Insights from Multi-Unit Level 1, 2 and 3 Probabilistic Risk Assessment Results for Light-Water Reactor Designs – What Can Be Extrapolated to Advanced Reactor Designs?

Susan E. Cooper, Erick Ball, Trey Hathaway, Keith Compton, Alan Kuritzky, Latonia Enos-Sylla (USNRC)

Selim Sancaktar (retired)

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OVERVIEW

- Background
- Sitewide dependency assessment
- Multi-unit (MU) core damage frequency results
- MU Level 2 and Level 3 results
- What could be different for advanced reactors?
- Extrapolating MU results to advanced reactors?

BACKGROUD

- USNRC is nearing completion of its sitewide, all hazards Level 3 PRA Project
- Reference site includes:
  - Two, nearly identical reactors (PWRs)
  - Two, hydraulically connected spent fuel pools (SFPs)
  - A dry cask storage (DCS) facility
- In addition to Level 1, 2, and 3 PRAs, the L3PRA project includes an integrated site risk (ISR) task that considers all radiological sources which:
  - Addressed at-power conditions only
    - Only internal events low power & shutdown addressed by L3PRA project due to limited resources; this limitation could be significant
  - Used results of the other PRAs in the L3PRA project
  - Produced integrated Level 3 consequence results

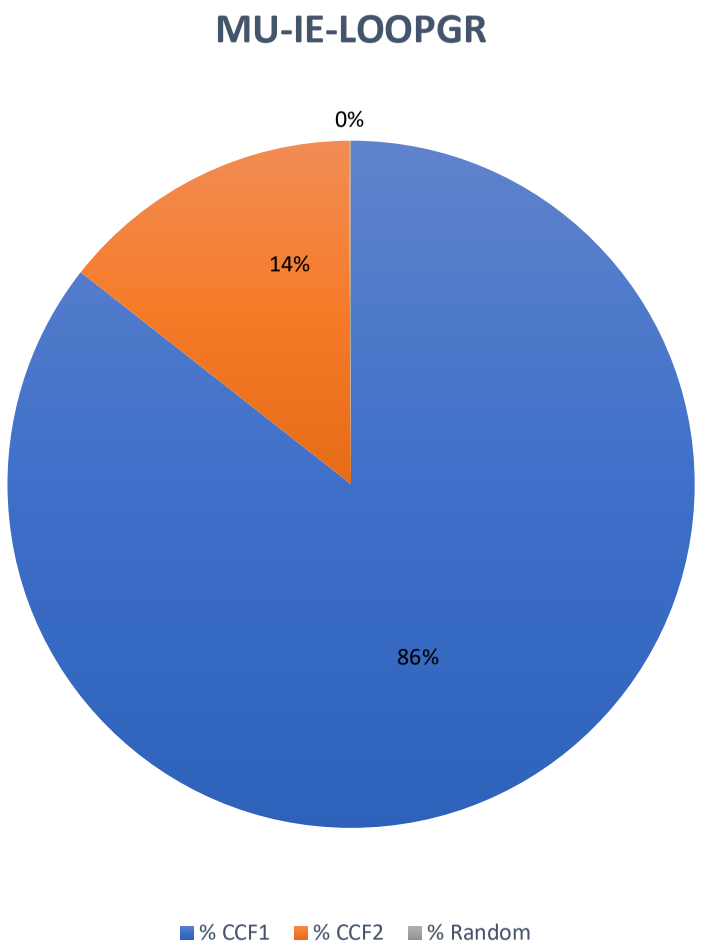
NRC's ISR Sitewide Dependency Assessment

- Used a formal, phased process for performing assessment
- High-level results:
  - Expected MU initiating events (e.g., losses of offsite power (LOOPs), seismic events, loss of service water, high winds)
  - A few shared resources (e.g., electric power, water supplies) & even fewer shared systems, structures, and components (SSCs)
  - Many identical components to model as MU common cause failures (CCFs)
  - A few fire scenarios that are considered "cascading" events
  - Some human & organizational dependencies
  - Expected hazard correlations for external events
- Overall, two units are mostly independent

