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Sandia National Laboratories

IAEA CRP I31033 : STATUS REPORT

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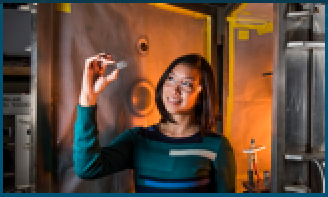

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IUP Integrated University Program

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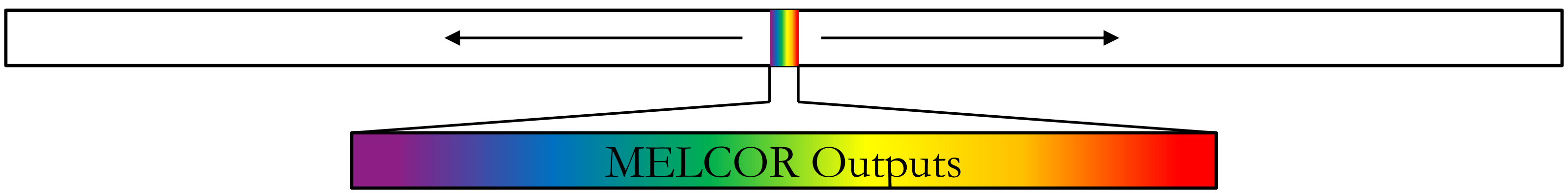
Contents

Glimpse of the Horizon

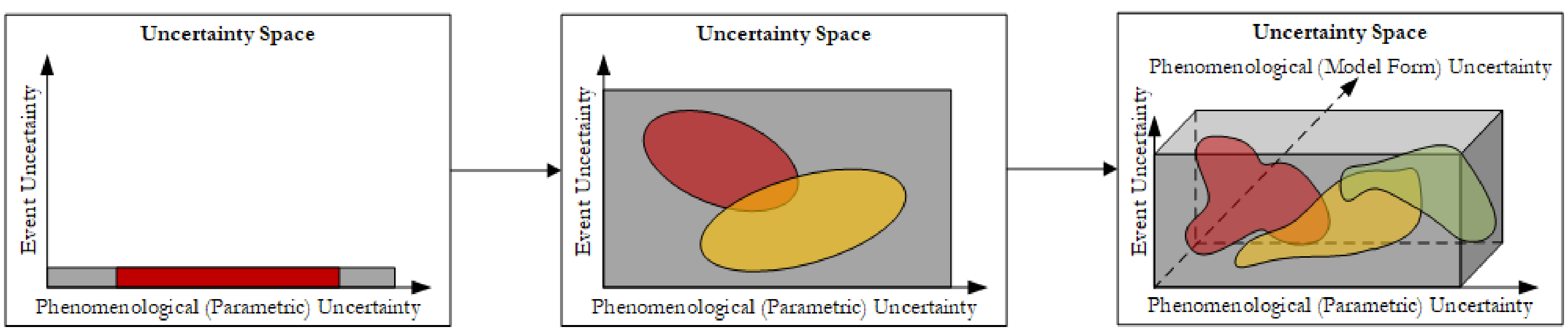
Developing insights

- Severe accident progression – what is/are the end-states, the releases, the risks?
- Model form error – Are the model assumptions accurate? Can they be improved?
- Model biases – Are the models imposing inappropriate, non-physical, or otherwise incorrect structure on accident progression simulations?
- Unknown unknowns – What are we missing?



Expansion of the uncertainty space domain

- Inclusion of other forms of uncertainty is a more "complete" representation of reality
- Gross bifurcations may emerge (due to model differences, modelling gaps, etc.)



