Open PSA Workshop 2012
Incorporating Success Criteria Uncertainty Into PSA

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Project Aim Overview

+ξ = "Addition of Noise/Error Vector"
A Short List of Uncertainties in PSA

Plant Based Failure Parameters
Hazard Frequencies – Internal & External
Human Factors Uncertainties
Existing Dependencies
Quantification of Dependencies
Uncertainty in Success Criteria
Uncertainties in Assumptions
Uncertainty in Bounding Analyses
Model Completeness

There are numerous sources of uncertainty
Quantifying the major sources of uncertainty would enhance the credibility and meaning of PSA results
Motivational Example: The Relevance of Uncertainties

- Conservative estimates are often used to avoid uncertainty. **However:**
- Conservative estimates are not uniformly applied across different systems
- This can distort the risk profile significantly
- Even if the conservatism is applied in a “fair” way the risk profile can still be distorted.
- Consider the following idealised case:
  - All failure parameters are known to “truly” follow a lognormal distribution
  - A conservative model is built using only 95th percentile estimates
  - A best estimate model is built using lognormal distributions
Conservative vs Best Estimate Plus Uncertainty

Conservative Tree

Example Top Event - e.g. Probability of Failure on Demand of System X

@FT1-UNCERTAINTY-1

Failure of Both Streams A & B

@FT1-UNCERTAINTY-2

Failure of Stream A - 95th Percentile Conservative Estimate

BE2

Failure of Stream B - 95th Percentile Conservative Estimate

BE3

Failure of Reservoir Tank 95th Percentile Conservative Estimate

BE1

Failure of Reservoir Tank or Associated Pipework

@FT1-UNCERTAINTY-3
Conservative vs Best Estimate Plus Uncertainty

Best Estimate Plus Uncertainty Tree

Example Top Event - e.g. Probability of Failure on Demand of System X

Failure of Both Streams A & B

Failure of Stream A Including Uncertainty

Failure of Stream B Including Uncertainty

Failure of Reservoir Tank or Associated Pipework

Failure of Reservoir Tank Including Uncertainty

BE5

BE6

BE4
### Results - Cutsets

Conservative Case (95th Percentiles) Basic Event Results

<table>
<thead>
<tr>
<th>No.</th>
<th>Prob.</th>
<th>%</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.75E-03</td>
<td>72.80</td>
<td>BE1</td>
</tr>
<tr>
<td>2</td>
<td>1.41E-03</td>
<td>27.30</td>
<td>BE2, BE3</td>
</tr>
</tbody>
</table>

Best Estimate Plus Uncertainty Basic Event Results

<table>
<thead>
<tr>
<th>No.</th>
<th>Prob.</th>
<th>%</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00E-03</td>
<td>90.92</td>
<td>BE4</td>
</tr>
<tr>
<td>2</td>
<td>1.00E-04</td>
<td>9.09</td>
<td>BE5, BE6</td>
</tr>
</tbody>
</table>

The results give significantly different parameter importance profiles.
Ultra-Conservative 99th Percentile Case

Ultra Conservative Case (99th Percentiles) Basic Event Results

<table>
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<tr>
<th>No.</th>
<th>Prob.</th>
<th>%</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.75E-03</td>
<td>50.88</td>
<td>BE1</td>
</tr>
<tr>
<td>2</td>
<td>9.51E-03</td>
<td>49.61</td>
<td>BE2</td>
</tr>
</tbody>
</table>

Best Estimate Plus Uncertainty Basic Event Results

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In practice it is almost impossible to know whether a conservative estimate is 95th or 99th percentile (etc)
Success Criteria Uncertainty

- Success criteria define the functions a safety system must fulfil in order to perform its duty.
- The success criteria can be defined in a nested manner with layers of detail.
- For example, the basic functions that must be performed following a baseline seismic event are: trip, shutdown and post trip cooling.
- Each function can be further decomposed, for example for AGRs:
  - Trip: The main guard-line, secondary guard-line or diverse guardline must send a trip signal
    » The secondary guard-line is activated by one of the trip parameters, e.g. Boiler gas outlet temperature
  - Post Trip Cooling: Feed to boilers must be maintained. Gas circulation must be maintained.
- At an appropriate level of detail the criteria is directly represented in the model. For example, 1003 EBF pumps must start and provide flow.
Examples of Success Criteria Used in AGR PSAs

- PTC: 1 GC in 1 fed quad (Operator initiated within 90 min)
- RSSE – 1 GC in 1 quad with Start Standby Boiler Feed
- RSSE – 1 GC in 1 quad with Emergency Boiler Feed
- Boiler Feed: 1 quad StStBF or EBF (within 3hr)
- 2 fed quads, BUFS (Operator initiated within 3hr)
- Recovery: 2 quads fed by fire hydrant in 8 hr
- One quadrant of forced gas circulation
- Operator cuts back feed within 2 hours
- Nitrogen injection commences within 5 hours
- Natural Circulation with 2004 boilers fed
Types of Success Criteria Used in PSA