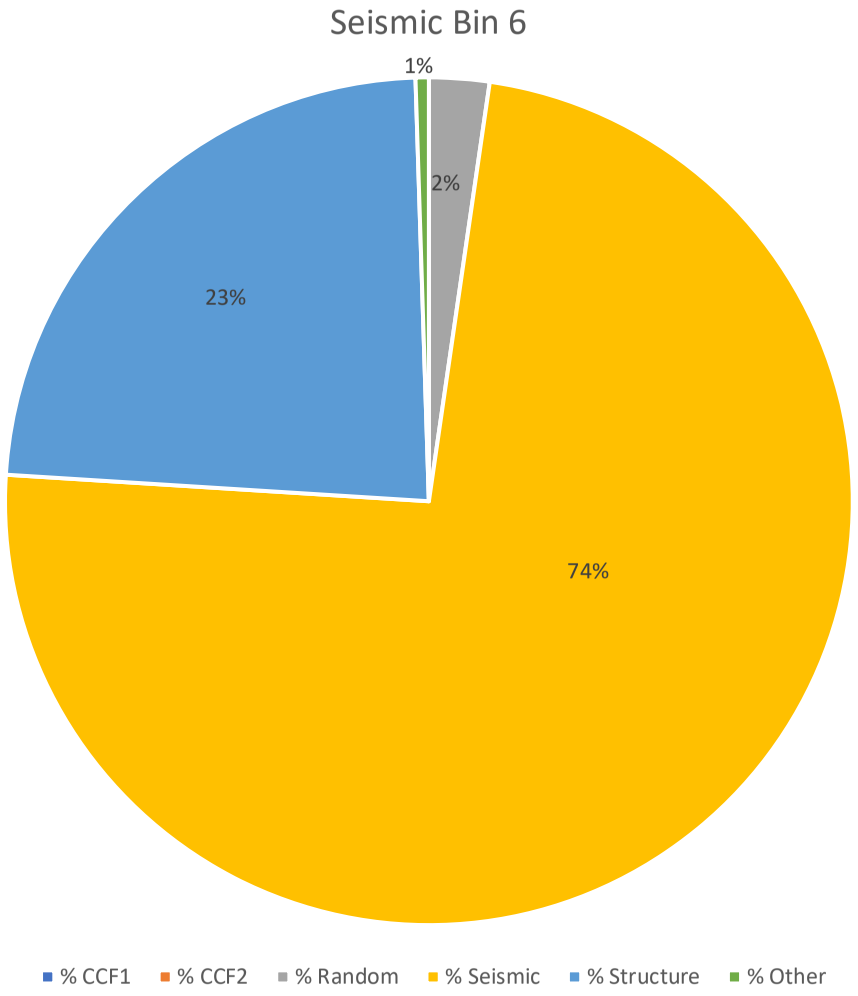
ISR Task's Multi-Unit CDF Results

- MUCDF results were produced by:
  - Using the cutsets from previously performed L3PRA project PRAs
  - Using the results of the sitewide dependency assessment
  - Assigning generic (& likely conservative) coupling factors for MU dependencies (e.g., MU common cause failures (CCFs))
- MUCDF results showed that:
  - Total MUCDF is between 10 and 15 percent of the single unit CDF
  - Contributions to total MUCDF:
    - 2 percent from selected fire scenarios
    - 6 percent from wind events
    - 14 percent from LOOPs (which also often resulted in station blackout (SBO))
    - 25 percent from loss of service water
    - 53 percent from seismic events
  - Significant contributors to MUCDF results:
    - Loss of offsite power events and lowest seismic bins: MU CCFs (CCF1 & CCF2)
    - Higher seismic bins: seismic correlations were dominant (SEISMIC & STRUCTURE)
  - Conditional probability of MU core damage given single unit core damage is equal to or approximately 1.0 for higher seismic bins

Sitewide dependency contributions to MUCDF for grid-related LOOPs



Sitewide dependency contributions to MUCDF for Seismic Bin 6



ISR Task's MU Level 2 and Level 3 Results

- MU Level 2 and Level 3 results were produced for two illustrative ISR scenarios:
  - Weather-related LOOPs (LOOPWR)
  - Seismic bin 6 events
- High-level MU Level 2 results showed that:
  - LOOPWR: Containment failure mode for SBO scenarios depends largely on physical phenomena such as hydrogen combustion and hot leg creep failure that are not correlated between units
  - Seismic bin 6: Containment isolation system seismic failure is coupled between units, but other containment failure modes remain mostly uncorrelated
- High-level MU Level 3 results showed that:
  - The sum of consequences computed for independent source terms may be sufficient for some of the metrics of interest, although this may overestimate results for collective doses and health effects.
  - This insight is consistent with the observation drawn from the single unit analyses that many consequences are either linear or sublinear with the magnitude of the release.

What could be different for advanced reactors?

- Advanced reactor sites likely will have:
  - More & smaller reactors
  - More shared systems and structures
  - Shared control rooms, operators, etc.
  - Advanced I&C, etc.
- Potential sitewide dependency implications:
  - MU CCFs of active equipment may not need to be modeled, or be as important
  - More likely to be dependencies between reactor units for all (or nearly all) operator actions
  - More correlated structural failures may need to be considered.
  - If there are shared systems, these dependencies (as for the existing LWRs) could be important
  - There may be "new" dependencies associated with I&C and automation (e.g., software failures)

Extrapolating MU results to advanced reactors?

- More “coupled” & potentially different types of MU dependencies
- Seismic events & LOOPs (power for I&C) likely most important
- For MU Level 1 PRA, “single unit” is not likely to be meaningful; instead, a multi-unit model would need to be developed as a first step
- For MU Level 2:
  - Coupling of post-core damage accident progression (e.g., combustion) is expected to be stronger
  - MU Level 2 models for sites with many reactors may be a computational challenge
- For MU Level 3, like LWRs, expect MU, multi-source releases to be bounded by the sum of the consequences

QUESTIONS?