Project Summary and Objectives

Defining Terms:

- Uncertainty Analysis (UA) : to determine the range of **simulation outcomes** that results from uncertainty in simulation inputs
  - Uncertainty analysis here is not synonymous with uncertainty quantification
- Sensitivity Analysis (SA): to determine the impact of, or sensitivity, of uncertainty in simulation outcomes to uncertainty in simulation inputs

Investigate model form uncertainty between two material interaction modelling options available in MELCOR

- Explore the range of MELCOR results produced by each respective model
- Inform future MELCOR model development
- This UA is different from previous SNL studies which considered source term and consequence uncertainty (e.g., NUREG/CR-7155)

Research Objectives:

- Comparison of the overall accident progression exhibited by each model
- Comparison of the distributions of different figures of merit
- Identification of correlations and/or biases that each model may introduce

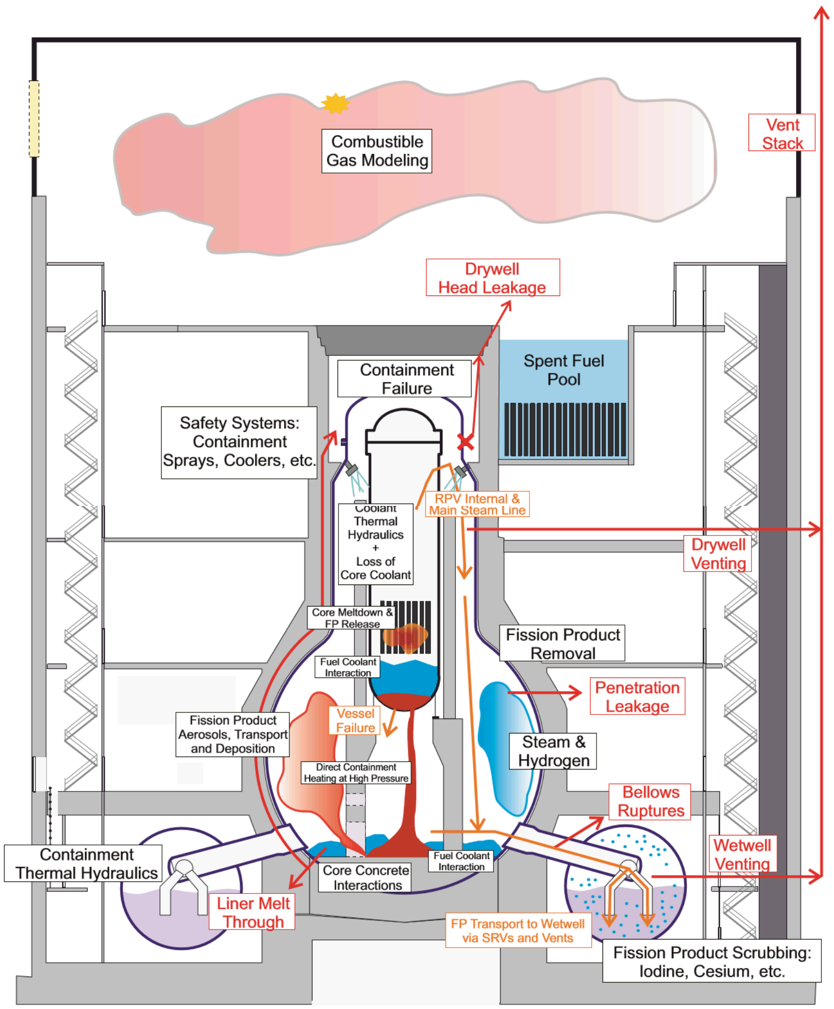
MELCOR V2.2. Overview

Models the spectrum of severe accident phenomena for multiple reactor types

Fast-running, primarily mechanistic models

Highly flexible structure

- Analysis-specific plant nodalization schemes
- Sensitivity coefficients
  - expose model parameters for user modification
- Control functions
  - incorporate external models (e.g. boundary conditions, system operation, preventative or mitigative measures, etc.)



Model Description and Boundary Conditions

Plant Model Description

- 1380 MW(th) BWR/3 reactor, Mk-I containment
- Two-train Isolation Condenser (42.4 MW per train)
- Core thermal hydraulic phenomena modeled in 26 control volumes (1 lower plenum, 25 core region)
- Core degradation phenomena modeled in 88 core cells (50 active core, 38 lower plenum)
- Containment phenomena modeled in 6 control volumes

Scenario Description

- Short-term Station Blackout
  - IC operation initially, but total loss of power <1 hour after initiating event
- Wetwell Venting
- Reactor Building Explosion

