Sources of Epistemic Uncertainties in Level 2 Risk Assessments

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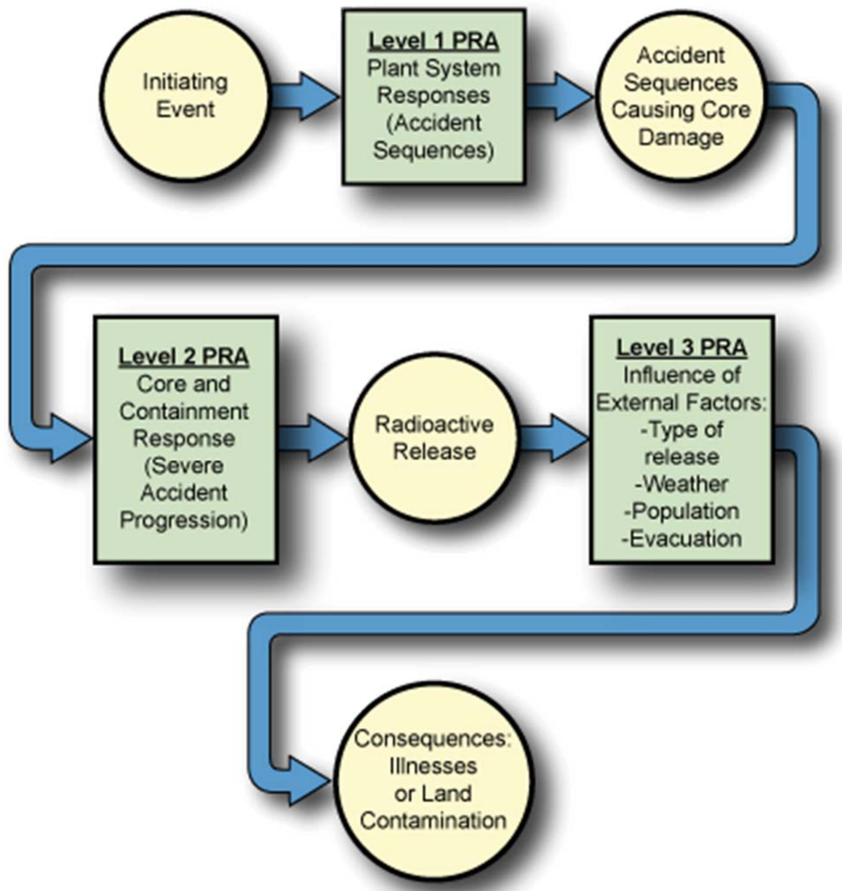
Overview of Level 2 Analysis



Sources of Uncertainty

- Level 1 – Level 2 Interface definitions
  - Scenario Development and assignment of Plant damage States (PDSs) or other binning schemes
- Event Progression
  - Deterministic analysis tools
  - Fundamental Phenomenological Uncertainty
- Event Likelihood (APET)
- Containment Response / Failure Modes
- Fission Product Transport and Release

Sources of Uncertainty in the Level 1–Level 2 Interfaces

- Level 2 PRA inherits uncertainties associated with the Level 1 model
  - Loss of detail due to aggregation of Level 1 Sequences
    - Aggregation can predispose outcomes to removing fine structure of sequences that may progress to large releases
  - Transference of Relevant Level 1 uncertainties. For example:
    - Onset and extent of RCP seal failure impacts TI-SGTR
    - Modeling assumptions included in treatment of ISLOCA directly impact Level 2 consequnces
    - Assumptions related to power recovery can influence late event progression and mitigation

Sources of Uncertainty in Severe Accident Event Progression

- Uncertainty embedded in severe accident assessment tools
  - Simplifications, assumptions and options embedded with computer models
  - Lack of knowledge regarding phenomenology
    - Process uncertainty
    - Detailed uncertainty with correlations
  - Event initiation Criteria

Sources of Uncertainty in Severe Accident Event Progression

- Simplifications, assumptions and options embedded with computer models
  - Computer codes provide for stylized events typically using reasonable assumptions
  - Details of assumptions and models can promote, reduce or ignore core melt progression sequences. For example:
    - Composition of corium in lower head and lower head failure process can influence consequential containment failure potential
    - Event initiation criteria, hydrogen mixing assumptions and treatment of containment geometry can impact number of severity of hydrogen burns
    - Expectation of corium fragmentation can impact “steam explosion” loadings.
    - Equipment survivability following in containment or Auxiliary Building events
  - Recognizing assumptions and understanding their impact on downstream inputs to Level 3 analyses of Level 2 design applications is important to properly characterize the uncertainty introduced.

