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Open PSA Workshop 2012
Incorporating Success Criteria Uncertainty Into PSA

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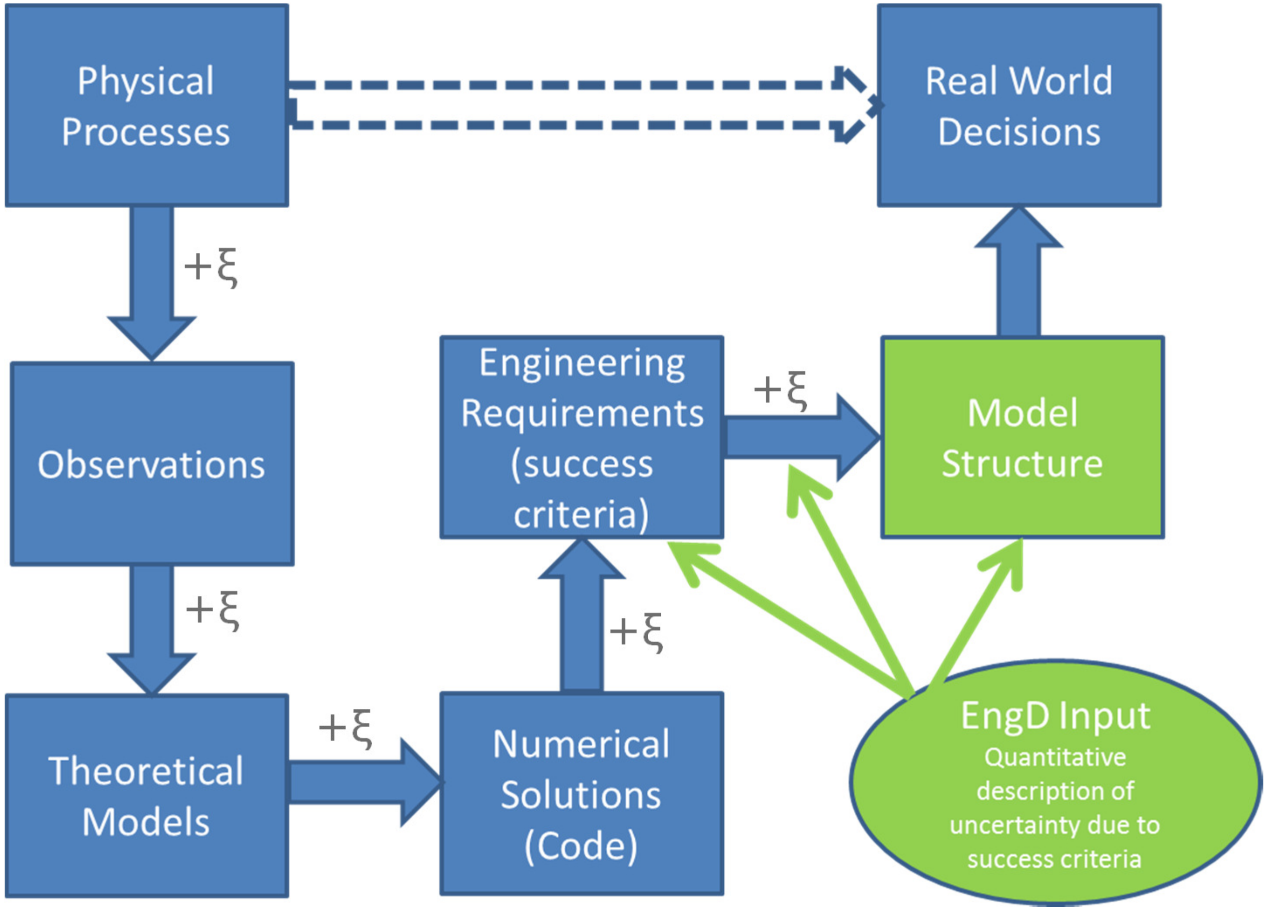
Project Aim Overview



+ξ ="Addition of Noise/Error Vector"

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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