Boundary Condition	Description
SRV Seizure	Not permitted
SRV Gasket Leak	Not permitted
Main Steam Line Rupture	Not permitted
Lower Head Penetration Failure	Not permitted
Lower Head Gross Creep Failure	Permitted
Drywell Head Flange leakage	Begins at 0.648 MPa pressure in the drywell
Main Steam Line Isolation Valve Closure	At 0.0 hours
Feedwater System Ceases Operation	At 0.0 hours
IC Train A Operation	0.1-0.28 hours 0.52-0.55 hours 0.63-0.67 hours 0.77-0.8 hours
IC Train B Operation	0.1-0.28 hours
Wetwell Venting	At 23.7 hours
Reactor Building Explosion	At 24.8 hours

Reference Case Simulations Specifications

Simulation length: 25 hours

MELCOR V2.2 r15348

Outputs

1. Overall Accident Progression
   - Key event timings
2. Hydrogen Generation
3. Thermal Hydraulic Response
   - Primary Coolant System Response
   - Containment Response
4. Reactor Core Degradation
5. RPV Lower Head Breach

Blue annotation – early in-vessel phase

White annotation – late in-vessel phase

Red annotation – ex-vessel phase

Input Record	Reference Case Parameter Values	
	INT Model	EUT Model
Material Interaction Model		
Material Interaction Model Activation	INT Model	EUT Model
MP_PRC: ZRO2-INT, UO2-INT	2479.0	–
Candling Models		
COR _SC: 1131(2)	2400.0	2400.0
COR _SC: 1141(2)	1.0	1.0
Fuel Rod Failure Models		
COR_ROD	Active (0)	Active (0)
COR_CCT: DRZRMN	0.0001	0.0001
COR_SC: 1132(1)	2479.0	2479.0
Debris Quenching and Dryout Models		
COR_EDR: DHYPD, DHYPB (Active Core)	0.01	0.01
COR_EDR: DHYPD, DHYPB (Lower Plenum)	0.002	0.002
COR_LP: HDBH2O	4000.0	4000.0
COR_LP: VFALL	1.5	1.5
COR _SC: 1244 (3)	0.15	0.15
COR_TST: IMPLZDM	Active (0)	Active (0)
Numerical Uncertainty		
CVH_SC: 4422 (2)	245334.08	245334.08