- There are numerous success criteria that are used in PSA models.
- The supporting analysis for the success criteria can be very different.
- The sources of uncertainty varies from case to case.
- The magnitude of the uncertainty in different success criteria can be very different.
- The purpose is to include those uncertainties which have the potential to significantly affect the results.
- Knowledge of the plant and the PSA model is vital in order to select significant uncertainties.
- The success criteria used in the models are typically described in a conservative way, rather than as best estimates.
Success Criteria Representation in PSA Models

- The uncertainties in success criteria can affect a PSA model in several ways:
  - Affect a single basic event
  - Affect multiple basic events
  - Affect the logic of the fault trees
  - Affect the logic of the event trees
- There may be several equivalent ways of representing a given uncertainty
- Uncertainty over a specified success criteria might be represented using several of the above methods
- Examples are given for each of the above methods
Success Criteria – Basic Event Uncertainty: N2 Example

- At AGRs a claim is placed on the nitrogen system to act as a back-up for secondary hold-down in the mid to long term.
- The nitrogen system must be capable of injecting nitrogen into the reactor within a specified timescale.
- The allowed timescale is dependent on the Xenon transient in the core post-trip.
- The time for a given reactivity insertion due to Xe decay is heavily dependent on the reactor operating history.
- This gives rise to a range of possible times that the nitrogen must be inserted within.
- There is uncertainty in the calculations of the time, however, in this instance the uncertainty in the calculations is small compared with the dependence on the operating history.
- The main impact of the time requirement on the PSA is on the operator reliability claim; in many instances the operator would actually have an extended amount of time available.
Success Criteria – Basic Event Uncertainty: N2 Example

- Rather than using a conservative estimate for the minimum time to insert nitrogen, a distribution can be used.
- Using NARA, there are discrete time intervals defined where an operator has extended time available to take an action. For example for CCR based actions:
  - More than 1 hour
  - More than 2 hours
  - More than 6 hours
  - More than 12 hours
- It should be noted that there are numerous other criteria in NARA that are important to the assessment of operator reliability in extended time situations.
- The best estimate distribution for the timescales required for injection of nitrogen can be used to assign expected weights to each of the above intervals.
- The utility of including such information is to estimate the risk importance of the operator action as accurately as possible.
Success Criteria – Fault Tree Example

- 1003 EBF pumps must provide LP flow.

- The requirements on the plant equipment to achieve the specified success criteria are developed in the underlying fault trees.
Fault Tree Representation of Success Criteria

Example: System Fault Tree Representing Cooling Requirements Following a Specified Transient

Currently

Analysis of required flow (e.g. Relap) → Best Estimate of Mass Flow → Conservative Estimate of Plant Requirements → Single “Correct” Fault Tree

With Uncertainty

Analysis of required flow (e.g. Relap) → Best Estimate Plus Uncertainty of Mass Flow → Distribution Estimate of Plant Requirements → Distribution Over Possible Fault Trees
Success Criteria: Uncertainty in Fault Tree Structure

- In principle can be addressed by assigning weights to the different fault tree logics according to the estimated uncertainty distribution for the success criteria.
- Requires the supporting analysis to incorporate uncertainty.
- The major sources of uncertainty are often already estimated in the supporting analysis.
Uncertainty Over Fault Tree Structure - Example

Exclusive OR

Failure of Sufficient Feed from EBF Pumps

Feed Failure in the Event that 1003 Pumps is Required

Feed Failure in the Event that 2003 Pumps is Required

Failure of All 3 Emergency Boiler Feed Pumps

Conditional Probability that 1003 Pumps is Required

Failure of 2003 Emergency Boiler Feed Pumps

Conditional Probability that 2003 Pumps is Required

0.95

0.05
Uncertainty Over Event Tree Structure

- Traditional event trees use only success and failure at each branch point.
- Established methods exist to introduce multiple outcomes from a single branch point, that are sometimes used for containment event trees and eventual consequences, but rarely used in Level 1 event trees.
- Conceptually the process is simple: assign probabilities, summing to 1, to the possible branches, as in the example.

Source: IAEA Training in Level 2 PSA Slides
Uncertainty and Model Size

- It is important to consider the practical implications of incorporating uncertainty.
- Consider including uncertainty over *every* gate in the model:
  - Assume three alternatives per gate.
  - The number of gates in the model including uncertainty in all of these gates is then cubic in the number of gates in the original model.
  - This affects both the man-effort required to construct and maintain the models, and also the running time for obtaining results.

- This indicates that a “brute force approach” is inadequate.
- A method of screening for “important” uncertainties will be necessary.
Summary

- The use best estimate plus uncertainty can have a significant effect on the risk profile and importance rankings compared to conservative methods.
- Success criteria uncertainty is a ubiquitous source of uncertainty that is minimally handled in current PSAs.
- The most appropriate way of incorporating success criteria uncertainty depends on the precise details of the case.
- The inclusion of uncertainty needs to be balanced against practical considerations.
Thanks for Listening

Any Questions?