EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-10: Task 11a - Detailed Fire Modeling and Single Compartment Fire Scenarios

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

Module II-10: TOPICS

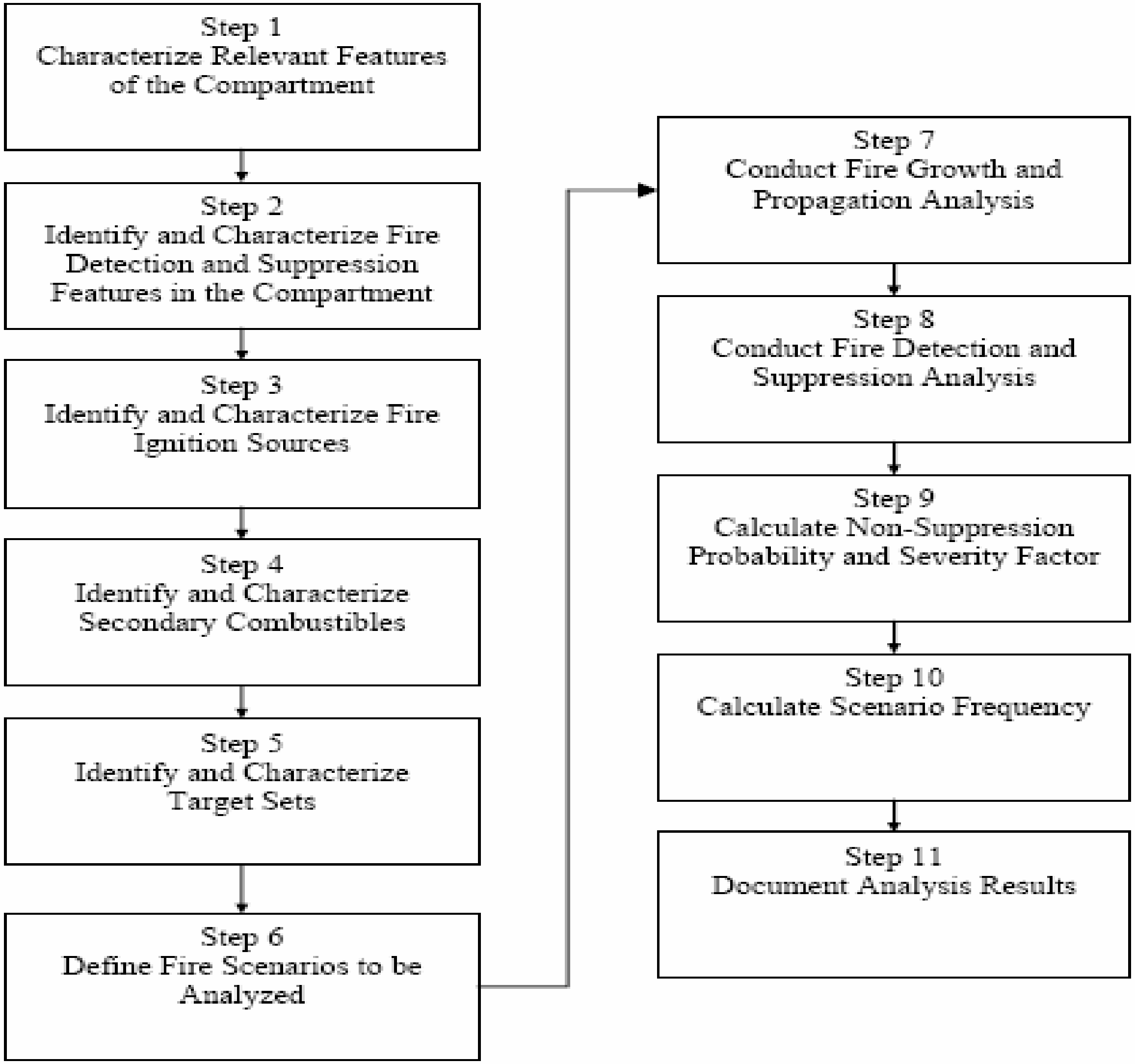
The objectives of this module are:

- 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 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.

Module II-10: PROCESS
General Task Structure



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

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

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 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)

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.

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.
  - 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.

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.)

- 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

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

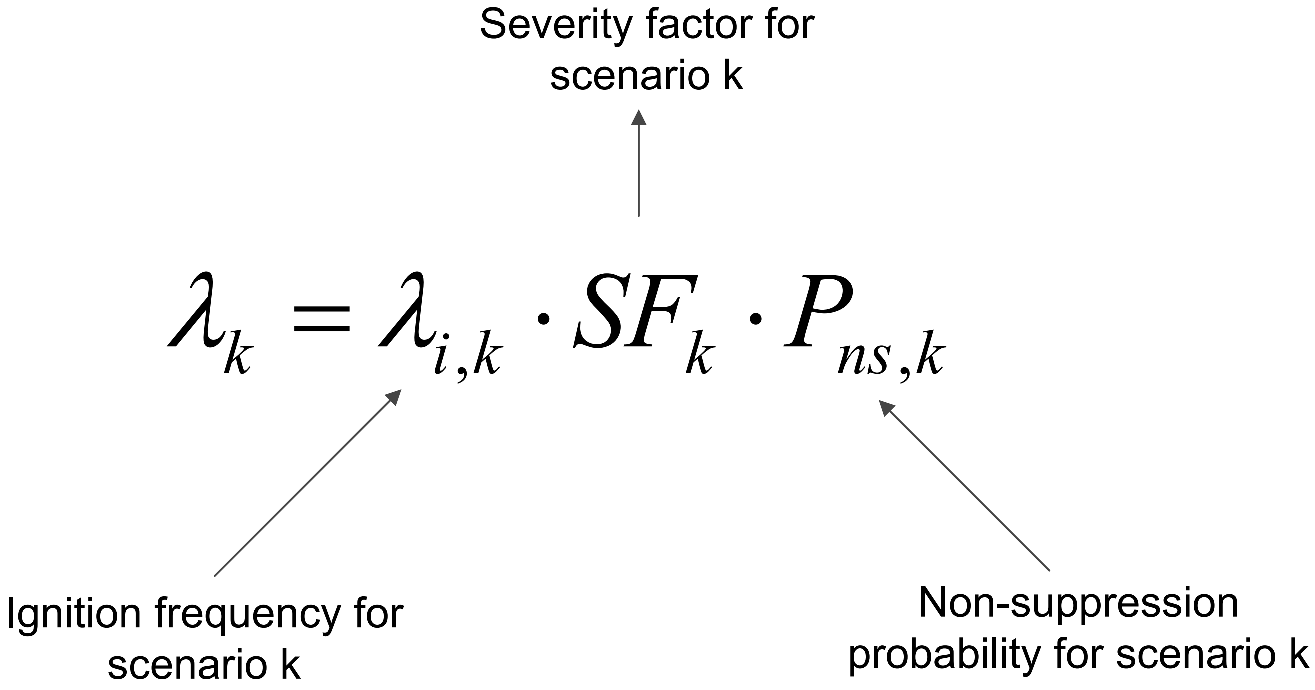
Module II-10: PROCESS
Fire Detection/Suppression Analysis

- 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

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

Module II-10: 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

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.