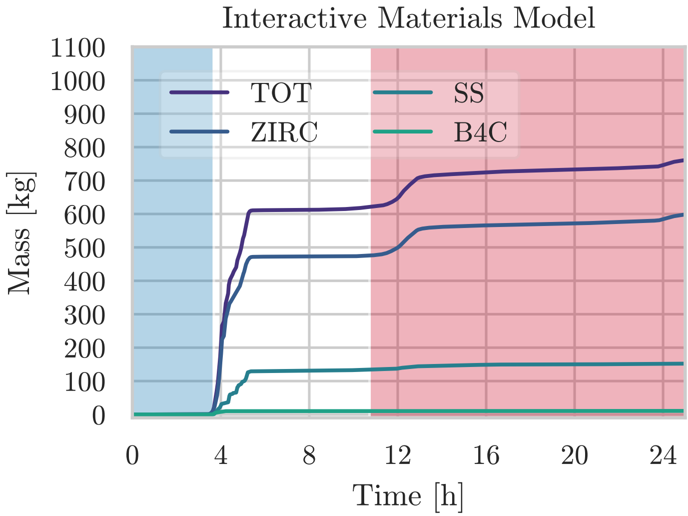
Overall Accident Progression

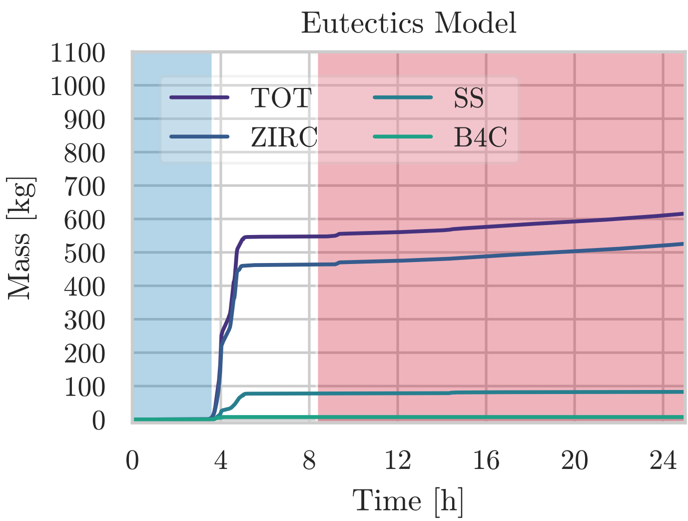
Event	INT model [h]	EUT Model [h]
Core Water Level at TAF	2.54	2.56
Core Water Level at 2/3 TAF	2.88	2.89
Core Water Level at 1/3 TAF	3.19	3.19
Core Water Level at BAF	4.00	3.97
Initial Gap Release	3.45	3.45
Initial Candling in Ring 1	3.69	3.64
Initial Particulate Debris Formation	3.64	3.70
Initial Core Plate Failure	5.05	5.01
Core Slump	5.25	5.01
Lower Plenum Dryout	7.56	6.36
Initial RPV Failure	10.72	8.34

Strong agreement in event timings is observed up until core plate failure (all <6 minutes), however, late core damage indicators such as lower plenum dryout and initial RPV failure demonstrate an accelerated accident progression is exhibited by the eutectics model.

Each reference cases exhibits a different type of initial debris formation. The interactive materials model simulation exhibits particulate debris formation first. Conversely, the eutectics model exhibits molten material formation (candling) initially.