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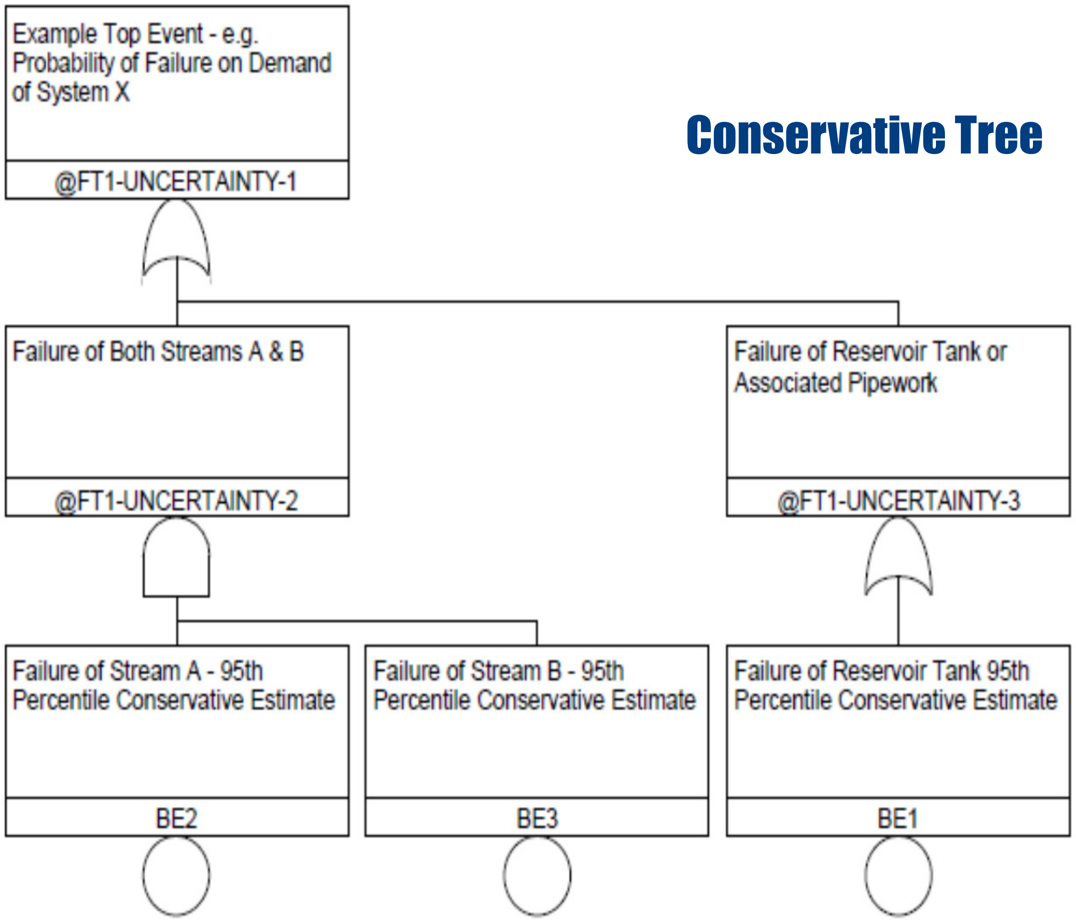
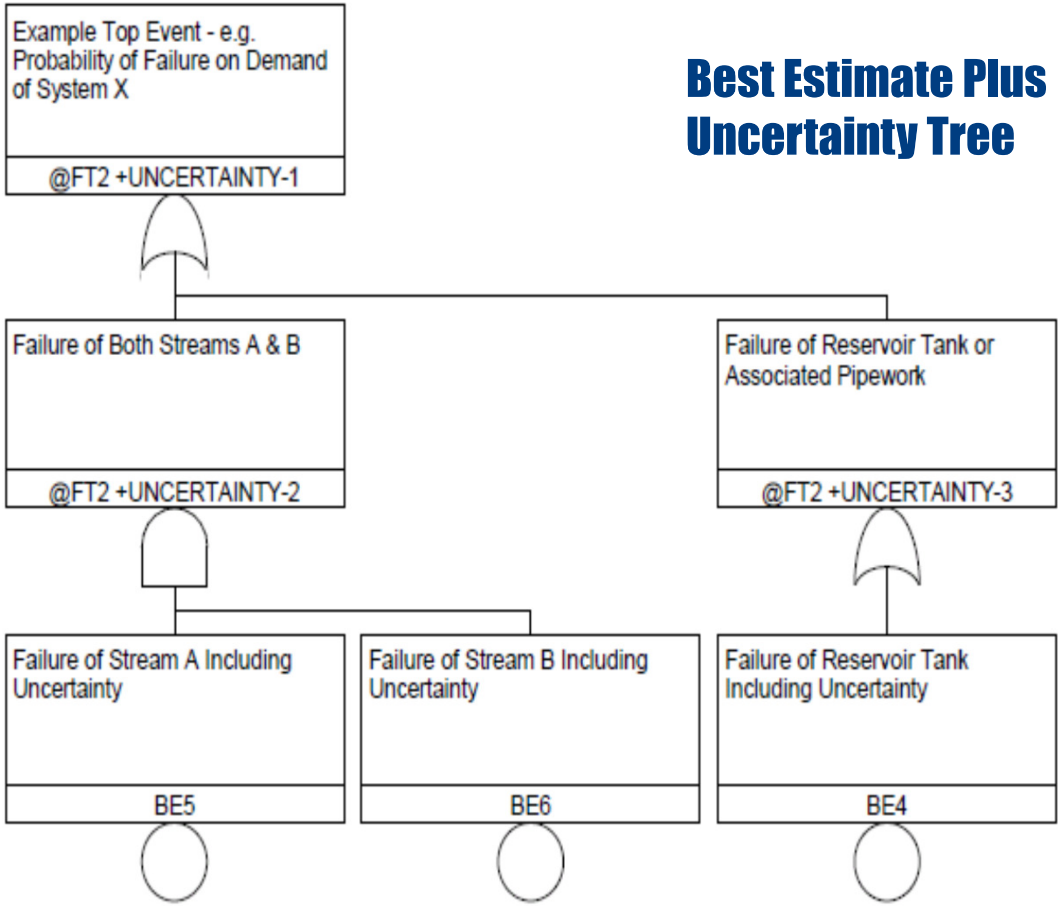
Conservative vs Best Estimate Plus Uncertainty