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EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-11 Pt. 1: Task 11, Special Fire Models Part 1

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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 10)

- 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

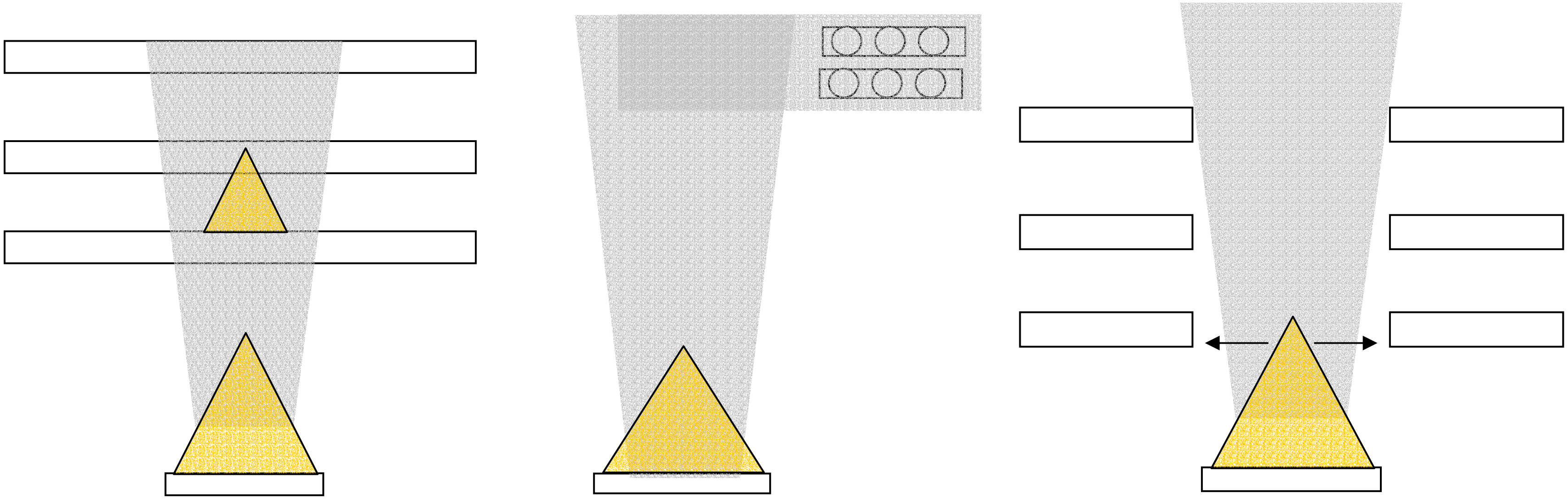
CABLE FIRES (2 of 9)

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 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

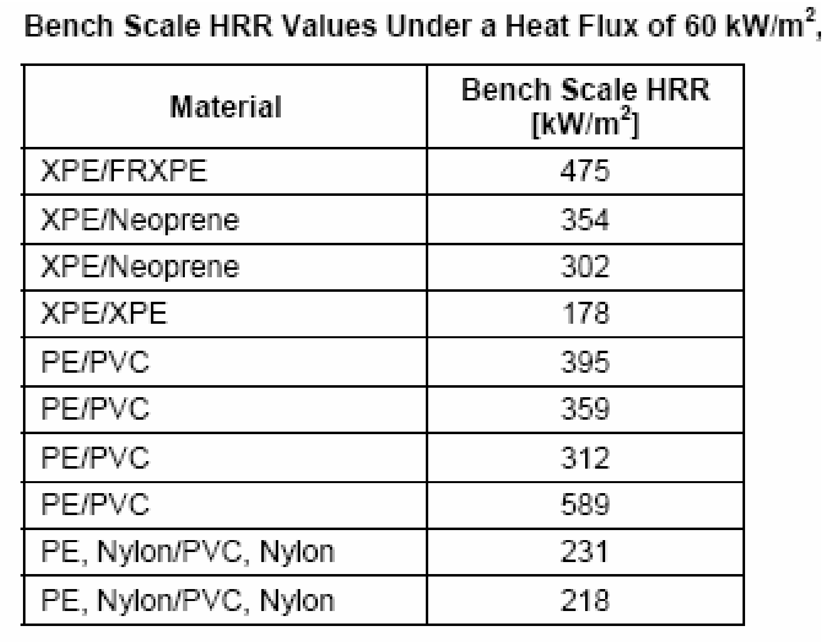


CABLE FIRES (4 of 9)

Heat release rate from cable fires

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

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



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

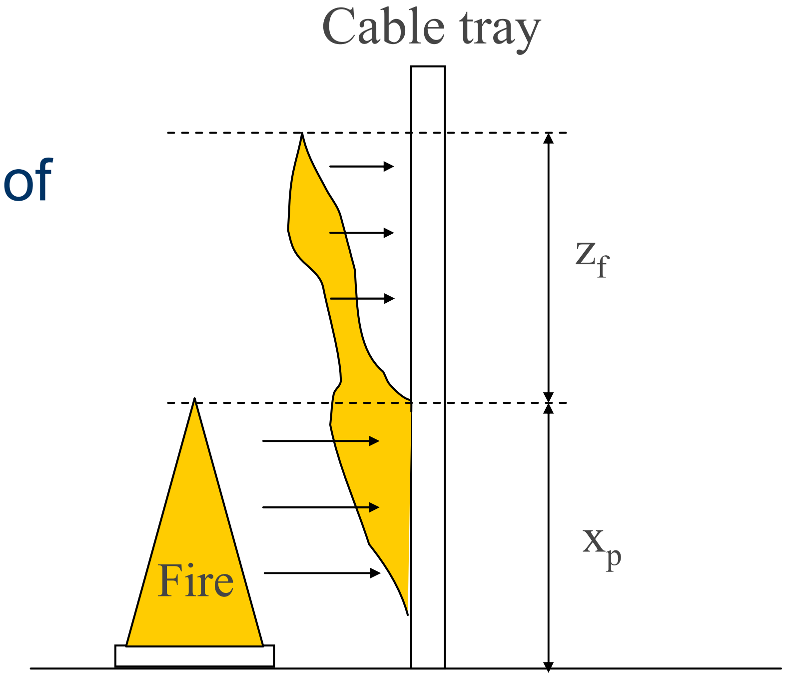
Material	Bench Scale HRR [kW/m^2]
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
PE/PVC	395
PE/PVC	359
PE/PVC	312
PE/PVC	589
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218

CABLE FIRES (5 of 9)

Flame spread

- kf is a constant with a value of 0.01 m²/kW

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

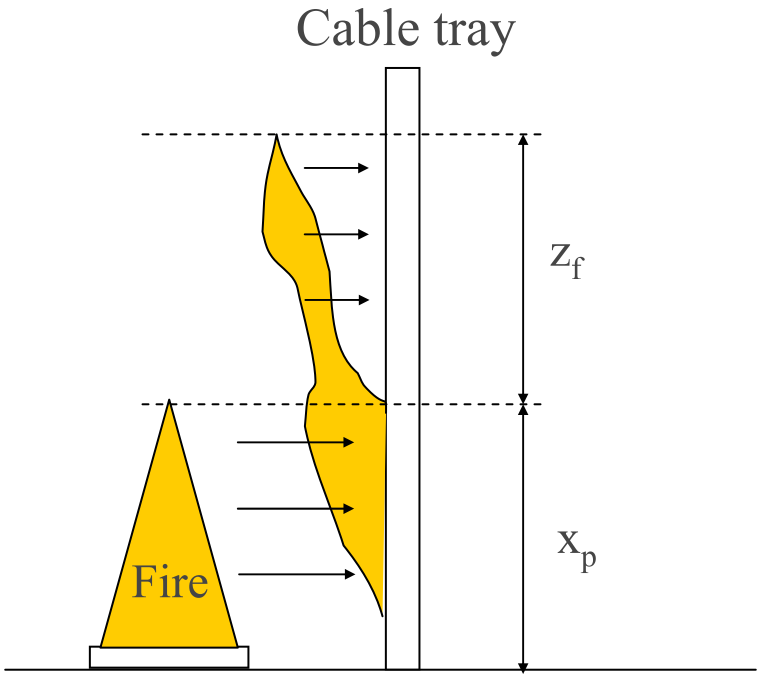


CABLE FIRES (6 of 9)

Flame spread model

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

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



CABLE FIRES (7 of 9)