Hydrogen Generation



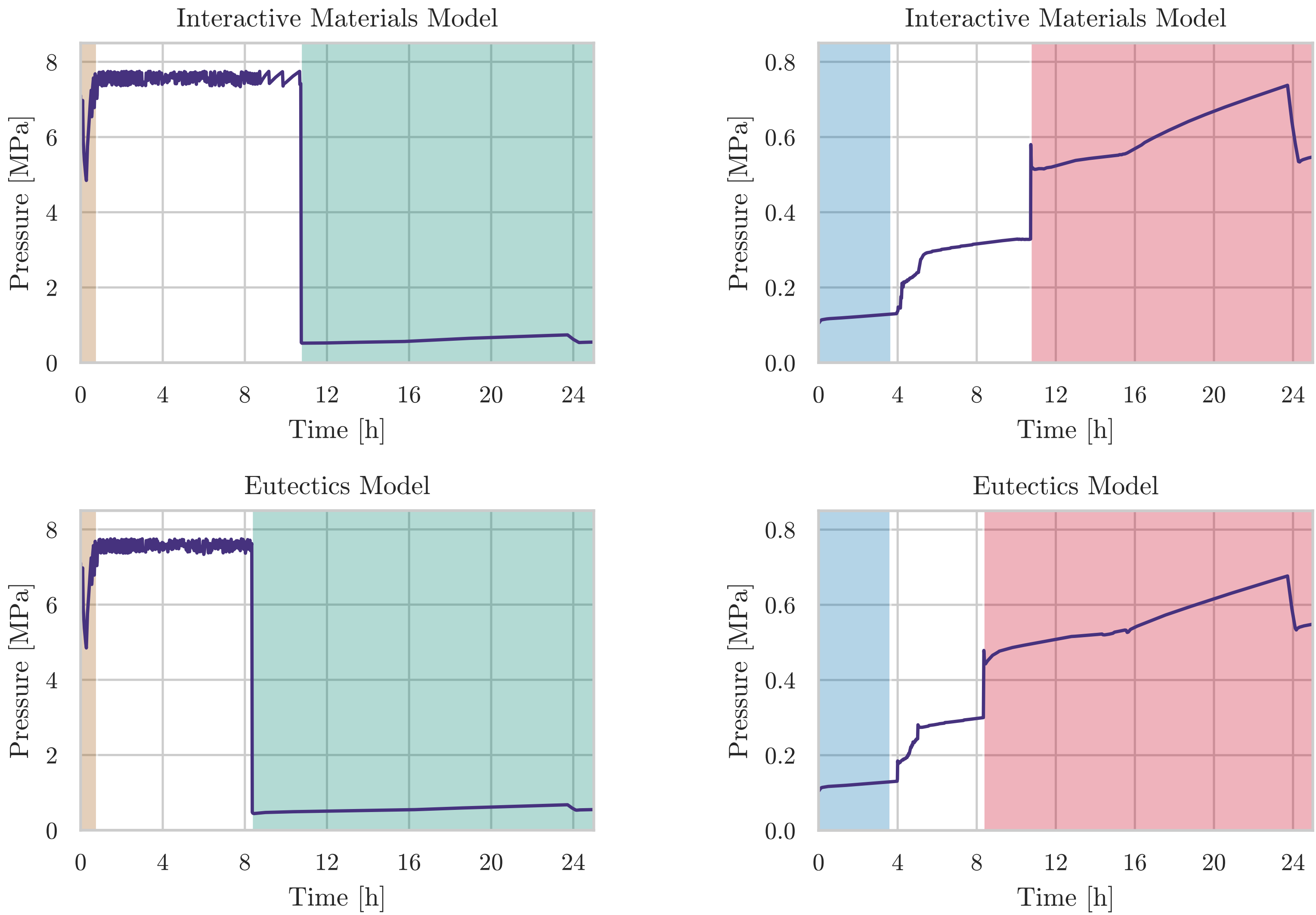


The interactive materials model simulation exhibits 145 kg more in-vessel hydrogen generation than the eutectics model simulation for every material.

Differences in hydrogen generation by stainless steel (SS) and Zirconium (ZIRC) are larger (~70 kg each).

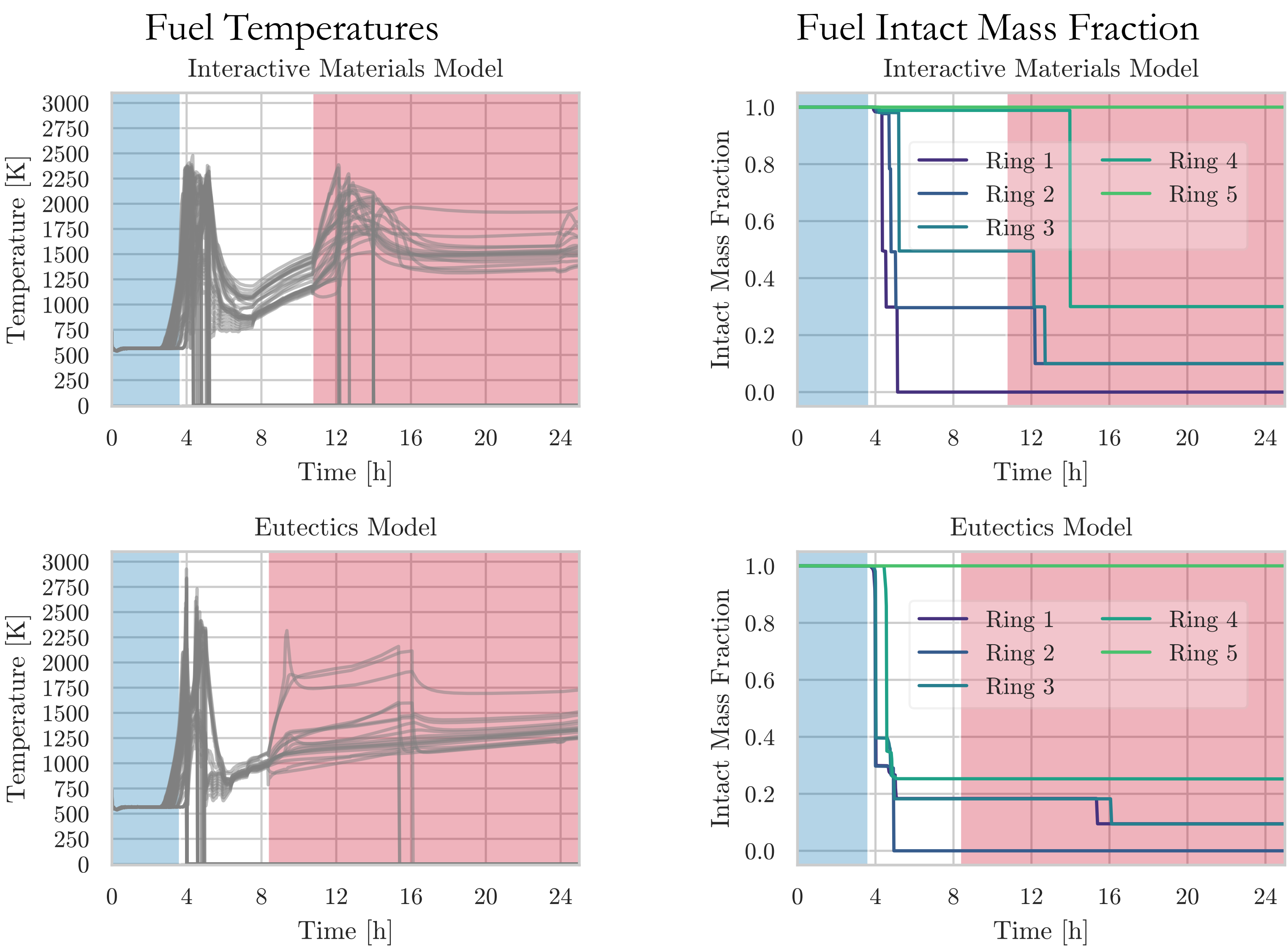
Investigation into the distribution of hydrogen generation (not shown for brevity) demonstrates that the interactive materials model reference case simulation also exhibits greater hydrogen generation in all core rings.

