EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-5: Task 6, Fire Ignition Frequency

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

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 the equipment of the same type.

FIRE IGNITION FREQUENCIES
General Approach

To establish the fire frequency at a specific 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	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})

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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

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 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

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

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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
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 FREQUENCIES
Location Weighting Factor (W_L)

Location weighting factor adjusts the plant level frequencies for those cases where a common location is shared among units of the same plant.

- All frequencies were developed per unit basis
- Examples: Turbine Building, Auxiliary Building, Control Room
- Example: W_L = 2.0 if the turbine building is shared between two units

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

Ignition source weighting factor is the fraction of an ignition source type found in a specific compartment.

- Need to count all the items belonging to one ignition source type in one unit
  - Necessitates a thorough plant walk-down and review of engineering documents
- Example: if there are two battery rooms in one unit, each housing one battery set, $W_{IS,J,L} = 0.5$
- Transients and cables are based on specific models

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

Plant equipment 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

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 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 locations in the bin definitions.

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		

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. (continued)

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 14– Electric Motors: The electrical motors with power rating greater than 5hp associated with various devices, not including those counted in other bins, are included in this bin. This may include elevator motors, valve motors, etc.

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

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 (continued)

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 (continued)

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)

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.

- $\lambda_{J,L} = \Sigma \lambda_{IS} W_L W_{IS,J,L}$

  summed over all ignition sources

FIRE IGNITION FREQUENCIES
Determination of Generic Fire Frequencies

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

- Large uncertainties
- Two stage Bayesian approach
- EPRI Fire Event Database (FEDB)
- Analysis of each event

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, reviewed the available information 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 for each unit
- Added reactor years of each unit to obtain site reactor years

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

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-6: Heat Release Rates Appendix G

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SAIC

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HEAT RELEASE RATES
Objectives

The objectives of this module are:

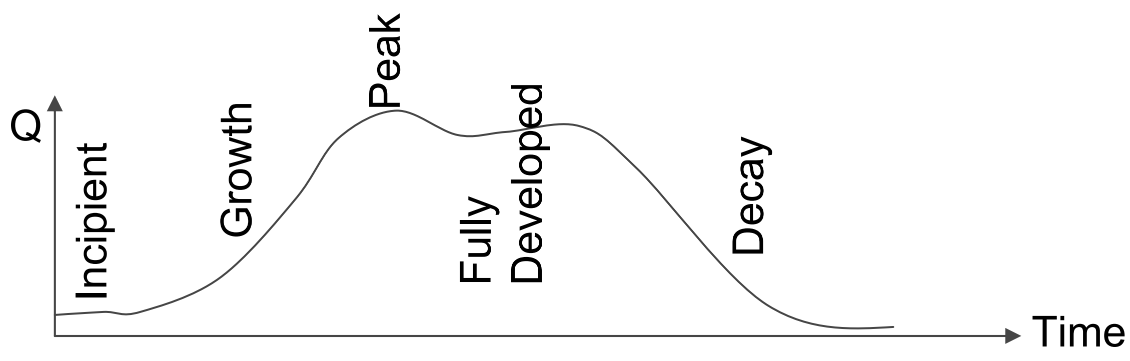
1. Define heat release rate and heat release rate profile
2. Review the recommended peak heat release rate values for typical ignition sources in NPP
3. Describe the method provided for developing heat release rate profiles for fixed and transient ignition sources in NPP

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 the fire intensity as a function of time



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
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 $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$
- Separate guidance for cables, pressurized oil and hydrogen fires