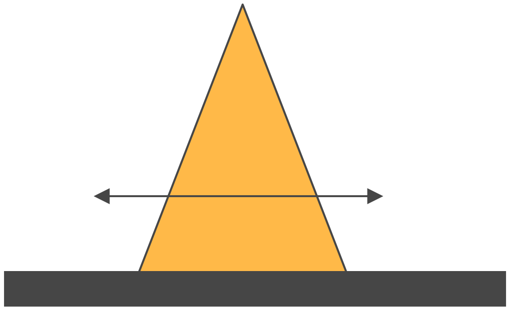
Example

- Material properties
  - PVC cables:
    - $K = 0.000192$ kW/m K
    - $\rho = 1380$ kg/m^3
    - $C_p = 1.289$ kJ/kg K
    - $T_{ig} = 218$°C
  - XPE cables:
    - $K = 0.000235$ kW/m K
    - $\rho = 1375$ kg/m^3
    - $C_p = 1.390$ kJ/kg K
    - $T_{ig} = 330$°C

CABLE FIRES (8 of 9)

Example

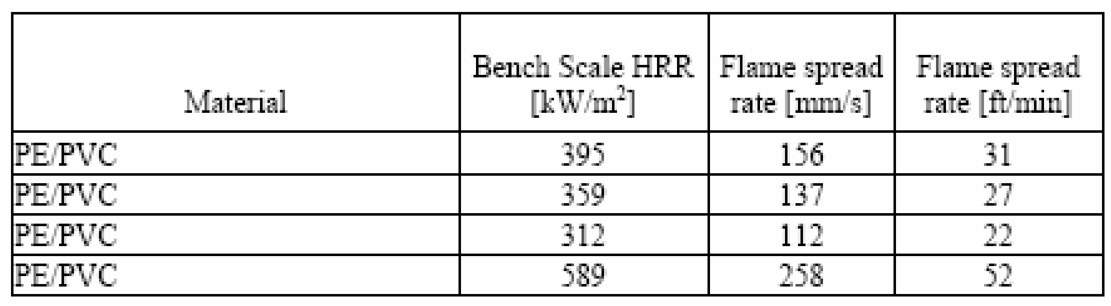
- Horizontal trays
  - Flame spread for XPLE cable = 0.3 mm/sec (~0.05′/min)
  - Flame spread for PVC cable = 0.9 mm/sec (~0.2′/min)



CABLE FIRES (9 of 9)

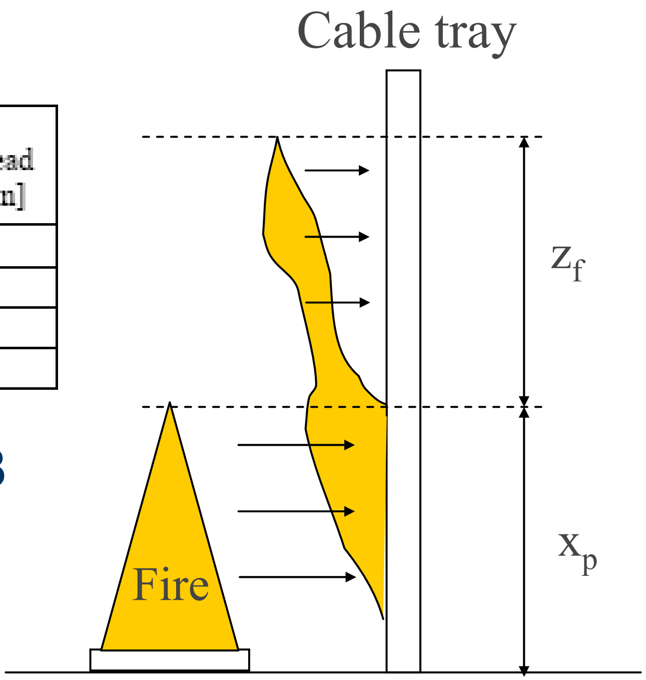
Example

- Vertical spread in cables
- PE/PVC cables

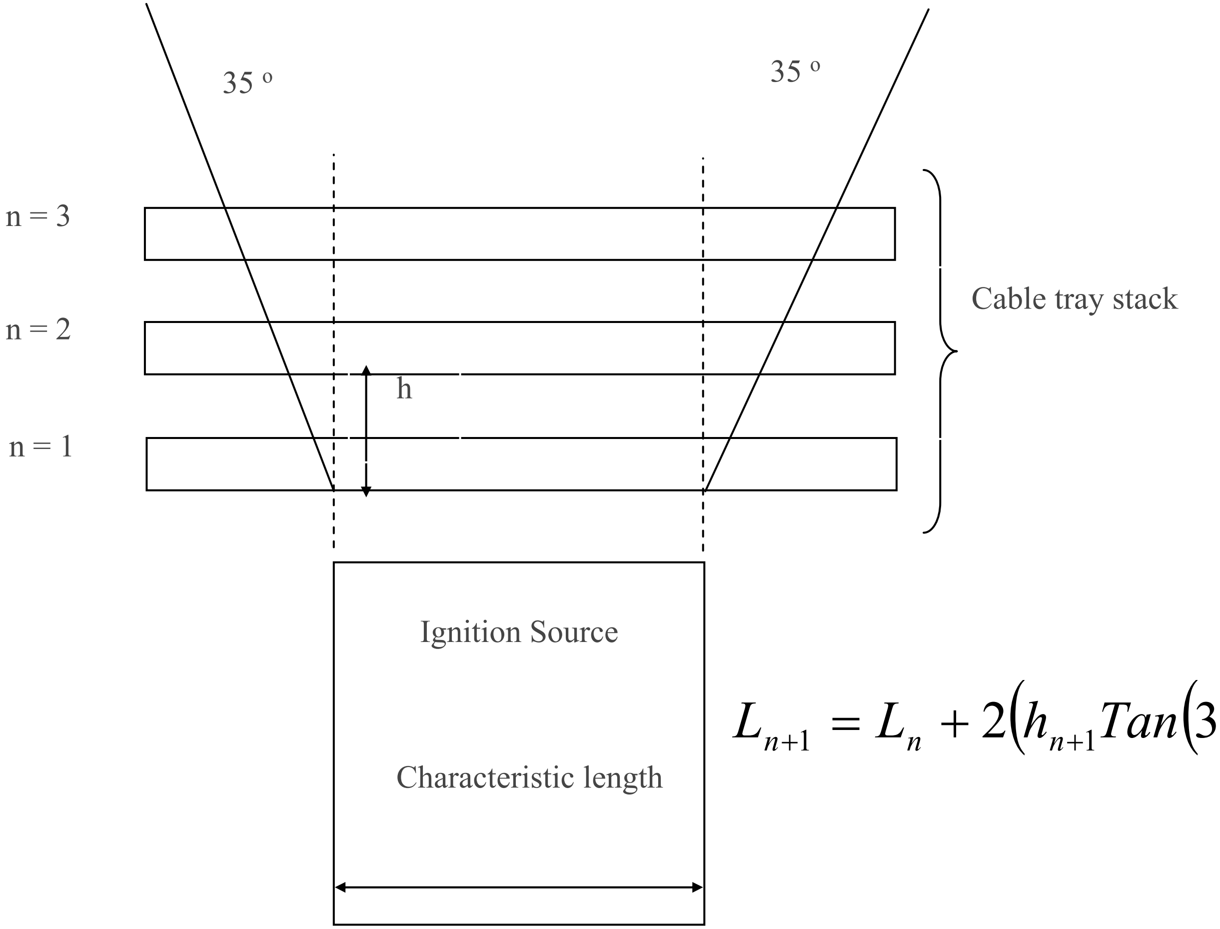


Material	Bench Scale HRR [kW/m²]	Flame spread rate [mm/s]	Flame spread rate [ft/min]
PE/PVC	395	156	31
PE/PVC	359	137	27
PE/PVC	312	112	22
PE/PVC	589	258	52

- The heat release rate for XPE cable is 178 kW/m². 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
- 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

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. This is 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.