Sources of Uncertainty in Severe Accident Event Progression

- Phenomenological Uncertainty
  - Despite much testing in the past two decades uncertainty in details of severe accident event progression exists. Some examples include:
    - Basemat melt-through and potential for and impact of crust formation.
    - Transition conditions and Likelihood of DDT in compartmentalized containments
    - Consequences of basemat melt-through
      - Fission product vitrification
      - Potential for groundwater/environmental release?
    - Hydrogen production during FCI following in-vessel corium relocation
    - Fission product plate-out on surfaces

Sources of Uncertainty in Severe Accident Event Progression

Phenomena	Experimental Programs	Knowledge-base
1. Decay heat and Fission Products		
Residual heat level		Reasonable
Partitioning of the decay heat between layers in case of stratified pool	Under discussion	Limited
FP and residual heat distribution between crust and pool	Under discussion	Limited
FP release from molten pool		Limited
2. Melt thermal hydraulics		
Single phase liquid pool	COPO, ACOPO, BALI, RASPLAV, SIMECO	Good
Complex mixtures	RASPLAV Salt, SIMECO	Limited
Stratified liquid pools	SIMECO	Limited
Oxidic and metallic pools (focusing effect)	Planned SIMECO, RASPLAV-Salt, COPO, BALI	Reasonable
Effect of crust formation on heat transfer	COPO, BALI, RASPLAV, SIMECO	Reasonable
3. Heat flux removal		
Gap formation and heat transfer	CTF[20], FOREVER[21], SONATA[22]	Limited
Boiling on downward curved surfaces	UCSB, Penn.St., SULTAN	Good
Debris bed dryout and coolability	POMECO[23]	Reasonable
Radiation from the upper surface		Reasonable
4. Melt relocation scenarios		
Formation of the initial molten pool in the core	CORA[24], PHEBUS-FP[25]	Reasonable
Melt pool growth and pathway of melt	PHEBUS-FP	Limited, depends on in-

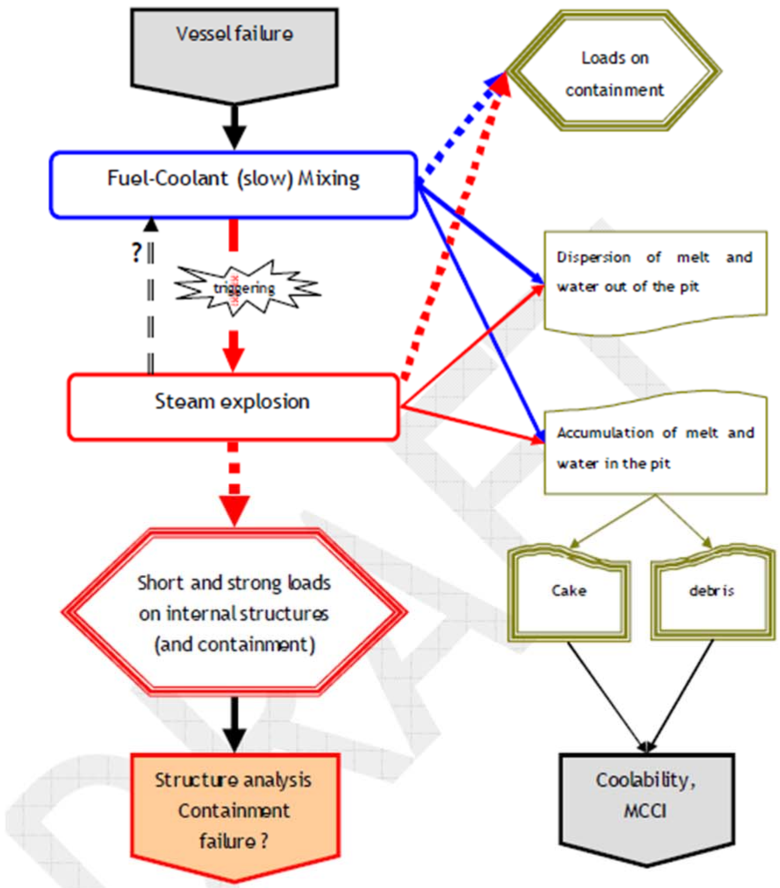
Sources of Uncertainty in Severe Accident Event Progression