Thermal Hydraulic Response



Thermal hydraulic phenomena follow similar progression in both reference case simulations – no thermal hydraulic accident signatures are unique to either material interaction model simulation.

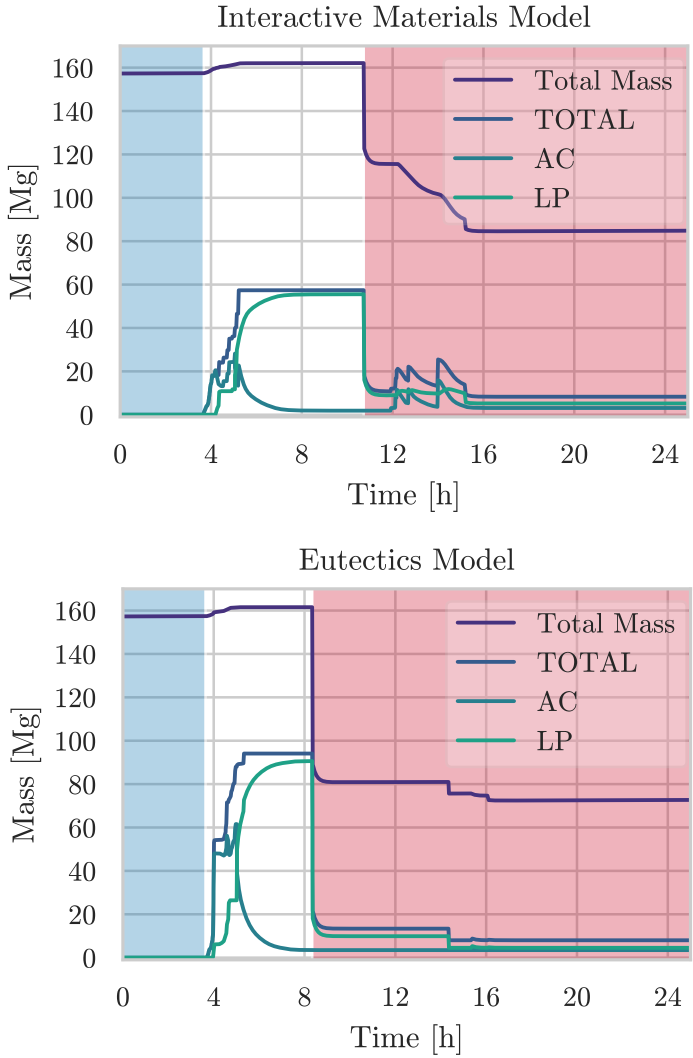
Reactor Core Degradation: Fuel Damage Progression