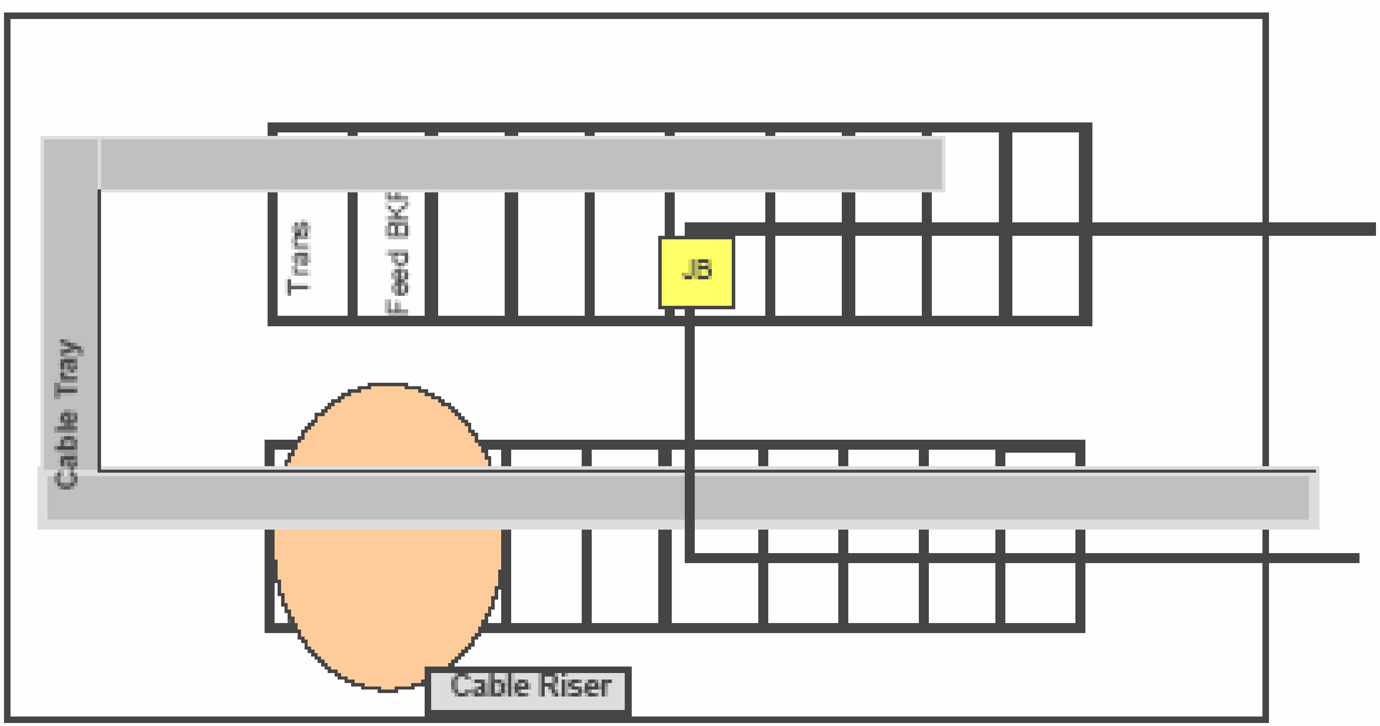
HIGH ENERGY ARCING FAULTS (6 of 16)

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.
- The second phase, i.e., the ensuing fire(s), is treated similar to electrical cabinet fires described else where 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 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 oC).
- 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 CO2 extinguishers.

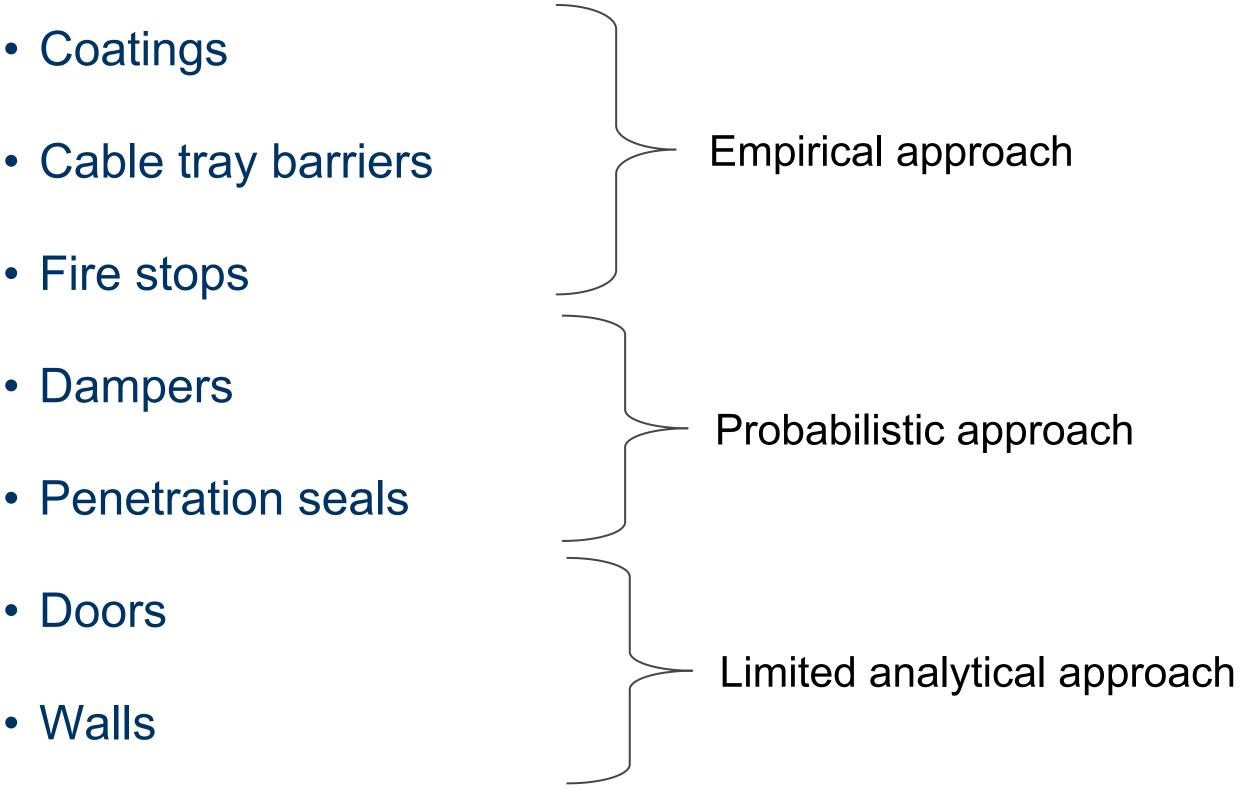
PASSIVE FIRE PROTECTION FEATURES (1 of 6)

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
- Dampers
- Penetration seals
- Doors
- Walls

Empirical approach

Probabilistic approach

Limited analytical approach

PASSIVE FIRE PROTECTION FEATURES (3 of 6)

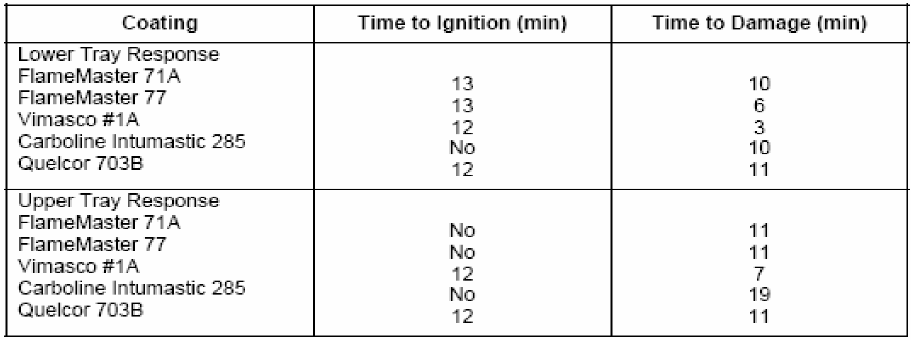
The analytical approach for modeling the response of passive fire protection features to fire generated conditions consists of a heat transfer analysis.