HEAT RELEASE RATES
Recommended Peak HRR Values

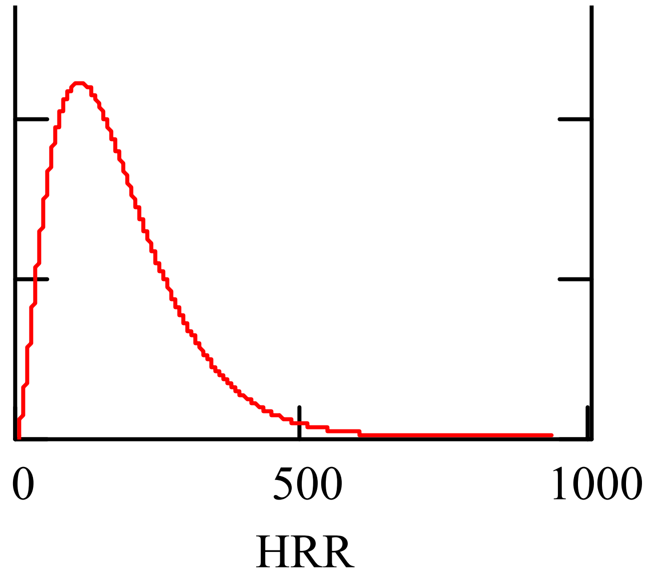
Recommended peak HRR values were developed based on expert judgment

- 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

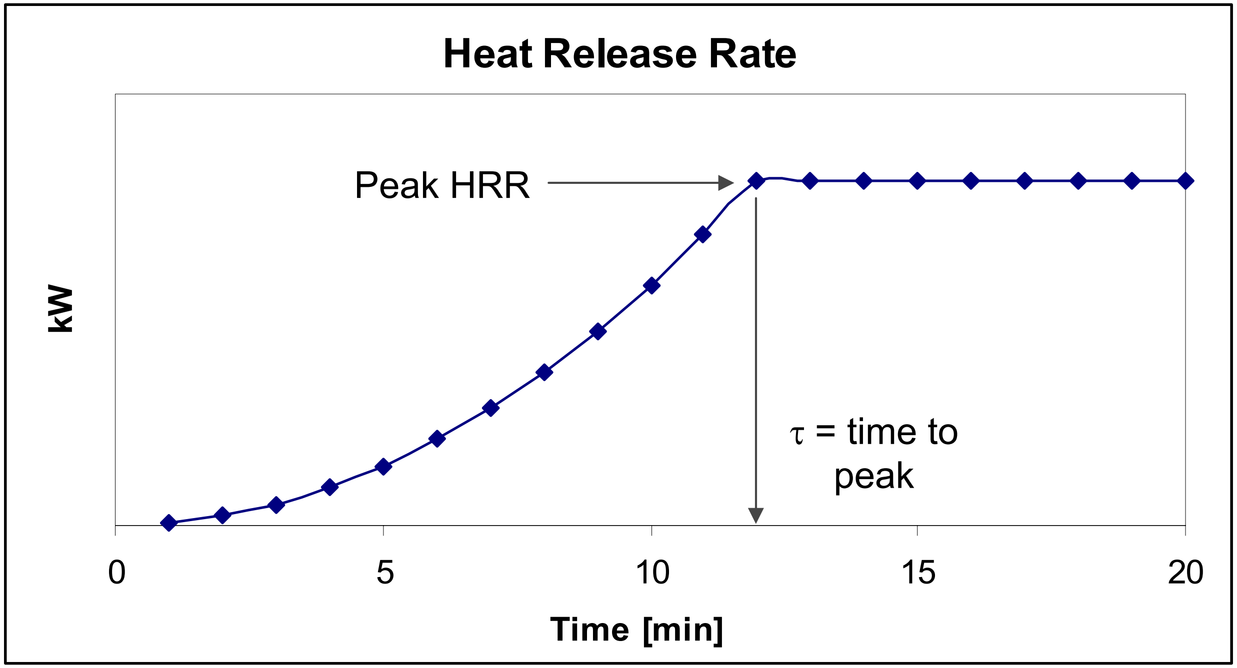
- The fire grows to its peak HRR in approximately 12 min
- The fire burns at its peak HRR for approximately 8 min
- Based on experiments reported in NUREG/CR4527