Conservative vs Best Estimate Plus Uncertainty



Best Estimate Plus Uncertainty Tree

Results - Cutsets

Conservative Case (95th Percentiles) Basic Event Results

No.	Prob.	%	Event	
1	3.75E-03	72.80	BE1	
2	1.41E-03	27.30	BE2	BE3

Best Estimate Plus Uncertainty Basic Event Results

No.	Prob.	%	Event	
1	1.00E-03	90.92	BE4	
2	1.00E-04	9.09	BE5	BE6

The results give significantly different parameter importance profiles

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Ultra-Conservative 99th Percentile Case

Ultra Conservative Case (99th Percentiles) Basic Event Results

No.	Prob.	%	Event	
1	9.75E-03	50.88	BE1	
2	9.51E-03	49.61	BE2	BE3

Best Estimate Plus Uncertainty Basic Event Results

No.	Prob.	%	Event	
1	1.00E-03	90.92	BE4	
2	1.00E-04	9.09	BE5	BE6

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 gaurdline 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, 1oo3 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 – 1GC 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 2oo4 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

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Success Criteria – Basic Event Uncertainty: N2 Example

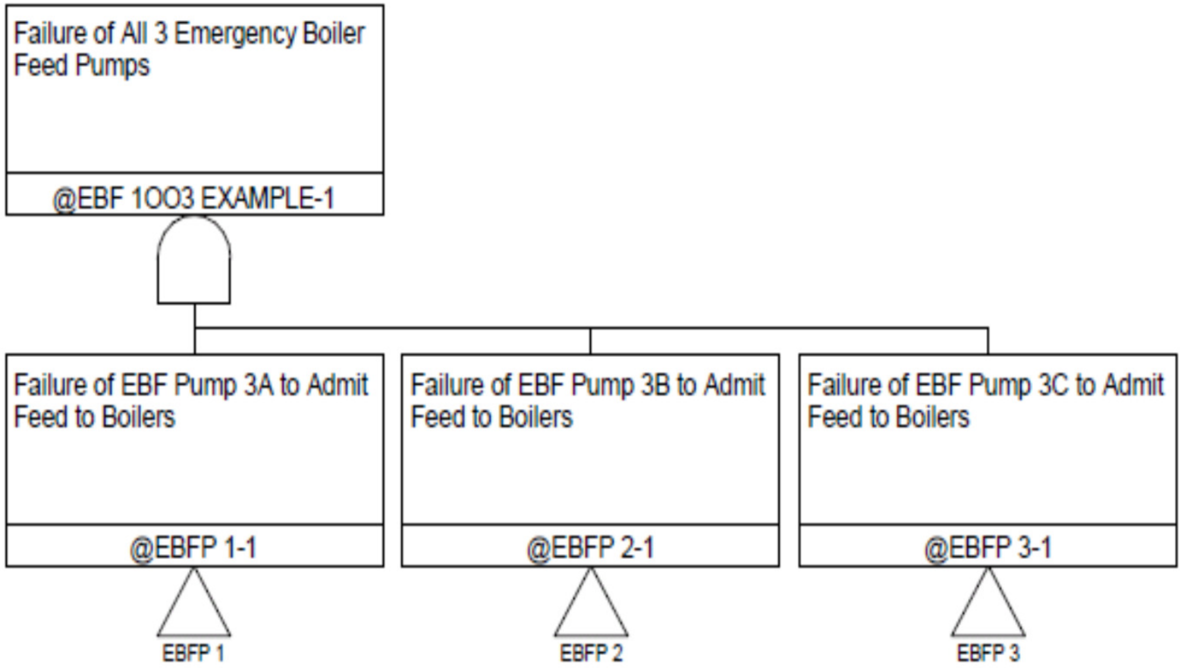
- At AGRs a claim is placed on the nitrogen system to act as a back-up for secondary hold-down in the mid to long term.
- The nitrogen system must be capable of injecting nitrogen into the reactor within a specified timescale.
- The allowed timescale is dependent on the Xenon transient in the core post-trip.
- 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

- 1oo3 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

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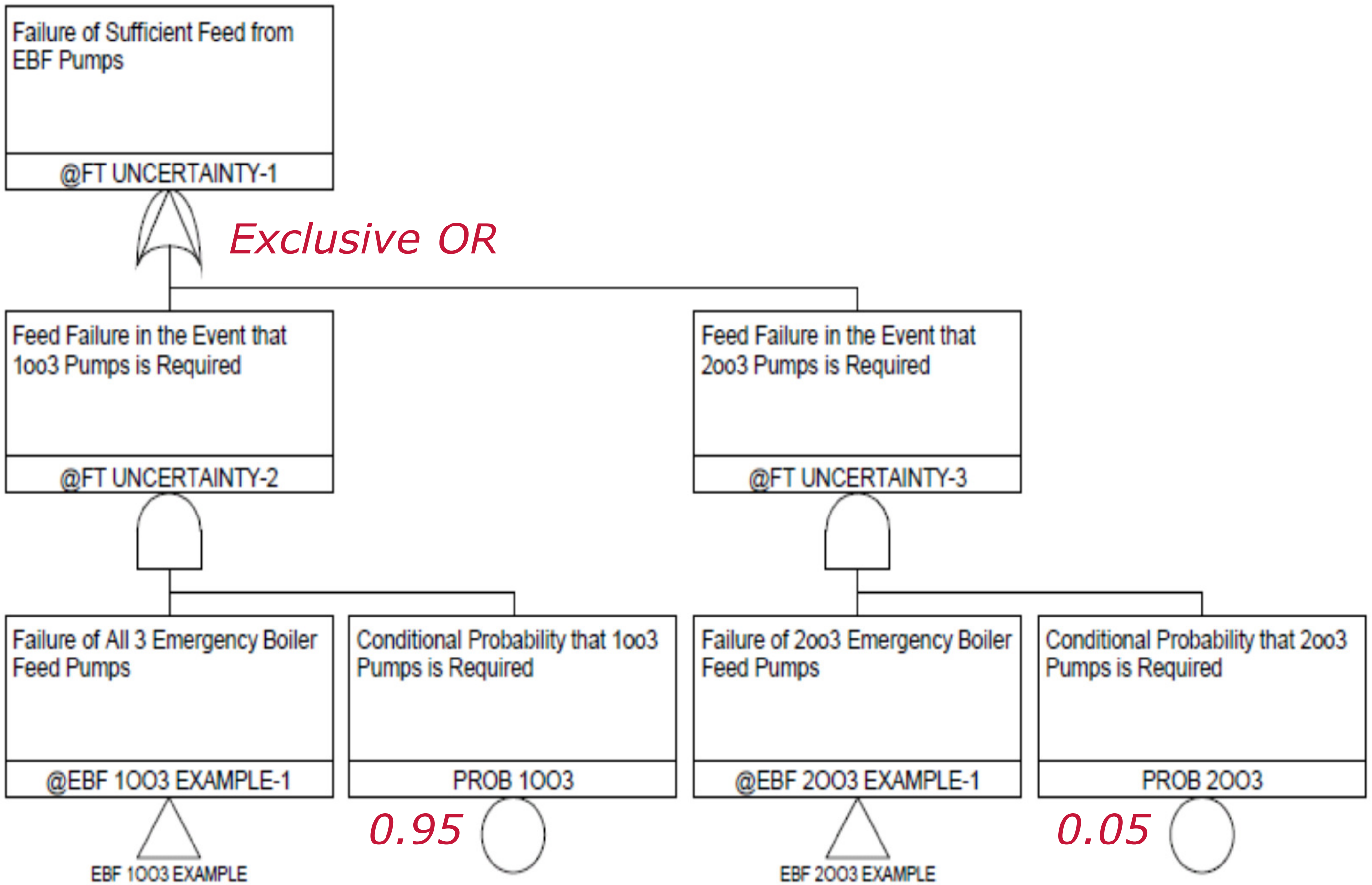
Success Criteria: Uncertainty in Fault Tree Structure

