE IGNITION FREQUENCIES

Purpose of Task 6

In Task 6, the ignition frequencies associated with fire ignition sources are established.

- Generic frequencies
- Plant specific experience
- Uncertainties

To be presented in two parts:

- 1. How to estimate location specific frequencies
- 2. How generic frequencies were put together

FIRE IGNITION FREQUENCIES
Assumptions

The model developed for estimating fire ignition frequencies is based on the following assumptions:

- Frequencies remain constant over time
- Total ignition frequency for an equipment type is the same for all plants
- Within each plant, ignition frequency is the same for all equipment of the same type.

FIRE IGNITION FREQUENCIES
General Approach

To establish the fire frequency of a fire compartment, the ignition frequencies associated with each ignition source of the compartment are added together.

- $\lambda_{J,L} = \Sigma \lambda_{IS} W_L W_{IS,J,L}$
  summed over all ignition sources

  Where:

  $\lambda_{J,L}$: Fire frequency associated with compartment J at location L

  λ_{IS}: Plant level fire ignition frequency associated with ignition source IS

  W_L: Location weighting factor

  $W_{IS,J,L}$: Ignition source weighting factor

FIRE IGNITION FREQUENCIES
Plant Level Frequency (λ_{IS})

Plant level fire ignition frequency covers all the equipment of the same type in the entire unit.

Examples:

– 2.1E-02 is the frequency per year of fires within a unit that involve pumps.

– 7.4E-03 is the frequency per year of transient fires within the turbine building of a unit.

FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6 -1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diesel Generator Room	[illegible]sel Generators	All	2.1E-02	0.16	0.84	0	0	0	0
11	Plant-Wide [illegible]	Cable fires caused by [illegible]tting	Power	2.0E-03	0	0	0	1.0	0	0
[illegible]	[illegible] Components	[illegible]	All	4.6E-03	1.0	0	0	0	0	0
15	Plant-Wide Components	Electrical Cabinets	All	4.5E-02	1.0	0	0	0	0	0
20	Plant-Wide Components	Off-gas/H2 Recombiner (BWR)	Power	4.4E-02	0	0	0	0	1.0	0
27	Transformer Yard	Transformer – Catastrophic[2]	Power	6.0E-03	1.0	0	0	0	0	
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

Ignition Frequency Bin

FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6 -1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
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2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Di Ro				.16	0.84	0	0	0	0
11	Pl Co				0	0	0	1.0	0	0
14	Pl Co				1.0	0	0	0	0	0
15	Pl Co				1.0	0	0	0	0	0
20	Pl Co				0	0	0	0	1.0	0
27	Tr				1.0	0	0	0	0	
32	Tu				.11	0.89	0	0	0	0

1. See App
2. See Sec

ID	Location
1	Battery Room
2	Containment (PWR)
4	Control Room
8	Diesel Generator Room

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Task 6: Fire Ignition Frequency

Slide 7

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FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6 -1
Fire Frequency Bins and Generic Frequencies

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2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diesel Ge Room									
11	Plant-Wid Compone									
14	Plant-Wid Compone									
15	Plant-Wid Compone									
20	Plant-Wid Compone									
27	Transform									
32	Turbine B									

1. See Appendix M
2. See Section 6.5.6 below for a definition.

ID	Location	Ignition Source (Equipment Type)
1	Battery Room	Batteries
2	Containment (PWR)	Reactor Coolant Pumps
4	Control Room	Main Control Boards
8	Diesel Generator Room	Diesel Generators

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Task 6: Fire Ignition Frequency

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FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6 -1
Fire Frequency Bins and Generic Frequencies

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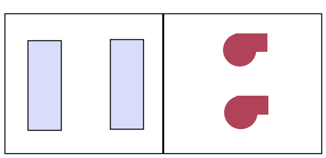
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
			Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
Batteries	All	7.5E-04	1.0	0	0	0	0	0
Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
Transients and Hotwork	Power	2.0E-03	0	0	0.44	0.56	0	0
Main Control Board	All	2.5E-03	1.0	0	0	0	0	0

Fire Ignition Frequency Quantification

Single Unit Plant



Room 1A   Room 1B

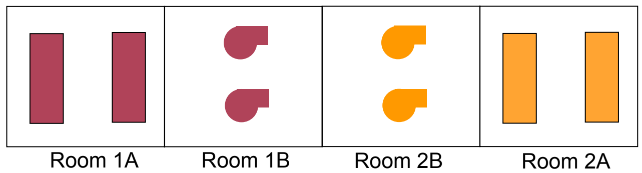
Count	1A	1B	Total
Elec. Cab.	2		2
PMP		2	2

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{2} \cdot 1$$

$$\lambda_{room-1B} = \lambda_{pmp-i} \cdot N_{pmp} = \lambda_{pmp-i} \cdot 2$$

Fire Ignition Frequency Quantification

Two Units, Two Units in Scope



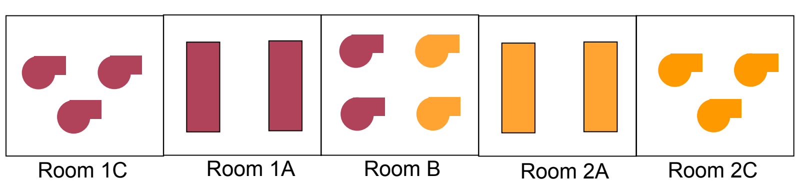
Count	1A	1B	2A	2B	Total
Elec. Cab.	2		2		4
Pump		2		2	4

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{4} \cdot 2$$

$$\lambda_{room-1B} = \lambda_{pmp-i} \cdot N_{pmp-1B} = \lambda_{pmp-i} \cdot 2$$

Fire Ignition Frequency Quantification

Two Units, Two Units in Scope, Shared Room



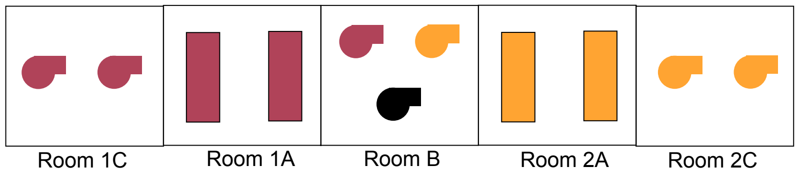
Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2		2			4
Pump		3		3	4	10

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{10} \cdot 2$$

$$\lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 4$$

Fire Ignition Frequency Quantification

Two Units, Two Units in Scope, Shared Room, Swing Pump

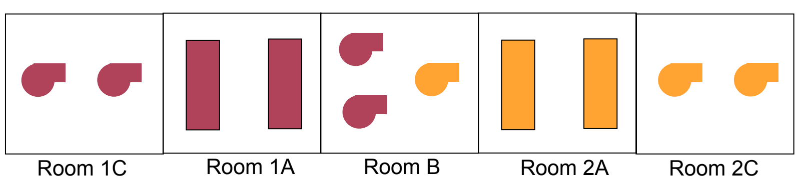


Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2		2			4
Pump		2		2	3	7

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{7} \cdot 2 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire Ignition Frequency Quantification

2 Units, One Unit in Scope, Shared Room

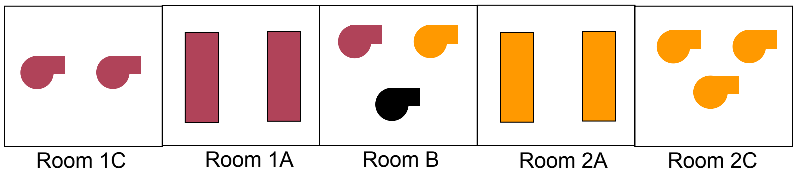


Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2					2
Pump		2			2	4

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{4} \cdot 1 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire Ignition Frequency Quantification

2 Units, One Unit in Scope, Shared Room, Swing Pump



Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2					2
Pump		2			1.5	3.5

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{3.5} \cdot 1 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

FIRE IGNITION FREQUENCIES
Procedure

The following procedure can be used to estimate location specific fire ignition frequencies:

- Step 1. Mapping plant ignition sources to generic sources,
- Step 2. Plant fire event data collection and review,
- Step 3. Plant specific updates of generic ignition frequencies,
- Step 4. Mapping plant-specific locations to generic locations,
- Step 5. Location weighting factors,
- Step 6. Fixed fire ignition source counts,
- Step 7. Ignition source weighting factors, and
- Step 8. Ignition source and compartment fire frequency evaluation.

FIRE IGNITION FREQUENCIES
Step 1. Mapping Plant Ignition Sources

Every plant equipment item should be mapped to one of the ignition frequency bins.

- Must be capable of initiating a fire
- Must be located in the buildings, compartments and plant areas considered for fire risk analysis
- If no matching bin, then the following approach may be used:
  - Characteristics of the source
  - Percentage of the time in operation
  - Past fire histories within the plant
  - Relevant past fire histories or frequency estimates not associated with the plant

• *Problem Set 06-01*

FIRE IGNITION FREQUENCIES
Step 2. Plant Fire Event Data Collection

Plant specific fire event data is needed to establish plant specific fire ignition frequencies.

- Are plant specific fire ignition frequencies warranted?
  - Repeated set of events
  - Events that cannot be mapped to a bin
- Unusual fire occurrence patterns
- May be selective in plant specific frequencies

FIRE IGNITION FREQUENCIES
Step 2. Plant Fire Event . . . (2)

Example:

- The following events have taken place:
  - Event 1: Fire in MCC-A because of breakers not properly engaging the bus bars.
  - Event 2: Fire in 125VAC-A panel. The fire was extinguished when 4kV bus-A was de-energized from the control room. Fire resulted from arcing of supply lead to one of the fittings connecting to a controller to the bus.
- Both fires can be included in the frequency analysis.
- Plant has been in commercial operation for 10 years.
- Both events should be mapped to Bin # 15 “Electrical Cabinets”
- 2/10 = 0.2, is 4 times greater than 0.045, Bin #15 frequency

• *Problem Sets 06-02 and 06-03 (Examples)*

FIRE IGNITION FREQUENCIES
Step 3. Plant Specific Frequencies (λ_{IS})

Bayesian approach can be used to estimate plant specific fire ignition frequencies.

- Uncertainty distributions of generic frequencies as the prior
- Possible double accounting of FEDB events

FIRE IGNITION FREQUENCIES
Steps 4/5. Plant-Specific Locations and W_L

Plant specific locations should be mapped to the bin definition locations.

Example:

Plant Specific Location	Bin Location	W_L
Emergency Battery Enclosure	Battery Room	Number of site units that share common set of batteries.
Main Control Room	Control Room	Number of site units that share the same control room.
Control Building	Control / Auxiliary / Reactor Building	Number of site units that share the same building type.
Primary Auxiliary Building		

- *Problem Sets 06-04 and 06-05*

FIRE IGNITION FREQUENCIES
Step 6. Fixed Fire Ignition Source Counts

To establish ignition source weighting factor, $W_{IS,J}$, for each compartment, it is necessary to obtain the total number of relevant items per bin.

- For shared locations, entire site should be considered
- Visual examination (recommended approach)
- Document review or computerized database
- Counting method for each bin

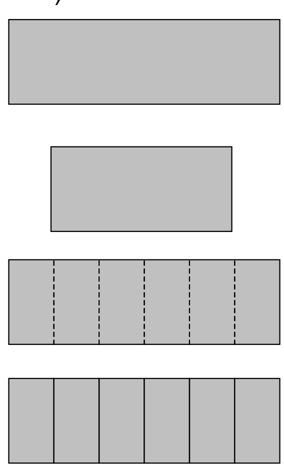
FIRE IGNITION FREQUENCIES
Step 6. (cont'd)

Examples:

- *Bin 1– Batteries:* Each bank of interconnected sets of batteries located in one place should be counted as one battery set. Cells may not be counted individually.
- *Bin 5– Cable Fires Caused by Welding and Cutting: . . .* Assume that all exposed cables (i.e., cables that are not in conduits or wrapped by noncombustible materials) have an equal likelihood of experiencing a fire caused by welding and cutting across the entire location. . . .
- *Bin 15– Electric Cabinets:* Electrical cabinets represent . . switchgears, motor control centers, DC distribution panels, relay cabinets. . . . Free standing electrical cabinets should be counted by their vertical segments, . . .

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs

- FAQ 06-0016 - Ignition source counting guidance for electrical cabinets. (Status: Closed)



Cabinet is not an outlier – Count = 1

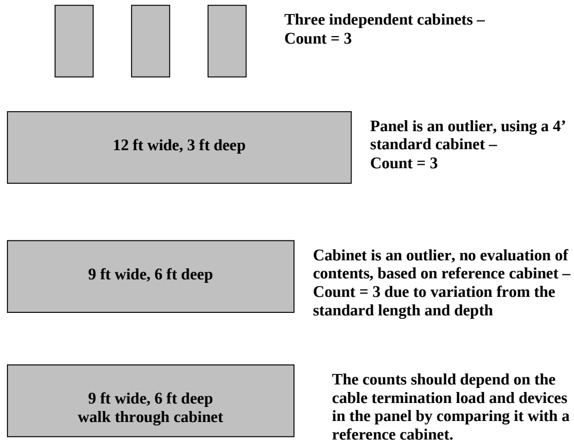
Cabinet is same as standard – Count = 1

Internal dividers are not solid – Count = 6

Internal dividers are solid – Count = 6

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 06-0016 - Continued.



FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 06-0017 - Ignition source counting guidance for high energy arcing faults. (Status: Closed)
  - Split Bin # 16 into:
    - Bin 16a – Low-voltage panels (480 to 1,000 V) - 4.8E-04/ry (mean)
    - Bin 16b – medium-voltage panels (> 1,000V) – 1.4E-03/ry (mean)
  - Counting method remains unchanged (i.e., vertical sections)
  - Self consistent within each new bins
- FAQ 06-0018 - Ignition source counting guidance for main control board. (Status: Closed)
  - There is a one-to-one correspondence between App. L and Bin 4.
  - Main Control Board is just the horseshoe.
  - All other electrical cabinets in the Main Control Room should be counted with other cabinets in the plant.

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 06-0031: Ignition source counting guidance clarifications and extensions (Status: Closed)
  - **Bin 14 – Electric motors**: clarifies guidance, provides for excluding small motors of 5 hp or less and totally enclosed motors.
  - **Bin 21 – Pumps**: provides for excluding small sampling pumps, and other pumps of 5 hp or less
  - **Bin 23 – Transformers**: provides for excluding dry transformers of 45 KVA or less
  - **Bin 26 – Ventilation subsystems**: clarifies that intent is to exclude small subsystems powered by motors of 5 hp or less (consistent with electric motors Bin 14)

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 07-0035: High energy arc faults in bus ducts (Status: Open)
  - Issue:
    - Guidance document is silent on topic
  - General approach to resolution:
    - Acknowledge potential for such events (e.g., Diablo Canyon 5/2000)
    - Provide plant wide frequency and counting/partitioning guidance
    - Provide zone of influence and scenario development guidance

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 08-0042: Cabinet Fire Propagation (Status: Open)
  - Issue:
    - Guidance provides conflicting language regarding propagation of fire from cabinets (Chapter 6 versus Appendix G) and definition of "well-sealed cabinets")
    - Implication for Step 6: you exclude well-sealed cabinets from cabinet count if contents are below 440V (see Vol. 2, Page 6-17)
  - General approach to resolution:
    - Clarify and expand definition of "well-sealed and robustly secured cabinets" (which will not propagate fires)

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 08-0048 Fire Frequency Trends (Status: Open)
  - Issue:
    - Fire frequency analysis may not reflect industry trends (i.e., towards reduced fire frequencies)
  - General approach to resolution:
    - Work is under way within EPRI team to determine if statistically significant fire frequency trends can be demonstrated through most recent time
    - Fire frequencies for one or more ignition source bins may be modified (up or down depending on trends)

• *Problem Sets 06-06 and 06-07*

FIRE IGNITION FREQUENCIES
Step 7. Ignition Source Weighting Factor ($W_{IS,J,L}$)

Ignition source weighting factors are evaluated for all the compartments identified in Task 1 and for all ignition sources identified in Step 1 of this Task.

- Countable items
  - Example: 2 pumps in compartment J of 50 pumps in the unit
    $W_{IS,J,L}$ = 2/50 = 0.04
- Transients – apportioned based on maintenance, occupancy and storage
- Large systems – ad-hoc method based on specific characteristics of the system
  - Examples: hydrogen gas distribution system, turbine/generator oil system

• *Problem Sets 06-08, 06-09 and 06-10*

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients

Transient fire frequencies are apportioned based on qualitatively estimated rating levels for (1) maintenance activities, (2) occupancy level and traffic density and (3) storage (temporary and permanent) of combustible and flammable materials.

- Five rating levels are used:
  - No (0) - Can be used only for those compartments where transients are precluded by design (administrative restrictions do not apply).
  - Low (1)–Reflects minimal level of the factor.
  - Medium (3)–Reflects average level of the factor.
  - High (10)–Reflects the higher-than-average level of the factor.
  - Very high (50)–Reflects the significantly higher-than-average level of the factor (only for "maintenance" influencing factor).

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients (2)

Table 6-3
Description of Transient Fire Influencing Factors

Influencing Factor	No (0)	Low (1)	Medium (3)
Maintenance	Maintenance activities during power operation are precluded by design.	Small number of PM/CM work orders compared to the average number of work orders for a typical compartment.	Average number of PM/CM work orders.
Occupancy	Entrance to the compartment is not possible during plant operation.	Compartment with low foot traffic or out of general traffic path.	Compartment not continuously occupied, but with regular foot traffic.

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients (3)

The following normalization equations are used:

- For *General Transients:*

  $W_{GT,J,L} = (n_{m,J,L} + n_{o,J,L} + n_{s,J,L})/N_{GT,L}$

  $N_{GT,L} = \Sigma(n_{m,i,L} + n_{o,i,L} + n_{s,i,L})$

  (summed over i, all compartments of location L)

- For *Transient Fires Caused by Welding and Cutting:*

  $W_{WC,J,L} = n_{m,J}/N_{WC}$

  $N_{WC} = \Sigma n_{m,i,L}$

  (summed over i, all the compartments of location L)

- For *Cable Fires Caused by Welding and Cutting:*

  $W_{CF,J} = n_{m,J} W_{Cable,J}/N_{CF}$

  $N_{CF} = \Sigma n_{m,i,L} W_{Cable,I}$

  (summed over i, all compartments of location L)

- *Problem Sets 06-11*

FIRE IGNITION FREQUENCIES
Step 8. Fire Frequency Evaluation

The fire frequency (generic or plant-specific) for each ignition source, $\lambda_{IS,J}$, can now be calculated using the data quantified in the preceding steps.

$$\lambda_{J,L} = \Sigma_{\text{summed over all ignition sources}} \lambda_{IS} W_L W_{IS,J,L}$$

Where:

$\lambda_{J,L}$: Fire frequency associated with compartment J at location L

λ_{IS}: Plant level fire ignition frequency associated with ignition source IS

W_L: Location weighting factor

$W_{IS,J,L}$: Ignition source weighting factor

FIRE IGNITION FREQUENCIES
Determination of Generic Fire Frequencies

The generic fire frequencies are based on the collective experience of U.S. nuclear power industry.

- Uncertainties
  - Consistency among plants reporting practices,
  - Completeness of event descriptions
  - Etc.
- Two stage Bayesian approach
- EPRI Fire Event Database (FEDB) up to December 31, 2000
- Analysis of each event

• FAQ 08-0048 - Fire Ignition Frequency (Status: Open)

FIRE IGNITION FREQUENCIES
Fire Event Data

EPRI's Fire Event Data Base (FEDB) was used to establish the historical fire events for generic fire frequency estimation.

- Licensee event reports
- Industry sources (e.g., NEIL and ANI)
- Various studies
- Specific plant data
- Individual event follow-up

FIRE IGNITION FREQUENCIES
Event Data Analysis

For each event, information was reviewed and the following were established:

Event Report Contents
- Occurrence date
- Plant type (i.e., PWR vs. BWR)
- Plant status (operating mode)
- Fire Location
- Fire Cause
- Initiating equipment and combustibles
- Detection and suppression information
- Severity related information
- Event description (narrative)

Event Analysis and Assignments
- Challenging?
- Location
- Ignition source
- Operating mode
- High energy arcing (electrical cab.)
- Suppression data
  - Prompt?
  - Supp. Curve Category (e.g. electrical)
  - Duration

FIRE IGNITION FREQUENCIES
Number of Events

For each plant and bin combination, the number of events were estimated using the following eight possible event classifications:

Table C-1
Fire Event Classifications and Frequency Estimation Action

Class. #	Information Deficiencies			Frequency Estimation Action	
	Known Plant	Known Op. Mode	Challenging Fire	Multiplier	Method of inclusion
1	Yes	Yes	Yes	1	As is
2	Yes	Yes	Undetermined	q	As is
3	Yes	No	Yes	p	As is
4	Yes	No	Undetermined	qp	As is
5	No	Yes	Yes	1	Distribute among units
6	No	Yes	Undetermined	q	Distribute among units
7	No	No	Yes	p	Distribute among units
8	No	No	Undetermined	qp	Distribute among units

FIRE IGNITION FREQUENCIES
Reactor Years

For each plant, two time periods were established – (1) power production mode and (2) low power or shutdown mode

- Assumed 62% capacity factor prior to 1994
- NUREG-1350 data for post 1994 capacity factors
- Total reactor years since initial commercial operation
- Added the reactor years of the units for multi-unit sites

FIRE IGNITION FREQUENCIES
Generic Fire Ignition Frequencies

#	Location	Ignition Source	# of Events	Total Reactor Years	RDAT Output			
					Mean	5%	50%	95%
1	Battery Room	Batteries	1.0	2486	7.5E-04	2.0E-05	3.2E-04	2.4E-03
2	Containment (PWR)	Reactor Coolant Pump	6.5	1089	6.1E-03	3.1E-04	3.6E-03	1.7E-02
3	Containment (PWR)	Transients and hotwork	2.4	1089	2.0E-03	1.3E-04	1.1E-03	5.9E-03
4	Control Room	Main control board	5.5	2486	2.5E-03	8.4E-05	1.2E-03	7.3E-03
5	Control/Auxiliary/Reactor Building	Cable fires caused by welding and cutting	2.0	1674	1.6E-03	3.1E-05	6.4E-04	5.0E-03
6	Control/Auxiliary/Reactor Building	Transient fires caused by welding and cutting	12.6	1674	9.7E-03	8.9E-05	2.4E-03	3.3E-02
7	Control/Auxiliary/Reactor Building	Transients	6.0	1674	3.9E-03	1.6E-04	2.2E-03	1.1E-02
8	Diesel Generator Room	Diesel generators	49.5	2486	2.1E-02	1.9E-03	1.2E-02	6.6E-02
9	Plant-Wide Components	Air compressors	5.0	2486	2.4E-03	3.8E-05	9.0E-04	7.9E-03

FIRE IGNITION FREQUENCIES
Concluding Remarks

Fire ignition frequency evaluation (Task 6) uses a mix of plant specific and generic information to establish the ignition frequencies for specific compartments and from that for specific fire scenarios.

- Generic fire ignition frequencies based on industry experience
- Elaborate data analysis method
- Frequencies binned by equipment type
- Methodology to apportion frequencies according to relative characteristics of each compartment

Workshop Problems for Task 6: Fire Ignition Frequency

Workshop Problem Set 06-01

Step 1: Mapping plant ignition sources to generic sources: Using the information provided in Tab 1.4, and Table 6-1 (see following pages) map the items listed in the following table to generic sources (bins) of Table 6-1.

Equipment ID	Equipment Description	Equipment Type*	Bin #*	Bin Description / Comment\
HPI-A	High pressure safety injection pump			
MOV-1	HPI valve			
MOV-5	RWST isolation valve			
BAT-B	Battery			
AOV-1 / (SOV-1)	Pilot operated relief valve			
PT-1	RCS pressure transmitter			
EDG-A	Emergency Diesel Generator			
MCC-B1	480 V Motor Control Center			
DC BUS-A	125 VDC Bus			
SUT-1	Startup Transformer			
MCB	Main Control Board			
SWGR-A	4160VAC Switchgear A			

* See Table 6-1 of NUREG/CR-6850 – EPRI 1011989

Table 6-1 -
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
3	Containment (PWR)	Transients and Hotwork	Power	2.0E-03	0	0	0.44	0.56	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
5	Control/Aux/Reactor Building	Cable fires caused by welding and cutting	Power	1.6E-03	0	0	0	1.0	0	0
6	Control/Aux/Reactor Building	Transient fires caused by welding and cutting	Power	9.7E-03	0	0	0	1.0	0	0
7	Control/Aux/Reactor Building	Transients	Power	3.9E-03	0	0	1.0	0	0	0
8	Diesel Generator Room	Diesel Generators	All	2.1E-02	0.16	0.84	0	0	0	0
9	Plant-Wide Components	Air Compressors	All	2.4E-03	0.83	0.17	0	0	0	0
10	Plant-Wide Components	Battery Chargers	All	1.8E-03	1.0	0	0	0	0	0
11	Plant-Wide Components	Cable fires caused by welding and cutting	Power	2.0E-03	0	0	0	1.0	0	0
12	Plant-Wide Components	Cable Run (Self-ignited cable fires)	All	4.4E-03	1.0	0	0	0	0	0
13	Plant-Wide Components	Dryers	All	2.6E-03	0	0	1.0	0	0	0
14	Plant-Wide Components	Electric Motors	All	4.6E-03	1.0	0	0	0	0	0

Table 6-1
Fire Frequency Bins and Generic Frequencies (Continued)

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
15	Plant-Wide Components	Electrical Cabinets	All	4.5E-02	1.0	0	0	0	0	0
16	Plant-Wide Components	High Energy Arcing Faults[1]	All	1.5E-03	0	0	0	0	0	1.0
17	Plant-Wide Components	Hydrogen Tanks	All	1.7E-03	0	0	0	0	1.0	0
18	Plant-Wide Components	Junction Boxes	All	1.9E-03	1.0	0	0	0	0	0
19	Plant-Wide Components	Misc. Hydrogen Fires	All	2.5E-03	0	0	0	0	1.0	0
20	Plant-Wide Components	Off-gas/H2 Recombiner (BWR)	Power	4.4E-02	0	0	0	0	1.0	0
21	Plant-Wide Components	Pumps	All	2.1E-02	0.54	0.46	0	0	0	0
22	Plant-Wide Components	RPS MG Sets	Power	1.6E-03	1.0	0	0	0	0	0
23a	Plant-Wide Components	Transformers (Oil filled)	All	9.9E-03	0	1.0	0	0	0	0
23b	Plant-Wide Components	Transformers (Dry)			1.0	0	0	0	0	0
24	Plant-Wide Components	Transient fires caused by welding and cutting	Power	4.9E-03	0	0	0	1.0	0	0

Table 6-1
Fire Frequency Bins and Generic Frequencies (Continued)

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
25	Plant-Wide Components	Transients	Power	9.9E-03	0	0	1.0	0	0	0
26	Plant-Wide Components	Ventilation Subsystems	All	7.4E-03	0.95	0.05	0	0	0	0
27	Transformer Yard	Transformer – Catastrophic[2]	Power	6.0E-03	1.0[3]		0	0	0	0
28	Transformer Yard	Transformer - Non Catastrophic[2]	Power	1.2E-02	1.0[3]		0	0	0	0
29	Transformer Yard	Yard transformers (Others)	Power	2.2E-03	1.0	0	0	0	0	0
30	Turbine Building	Boiler	All	1.1E-03	0	1.0	0	0	0	0
31	Turbine Building	Cable fires caused by welding and cutting	Power	1.6E-03	0	0	0	1.0	0	0
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0
33	Turbine Building	Turbine Generator Excitor	Power	3.9E-03	1.0	0	0	0	0	0
34	Turbine Building	Turbine Generator Hydrogen	Power	6.5E-03	0	0	0	0	1.0	0
35	Turbine Building	Turbine Generator Oil	Power	9.5E-03	0	1.0	0	0	0	0
36	Turbine Building	Transient fires caused by welding and cutting	Power	8.2E-03	0	0	0	1.0	0	0
37	Turbine Building	Transients	Power	8.5E-03	0	0	1.0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.
3. The event should be considered either as an electrical or oil fire, whichever yields the worst consequences.

Workshop Problem Set 06-02 (Example)

Step 2: Plant Fire Event Data Collection and Review: Two example cases of fire events for the sample nuclear power plant is presented below:

Fire Event # 1

Event date: January 1, 2007

Event Description: At approximately 16:49, a fire resulted from a short caused by the slabs on the MCC-A breakers not properly engaging the bus bars. As a result of a short, insulation on some wires ignited, resulting in a fire. The fire was discovered immediately by employees who extinguished the blaze with portable fire extinguishers. Damage was confined to the cabinet where the fire occurred, located inside the motor control center.

Should this event be considered in fire frequency calculation? Yes

Basis: The event occurred during power operation. Extent of damage was sufficient to render the ignition source inoperable and the flames and hot gases threatened the integrity of other items nearby.

Associated Bin ID # per Table 6-1 of Ref.1: 15

Bin Location: Plant-wide components

Bin Description: Electrical Cabinets

Basis: The fire was initiated in an MCC. An MCC is considered an electrical cabinet.

Fire Event # 2

Event date: February 1, 2007

Event Description: A fire occurred in the 120VAC-A panel. The fire was extinguished when 4kV bus-A was de- energized from the control room. Fire resulted from arcing of supply lead to one of the fittings connecting to a controller to the bus. Problems have been previously experienced with this type of devices in other plants.

