Initiating Events

Lecture 4-1
Key Topics

- NPP PRA definition of “initiating event”
- Methods to identify initiating events
- Fundamental ethos: search for failures
Resources

NPP PRA – The “What”

- Levels
  - Level 1 (core/fuel damage)
  - Level 2 (radioactive release)
  - Level 3 (offsite consequences)
- Hazards
  - Internal events (hardware, human, LOOP)
  - Internal hazards (flood, fire, heavy load drops, …)
  - External hazards (seismic, flood, wind, …)
- Operating Mode
  - At power
  - Low power/shutdown
- Sources
  - Core
  - Spent fuel pool
  - Other (e.g., dry cask storage)

Risk ≡ \{s_i, C_i, p_i\}
NPP PRA – The “How” (Big Picture)
The General Modeling Process – One View

Formulation
- Develop understanding
  - Possible scenarios
  - Key processes and parameters
  - Modeling issues
  - Interactions with other analyses
- Select scenarios for analysis
- Select computational tool(s)

Analysis
- Collect data
  - Generic
  - Plant-specific
- Build model(s)
  - Direct input
  - External submodels
- Perform computations

Interpretation
- Results for analyzed scenarios
- Implications for other scenarios
Where to start? Before the storm…*

It’s Christmas Eve at the Bunbury Bay Nuclear Power Plant, “Old Reliable” to the crew and local residents, most of whom have friends or family working at the plant.

A severe Nor’easter took down powerlines a month ago, but, as with past blizzards, the plant rode it out, providing needed power to the region. Most of the workers, who had put in long hours to cope with the November storm and its aftermath, are home for a well-deserved rest over the holiday, and Old Reliable is purring along with a nearly minimum crew. (Some unlucky workers are earning overtime working on the plant’s newer, air-cooled EDG, which is down for emergency repairs.) A low pressure area, formed in the Atlantic some two days ago, is being tracked but the disturbance is small. Although there are indications of intensification, weather forecasts provide no cause for serious alarm. There’s snow on the ground and chestnuts are roasting…

*Thanks to Pierre LeBot (EDF) for parts of this story.
Where to start? The storm hits…

At around 3 pm, winds in the region start to rise; blowing snow cuts visibility and trees are swaying. The plant receives a warning that the disturbance had become a storm but its intensity and direction are unclear. Considering the conditions of the roads and crew, past plant performance, and the uncertainty in the weather model predictions, the plant manager decides to alert off-duty senior staff, but not to recall any workers.

At 5 pm, the storm hits the coast. Around 8:30 pm, severe wind gusts take down multiple power lines, disrupting the grid. The plant loses offsite power and trips at 8:32, and the water-cooled EDG starts and loads as designed. At 11:16 pm, wind-driven waves, on top of severe storm surge and an abnormally high tide (a beyond-design basis hazard combination), overtop and damage the protective seawall and start flooding the pump house, endangering service water (normal and emergency). The plant (an old, isolation condenser design) starts preparing to enter SBO conditions. Fortunately, an offsite power line is recovered at 11:34. Recognizing the unreliability of the grid under storm conditions, the plant starts reviewing its procedures to stay at hot shutdown conditions until grid stability can be assured. However, offsite power remains available and the plant achieves cold shutdown early Christmas morning.
### Possible Choices

<table>
<thead>
<tr>
<th>Event</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>November storm</td>
<td>Sets up plant workforce, activities, and attitudes, and offsite conditions. Could support risk-informed post-storm operations decisions</td>
</tr>
<tr>
<td>Low pressure formation</td>
<td>Natural starting point if using storm simulation modeling. Could support risk-informed early storm preparations.</td>
</tr>
<tr>
<td>Storm warning (3 pm)</td>
<td>Deteriorating conditions; warning triggers decision (whether to recall staff). Could support risk-informed response.</td>
</tr>
<tr>
<td>Storm hits coast</td>
<td>Natural “event” for storm-oriented analysis.</td>
</tr>
<tr>
<td>LOOP</td>
<td>Start of nuclear transient.</td>
</tr>
<tr>
<td>Pumphouse flooding</td>
<td>Not a great choice for a literal analysis, but could be “moved up” to coincide with LOOP in a PRA.</td>
</tr>
</tbody>
</table>
**Convention for “Initiating Event”**

<table>
<thead>
<tr>
<th>Initiating Event, Initiator</th>
</tr>
</thead>
<tbody>
<tr>
<td>An event that perturbs the steady-state operation of the plant and could lead to an undesired plant condition.</td>
</tr>
</tbody>
</table>

In a PRA, an initiating event is an event originating from an internal or external hazard that both challenges normal plant operation and requires successful mitigation. As such, these events represent the beginning of accident sequences modeled in the PRA. Having a reasonably complete set of initiating events is crucial in determining what events could propagate to core damage.

