Module III – Fire Analysis

Fire Scenarios

Joint EPRI/NRC-RES Fire PRA Workshop

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

Let's talk about fire scenarios in a risk analysis…

- In fire PRA we look for and analyze fires that may:
  - Cause an initiating event – an upset to normal at-power plant operations such that reactor shutdown is required
  - Damage mitigating equipment – that set of plant equipment that operators would rely on to achieve safe shutdown
- To do this we:
  - Identify fire sources,
  - Analyze the potential impact of fires on the surroundings,
  - Assess fire protection systems and features,
  - Assess the plant and operator's response to fire-induced damage
- The final result is expressed as a fire-induced core damage frequency (CDF) – an estimate of the frequency of fires leading to core damage

So what is a Fire Scenario?

- A set of elements representing a fire event:
  - The ignition source, e.g., electrical cabinets, pumps
  - Intervening combustibles, e.g., cables
  - Targets (e.g., power, instrumentation or control cables) whose fire-induced failure may cause an initiating event and/or complicate post-fire safe shutdown
  - Fire protection features, e.g., automatic sprinklers
  - The compartment where the fire is located
  - A time line

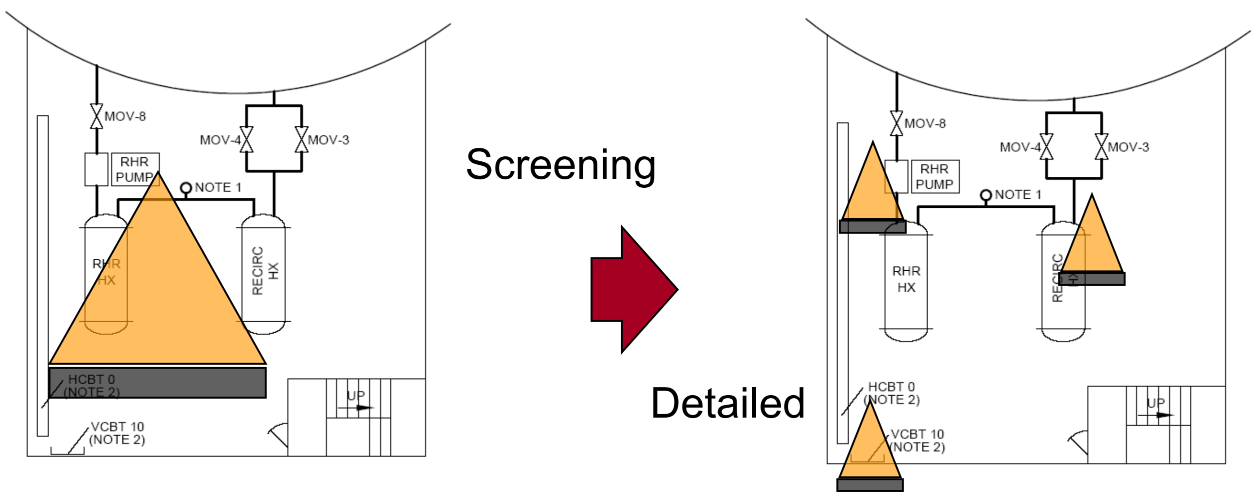
Fire Scenario Time Line

Timeline includes the following elements (not necessarily in this order):

1. Scenario starts with ignition of a fire in a specific fire source
2. Fire growth involving the affected fuel,
3. Heat transfer from the fire to other items within the zone of influence,
4. Propagation of the fire to other materials,
5. Damage to identified PRA targets (e.g., cables and equipment),
6. Detection of the fire
   – Detection can actually occur before ignition given an incipient detection system…
7. Automatic initiation of suppression systems if present,
8. Manual fire fighting and fire brigade response,
9. Successful fire extinguishment ends the scenario.

Fire Scenario - *Level of Detail*

- In practice, varying levels of detail are used to define the fire scenarios in a typical Fire PRA.
  - Level of detail may depend on initial stages of screening, anticipated risk significance of the scenario
- In principle, at any level of detail, a fire scenario represents a collection of more detailed scenarios.