- 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 can 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.
- 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

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-11 Pt. 2: Special Fire Models Part 2

Steve Nowlen - Sandia National Laboratories

Joint RES/EPRI Fire PRA Workshop
May 24-26, 2006
Rockville, MD

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

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

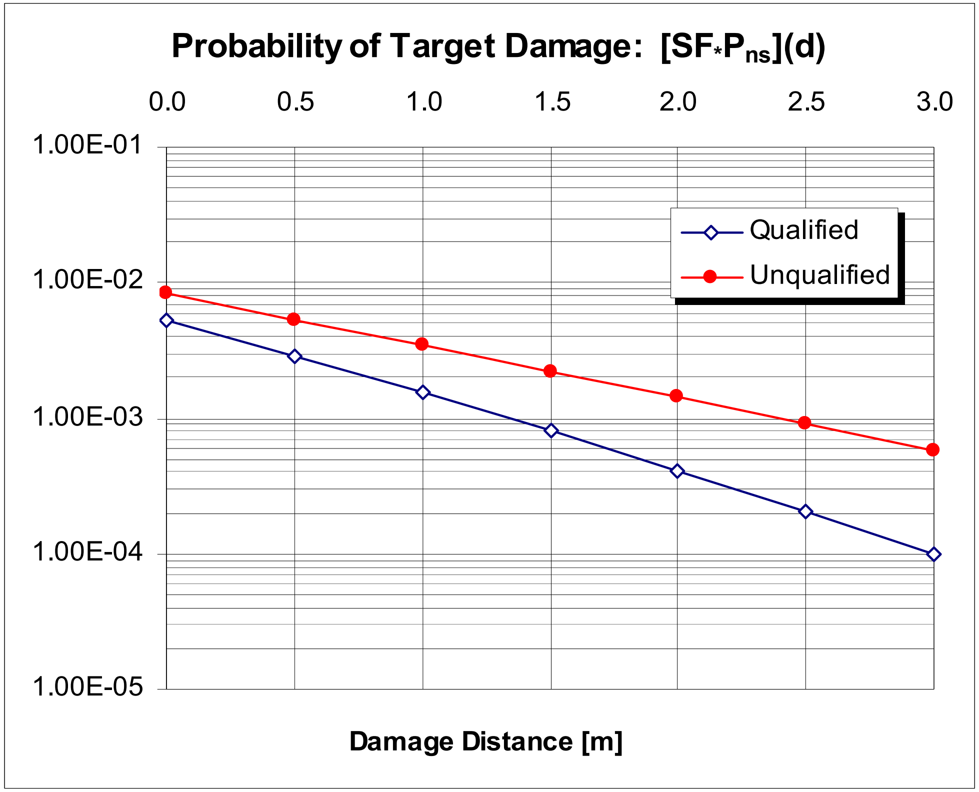
- The MCB model is built on several assumptions that are specific to the MCB and the MCR
  - MCB fire frequency partitioning approach
  - Suppression times for MCR fires
  - Fire characteristics of a MCR type control panel (peak HRR and growth profile)
  - Damage limits for control components
- This 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 rack 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 II-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



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 II-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 II-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 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 II-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 II-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 involve 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 II-11, Pt. 2: Special Models Part 2

Turbine Generator Set Fires: Catastrophic Failure

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

  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 II-11, Pt. 2: Special Models Part 2

Hydrogen Fires

- This discussion (Appendix N) applies to general hydrogen fires
  - Including TG set fires
  - Also other source of hydrogen leaks and releases (e.g., recombiners, storage tanks, piping, etc.)
- The intent was to provide more 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 II-11, Pt. 2: Special Models Part 2

Hydrogen Fires

- Two general types of fires:
  - Jet fires originating at point of a H2 leak
    - Critical question will be flame length
  - Explosions
    - If there is a mechanism for the release of large quantities of H2 (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

Module II-11, Pt. 2: Special Models Part 2

End of Module

- Questions?
- Comments?
- Discussion?

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-12: Detection and Suppression Appendix P

Francisco Joglar - SAIC

Joint RES/EPRI Fire PRA Workshop
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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

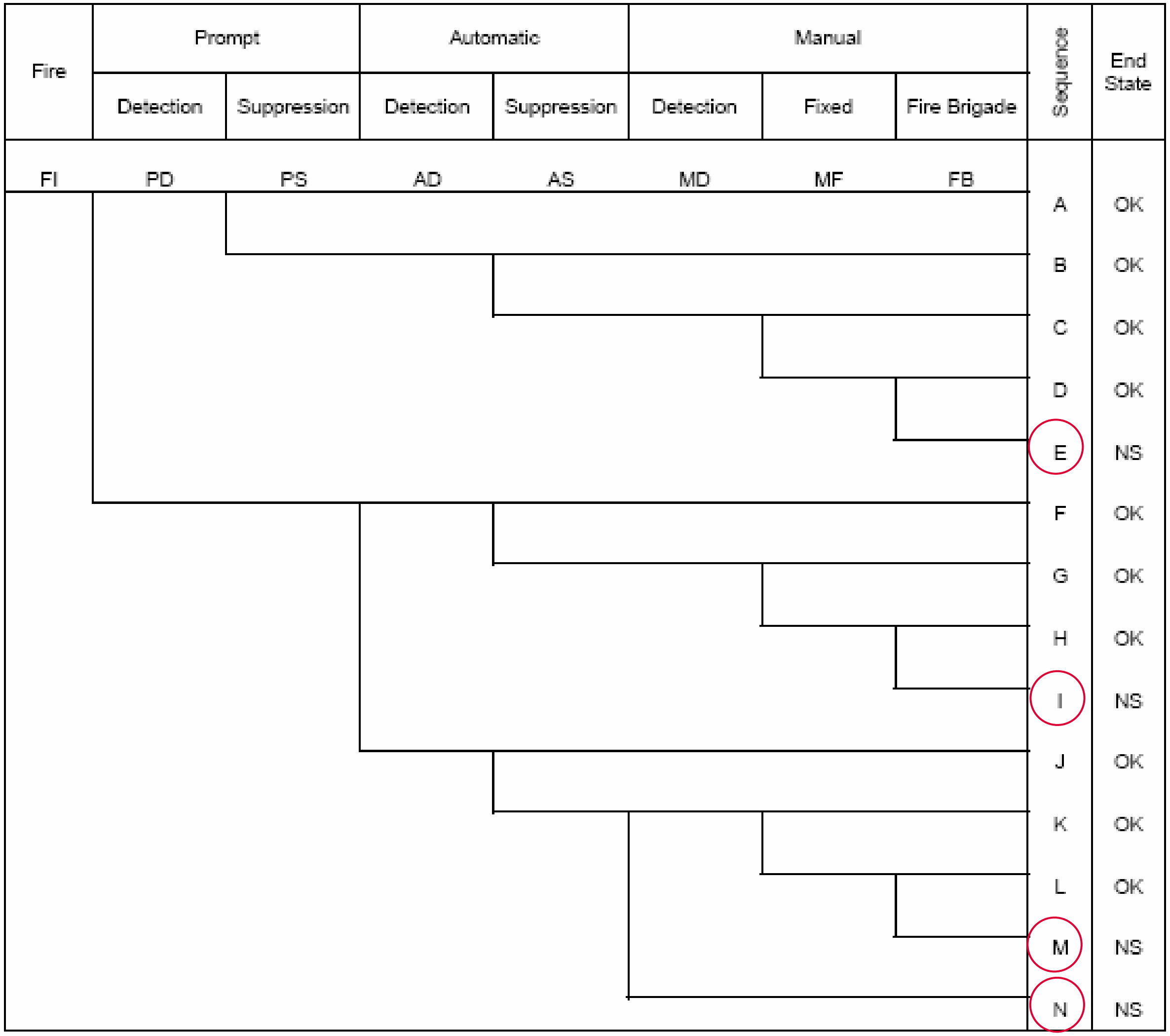
- Effectiveness – Will the system detect/control the fire?
  - Designed, installed and maintained according to the code of record and fire protection engineering judgment
  - Based on the specific characteristics of the postulated fire scenario
- Available – Probability of the system operating upon demand