relocation to the lower head		vessel design
Melt composition		Limited
Additives: FeO, B_4C, etc.	RASPLAV, PHEBUS-FP, CORA	Limited
Interaction with structures	MP tests	Limited
5. Melt composition and chemistry		
Mass of metallic and oxidic components		Limited
Chemistry in liquid phase (melt stratification)	RASPLAV	Limited
Hypostoichiometric oxides and metallic U behavior	RASPLAV, indirectly	Limited
Crust formation	RASPLAV	Limited
Intermetallic reactions	RASPLAV Planned	Limited
Corium properties (UO_2-Zr-ZrO_2)	RASPLAV	Reasonable
6. Vessel failure modes		
Vessel breach, high pressure	LHF (Sandia)[26]	Reasonable
Creep simulation and low pressure breach	OLHF[27], FOREVER	
Irradiated vessel		
Vessel impingement	MVI Project[28]	Reasonable
7. Transient processes		
Jet formation		
Steam explosion	FARO[29], KROTOS[30]	Limited
Fragmentation		
Dynamic loads		Reasonable
Vessel breach		Limited

Sources of Uncertainty in the Estimation of Event Likelihood

- Ties directly to Core Melt Progression
  - APET branches identify many pathways through a core melt progression process, affecting important parameters that influence contaiment challenges. These include:
    - In Vessel FCI Failure (alpha-Mode)
    - Potential for lower head breach (following core re-location)
    - Timing and rate of hydrogen production
    - Potential of DDT
    - Severity of "steam explosions"
    - Likelihood of coolability of corium "in vessel", "in containment"
    - Uncertainty related to Operator actions and resource availability
    - Impact of Hydrogen Transport outside of containment on equipment operation
  - These and other branch points need characterization to understand the distribution of end states.
  - AMSAMPA provides some guidance on defining the probability distributions for some of the above issues
  - Issues may also be characterized by decomposition trees.

Sources of Uncertainty in the Estimation of Event Likelihood: progression of a Steam Explosion Event



Sources of Uncertainty in the Calculation of Containment Failure Mode

- End state of Level 2 assessment is to input Consequence analysis. To this end the Level 2 analysis should provide a coherent picture of:
  - (a) timing of the breach,
  - (b) location of breach
  - (c) type of breach (timing of opening)
  - (d) containment pressure at breach and
  - (e) radionuclide content and distribution.
- Uncertainty in these areas will have a direct impact on the prediction of public consequences.

Sources of Uncertainty in the Calculation of Containment Failure Mode

- Uncertainities in several containment failure modes can be well characterized using traditional structural analyses.
  - Fragility curve readily determined for quasi-steady over-pressure challenges.
  - Detonation failures potential and characteristics more complicated.
  - Status of containment penetrations following severe accident behaviors
  - Basemat melt-through more uncertain due to corium coolability uncertainty but, bounding consequence assessments can be established in the context of pubic impact.

Sources of Uncertainty in Fission Product Evolution and Releases

- Severe accident computer codes provide a good assessment of fission product evolution during a core melt-progression scenario.
- Uncertainty characterization focus is on the potential release of evolved material. If a level 3 analysis is performed, uncertainty assessment should consider:
  - Plate-out and settling are important processes particularly for tracking iodine
  - Transport in pipes important for ISLOCA consequences
  - Scrubbing via water pools /sprays
  - Potential for re-evolution
- These issues may be treated via computer sensitivity studies tempered by review of experiments

Closing Thoughts

- NUREG-1855 requires Level 1epistemic uncertainties be characterized.
- Level 2 issues are not as well understood as those involved in Level 1 Internal events PRA
- Characterization of Level 2 uncertainties can be characterized qualitaitively.
- However, quantitative approaches are also needed for applications.
  - To support Level 3 models there should be considerations of developing decomposition trees for various phenomena, assigning probability distributions to the model components and propagating these uncertainties via APET models directly into release categories
- Hybred approaches may also be effective

  Since Level 3 consequences are driven by large release scenarios, going forward, it is possible that adequate resolution and impact characterization may be established by focusing on propagating potential high release scenarios with lesser resolution for low impact (e.g. intact sequences)