Level II Uncertainties

Rich Denning
February 29, 2012

Applications of Level II Results

- Significance of uncertainties depends on the application
- Historically, the principal regulatory use of Level II results has been for the calculation of LERF
  - NUREG/CR-6595, An Approach for Estimating the Frequencies of Various Containment Failure Modes and Bypass Events – approved approach
  - To the extent that utilities relied on generic results – this approach did not achieve potential value of identifying plant-specific vulnerabilities
- Applications may be changing post-Fukushima

Grouping PD States - L1

- Source of Uncertainty – Separation between Levels 1 and 2 is artificial.
- Discussion – Grouping is performed to simplify the analysis. The process leads to loss of information. Important to allow recovery actions across the boundary. Need to perform more seamless Level I/II studies to assess importance.
- Significance - Medium

Approach to Uncertainty Analysis - UA1

- Source of Uncertainty – The approach to the uncertainty analysis can introduce uncertainties
- Discussion – Uncertainties introduce changes in the order of events. Dynamic event trees enable consistent phenomenological analyses to be performed. Although there is some apparent arbitrariness in designation of uncertainties as aleatory or epistemic, insufficient attention is paid to what the quoted uncertainty is intended to represent.
- Significance - Medium

Containment Response - CP-1

- Source of Uncertainty – Ability to identify primary containment structural vulnerabilities
- Discussion – Potential vulnerabilities have been identified for different types of containment. Failure to consider all these vulnerabilities for a specific design introduces uncertainty. The potential exists for unrecognized vulnerabilities in a specific containment due to construction or design faults.
- Significance – Medium to High

Containment Response - CP-2

- Source of Uncertainty – Ability to assess probability of containment failure given quasi-steady load
- Discussion – SNL (international) model containment failure experiments have provided validation basis. Ability to determine failure pressure given defined conditions has significant uncertainty (greater for concrete containments). Significant uncertainties associated with construction detail and ageing effects. Basis for developing fragility curve is typically subjective.
- Significance – High

Containment Systems Response - CP-3

- Source of Uncertainty – Consideration of the response of containment systems to overpressure or over-temperature loads.
- Discussion – Are there other systems such as fan-coolers that could fail as a result of over-pressure, over-temperature or dynamic loads and subsequently impact containment failure.
- Significance – Medium

Containment Systems Response – CP-4

- Source of Uncertainty – Containment response to dynamic loads.
- Discussion – Given a dynamic load (such as a hydrogen detonation or a steam explosion in the reactor cavity) how well can we predict the performance of the structure and the associated impact on containment integrity?
- Significance – Medium. Not clear that dynamic loads will have significant probability.

Containment Systems Response – CP-5

- Source of Uncertainty – Failure to isolate
- Discussion – Not a phenomenological issue. Unclear (to me) how much effort has been invested at each plant in assessing probability of pre-existing leakage above design basis or inability to isolate systems penetrating containment. The leakage requirements for essential systems like RHR and their ability to perform post accident are unclear.
- Significance – Potentially high (I may just not understand current state of knowledge)

Containment Systems Response – CP-6

- Source of Uncertainty – Bypass scenarios
- Discussion – Considerable effort has been expended in addressing interfacing systems LOCA, SGTR accidents in which tube rupture is the initiating event, and induced SGTR. The potential implications are so high that for any given plant design the impact of uncertainties must be considered. These uncertainties are significant.
- Significance – Potentially high

Severe Accident Progression - SA-1

- Source of Uncertainty – Capability of systems code to model core degradation and reconfiguration within core region
- Discussion – The degree of fidelity with which core degradation and slumping can be predicted affects the extent of metal-water reaction (hydrogen production), the time-temperature, and surface-to-mass history of the melt (affecting radionuclide release), the ability of ECC recovery to actually cool the core, and the amount of hydrogen produced during recovery.
- Significance – High

Severe Accident Progression - SA-2

- Source of Uncertainty – Capability of systems code to model loop behavior
- Discussion – The degree of fidelity with which the flow patterns are predicted in the hot legs and SG affect the likelihood of creep failure of the hot leg, surge line and SG tubes. Applicability of incremental damage creep rupture models to dynamic heat-up of structure is uncertain.
- Significance – High

Severe Accident Progression - SA-3

- Source of Uncertainty – Capability for analysis of HPME
- Discussion – The degree of fidelity with which systems codes model HPME is inadequate. The ability of tailored analyses to estimate associated loads is system geometry dependent and pre-existing hydrogen dependent. Amount of retention on pathway to containment uncertain.
- Significance – Medium. A data base exists and tools are available to support plant-specific dependent analyses.

Severe Accident Progression - SA-4

- Source of Uncertainty – Capability of analysis of lower vessel failure modes
- Discussion – The conditions associated with a molten pool in the lower head region and mode of vessel failure are very uncertain. Ability to model side failure, unzipping, localized attack, or penetration failure depend on nature of the pool or debris. For some plants, uncertain whether vessel could be externally coolable. Coolability following reflooding is uncertain. Rocket mode of containment failure can probably be precluded.
- Significance – Medium. High if related to prevention of core concrete attack.