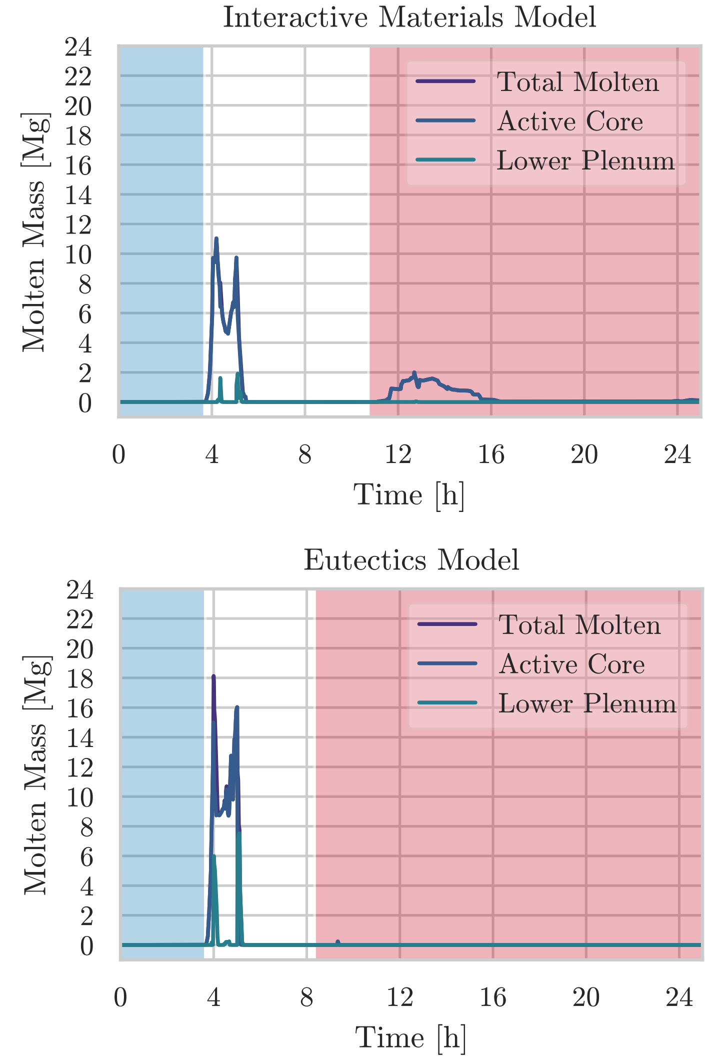
Higher fuel and cladding temperatures are achieved in the eutectics model simulation. Earlier, accelerated degradation of fuel components is observed in the eutectics model simulation.