Fire Scenario *Initial Screening Stage*

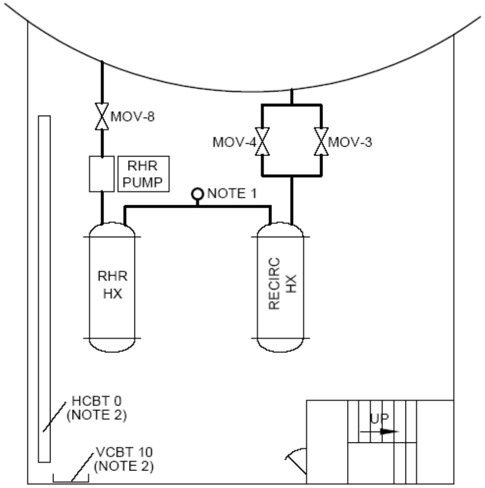
- In the initial stages of screening, fire scenarios are defined in terms of compartments and loss of all items within each compartment.
  - Assumes all items fail in the worst failure mode
  - Detection and suppression occur after the worst damage takes place
  - Fire does not propagate to adjacent compartments
- In multi-compartment fire propagation analysis, a similar definition is used in the initial screening steps for combinations of adjacent compartments.

Detailed Scenario Identification Process

- In the detailed analysis tasks, the analyst takes those fire scenarios that did not screen out in the initial stage and breaks them down into scenarios using greater level of detail.
  - Level of detail depends on the risk significance of the unscreened scenario
  - Details may be introduced in terms of . . .
    - Sub-groups of cables and equipment within the compartment
    - Specific ignition sources and fuels
    - Fire detection and suppression possibilities

Example – Screening Level

- At the screening level, a fire in this compartment fails all equipment and cables shown in this diagram.
- The fire is assumed to be confined to this room



NOTES:

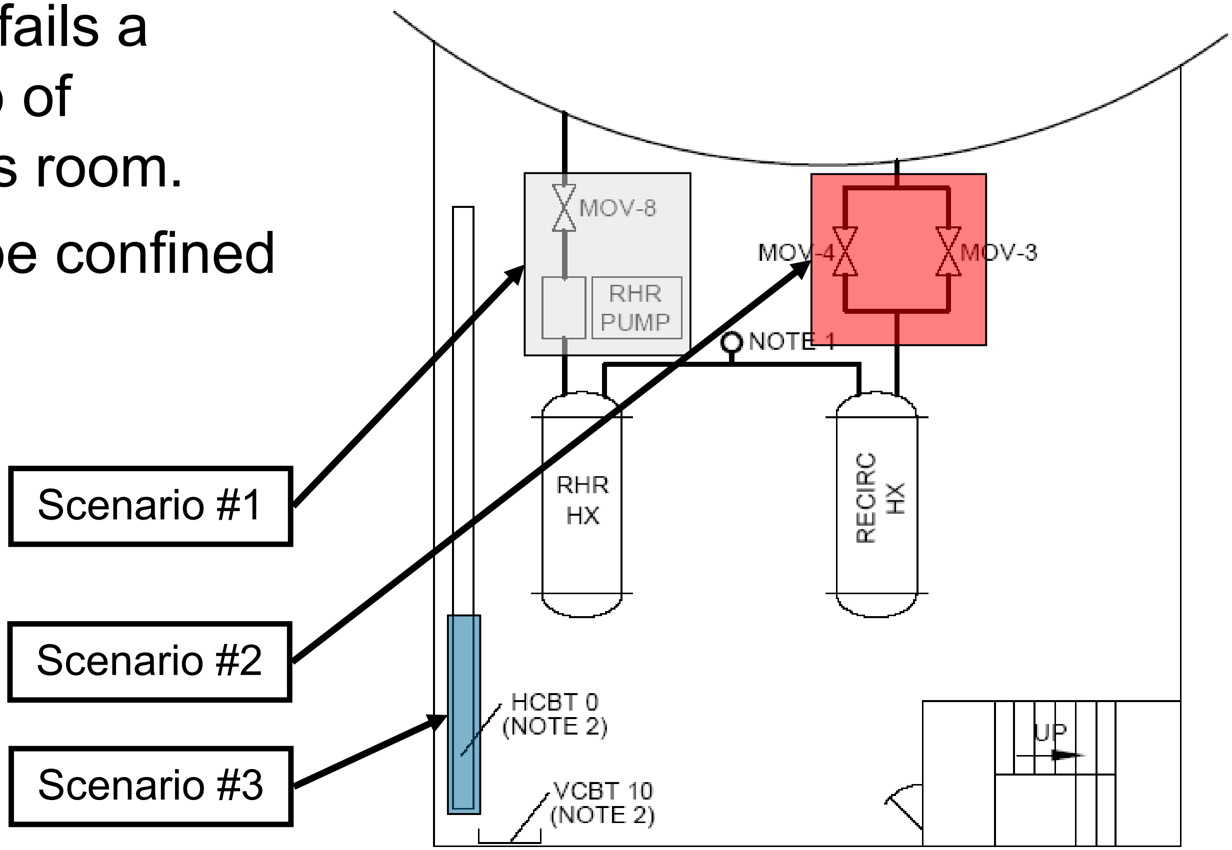
1. VERTICAL PIPE PENETRATION TO UPPER ELEVATION.