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
Fire Growth in Electrical Cabinets

The t² 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
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

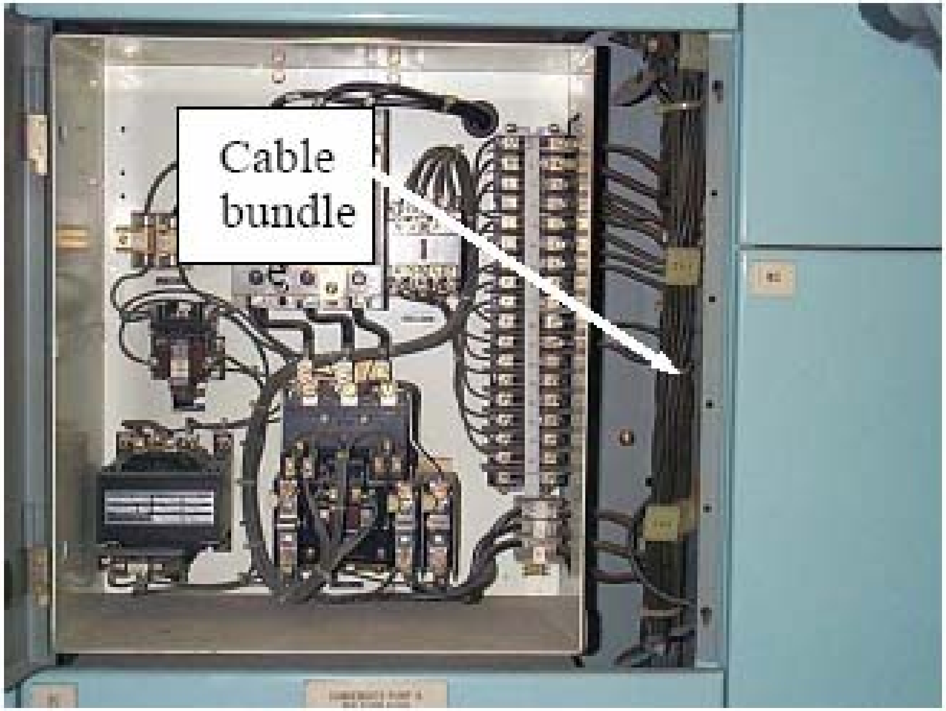
By visual examination:

- 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
  - $\alpha = 1.9$, $\beta = 53.7$
- 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

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-7: Fire Severity

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FIRE SEVERITY
Purpose

A uniform methodology is 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 (here it is defined by heat release rates).
- quantified in combination with *Non-Suppression Probability.*

FIRE SEVERITY
Severity Factor Concept (continued)

The combination of *Severity and Non-Suppression Factors* are calculated from the following equation:

$$SF_k \cdot P_{NS,k} = \int_{All\ t_{damage}} \frac{dP_{dam}(t)}{dt} P_{\sup p}(t_{\sup p} \geq t)dt$$

Where:

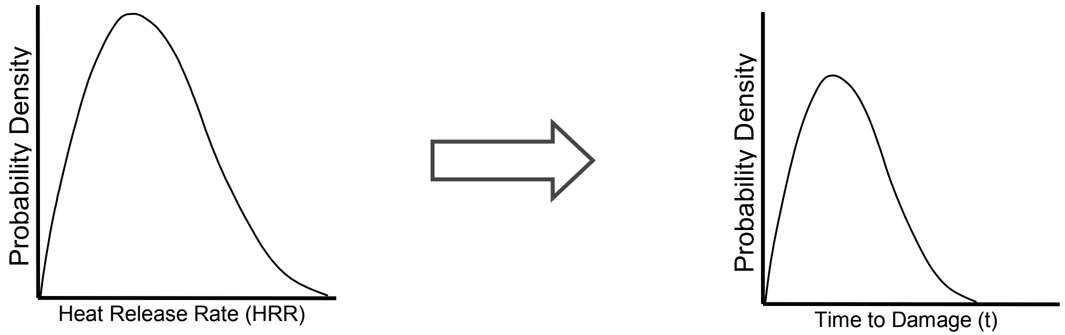
$P_{dam}(t)$: The probability of target set damage before time t.

