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Important Considerations in Selecting a Simulation End-Time in Level 2 PSA Deterministic Analyses

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Presentation outline

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- Severe Accident Modeling Uncertainty
- HRA Challenges
- Other Accident Management Aspects
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  - Probabilistic results
- Conclusions

Introduction

- Historically, PSA for nuclear power plants has not explicitly modeled the role of long-term resources in terminating the accident post core damage.
- This is becoming difficult to justify in light of:
  - The maturity of accident management and emergency preparedness
  - The desire to improve realism
  - The possibility of additional failures significantly after the initiating event
  - The relative slowness with which some accidents progress (e.g., spent fuel pool accidents)
- Selection of a truncation time must consider multiple factors, some of which are discussed here

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Severe Accident Modeling Uncertainty

- Small changes in the simulation can have a large impact on the predicted releases due to threshold effects.
  - Not specifically considered here but, in general, overall uncertainty will increase with an increasing end-time.
- The following phenomena have significant uncertainty and affect the prediction of environmental release
  - The melt makeup, distribution, and behavior of molten-core concrete interaction (MCCI) are all uncertain. They can greatly affect the prediction of ex-vessel coolability and timing of over-pressurization versus basemat melt-through.
  - Tear-before-rupture and gross failure models of containment failure can affect prediction of long-term releases if the accident is not mitigated.
  - Some severe accident models predict large releases of molybdenum from the ex-vessel debris when the metals are oxidized. This issue is unique to long-running scenarios.

HRA Challenges

- Human reliability analysis (HRA) for severe accident scenarios is particularly challenging for long-running scenarios. Many uncertainties combine to influence what operationally will be included such as:
  - Actions to be included in the HRA
  - Success criteria for human action
  - Context factors that challenge human actions
  - Time available for human action
- The NRC developed the Integrated Human Event Analysis System (IDHEAS-G) which offers a general framework for addressing these uncertainties.
- The IDHEAS-G method provides a structured process for identifying key human actions in complicated, long-lasting scenarios and can assist PSA analysts in determining the analysis scope and assumptions.

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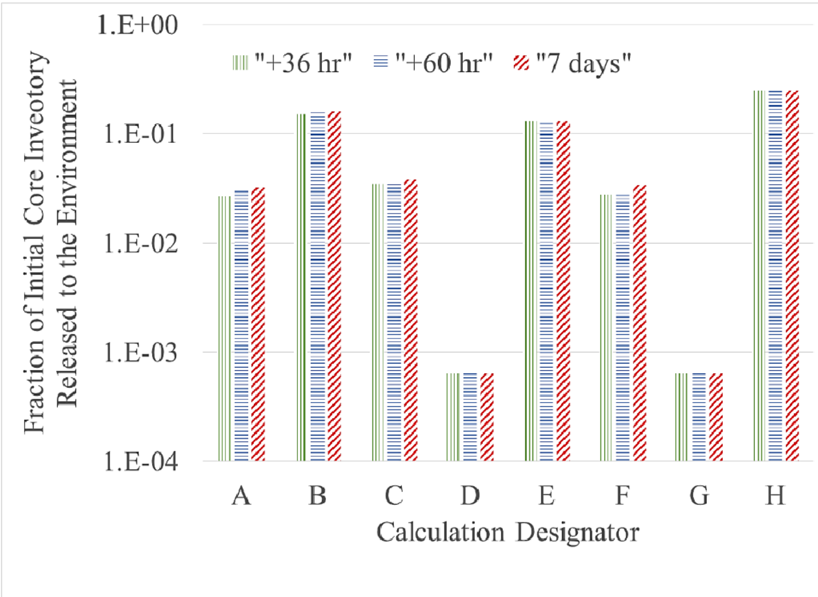
Other Accident Management Aspects

- Flammability within containment:
  - MCCI can increase the concentration of inertents in containment
  - Uncertainties in containment leakage, prior combustions, ignition frequency, and human actions make it difficult to determine whether a sizeable combustion will occur.
- Transit of combustibles to surrounding structures:
  - Uncertainties in the transit pathways and failure mechanisms make it speculative to predict how leakage will be distributed.
  - The coarse characterization of the modeling of surrounding structures was previously justified by conservative assumptions on retentions. However, the Fukushima Daiichi accident demonstrates that building failure can affect the release and accident response.
- Sustained high temperature and pressure impact on equipment:
  - Making conservative assumptions as to the survivability of equipment is difficult. The margin has both aleatory and epistemic uncertainty that is not well-characterized and exacerbated in the long term by sustained high temperatures (200 – 300 C) and pressures (0.6 – 0.9 MPa).