DETECTION & SUPPRESSION
Fire Detection and Suppression Systems

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

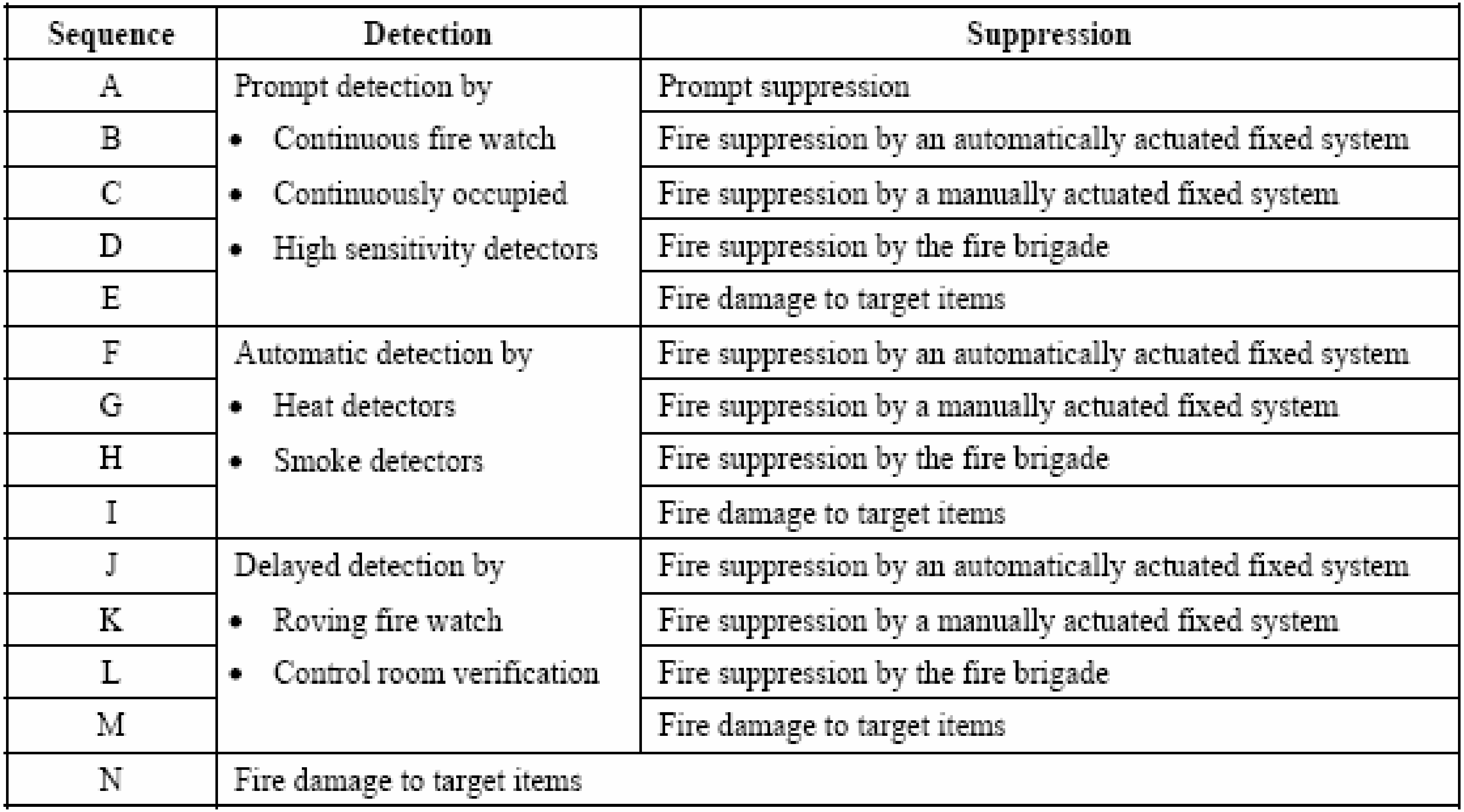
- Fire Detection
  - Prompt detection
  - Automatic detection
  - Delayed detection
- Fire Suppression
  - Prompt suppression
  - Automatic suppression
  - Manually actuated fixed suppression
  - Manual suppression

DETECTION & SUPPRESSION
Detection-Suppression Event Tree



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

DETECTION & SUPPRESSION
Detection-Suppression Event Tree



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

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

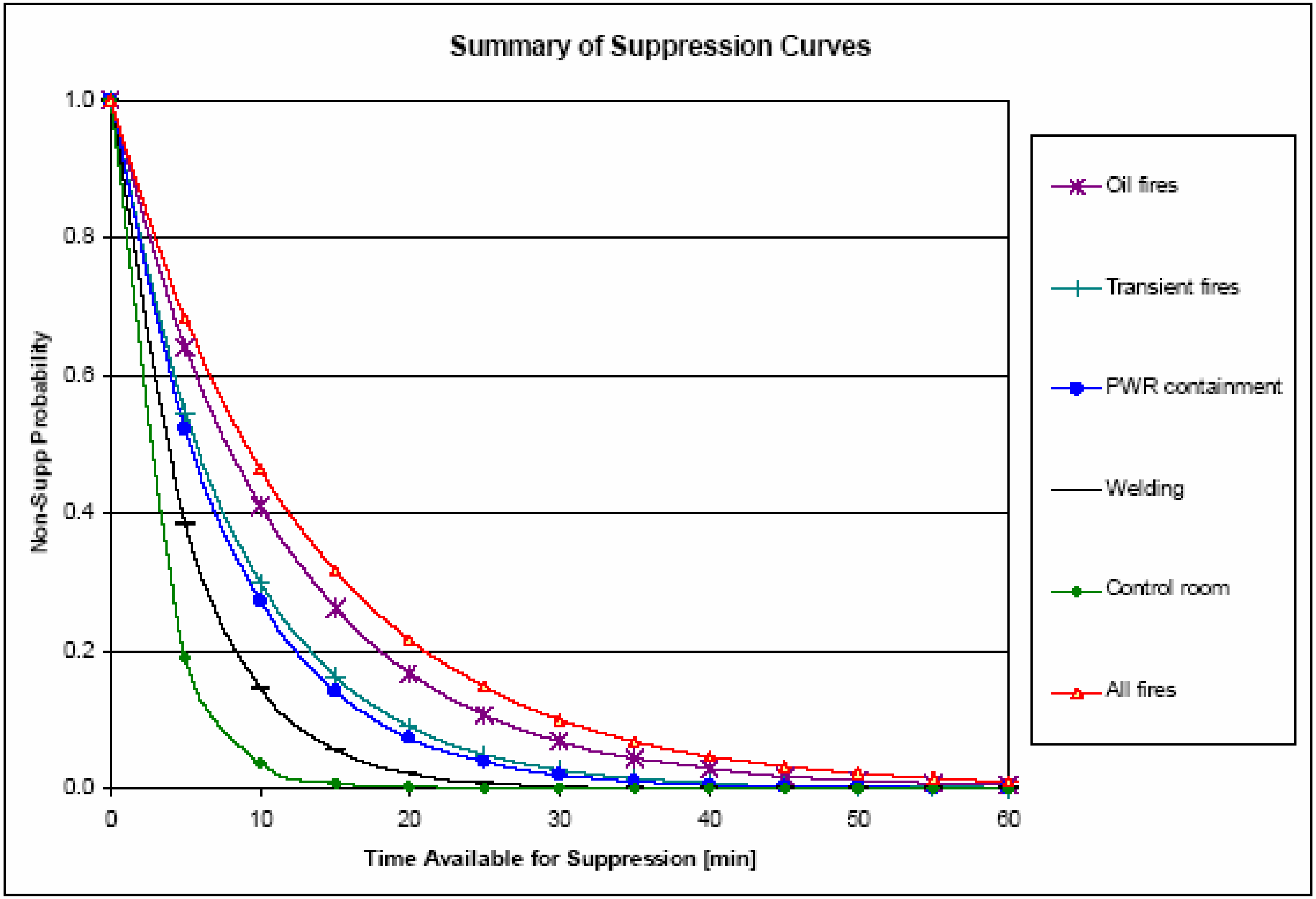
- Developed with the “suppression time” field. If the suppression time was not available, the “duration” field was used.
- Data do not include supervised burn-outs, fires suppressed with automatic systems, and self-extinguished fires.
- Do not include time to detection or fire brigade response.