Should this event be considered in fire frequency calculation? Yes

Basis: The event occurred during power operation. Extent of damage was sufficient to render the ignition source (i.e., 120VAC bus) inoperable and threaten the integrity of other items nearby.

Associated Bin ID # per Table 6-1 of Ref.1: 15

Bin Location: Plant-wide components

Bin Description: Electrical Cabinets

Basis: The fire was initiated in a 120VAC panel, which is considered as an electrical cabinet.

Workshop Problem Set 06-03 (Example)

Step 3: Plant Specific Updates of Generic Ignition Frequencies: The following bullets provide a sample discussion of how plant specific fire events are treated:

- The two events presented above are considered as "challenging" per the definition provided in Chapter 6 of NUREG/CR-6850 (EPRI-1011989). Therefore, it is included in a statistical analysis of the fire frequency (e.g., Bayesian update of generic frequencies.)
- Plant has been in commercial operation for 20 years.
- Both events should be mapped to Bin # 15 "Electrical Cabinets"
- A Bayesian update of the uncertainty distribution given in Table C-3 for Bin # 15 can be conducted using 2 events in 20 years. The resulting distribution has an approximate mean value of 0.1 per year. This is the frequency of a fire at any one of the electrical cabinets of the plant included in the Fire PRA.

Workshop Problem Set 06-04

Step 4: Mapping Plant-Specific Locations to Generic Locations: Using the information provided in this Sample Package, map the items listed in the following table to the applicable generic locations provided in NUREG/CR 6850. Note that some of the compartments may map to more than one Generic Location.

Step 5: Location Weighting Factors: Assign the location weighting factors of the Fire Compartments in the following table.

Comp. #	Compartment	Plant Area	Generic Location(s)	Comment	W_L
1	Main Control Room	Auxiliary Building			1.0
					1.0
3	Cable Spreading Room	Auxiliary Building			1.0
4A	RHR Pump Room	Auxiliary Building			1.0
					1.0
5	Battery Room A	Auxiliary Building			1.0
					1.0
14	Stairway	Auxiliary Building			1.0
7	Containment	Containment			1.0
12	Turbine Bldg El. 0 Ft	Turbine Building			1.0
					1.0
15	Battery Room 1	Turbine Building			1.0
					1.0

Workshop Problem Set 06-05

Step 6: Fixed Fire Ignition Source Counts: Estimate the ignition source counts for only those items that are noted under each picture and are visible in the foreground of the picture:

Electrical Panels: ________________

Electrical Panels: ________________

Transformers: ________________

Transformers: ________________

Electrical Panels: ________________

Transformers: ________________

Electrical Panels: ________________

Electrical Panels: ________________

Electrical Panels: ___________________

Electrical Panels: ___________________

Workshop Problem Set 06-06

Step 6: Fixed Fire Ignition Source Counts: Estimate the ignition source counts for the ignition sources (bins) present in the compartments identified below.

			Bin # and Description (per Table 6-1)												
			1	2	8	4	9	10	14	15	16	21	23a	23b	29
			Batteries	Reactor Coolant Pump	Diesel Generators	Main Control Board	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)	Yard transformers (Others)
#	Compartment	Plant Area	BAT	RCP	DG	MCB	AC	BC	EM	EC	HEAF	PMP	XFMR-Dry	XFMR-Oil	XFMR-Yard
1	Main Control Room	Control/Aux/Reactor Building													
3	Cable Spreading Room	Control/Aux/Reactor Building													
4A	RHR Pump Room	Control/Aux/Reactor Building													
5	Battery Room A	Plant Wide Components													
10	Switchgear Room A	Plant Wide Components													
14	Stairway	Plant Wide Components													
7	Containment	Containment													
8A	DG-A Room	Plant Wide Components													
12	Turbine Bldg El. 0 Ft	Plant Wide Components													
15	Battery Room 1	Plant Wide Components													
		Total													

Workshop Problem Set 06-07

Step 7: Ignition Source Weighting Factors: Using the information provided in the solution to the preceding problem, estimate the ignition source weighting factor for the following items:

$W_{BAT,Comp15,Turbine\ Bldg}$ =

$W_{PUMP,Comp2,Aux\ Bldg}$ =

$W_{HEAF,Comp10,Aux\ Bldg}$ =

Workshop Problem Set 06-08

Step 7: Ignition Source Weighting Factors: Using the information provided in the solution for Problem Set 06-06, calculate the ignition source weighting factors for the components listed below.

			Bin # and Description (per Table 6-1)												
			1	2	8	4	9	10	14	15	16	21	23a	23b	29
			Batteries	Reactor Coolant Pump	Diesel Generators	Main Control Board	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)	Yard transformers (Others)
#	Compartment	Plant Area	BAT	RCP	DG	MCB	AC	BC	EM	EC	HEAF	PMP	XFMR-Dry	XFMR-Oil	XFMR-Yard
1	Main Control Room	Control/Aux/Reactor Building													
3	Cable Spreading Room	Control/Aux/Reactor Building													
4A	RHR Pump Room	Control/Aux/Reactor Building													
5	Battery Room A	Plant Wide Components													
10	Switchgear Room A	Plant Wide Components													
14	Stairway	Plant Wide Components													
7	Containment	Containment													
8A	DG-A Room	Plant Wide Components													
12	Turbine Bldg El. 0 Ft	Plant Wide Components													
15	Battery Room 1	Plant Wide Components													

Workshop Problem Set 06-09

Transient Ignition Source Weighting Factors: Consider a hypothetical plant. The entire plant is composed of the following three (3) compartments with the following characteristics:

<u>Compartment 1</u>:

- Houses the Steam Driven Auxiliary Feedwater Pump
- The pump has required major maintenance once per year
- The compartment is in the Auxiliary Building separated from other compartments with 3-hour rated walls, floor and ceiling and one access door
- The lubricating oils of this and other equipment are stored in this compartment.
- All cables are in open bottom and open top cable trays
- The total amount of cables in this compartment is 1,000 lbs.

<u>Compartment 2</u>:

- Houses the High Pressure Injection Pump
- The pump has required major maintenance once per four years
- The compartment is in the Auxiliary Building separated from other compartments with 3-hour rated walls, floor and ceiling and one access door
- There are no other items in this room except for the pump.
- All cables are inside conduits
- The total amount of cables in the room is 1,000 lbs.

<u>Compartment 3</u>:

- Houses 480VAC MCC
- The MCC has never required any major maintenance since installation 15 years ago
- The compartment is a passageway in the Auxiliary Building with frequent foot traffic
- The compartment contains coveralls and other radiation protection related clothing items
- All cables are in open bottom and open top cable trays
- The total amount of cables in this compartment is 10,000 lbs.

A. Enter the influencing factors for each compartment and category:

	Influencing Factor			Cable Run (self-ignited cable fires)
Compartment	Maintenance	Occupancy	Storage	
Compartment 1				
Compartment 2				
Compartment 3				
Total				

B. Calculate the ignition source weighting factors for each compartment

Compartment	General Transients	Transient fires caused by welding and cutting	Cable fires caused by welding and cutting	Cable Run (self-ignited cable fires)
Compartment 1				
Compartment 2				
Compartment 3				
Total				

C. Calculate the ignition frequencies for each compartment

	General Transients	Transients fires caused by welding and cutting	Cable fires caused by welding and cutting	Cable Run (self-ignited cable fires)
Total Location Frequency (/ry)	*3.90E-03*	*9.70E-03*	*1.60E-03*	*4.40E-03*
Compartment 1				
Compartment 2				
Compartment 3				

Table 6-3
Description of Transient Fire Influencing Factors

Influencing Factor	No (0)	Low (1)	Medium (3)	High (10)	Very High (50)
Maintenance	Maintenance activities during power operation are precluded by design.	Small number of PM/CM work orders compared to the average number of work orders for a typical compartment.	Average number of PM/CM work orders.	Large number of (PM)/(CM) work orders compared to the average number of work orders for a typical compartment.	Should be assigned to plant areas that may experience significantly more (PM)/(CM) work orders compared to the average number of work orders for a typical compartment.
Occupancy	Entrance to the compartment is not possible during plant operation.	Compartment with low foot traffic or out of general traffic path.	Compartments not continuously occupied, but with regular foot traffic.	Continuously occupied compartment.	Not applicable
Storage	Entrance to the compartment is not possible during plant operation.	Compartment where no combustible/ flammable materials are stored.	Compartments where all combustible/ flammable material is stored in closed containers placed in dedicated fire-safe cabinets.	Compartments where combustible/ flammable materials may sometimes be brought in and left in either open containers for a short time or in a closed container, but outside a dedicated fire-safe cabinet for an extended time.	Not applicable

From Page 6-24 of NUREG/CR-6850 (EPRI-1011989)

For *general transients* (i.e., Bins 3, 7, 25, and 37), the following equation should be used to establish the ignition source weighting factor:

$$W_{GT,J,L} = (n_{m,J,L} + n_{o,J,L} + n_{s,J,L})/N_{GT,L}$$

$$N_{GT,L} = \Sigma (n_{m,i,L} + n_{o,\ i,L} + n_{s,\ i,L})$$

(summed over i, all compartments of location L).

where:

$n_{m,J,L}$ = Maintenance influence factor rating of compartment J of location L,

$n_{o,J,L}$ = Occupancy influence factor rating of compartment J of location L, and

$n_{s,J,L}$ = Storage influence factor rating of compartment J of location L.

In the case of *transient fires caused by welding and cutting* (i.e., Bins 6, 24, and 36), the following equation should be used:

$$W_{WC,J,L} = n_{m,J}/N_{WC}$$

$$N_{WC} = \Sigma\ n_{m,i,L}$$

(summed over i, all the compartments of location L).

For *cable fires caused by welding and cutting* (i.e., Bins 5, 11, and 31), the following equation should be used:

$$W_{CF,J} = n_{m,J}\, W_{Cable,J}\ /N_{CF}$$

$$N_{CF} = \Sigma\ n_{m,i,L}\ W_{Cable,i}$$

(summed over i, all compartments of location L),

where:

$W_{Cable,i}$ = Cable load of compartment i, based on the ratio of quantity of cables in compartment i over the total quantity of cables in the location.

Transients and Cable Fire (Count, Ignition Source Weighting Factor and Frequency)

	Count						Weighting Factors				Frequency		
	Cable Run (10^6 BTU)	Maintenance	Storage	Occupancy	Cable Quantity x Maintenance		General Transients	Cable Fires Due to Hotwork	Transients due to Hotwork		General Transients	Cable Fires Due to Hotwork	Transients due to Hotwork
	Control / Aux. / Reactor Building												
1 Main Control Room	300	1	10	10	300		0.64	3.5E-01	0.2		2.5E-03	5.6E-04	1.9E-03
2 Aux Bldg El. 0 Ft	6	1	1	1	6		0.09	7.0E-03	0.2		3.5E-04	1.1E-05	1.9E-03
3 Cable Spreading Room	549	1	1	1	549		0.09	6.4E-01	0.2		3.5E-04	1.0E-03	1.9E-03
4A RHR Pump Room	1	1	1	1	1		0.09	1.2E-03	0.2		3.5E-04	1.9E-06	1.9E-03
4B AFW Pump Room	1	1	1	1	1		0.09	1.2E-03	0.2		3.5E-04	1.9E-06	1.9E-03
Total		*5*	*14*	*14*	*857*						*3.90E-03*	*1.60E-03*	*9.70E-03*
	Plant Wide Components												
5 Battery Room A	1	1	1	1	1		0.05	4.2E-04	0.03		4.5E-04	8.3E-07	1.5E-04
6 Battery Room B	0	1	1	1	0		0.05	--	0.03		4.5E-04	--	1.5E-04
9 SWG Access Room	1.6	1	1	1	1.6		0.05	6.7E-04	0.03		4.5E-04	1.3E-06	1.5E-04
10 Switchgear Room A	10	3	1	3	30		0.11	1.3E-02	0.09		1.1E-03	2.5E-05	4.6E-04
11 Switchgear Room B	80	3	1	3	240		0.11	1.0E-01	0.09		1.1E-03	2.0E-04	4.6E-04
14 Stairway	0	1	1	3	0		0.08	--	0.03		7.5E-04	--	1.5E-04
7 Containment	0	1	1	1	0		0.05	--	0.03		4.5E-04	--	1.5E-04
8A DG-A Room	218	3	1	1	654		0.08	2.7E-01	0.09		7.5E-04	5.5E-04	4.6E-04
8B DG-B Room	218	3	1	1	654		0.08	2.7E-01	0.09		7.5E-04	5.5E-04	4.6E-04
12 Turbine Bldg El. 0 Ft	80	10	1	3	800		0.21	3.3E-01	0.31		2.1E-03	6.7E-04	1.5E-03
15 Battery Room 1	0	1	1	1	0		0.05	--	0.03		4.5E-04	--	1.5E-04
13 Yard	0	1	1	1	0		0.05	--	0.03		4.5E-04	--	1.5E-04
14 Intake Structure	6	3	1	1	18		0.08	7.5E-03	0.09		7.5E-04	1.5E-05	4.6E-04
Total		*32*	*13*	*21*	*2398.6*						*9.90E-03*	*2.00E-03*	*4.90E-03*

Ignition Frequencies by Bin and Compartment (part 1 of 2)

			Batteries	Reactor Coolant Pump	Diesel Generators	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)
Generic Frequency			7.5E-04	6.1E-03	2.1E-02	2.4E-03	1.8E-03	4.6E-03	4.5E-02	1.5E-03	2.1E-02	9.9E-03	9.9E-03
Compartment and Associated Freq.													
1	Main Control Room	1.1E-02							3.3E-04				
2	Aux Bldg El. 0 Ft	7.2E-03						2.0E-03			6.0E-03		
3	Cable Spreading Room	6.2E-03											
4A	RHR Pump Room	7.2E-03						2.0E-03			3.0E-03		
4B	AFW Pump Room	6.4E-03									6.0E-03		
5	Battery Room A	4.7E-04	2.5E-04										
6	Battery Room B	9.1E-04	2.5E-04										
9	SWG Access Room	1.1E-02							9.9E-03				
10	Switchgear Room A	1.5E-02					6.0E-04		7.9E-03	3.8E-04		5.0E-03	
11	Switchgear Room B	1.7E-02					6.0E-04		7.9E-03	3.8E-04		5.0E-03	
14	Stairway	6.6E-04											
7	Containment	3.2E-03						6.6E-04			3.0E-03		
8A	DG-A Room	1.8E-02			1.1E-02								
8B	DG-B Room	1.8E-02			1.1E-02								
12	Turbine Bldg El. 0 Ft	6.5E-02	2.5E-04			2.4E-03	6.0E-04		1.9E-02	7.5E-04	3.0E-03		9.9E-03
15	Battery Room 1	4.5E-04											
13	Yard	2.6E-03											
14	Intake Structure	1.1E-03											

<u>Ignition Frequencies by Bin and Compartment (part 2 of 2)</u>

		Yard transformers (Others)	Main Control Board	Cable Run	Junction Box	MG Sets	MFW Pumps	TG Oil	TG Exciter	TG Hydrogen
	Generic Frequency	2.2E-03	2.5E-03	4.4E-03	1.9E-03	1.6E-03	1.3E-02	9.5E-03	3.9E-03	6.5E-03
	Compartment									
1	Main Control Room		2.5E-03	9.0E-04						
2	Aux Bldg El. 0 Ft			1.8E-05	7.7E-06					
3	Cable Spreading Room			1.6E-03	7.1E-04					
4A	RHR Pump Room			3.0E-06	1.3E-06					
4B	AFW Pump Room			3.0E-06	1.3E-06					
5	Battery Room A			3.0E-06	1.3E-06					
6	Battery Room B									
9	SWG Access Room			4.8E-06	2.1E-06					
10	Switchgear Room A			3.0E-05	1.3E-05					
11	Switchgear Room B			2.4E-04	1.0E-04					
14	Stairway									
7	Containment									
8A	DG-A Room			6.5E-04	2.8E-04					
8B	DG-B Room			6.5E-04	2.8E-04					
12	Turbine Bldg El. 0 Ft			2.4E-04	1.0E-04			9.5E-03	3.9E-03	6.5E-03
15	Battery Room 1									
13	Yard	2.2E-03								
14	Intake Structure			1.8E-05	7.7E-06					

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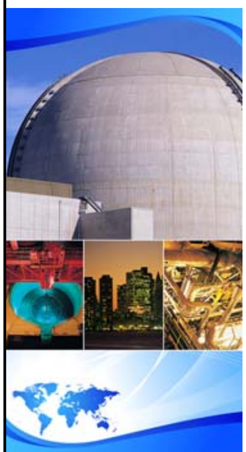


EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix G: Heat Release Rates

Joint RES/EPRI Fire PRA Course
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HEAT RELEASE RATES
Objectives

The objectives of this module are:

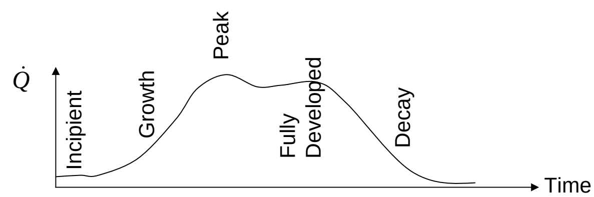
1. Define heat release rate and heat release rate profile
2. Review the recommended peak heat release rate values for typical ignition sources in NPPs
3. Describe the method provided for developing heat release rate profiles for fixed and transient ignition sources in NPPs

NOTE: Appendix G recommends values for ignition sources only. Heat release rates associated with fires propagating outside of the ignition source have to be evaluated accordingly.

HEAT RELEASE RATES
Definition

Definition: Heat generated by a burning object per unit time.

- $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$ BTU/sec or KW
- m” is burning rate [kg/s-m^2], ΔH_c is heat of comb [kJ/kg], A is area [m^2]
- Equivalent terms: energy release rate, fire intensity, fire power
- HRR profile describes fire intensity as a function of time



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Module III: Heat Release Rates Appendix G

Slide 3

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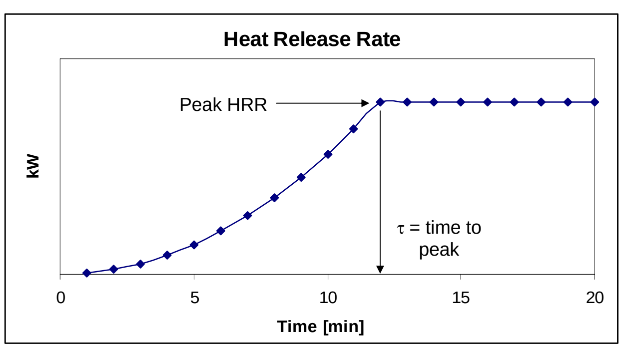
HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

The t^2 function is recommended for modeling the growth phase of the fire

$$\dot{Q}(t) = Min\left(\dot{Q}_{peak}, \dot{Q}_{peak} \cdot \left(\frac{t}{\tau}\right)^2\right)$$



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HEAT RELEASE RATES
HRR Profile

The HRR profile can be expressed as a constant or as a function of time

- Incipient stage: Not recommended to be modeled
  - Duration and intensity are uncertain
- Growth: Depends on the fuel and geometry of the scenario
  - Based on engineering judgment and/or experimental observations
- Fully developed: Usually after the fire reaches its peak intensity
  - Also known as steady burning
  - Starts at ignition if the growth period is not considered
  - A constant fire intensity should the the peak heat release rate of the profile
- Decay: In general, less hazardous conditions than the growth and fully developed stage

HEAT RELEASE RATES
HRR Profile – Related FAQs

- FAQ 08-0045 Cabinet Fires (Status: Open)
  - Issue:
    - Fire growth recommendations for electrical cabinets do not include consideration of an incipient stage (e.g., pre-ignition heating and generation of un-burned pyrolysates which might be detected)
  - General approach to resolution:
    - No clear resolution approach has yet been developed

HEAT RELEASE RATES
HRR Profile – Related FAQs (continued)

- FAQ 08-0052 Transient Fires (Status: Open)
  - Issue:
    - No guidance on fire growth times for transient fires
    - Guidance not clear as to which non-suppression curve would apply to transient fires in the MCR (i.e., transient curve or MCR curve)
  - General approach to resolution:
    - Review existing test data and develop guidance for transient fire growth times
    - Clarify non-suppression curve application for this case

HEAT RELEASE RATES
HRR Profile – Related FAQs *(continued)*

- FAQ 08-0044 MFW Pump Oil Fires (Status: Open)
  - Issue:
    - Guidance for large oil spill and fire is generating conservative results, especially in the case of MFW pump fires (relatively high frequency of large release compared to experience base)
  - General approach to resolution:
    - Provide an alternative approach and revised fire frequencies for leaks and spills from higher volume circulating oil/lubrication systems

HEAT RELEASE RATES
Fixed Ignition Sources

The methodology recommends heat release rate values for various fixed ignition sources

- Vertical cabinets
  - Open/closed
  - Qualified/unqualified cables
- Pumps (electrical fires)
- Electric motors
- HRR for flammable liquid fires should be calculated using the equation $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$
- Separate guidance for cables, pressurized oil and hydrogen fires

HEAT RELEASE RATES
Recommended Peak HRR Values

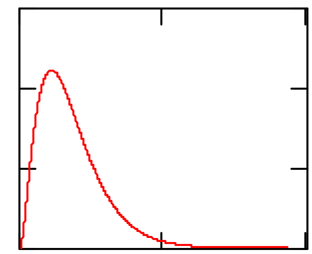
Recommended peak HRR values were developed based on expert judgment

- Expert panel included the EPRI/NRC-RES Fire Risk Re-quantification Study research team with expertise in fire behavior/phenomena.
- Values are expressed as probability distributions. The panel identified the 75th and 98th percentiles of the distribution for peak HRR.
- Primary sources of information included NUREG/CR-4527 and VTT publications
- Gamma distribution selected:
  - Only positive values starting at 0 kW
  - Values in the same order of magnitude

HEAT RELEASE RATES
Recommended Peak HRR Values

Example distribution developed by the expert panel

- 75^{th} = 232 kW
- 98^{th} = 464 kW
- α = 2.6
- β = 67.8



HEAT RELEASE RATES
Recommended Peak HRR Values

Ignition Source	HRR kW (Btu/s)		Gamma Distribution	
	75th	98th	α	β
Vertical cabinets with qualified cable, fire limited to one cable bundle	69 [1] (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Vertical cabinets with qualified cable, fire in more than one cable bundle	211 [2] (200)	702 [3] (665)	0.7 (0.7)	216 (204)
Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 [4] (85)	211 [2] (200)	1.6 (1.6)	41.5 (39.5)
Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 [5] (220)	464 [6] (440)	2.6 (2.6)	67.8 (64.3)
Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 [5] (220)	1002 [7] (950)	0.46 (0.45)	386 (366)
Pumps (electrical fires)	69 (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Motors [8]	32 (30)	69 (65)	2.0 (2.0)	11.7 (11.1)

*See report for footnotes

HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

The methodology suggests a fire growth rate for electrical cabinet fires

- The fire grows to its peak HRR in approximately 12 min
- The fire burns at its peak HRR for approximately 8 min
- Based on experiments reported in NUREG/CR-4527

Test	Units in Minutes		
	Time to Peak	Steady Burning	Time to Decay
ST1	7	8	15
ST2	6	11	17
ST3	10	8	18
ST4	14	3	17
ST5	8	9	17
ST6	8	17	25
ST7	18	7	25
ST8	10	20	30
ST9	10	10	20
ST10	10	20	30
ST11	18	2	20
PCT1	11	10	21
PCT2	12	2	14
PCT3	13	14	27
PCT4a	16	0	16
PCT4c	16	0	16
PCT5	17	0	17
PCT6	11	0	11
Test 21	4	14	18
Test 22	9	2	11
Test 23	10	0	10
Test 24	12	0	12
Average	**11.4**	**7.1**	**19**

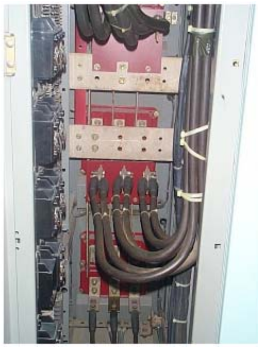
HEAT RELEASE RATES
Assigning HRR Values to Electrical Cabinets

A visual examination of the interior of the cabinet is recommended

- Identify openings in the cabinet walls
- Identify type of cable: qualified/unqualified
- Identify cable bundles
- Qualitatively determine if a fire can propagate from one bundle to another
- Select the appropriate peak HRR probability distribution

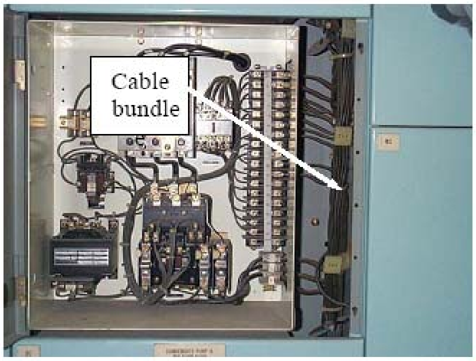
HEAT RELEASE RATES
Examples

By visual examination:
- More than one cable bundle
- Assuming qualified cable, select distribution with 75th = 211 kW, 98th =702 kW



HEAT RELEASE RATES
Examples

By visual examination:
- Only one cable bundle
- Assuming qualified cable, select distribution with 75th = 69 kW, 98th = 211 kW



HEAT RELEASE RATES
Transient Ignition Sources

The peak HRR for transient fires is also characterized with a gamma probability distribution

- Gamma distribution:
  - 75^{th} = 135 BTU/s, 98^{th} = 300 BTU/s (142 & 317 kW respectively)
  - α = 1.9, β = 53.7
- Applicable only to localized transient combustibles (trash cans, etc.)
- Not applicable to flammable liquid transient fires

HEAT RELEASE RATES
Concluding Remarks

Peak HRR values are recommended for some typical fixed and transient ignition sources in NPP fire scenarios

- Values are for localized ignition source (not for fires propagating outside the ignition source)
- HRR for flammable liquid fires can be calculated from fundamental equations
- HRR for "solid" ignition sources are generally expressed as probability distributions based on experimental data and expert judgment

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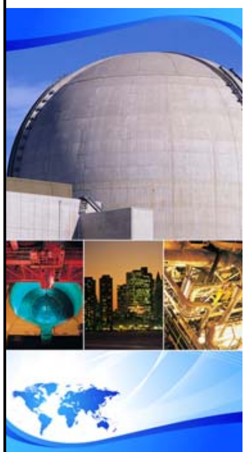

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix I: Damage Criteria

Joint RES/EPRI Fire PRA Course

June 2009

Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Damage Criteria
Damage Thresholds

- Damage (or Failure) Threshold: the minimum value of an exposure environment parameter that *can* lead to the failure of the damage target of interest within the timescale of the fire
  - Can be a temperature – exposure to high temperatures such as in a hot gas layer or fire plume
  - Can be a radiant heat flux – generally due to direct radiant heating from the luminous flame zone of a fire
  - In theory, it could be a minimum smoke density, but we aren't that smart (more on smoke shortly)

Damage Criteria
Damage Thresholds

- Damage thresholds are of primary interest to Task 8 – Scoping Fire Modeling
  - We use damage thresholds mainly when screening out specific fire ignition sources
    - If a fire source cannot damage any target, or ignite any secondary combustible, then we screen that source out of the analysis as non-threatening (more on Task 8 later)
  - *Also Note:* If an electrical cable is damaged, we assume that it will also be ignited
    - Arcing when a cable short circuits will ignite the cable based on testing experience

Damage Criteria
Damage Thresholds

- Damage Threshold is specific to the damage target and procedure deals mainly with the following:
  - Electrical Cables
    - Thermoset
    - Thermoplastic
  - Electronics and integrated circuit devices
- For other devices (e.g., motors, switchgear, etc.) look at the cables and supporting controls or electronics
  - Example: A pump is fed by power cables, and those cables are generally more vulnerable to fire damage than the pump itself

Damage Criteria
Damage Thresholds

- Some items are considered invulnerable to fire-induced damage:
  - Ferrous metal pipes and tanks
  - Passive components such as flow check valves
  - Concrete structural or partitioning elements except when considering random failure likelihood in multi-compartment scenarios
    - i.e., we *do not* consider fire-induced structural failure of concrete
- Things you still need to watch for:
  - Soldered piping (e.g., air/gas lines that are soldered copper)
  - Flexible boots/joints/sleeves on piping (e.g., the Vandellos scenario)
  - Exposed structural steel given a very large fire source (e.g., catastrophic loss of the main TG set – more later)

Damage Criteria
Damage Thresholds

- The following are defined as generic damage thresholds for the most common damage targets – cables:

Table H-1: Damage Criteria for Electrical Cables – Generic Screening Criteria for the Assessment of the Ignition and Damage Potential of Electrical Cables [See Ref 8-1]

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic	6 kW/m² (0.5 BTU/ft2s)	205°C (400°F)
Thermoset	11 kW/m² (1.0 BTU/ft2s)	330°C (625°F)

- And electronics:
  - 3 kW/m² (0.25 BTU/ft²) and 65°C (150°F)
  - If needed, assume ignition properties same as thermoplastic cables:
    6 kW/m² (0.5 BTU/ft²) and 205°C (400°F).