Initiating events can arise from the following:

- **Internal Hazards, which include:**
  - Internal event *(see Internal Event)*
  - Floods *(see Internal Flood)*
  - Fires *(see Appendix A for fire terms)*

- **External Hazards, which include:**
  - Floods *(see External Flood)*
  - High winds *(see High Winds)*
  - Seismic events *(see Hazard Analysis)*
  - Other external hazards

These hazards result in different types of initiating events. Examples of initiating events are transients *(see Transient)* and loss-of-coolant accidents *(see Loss-of-Coolant Accident)*.

The terms initiating event and initiator are both used in a PRA context and generally have the same meaning. In some cases, the term initiator may refer to a class of initiators (e.g., transient), while the term initiating event may refer to the actual event (e.g., loss of a feedwater pump resulting in a transient).
Identifying Initiating Events

• Tools/approaches include:
  – Failure Modes and Effects Analysis (FMEA)
  – Hazard and Operability Studies (HAZOPS)
  – Master Logic Diagrams (MLD)
  – Heat Balance Fault Trees
  – Review of past events
  – Comparison with other studies
  – Feedback from plant model

• If it’s not in the model, it can’t be analyzed. “Use your imagination…”
...but

- Frame as a “search” (more active, directed than “imagining”)
- Screen out unimportant events to enable practical solution and avoid distractions
  - Limited analysis resources
  - Risk masking from overly conservative analyses
- Recognize challenges
  - Completeness
  - Data relevance (and “rectifiability”)
Example for Demonstrations: A Simple Boiler

<table>
<thead>
<tr>
<th>Steam Flow</th>
<th>Liquid Level</th>
<th>Desired State</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{M} \leq \dot{m}^*$</td>
<td>$\alpha_1 &lt; L &lt; \alpha_2$</td>
<td>Open</td>
</tr>
<tr>
<td>$\dot{M} \leq \dot{m}^*$</td>
<td>$L \geq \alpha_2$</td>
<td>Open</td>
</tr>
<tr>
<td>$\dot{M} \leq \dot{m}^*$</td>
<td>$L \leq \alpha_1$</td>
<td>Closed</td>
</tr>
<tr>
<td>$\dot{M} &gt; \dot{m}^*$</td>
<td>-</td>
<td>Closed</td>
</tr>
</tbody>
</table>
FMEA – Principles

• Inductive approach – postulate failures and determine effects
• Apply to all elements in system
• Uses standardized terms
• FMECA: add “criticality analysis”

<table>
<thead>
<tr>
<th>No.</th>
<th>Failure Mode</th>
<th>Cause of Failure</th>
<th>Possible Effects</th>
<th>Probability</th>
<th>Criticality</th>
<th>Possible Action to Reduce Failure Rate or Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structural failure (rupture)</td>
<td>a. Poor workmanship</td>
<td>Damage by missile</td>
<td>0.0006</td>
<td>Critical</td>
<td>Manufacturing process control for workmanship to meet standards. Quality control of basic materials to eliminate defects. Inspection and testing of completed cases. Suitable packaging to protect motor during transportation.</td>
</tr>
<tr>
<td>2</td>
<td>Physical binding or jamming</td>
<td>b. Defective materials</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Vibration</td>
<td>c. Transportation damage</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>Fails to remain (in position)</td>
<td>d. Handling damage</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>Fails to open</td>
<td>e. Overpressurization</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>Fails to close</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>Fails open</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>Fails closed</td>
<td></td>
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<tr>
<td>9</td>
<td>Internal leakage</td>
<td></td>
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<tr>
<td>10</td>
<td>External leakage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Fails out of tolerance (high)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Fails out of tolerance (low)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Inadvertent operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Intermittent operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Erratic operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Erroneous indication</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>17</td>
<td>Restricted flow</td>
<td></td>
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<td></td>
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<tr>
<td>18</td>
<td>False actuation</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### FMEA Partial Example (Boiler Problem)

<table>
<thead>
<tr>
<th>Component</th>
<th>Failure Mode</th>
<th>Cause(s)</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Vessel</td>
<td>Rupture</td>
<td>a. Overpressure</td>
<td>a. Stops operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Impact</td>
<td>b. Hazards to operators, other components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Corrosion</td>
<td>i. Steam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. Faulty materials</td>
<td>ii. Flooding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. Faulty construction</td>
<td>iii. Missile(s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. Faulty installation</td>
<td>iv. Displacement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g. ...</td>
<td></td>
</tr>
<tr>
<td>Feedwater Pump</td>
<td>Fails to run</td>
<td>a. Mechanical failure (e.g., binding, rotor crack)</td>
<td>a. Stops system operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. Clogging</td>
<td>b. Creates demand for system response</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. Loss of power</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. Incorrect control signal</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. Incorrect operator action</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. ...</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HAZOP – Principles