2. PENETRATION TO UPER FLOOR IS SEALED.

HCBT: HORIZONTAL CABLE TRAY
VCBT: VERTICAL CABLE TRAY

Example – Detailed Analysis

- At the detailed level, a fire in this compartment fails a specific sub-group of components in this room.
- The fire may still be confined to this room



Select and Describe Fire Scenarios

- Selecting scenarios is dependent on the objectives of the fire risk quantification
  - How many fire scenarios are enough to demonstrate the objective?
  - Which scenarios are the appropriate ones given objectives?
  - What fire conditions are actually modeled?
  - Analysis should represent a complete set of fire sources and conditions as relevant to the analysis objectives
  - A full-scope fire PRA tries to capture all fire scenarios that may represent contributors to plant core damage risk
- Selection of scenarios is dependent on the hazard characteristics of the area
  - Combustibles, layouts, fire protection
- The fire scenario should challenge the conditions being considered
  - Can the fire cause damage? vs. Which fire can cause damage?
  - Fires that don't propagate or cause damage are generally not risk contributors

Select and Describe Fire Scenarios

1. Scenarios begin with an ignition source – what/where does the fire start and what are the fire characteristics
2. Consider intervening combustibles – fire propagation beyond the fire source needs to be considered
3. There should be at least one damage target identified. Often it is a set of damage targets rather than just one (e.g., a group of important cables).
4. Include fire protection system and features (active or passive) that may influence the outcome of the event (there is a pain/gain decision point here)

Select and Describe Fire Scenarios

5. Sometimes, multiple ignition sources or targets can be combined into one scenario (e.g., a bank of cabinets all with the same cables overhead)
6. Sketch the scenario on a compartment layout drawing and try to qualitatively describe the conditions that a fire might generate. After the analysis, compare this qualitative prediction with the modeling results.
7. Do not neglect the importance of details such as ceiling obstructions, soffits, open or closed doors, ventilation conditions, spatial details (e.g., target position relative to fire source), etc.

Scenario Quantification

General quantification of CDF is based on a five-part formula:

$$CDF_{scenario} = \lambda \cdot W \cdot SF \cdot P_{ns} \cdot CCDP$$

- λ = Ignition frequency for the postulated ignition source group (e.g., pumps)
- W = A weighting factor for the likelihood that the fire occurs in a specific ignition source (this pump…) or plant location (this room…)
- SF = A severity factor reflecting percentage of fires large enough to generate the postulated damage if left unsuppressed
- P_{ns} = Non suppression probability – the probability that given the fire, it goes unsuppressed long enough that the target set is damaged
- CCDP = The conditional core damage probability – probability that given loss of the target set, operators fail to achieve safe shutdown and the core is damaged.

In practice, we often quantify scenarios in a progression of more detailed steps:

- A fire in a specific plant location $$CDF_{is} \approx \lambda_g \cdot W_{is} \cdot 1 \cdot 1 \cdot 1$$
- …That is severe enough to threaten targets $$CDF_{is} \approx \lambda_g \cdot W_{is} \cdot SF \cdot 1 \cdot 1$$
- …That goes unsuppressed long enough to cause damage $$CDF_{is} \approx \lambda_g \cdot W_{is} \cdot SF \cdot P_{ns} \cdot 1$$
- …That prevents safe shutdown $$CDF_{is} \approx \lambda_g \cdot W_{is} \cdot SF \cdot P_{ns} \cdot CCDP$$