DETECTION & SUPPRESSION
Selection of Suppression Curves

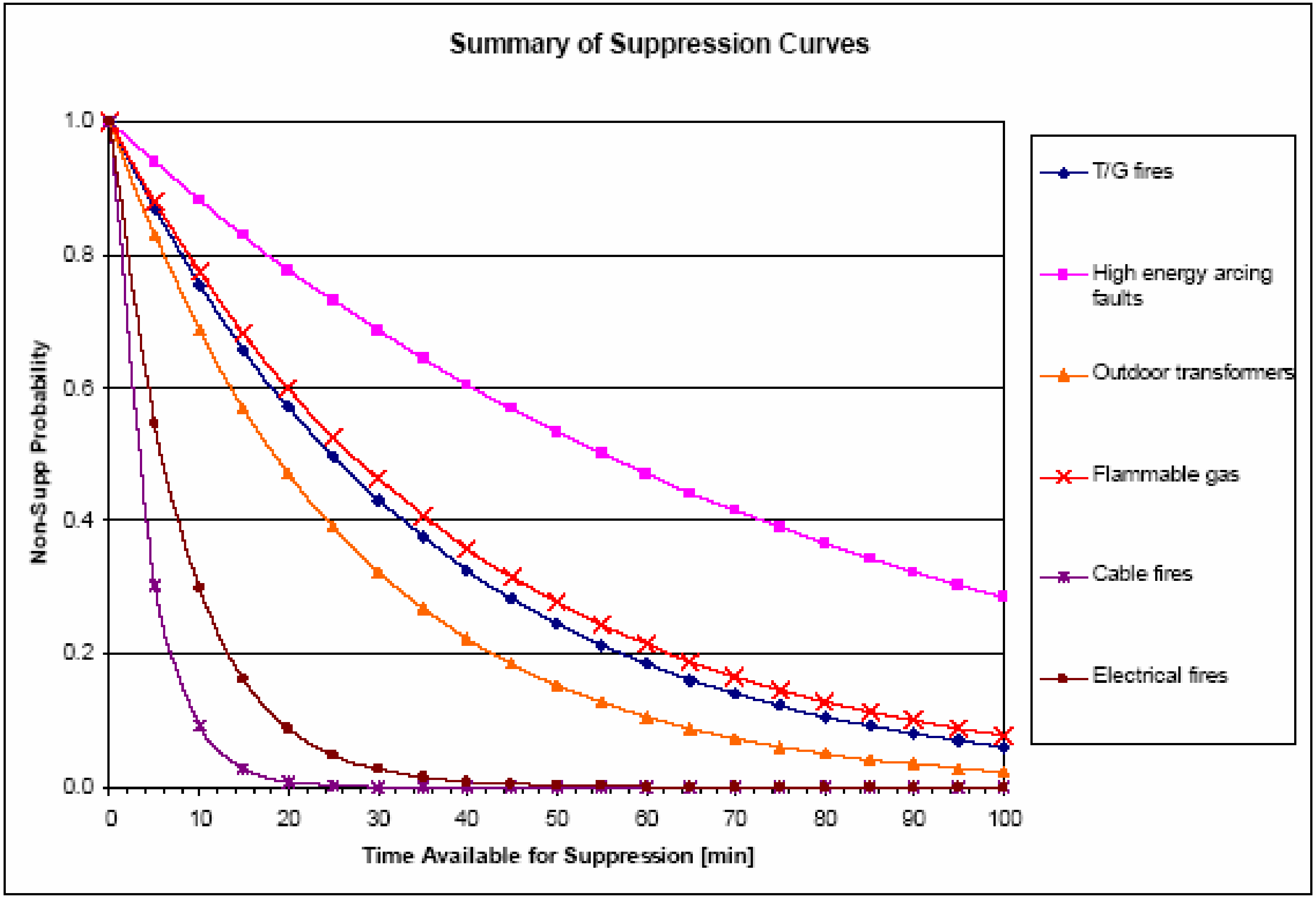
The suppression curve should be selected based on the type of postulated fire.

- 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

$$P = e^{-\lambda t_{dam}}$$

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:

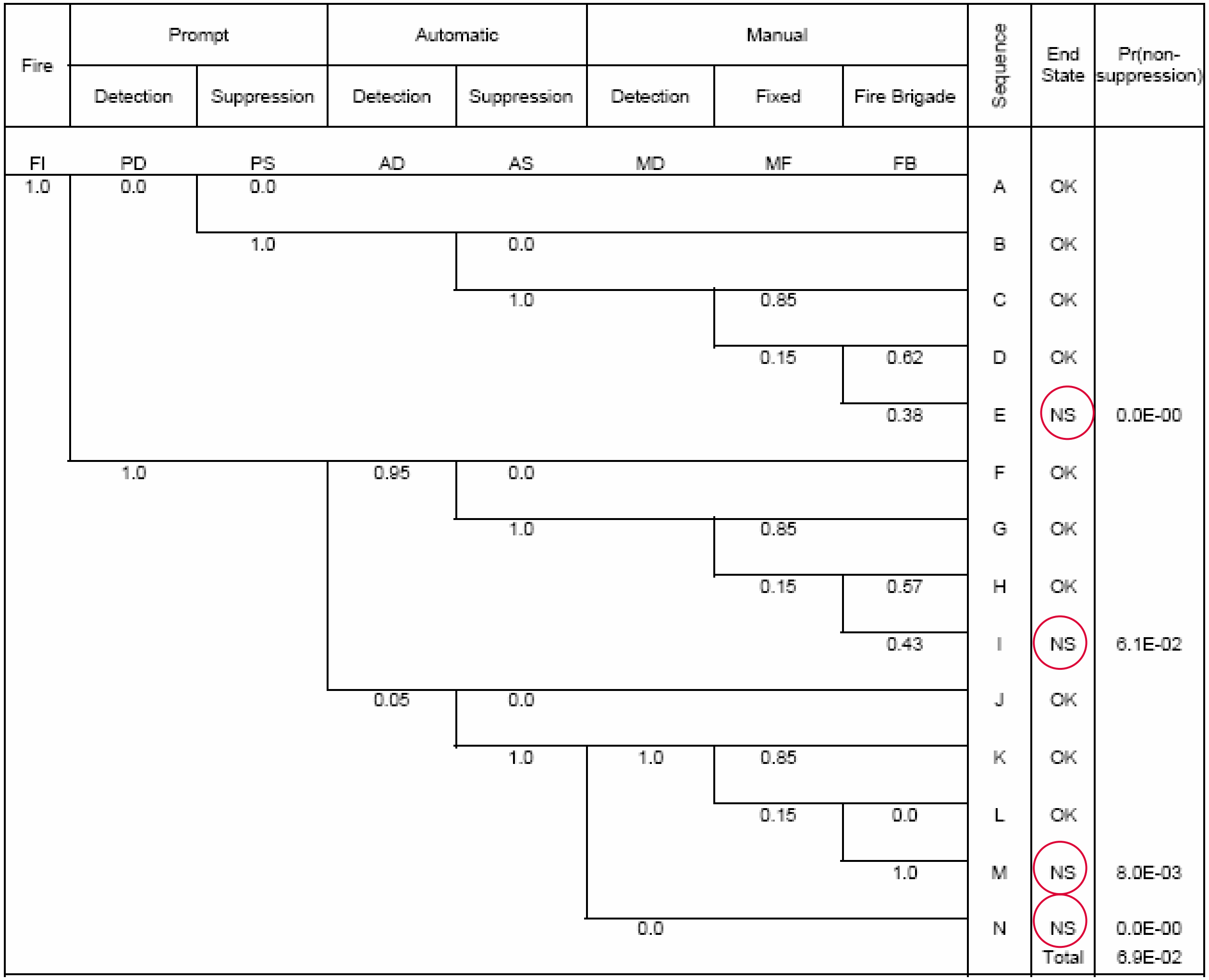
- Between automatic detection and suppression
  - Example: control panel for a gaseous suppression system
- Between actuated barriers and fire suppression systems
- Between safe shutdown capabilities and automatic suppression
  - Example: crediting fire fighting water for core injection, heat removal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

