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Uncertainty in Low Power and Shutdown PRA Models

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ENGINEERING RISK SOLUTIONS

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Objectives:

1. Purpose/Perspective

2. Review of Uncertainty in LPSD Tasks

3. Summary

Purpose/Perspective:

Purpose of an uncertainty analysis is to:

a) Demonstrate a <u>level of confidence</u> in the PRA results

b) Establish the <u>contribution of individual input parameters</u>, assumptions and modeling techniques <u>to variance in risk</u>

- Depends on the combination of variance and sensitivity of the individual inputs
- Inputs with a high contribution to variance of risk prediction need to be carefully scrutinized to ensure representation is reasonable.

c) Proper use of uncertainty in quantifying risk model should allow a <u>more realistic representation of the best estimate risk</u> by avoiding the use of conservative inputs.

Review of Uncertainty in LPSD Tasks

- **Low Power and Shutdown PRA Tasks are Similar to Full Power PRA (with additions)**
  1. **Scope Definition**
  2. **Plant Operational State (POS)**
  3. Initiating Event (IE)
  4. Accident Sequence Progression (AS)
  5. Success Criteria (SC)
  6. Systems Modeling (SY)
  7. Data (DA)
  8. Human Reliability (HR)
  9. Quantification (QU)
  10. LERF (LE)
- **Hazards – Internal and External Spatial Events**

LPSD Tasks – Scope Definition

- **Uncertainty Contributions from the LPSD Scope Task:**
  - Comprehensiveness & extent of LPSD study
    - Hazards other than internal events
    - Outage types to be considered (forced or refueling)
    - Fuel Location
      - Example, whether Spent Fuel Pool is included or excluded
  - Endstates Modeled
    - Sometimes model Boiling and not LERF
  - Type of Model
    - Configuration risk management tool (for outage risk management)
      - To understand relative risk as compared to calculation of absolute risk values (such as for aggregation with other risk results in a RG 1.174 submittal)
    - Sometimes Qualitative/Defense-in-Depth approach
  - General level of detail of overall study
    - Train level vs. component level

LPSD Tasks – Plant Operational States

- **Uncertainty Contributions from the LPSD POS Task:**
  - Types of POS's modeled
    - Completeness in POS identification
    - Typically a limited subset is selected
      - Example, PRA limited to PWR midloop operations
  - POS characterization
    - Entrance time relative to plant scram or shutdown
      - Short time involves higher decay heat loads
    - Duration
      - Longer duration increases risk exposure from POS
  - POS Grouping
    - Typically a limited subset is selected
      - Example, POS approach that groups Early (before core reload) and Late (after core reload)
  - POS Quantification
    - Durations vary as "No 2 outages are the same"

LPSD Tasks – Initiating Events (IE)

- **Uncertainty Contributions from the LPSD IE Task:**
  - Types of IEs modeled
    - Completeness in IE identification
    - Typically a limited subset is selected (or created via Grouping)
    - LOCAs become Loss of Inventory and may be caused by Outage maintenance or re-alignment activities or load drops
  - Frequencies of IEs modeled
    - Availability and applicability of "industry average" frequencies (used directly or in Bayesian updates)
      - Limited industry data compared with full power internal event IEs
      - Consistency of IE definitions used when reviewing data
      - No source similar to NUREG/CR-6928 (used for full power IE frequencies)
        - Except for loss of offsite power (NUREG/CR-6890)
    - Limited plant-specific data
      - Consistency in characterization with "industry average" efforts
      - Many plants would have no events
    - Specific examples of difficulties shown on following slide
      - Typically resulting from limited number of events

LPSD Tasks – Initiating Events (IE)

- **Example Uncertainties in Generating Industry Average Initiating Event Frequencies**
  - BWR loss of residual heat removal capability (> 15 min)
    - 2 events, 34.84 reactor shutdown years (rsy), 1997 - 2006
      - Mean of 7.1E-2/rsy
      - But statistical analysis indicates BWR data can be grouped with PWR data
      - Grouped mean = 2.0E-2/rsy
      - Large differences in 5^{th} and 95^{th} percentiles
  - BWR loss of inventory due to LOCA
    - 0 events, 110.6 rsy, 1988 – 2006
      - Mean of 4.5E-3/rsy
      - But statistical analysis indicates BWR data can be grouped with PWR events
      - Grouped mean = 7.4E-3/rsy
      - Large differences in 5^{th} and 95^{th} percentiles

LPSD Tasks – Accident Sequence (AS)

- **Uncertainty Contributions from the LPSD AS Task:**
  - End state determination
    - Example, how to treat the sequence where the time to boil and/or time to core damage is greater than 48 hours.
  - Mission time selection
  - Decay heat level(s)
    - Some times "Early" and "Late" event trees are merged into one to limit the number of quantifications. While this is likely bounding, it can be conservative (especially with drop in decay heat due to new fuel)
  - Treatment of recovery of mitigating systems and/or support systems
  - Modeling of reactivity phenomena
  - Containment Isolation often captured as Open or Closed

LPSD Tasks – Success Criteria (SC)