P_{supp} (t_{supp} > t): Probability of suppression taking place after time t

FIRE SEVERITY
Probability of Damage Estimation

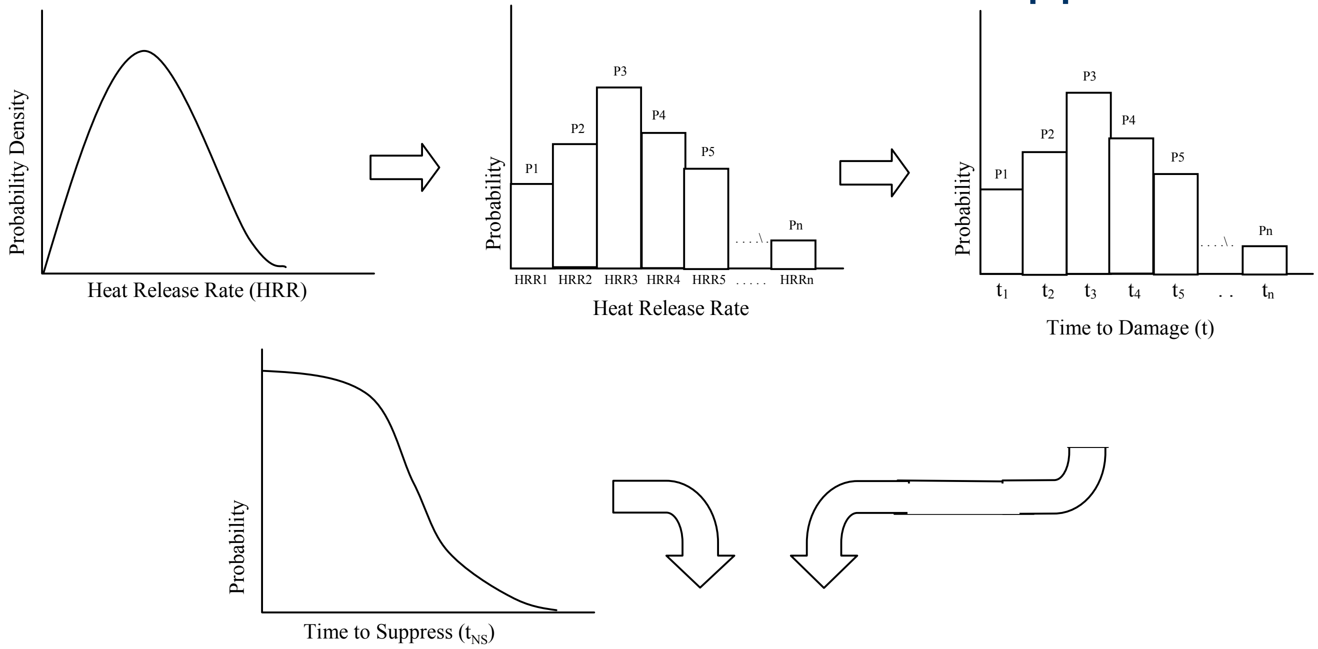
Probability of damage before time t is estimated using complex fire spread and propagation models.

- Heat release rate is a key parameter of the analysis
- Assuming a known heat release rate, compartment characteristics, and 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
Severity Factor Estimation Process

Severity factor is estimated using discretized probability distributions for heat release rate and non-suppression.



