Dynamic Modelling of Severe Accident Management for CANDU Reactors in PSA

Alexander Trifanov, Kinectrics, Inc.

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Outline

- Background
- Overview of severe accident progression in CANDU
- Typical SAMG for CANDU
- Approach for modelling of SAMG in PSA
- Conclusions
Background

Accident mitigation using Severe Accident Management Guidance (SAMG):

- Symptom-based
- Non-prescriptive as opposed to Emergency Operating Procedures (EOP)
- As many viable mitigating strategies as possible to regain control of the plant
- Consider unusual equipment configurations
- Restore failed equipment
- Use mobile systems (FLEX)
- Timing of accident progression significantly impacts available options

Difficult to model in PSA using static methods
Background

**Static PSA**
Mature methodology
Static Event Trees / Fault Trees
Limited set of accident sequences defined by analyst represented by bounding scenarios
Limited use of time history
Well established development process and models easy to quantify on most PCs

**Dynamic PSA**
Methodology in development
Dynamic Event Trees Branching
Automatic generation of accident sequences based on accident progression history
Time-dependent process variables
Quantification process requires development of ET branching algorithms and powerful computers
Generic CANDU accident progression

In case of SBO:

<table>
<thead>
<tr>
<th>Heat Sink</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Generator (SG)</td>
<td>1-2h</td>
</tr>
<tr>
<td>SG Emergency Cooling</td>
<td>1-3h</td>
</tr>
<tr>
<td>Deaerator inventory drain to SG</td>
<td>4-6h</td>
</tr>
<tr>
<td>Primary heat transport boil-off</td>
<td>1-2h</td>
</tr>
<tr>
<td>Moderator boil-off</td>
<td>3-6h</td>
</tr>
<tr>
<td>Shield tank water boil-off</td>
<td>2-4h</td>
</tr>
</tbody>
</table>

After depletion of all heat sinks, corium would melt through shield tank wall, fall on containment floor and initiate core-concrete interaction.
Generic CANDU accident progression

- Restoring water supply to steam generators and primary heat transport prevents fuel failure
- Restoring water supply to Calandria prevents core structural disintegration
- Restoring water supply to shield tank prevents core collapse on the Containment floor
Emergency Mitigating Equipment (FLEX)

Mobile systems stored off-site
Flexible configuration

Water source

Power source
Increasing complexity of decision-making and stress.
Typical SAMG for CANDU

SCST symptoms override the DFC symptoms

Symptom-based Supported by computational aids

Multiple choices of strategies and supporting systems
Analysis approach

- Initiators
- System configurations
- Crew decision making simulator
- Accident sequence generator
- Accident analysis code
- Sequence analysis
- System Reliability Models
- IE frequency
- HRA
- Sequence
- Frequency
- Importance
- Uncertainty
Simplified ET prior to transition to SAMG

<table>
<thead>
<tr>
<th>TRANS</th>
<th>INT-LOCA</th>
<th>ECI</th>
<th>SD-HS</th>
<th>INT-HS</th>
<th>EME-SG</th>
<th>ECR</th>
<th>EME-PHTS</th>
<th>SAMG</th>
<th>Fuel Damage Category</th>
<th>Sequence Number</th>
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<tbody>
<tr>
<td>Transient with Successful Reactor Shutdown</td>
<td>Interfacing LOCA</td>
<td>Emergency Coolant Injection</td>
<td>Shutdown Heat Sink (Steam Generators, Shutdown Cooling System, Emergency Water)</td>
<td>Interim Heat Sink (Passive supply of water to Steam Generators)</td>
<td>Emergency Mitigating Equipment water supply to Steam Generators</td>
<td>Emergency Coolant Recovery</td>
<td>Emergency Mitigating Equipment water supply to Primary Heat Transport System</td>
<td>Transition to Severe Accident Management Guidance</td>
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<td>N/A</td>
<td>9H+</td>
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<td>S-001</td>
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<td>SUCCESS</td>
<td>S-001</td>
<td>SUCCESS</td>
<td>S-002</td>
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</tbody>
</table>
Simplified severe accident ET
Simplified severe accident ET

Strategy 1:
Depressurise
Cont. using ACUs

Success
Hydrogen recombiners fail

Success
Large Release

Failure
Strategy 2

Strategy 2:
Depressurise Cont. using filtered venting

Success
Site becomes uninhabitable

Success
Large Release

Failure
Strategy 3

Strategy 3:
...

Failure
Potential branching of SAMG mitigation
Dynamic presentation of accident progression
Conclusions

- SAMG are difficult to incorporate in PSA using static models
  - Cues, mitigating options, and likelihood of success significantly depend on the timing and phenomena of accident progression
  - SAMG actions have positive and negative effects
  - There are multiple options

- Dynamic modelling can generate families of ETs based on parameters predicted by the coupled deterministic model

- ET branching algorithm is relatively complex
  - Potentially contradictive and overriding symptoms
  - Decision making by the crew to select strategy and equipment
  - Use of FLEX
  - Potential restoration of failed equipment
  - Impact of plant condition degradation on operator performance

- Need significant computational capability
Thank you for Attention!

Questions?