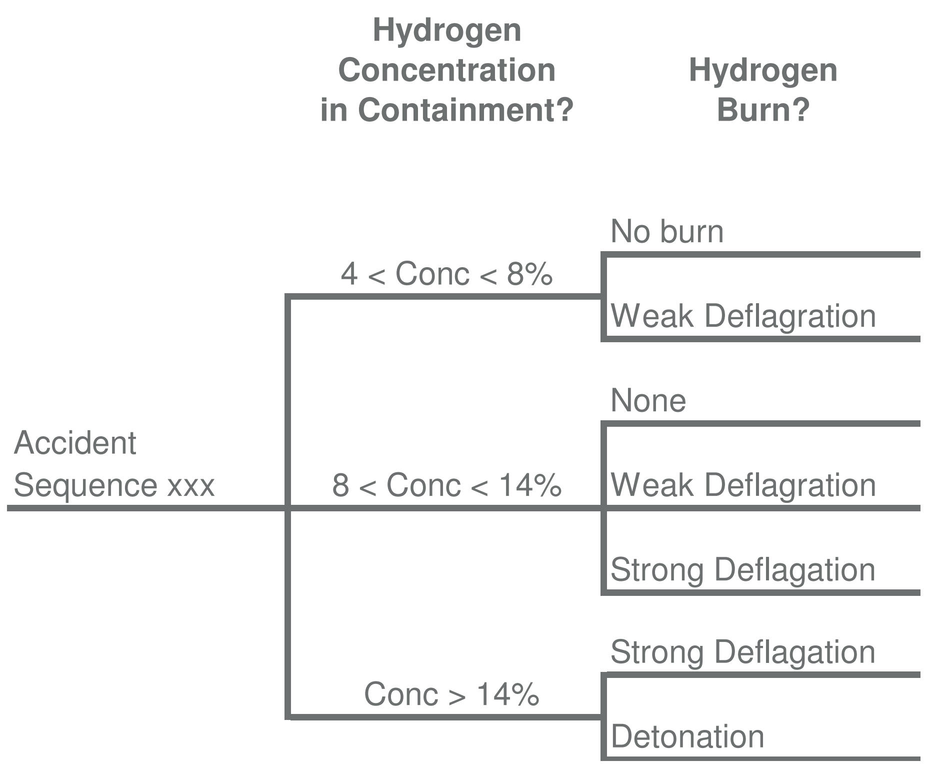
- In principle can be addressed by assigning weights to the different fault tree logics according to the estimated uncertainty distribution for the success criteria.
- Requires the supporting analysis to incorporate uncertainty.
- The major sources of uncertainty are often already estimated in the supporting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

Uncertainty Over Fault Tree Structure - Example



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.

Questions or Comments?

Thanks for Listening

Any Questions?