HRR Values	HRR1	HRR2	HRR3	HRR4	....	HRRn
Individual Severity Factor	P_1	P_2	P_3	P_4	....	P_n
Time to damage	t_1	t_2	t_3	t_4	....	t_n
Prob. of supp. after damage	P_{NS1}	P_{NS2}	P_{NS3}	P_{NS4}	....	P_{NSn}

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 factor 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.

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

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 8: Damage Criteria

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Joint RES/EPRI Public Workshop

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Charlotte, NC

Module 8: Damage Criteria
Scope of this Module

- Module 8 is all about equipment and cable damage criteria
  - How to estimate damage or failure thresholds
  - How (and when) to estimate time to damage?
  - What do you do about smoke damage?
- Support both Task 8 – Scoping Fire Modeling and Task 11 – Detailed Fire Modeling
- Covered by Appendices H and T in the report
- This is NOT the failure modes and effects stuff for cables – that is under the circuits tasks!

Module 8: 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)

Module 8: 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

Module 8: 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

Module 8: 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)

Module 8: 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/m^2 (0.5 BTU/ft2s)	205°C (400°F)
Thermoset	11 kW/m^2 (1.0 BTU/ft2s)	330°C (625°F)

- and electronics:
  - 3 kW/m^2 (0.25 BTU/ft^2) and 65°C (150°F)
  - If needed, assume ignition properties same as thermoplastic cables: 6 kW/m^2 (0.5 BTU/ft^2) and 205°C (400°F).

Module 8: 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.

Module 8: 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

Module 8: 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?

Module 8: 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

Module 8: 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

Module 8: 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

Module 8: 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

Module 8: 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

Module 8: 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

Module 8: Damage Criteria
End of Module

- Questions?
- Comments?
- Discussion?

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-9: Scoping Fire Modeling Task 8 and Appendix F

Francisco Joglar

SAIC

Joint RES/EPRI Public Workshop

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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
- 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

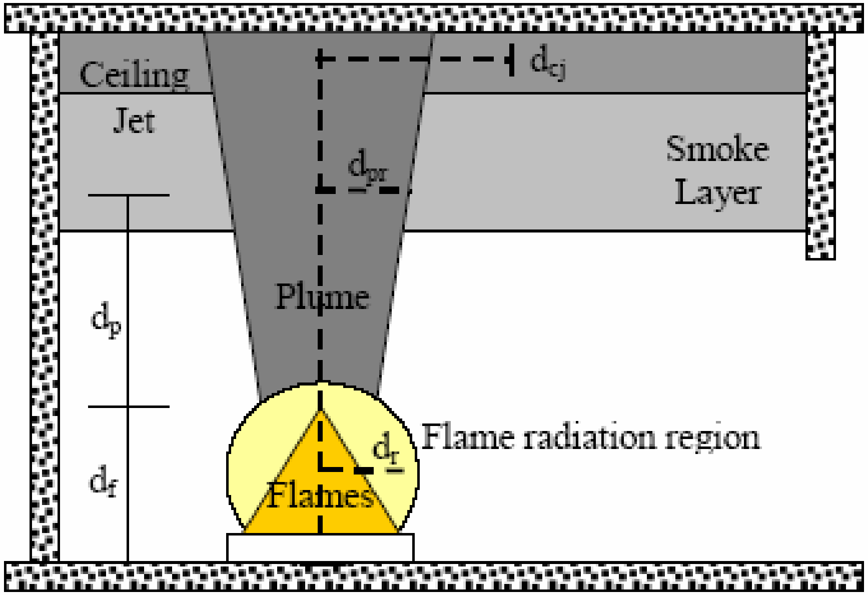
Any ignition source can be screened if a postulated fire will not damage or ignited equipment in the compartment.

