Scenario Exploration and Timeline Analysis for Microreactors

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Motivation on Scenario and Uncertainty Research and Development

- Advanced reactors will be able to use risk insights for many design aspects
  - Example risk-informed approach is found in the Nuclear Regulatory Commission’s SECY-19-0117
  - Probability is widespread through the guidance via a safety case
  - Probabilistic concepts are built into metrics, such as the frequency-consequence curve
- We need bounding scenarios for screening and scoping purposes
- We need realistic scenarios for input into the licensing basis safety-case
  - These scenarios must include timing and physics
- We need to manage inherent uncertainty
- We need to automate the safety-case creation as much as possible
Advanced Reactor Design Attributes have Links to Frequency-Consequence Metrics

(derived from NEI 18-04)
Attributes of the Demonstration Infrastructure

• Simulation to develop a risk-informed safety case
  − A highly transparent, traceable, scrutable framework
  − Used to inform all stakeholders (developers, regulators, operators)

• Leverage established technologies (e.g., EMRALD) for simulations
  − Risk scenario-based analyses & treatment of associated uncertainties
    • Uncertainties are captured by automating the “state space”
    • The state space represents variations in scenarios and outcomes

• Manage complex workflows to facilitate successful design evolution
  − Inform security design evolution from early design to operations
  − Also support creation of the technical basis
Modeling and Analysis in EMRALD (notional)

- Detection and Assessment
- Barriers
- Nonlethal Delay
- Responders Arrive Onsite

Assets Protected
- Assets Protected
- Recovery Actions
- Target Sabotage

Time Progression
Timeline Analysis in EMRALD

Plant Timeline
- Plant Action: $T_{Action}$
- Plant Safe: $T_{Safe}$
- Plant Recovered: $T_{Recovery}$

Responders Action: $T_{Responders}$

Detected and Assessment
- $T_{Detection}$

Adversary Timeline
- Barriers: $T_{Barriers}$
- Sabotage: $T_{Sabotage}$
- Release: $T_{Release}$

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Example: Adversary Sequence Modeling in EMRALD

This is a hypothetical facility for demonstration purposes only.
Library of Barriers and Other Model Pieces

Barriers
- Fences
- Sticky Foam
- Concrete Walls
- Security Doors
- Etc.

Properties
- Delay Time
- Equipment Requirements
- Detection Probability
- Etc.
Consequence Analysis

Get Fail Time 1

- Breach
  - Immediate Actions
  - Event Actions
    - GetPidsTime
      - RunScript2
      - UpdateInitTime
      - UpdateInitTime2
      - GetGetTime
    - IF PidsAdvActive
      - GoToGetTime
    - IF PidsAdvDefeated
      - GoToGetTime

- DGSabotage
  - Immediate Actions
  - Event Actions
    - GetFDBTime
      - RunScript3
      - UpdateInitTime
      - UpdateInitTime2
      - GetGetTime
    - IF AdvActive and DGSRemains
      - GoToDGTime
    - IF AdvDefeated and DGSabotaged
      - GoToDGTime
    - IF AdvActive and DGSabotaged
      - GoToDGTime
    - IF AdvDefeated and DGSabotaged
      - GoToDGTime

- MELCOR Analysis
  - Immediate Actions
    - PlantContinueOperation
      - End
        - Immediate Actions
          - Event Actions

Get Fail Time 2

- Breach
  - Immediate Actions
  - Event Actions
    - GetPidsTime
      - RunScript2
      - UpdateInitTime
      - UpdateInitTime2
      - GetGetTime
    - IF PidsAdvActive
      - GoToGetTime
    - IF PidsAdvDefeated
      - GoToGetTime

- DGSabotage
  - Immediate Actions
  - Event Actions
    - GetFDBTime
      - RunScript3
      - UpdateInitTime
      - UpdateInitTime2
      - GetGetTime
    - IF AdvActive and DGSRemains
      - GoToDGTime
    - IF AdvDefeated and DGSabotaged
      - GoToDGTime
    - IF AdvActive and DGSabotaged
      - GoToDGTime
    - IF AdvDefeated and DGSabotaged
      - GoToDGTime

- MELCOR Analysis
  - Immediate Actions
    - PlantContinueOperation
      - End
        - Immediate Actions
          - Event Actions

Get Fail Time 3

- ElectricalSystem
  - Immediate Actions
  - Event Actions
    - GetElectricalTime
      - RunScript4
      - UpdatePlacement
      - UpdateElectricalStatus
      - UpdateInitTime3
      - IF AdvActive and ElectricalIntact
        - GoToElectrical
      - IF AdvDefeated and ElectricalIntact
        - GoToElectrical
      - IF AdvActive and ElectricalIntact
        - GoToElectrical
      - IF AdvDefeated and ElectricalIntact
        - GoToElectrical

- MELCOR Analysis
  - Immediate Actions
    - PlantContinueOperation
      - End
        - Immediate Actions
          - Event Actions

Get Fail Time 4

- BWREquipment
  - Immediate Actions
  - Event Actions
    - GetEquipmentTime
      - RunScript5
      - UpdatePlacement
      - UpdateEquipmentStatus
      - UpdateInitTime4
      - IF AdvActive and EquipmentIntact
        - GoToEquipment
      - IF AdvDefeated and EquipmentIntact
        - GoToEquipment
      - IF AdvActive and EquipmentIntact
        - GoToEquipment
      - IF AdvDefeated and EquipmentIntact
        - GoToEquipment

- MELCOR Analysis
  - Immediate Actions
    - PlantContinueOperation
      - End
        - Immediate Actions
          - Event Actions

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## Sample Results & Insights

### Performance Comparison

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPS config</td>
<td></td>
</tr>
<tr>
<td>Target Set Protection</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
</tr>
</tbody>
</table>

The image shows a graph with two distributions indicating early arrival due to offsite detection. The graph compares adversary attack time with responder’s arrival time.

**Legend:**
- Red line: Adversary attack time
- Blue line: Responder’s arrival time

**Graph Details:**
- X-axis: Time (in units of some metric)
- Y-axis: Density
- Data points indicate early arrival due to offsite detection.
Summary: EMRALD Capabilities for Adv. Reactors

Different Attack Scenarios
- Different paths
- Adversary capabilities
  - Strategies
  - Equipment
  - Variations

Portfolio of Hazards/Targets
- List of targets: target super-set
- Combination of targets
- Initiating events as starting point
- Ability to integrate with other hazard types

Different Plant Layout
- Target set
- Topology
  - Geographical entities
  - Impact on timings
  - Plant structures
- Security posture
  - Protective strategies
  - Barriers
  - Responses
  - Law enforcement
  - Recalling off-duty personnel
- Important physics of the advanced reactor

Consequences from EMRALD
- Based on what has failed during a scenario
- To achieve insights that give frequency / consequence curve
- Level 2-3 analysis in EMRALD
  - Capture impact on timings
  - Integration with thermal hydraulics codes: MELCOR / MAAP / RELAP5

Sample Space
- Timings
- Probabilities
- Outcomes

Results & Insights
- Quantitative and qualitative results
- Sensitivities
- Visualization

https://github.com/inl-labtrack/EMRALD

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