- **Uncertainty Contributions from the LPSD SC Task:**
  - Available systems and/or trains
  - Decay heat level(s)
  - Limited detailed thermal-hydraulic coverage
    - Wide range of POS/timing/other combinations included in LPSD model
    - Typically must use a more limited set of detailed SC analyses
    - Often existing calculations are conservative licensing calculations
      - Example, time to boil and/or core damage start with initial temperature of 190F vice typical operating levels
  - Calculation inputs/assumptions often drive results (similar to full power)
    - Example – Volume of coolant modeled during PWR midloop may be limited to water in the RPV or it may consider a portion of water in the RCS loops.
    - Complexities
      - Example 1, amount of credit for SG reflux cooling

LPSD Tasks – System Models (SY)

- **Uncertainty Contributions from the LPSD SY Task:**
  - Generally similar to full power modeling
  - Variations by POS
  - Modeling of train/component unavailability (UA)
  - Complexity with interlocks/protective features
    - Example 1, RHR pump protective trips may be over-ridden by Safety Actuation start signals during Full Power but may impact system operation during Shutdown (when the systems are manually started).
    - Example 2, sometimes temporary systems are installed such as a temporary diesel or temporary air compressor (potentially different type/size/reliability from permanent system).
    - Example 3, maintenance alignments may preclude or impact system restoration.

LPSD Tasks – Data (DA)

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- **Uncertainty Contributions from the LPSD DA Task:**
  - Modeling of component or train UA
    - Maintenance is not allowed within certain POSs, but potentially increases as Tech Spec limits are relaxed in other POSs
    - Industry average UA for components not available for LPSD
      - Multiply full power UA estimates by factor (5 to 10?)
        - See next slide for estimate for EDGs
      - Increase full power UA estimates based on Tech Spec completion times
    - Plant-specific and POS-specific UA modeling important
  - Component unreliability uncertainties generally similar to full power modeling, but some components may vary such as sump plugging
  - Common-cause failure (CCF) uncertainties similar to full power modeling
  - Repair/recovery uncertainty large

LPSD Tasks – Data (DA)

- **Example EDG UA Multiplier for the LPSD DA Task:**
  - NUREG/CR-6890, Vol. 2, Table A-3
    - Unplanned demand data for EDGs
      (responding to a loss of power to the 4 kV safety bus)
      - Unplanned demands during full power operation
        - 1 EDG UA event in 95 unplanned demands
        - MLE = 0.010
      - Unplanned demands during LPSD operation
        - 6 EDG UA events in 67 unplanned demands
        - MLE = 0.090
      - Ratio (UAshutdown/UAfullpower) = 9

LPSD Tasks – Human Reliability (HR)

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- **Uncertainty Contributions from the LPSD HR Task:**
  - More operator actions, fewer automatic actuation systems
  - Uncertainties large in HR modeling for LPSD
    - Potential dependency issues between IEs and human failure events (HFEs) modeled in LPSD
      - Example, if a maintenance activity caused an initiating event then potentially improved plant response (as operators realize what just happened) or potentially degraded plant response (as operators believe they are taking the correct response).
    - HRA dependency models (from THERP) were intended for actions to be “close-in-time” if separated by a few minutes.
      - But often in a shutdown model a dependency between “failure to restore DHR before boiling” and “failure to restore DHR before core damage”
        - This is typically >90 minutes, and is often hours.
    - Plant response Procedures & Training for operators are typically different from Full Power
    - Potentially fewer control room indications available
    - Ranges of timings for diagnosis and action
    - HRA methods cannot adequately calculate HEPs when long time windows (e.g. ten hours or more)
      - Run into minimum HEP limits and/or the issue when to declare “negligible”

LPSD Tasks – Quantification

- **Uncertainty Contributions from the LPSD QU Task:**
  - Generally similar to uncertainties in the Full Power QU task
  - Aggregation issues
    - Understanding & managing multiple quantifications & sets of results
    - Development of Importance across POSs (multiple PRAs)
  - Risk Metrics
    - Instantaneous CDF vs. Average CDF vs. Cumulative CDF

LPSD Tasks – Large Early Release

- **Uncertainty Contributions from the LPSD LE Task:**
  - LPSD-specific considerations
    - Containment status (open or closed), and recovery
    - Fuel location
    - Timing from scram/shutdown – radionuclide inventory decay may be such that LERF not possible after a certain period of time

LPSD Tasks – Hazards/Spatial

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- **Uncertainty Contributions from the LPSD Hazards Task:**
  - Draft NRC LPSD Fire NUREG released for comment
  - Generally affected by uncertainty issues for LPSD plus uncertainty issues from the Hazard group.

Summary

- **Uncertainty Generalizations for the LPSD Tasks:**
  - LPSD models have been around for decades but are relatively immature as they have not received as much use, review and application
  - LPSD PRA Standard has not been published.
  - PRA process is the same as for full power, but POS's can vary widely
    - Reduced inventory, early with RPV head removed
    - Refueling basin flooded, late
  - Multiple POSs with multiple event trees lead to configuration control challenges
  - Plant level of activities increased, procedures & training can vary from Full Power
  - Not as much industry average supporting information compared with Full Power
  - Recognized in a 2005 OECD report as an issue that would benefit from guidance

Questions/Discussion?