- 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 are 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)
- Collect damage criteria information for the equipment in the room
  - Qualified/Unqualified cables, solid state equipment etc.
- Develop and document zone of influences in each compartment

SCOPING FIRE MODELING
Step 1: Example of ZOI Form

Plant ______

Fire Area ______

Compartment ______

Room Geometry

Opening area [m2]	2.0
Height of opening [m]	2.0
Room length [m]	32.0
Room width [m]	32.0
Room height [m]	6.4
Ambient temperature [C]	20

Material	Concrete
Thermal conductivity [kW/mK]	0.001
Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.30

Damage Criteria	UQ	Q
Temperature [C]	205	330
Heat flux [kW/m2]	6	11

Ignition Source

Fire duration [sec]	600
Fire diameter [m]	0.60
Fire location factor	1.00
Fire elevation [m]	0.00
Radiated fraction	0.40

ZONE OF INFLUENCE

PE/PVC Cable	Vertical cabinets with qualified cable, fire limited to one cable bundle	Vertical cabinets with qualified cable, fire in more than one cable bundle	Vertical cabinets with unqualified cable, fire limited to one cable bundle	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	Pumps	Motors	Transient combustibles
98th Per HRR (kW)	211	702	211	464	1002	211	69	317
Flames (m)	1.4	2.6	1.4	2.1	3.1	1.4	0.7	1.7
Plume (m)	2.2	3.9	2.2	3.2	4.6	2.2	1.2	2.7
Ceiling Jet (m)	0.1	0.2	0.1	0.1	0.3	0.1	0.02	0.1
Flame Radiation (m)	1.1	1.9	1.1	1.6	2.3	1.1	0.6	1.3
Smoke Layer (kW)	3198	3198	3198	3198	3198	3198	3198	3198

Qualified Cable

98th Per HRR (kW)	211	702	211	464	1002	211	69	317
Flames (m)	1.4	2.6	1.4	2.1	3.1	1.4	0.7	1.7
Plume (m)	1.6	3.0	1.6	2.5	3.6	1.6	0.8	2.0
Ceiling Jet (m)	0.03	0.10	0.03	0.07	0.14	0.03	0.01	0.04
Flame Radiation (m)	0.8	1.4	0.8	1.2	1.7	0.8	0.4	1.0
Smoke Layer (kW)	6938	6938	6938	6938	6938	6938	6938	6938

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

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.

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 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 II: Task 11a - Detailed Fire Modeling, Single-compartment fires