- Extension of FMEA
- Includes process parameter deviations
- Guide words “to stimulate creative thinking”
- Used extensively in chemical process industry

### TABLE 3.6. Process Parameter Deviations for HAZOP

<table>
<thead>
<tr>
<th>Process Parameter</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>No flow, Reverse flow, More flow, Extra flow, Change in flow proportions, Flow to wrong place</td>
</tr>
<tr>
<td>Temperature</td>
<td>Higher temperature, Lower temperature</td>
</tr>
<tr>
<td>Pressure</td>
<td>Higher pressure, Lower pressure</td>
</tr>
<tr>
<td>Volume</td>
<td>Higher level (in a tank), Lower level (in a tank), Volume rate changes faster than expected, Proportion of volumes is changed</td>
</tr>
<tr>
<td>Composition</td>
<td>More component A, Less component B, Missing component C, Composition changed</td>
</tr>
<tr>
<td>pH</td>
<td>Higher pH, Lower pH, Faster change in pH</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Higher viscosity, Lower viscosity</td>
</tr>
<tr>
<td>Phase</td>
<td>Wrong phase, Extra phase</td>
</tr>
</tbody>
</table>

# HAZOP Partial Example (Boiler Problem)

<table>
<thead>
<tr>
<th>Process Parameter</th>
<th>Deviation</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Flow</td>
<td>No Flow</td>
<td>a. Stops operation&lt;br&gt;b. Creates demand for system response (stop feedwater). If response fails, could lead to overfilling and possible flooding elsewhere</td>
</tr>
<tr>
<td>Gas Flow</td>
<td>More Flow</td>
<td>a. Increases steam generation rate. Depending on steam flow setpoint, could trigger system shutdown.&lt;br&gt;b. Increases water boiloff rate. If feedwater can’t compensate and steam flow setpoint isn’t reached, could cause dryout and gas tube rupture.</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
“Master Logic Diagram” – Principles

- Deductive approach
- Basically a fault tree; shows how a top event can occur
- “Heat Balance Fault Tree” is similar concept

A Classic NPP MLD

Identification Methods

MLD for a Space Application

MLD Partial Example (Boiler Problem)

- High Steam Flow Trip
  - Spurious Trip
    - Trip Logic Failure
      - T1
    - Sensor Failure
  - High Steam Flow
    - Insufficient Feedwater
      - Loss of FW Source
        - T3
      - Excessive Heat
        - T2
      - Pump Failure
      - Pump Tripped
      - Flow Path Blocked
Other Frameworks

• Different representations of causality can:
  – Stimulate imagination
  – Facilitate communication with like-minded

• Example: “bowtie diagrams” are advocated for process applications

Operational Experience (OpE)

- Illustrates mechanisms and complexities that might otherwise be missed
- Examples
  - Water hammer in fire main causes reactor building flood
  - Lighted candle causes cable fire
  - Boat wake rocks submarine and causes reactivity accident
- OpE also can indicate where imagination might be going too far
- Non-NPP experience is potentially valuable (e.g., see Kletz)
Other Studies (NPP)

- Loss of offsite power
  - Plant-centered
  - Switchyard
  - Grid
  - Severe weather
- Loss of safety-related bus
- Loss of instrument or control air
- Loss of safety-related cooling water
- Loss of feedwater
- General transient
- Steam generator tube rupture
- Loss of coolant accident
  - Very small LOCA
  - Small LOCA
  - Medium LOCA
  - Large LOCA
  - Excessive LOCA
  - Interfacing system LOCA
  - Stuck-open relief valve
- High energy line break
Including External Hazards

- Internal events
- Internal floods
- Internal fires
- Seismic events
- External floods
- High winds

Further discussion in Lecture 6-2
NPP PRA is a systems modeling enterprise => uses “divide and conquer” approach => caution needed at task interfaces (e.g., between initiating event analysis and event sequence analysis)
- Gaps
- Mismatches

Iteration (which “fuzzifies” interfaces) is important. Examples:
- Initiating event analysis considers “importance” of postulated event; early judgments needed to start other tasks can/should be revisited
- Internal and external hazards analyses use internal events models (Lecture 6-2); can suggest model modifications based on results and insights
To postulate how things might fail, first need to know how things are supposed to work => “Initial Information Collection” step (a.k.a. “Plant Familiarization”) is critical

Checklists (e.g., based on past studies) are useful, but concept of active searching is key, especially for new systems.

Multiple approaches/tools provide different perspectives and can help ensure completeness.