Damage Criteria
Damage Thresholds

- For additional rules related to damage criteria, see H.1.1; e.g.:
  - Cables in conduit: potential damage targets, but will not contribute to fire growth and spread – no credit to conduit for delaying the onset of thermal damage.
  - Cables coated by a fire-retardant coating: treat as exposed cables for damage purposes – coating may slow the subsequent spread of fire, but we are NOT specific here.

Damage Criteria
Damage Thresholds

- Plant-specific or product-specific damage thresholds *may be used* if appropriate basis is established
  - Report provides some references for information specific to many popular types and brands of cables
  - Example:

Table H-4
Failure Temperatures for Specific Cable Products as Reported in Table 5 of Reference H.2

Cable Manufacturer	Description of Cable Tested	Failure Threshold (°C)
Brand Rex	Cross-linked polyethylene (XLPE) Insulation, Chlorosulfonated Polyethylene (CSPE) Jacket, 12 AWG, 3-Conductor (3/C), 600 Volt (V)	385
Rockbestos	Firewall III, Irradiation XLPE Insulation, Neoprene Jacket, 12 AWG, 3/C, 600 V	320-322
Raychem	Flamtrol, XLPE Insulation, 12 AWG, I/C, 600 V	385-388
Samuel Moore	Dekoron Polyset , Cross-Linked Polyolefin (XLPO) Insulation, CSPE Jacket, 12 AWG, 3/C and Drain	299-307
Anaconda	Single Conductors Removed From: Anaconda Y Flame- Guard Flame Retardant (FR) Ethylene Propylene (EP), Ethylene Propylene Rubber (EPR) Insulation, Chlorinated Polyethylene (CPE) Jacket, 12 AWG, 3/C, 600 V	381
Anaconda	Anaconda Flame-Guard EP, EPR Insulation, Individual CSPE Jacket, Overall CSPE Jacket, 12 AWG, 3/C, I000 V	394
Okonite	Okonite Okolon, EPR Insulation, CSPE Jacket, 12 AWG, I/C, 600 V	387

Damage Criteria
Damage Time

- It is both appropriate and desirable to consider damage time during Task 11 – Detailed Fire Modeling
  - At the threshold exposure condition, damage times may be prolonged (e.g., 30 minutes or more)
  - As exposure conditions increase in severity, time to damage decreases (e.g., to as little as a few seconds)
  - Consideration of time to damage allows for a more realistic assessment of the non-suppression probability
    - How long do you have to put the fire out before damage occurs?

Damage Criteria
Damage Time

- Two general approaches to damage time analysis:
  - Direct modeling of target thermal response
    - Use a fire model to predict the temperature response of the target
    - When the predicted temperature of the target reaches the damage threshold, assume target failure
    - Catch: need fire model that does target response calculation
  - Empirical approach (e.g. SDP)
    - Predict the peak exposure condition (temperature or heat flux)
    - Use a look-up table to estimate time to damage
    - Catch: look-up tables currently only available for generic thermoset and thermoplastic cables

Damage Criteria
Damage Time

- Example of the Time to Damage look-up tables:

Table H-5: Failure Time-Temperature Relationship for Thermoset cables (Table A.7.1 from reference H.6).

Exposure Temperature		Time to Failure (minutes)
°C	°F	
330	625	28
350	660	13
370	700	9
390	735	7
410	770	5
430	805	4
450	840	3
470	880	2
490 (or greater)	915 (or greater)	1

Damage Criteria
Smoke Damage

- Appendix T provides an extended discussion of current knowledge regarding smoke damage
  - This is about smoke and the failure of equipment
  - It is not about the impact of smoke on people
- We are interested in short-term damage
  - Within the time scale of the fire scenario including plant shutdown
  - We do not consider longer term issues such as corrosion leading to failure some days or weeks after a fire

Damage Criteria
Smoke Damage

- Bottom Line: Some components are known to be vulnerable to smoke damage, but it takes a dense exposure to cause short term damage

- So what are the vulnerable components?
  - High voltage switching equipment (arcing)
  - High voltage transmission lines (arcing)
  - Devices such as strip chart recorders that are dependent on fine mechanical motion (binding)
  - Un-protected printed circuit cards (deposition and shorting)
    - e.g., exposed within a panel and not provided with a protective coating

Damage Criteria
Smoke Damage

- Smoke damage is assessed on an empirical basis:
  - We don't set quantitative thresholds
  - We don't try to use fire models
  - You should consider the potential failure of vulnerable components due to smoke as a part of your damage target set

Damage Criteria
Smoke Damage

- Assume that vulnerable components adjacent to or connected to the fire source will be damaged by smoke:
  - Within the same electrical cabinet or housing as a fire source
    - e.g. given a panel fire, the whole panel is lost due to smoke and/or heat
  - In an adjacent cabinet if the cabinet-to-cabinet partitions is not well-sealed
  - In a common *stack* of electrical cubicles
  - In a nearby cabinet with a direct connection to the fire source
    - e.g., a shared or common bus-duct

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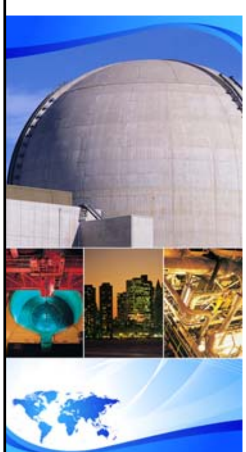


EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix G: Heat Release Rates

Joint RES/EPRI Fire PRA Course
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

HEAT RELEASE RATES
Objectives

The objectives of this module are:

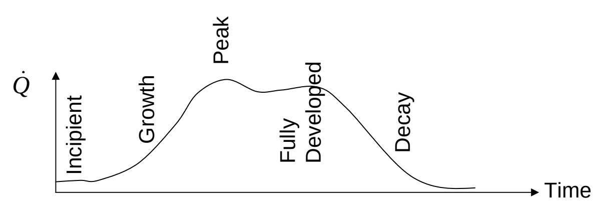
1. Define heat release rate and heat release rate profile
2. Review the recommended peak heat release rate values for typical ignition sources in NPPs
3. Describe the method provided for developing heat release rate profiles for fixed and transient ignition sources in NPPs

NOTE: Appendix G recommends values for ignition sources only. Heat release rates associated with fires propagating outside of the ignition source have to be evaluated accordingly.

HEAT RELEASE RATES
Definition

Definition: Heat generated by a burning object per unit time.

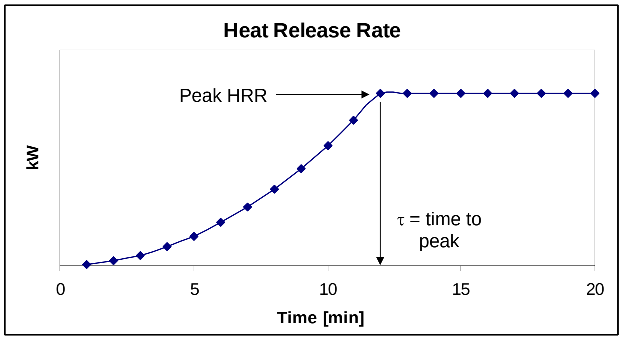
- $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$ BTU/sec or KW
- m" is burning rate [kg/s-m^2], ΔH_c is heat of comb [kJ/kg], A is area [m^2]
- Equivalent terms: energy release rate, fire intensity, fire power
- HRR profile describes fire intensity as a function of time



HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

The t^2 function is recommended for modeling the growth phase of the fire

$$\dot{Q}(t) = Min\left(\dot{Q}_{peak,}\,\dot{Q}_{peak}\cdot\left(\frac{t}{\tau}\right)^2\right)$$



HEAT RELEASE RATES
HRR Profile

The HRR profile can be expressed as a constant or as a function of time

- Incipient stage: Not recommended to be modeled
  - Duration and intensity are uncertain
- Growth: Depends on the fuel and geometry of the scenario
  - Based on engineering judgment and/or experimental observations
- Fully developed: Usually after the fire reaches its peak intensity
  - Also known as steady burning
  - Starts at ignition if the growth period is not considered
  - A constant fire intensity should the the peak heat release rate of the profile
- Decay: In general, less hazardous conditions than the growth and fully developed stage

HEAT RELEASE RATES
HRR Profile – Related FAQs

- FAQ 08-0045 Cabinet Fires (Status: Open)
  - Issue:
    - Fire growth recommendations for electrical cabinets do not include consideration of an incipient stage (e.g., pre-ignition heating and generation of un-burned pyrolysates which might be detected)
  - General approach to resolution:
    - No clear resolution approach has yet been developed

HEAT RELEASE RATES
HRR Profile – Related FAQs (continued)

- FAQ 08-0052 Transient Fires (Status: Open)
  - Issue:
    - No guidance on fire growth times for transient fires
    - Guidance not clear as to which non-suppression curve would apply to transient fires in the MCR (i.e., transient curve or MCR curve)
  - General approach to resolution:
    - Review existing test data and develop guidance for transient fire growth times
    - Clarify non-suppression curve application for this case

HEAT RELEASE RATES
HRR Profile – Related FAQs *(continued)*

- FAQ 08-0044 MFW Pump Oil Fires (Status: Open)
  - Issue:
    - Guidance for large oil spill and fire is generating conservative results, especially in the case of MFW pump fires (relatively high frequency of large release compared to experience base)
  - General approach to resolution:
    - Provide an alternative approach and revised fire frequencies for leaks and spills from higher volume circulating oil/lubrication systems

HEAT RELEASE RATES
Fixed Ignition Sources

The methodology recommends heat release rate values for various fixed ignition sources

- Vertical cabinets
  - Open/closed
  - Qualified/unqualified cables
- Pumps (electrical fires)
- Electric motors
- HRR for flammable liquid fires should be calculated using the equation $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$
- Separate guidance for cables, pressurized oil and hydrogen fires

HEAT RELEASE RATES
Recommended Peak HRR Values

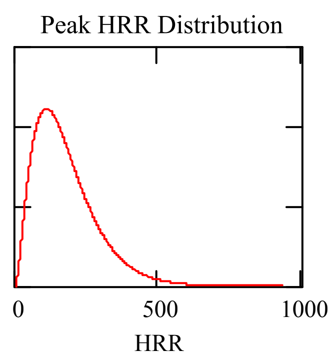
Recommended peak HRR values were developed based on expert judgment

- Expert panel included the EPRI/NRC-RES Fire Risk Re-quantification Study research team with expertise in fire behavior/phenomena.
- Values are expressed as probability distributions. The panel identified the 75^{th} and 98^{th} percentiles of the distribution for peak HRR.
- Primary sources of information included NUREG/CR-4527 and VTT publications
- Gamma distribution selected:
  - Only positive values starting at 0 kW
  - Values in the same order of magnitude

HEAT RELEASE RATES
Recommended Peak HRR Values

Example distribution developed by the expert panel

- 75^{th} = 232 kW
- 98^{th} = 464 kW
- α = 2.6
- β = 67.8



HEAT RELEASE RATES
Recommended Peak HRR Values

Ignition Source	HRR kW (Btu/s)		Gamma Distribution	
	75th	98th	α	β
Vertical cabinets with qualified cable, fire limited to one cable bundle	69 [1] (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Vertical cabinets with qualified cable, fire in more than one cable bundle	211 [2] (200)	702 [3] (665)	0.7 (0.7)	216 (204)
Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 [4] (85)	211 [2] (200)	1.6 (1.6)	41.5 (39.5)
Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 [5] (220)	464 [6] (440)	2.6 (2.6)	67.8 (64.3)
Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 [5] (220)	1002 [7] (950)	0.46 (0.45)	386 (366)
Pumps (electrical fires)	69 (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Motors [8]	32 (30)	69 (65)	2.0 (2.0)	11.7 (11.1)

*See report for footnotes

HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

The methodology suggests a fire growth rate for electrical cabinet fires

- The fire grows to its peak HRR in approximately 12 min
- The fire burns at its peak HRR for approximately 8 min
- Based on experiments reported in NUREG/CR-4527

Test	Units in Minutes		
	Time to Peak	Steady Burning	Time to Decay
ST1	7	8	15
ST2	6	11	17
ST3	10	8	18
ST4	14	3	17
ST5	8	9	17
ST6	8	17	25
ST7	18	7	25
ST8	10	20	30
ST9	10	10	20
ST10	10	20	30
ST11	18	2	20
PCT1	11	10	21
PCT2	12	2	14
PCT3	13	14	27
PCT4a	16	0	16
PCT4c	16	0	16
PCT5	17	0	17
PCT6	11	0	11
Test 21	4	14	18
Test 22	9	2	11
Test 23	10	0	10
Test 24	12	0	12
Average	**11.4**	**7.1**	**19**

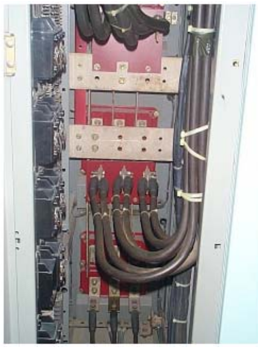
HEAT RELEASE RATES
Assigning HRR Values to Electrical Cabinets

A visual examination of the interior of the cabinet is recommended

- Identify openings in the cabinet walls
- Identify type of cable: qualified/unqualified
- Identify cable bundles
- Qualitatively determine if a fire can propagate from one bundle to another
- Select the appropriate peak HRR probability distribution

HEAT RELEASE RATES
Examples

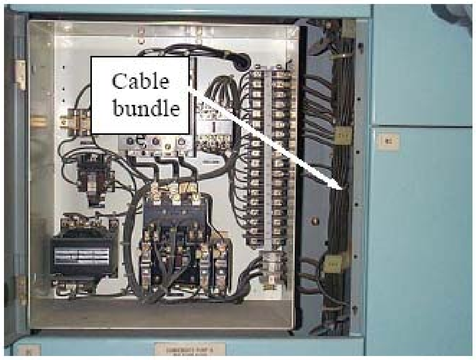
By visual examination:
- More than one cable bundle
- Assuming qualified cable, select distribution with 75^{th} = 211 kW, 98^{th} =702 kW



HEAT RELEASE RATES
Examples

By visual examination:

- Only one cable bundle
- Assuming qualified cable, select distribution with 75th = 69 kW, 98th = 211 kW



HEAT RELEASE RATES
Transient Ignition Sources

The peak HRR for transient fires is also characterized with a gamma probability distribution

- Gamma distribution:
  - 75th = 135 BTU/s, 98th = 300 BTU/s (142 & 317 kW respectively)
  - $\alpha = 1.9$, $\beta = 53.7$
- Applicable only to localized transient combustibles (trash cans, etc.)
- Not applicable to flammable liquid transient fires

HEAT RELEASE RATES
Concluding Remarks

Peak HRR values are recommended for some typical fixed and transient ignition sources in NPP fire scenarios

- Values are for localized ignition source (not for fires propagating outside the ignition source)
- HRR for flammable liquid fires can be calculated from fundamental equations
- HRR for “solid” ignition sources are generally expressed as probability distributions based on experimental data and expert judgment

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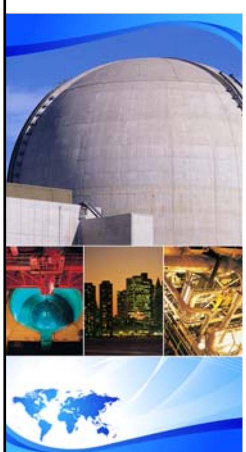

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix I: Damage Criteria

Joint RES/EPRI Fire PRA Course

June 2009

Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Damage Criteria
Damage Thresholds

- Damage (or Failure) Threshold: the minimum value of an exposure environment parameter that *can* lead to the failure of the damage target of interest within the timescale of the fire
  - Can be a temperature – exposure to high temperatures such as in a hot gas layer or fire plume
  - Can be a radiant heat flux – generally due to direct radiant heating from the luminous flame zone of a fire
  - In theory, it could be a minimum smoke density, but we aren't that smart (more on smoke shortly)

Damage Criteria
Damage Thresholds

- Damage thresholds are of primary interest to Task 8 – Scoping Fire Modeling
  - We use damage thresholds mainly when screening out specific fire ignition sources
    - If a fire source cannot damage any target, or ignite any secondary combustible, then we screen that source out of the analysis as non-threatening (more on Task 8 later)
  - *Also Note:* If an electrical cable is damaged, we assume that it will also be ignited
    - Arcing when a cable short circuits will ignite the cable based on testing experience

Damage Criteria
Damage Thresholds

- Damage Threshold is specific to the damage target and procedure deals mainly with the following:
  - Electrical Cables
    - Thermoset
    - Thermoplastic
  - Electronics and integrated circuit devices

- For other devices (e.g., motors, switchgear, etc.) look at the cables and supporting controls or electronics
  - Example: A pump is fed by power cables, and those cables are generally more vulnerable to fire damage than the pump itself

Damage Criteria
Damage Thresholds

- Some items are considered invulnerable to fire-induced damage:
  - Ferrous metal pipes and tanks
  - Passive components such as flow check valves
  - Concrete structural or partitioning elements except when considering random failure likelihood in multi-compartment scenarios
    - i.e., we *do not* consider fire-induced structural failure of concrete

- Things you still need to watch for:
  - Soldered piping (e.g., air/gas lines that are soldered copper)
  - Flexible boots/joints/sleeves on piping (e.g., the Vandellos scenario)
  - Exposed structural steel given a very large fire source (e.g., catastrophic loss of the main TG set – more later)

Damage Criteria
Damage Thresholds

- The following are defined as generic damage thresholds for the most common damage targets – cables:

Table H-1: Damage Criteria for Electrical Cables – Generic Screening Criteria for the Assessment of the Ignition and Damage Potential of Electrical Cables [See Ref 8-1]

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic	6 kW/m² (0.5 BTU/ft2s)	205°C (400°F)
Thermoset	11 kW/m² (1.0 BTU/ft2s)	330°C (625°F)

- And electronics:
  - 3 kW/m² (0.25 BTU/ft²) and 65°C (150°F)
  - If needed, assume ignition properties same as thermoplastic cables:
    6 kW/m² (0.5 BTU/ft²) and 205°C (400°F).

Damage Criteria
Damage Thresholds

- For additional rules related to damage criteria, see H.1.1; e.g.:
  - Cables in conduit: potential damage targets, but will not contribute to fire growth and spread – no credit to conduit for delaying the onset of thermal damage.
  - Cables coated by a fire-retardant coating: treat as exposed cables for damage purposes – coating may slow the subsequent spread of fire, but we are NOT specific here.

Damage Criteria
Damage Thresholds

- Plant-specific or product-specific damage thresholds *may be used* if appropriate basis is established
  - Report provides some references for information specific to many popular types and brands of cables
  - Example:

Table H-4
Failure Temperatures for Specific Cable Products as Reported in Table 5 of Reference H.2

Cable Manufacturer	Description of Cable Tested	Failure Threshold (°C)
Brand Rex	Cross-linked polyethylene (XLPE) Insulation, Chlorosulfonated Polyethylene (CSPE) Jacket, 12 AWG, 3-Conductor (3/C), 600 Volt (V)	385
Rockbestos	Firewall III, Irradiation XLPE Insulation, Neoprene Jacket, 12 AWG, 3/C, 600 V	320-322
Raychem	Flamtrol, XLPE Insulation, 12 AWG, I/C, 600 V	385-388
Samuel Moore	Dekoron Polyset , Cross-Linked Polyolefin (XLPO) Insulation, CSPE Jacket, 12 AWG, 3/C and Drain	299-307
Anaconda	Single Conductors Removed From: Anaconda Y Flame- Guard Flame Retardant (FR) Ethylene Propylene (EP), Ethylene Propylene Rubber (EPR) Insulation, Chlorinated Polyethylene (CPE) Jacket, 12 AWG, 3/C, 600 V	381
Anaconda	Anaconda Flame-Guard EP, EPR Insulation, Individual CSPE Jacket, Overall CSPE Jacket, 12 AWG, 3/C, I000 V	394
Okonite	Okonite Okolon, EPR Insulation, CSPE Jacket, 12 AWG, I/C, 600 V	387

Damage Criteria
Damage Time

- It is both appropriate and desirable to consider damage time during Task 11 – Detailed Fire Modeling
  - At the threshold exposure condition, damage times may be prolonged (e.g., 30 minutes or more)
  - As exposure conditions increase in severity, time to damage decreases (e.g., to as little as a few seconds)
  - Consideration of time to damage allows for a more realistic assessment of the non-suppression probability
    - How long do you have to put the fire out before damage occurs?

Damage Criteria
Damage Time

- Two general approaches to damage time analysis:
  - Direct modeling of target thermal response
    - Use a fire model to predict the temperature response of the target
    - When the predicted temperature of the target reaches the damage threshold, assume target failure
    - Catch: need fire model that does target response calculation
  - Empirical approach (e.g. SDP)
    - Predict the peak exposure condition (temperature or heat flux)
    - Use a look-up table to estimate time to damage
    - Catch: look-up tables currently only available for generic thermoset and thermoplastic cables

Damage Criteria
Damage Time

- Example of the Time to Damage look-up tables:

Table H-5: Failure Time-Temperature Relationship for Thermoset cables (Table A.7.1 from reference H.6).

Exposure Temperature		Time to Failure (minutes)
°C	°F	
330	625	28
350	660	13
370	700	9
390	735	7
410	770	5
430	805	4
450	840	3
470	880	2
490 (or greater)	915 (or greater)	1

Damage Criteria
Smoke Damage

- Appendix T provides an extended discussion of current knowledge regarding smoke damage
  - This is about smoke and the failure of equipment
  - It is not about the impact of smoke on people
- We are interested in short-term damage
  - Within the time scale of the fire scenario including plant shutdown
  - We do not consider longer term issues such as corrosion leading to failure some days or weeks after a fire

Damage Criteria
Smoke Damage

- Bottom Line: Some components are known to be vulnerable to smoke damage, but it takes a dense exposure to cause short term damage
- So what are the vulnerable components?
  - High voltage switching equipment (arcing)
  - High voltage transmission lines (arcing)
  - Devices such as strip chart recorders that are dependent on fine mechanical motion (binding)
  - Un-protected printed circuit cards (deposition and shorting)
    - e.g., exposed within a panel and not provided with a protective coating

Damage Criteria
Smoke Damage

- Smoke damage is assessed on an empirical basis:
  - We don't set quantitative thresholds
  - We don't try to use fire models
  - You should consider the potential failure of vulnerable components due to smoke as a part of your damage target set

Damage Criteria
Smoke Damage

- Assume that vulnerable components adjacent to or connected to the fire source will be damaged by smoke:
  - Within the same electrical cabinet or housing as a fire source
    - e.g. given a panel fire, the whole panel is lost due to smoke and/or heat
  - In an adjacent cabinet if the cabinet-to-cabinet partitions is not well-sealed
  - In a common *stack* of electrical cubicles
  - In a nearby cabinet with a direct connection to the fire source
    - e.g., a shared or common bus-duct

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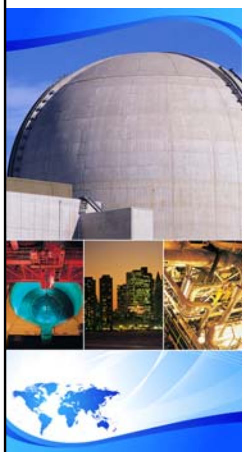


EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III:
Task 8: Scoping Fire Modeling & Appendix F

Joint RES/EPRI Fire PRA Course
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SCOPING FIRE MODELING
Objectives

The objectives of this module are:

- Describe the process of screening ignition sources
- Describe the concept of zone of influence (ZOI)
- Describe the recommended walk down
- Review the walk down forms
- Describe how to update the fire ignition frequencies calculated in Task 6 with the screening results

SCOPING FIRE MODELING
Interfaces

- Inputs for this task
  - PRA equipment list, Task 2
  - List of ignition sources in each compartment, Task 6
  - Room geometry
  - Types of ignition sources and targets
- Output from this task
  - Revised compartment fire ignition frequencies
  - List of potential fire scenarios to be analyzed in Task 11

SCOPING FIRE MODELING
Screening Ignition Sources

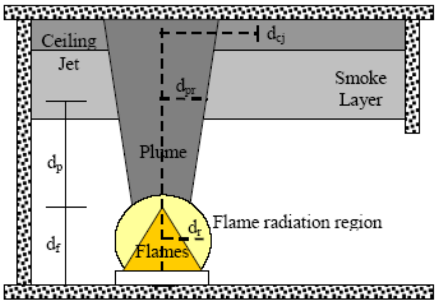
Any ignition source can be screened if a postulated fire will not damage or ignite equipment in the compartment.

- By screening the ignition source, its frequency contribution is eliminated, reducing the compartment frequency.
- It is recommended to use the 98^{th} percentile of the probability distributions for peak HRR.
- A walk down is strongly recommended.

SCOPING FIRE MODELING
The Zone of Influence (ZOI)

The zone of influence is the region in the compartment where a target will be damaged if exposed to fire conditions generated by a
specific ignition source.

- The ZOI has 5 distinct regions:
  - Flames
  - The fire plume
  - The ceiling jet
  - The hot gas layer
  - Flame radiation region



SCOPING FIRE MODELING
Task 8: Recommended Steps

5 steps for conducting Task 8

1. Preparation for walk down
2. Plant walk down and screen ignition sources
3. Verification of screened ignition sources
4. Calculation of severity factors
5. Calculation of revised fire frequency

SCOPING FIRE MODELING

Step 1: Preparation for Walk down

It is recommended that walk down forms be prepared for each compartment to be visited

- Create a list of ignition sources in each compartment.
  - Equipment counted in Task 6
  - Flag equipment in the PRA equipment list created in Task 2
  - Assigned a HRR to each ignition source (98th percentile of the pdf)
- Workshop Problem 08-01

- Collect damage criteria information for the equipment in the room
  - Qualified/Unqualified cables, solid state equipment etc.
- Workshop Problem 08-02

- Develop and document zone of influences in each compartment

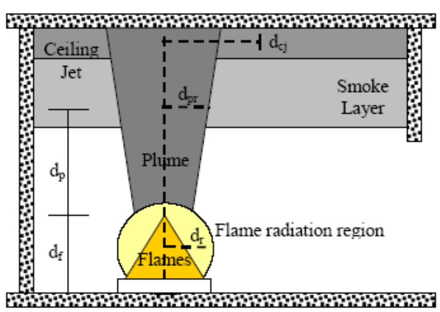
SCOPING FIRE MODELING

Step 1: Alternative Models for Zone of Influence

- Smoke or hot gas layer: MQH model

$$T = T_{amb} + 6.85 \cdot \left(\frac{\dot{Q}_f^2}{A_o \sqrt{H_o}\, h_k A_T} \right)^{1/3}$$

$$h_k = \begin{cases} \sqrt{\dfrac{k \cdot d_m \cdot c_p}{t}} & t < t_p \\ \dfrac{k}{th} & t \ge t_p \end{cases} \qquad t_p = \frac{th^2}{4 \cdot \left(k / (d_m \cdot c_p) \right)}$$



Input Parameters:
- T_{amb}: Ambient temperature (ºC)
- Q_f: Fire heat release rate (kW)
- A_o: Opening area (or sum of opening areas) (m^2)
- H_o: Height of opening [m]
- A_T: Internal surface area of the room (not including opening area) (m^2)
- k: Thermal conductivity of wall material (kW/m-ºC)
- d_m: Density of wall material (kg/m^3)
- c_p: Specific heat of wall material (kJ/kg-ºC)
- th: Wall thickness (m)
- t: Time value (sec)

SCOPING FIRE MODELING
Step 1: Example Calculation for Room Temperature

$$T = T_{amb} + 6.85 \cdot \left(\frac{\dot{Q}_f^2}{A_o \sqrt{H_o} h_k A_T} \right)^{1/3}$$

$$h_k = \begin{cases} \sqrt{\dfrac{k \cdot d_m \cdot c_p}{t}} & t < t_p \\ \dfrac{k}{th} & t \geq t_p \end{cases} \qquad t_p = \frac{th^2}{4 \cdot \left(k / (d_m \cdot c_p) \right)}$$

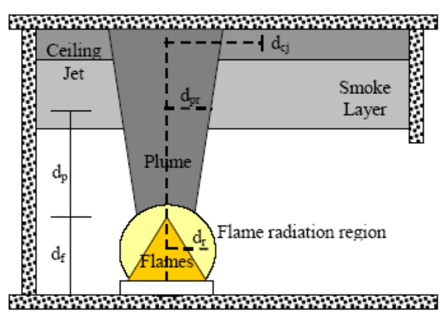
MQH Temperature Correlation	
Inputs	
Ambient temperature [C]	20
Duration [sec]	1200
Opening area [m2]	3
Height of opening [m]	3
Room length [m]	37
Room width [m]	37
Room height [m]	8
Thermal conductivity [kW/mK]	0.0014
Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.6
HRR [kW]	9500
Results	
Room Temp [C]	**327**

SCOPING FIRE MODELING
Step 1: Alternative Models for Zone of Influence

- Flame height and fire plume: Heskestad's models

$$L = 0.235 \dot{Q}_f^{2/5} - 1.02D$$

Input Parameters:
- Q_f: Fire heat release rate (kW)
- D: Fire diameter (m)



$$T_{pl} = T_{amb} + 25 \left(\frac{\left(k_f \dot{Q}_f (1 - \chi_r) \right)^{2/5}}{\left((H_p - F_e) - z_o \right)} \right)^{5/3}$$

$$z_o = 0.083 \dot{Q}_f^{2/5} - 1.02D$$

Input Parameters:
- T_{amb}: Ambient temperature (ºC)
- k_f: Fire location factor
- Q_f: Fire heat release rate (kW)
- F_e: Fire elevation (m)
- H_p: Target height measured from the floor (m)
- X_r: Irradiated fraction of the heat release rate (FIVE recommends 0.4)
- D: Plume diameter (m)

SCOPING FIRE MODELING
Step 1: Example Calcs for Flame Height and Plume Temp

$$L = 0.235\dot{Q}_f^{2/5} - 1.02D$$

$$T_{pl} = T_{amb} + 25\left(\frac{\left(k_f\dot{Q}_f(1-\chi_r)\right)^{2/5}}{\left((H_p - F_e) - z_o\right)}\right)^{5/3}$$

$$z_o = 0.083\dot{Q}_f^{2/5} - 1.02D$$

Heskdestad's Flame Height Correlation	
Inputs	
Fire diameter [m]	0.6
HRR [kW]	250
Results	[m]
Flame height [m]	**1.5**

Heskestad's Plume Temperature Correlati	
Inputs	
Ambient temperature [C]	20
Fire location factor	1
HRR [kW]	1375
Fire elevation [m]	0
Target Elevation [m]	3.7
Radiation Fraction	0.40
Fire Diameter [m]	1
Results	
Plume Temp [C]	**328**

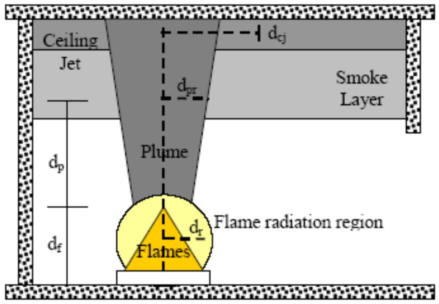
SCOPING FIRE MODELING
Step 1: Related FAQ

- FAQ 08-0043 (Status: Open)
  - Issue:
    - Guidance for placement of a cabinet fire (the source location) suggests inspecting cabinet contents and placing fire at fuel location
    - Applicants would prefer a “one size” approach less conservative than placing on top of cabinet that would not require internal inspection
  - General approach to resolution:
    - RES/EPRI teams are debating merits of general application of fire protection SDP approach – place fire 1 foot below cabinet top (unless top is unsealed or vented)

SCOPING FIRE MODELING
Step 1: Alternative Models for Zone of Influence

- Flame Radiation: Point Source Model

$$\dot{q}''_{irr} = \frac{\dot{Q}_f \chi_r}{4\pi R^2}$$



Input Parameters:
- Q_f: Fire heat release rate (kW)
- R: Distance from flames (m)
- X_r: Irradiated fraction of the heat release rate (FIVE recommends 0.4)
- D: Fire diameter (m)

SCOPING FIRE MODELING
Step 1: Example calculation for flame radiation

$$\dot{q}''_{irr} = \frac{\dot{Q}_f \chi_r}{4\pi R^2}$$

Point Source Flame Radiation Model	
Inputs	
Fire heat release rate [kW]	317
Radiation fraction	0.40
Distance from flames [m]	1.5
Results	
Heat flux [kW/m2]	**4.5**

- Workshop problem 08-03

SCOPING FIRE MODELING
Step 2: Plant Walk down and Screening IS

During the walk down, equipment in the room is subjected to fire conditions from each ignition source using the ZOI.