Bijan Najafi, SAIC

EPRI/NRC-RES Fire PRA Workshop

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TOPICS

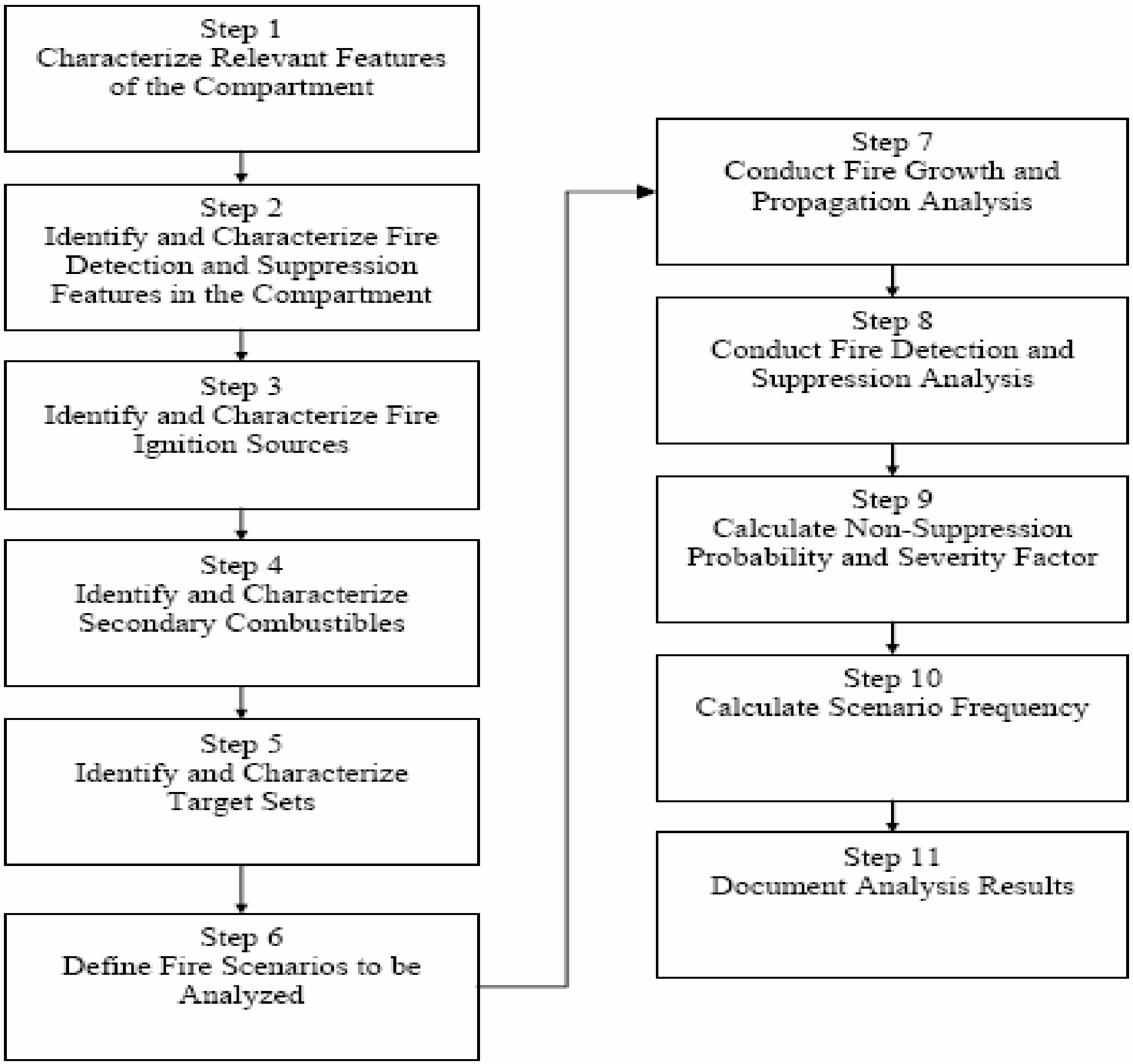
The objectives of this module are:

- 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

FIRE MODELING

- **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 events
  - 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, i.e., cables, habitability, etc.

PROCESS


Step 1
Characterize Relevant Features of the Compartment
Step 2
Identify and Characterize Fire Detection and Suppression Features in the Compartment
Step 3
Identify and Characterize Fire Ignition Sources
Step 4
Identify and Characterize Secondary Combustibles
Step 5
Identify and Characterize Target Sets
Step 6
Define Fire Scenarios to be Analyzed
Step 7
Conduct Fire Growth and Propagation Analysis
Step 8
Conduct Fire Detection and Suppression Analysis
Step 9
Calculate Non-Suppression Probability and Severity Factor
Step 10
Calculate Scenario Frequency
Step 11
Document Analysis Results

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

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 fires 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)

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.

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.
  - 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 may benefit if some information on target location within the compartment is available or can be postulated with reasonable confidence
- Identify failure modes of equipment due to fire damage to the equipment or associated circuits.

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

PROCESS
Select Fire Scenarios (Cont.)

- 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 compartment with few fire source and many target sets (e.g., a switchgear room), start with an ignition source, postulate potential growth and propagation to other combustibles and 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 target (e.g., a PWR auxiliary building),
    - Close source/target combinations, AND
  - In all cases the scenario where a fire has the best chance for spread and potential room-wide damage should be postulated

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

PROCESS
Conduct 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

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

PROCESS
Calculate Fire Scenario Frequency

Severity factor for scenario k

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

Ignition frequency for scenario k

Non-suppression probability for scenario k

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.