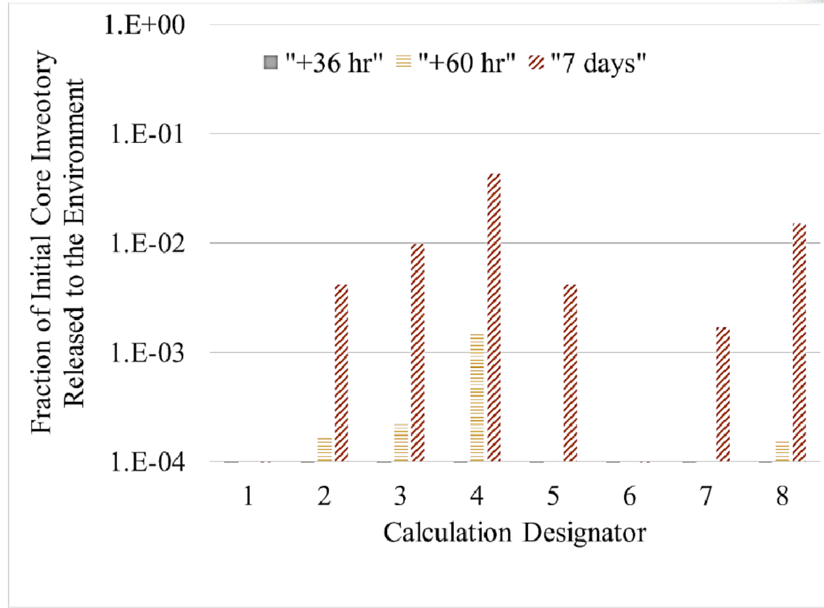
End-time Effect on Radiological Release Results

- Given the preceding points, is it practical to reliably predict accident consequences during long-running scenarios?
- To inform this question, a suite of contemporary MELCOR severe accident simulations were scrutinized.
  - It is important to note that these scenarios:
    - Have a very low combined likelihood of occurrence.
    - Are typical of PSA-oriented scenarios for a US PWR with a large, dry containment and employ typical MELCOR modeling assumptions.
    - Have boundary conditions that do not include mitigation actions much beyond vessel breach.
    - Have a range of potential outcomes based on modeling assumptions and boundary conditions
- There were two fundamental trends of interest in the results:
  - Bypass and early failure scenarios lead to the highest radiological releases, regardless of truncation time.
  - Bypass and early containment failure radiological releases for volatile chemical classes are insensitive to truncation time.

End-time Effect on Radiological Release Results



Cumulative Cs releases for Bypass and Early Failure scenarios



Cumulative Cs releases for Late and No Containment Failure scenarios

- The results suggest that to a first order, the consequences that would be predicted from such environmental release estimates are not sensitive to truncation time.
- This finding is consistent with general practitioner experience/expectation.

End-time Effect on Probabilistic Results

- To further explore the effect of simulation end-time, an example is provided showing its impact on common Level 2 PSA risk surrogates.
  - There is significant variability in the US as to what quantitative definition is used to operationalize the qualitative definitions.
- A sample release category profile (provided in the associated paper), loosely based on typical internal events Level 2 PSA results for operating US PWRs, is applied to several definitions of the following risk surrogates:
  - Large Early Release Frequency (LERF)
  - Large Release Frequency (LRF)
  - Conditional Containment Failure Probability (CCFP)

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Synopsis of Results

	Risk surrogate: Truncated at 48 hours after core damage / Truncated 7 days after event initiation		
	LERF	LRF	CCFP
NUREG/CR-6595	4% / 4%	-	
NUREG/CR-6094	-	10% / 10%	
EPRI PSA Applications Guide	6% / 6%	-	
EPRI URD	-	14% / 14%	16% / 66%
ENSI	-	16% / 16%	
STUK	-	16% / 16%	
Definition unique to this paper	5% / 5% (injuries) 4% / 4% (fatalities)	12% / 16%	

- LERF is not sensitive to simulation end-time or definition
- LRF is only sensitive to simulation end-time for the newly proposed definition and is somewhat sensitive to the definition selected
- CCFP is extremely sensitive to simulation end-time

Conclusions

- There are many important considerations when choosing a simulation end-time.
- Only a subset of the deterministic and probabilistic results are inherently sensitive to the end-time selection. Therefore, the selection can be made in concert with the specific goals of the analysis.
- The selection of the risk surrogate definition can be as or more important as the selection of a simulation end-time.
- The observations in the paper are not intended as guidance with respect to regulatory requirements. Also, future evolution of modeling techniques may affect the conclusions that have been made.