- Take the opportunity to verify & improve Task 6 counting
- Document location of ignition sources and reasons for screen/no-screen decisions
- If ignition sources are not screened, document location of affected equipment and which fire-generated condition affected it.
- Do not screen:
  - Oil fires
  - Cables
  - Interconnected cabinets
- Workshop problem 08-04

SCOPING FIRE MODELING
Step 3: Verification of Screened IS

It is important to verify that fire damage to the ignition source itself is not risk significant

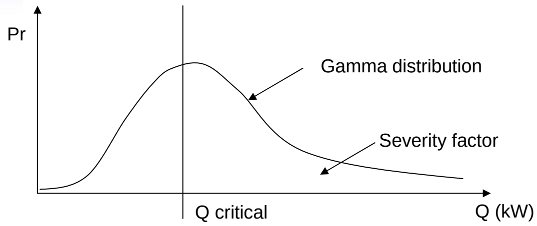
1. Do not screen equipment in the PRA equipment list
2. If loss of the ignition source results in a trip (automatic or manual), but no equipment contributing to the CCDP are lost, compare the ignition source fire frequency with the random frequency of the trip it causes.
3. If loss of the ignition source results in both a trip (automatic or manual) and loss of one or more components contributing to the CCDP, add a fire-induced sequence using the ignition source fire frequency and the corresponding CCDP model with the damaged components set to fail (failure probability = 1.0).

SCOPING FIRE MODELING
Task 8: Calculation of Severity Factors

For each unscreened ignition source, calculate the severity
factor using the appropriate probability distribution for peak
HRR.

- Determine the heat release rate required for damaging equipment
- This require information gathered during the walk downs!

SCOPING FIRE MODELING
Task 8: Calculation of Severity Factors



Case	Ignition Source	HRR kW (Btu/s) HRR	HRR kW (Btu/s) 98th	Gamma Distribution α	Gamma Distribution β
1	Vertical cabinets with qualified cable, fire limited to one cable bundle	69	211	0.84	59.3
2	Vertical cabinets with qualified cable, fire in more than one cable bundle	211	702	0.7	216
3	Vertical cabinets with unqualified cable, fire limited to one cable bundle	90	211	1.6	41.5
4	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232	464	2.6	67.8
5	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232	1002	0.46	386
6	Pumps (electrical fires)	69	211	0.84	59.3
7	Motors	32	69	2	11.7
8	Transient Combustibles	142	317	1.8	57.4

Table E-5
Discretized Distribution for Case 4 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire in more than One Cable Bundle Closed Doors)

Bin	Heat Release Rate - kW (Btu/s) Lower	Heat Release Rate - kW (Btu/s) Upper	Heat Release Rate - kW (Btu/s) Point Value	Severity Factor (P_i)
1	0 (0)	53 (50)	36 (34)	0.082
2	53 (50)	106 (100)	80 (76)	0.213
3	106 (100)	158 (150)	131 (124)	0.224
4	158 (150)	211 (200)	184 (174)	0.177
5	211 (200)	264 (250)	235 (223)	0.122
6	264 (250)	317 (300)	288 (273)	0.077
7	317 (300)	369 (350)	341 (323)	0.046
8	369 (350)	422 (400)	394 (373)	0.027
9	422 (400)	475 (450)	446 (423)	0.015
10	475 (450)	528 (500)	499 (473)	0.008
11	528 (500)	580 (550)	552 (523)	0.004
12	580 (550)	633 (600)	603 (572)	0.002
13	633 (600)	686 (650)	656 (622)	0.001
14	686 (650)	739 (700)	709 (672)	0.001
15	739 (700)	Infinity	816 (773)	0.001

- Workshop problem 08-05

SCOPING FIRE MODELING
Task 8: Calculation of Revised Fire Frequency

Plant ____________
Fire Area ____________
Compartment ____________

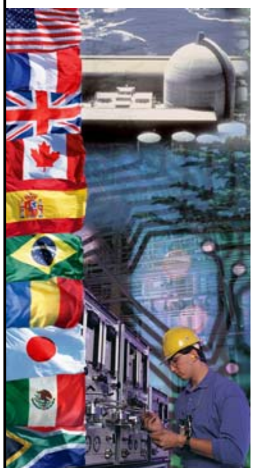
Dmage Criteria	
Temperature [C]	205
Heat flux [kW/m2]	6

Pre-Walkdown Inputs		WALKDOWN INPUTS						Input	
Equip ID	HRR PDF	Fire Condition	Dist to Target (m)	Calculated HRR [kW]	Critical 98th HRR [kW]	Screen ?	SF	(Task 6) λ	Adjusted λ
Cabinet A	1	Flames	0.5	49	211	No	3.4E-01	1.0E-04	3.44E-05
Cabinet B	1	Plume	3	401	211	Yes	0.0E+00	1.0E-04	0
Cabinet C	3	Ceiling jet	1.5	4870	211	Yes	0.0E+00	1.0E-04	0
Pump	6	Plume	2	179	211	No	3.0E-02	1.0E-04	2.97E-06
Motor	7	Flame radiation	2.5	1178	69	Yes	0.0E+00	1.0E-04	0
					Adusted compartment frequency, λ_C =				3.7E-05

SCOPING FIRE MODELING
Concluding Remarks

Task 8 is intended for screening fixed ignition sources. As a result of the screening, the compartment frequencies may be reduced, and a preliminary list of potential fire scenarios for detailed evaluation in Task 11 is developed.

- A detailed walk down is recommended
- Analysts should take the opportunity to review the equipment count made for Task 6 and/or improve it.



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix E: Fire Severity

Joint RES/EPRI Public Workshop
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

FIRE SEVERITY
Purpose

- A uniform methodology has been developed to define the severity of a fire.
  - Severity factor concept
  - Based on heat release rate
  - Standardized cases

FIRE SEVERITY
Severity Factor Concept

- Severity Factor is . .
  - A simplified, one parameter representation of a very complex phenomenon (i.e., fire) influenced by a large number of factors.
  - Defined as the conditional probability that, given a fire has occurred, it is of certain severity (it is defined here through heat release rate).
  - Quantified in combination with *Non-Suppression Probability.*

FIRE SEVERITY
Severity Factor Concept

HRR (kW)	Probability	Probability of exceeding	Damage?
11	0.445	1.000	No
36	0.219	0.555	No
61	0.129	0.336	No
87	0.078	0.207	No
112	0.048	0.129	Yes
137	0.030	0.081	Yes
162	0.019	0.051	Yes
187	0.012	0.032	Yes
212	0.007	0.020	Yes
237	0.005	0.013	Yes
262	0.003	0.008	Yes
287	0.002	0.005	Yes
312	0.001	0.003	Yes
337	0.001	0.002	Yes
405	0.001	0.001	Yes
Total	1.000		

$$\lambda_{damage} = \lambda_{Fire} \times 0.129$$

FIRE SEVERITY
Severity Factor Concept

HRR (kW)	Probability P_i	Probability of exceeding	Damage	t_s (min)	$P_{NS,i}$	$P_i\ P_{NS,i}$
11	0.445	1.000	No	No Damage	0.0	0.0E+00
36	0.219	0.555	No	No Damage	0.0	0.0E+00
61	0.129	0.336	No	No Damage	0.0	0.0E+00
87	0.078	0.207	No	No Damage	0.0	0.0E+00
112	0.048	0.129	Yes	28	0.03	1.7E-03
137	0.030	0.081	Yes	24	0.06	1.7E-03
162	0.019	0.051	Yes	20	0.09	1.7E-03
187	0.012	0.032	Yes	16	0.15	1.8E-03
212	0.007	0.020	Yes	13	0.21	1.5E-03
237	0.005	0.013	Yes	11	0.27	1.3E-03
262	0.003	0.008	Yes	9	0.34	1.0E-03
287	0.002	0.005	Yes	7	0.43	8.6E-04
312	0.001	0.003	Yes	5	0.55	5.5E-04
337	0.001	0.002	Yes	3	0.70	7.0E-04
405	0.001	0.001	Yes	1	0.89	8.9E-04
Total	1.000					0.014

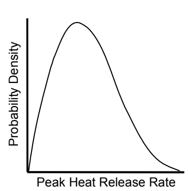
* t_s: Time available for suppression

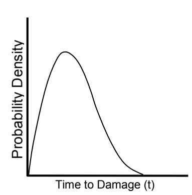
** P_{NS} = Prob. of non-suppression = $\exp(-\lambda\ t_s)$

$$\lambda_{damage} = \lambda_{Fire} \times 0.014$$

FIRE SEVERITY
Probability of Damage Estimation

- Probability of damage before time t is estimated using complex fire spread and propagation models.
  - Heat release rate is a key parameter of the analysis
  - Assuming a known heat release rate, specific features of the compartment, ignition source, and target set configuration, time to damage can be calculated.
  - Since heat release rate is expressed with a probability distribution, the time to damage can be expressed with a probability distribution





FIRE SEVERITY
Heat Release Rate Distributions

The heat release rate of the following equipment classes have been defined:

Case	Ignition Source	HRR (Btu/s)	
		75th	98th
1	Vertical cabinets with qualified cable, fire limited to one cable bundle	65	200
2	Vertical cabinets with qualified cable, fire in more than one cable bundle	200	665
3	Vertical cabinets with unqualified cable, fire limited to one cable bundle	85	200
4	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	220	440
5	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	220	950
6	Pumps (electrical fires)	65	200
7	Motors	30	65
8	Transient Combustibles	135	300

FIRE SEVERITY
Heat Release Rate Distribution - Example

Table E-1
HRR Distribution for Vertical Cabinets with Qualified Cables, Fire Limited to One Cable Bundle

Bin	Heat Release Rate (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0	25	10.5	0.446
2	25	50	36	0.219
3	50	75	61	0.129
4	75	100	87	0.078
5	100	125	112	0.048
6	125	150	137	0.030
7	150	175	162	0.019
8	175	200	187	0.012
9	200	225	212	0.007
10	225	250	237	0.005
11	250	275	262	0.003
12	275	300	287	0.002
13	300	325	312	0.001
14	325	350	337	0.001
15	350	Infinity	405	0.001

FIRE SEVERITY
Severity Factor for Oil Spill Fires

- The severity factors for oil spills are recommended to be established from the following steps:

  1. Determine the amount of oil that can be spilled in the room.
  2. Assign a severity factor of 0.02 to a scenario consisting of 98% or more of the amount of oil spilled and ignited.
  3. Assign a severity factor of 0.98 to a scenario consisting of 10% of the amount of oil spilled and ignited.

- This approach is being revisited in FAQ 07-0044.

FIRE SEVERITY
Severity Factor for Other Ignition Sources

- The following notes address ignition sources not covered in the preceding discussions:
  - Cable fires:
    - Heat release rate is established using fire propagation modeling
    - Severity factor = 1.0 may be used where target damage can be ascertained
  - High-energy arcing faults:
    - Severity factor = 1.0 within zone of influence
  - Catastrophic transformer fires in the transformer yard:
    - Severity factor = 1.0 within zone of influence
  - Non-catastrophic transformer fires in the transformer yard:
    - Generally not modeled, otherwise use severity factor = 1.0 within zone of influence
  - Other fires in the transformer yard:
    - Depending on the item burning, the heat release rate of similar devices may be used.

FIRE SEVERITY
Frequency Bins and HRR Distributions

Table 11-1
Recommended Severity Factors . . . for Ignition Sources in the Frequency Model

ID	Location	Ignition Source	HRR Distribution Category
1	Battery Room	Batteries	Electric motors
2	Containment (PWR)	Reactor coolant Pump	Pumps (Electrical)/Oil spills
4a	Control Room	Electrical cabinets	Applicable electrical cabinet
4b	Control Room	Main control board	See Appendix L
5	Control/Auxiliary/ Reactor Building	Cable fires caused by welding and cutting	Assume 1.0
6	Control/Auxiliary/ Reactor Building	Transient fires caused by welding and cutting	Transients
21	Plant-Wide Components	Pumps	Pump (Electrical)/Oil spills

FIRE SEVERITY
Concluding Remarks

- Severity Factor provides an adjustment to ignition frequency to account for the severity of the fire.
  - It is tied to the heat release rate
  - It is estimated in concert with probability of non-suppression
  - Specific cases have been developed
  - Guidance is provided for other cases

Workshop Problems on Task 8: Scoping Fire Modeling

This handout includes workshop problems on the different steps of Task 8: Scoping Fire Modeling. Problems are grouped by steps.

Step 1: Preparation for Walkdown

Step 1 has three sub-steps: 1) Estimate heat release rate for fixed ignition source screening, 2) Target and intervening combustibles damage or ignition criteria, and 3) Develop a zone of influence.

Workshop problem 08-01:

Step 1.1: Estimate heat release rate for fixed ignition source screening: Assign a heat release rate to the ignition sources depicted in the pictures of the following Table 08-01. For this exercise, assume that the plant has a mix of qualified and unqualified cables. The heat release rates are listed in Table E-1 of NUREG/CR-6850.

Table 08-01: Inputs for Workshop problems 1

Ignition Source	Table E-1 Case	98th Percentile HRR	Justification
 Dry transformer			
 Fire protection panel			
 Ventilation sub-system			

Ignition Source	Table E-1 Case	98th Percentile HRR	Justification
 Pumps			

Workshop Problem Set 08-02:

Step 1.2: Target and intervening combustible damage and ignition criteria: Assign damage criteria to the ignition sources depicted in Table 08-01. For this exercise, assume that the plant has a mix of thermoset and thermoplastic cable. Generic damage criteria are listed in Table H-1 of NUREG/CR-6850.

Table 08-02: Inputs for workshop problem 2

Target/Intervening Combustible	Damage Criteria	Justification
Cables in a ladder back tray		
Cables in a solid tray		
Theromset cable in a conduit		
Motor operated valve (MOV).		
Cabinet with a solid state device		

Workshop Problem Set 08-03

Step 1.3: Develop zone of influence: Calculate the heat release rate required for generating target damage for the following ignition source/target combination and determine if the ignition source can be screened. Use the engineering calculations described in NUREG-1805 for determining the heat release rate value.

- Target in the hot gas layer:
  - A cable tray target is located near the ceiling in a room approximately 21’ by 7’ and has a normally closed door on each end. The room is approximately 20’ high. The inside walls of the MCC room are reinforced concrete. There is one MCC cabinet in the room. The MCC cabinet has unqualified cable.

- Target subjected to flame impingement or fire plume temperatures:
  - A vertical cable tray is located 5’ ft from a floor based ventilation subsystem.

- Target subjected to flame radiation:
  - A conduit is located 3 ft from a battery charger with qualified cable.

Workshop Problem Set 08-04

Step 2: Plant Walkdown**:** Inspect the ignition source and target combination in the pictures included in Table 08-03 and determine the appropriate zone of influence calculation necessary.

Table 08-03: Inputs for Workshop problems 1

Ignition Source	Ignition Source/Target	Zone of Influence	Distance
			
			
			

Ignition Source	Ignition Source/Target	Zone of Influence	Distance
			
			
			
			

Step 3: Verification of Screened Ignition Sources

No workshop problem for Step 3.

Workshop Problem Set 08-05

Step 4: Calculation of Severity Factors: Calculate the severity factors for the ignition source and target combinations listed in Workshop Problem 08-03. Use the results of Workshop Problem Set 08-03 as inputs to this exercise.

- Target in the hot gas layer

- Target subjected to flame impingement or plume temperatures

- Target subjected to flame radiation

Workshop Problem Set 08-06

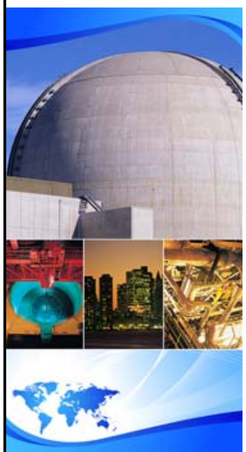
Step 5: Calculation of Revised Compartment Fire Frequency: Determine a revised compartment ignition frequency for switchgear room A assuming the walkdown results listed in Table 08-04.

Table 08-04: Summary of Task 8 calculations

Equipment Description	Count	Fire Condition	Measured Distance (ft)	Table E-1 Case	Critical HRR (Table E-1)	Room Area (ft2)	Room Height (ft)	Calculated HRR (kW)	Room Temp (F)	Screened	Severity Factor	Count Task 8
Train A 4160 V Bus	8	flame or plume	1.7	9	Do Not Screen	1350	20	7	N/A	No	**1.00**	**8.00**
Train A 480 V Load Center	6	flame radiation	4.9	9	Do Not Screen	1350	20	401	N/A	No	**1.00**	**6.00**
Train A Station Service Transformer	1	flame radiation	4.5	9	Do Not Screen	1350	20	336	N/A	No	**1.00**	**1.00**
Train A Battery Charger	1	flame or plume	2.9	4	464	1350	20	25	264	No	**0.98**	**0.98**
Train A 125 VDC Bus	8	flame or plume	0.7	4	464	1350	20	1	264	No	**1.00**	**8.00**
Train A 125 VDC Panel	1	flame radiation	2.8	4	464	1350	20	129	264	No	**0.60**	**0.60**
Train A Inverter	1	flame radiation	2.0	4	464	1350	20	64	264	No	**0.88**	**0.88**

Table 08-05: Comparison of switchgear room A ignition frequency

Task 6	Switchgear Room A	**≈ 1.5E-02**
Task 8	Switchgear Room A	**≈ 1.5E-02**



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 11, Special Fire Models Part 1

Joint RES/EPRI Fire PRA Course
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

FIRE MODELS

- Generally computational fire models are developed to estimate extent and timing of fire growth
- There are fire scenarios critical to NPP applications that are beyond capability of existing computational fire models
  - Special models are developed for prediction of consequences of such scenarios, based on a combination of:
    - Fire experiments,
    - Operating experience, actual fire events
    - Engineering judgment

SPECIAL MODELS

- Cable fires (modified from IPEEE approaches)
  - Cable spreading room and cable tunnel fire risk
- High energy arcing faults (new)
  - Switchgear room
- Fire propagation to adjacent cabinets (consolidation)
  - Relay room
- Passive fire protection features (consolidation)

SPECIAL MODELS (Part 2)

- Main control board (new)
- Hydrogen fires (new)
- Turbine generator fires (new)
- Smoke damage (consolidation of research – new risk analysis guidance)

CABLE FIRES (1 of 9)

- No generalized analytical theory is available to accurately model cable fires in all possible configurations in commercial nuclear plants.
- Most of the information compiled for this appendix is in the form of flammability parameters derived from experiments or correlations also developed from experimental data.
- The amount of experimental evidence and analytical tools available to model cable tray fires is relatively small when compared to the vast number of possible fire scenarios that can be postulated for NPPs
- Simplification of these scenarios will be needed

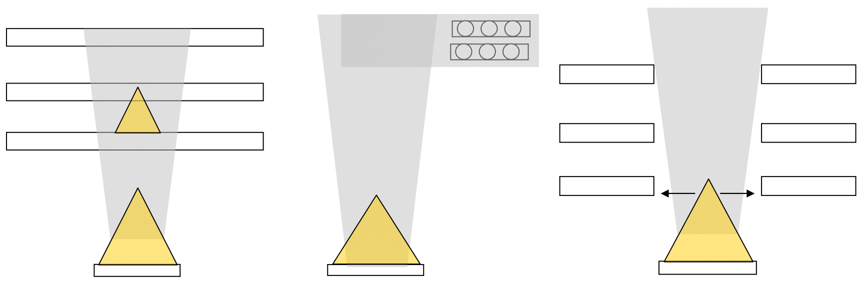
CABLE FIRES (2 of 9)

Scenarios involving cable fires may start as:

- Self-ignited cable fires
  - Postulate self ignited cable fires in unqualified cables only
  - Self ignited cable fires should be characterized by a cable mass ratio (mass of cables in the room / mass of cables in the plant) representative of the scenario.
  - Cable mass ratio is equivalent to the severity factor
- Or as secondary fires caused by fixed or transient fire sources
  - Cable fires caused by welding & cutting should be postulated in both qualified and unqualified cables.

CABLE FIRES (3 of 9)

Cable tray ignition: Simplified cases



CABLE FIRES (4 of 9)

Heat release rate from cable fires

- q_{bs}: bench scale heat release rate per unit area
- A: burning area
  - Length of the ignition source times tray width

$$\dot{Q}_{ct} = 0.45 \cdot \dot{q}_{bs} \cdot A$$

Bench Scale HRR Values Under a Heat Flux of 60 kW/m^2,

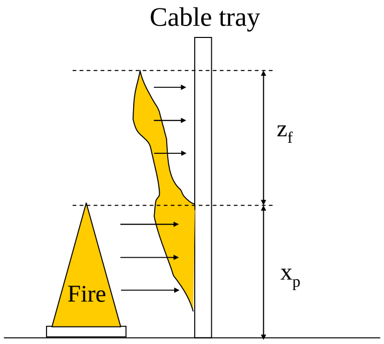
Material	Bench Scale HRR [kW/m^2]
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
PE/PVC	395
PE/PVC	359
PE/PVC	312
PE/PVC	589
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218

CABLE FIRES (5 of 9)

Flame spread

- k_f is a constant with a value of 0.01 m^2/kW

$$z_f = x_p \cdot \left(k_f \dot{Q}'' - 1\right)$$

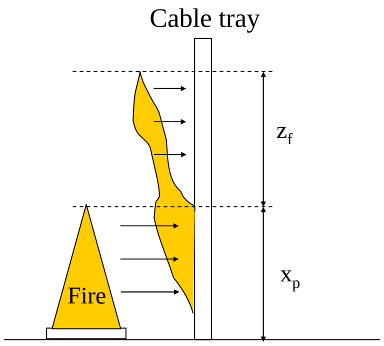


CABLE FIRES (6 of 9)

Flame spread model

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

- Horizontal trays
  - δ is assumed to be 2 mm
  - q" is assumed as 70 kW/m^2
- Vertical trays
  - δ is assumed to be z_f
  - q" is assumed as 25 kW/m^2



CABLE FIRES (7 of 9)

Example

- Material properties

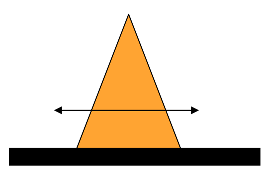
- PVC cables:
  - K = 0.000192 kW/m K
  - ρ = 1380 kg/m^3
  - C_p = 1.289 kJ/kg K
  - T_{ig} = 218°C

- XPE cables:
  - K = 0.000235 kW/m K
  - ρ = 1375 kg/m^3
  - C_p = 1.390 kJ/kg K
  - T_{ig} = 330°C

CABLE FIRES (8 of 9)

Example

- Horizontal trays
  - Flame spread for XPLE cable = 0.3 mm/sec (~0.05′/min)
  - Flame spread for PVC cable = 0.9 mm/sec (~0.2′/min)



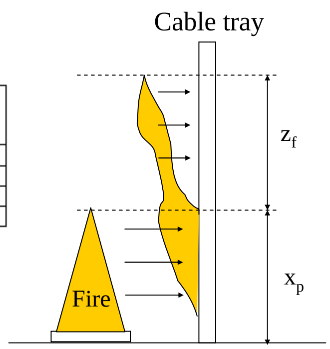
CABLE FIRES (9 of 9)

Example

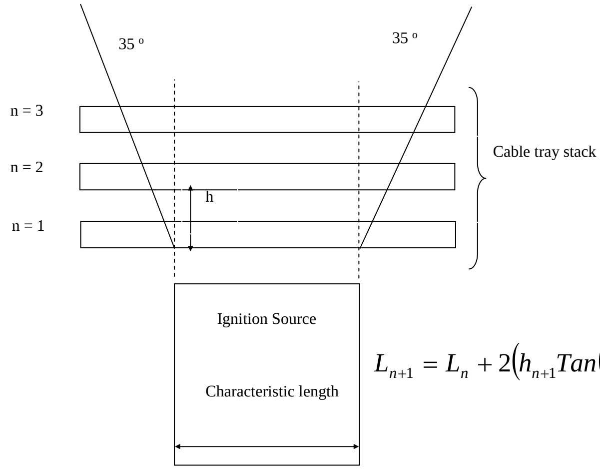
- Vertical spread in cables
- PE/PVC cables

Material	Bench Scale HRR [kW/m²]	Flame spread rate [mm/s]	Flame spread rate [ft/min]
PE/PVC	395	156	31
PE/PVC	359	137	27
PE/PVC	312	112	22
PE/PVC	589	258	52

- The heat release rate for XPE cable is 178 kW/m^2. Using these inputs, the estimated flame spread is 11 mm/sec (2 ft/min)



FIRE PROPAGATION IN CABLE TRAY STACKS WITH RG 1.75 SEPARATION (1 of 2)



$$L_{n+1} = L_n + 2\left(h_{n+1} Tan\left(35^o\right)\right)$$

FIRE PROPAGATION IN CABLE TRAY STACKS WITH RG 1.75 SEPARATION (2 OF 2)

- First tray to second tray: 4 minutes after ignition of first tray
- Second tray to third tray: 3 minutes after ignition of second first tray
- Third tray to fourth tray: 2 minutes after ignition of third tray
- Fourth tray to fifth tray: 1 minute after ignition of fourth tray
- Balance of trays in stack: 1 minute after ignition of fifth tray

FIRE PROPAGATION IN CABLE TRAY STACKS WITH RG 1.75 SEPARATION (2 OF 2) (cont'd)

- If there is a second stack of cable trays next to the first stack, spread to the first (lowest) tray in the second stack will be assumed to occur concurrent with spread of fire to the third tray in the original stack .
- Subsequent spread of fire in the second stack will mimic the continued growth of fire in the first stack (e.g., the second tray in the second stack will ignite within 2 minutes of the first tray in the second stack - at the same time as the fourth tray in the first stack.)
- Fire spread will occur at the same rate to stacks on either or both sides of the original stack

FIRE PROPAGATION IN CABLE TRAY STACKS Related FAQ

- FAQ 08-0049 (Status: Open)
  - Issue:
    - The cable fire empirical spread model (tray-to-tray, stack-to-stack) has been misapplied in pilot applications
    - Reviewers concluded that misapplication resulted in very conservative fire growth and risk results
  - General approach to resolution:
    - Clarify the bounds of the empirical model to avoid misapplication

HIGH ENERGY ARCING FAULTS (1 of 16)

Definition

- Rapid release of electrical energy in the form of heat, vaporized copper, and mechanical force.
- An arc is a very intense discharge of electrons between two electrodes that are carrying an electric current. The arc is created by the flow of electrons through charged particles of gas ions that exist as a result of vaporization of the conductive material.