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

$$P_{ns} = 6.9E - 2$$

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

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-13: Task 11b, Detailed Fire Modeling and Multi-Compartment Fire Scenarios

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Joint RES/EPRI Fire PRA Workshop
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Rockville, MD

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 heavily 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 are one 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 (Continued)

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 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 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

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module II-14: Task 11c - Main Control Room Fire Scenarios

Francisco Joglar - SAIC

Joint RES/EPRI Fire PRA Workshop

May 24-26, 2006

Rockville, MD

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

Fire Modeling in the Main Control Room
Objectives

The objectives of this module are:

- 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 calculate:
    - Forced control room abandonment time
    - Conditional probability of damage to a target set

Fire Modeling in the Main Control Room
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 may be installed within a short distance
  - small fires within control panels may be risk-significant.
- The room is continuously occupied, which provides the capability of "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).

Fire Modeling in the Main Control Room 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

Fire Modeling in the Main Control Room
Step 2: Control Room Fire Frequency

The MCR fire frequency includes contributions form the PWC-main control board, PWC-Electrical cabinets, PWC-Self Ignited Cable Fires, Control/Aux/Reactor Bldg – general transient fires, and Control/Aux/Reactor Bldg – transient and cable fires caused by welding and cutting as follows:

$$\begin{aligned}\lambda_{\text{MCR}} = W_{\text{L,MCR}}(\lambda_{\text{MCB}} &+ W_{\text{PWC,Elec.Cab,MCR}}\,\lambda_{\text{PWC,Elec.Cab.}}\\ &+ W_{\text{PWC,SICF}}\,\lambda_{\text{PWC,SICF}} + W_{\text{transients,MCR}}\lambda_{\text{transient}}\\ &+ W_{\text{welding,MCR}}(\lambda_{\text{welding}} + \lambda_{\text{welding-cables}}))\end{aligned}$$

Fire Modeling in the Main Control Room
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.

Fire Modeling in the Main Control Room
Step 7: Define Fire Scenarios

Four types of fire scenarios are specifically recommended for evaluation

- Fire inside one control panel or multiple adjacent control panels (including the main control board) that open into each other,
- Fires affecting two adjacent control cabinets that do not open into each other; and
- Fires affecting two nonadjacent control cabinets,
- Transient fires

Fire Modeling in the Main Control Room
Step 8: Fire Growth and Propagation Analysis

The methodology suggest the following specific approaches for conducting fire growth and propagation analysis:

- Fire inside a control cabinet
  - Use appendix L
- Two adjacent but separated control cabinets
  - No propagation if panels are separated by a double door with an air gap (Appendix S)
  - If separated by a single wall, $\lambda_{Adjacent\,Cabinets}(d_a) = \lambda_{MCB}[SF \cdot P_{ns}](d_a)P_{ns}(15\,\text{min})$
  - If open back panels, check for direct radiation or other damaging fire generated conditions
- Non-Adjacent cabinets
  - Very small likelihood of damage a non-adjacent cabinet
  - Check for transient fires between panels
  - Assume time to target damage of 15 min if there is direct exposure from the fire to the panel walls

Fire Modeling in the Main Control Room
Step 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

Fire Modeling in the Main Control Room
Step 10: Estimate Failure Prob Using ASP

Two approaches may be followed:

- An overall failure probability is estimated representing the failure of the 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.

Fire Modeling in the Main Control Room

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 more than control room habitability conditions

Fire Modeling in the Main Control Room
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/m2. 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 its more than 0.4 m away. A light-emitting object will not be seen if its more than 1 m away.
- A panel fire affects two target items 2.13 m (7′) apart.

Fire Modeling in the Main Control Room
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.

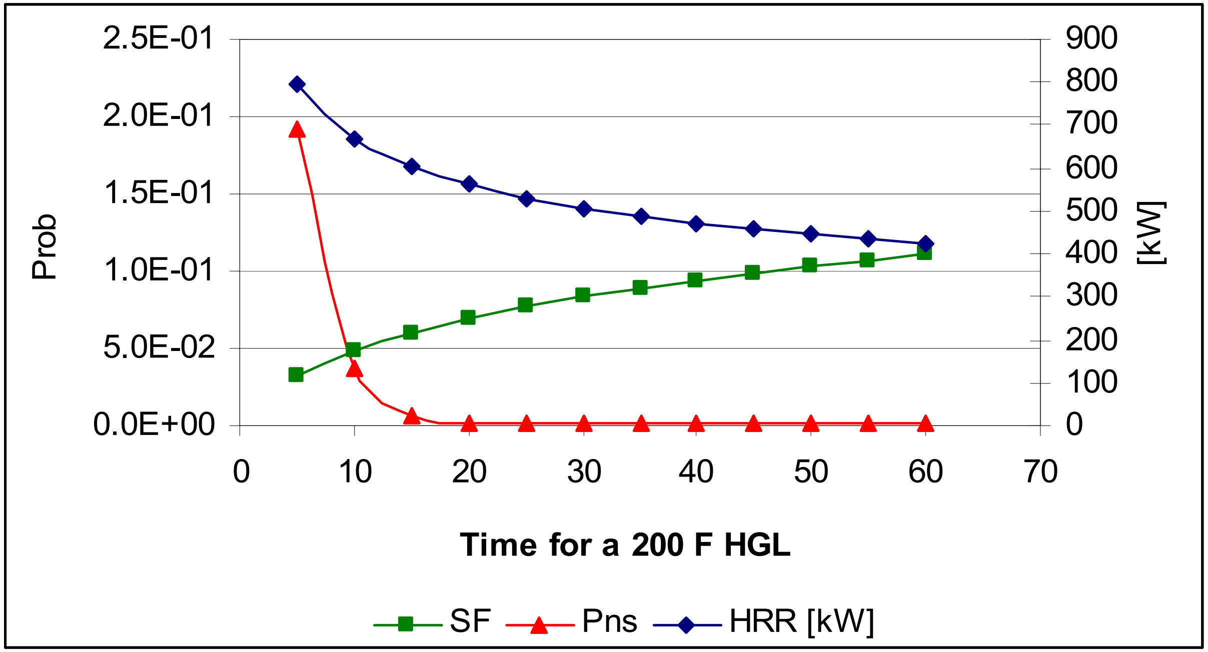
Fire Modeling in the Main Control Room
Example

- Credit prompt detection
- Suppression by fire brigade
  - Pns from CR suppression curve
- SF from probability distribution for vertical cabinets with unqualified cable and fire propagating to more than one bundle.

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

Fire Modeling in the Main Control Room

Example (Cont)



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

Fire Modeling in the Main Control Room

Concluding Remarks

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

- Recommended fire scenarios for the MCR
- Evaluation of MCR abandonment due to fire generated conditions