Severe Accident Progression - SA-5

- Source of Uncertainty – Potential for FCI in lower head region.
- Discussion – High confidence that alpha-mode failure is not physically realistic. OECD SERENA program results indicate that steam explosion in lower head is not sufficiently energetic to fail vessel (D. Magallon, Ref. 1)
- Significance – Low. Uncertainties not high enough to indicated significant failure mode.

Severe Accident Progression - SA-6

- Source of Uncertainty – Potential for FCI in reactor cavity region
- Discussion – Steam explosion more likely in cavity than in-vessel (subcooled water, low-pressure, weaker structures than vessel). Unclear potential effect of structural failures in cavity/pedestal region on containment integrity. Could have beneficial effect related to debris coolability and reduced core-concrete attack.
- Significance – High. Can affect SAMG strategy.

Severe Accident Progression - SA-7

- Source of Uncertainty – Potential for combustible and non-condensable gas production during core-concrete attack.
- Discussion – Core-concrete penetration models provide fairly predictable production rates of gases. Potential addition to in-vessel combustible gas production is substantial affecting potential for late hydrogen combustion event.
- Significance – High. Can affect SAMG strategy.

Severe Accident Progression - SA-8

- Source of Uncertainty – Potential for basemat penetration or failure of structures.
- Discussion – Core-concrete models have reasonable data base considering experimental difficulty. Significant uncertainties exist regarding layering of material which affects rate of penetration and axial versus radial penetration. More attention required on effect of undermining support structures.
- Significance – High. Can affect SAMG strategy.

Severe Accident Progression - SA-9

- Source of Uncertainty – Horizontal spread of corium on floor and direct attack of containment
- Discussion – The potential may exist for direct attack of Mark I liner. Considerable data and analytic effort in the past.
- Significance – High.

Containment Loads – CL-1

- Source of Uncertainty – Magnitude of combustible gas release and distribution within containment
- Discussion – Relates to SA-1 and SA-7 with regard to production. System codes are incapable of addressing adequately. Separate effects codes can provide insights into compartment concentrations and stratification.
- Significance – High.

Containment Loads – CL-2

- Source of Uncertainty – Likelihood of accumulating combustible gases to high levels prior to ignition.
- Discussion – System codes cannot address adequately. Some knowledge of ignition requirements as a function of concentrations. Significant uncertainty in likelihood of ignition source of different energy levels.
- Significance – High.

Containment Loads – CL-3

- Source of Uncertainty – Magnitude of hydrogen combustion energetics
- Discussion – System codes cannot address adequately. Good understanding of flammability limits, thresholds for deflagration and detonation for hydrogen. Less understanding of combination of hydrogen and CO. Limited understanding of conditions resulting in transition to detonation.
- Significance – High. Could affect containment design modifications.

Radionuclide Release and Transport – RN-1

- Source of Uncertainty – Release of radionuclide groups from fuel in-vessel
- Discussion – Epistemic uncertainties remain substantial. Source terms should be calculated mechanistically for different scenarios and plant designs. Closely related to SA-1 uncertainties. Uncertainties in volatile releases not too important because they are high (bounded by unity). Uncertainties in low volatile groups very high but unlikely to be important.
- Significance – Medium.

Radionuclide Release and Transport – RN-2

- Source of Uncertainty – Radionuclide chemical forms
- Discussion – Understanding of chemical forms is improving but there are still significant uncertainties. Systems codes typically do not consider chemical kinetics. Iodine remains the major chemical form issue with some potential for volatile species (including organic iodides). Evolution of iodine from pools is also a source of significant uncertainty. A principal form of Cs appears to be Cs molybdate.
- Significance – High.

Radionuclide Release and Transport – RN-3

- Source of Uncertainty – Retention during transport in primary system and re-evolution
- Discussion – Uncertainties in retention are large. Poor agreement with experiment. Uncertainties associated with re-evolution are also large. Extent of vapor deposition and reaction with surface unclear. Aerosols tend to be hard to remove from surface.
- Significance – Medium. Some tendency for uncertainties to balance.

Radionuclide Release and Transport – RN-4

- Source of Uncertainty – Aerosol formation, transport and deposition
- Discussion – Aerosol mechanics are well understood but the methods used to examine aerosol formation, growth, interactions and deposition in system codes are crude. Some uncertainties are associated with charge effects, shape factors, and hygroscopicity.
- Significance – High.

Radionuclide Release and Transport – R5

- Source of Uncertainty – Grouping of radionuclides into groups
- Discussion – For many groups, the chemical characteristics of different elements within a group are unnatural and can vary substantially. Radioactive transformation of elements is not taken into account as it affects reactions and potential for release. Transport of heat source is tied to the groupings.
- Significance - Medium

Radionuclide Release and Transport – R6

- Source of Uncertainty – Release of radionuclides during core-concrete attack
- Discussion – The uncertainties associated with core-concrete release are larger than for in-vessel release. Uncertainty in release of residual volatile radionuclides not too large because effectively they will all evolve. Uncertainties in release of low-volatiles (which is larger than for in-vessel) is high and of greater importance than for in-vessel release.
- Significance - High