HIGH ENERGY ARCING FAULTS (2 of 16)

Scope

- Switchgears
- Load centers
- Bus bars

} More than 440 V

- Oil filled outdoor transformers are addressed separately

HIGH ENERGY ARCING FAULTS (3 of 16)

General characteristics of HEAF events (from FEDB)

- Indications of heavy smoke in the area, which may delay identification of the fire origin and whether the fire is still burning.
- In nearly all of these events, the HEAF initiates in the feed breaker cubicle, because this is where most of the electrical energy in a high-energy cabinet resides.
- HEAFs occurring in 480V switchgears did not report damage beyond the switchgear itself, but some resulted in the cabinet opening.

HIGH ENERGY ARCING FAULTS (4 of 16)

General characteristics of HEAF events (from FEDB)

- Initial use of fire extinguishers may be ineffective in severe HEAF events regardless of the extinguishing agent (CO2, Halon, or dry chemical). The fires were eventually suppressed with water by the fire brigade.
- No conclusions can be made regarding the effectiveness of fixed fire suppression systems for the ensuing fire. Only one event was successfully suppressed, with an automatic Halon system.
- Durations of the fires involving HEAF range from minutes to over an hour. The short durations generally reflect events that do not result in large ensuing fire(s), either in the device itself or external fires.

HIGH ENERGY ARCING FAULTS (5 of 16)

General characteristics of HEAF events (from FEDB)

- Sustained fires after the initial HEAF involve combustible materials (cable insulation, for the most part) near the cabinet.
- Damage may extend to cables and cabinets in the vicinity of the high-energy electrical cabinet.
- Damage to cabinet internals and nearby equipment (if observed) appears to occur relatively early in the event.

HIGH ENERGY ARCING FAULTS (6 of 16)

The arcing or energetic fault scenario in these electrical devices consists of two distinct phases, each with its own damage characteristics and detection/suppression response and effectiveness.

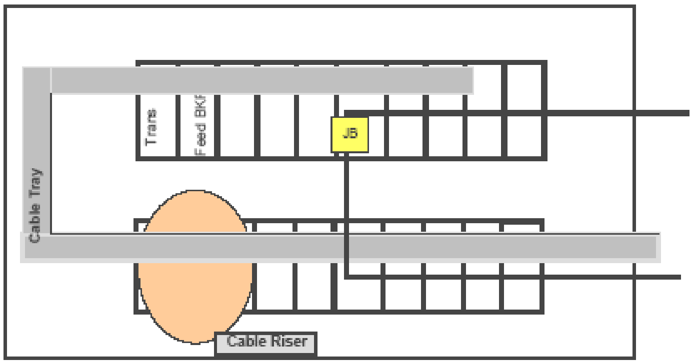
- The first phase is a short, rapid release of electrical energy followed by ensuing fire(s) that may involve the electrical device itself, as well as any external exposed combustibles, such as overhead exposed cable trays or nearby panels, that may be ignited during the energetic phase.

HIGH ENERGY ARCING FAULTS (6 of 16) (cont'd)

- The second phase, i.e., the ensuing fire(s), is treated similar to electrical cabinet fires described elsewhere in this procedure, with one distinction. Any closed electrical cabinet subject to a HEAF is opened to a fully ventilated fire. In dealing with postulated switchgear and load center fires, both phases should be considered.

HIGH ENERGY ARCING FAULTS (7 of 16)

The zone of influence



HIGH ENERGY ARCING FAULTS (8 of 16)

High-Energy Phase: The zone of influence

- The initial arcing fault will cause destructive and unrecoverable failure of the faulting device, e.g., the feeder breaker cubicle, including the control and bus-bar sections.
- The next upstream over-current protection device in the power feed circuit leading to the initially faulting device will trip open, causing the loss of all components fed by that electrical bus. This fault may be recoverable if the initial faulting device can be isolated from the feeder circuit.
- The release of copper plasma and/or mechanical shock will cause the next directly adjoining/adjacent switchgear or load center cubicles within the same cabinet bank and in all directions (above, below, to the sides) to trip open.

HIGH ENERGY ARCING FAULTS (9 of 16)

High-Energy Phase: The zone of influence

- Any unprotected cables that drop into the top of the panel in an open air-drop configuration will ignite.
  - Cables in conduit or in a fire wrap are considered protected in this context. In other words, if cables are protected (i.e., not exposed) by conduit or fire wrap, they are assumed damaged, but not ignited, and they do not contribute to the fire load.
  - Armored cables with an exposed plastic covering are considered unprotected in this context.
- Exposed cables, or other exposed flammable or combustible materials or transient fuel materials located within this same region (0.9 m (*3'*) horizontally) will be ignited.

HIGH ENERGY ARCING FAULTS (10 of 16)

High-Energy Phase: The zone of influence

- Any unprotected cables in the *first* overhead cable tray will be ignited concurrent with the initial arcing fault provided that this first tray is within 1.5 m (*5'*) vertical distance of the top of the cabinet. The cable tray fire will propagate to additional trays consistent with the approach provided for the treatment of cable tray fires elsewhere in this document, assuming that the time to ignition of the first tray is zero rather than the normal 5 minutes.
  - This applies to any cable tray located directly above the panel.
  - This applies to any cable tray above the aisle way directly in front of, or behind, the faulting cabinet, provided some part of that tray is within 0.3 m (12") horizontally of the cabinet's front or rear face panel.
  - Cables in conduit or in a fire wrap are considered protected in this context.
  - Armored cables with an exposed plastic covering are considered unprotected in this context

HIGH ENERGY ARCING FAULTS (11 of 16)

High-Energy Phase: The zone of influence

- Any vulnerable component or movable/operable structural element located within 0.9 m (*3'*) horizontally of either the front or rear panels/doors, and at or below the top of the faulting cabinet section, will suffer physical damage and functional failure.
  - This will *include* mobile/operable structural elements like fire dampers and fire doors.
  - This will *include* potentially vulnerable electrical or electromechanical components such as cables, transformers, ventilation fans, other cabinets, etc.
  - This will *exclude* fixed structural elements such as walls, floors, ceilings, and intact penetration seals.
  - This will *exclude* large components and purely mechanical components such as large pumps, valves, major piping, fire sprinkler piping, or other large piping (1" diameter or greater).
  - This may *include* small oil feed lines, instrument air piping, or other small piping (less than 1" diameter).

HIGH ENERGY ARCING FAULTS (12 of 16)

- In the case of bus ducts, the following equipment should be assumed damaged and/or ignited
  - The entire length of the bus duct.
  - Any cable (damage or ignition) or combustibles (ignition only) immediately adjacent to the bus duct.
  - Equipment connected to the bus duct.
  - If there are fire barriers along the length of the bus duct, these can be credited to limit damage and/or ignition. It may be assumed that the damage and/or ignition from a arcing fault in the bus duct is limited to one side of the fire barrier, except when analyzing multi-compartment fire scenarios that account for failure of the fire barrier(s).

HIGH ENERGY ARCING FAULTS (13 of 16)

Detection and Suppression

- The amount of smoke from any damaging HEAF event is expected to activate any smoke detection system in the area.
- Manual suppression by plant personnel and the fire brigade may be credited to control and prevent damage outside the initial ZOI from ensuing fires.
- Separate suppression curves are developed for these fires documented in Appendix P to the Fire Modeling procedure.

HIGH ENERGY ARCING FAULTS (14 of 16)

Modeling HEAF in the Fire PRA

- Identify the equipment in the room where a HEAF can be generated. As indicated earlier, this equipment includes, for the most part, 4160 V to 440 V switchgear cabinets, load centers, and bus bars.
- Two types of initiating events should be postulated for each identified equipment:
  - A HEAF event with an ensuing fire, and
  - A regular equipment fire (no HEAF).

HIGH ENERGY ARCING FAULTS (15 of 16)

Non-Suppression Probability and Severity Factors

- Assign a generic frequency for HEAFs listed in Task 6, and apportion it with the location and ignition source weighting factors to the equipment under analysis.
- Assume targets in the ZOI are damaged at time zero.
- The probability of no manual suppression for the targets in the ZOI is 1.0.
- The severity factor for a scenario consisting of targets in the ZOI only is 1.0.
- Probability of no automatic suppression for targets in the ZOI is 1.0
- The probability of no manual suppression for targets outside the ZOI can be calculated using the detection suppression event tree described in Appendix P, with the HEAF manual suppression curve.

HIGH ENERGY ARCING FAULTS (16 of 16)

Example

- Consider a HEAF scenario consisting of a switchgear cabinet affecting two targets. A stack of three cable trays is above the cabinet. The first tray in the stack is 0.9 m (3′) above the cabinet. It has been determined that one of the targets is in the first tray. The other target is in the third tray.
- According to the approach provided in Section M.3, the first target is assumed ignited at the time of the HEAF. The second target is damaged at time 7 minutes (4 minutes for fire propagation from the first to the second tray, and 3 minutes for fire propagation from the second to the third tray).
  - A scenario involving target in the first tray $CDF_i = \lambda_g \cdot W_L \cdot W_{is} \cdot CCDP_i$
  - A scenario involving the two targets $CDF_i = \lambda_g \cdot W_L \cdot W_{is} \cdot P_{ns} \cdot CCDP_i$

FIRE PROPAGATION TO ADJACENT ELECTRICAL CABINETS (1 of 3)

Analytical fire models may be used in all types of fire propagation and damage scenarios.

- This appendix discusses empirical approaches for determining:
  - Fire propagation to adjacent cabinets
  - Fire induced damage in adjacent cabinets
- Empirical approach based on SNL and VTT experiments

FIRE PROPAGATION TO ADJACENT ELECTRICAL CABINETS (2 of 3)

The empirical model for fire propagation consists of the following rules:

- Assume no fire spread if either:
  - Cabinets are separated by a double wall with an air gap, or
  - Either the exposed or exposing cabinet has an open top, *and* there is an internal wall, possibly with some openings, *and* there is no diagonal cable run between the exposing and exposed cabinet.
- If fire spread cannot be ruled out, or cabinets are separated by a single metal wall, assume that no significant heat release occurs from the adjacent cabinet for 10 minutes if cables in the adjacent cabinet are in direct contact with the separating wall, and 15 minutes if cables are not in contact with the wall.

FIRE PROPAGATION TO ADJACENT ELECTRICAL CABINETS (3 of 3)

The empirical model for fire damage consists of the following rules:

- Assume loss of function in an adjacent cabinet if there is not a double wall with an air gap.
- Assume no damage in the second adjacent cabinet occurs until after the fire propagates to the adjacent cabinet. Assume damage can occur earlier if there are large openings in a wall and plenum areas in which a hot gas layer is likely to form.
- Assume no damage to an adjacent cabinet if:
  - There is a double wall with an air gap, and
  - There are no sensitive electronics in the adjacent cabinet (or the sensitive electronics have been "qualified" above 82°C).
- Assume damage to sensitive electronics occurs at 10 minutes if there is a double wall with an air gap.
- Assume damage to sensitive electronics can be prevented before 10 minutes if the fire is extinguished and the cabinet is cooled, e.g., by CO_2 extinguishers.

PASSIVE FIRE PROTECTION FEATURES (1 of 6)

Most of the fire protection capabilities of passive fire protection features cannot be evaluated using analytical fire modeling tools.

- Empirical approaches
- Limited analytical approaches
- Probabilistic approaches

PASSIVE FIRE PROTECTION FEATURES (2 of 6)

Passive fire protection refers to fixed features put in place for reducing or preventing fire propagation. Some examples are:

- Coatings
- Cable tray barriers
- Fire stops

} Empirical approach

- Dampers
- Penetration seals

} Probabilistic approach

- Doors
- Walls

} Limited analytical approach

PASSIVE FIRE PROTECTION FEATURES (3 of 6)

The analytical approach for modeling the response of passive fire protection features to fire generated conditions consists of a heat transfer analysis.

- The boundary conditions are the fire generated conditions. In general, these consist of the heat flux exchanges at the surface of the passive feature.
  - Thermo-physical properties of the material are necessary. These properties are readily available for some materials like concrete or steel.
- Models can be used for estimating the temperature profile throughout the thickness of the barrier
- Effects of cracks and gaps in doors or walls should be evaluated only with the objective of analyzing smoke migration.

PASSIVE FIRE PROTECTION FEATURES (4 of 6)

The empirical approaches consist of replicating the thermal response of fire protection features observed in fire tests in the postulated fire scenarios.

- Coatings: SNL tests
  - The cable tray configurations included both a single cable tray and a two-tray stack. Exposure fires included either a gas burner or a diesel fuel pool fire.
- Assume coated, nonqualified cables will not ignite for at least 12 minutes, and coated, nonqualified cables will not be damaged for at least 3 minutes for large exposure fires, and for cable tray fires, more likely about 10 minutes.

Coating	Time to Ignition (min)	Time to Damage (min)
Lower Tray Response		
FlameMaster 71A	13	10
FlameMaster 77	13	6
Vimasco #1A	12	3
Carboline Intumastic 285	No	10
Quelcor 703B	12	11
Upper Tray Response		
FlameMaster 71A	No	11
FlameMaster 77	No	11
Vimasco #1A	12	7
Carboline Intumastic 285	No	19
Quelcor 703B	12	11

PASSIVE FIRE PROTECTION FEATURES (5 of 6)

The empirical approaches consist of replicating the thermal response of fire protection features observed in fire tests in the postulated fire scenarios.

- Cable tray barriers and fire stops: SNL tests (same configuration as coating tests)
- The following systems were tested:
  - Ceramic wool blanket wrap, solid tray bottom covers, solid tray top cover with no vents, solid tray bottom cover with vented top cover, one-inch insulating barrier between cable trays, and fire stops.
- Propagation of the fire to the second tray was prevented in each case.

PASSIVE FIRE PROTECTION FEATURES (5 of 6) (cont'd)

- Barriers seem to substantially delay cable damage for qualified cable. The barriers did not delay cable damage for nonqualified cable.

- Results considered most appropriate to exposure fires with smaller HRR and to cable trays in a stack threatened by fires in lower trays.
  - Each barrier prevents cable tray ignition until well after the fire brigade reaches the scene (i.e., greater than 20 minutes),
  - Each barrier prevents damage in *qualified* cable with solid tray bottom covers until well after the fire brigade reaches the scene.

PASSIVE FIRE PROTECTION FEATURES (6 of 6)

Probabilistic modeling of passive fire suppression systems

- Dampers: Equipment unavailability obtained from inspection results

- Penetration seals: Equipment unavailability obtained from inspection results

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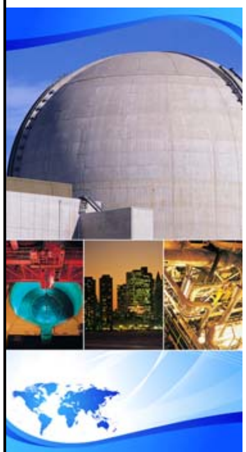


EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 11, Special Fire Models Part 2

Joint RES/EPRI Fire PRA Workshop
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Module III-11, Pt. 2: Special Models Part 2
Scope of this Module

- Module III-11, Pt. 2 covers the three remaining "Special Models"
  - Main Control Board Fires (Appendix L)
  - Turbine Generator (TG) Set Fires (Appendix O)
  - Hydrogen Fires (Appendix N)

Module III-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- The main control board (MCB) presents many analysis challenges
  - Design practices vary widely
    - Configuration of the boards themselves
    - Relay rack room versus main control room
    - Separation and partitioning within MCB
  - MCB may be important to risk, but IPEEE vintage approaches were identified as a weakness of those studies
  - Fire models cannot currently predict in-panel fire behavior, so an alternative approach is needed
- A method is provided to assess the likelihood that a fire in the MCB will grow large enough to damage a specific target set as defined by a specific physical region of the board

Module III-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

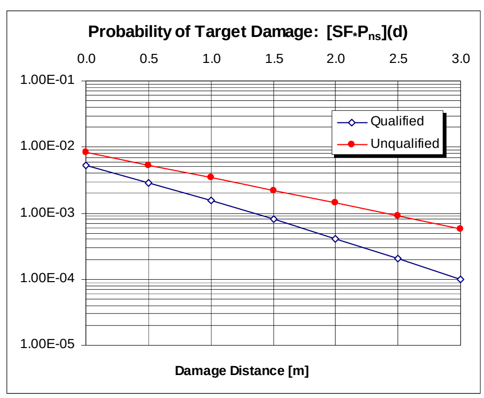
- The MCB model is built on several assumptions that are specific to the MCB and the MCR
  - MCB fire frequency partitioning approach
  - Suppression times for MCR fires
  - Fire characteristics of a MCR type control panel (peak HRR and growth profile)
  - Damage limits for control components
- This model applies ONLY to the MCB itself
  - Not intended for other electrical cabinets/panels
  - Not intended for MCR “back-panels”
  - Not intended for the relay room or other similar areas

Module II-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- To use the model you must first identify your target set
  - Example: two control switches on the MCB
- Determine the minimum separation distance between the most remote members of the damage set
  - Consider cable routing within the panel!
- Using this distance, go to the probability curve and estimate the conditional probability that given a fire somewhere in the MCB, the specific zone encompassing the target set will be damaged
- The resulting number includes BOTH the severity factor AND the probability of non-suppression
  - It does not include fire frequency!

Module III-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- Example:
  - Target set is two switches located 0.5 m apart from each other
  - Inspection shows that the cables leading to each switch are routed in opposite directions such that 2 ft is the minimum separation distance between the switches The MCB contains only IEEE-383 certified low-flame-spread cables
  - The conditional probability that a fire occurring somewhere in the MCB will damage the target set is approximately 3.0E-3



Main Control Room Fire Analysis

Step 8: Fire Growth . . . (cont'd)

A probabilistic model of fire spread in the main control board estimates the likelihood that a set of targets separated by a predetermined distance would be affected by a fire.

- Difficult to model fire spread within a cabinet using current state-of-the-art analytical tools.
- Probabilistic model based on EPRI's Fire Events Database and cabinet fire experiments reported in NUREG/CR-4527.
- The likelihood is a combination of severity factors and non-suppression probabilities

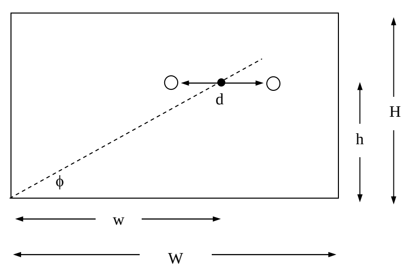
$$\lambda(d) = \lambda_{MCB}[SF \cdot P_{ns}](d)$$

Main Control Room Fire Analysis

Step 8: Fire Growth . . . (cont'd)

The likelihood is a combination of severity factors and non-suppression probabilities integrated over all possible fire events inside the panel that may damage the postulated target set.

- All possible fire origin locations



$$\lambda(d) = \lambda_{MCB}[SF \cdot P_{ns}](d)$$

$$[SF \cdot P_{ns}](d) = \frac{1}{H \cdot W}\int_0^H \int_0^W SF(d,w,h) \cdot P_{ns}(d,w,h)\,dw\,dh$$

Module II-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires

- Four types of fires can occur involving the turbine generator set, and each is treated differently:
  - Electrical fires in the exciter
  - Hydrogen fires:
  - General oil fires
  - Catastrophic failure (e.g., blade ejection)

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Exciter Fires

- Exciter fires do occur, but all evidence indicates fires remain small and non-threatening
  - No evidence of any exciter fire that led to damage to anything other than the exciter itself
  - No attempt was made to estimate likelihood of a severe exciter fire (one that challenges external targets)
- Recommended Practice:
  - Assume exciter fires remain confined to the exciter
  - Verify for your application, but should not represent a significant risk contributor

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Hydrogen Fires

- Database shows 13 TG set hydrogen fires, two categorized as severe, the rest were fires due to small leaks (generally associated with seals) with limited damage range
- For small fires:
  - Assume damage will be limited to within a few feet of the point of release
  - Secondary ignitions should be considered and treated if there are nearby combustibles
  - See more in Hydrogen Fires discussion (Appendix N)

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Hydrogen Fires

- For severe fires, widespread damage may occur due to an explosion or detonation of the hydrogen gas.
  - Assume fire may damage all Fire PRA cables and equipment within the line of site of the generator and its bearings (including above and below)
  - Hydrogen explosion could cause some structural damage as well
  - For further discussion – see Hydrogen Fires

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Catastrophic Failure

- International experience includes a few fires initiated by catastrophic turbine failure that resulted in widespread damage including structural damage
  - Examples: Vandellos (1989), Narora (1993), Chernobyl Unit 2 (1991)
  - Events involved a combination of turbine blade ejection, hydrogen release, and large oil fires.
- Domestically, only one event came close to involving all of these elements (Salem, 1991)
  - Event involved minor damage due to existence of an automatic suppression system and prompt fire brigade response
  - Indicates that both automatic fire suppression systems and fire brigade should be credited to prevent catastrophic consequences observed internationally

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Catastrophic Failure

- Screening approach: assume the *conditional probability* that, given a T/G set fire, the event will involve catastrophic failure (e.g., blade ejection), hydrogen, and oil fires is:

  1 over 38 events or 0.025

  - With *successful* suppression, damage would be limited to the T/G system, as was the case at Salem
  - In case of failure of all suppression, automatic and manual, assume loss of all Fire PRA cables and equipment in the Turbine Building
    - Possible failure of exposed structural steel as well
  - Estimate screening CDF contribution, refine as appropriate

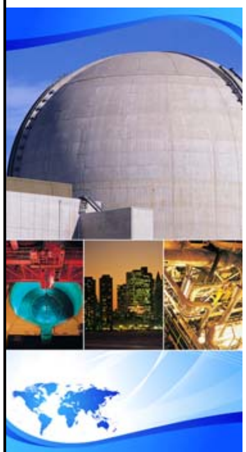
Module III-11, Pt. 2: Special Models Part 2
Hydrogen Fires

- This discussion (Appendix N) applies to general hydrogen fires
  - Including TG set fires
  - Also fires from other sources of hydrogen leaks and releases (e.g., recombiners, storage tanks, piping, etc.)
- The intent was to provide general discussion of hydrogen fires and their potential effects
- The discussion stops short of recommending modeling approaches, but does provide references to various information resources

Module III-11, Pt. 2: Special Models Part 2
Hydrogen Fires

- Two general types of fires:
  - Jet fires originating at point of a H_2 leak
    - Critical question will be flame length
  - Explosions
    - If there is a mechanism for the release of large quantities of H_2 (e.g., a large leak, a prolonged leak that might not be ignited early), then likelihood of a hydrogen explosion is high
    - References provide additional resources for assessing damage potential for an explosion scenario
    - Critical question will be the severity of the overpressure

EPRI/NRC-RES FIRE PRA METHODOLOGY



Module III
Detection and Suppression
Appendix P

Joint RES/EPRI Fire PRA Course

June 2009

Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

DETECTION & SUPPRESSION
Objectives

The objectives of this module are:

- Describe the process for calculation the non-suppression probability
- Describe the assumptions underlying the recommended approach for determining the non-suppression probability.

DETECTION & SUPPRESSION
Generalities

State of the art fire models do not have the capabilities of modeling the effects of all the different fire detection and suppression strategies available in NPP fire scenarios.

- Time to target damage and non suppression probabilities are independent calculations
- The time to target damage is an input to the detection/suppression analysis

DETECTION & SUPPRESSION
Crediting a Fire Det or Supp System

Detection and suppression systems can be credited in the fire PRA if they are effective and available

- Effectiveness – Will the system detect/control the fire?
  - Designed, installed and maintained according to the code of record and fire protection engineering judgment
  - Based on the specific characteristics of the postulated fire scenario
- Available – Probability of the system operating upon demand

DETECTION & SUPPRESSION
Fire Detection and Suppression Systems

The following fire detection and suppression systems are considered in the recommended approach:

- Fire Detection
  - Prompt detection
  - Automatic detection
  - Delayed detection
- Fire Suppression
  - Prompt suppression
  - Automatic suppression
  - Manually actuated fixed suppression
  - Manual suppression

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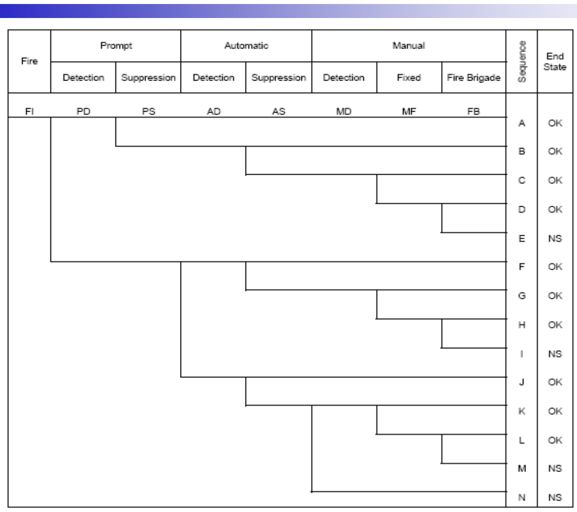
DETECTION & SUPPRESSION
Detection-Suppression Event Tree



$$P_{ns} = E + I + M + N$$

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Module III: Detection and Suppression Appendix P

Slide 6

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DETECTION & SUPPRESSION
Detection-Suppression Event Tree

Sequence	Detection	Suppression
A	Prompt detection by	Prompt suppression
B	• Continuous fire watch	Fire suppression by an automatically actuated fixed system
C	• Continuously occupied	Fire suppression by a manually actuated fixed system
D	• High sensitivity detectors	Fire suppression by the fire brigade
E		Fire damage to target items
F	Automatic detection by	Fire suppression by an automatically actuated fixed system
G	• Heat detectors	Fire suppression by a manually actuated fixed system
H	• Smoke detectors	Fire suppression by the fire brigade
I		Fire damage to target items
J	Delayed detection by	Fire suppression by an automatically actuated fixed system
K	• Roving fire watch	Fire suppression by a manually actuated fixed system
L	• Control room verification	Fire suppression by the fire brigade
M		Fire damage to target items
N	Fire damage to target items	

DETECTION & SUPPRESSION
Prompt Detection and Suppression

- Prompt detection
  - Assume 1.0 if a continuous fire watch is credited or in-cabinet detection is available for fires postulated inside cabinets
  - Justify the use of 1.0 if an incipient fire detection system is available
  - Assume 0 if automatic or delayed detection only are credited
- Prompt suppression
  - Credit prompt suppression in hot work fire scenarios
  - Probability is obtained from the welding suppression curve

DETECTION & SUPPRESSION
Automatic Detection and Suppression

- Automatic detection
  - Assume a probability of failure no larger than 0.05. This the unreliability for halon systems reported in NSAC 179L.
  - Check for availability!

- Automatic suppression (from NSAC 179L)
  - Halon systems = 0.05
  - CO_2 systems = 0.04
  - Wet pipe sprinklers = 0.02
  - Deluge or pre-action = 0.05
  - Check for availability!

DETECTION & SUPPRESSION
Delayed Detection and Suppression

- Delayed detection
  - Assume 1.0 – All fires will eventually be detected
  - Compare time to target damage Vs time to detection and suppression

- Delayed suppression
  - Probability of fire brigade suppression is obtained from the suppression curves
  - Manual actuation of fixed fire suppression systems should include human reliability analysis.

DETECTION & SUPPRESSION
Detection - Related FAQ

- FAQ 08-0046 Incipient Detection (Status: Open)
  - Issue:
    - Methodology provides no approach for crediting incipient fire detection systems
  - General approach to resolution:
    - Develop an approach that would credit these systems

DETECTION & SUPPRESSION
Suppression Curves

The suppression curves were developed using FEDB data after 1/1/81

- Developed with the "suppression time" field. If the suppression time was not available, the "duration" field was used.
- Data do not include supervised burn-outs, fires suppressed with automatic systems, and self-extinguished fires.
- Do not include time to detection or fire brigade response.

DETECTION & SUPPRESSION
Suppression Curves – Related FAQ

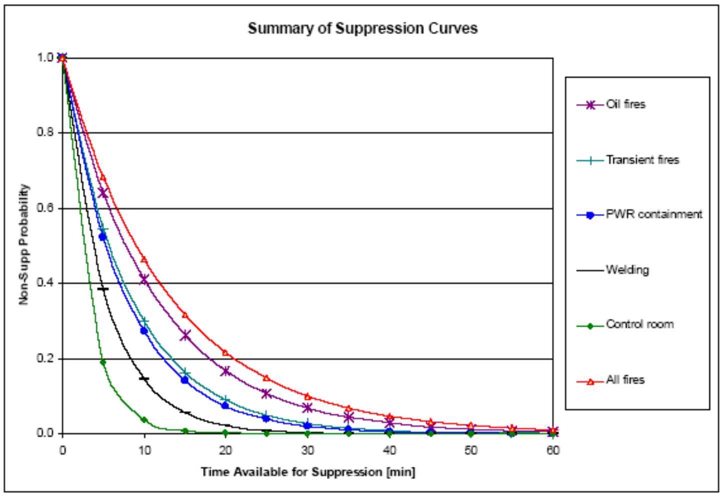
- FAQ 08-0050 Fire Brigade Response (Status: Open)
  - Issue:
    - The fire non-suppression curves as cited as reflecting suppression performance *after* fire brigade response time but a significant fraction of the duration data used in curves includes brigade response time
    - Fire brigade may not be getting adequate credit for suppressing fires prior to damage
  - General approach to resolution:
    - EPRI team has reviewed data and proposed an alternative set of non-suppression curves that would include fire brigade response time

DETECTION & SUPPRESSION
Selection of Suppression Curves

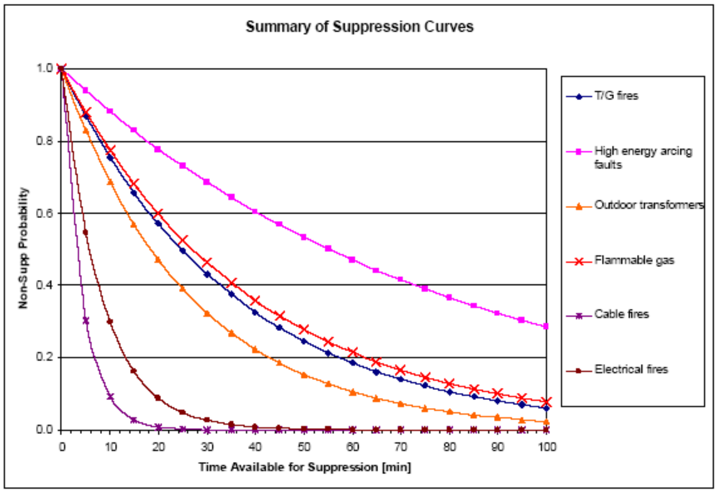
The suppression curve should be selected based on the type of postulated fire.

- For prompt suppression by a welding fire watch, use the welding suppression curve
- If the fire watch is not successful, an appropriate suppression curve should be selected depending on the combustibles ignited due to hot work activities.

DETECTION & SUPPRESSION
Suppression Curves



DETECTION & SUPPRESSION
Suppression Curves



DETECTION & SUPPRESSION
Suppression Curves

$$P = e^{-\lambda\left[t_{dam} - \left(t_{\det} + t_{brig}\right)\right]}$$

Suppression curve	n	T	Mean	5th Percentile	50th Percentile	95th Percentile
T/G fires	21	749	0.03	0.02	0.03	0.04
Control room	6	18	0.33	0.15	0.32	0.58
PWR containment	3	23	0.13	0.04	0.12	0.27
Outdoor transformers	14	373	0.04	0.02	0.04	0.06
Flammable gas	5	195	0.03	0.01	0.02	0.05
Oil fires	36	404	0.09	0.07	0.09	0.11
Cable fires	5	21	0.24	0.09	0.22	0.44
Electrical fires	114	942	0.12	0.10	0.12	0.14
Welding fires	19	99	0.19	0.13	0.19	0.27
Transient fires	24	199	0.12	0.08	0.12	0.16
High energy arcing faults	3	239	0.01	0.00	0.01	0.03
All fires	250	3260	0.08	0.07	0.08	0.08

DETECTION & SUPPRESSION
Dependencies

The following dependencies in suppression analysis could be important:

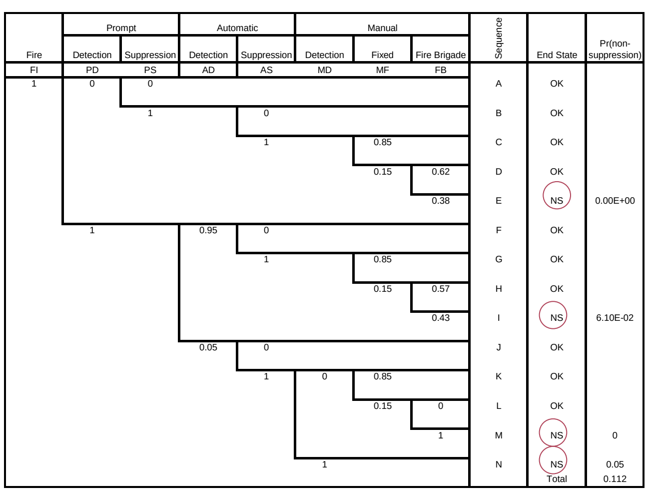
- Between automatic detection and suppression
  - Example: control panel for a gaseous suppression system
- Between actuated barriers and fire suppression systems
- Between safe shutdown capabilities and automatic suppression
  - Example: crediting fire fighting water for core injection, heat removal or secondary heat removal
- Between manual and automatic suppression

DETECTION & SUPPRESSION
Example

The scenario consists of an MCC fire affecting a target in the hot gas layer.

- The room is equipped with a smoke detection system and a manually activated fire suppression system
- Using fire modeling
  - Time to smoke detection = 1 min
  - Time to target damage = 15 min
- From fire drill records and/or plant procedures
  - Brigade response time = 7 min
  - Time to manually actuate the suppression system will not be less than 10 min
  - Time to delayed detection is assumed to be 15 min

DETECTION & SUPPRESSION
Example



- Time available for supp:
  - 15-1-7 = 7 min
- Using the electrical curve
  - P = EXP(-0.12x7)
  - P = 0.43
- Failure of gaseous supp system:
  - P = 0.05 + 0.1

$$P_{ns} = E + I + M + N$$

$$P_{ns} = 0.112$$

DETECTION & SUPPRESSION
Concluding Remarks

The non-suppression probability is credited in Task 11, detailed fire modeling

- Target damage is evaluated assuming no detection/suppression capabilities in the room
- The time to target damage is an input to the detection and suppression analysis.
- The recommended approach includes an event tree capturing prompt, automatic, and delayed detection and suppression capabilities
- The event tree may need to be modified depending on the scenario

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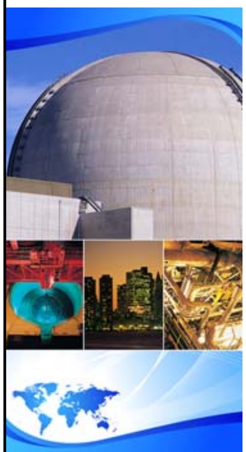


EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 11a: Detailed Fire Modeling and Single Compartment Fire Scenarios

Joint RES/EPRI Fire PRA Course
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Module II-10: TOPICS

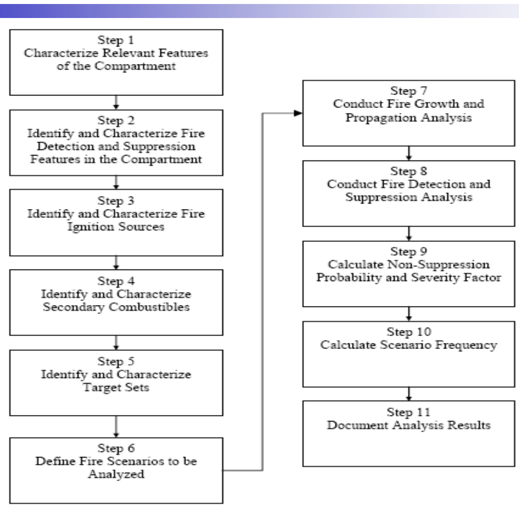
The objectives of this module are:

- Describe the process of fire modeling for a single fire compartment
- The outcome of this activity is the extent and timing of fire damage within the compartment

Module II-10: FIRE MODELING
Role and Scope

- **Fire modeling:** An approach for predicting various aspects of fire generated conditions
  - Requires idealization and/or simplifications of the physical processes involved
  - Departure of the fire system from this idealization can affect the accuracy and validity
- **Fire scenario:** A set of elements representing a fire event
  - Fire source/initiation
  - Fire growth
  - Fire propagation (room heating, HEAF, intervening combustibles, etc.)
  - Active fire protection features, e.g., detection/suppression
  - Passive fire protection features, e.g., fire stops
  - Target sets (cables), habitability, etc.

Module II-10: PROCESS
General Task Structure



Module II-10: PROCESS
Characterize Fire Compartment

- Information on compartment geometry that can impact fire growth
  - Size and shape, e.g., ceiling soffit or beam pocket
  - Boundary construction and material
  - Ventilation
- Fire protection systems and features
  - Fixed detection systems
  - Fixed fire suppression systems, water or gaseous
  - Manual detection
  - Fire brigade
  - Internal fire barriers and stops, e.g., ERFBS
- Problem 11a-01, 11a-02

Module II-10: PROCESS
Identify/Characterize Fire Sources

- Location within the compartment, type, size, initial intensity, growth behavior, severity/likelihood relationship, etc.
- Estimate frequency of ignition for the ignition source.
- Example of fire events involving typical ignition sources
  - Oil or liquid spill fires (Characterization described in Appendix G)
  - Oil or flammable liquid spray fires (Characterization described in Appendix G)
  - General fires involving electrical panels (Characterization described in Appendices G, L & S)
  - High energy arcing faults events (Characterization described in Appendix M)
  - Cable fires (Characterization described in Appendix R)
  - Hydrogen fires (Characterization described in Appendix N)
  - Transient fuel materials (Characterization described in Appendices G & S)
- Problem 11a-03

Module II-10: PROCESS
Identify/Characterize Secondary (intervening) Combustibles

- May include,
  - Overhead raceways,
  - Cable air-drops,
  - Stored materials,
  - Electrical panels,
  - Construction materials, etc.
- The information provided should describe
  - Relative proximity of the secondary combustibles to the fire ignition source
  - Configuration of the secondary combustible.
- Example problem on step 4

Module II-10: PROCESS
Identify/Characterize Target Sets

- Each target set should be a subset of the fire PRA components and circuits (i.e., cables) present in the compartment.
  - Target sets associated to PRA components can be identified by examining the associated CCDP, once damaged component failure probabilities are set to 1.0.
  - Those subgroups with very small CCDP may be ignored as insignificant contributors to fire risk.
  - Check for possibility of spurious actuations due to cable fires inside the compartment under analysis. Spurious actuations may generate the need of evaluating important scenarios.
- Fire modeling should have information on target location within the compartment available.
  - If complete routing information is not available, the analyst must justify target selection process and the corresponding impacts in the Fire PRA model.
  - Routing by exclusion OK (from a compartment, from a set of raceways…)
- Identify failure modes of equipment due to fire damage to the equipment or associated circuits.
- Example problem on Step 5

Module II-10: PROCESS
Select Fire Scenarios

- Fire scenarios should take the following into consideration:
  - Selected scenarios should reflect the objective of fire modeling, in this case impacting the components and circuits of interest to safety
  - Selected scenarios should represent a complete set of fire conditions that are important to the objective
  - Selected scenarios should challenge the conditions being estimated, e.g., scenarios that challenge habitability if manual action is of interest
  - The list of postulated fire scenarios should include those involving fixed and transient ignition sources

Module II-10: PROCESS
Select Fire Scenarios (cont'd)

- Approach to selection of fire scenarios is highly dependent on fire compartment hazard profile, i.e., location and amount of fire source and combustibles and the location and number of potential targets. In general,
  - In compartments with few fire sources and many target sets (e.g., a switchgear room), start with an ignition source, postulate potential growth and propagation to other combustibles and then postulate damage to the closest target set that may be exposed to the specific fire
  - In compartments with many fire sources and few potential targets (e.g., a PWR turbine building), start with potential target sets
  - In compartments with many fire sources and many potential targets (e.g., a PWR auxiliary building),
    - Nearby source/target combinations, and
    - Always include that fire scenario most likely (all factors considered) to cause wide-spread damage (may be driven by fire source characteristics, fire spread potential, or by fire protection systems and features)
- Workshop problem 11a-04

Module II-10: PROCESS
Conduct Fire Growth and Propagation

- Select fire modeling tool depending on the characteristics of each scenario
  - Empirical rule sets
  - Hand calculations
  - Zone models
  - Field models
- Analyze fire growth and spread to secondary combustibles
- Estimate resulting environmental conditions
- Estimate time to target set damage
- Workshop problem 11a-05 to 11a-08

Module II-10: PROCESS
Hand Calcs – NUREG 1805

02.1_Temperature_NV.xls
02.2_Temperature_FV.xls
02.3_Temperature_CC.xls
03_HRR_Flame_Height_Burning_Duration_Calculation.xls
04_Flame_Height_Calculations.xls
05.1_Heat_Flux_Calculations_Wind_Free.xls
05.2_Heat_Flux_Calculations_Wind.xls
05.3_Thermal_Radiation_From_Hydrocarbon_Fireballs.xls
06_Ignition_Time_Calculations.xls
07_Cable_HRR_Calculations.xls
08_Burning_Duration_Soild.xls
09_Plume_Temperature_Calculations.xls

09_Plume_Temperature_Calculations.xls
10_Detector_Activation_Time.xls
13_Compartment_ Flashover_Calculations.xls
14_Compartment_Over_Pressure_Calculations.xls
15_Explosion_Claculations.xls
16_Battery_Room_Flammable_Gas_Conc.xls
17.1_FR_Beams_Columns_Substitution_Correlation.xls
17.2_FR_Beams_Columns_Quasi_Steady_State_Spray_Insulated.xls
17.3_FR_Beams_Columns_Quasi_Steady_State_Board_Insulated.xls
17.4_FR_Beams_Columns_Quasi_Steady_State_Uninsulated.xls
18_Visibility_Through_Smoke.xls

Module II-10: PROCESS
Hand Calcs – NUREG 1805

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0 (SI Units)

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS **SI UNITS**

COMPARTMENT INFORMATION

Compartment Width (w_c)	17.40	m	57.09 ft
Compartment Length (l_c)	14.40	m	47.24 ft
Compartment Height (h_c)	4.00	m	13.12 ft
Vent Width (w_v)	1.00	m	3.28 ft
Vent Height (h_v)	2.00	m	6.56 ft
Top of Vent from Floor (V_T)	2.00	m	6.56 ft
Interior Lining Thickness (□)	0.60	m	23.62 in

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	20.00	°C	68.00 °F 293.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (□$_a$)	1.20	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Interior Lining Thermal Inertia (k□c)	2.9	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K
Interior Lining Specific Heat (c)	0.75	kJ/kg-K
Interior Lining Density (□)	2400	kg/m³

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	k□c $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	□ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

Select Material
Concrete
Scroll to desired material then Click the selection

FIRE SPECIFICATIONS

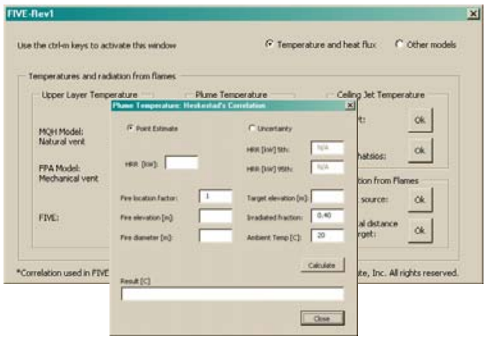
Fire Heat Release Rate (Q) 200.00 kW

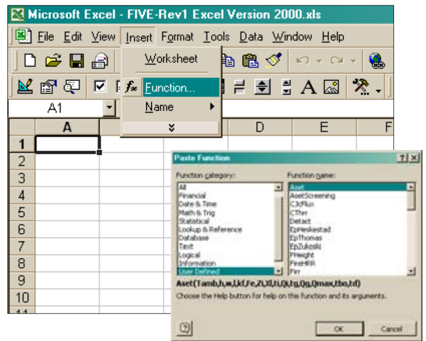
Calculate

Module II-10: PROCESS
Hand Calcs – FIVE-Rev1

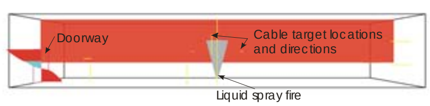
- More than ten years after FIVE, most of the equations are still considered "State-of-the-Art"
- A revision of the quantitative fire hazard techniques in FIVE
- Most of the hand calculations in the original EPRI publication and some other models available in the fire protection engineering literature
  – 4 stage heat release rate profile based on t^2 growth
  – Heskestad's flame height model
  – A radiation model from a cylindrical flame to targets
  – Models for velocity of plume and ceiling jet flows
  – Model for plume diameter as a function of height
  – MQH model for room temperature
  – Model for visibility through smoke

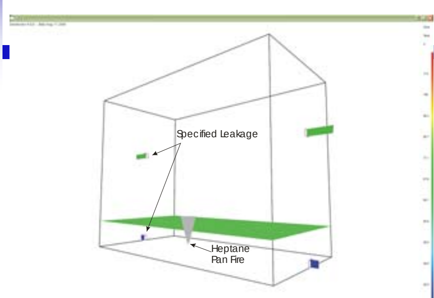
Module II-10: PROCESS
Hand Calcs – FIVE-Rev1

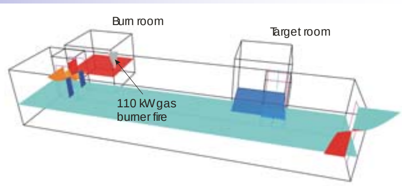


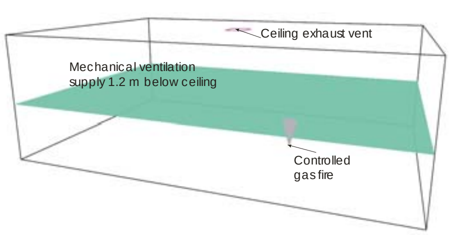


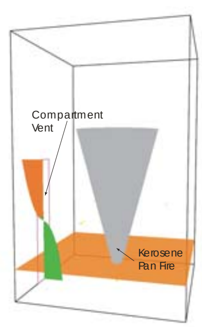
CFAST



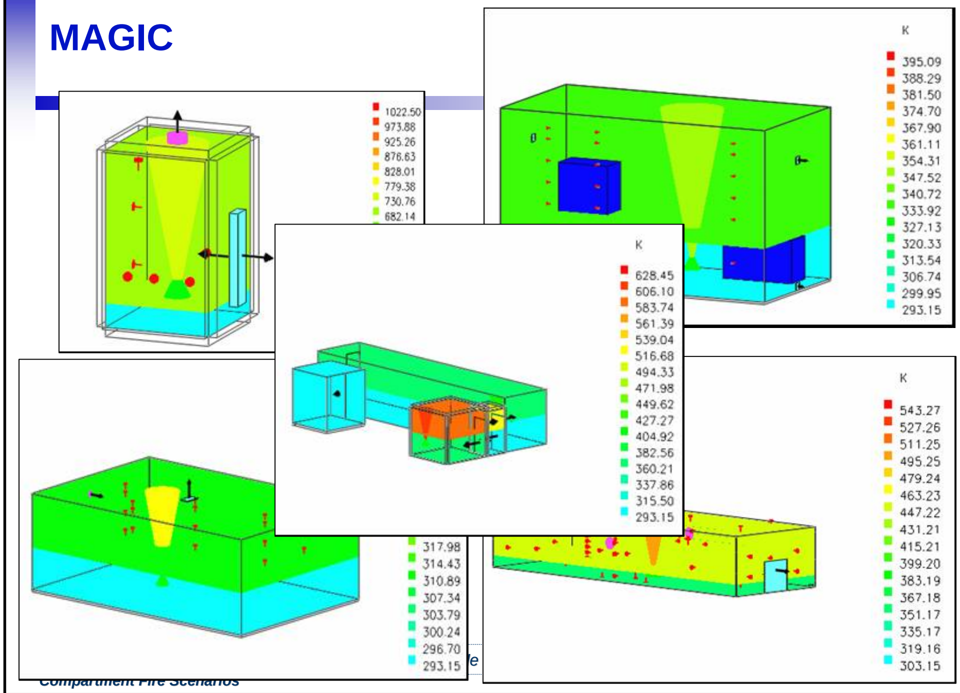




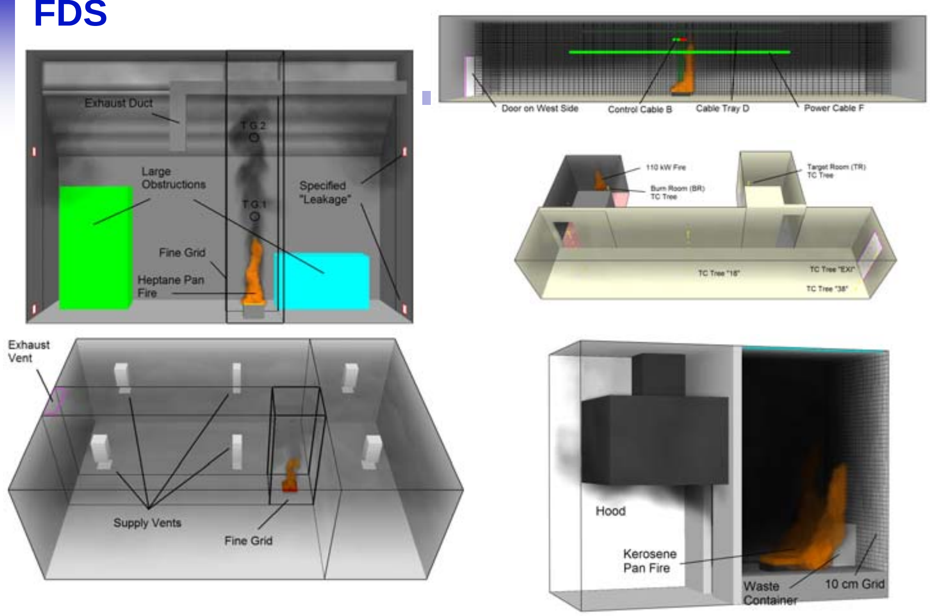




MAGIC


1022.50
973.88
925.26
876.63
828.01
779.38
730.76
682.14
K
395.09
388.29
381.50
374.70
367.90
361.11
354.31
347.52
340.72
333.92
327.13
320.33
313.54
306.74
299.95
293.15
K
628.45
606.10
583.74
561.39
539.04
516.68
494.33
471.98
449.62
427.27
404.92
382.56
360.21
337.86
315.50
293.15
317.98
314.43
310.89
307.34
303.79
300.24
296.70
293.15
K
543.27
527.26
511.25
495.25
479.24
463.23
447.22
431.21
415.21
399.20
383.19
367.18
351.17
335.17
319.16
303.15

FDS


Exhaust Duct
T.G.2
T.G.1
Large Obstructions
Specified "Leakage"
Fine Grid
Heptane Pan Fire
Door on West Side
Control Cable B
Cable Tray D
Power Cable F
110 kW Fire
Burn Room (BR) TC Tree
Target Room (TR) TC Tree
TC Tree "18"
TC Tree "EXI"
TC Tree "38"
Exhaust Vent
Supply Vents
Fine Grid
Hood
Kerosene Pan Fire
Waste Container
10 cm Grid

Module II-10: PROCESS
Fire Detection/Suppression Analysis

- Assess fire detection timing
- Assess timing, reliability, and effectiveness of fixed fire suppression systems
- Assess manual fire brigade response
- Estimate probability of fire suppression as a function of time
- Workshop problem 11a-09

Module II-10: PROCESS
Calculate Severity Factor

- The time to target damage, and as a result the non-suppression probability, is a function of the postulated heat release rate
- The severity factor should be calculated in combination with the non-suppression probability
- Workshop problem 11a-10, 11a-11

Module II-10: PROCESS
Calculate Fire Scenario Frequency

Severity factor for scenario k

$$\lambda_k = \lambda_{i,k} \cdot \int SF_k \cdot P_{ns,k}$$

Ignition frequency for scenario k

Integrated over all HRRs

Non-suppression probability for scenario k

Module II-10: PROCESS
Document Analysis Results

- The first tier documentation should be sufficient in detail to allow for an independent reader to understand
  - Scenarios postulated, the basis for their selection and analysis,
  - The tools utilized in the analysis and basis for selection,
  - The final results of the analysis
- The second tier documentation should provide the details of each individual analysis performed including:
  - Details of scenario selection process,
  - The fire modeling analyses performed
- All specific considerations and assumptions should be recorded clearly.

Workshop Problems on Task 11a: Detailed Fire Modeling

This handout includes workshop problems on the different steps of Task 11: Detailed Fire Modeling. Problems are grouped according to the steps defined in NUREG/CR-6850. Detailed fire modeling will be conducted in the switchgear access room (Room 9) located in elevation 20 ft of the auxiliary building.

Workshop Problem Set 11a-01

***Step 1a: Identify and Characterize Compartments*:** Review the following information necessary for fire modeling purposes.

- Room size: For the purpose of this exercise, assume the size of the room is 45’ by 22’ by 20’ high.
- Wall boundaries: The surfaces, floor, ceiling, and walls are reinforced concrete. All the surfaces are 2’ thick.
- Doors: The room has three doorways: 1) a double door connecting to switchgear room A, 2) a double door connecting to switchgear room B, and 3) a single door connecting to the stairwell. The size of a single door is 6.5’ by 3’.
- Mechanical Ventilation: The switchgear access room has a mechanical ventilation system with a balance 5 air changes per hour.

Workshop Problem Set 11a-02

***Step 2a: Identify and Characterize fire Detection and Suppression Features and Systems*:** Review the following information necessary for fire modeling purposes.

- Prompt detection: Prompt detection is not credited since there is no incipient fire detection system in the room and no continuous fire watch.
- Prompt suppression: Prompt suppression is not credited since there is no continuous fire watch in the room.
- Fixed fire detection system/s (type, and sensor location): An automatic fire detection system is credited since the room is equipped with an automatic fire detection system. The location of the relevant detectors is specified in the corresponding scenario descriptions later in this document.
- Fixed fire suppression system/s (type and nozzle location): An automatic CO_2 system is credited since the room is equipped with an automatic CO_2 system. Upon smoke detection alarm, a timer starts providing 60 seconds delay for life safety purposes. The CO_2 is released after the delay time. The soak time is approximately 20 min.
- Fire brigade arrival time: The fire brigade arrival time is assumed to be 15 min.
- Delayed detection: Delayed detection is credited and assumed to be 15 minutes (consistent with the example in page P-14 of NUREG/CR-6850).

Workshop Problem Set 11a-03

Step 3a: Characterize Fire Ignition Sources: From the Task 6 (Fire Ignition Frequencies) calculation package, list the fixed ignition sources located in the switchgear access room (room 9) and assign a heat release rate probability distribution to each of them from Table G-1 of NUREG/CR-6850.

Solution: Table 1 lists the recommended answer to workshop problem 3.

Table 1: Summary of ignition source characteristics in the switchgear access room.

Equipment ID	Equipment Description	Case (Table E-1 of NUREG/CR-6850)	HRR Profile (Page G-6 in NUREG/CR-6850)
MCC-A1			
MCC-B1			
VITAL-A			
VITAL-B			
Transients			

Step 4a: Identify Secondary Combustibles: No workshop problem is associated with this step. The following discussion provides an example of how to identify and characterize secondary combustibles.

<u>Sample Analysis for Step 4a:</u>
For the purpose of this example, let's assume that there is one cable tray stack above each cabinet in the room. Each stack has two trays. The first tray is 1' above each cabinet. The second tray in the stack is 1.5' above the first tray. The trays are ladder-back. A pictorial representation of the secondary combustibles in provided in Figure 1.

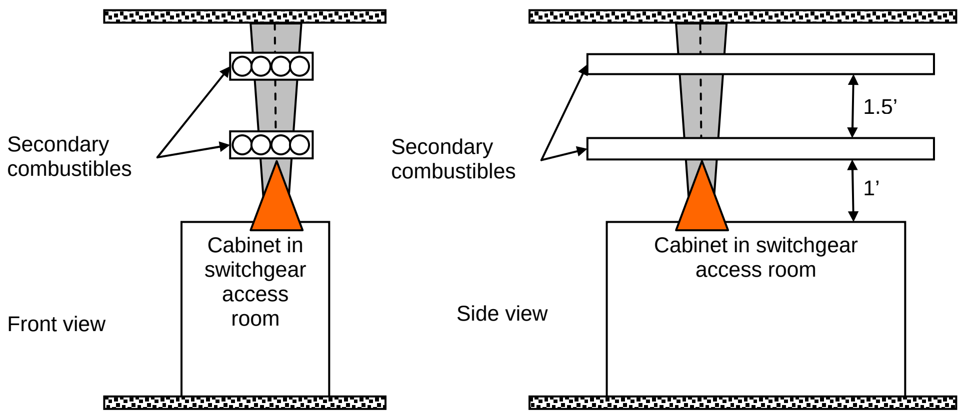


Figure 1: Pictorial representation of the secondary combustibles. Drawing not to scale.

From Table 1, the cabinets in the switchgear access room will have a peak heat release rate of 211 kW. Heskestad's flame height correlation (Chapter 3 of NUREG 1805) suggests a flame height of approximately 4.6' above the ignition source. Therefore, the cable tray stack above the cabinet is expected to ignite and contributing to the fire intensity. Table 2 lists the Heskestad's flame height correlation analysis.

Table 2: Heskestad's flame height correlation analysis.

Heskdestad's Flame Height Correlation	
Inputs	
Fire diameter [m]	0.6
HRR [kW]	211
Results	
Flame height [m]	**1.4**
Flame height [ft]	**4.6**

Step 5a: Identify and Characterize Target Sets: No workshop problem is associated with this step. The following discussion provides an example of how to identify and characterize target sets. In practice, this step requires highlighting of cable tray and conduit targets in room layout drawings based on cable routing analysis and plant walkdowns.

<u>Sample Analysis for Step 5a:</u>
For the purpose of this exercise, let's assume that there are two target sets in the room: 1) HCBT-35A and HCBT-35B, and 2) VCBT-20A, and VCBT-20B.   These trays are identified in Figure 2. The trays have both thermo-set and thermo-plastic cables. Specifically, a fire damaging either the two horizontal trays or the two vertical trays will generate the postulated plant condition.

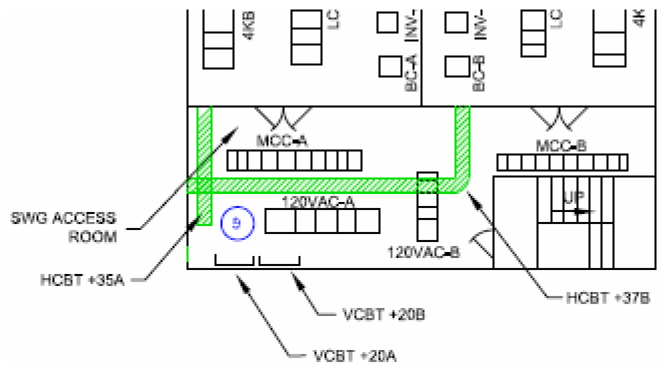


Figure 2: Cable tray locations in the switchgear access room

Tray locations:

- HCBT 35A: This horizontal tray comes into the switchgear access room from switchgear room A.   The tray is the second tray in an elevated stack. The lowest tray in the stack is at elevation 33' (13' from the floor). The target tray, HCBT 35A, is at elevation 35' (15' ft from the floor and 2' above the lowest tray in the stack).

- HCBT 37B: This horizontal tray comes in the south direction into the switchgear access room from switchgear room B and turns west.   The tray is the first tray in an elevated stack. It is located at elevation 37' (17' from the floor). At the point the cable tray crosses HCBT 35A, it is the third tray in the stack.

- VCBT 20A: This is a vertical cable tray in the south west corner of the room. The tray comes into the room through a floor penetration at elevation 20' and runs up to the ceiling.

- VCBT 20B: This is a vertical cable tray in the south west corner of the room. The tray comes into the room through a floor penetration at elevation 20' and runs up to the ceiling.

Workshop Problem 11a-04

Step 6a: Define the Fire Scenarios to be Analyzed: Define the fire scenarios to be analyzed in the switchgear access room using the information provided or collected in the first five steps.

- Fixed ignition source fire scenarios:

Solution:

- Transient ignition source fire scenarios:

Solution:

Step 7a: Conduct Fire Growth and Propagation Analysis: For the purpose of this workshop, only two of the fire scenarios listed in the previous section are analyzed in detail: Scenario 1, and Scenario 4.

Workshop Problem 11a-05:

Determine if a fire in the ignition sources associate with scenarios 1 and 4 can produce room wide damage in the switchgear access room. If the ignition sources alone are not expected to generate room wide damage, determine the amount of secondary combustibles necessary to achieve it.

Solution:

Workshop Problem 11a-06

Determine the time to target damage, time to smoke detection, time to automatic suppression and the fire brigade arrival time for scenario 1.

Solution:

Workshop Problem 11a-07

Determine the time to target damage, time to smoke detection, time to automatic suppression and the fire brigade arrival time for scenario 4.

Solution:

Workshop Problem 11a-08

Let's assume that MCC-A1, which is the ignition source in scenario 1 it's a 4160V switchgear. In this case, a high energy arcing fault event should be also postulated and evaluated. Determine if the cable tray targets will be within the zone of influence of a high energy arcing fault.

Solution:

Step 8a: Conduct Fire Detection and Suppression Analysis*:* The detection and suppression is reflected in the risk analysis with the non-suppression probability, which is calculated using a Detection/Suppression event tree approach discussed in Appendix P of NUREG/CR-6850, Detection and Suppression Analysis. Recall that the switchgear access room is equipped with a smoke detection system, and an automatic CO_2 system. The CO_2 system has a 60 second warning alarm delay. In addition to these fixed systems, the fire brigade can also provide manual suppression activities.

Considering the above fire protection features, the suppression strategy in the switchgear access room can be summarized as:

1. Indication of smoke detection in control room
2. Control room sends an operator to the switchgear access room to confirm the fire
3. If fire is confirmed, the operator first if the automatic CO_2 system operated.
4. If further suppression activities are warranted after any of the automatic systems, manual suppression by the fire brigade may be used.

Workshop Problem Set 11a-09

Develop a detection suppression event tree for the fire protection strategy defined above.

Solution:

Workshop Problem 11a-10

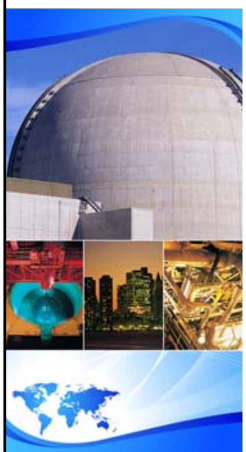
Step 9a: Calculate Conditional Non-Suppression Probability and Severity Factor:
Determine the severity factor and the non-suppression probability for scenario 1.

Solution:

Workshop Problem 11a-11

***Step 10a: Calculate Scenario Frequency*:** Using the ignition frequency calculated in Task 6 for the ignition sources in the switchgear access room, and the severity factor and non-suppression probability calculated in the previous step for scenario 1, determine the frequency for fire scenario 1.

Solution:



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III

Task 11b: Main Control Room Fire Analysis and Appendix L

Joint RES/EPRI Fire PRA Workshop
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Main Control Room Fire Analysis

Objectives

The objective of this module is:

- Describe the recommended approach for detailed fire modeling in the main control room. Specifically:
  - Differences between the main control room and other compartments
  - Criteria for abandonment due to fire generated environmental conditions
  - Description of how to analyze:
    - Conditional probability of damage to a target set
    - Forced control room abandonment time

Main Control Room Fire Analysis
What is Different in the MCR?

- The control and instrumentation circuits of all redundant trains for almost all plant systems are present in the control room.
  – Redundant train controls can be within a short distance of each other
  – Small fires within control panels could be risk-significant
- The room is continuously occupied, which provides the capability for "prompt detection and suppression."
- Evaluating control room abandonment conditions is necessary.
  – Abandonment refers to situations in which control room operators are forced to leave due to untenable fire generated conditions (temperature, toxicity, and visibility).

Main Control Room Fire Analysis
Recommended Steps

- Step 1: Identify and characterize main control room features
- Step 2: Estimate control room fire frequency
- Step 3: Identify and characterize fire detection and suppression features and systems
- Step 4: Characterize alternate shutdown features
- Step 5: Identify and characterize target sets
- Step 6: Identify and characterize ignition sources
- Step 7: Define fire scenarios
- Step 8: Conduct fire growth and propagation analysis
- Step 9: Fire detection and suppression analysis and severity factor
- Step 10: Estimate failure probability of using alternate shutdown features
- Step 11: Estimate probability of control room abandonment
- Step 12: Calculate scenario frequencies
- Step 13: Document analysis results

Main Control Room Fire Analysis
Step 1: Identify and Characterize MCR Features

The specific features of the control room and the control board are identified.

- Control room dimensions
- Other adjacent compartments included in the MCR proper
- Location, shape, dimensions and special features of the control panels and other electrical panels
- Main control board layout and location of various controls and displays
- Cable penetration into the control room and into the control panels
- Ventilation system characteristics
- False ceiling features and the ceiling above it

- *Problem Set 11b-01 (Example)*

Main Control Room Fire Analysis
Step 4: Characterize Alternate Shutdown Features

The features of alternate shutdown capability vary widely among NPP's

- In general, a control panel is installed at a location away from the control room where the operators can control and monitor key core cooling functions and parameters independent of the MCR.
- In other plants, alternate shutdown capability is achieved through a set of control points and control panels located at various points of the plant requiring coordinated actions of several operators.
- It is necessary for the fire risk analysts to understand the alternate shutdown capability of the plant.
  - For example, the analyst may select safety-related target sets on the panel that are not backed up by an alternate shutdown control or instrumentation circuit.
- *Problem Set 11b-04 (Example)*

Main Control Room Fire Analysis
Step 5: Identify and Characterize Target Sets

The target sets can be identified by systematically examining combinations of control and instrumentation items found on the control panels, electrical cabinets, wireways, and cable raceways inside the MCR.

- Examine the control panels from one end to the other
- Groups of adjacent controls and instrumentation
- Cursory and conservative estimation of the CCDP/CLERP as the basis
- Elements of a set are located within the reach of a potential fire
- Exposure fire affecting multiple cabinets
- *Problem Set 11.b-05*

Main Control Room Fire Analysis
Step 6: Identify and Characterize Ignition Sources

The final product of this step is a list of ignition sources, their relevant characteristics, and fire ignition frequencies associated with each source

- Similar to Step 3.a of single compartment analysis
- Type, quantity, dimensions and heat release rate profile of each source
- Main control board as ignition source
- Assume fire might occur at any point on a control panel
- Other control panels, electrical cabinets, wireways, and cable raceways
- Kitchen appliances and other electrical devices?
- Transient combustible fires

- *Problem Set 11.b-06*

Main Control Room Fire Analysis

Step 7: Define Fire Scenarios

Four types of fire scenarios are specifically recommended for evaluation

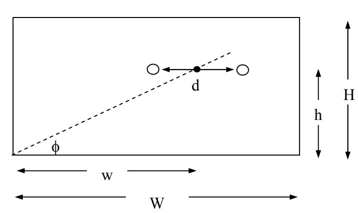
- Fire inside the main control board and stand-alone electrical cabinets that open into each other,
- Fires affecting two adjacent electrical cabinets that do not open into each other,
- Fires affecting two non-adjacent electrical cabinets, and
- Transient fires

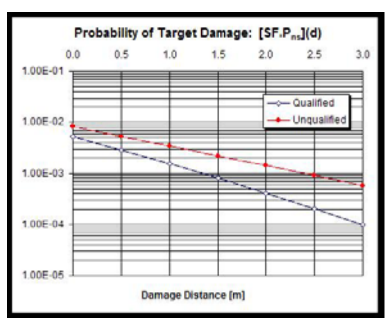
Main Control Room Fire Analysis

Steps 8 and 9: Non-Supp Prob & Severity Factor

The non-suppression probability and severity factors are calculated as recommended in the approach for single compartment fires

- For fires inside a control panel, use the method described in Appendix L





Main Control Room Fire Analysis
Step 10: Estimate Failure Prob Using ASP

Two approaches may be followed:

- An overall failure probability is estimated representing the failure of successful usage of alternate shutdown means.
- The alternate shutdown procedure is integrated in the plant response model (i.e., the fault trees and event trees). The core damage sequences are adjusted to include failures associated with alternate shutdown means, and the human error probabilities are reevaluated based on the alternate shutdown procedures.

Main Control Room Fire Analysis
Step 11: Estimate Prob of Control Room Abandonment

The final decision to abandon the control room is assumed to depend on habitability conditions.

- The analyst may postulate that the alternate shutdown procedure would be activated
- The time to activate the alternate shutdown procedure is suggested to be established based on plant operating procedures rather than control room habitability conditions
- Abandonment possibility should be examined for all postulated target damage scenarios

Main Control Room Fire Analysis
Step 11: Estimate Prob of Control Room Abandonment

Abandonment criteria based on habitability conditions

- Temperature, or heat flux
  - The heat flux at 6′ above the floor exceeds 1 kW/m^2. This can be considered as the minimum heat flux for pain to skin. A smoke layer of approximately 95°C (200°F) could generate such heat flux.

$$\dot{q}'' = \sigma \cdot T_{sl}^4 \approx 1.0 \quad kW/m^2$$

- The smoke or hot gas layer descends below 6′ from the floor
- Visibility
  - Optical density of the smoke is less than 3.0 m^{-1}. With such optical density, a light-reflecting object would not be seen if it is more than 0.4 m away. A light-emitting object will not be seen if it is more than 1 m away.
- A panel fire affects two target items 2.13 m (7′) apart.

Main Control Room Fire Analysis
Step 11: Estimate Prob of Control Room Abandonment

The conditional probability of abandonment can be estimated based on the calculated evacuation time.

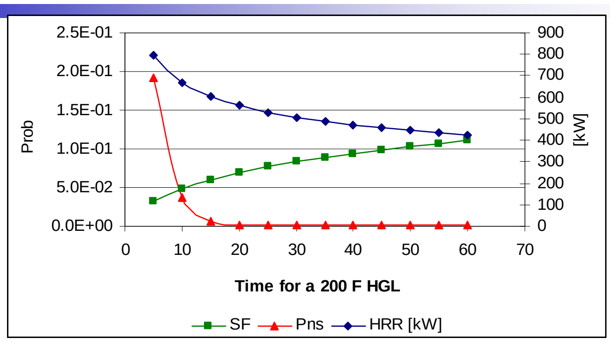
- Determine the heat release rate generating abandonment conditions
- Calculate the severity factor for fires of this size
- Determine the time for abandonment
  - Time to reach untenable conditions such as 200°F hot gas layer or smoke density conditions of 3.0 m^{-1}
- Calculate non-suppression probability
- Multiply the severity factor and non-suppression probability to determine conditional abandonment probability.

Main Control Room Fire Analysis
Example

- Credit prompt detection
- Suppression by fire brigade
  - P_{ns} from CR suppression curve
- SF from probability distribution for vertical cabinets with unqualified cable and fire propagating to more than one bundle.
- *Problem Set 11.b-08 (Example)*

Inputs	
Ambient temperature [C]	20
Duration [sec]	
Opening area [m2]	4
Height of opening [m]	2
Room length [m]	20
Room width [m]	15
Room height [m]	6
Thermal conductivity [kW/mK]	0.0014
Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.15
Temperature for abandonment [C]	93

Main Control Room Fire Analysis
Example (cont'd)



Duration [Min]	Required HRR [kW]	SF	Pns	SF*Pns
5	**794**	3.2E-02	1.9E-01	6.1E-03
10	**668**	4.8E-02	3.7E-02	1.8E-03
15	**603**	6.0E-02	7.1E-03	4.2E-04
20	**561**	6.9E-02	1.4E-03	9.4E-05
25	**531**	7.7E-02	2.6E-04	2.0E-05

Main Control Room Fire Analysis
Concluding Remarks

The main control room has unique characteristics that are addressed in detail in Task 11b.

- Recommended fire scenarios for the MCR

- Evaluation of MCR abandonment due to fire generated conditions

Workshop Problems for Task 11b: Detailed Fire Modeling in the Main Control Room

Workshop Problem Set 11b-01

Step 5.b: Identify and characterize target sets: Using the information provided in Tab 1.4, identify five target sets for the Main Control Board by inspecting drawings DWG A-07 and A-09.

Target Set ID	Items in the target set	Basis for selecting target set
MCR-01		
MCR-02		
MCR-03		
MCR-04		
MCR-05		

Workshop Problem Set 11b-02

Step 8b: Conduct Fire Growth and Propagation Analysis

Step 9b: Detection and Suppression Analysis and Severity Factor: Using the information provided in the solution to Problem Set 11b-01and Figure L-1 (see below) calculate scenario frequency:

MCR-01

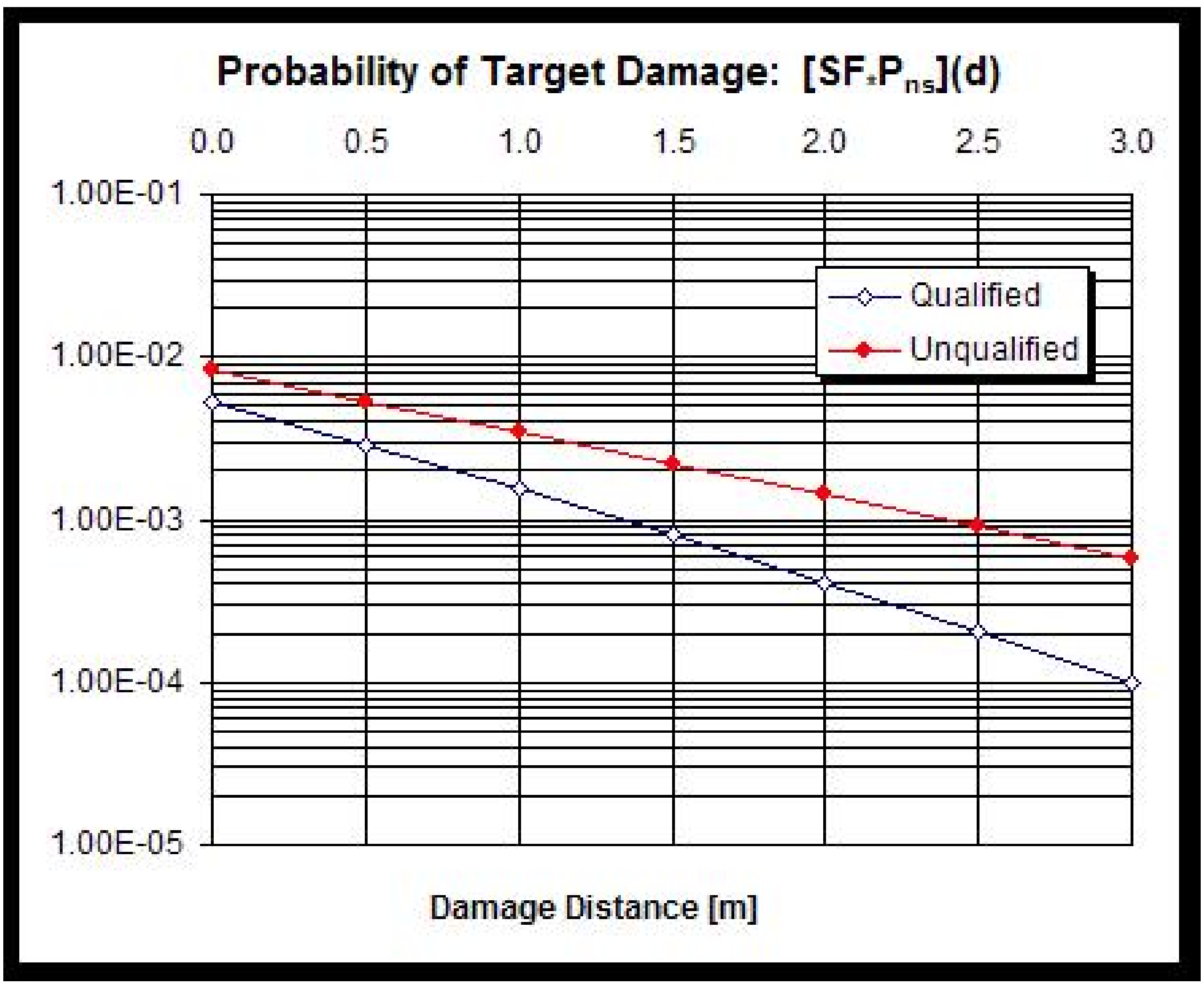
$SFxPNS_{MCR-01}$ = ____________

λ_{MCR-01} = 2.5E-03 x ___________ = __________ per reactor year

MCR-02

$SFxPNS_{MCR-02}$ = ____________

λ_{MCR-02} = 2.5E-03 x ___________ = __________ per reactor year



Workshop Problem Set 11b-03 (Example)

Step 11.B: Estimate Probability of Control Room Abandonment: The following is an example case presented here as an illustration on how the probability of abandonment can be estimated The probability of abandonment represents the likelihood of a fire generating adverse environmental conditions meeting the criteria for control room evacuation described in Task 11 of NUREG/CR-6850. The abandonment criteria suggests that analysts must assume operators will leave the control room if:

- The room or hot gas layer temperature reaches 200 ^oF (93 ^oC).
- The heat flux to the control room floor is above 1 kW/m^2,
- The hot gas layer is 6 ft or lower above the floor and has and optical density of 3.0 1/m. Such optical density will prevent operators to see through smoke.

Considering these criteria, the abandonment probability was calculated as follows:

1. From Task 6, the ignition sources in the main control room are:
   - the main control board,
   - vertical electrical cabinets and
   - transients.

2. The probability distribution for heat release rate Case 5 in Table E-1 of NUREG/CR-6850 has been assigned to the main control board and other electrical cabinets. This distribution applies to cabinets with un-qualified cables and fire spreading to more than one cable bundle.
3. The time to abandonment was calculated deterministically for the range of heat release rate values defined by the probability distributions listed in item 1 above. The zone model MAGIC was used for these calculations. Relevant inputs to MAGIC include the geometry of the main control room complex, and the mechanical ventilation system. The time to abandonment is the shortest time when one of the three defined above criteria is met.
4. Each MAGIC result (i.e., the time to abandonment resulting from a specific heat release rate input) is associated with a severity factor from the corresponding probability distribution for heat release rate. Similarly, there is a corresponding non-suppression probability for each MAGIC result. The non-suppression probability captures the likelihood that the fire will not be suppressed before the calculated abandonment time.
5. The resulting abandonment probability and average abandonment times are a weighted average of all the probabilities of fire sizes and corresponding non-suppression probabilities.

Table 1 summarizes the calculation of abandonment probabilities and average abandonment times for electrical cabinets. The first column in Table 1 refers to the heat release rate value used in MAGIC for determining the time to abandonment. The column labeled SF lists the severity factor associated with the heat release rate value (taken from Appendix E of NUREG/CR-6850). The Time column lists the resulting time to abandonment calculated with MAGIC. The column labeled P_{ns} lists the non-suppression probabilities. In general, $P_{ns} = \exp(-\lambda t)$ where λ for the control room is 0.33 (see Appendix P of NUREG/CR-6850), and t is the time listed in the "Time" column.

The average abandonment time is calculated as

$$\hat{t}_{ab} = \frac{\sum t_i \cdot SF_i \cdot P_{ns-i}}{\sum SF_i \cdot P_{ns-i}}$$

which is the weighted average of the abandonment times calculated with MAGIC. The abandonment probability is calculated as

$$P_{ab} = \sum SF_i \cdot P_{ns-i}$$

which can also be interpreted as an average non-suppression probability since the SF_i's for all possible heat release rates add to one. The following results are obtained using the two equations above:

- Electrical cabinets: Average abandonment time is approximately 8 minutes and the probability of abandonment is approximately 1.3E-2.
- Transient fires: For the purpose of this study, the time to abandonment and the abandonment probability calculated for electrical cabinet fires is assumed to be the same as for transient fires. This is a conservative assumption since the heat release rate profiles for the electrical cabinet fire suggests higher fire intensities with faster profiles that are expected to result in faster abandonment times.

Table 1: Time to abandonment and abandonment probability analysis for electrical cabinet fires. Calculations assume no mechanical ventilation system in the room.

HRR [kW]	SF	Time to Abb (min)	Pns	SF·Pns
1	0.0E+00	60	2.5E-09	0.0E+00
42	6.4E-01	60	2.5E-09	1.6E-09
197	1.6E-01	16	5.1E-03	7.9E-04
337	8.1E-02	11	3.1E-02	2.5E-03
475	4.7E-02	9	4.9E-02	2.3E-03
612	2.9E-02	8	6.4E-02	1.9E-03
749	1.8E-02	8	8.0E-02	1.4E-03
886	1.1E-02	7	9.4E-02	1.0E-03
1024	7.0E-03	7	1.1E-01	7.7E-04
1162	5.0E-03	6	1.2E-01	6.2E-04
1299	3.0E-03	6	1.4E-01	4.1E-04
1436	2.0E-03	6	1.5E-01	2.9E-04
1573	1.0E-03	6	1.5E-01	1.5E-04
1710	1.0E-03	6	1.6E-01	1.6E-04
1847	1.0E-03	5	1.7E-01	1.7E-04
2276	1.0E-03	5	2.0E-01	2.0E-04

Simulations with MAGIC Software Package

As mentioned earlier, time to abandonment calculations were conducted using the zone model MAGIC. MAGIC is a fire two-zone model, which provides the capability of simulating the development of a hot gas layer in rooms with and without mechanical ventilation systems. Key inputs to MAGIC includes: 1) room geometry, 2) wall thickness and construction, 3) specifications of the mechanical ventilation system, 4) fire size and 5) fuel properties.

The control room was modeled in MAGIC as a single room. The fire was located in the center of the common control room area. Figure 1 illustrates the geometry as modeled in MAGIC. Notice that the control room area was modeled as having a rectangular floor base with equivalent floor area. Simulation times were 20 minutes.

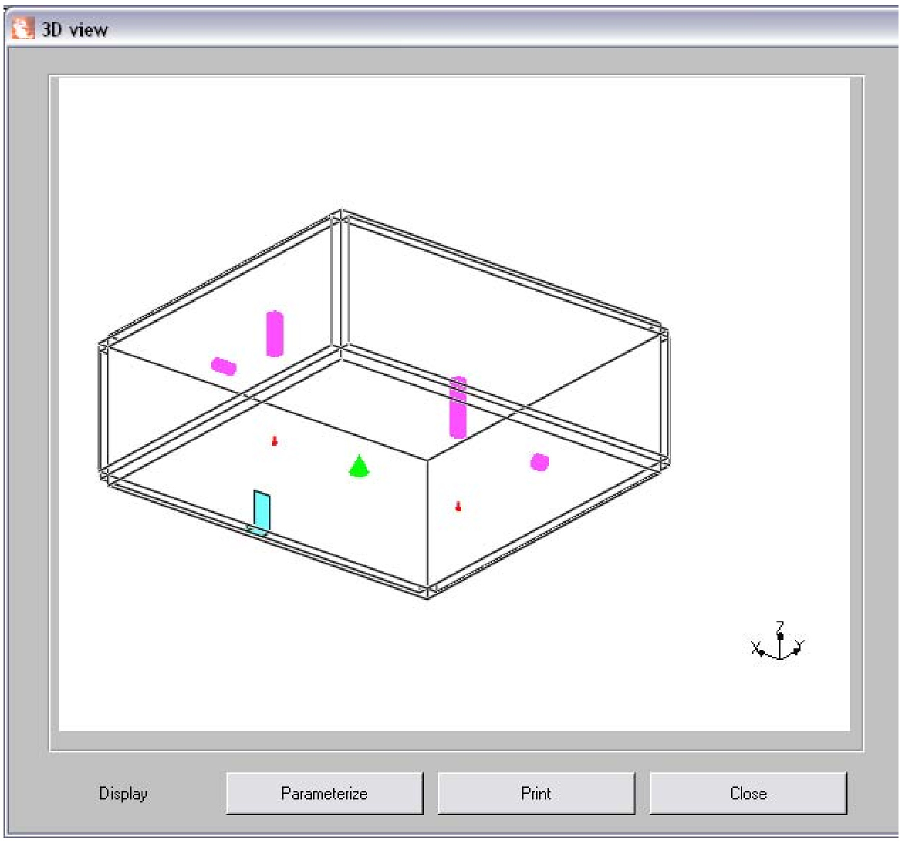


Figure 1: Control room geometry as modeled in MAGIC

The following were considered when running MAGIC:

- Room size and construction: The control room area was modeled with an effective floor area of 67' x 60' and a ceiling height of 23'.
- All wall materials were modeled as 2' thick concrete.
- Horizontal openings: As illustrated in Figure 1 above, the control room was modeled as having one 3' x 6' open door.
- Mechanical ventilation: The mechanical ventilation system is modeled as a balanced supply/exhaust system with a flow rate of 2.73 m^3/s. The room also has a smoke extraction system with two vents, each extracting 3.7 m^3/s. This system is manually activated by the fire brigade.

- For the purpose of the simulation, it is assumed that the smoke extraction system operates 10 minutes after the fire starts. At this point, the normal system is turned off.
- Heat release rate profiles: The heat release rate profiles follow the guidance provided in Appendices E & G of NUREG/CR-6850. That is, the peak heat release rates listed in Tables E-6 and E-9 in NUREG/CR-6850 for electrical cabinets and transients respectively were used. It was assumed that the growth profile is t^2 growing to a peak in approximately 12 minutes.
- Fuel Properties: Fuel was assumed to have a soot yield of 0.18.

Relevant outputs/Abandonment criteria

MAGIC creates one output file for each simulation. The output files contain the information necessary for determining the time to abandonment. Specifically, the following outputs were evaluated:

- hot gas layer temperature in the MCR area,
- hot gas layer height in the MCR area,
- Total heat flux to Target 1, and
- optical density in the MCR area.

Specific MAGIC inputs are included in the MAGIC input files. Figure 2 illustrates a snapshot of a MAGIC simulation with and without mechanical ventilation. Notice that the simulation with no mechanical ventilation suggests the development of a hot gas layer and flows moving out through the open doors.

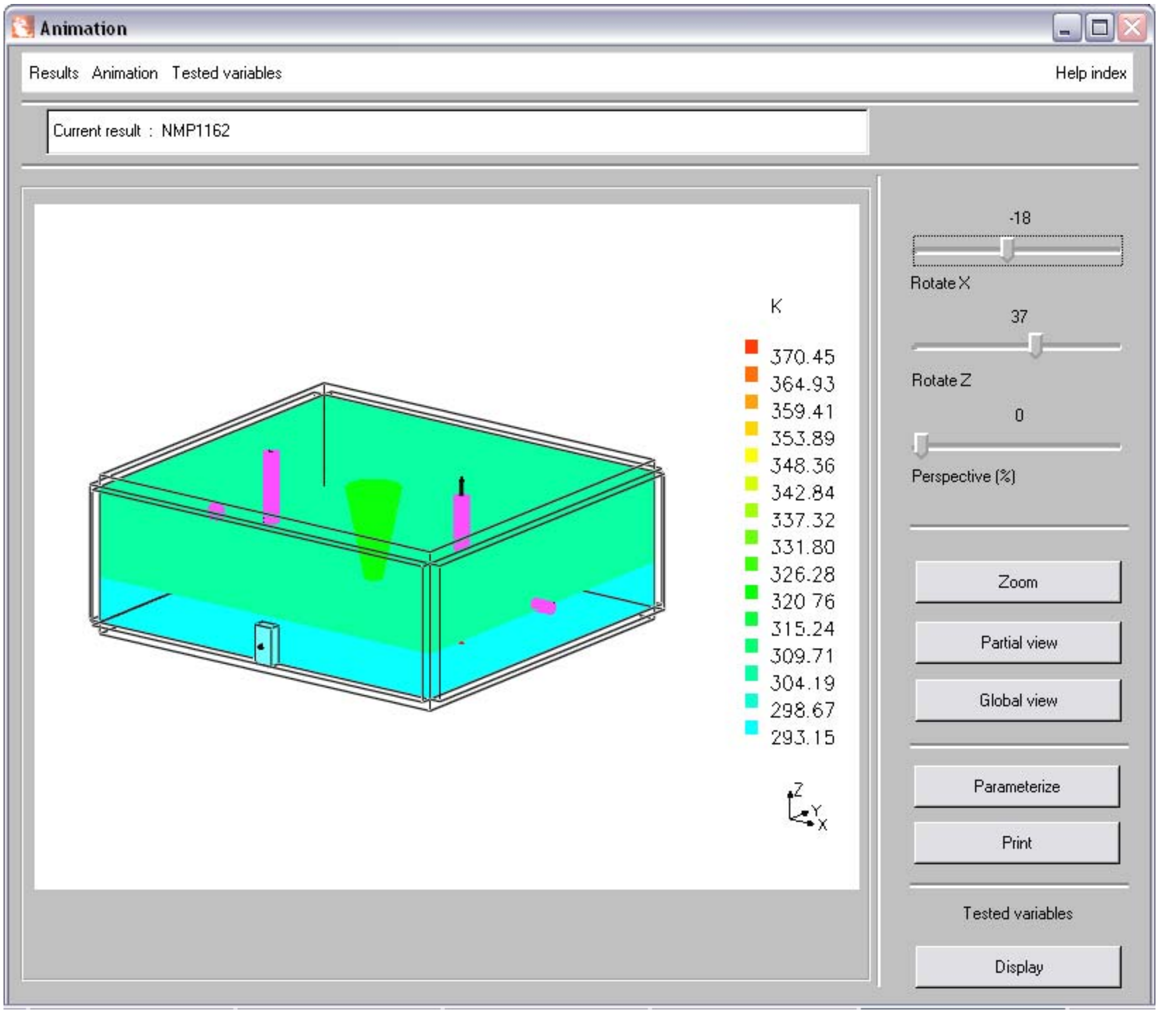
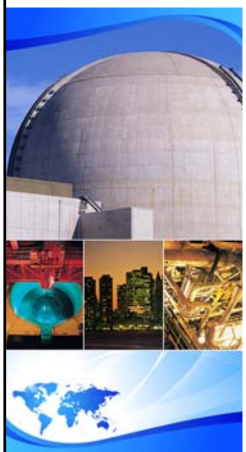


Figure 2: Pictorial representation of a MAGIC simulation of the control room fire

EPRI/NRC-RES FIRE PRA METHODOLOGY



Module III
Task 11c - Multi-Compartment Fire Analysis

Joint RES/EPRI Fire PRA Workshop
June 2009
Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

MULTI-COMPARTMENT FIRES
Objective

Fire scenarios involving multiple, interconnected or adjacent fire compartments are analyzed in this part of Task 11.

- Fire propagation
- Smoke propagation
- A rare event in U.S. NPP fire experience
- Screening process

MULTI-COMPARTMENT FIRES
Overall Approach

Multi-compartment analysis is focused on screening of potential scenarios before any detailed analysis is attempted.

– Single compartment analysis to be conducted before this step

– Reduce number of multi-compartment combinations

– Same analytical approach as in Detailed Fire Modeling

MULTI-COMPARTMENT FIRES
Definitions

The following two terms are specifically defined for this part of the analysis:

– *Exposing Compartment*: The compartment where fire ignition occurs

– *Exposed Compartment*: The compartments where fire from the exposing compartment propagates to

MULTI-COMPARTMENT FIRES
Analysis Steps

The following steps define one possible approach for multi-compartment fire risk analysis:

- Step 1.c: Exposing and Exposed Compartments Matrix
- Step 2.c: First Screening–Qualitative
- Step 3.c: Second Screening–Low Fire Load Exposing Compartments
- Step 4.c: Third Screening–Frequency of Occurrence
- Step 5.c: Fourth Screening–CDF Based
- Step 6.c: Detailed Analysis
- Step 7.c: Document the Analysis

MULTI-COMPARTMENT FIRES
Step 1.c: Exposing and Exposed Compartments Matrix

Develop a matrix to identify all potential multi-compartment fire scenarios that start with an *exposing* compartment and propagate into a set of *exposed* compartments.

- Well defined pathways
- Means of propagation (i.e., hot gas, smoke, etc.)
- Special characteristics to be noted (e.g., self closing doors, fire dampers and vents near the ceiling)
- More than one exposed compartment
- Supported by a walk-down

MULTI-COMPARTMENT FIRES
Step 1.c: Exposing and Exposed Matrix (cont'd)

The following rules are suggested to identify multi-compartment scenarios:

- Postulate only one barrier failure (e.g., door left open)
  - Unless there is a clear reason to assume common cause failure of multiple barriers
- Assume minimal smoke damage
- Hot gas can travel to all physically possible exposed compartments
  - For a large number of compartments open into each other, detailed analysis may be warranted

MULTI-COMPARTMENT FIRES
Step 1.c: Exposing and Exposed Matrix (cont'd)

Example:

#	Exposing Compartment		#	Exposed Compartment		#	Path	Comments
	ID	Name		ID	Name			
1	9	SWG Access Room	1.1	10	Swtich Gear Room A	1.1.1	Door	The door is 3-hr rated and normally closed
						1.1.2	Opening	Ventilation opening between rooms with fusible link activated fire dampers.
			1.2	11	Swtich Gear Room B	1.2.1	Door	The door is 3-hr rated and normally closed
						1.2.2	Opening	Ventilation opening between rooms with fusible link activated fire dampers.
			1.3	--	Stairway	1.3.1	Door	The door is 3-hr rated and normally closed
2	4A	RHR Room	2.1	4B	AFW Pump Room	2.1.1	Door	The door is 3-hr rated and normally closed
						2.1.2	HVAC Duct	There are two HVAC ducts with opening in both compartments providing intake and discharge
			2.2	--	Stairway	2.2.1	Door	The door is 3-hr rated and normally closed
3	4B	AFW Pump Room	3.1	4A	RHR Room	3.1.1	Door	The door is 3-hr rated and normally closed
						3.1.2	HVAC Duct	There are two HVAC ducts with opening in both compartments providing intake and discharge

MULTI-COMPARTMENT FIRES
Step 2.c: First Screening – Qualitative

The first screening of the scenarios can be based on the contents of the exposed compartments.

The following criteria may be used:

- The exposed compartment(s) do not contain any Fire PRA components or cables, or
- The Fire PRA components and cables of the exposed compartment(s) are identical to or less than those in the exposing compartment.

MULTI-COMPARTMENT FIRES
Step 3.c: Second Screening–Low Fire Load

Exposing compartments that do not include combustible loading sufficient for generating a hot gas layer in any of the exposed compartments can be screened out.

- Conservative HRR values
  - Ignition sources with highest 98% HRR
  - Add HRR of intervening combustibles
- Determine damaging HRR values
  - Hand calculations
  - Hot gas layer damage in exposed compartment
- Compare HRRs

MULTI-COMPARTMENT FIRES
Step 4.c: Third Screening–Occurrence Frequency

Scenario likelihood is established from the following three parameters:

- Ignition frequency
- Combined severity factor and non-suppression probability
  - HRR comparison (preceding step) can give the severity factor
  - May assume P_{NS} = 1.0
- Barrier failure probability

MULTI-COMPARTMENT FIRES
Step 4.c: Third Screening / *Barrier Failure*

Generally, data on barrier failure probability is sparse, and what is available is subject to many limitations.

- Initial attempt may be based on a screening value
  - May use Pr(barrier failure) = 0.1 for screening
- For scenarios that do not screen out, may use the following:
  - For water curtain, use detection and suppression approach
  - Verify that there are no plant-specific barrier failure problems
  - Use the following *generic* barrier failure probabilities
    - Type 1 – fire, security, and water tight doors – 7.4E-03
    - Type 2 - fire and ventilation dampers – 2.7E-03
    - Type 3 - penetration seals, fire walls – 1.2E-03

MULTI-COMPARTMENT FIRES
Step 5.c: Fourth Screening–CDF Based

Those scenarios that survive the preceding screening steps may be screened based on their CDF.

– Assume all PRA components and cables of exposing and exposed compartments are failed

– Estimate CCDP

– Use scenario frequency of preceding step

MULTI-COMPARTMENT FIRES
Step 6.c: Detailed Analysis

Those scenarios that do not screen out in the preceding steps may be analyzed using the same methods as for single compartments.

– Same set of steps as in single compartment analysis

– Include target sets from exposed compartment(s)

MULTI-COMPARTMENT FIRES
Concluding Remarks

Multi-compartment fire analysis should be performed to ensure completeness of the Fire PRA.

- Compartment partitioning process (Task 1) has a direct impact on this task
- Develop a matrix of exposing and exposed compartments to ensure completeness
- Screening analysis is necessary to limit the level of effort
- Barrier failure probabilities should be treated conservatively
- May have to revisit some of the partitioning definitions

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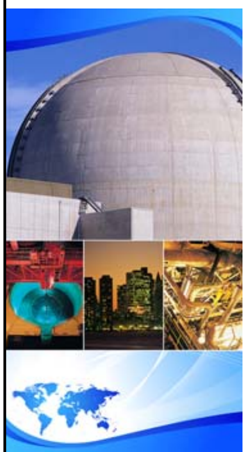

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 13: Seismic Fire Interactions

Joint RES/EPRI Public Workshop
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Palo Alto, CA

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Task 13 - Seismic Fire Interactions
Scope of this Task

- Task 13 covers the Seismic Fire Interactions review
  - Little has changed compared to the guidance available in the IPEEE days
  - The review remains a qualitative, walk-down based approach to identify and address potential vulnerabilities or weaknesses
  - The procedure does not recommend any quantitative work in this area

<u>The main goal of the outlined methodology is to verify that the the risk associated with seismically induced fires is low.</u>

Task 13: Seismic Fire Interactions
Seismically Induced Fires

A severe seismic event may cause fires inside or outside an NPP by damaging . . .

- Pipes and storage tanks containing flammable liquids or gases
- Electrical equipment

An EPRI study and NPPs experiencing earthquakes have demonstrated that these events are rare.

Task 13: Seismic Fire Interactions
Background

- Seismic Fire Interactions originated with the Fire Risk Scoping Study (NUREG/CR-5088, 1989)
- The conclusion of that study was:

  "It would appear that this is an issue which is more easily corrected than quantified. A series of simple steps was outlined which if implemented on a plant specific basis would significantly reduce the potential impact of such considerations."

  This conclusion remains valid today.

Task 13: Seismic Fire Interactions
Key Compartments

- The review should focus on those compartments that house equipment and cables needed to support post-seismic safe shutdown
  - Review your seismic-related procedures and identify key equipment (components and cables) and any required manual actions
  - To the extent possible, map equipment to compartments
  - Identify the associated compartments and focus efforts on these compartments
    - Areas/compartments housing the key equipment (components and cables)
    - Areas where a manual action takes place
    - Access paths for manual actions

Task 13: Seismic Fire Interactions
Seismically-Induced Fires

- Potential sources:
  - Unanchored electrical equipment such as that where motion during seismic event might cause a fire
  - Unanchored gas cylinders
  - Flammable gas piping
  - Flammable liquid piping or storage tanks

- If any *significant* sources are identified, consider potential plant modifications to minimize potential hazard.

Task 13: Seismic Fire Interactions
Degradation of FP Systems and Features

- Review:
  - General plant practice related to seismic restraints for fire protection systems and features
  - Installed systems and features; assess potential for seismic-induced failure
- Assess potential significance of system or feature failure to post-seismic event operations.
- If any potential vulnerabilities are identified, consider fixes to reduce likelihood of failure.

Task 13: Seismic Fire Interactions
Spurious Detection Signals

- A seismic event will likely trigger activation of various fire detection systems – especially smoke detectors
- Consider how the operators will respond to multiple fire detection signals
  - You can't ignore them even though many may be false
  - Have you identified the issue in your response procedures?
  - Have you (can you) prioritize your response based on the important compartments?
- Consider potential procedural enhancements to recognize and deal with this issue

Task 13: Seismic Fire Interactions
Spurious Suppression Actuation/Release

- Review the fixed fire protection systems in key areas for the potential that they might spuriously operate
  - Got any of those mercury switches left?
  - How about a non-seismic deluge valve?
  - What happens if a sprinkler head is damaged or a pipe breaks?
  - Are storage tanks for gaseous suppressants seismically robust?
- If any potential vulnerabilities are identified, consider fixes to reduce likelihood of spurious suppressant release.

Task 13: Seismic Fire Interactions
Manual Fire Fighting

- Access pathways to key areas – could something block the path and are there alternative paths?
- Required fire fighting assets – will assets remain available after an earthquake?
  - Especially fire water system and fire hoses
- Do post-seismic response procedures allow for manual fire fighting needs and responsibilities?
- If any potential vulnerabilities are identified, consider fixes

Task 13: Seismic Fire Interactions
Summary

- Seismic fire interaction is considered a low risk phenomenon
- NPP and other industry experiences partly verify this premise
- A qualitative approach is suggested for verifying that plant specific conditions confirm low risk notion
- Systemic or procedural upgrades are recommended for identified potential vulnerabilities

Table E-1
List of Heat Release Rate Distributions

Case	Ignition Source	HRR kW (Btu/s)		Gamma Distribution		Reference
		75th	98th	α	β	
1	Vertical cabinets with qualified cable, fire limited to one cable bundle	69 (65)	211 (200)	0.84 (0.83)	59.3 (56.6)	Table G-1
2	Vertical cabinets with qualified cable, fire in more than one cable bundle	211 (200)	702 (665)	0.7 (0.7)	216 (204)	Table G-1
3	Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 (85)	211 (200)	1.6 (1.6)	41.5 (39.5)	Table G-1
4	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 (220)	464 (440)	2.6 (2.6)	67.8 (64.3)	Table G-1
5	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 (220)	1002 (950)	0.46 (0.45)	386 (366)	Table G-1
6	Pumps (electrical fires)	69 (65)	211 (200)	0.84 (0.83)	59.3 (56.6)	Table G-1
7	Motors	32 (30)	69 (65)	2.0 (2.0)	11.7 (11.1)	Table G-1
8	Transient Combustibles	142 (135)	317 (300)	1.8 (1.9)	57.4 (53.7)	Section G-4

Table E-2
Discretized Distribution for Case 1 Heat Release Rate (Vertical Cabinets with Qualified Cable, Fire Limited to One Cable Bundle)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	26 (25)	11 (10.5)	0.446
2	26 (25)	53 (50)	38 (36)	0.219
3	53 (50)	79 (75)	64 (61)	0.129
4	79 (75)	106 (100)	92 (87)	0.078
5	106 (100)	132 (125)	118 (112)	0.048
6	132 (125)	158 (150)	145 (137)	0.030
7	158 (150)	185 (175)	171 (162)	0.019
8	185 (175)	211 (200)	197 (187)	0.012
9	211 (200)	237 (225)	224 (212)	0.007
10	237 (225)	264 (250)	250 (237)	0.005
11	264 (250)	290 (275)	276 (262)	0.003
12	290 (275)	317 (300)	303 (287)	0.002
13	317 (300)	343 (325)	329 (312)	0.001
14	343 (325)	369 (350)	356 (337)	0.001
15	369 (350)	Infinity	427 (405)	0.001

Table E-3
Discretized Distribution for Case 2 Heat Release Rate (Vertical Cabinets with Qualified Cable, Fire in more than One Cable Bundle)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	90 (85)	34 (32.7)	0.506
2	90 (85)	179 (170)	130 (123)	0.202
3	179 (170)	269 (255)	221 (209)	0.113
4	269 (255)	359 (340)	310 (294)	0.067
5	359 (340)	448 (425)	400 (379)	0.041
6	448 (425)	538 (510)	490 (464)	0.026
7	538 (510)	628 (595)	579 (549)	0.016
8	628 (595)	717 (680)	669 (634)	0.010
9	717 (680)	807 (765)	759 (719)	0.006
10	807 (765)	897 (850)	848 (804)	0.004
11	897 (850)	986 (935)	938 (889)	0.003
12	986 (935)	1076 (1020)	1028 (974)	0.002
13	1076 (1020)	1166 (1105)	1118 (1060)	0.001
14	1166 (1105)	1255 (1190)	1208 (1145)	0.001
15	1255 (1190)	Infinity	1462 (1386)	0.001

Table E-4
Discretized Distribution for Case 3 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire Limited to One Cable Bundle)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	26 (25)	15 (14.2)	0.227
2	26 (25)	53 (50)	39 (37)	0.261
3	53 (50)	79 (75)	65 (62)	0.192
4	79 (75)	106 (100)	92 (87)	0.126
5	106 (100)	132 (125)	118 (112)	0.079
6	132 (125)	158 (150)	143 (136)	0.048
7	158 (150)	185 (175)	170 (161)	0.028
8	185 (175)	211 (200)	196 (186)	0.016
9	211 (200)	237 (225)	223 (211)	0.010
10	237 (225)	264 (250)	249 (236)	0.005
11	264 (250)	290 (275)	275 (261)	0.003
12	290 (275)	317 (300)	302 (286)	0.002
13	317 (300)	343 (325)	328 (311)	0.001
14	343 (325)	369 (350)	354 (336)	0.001
15	369 (350)	Infinity	414 (392)	0.001

Table E-5
Discretized Distribution for Case 4 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire in more than One Cable Bundle Closed Doors)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	53 (50)	36 (34)	0.082
2	53 (50)	106 (100)	80 (76)	0.213
3	106 (100)	158 (150)	131 (124)	0.224
4	158 (150)	211 (200)	184 (174)	0.177
5	211 (200)	264 (250)	235 (223)	0.122
6	264 (250)	317 (300)	288 (273)	0.077
7	317 (300)	369 (350)	341 (323)	0.046
8	369 (350)	422 (400)	394 (373)	0.027
9	422 (400)	475 (450)	446 (423)	0.015
10	475 (450)	528 (500)	499 (473)	0.008
11	528 (500)	580 (550)	552 (523)	0.004
12	580 (550)	633 (600)	603 (572)	0.002
13	633 (600)	686 (650)	656 (622)	0.001
14	686 (650)	739 (700)	709 (672)	0.001
15	739 (700)	Infinity	816 (773)	0.001

Table E-6
Discretized Distribution for Case 5 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire in more than One Cable Bundle Open Doors)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	137 (130)	42 (39.5)	0.638
2	137 (130)	274 (260)	197 (187)	0.155
3	274 (260)	411 (390)	337 (319)	0.081
4	411 (390)	549 (520)	475 (450)	0.047
5	549 (520)	686 (650)	612 (580)	0.029
6	686 (650)	823 (780)	749 (710)	0.018
7	823 (780)	960 (910)	886 (840)	0.011
8	960 (910)	1097 (1040)	1024 (971)	0.007
9	1097 (1040)	1234 (1170)	1162 (1101)	0.005
10	1234 (1170)	1372 (1300)	1299 (1231)	0.003
11	1372 (1300)	1509 (1430)	1436 (1361)	0.002
12	1509 (1430)	1646 (1560)	1573 (1491)	0.001
13	1646 (1560)	1783 (1690)	1710 (1621)	0.001
14	1783 (1690)	1920 (1820)	1847 (1751)	0.001
15	1920 (1820)	Infinity	2276 (2157)	0.001

Table E-7
Discretized Distribution for Case 6 Heat Release Rate (Pumps – Electrical Fires)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	26 (25)	11 (10.5)	0.446
2	26 (25)	53 (50)	38 (36)	0.219
3	53 (50)	79 (75)	64 (61)	0.129
4	79 (75)	106 (100)	92 (87)	0.078
5	106 (100)	132 (125)	118 (112)	0.048
6	132 (125)	158 (150)	145 (137)	0.030
7	158 (150)	185 (175)	171 (162)	0.019
8	185 (175)	211 (200)	197 (187)	0.012
9	211 (200)	237 (225)	224 (212)	0.007
10	237 (225)	264 (250)	250 (237)	0.005
11	264 (250)	290 (275)	276 (262)	0.003
12	290 (275)	317 (300)	303 (287)	0.002
13	317 (300)	343 (325)	329 (312)	0.001
14	343 (325)	369 (350)	356 (337)	0.001
15	369 (350)	Infinity	427 (405)	0.001

Table E-8
Discretized Distribution for Case 7 Heat Release Rate (Motors)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	7 (7)	5 (4.4)	0.132
2	7 (7)	15 (14)	12 (11)	0.227
3	15 (14)	22 (21)	18 (17)	0.205
4	22 (21)	30 (28)	25 (24)	0.153
5	30 (28)	37 (35)	33 (31)	0.105
6	37 (35)	44 (42)	40 (38)	0.069
7	44 (42)	52 (49)	47 (45)	0.043
8	52 (49)	59 (56)	55 (52)	0.027
9	59 (56)	66 (63)	62 (59)	0.016
10	66 (63)	74 (70)	70 (66)	0.010
11	74 (70)	81 (77)	77 (73)	0.006
12	81 (77)	89 (84)	84 (80)	0.003
13	89 (84)	96 (91)	92 (87)	0.002
14	96 (91)	103 (98)	99 (94)	0.001
15	103 (98)	Infinity	116 (110)	0.001

Table E-9
Discretized Distribution for Case 8 Heat Release Rate (Transients[1])

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	37 (35)	22 (21.2)	0.169
2	37 (35)	74 (70)	55 (52)	0.249
3	74 (70)	111 (105)	92 (87)	0.205
4	111 (105)	148 (140)	128 (121)	0.143
5	148 (140)	185 (175)	165 (156)	0.093
6	185 (175)	222 (210)	202 (191)	0.058
7	222 (210)	258 (245)	238 (226)	0.035
8	258 (245)	295 (280)	275 (261)	0.020
9	295 (280)	332 (315)	312 (296)	0.012
10	332 (315)	369 (350)	349 (331)	0.007
11	369 (350)	406 (385)	386 (366)	0.004
12	406 (385)	443 (420)	423 (401)	0.002
13	443 (420)	480 (455)	460 (436)	0.001
14	480 (455)	517 (490)	497 (471)	0.001
15	517 (490)	Infinity	578 (548)	0.001

Table H-1
Damage Criteria for Electrical Cables – Generic Screening Criteria for the Assessment of the Ignition and Damage Potential of Electrical Cables [See Ref 8-1]

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic	6 kW/m^2 (0.5 BTU/ft2s)	205°C (400°F)
Thermoset	11 kW/m^2 (1.0 BTU/ft2s)	330°C (625°F)

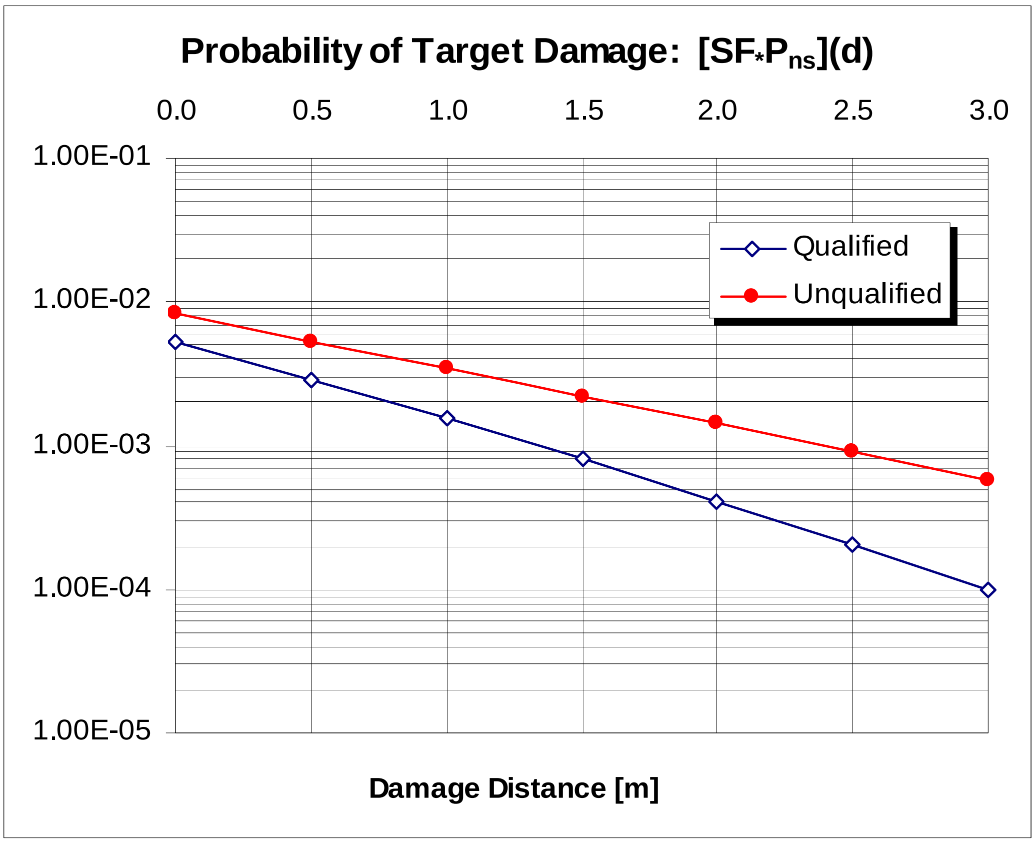

Figure L-1
Likelihood of Target Damage Calculated as the Severity Factor Times the Probability
of Non-suppression for MCB Fires

Table P-2
Probability Distribution for Rate of Fires Suppressed per Unit Time, λ

Suppression Curve	Number of Events in Curve	Total Duration	λ Mean	5th Per	50th Per	95th Per
T/G fires	21	749	0.03	0.02	0.03	0.04
Control room	6	18	0.33	0.15	0.32	0.58
PWR containment	3	23	0.13	0.04	0.12	0.27
Outdoor transformers	14	373	0.04	0.02	0.04	0.06
Flammable gas	5	195	0.03	0.01	0.02	0.05
Oil fires	36	404	0.09	0.07	0.09	0.11
Cable fires	4	11	0.24	0.12	0.33	0.70
Electrical fires	112	937	0.12	0.10	0.12	0.14
Welding fires	19	99	0.19	0.13	0.19	0.27
Transient fires	24	199	0.12	0.08	0.12	0.16
High energy arcing faults	5	118	0.01	0.02	0.04	0.08
All fires	250	3260	0.08	0.07	0.08	0.08

Table P-3
Numerical Results for Suppression Curves

Time (min)	T/G fires	High energy arcing faults	Outdoor transformers	Flammable gas	Oil fires	Electrical fires	Transient fires	PWR containment	Welding	Control room	Cable fires	All fires
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	0.87	0.94	0.83	0.88	0.64	0.55	0.55	0.52	0.38	0.19	0.30	0.68
10	0.76	0.88	0.69	0.77	0.41	0.30	0.30	0.27	0.15	0.04	0.09	0.46
15	0.66	0.83	0.57	0.68	0.26	0.16	0.16	0.14	0.06	0.01	0.03	0.32
20	0.57	0.78	0.47	0.60	0.17	0.09	0.09	0.07	0.02	0.00	0.01	0.22
25	0.50	0.73	0.39	0.53	0.11	0.05	0.05	0.04	0.01	*	0.00	0.15
30	0.43	0.69	0.32	0.46	0.07	0.03	0.03	0.02	0.00	*	*	0.10
35	0.37	0.64	0.27	0.41	0.04	0.01	0.01	0.01	0.00	*	*	0.07
40	0.33	0.61	0.22	0.36	0.03	0.01	0.01	0.01	*	*	*	0.05
45	0.28	0.57	0.18	0.32	0.02	0.00	0.00	0.00	*	*	*	0.03
50	0.25	0.53	0.15	0.28	0.01	0.00	0.00	0.00	*	*	*	0.02
55	0.21	0.50	0.13	0.24	0.01	0.00	0.00	*	*	*	*	0.01
60	0.19	0.47	0.11	0.21	0.00	*	*	*	*	*	*	0.01
65	0.16	0.44	0.09	0.19	0.00	*	*	*	*	*	*	0.01
70	0.14	0.42	0.07	0.17	0.00	*	*	*	*	*	*	0.00
75	0.12	0.39	0.06	0.15	0.00	*	*	*	*	*	*	0.00
80	0.11	0.37	0.05	0.13	*	*	*	*	*	*	*	0.00
85	0.09	0.34	0.04	0.11	*	*	*	*	*	*	*	0.00
90	0.08	0.32	0.03	0.10	*	*	*	*	*	*	*	0.00
95	0.07	0.30	0.03	0.09	*	*	*	*	*	*	*	*
100	0.06	0.29	0.02	0.08	*	*	*	*	*	*	*	*

* A value of 1E-3 should be used