Reactor Core Degradation: Debris Formation

Debris Mass Distribution



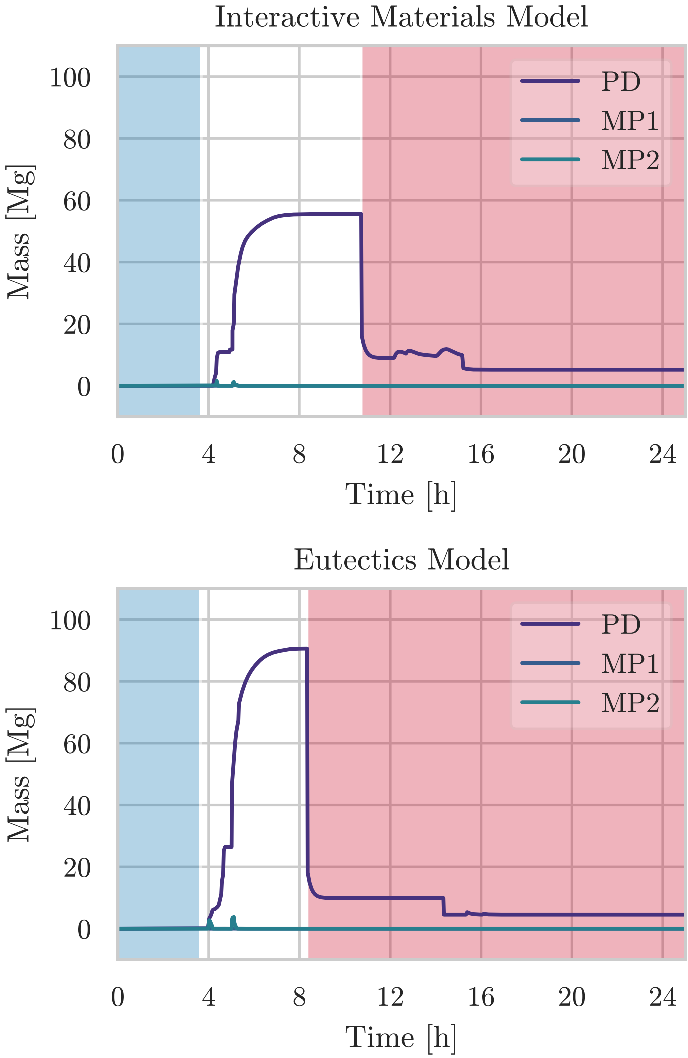
Molten Mass



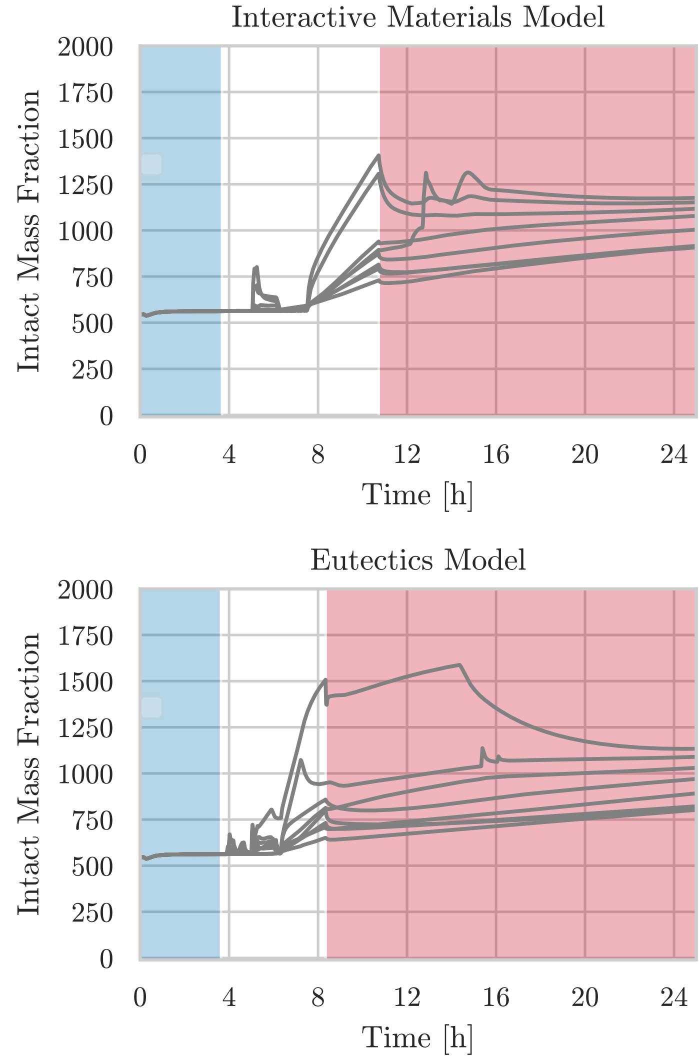
The eutectics model reference case simulation exhibits greater molten masses throughout the late in-vessel accident phase as well as greater overall debris masses

RPV Lower Head Breach

Lower Plenum Debris Masses



Lower Head Inner Wall Temperatures



Lower plenum debris is primarily solid particulate debris in both simulations. The eutectics model simulation exhibits accelerated lower head heat-up and a higher peak temperature prior to failure.

Methodology

Not a "best-estimate" uncertainty analysis – not attempting to quantify the uncertainty in a traditional sense

Identify the underlying biases of each model through an "exploratory" uncertainty analysis

- Not using "best-estimate" distributions of input parameters or attempting to establish "best-estimate" distributions of FOMs
- Uniform distributions are utilized to promote coverage of the uncertainty space and perform a "blind" comparison of models
  - Removal of a priori biases on input and result distributions to investigate model form bias

Comparison

- Qualitative comparison of results (magnitudes, timings, and distribution/clustering characteristics)
- Quantitative comparison of results (minimums, maximums, etc.)
- Pointedly avoiding application of statistical methods that may impose misleading "artifacts" and inappropriate structure to the data

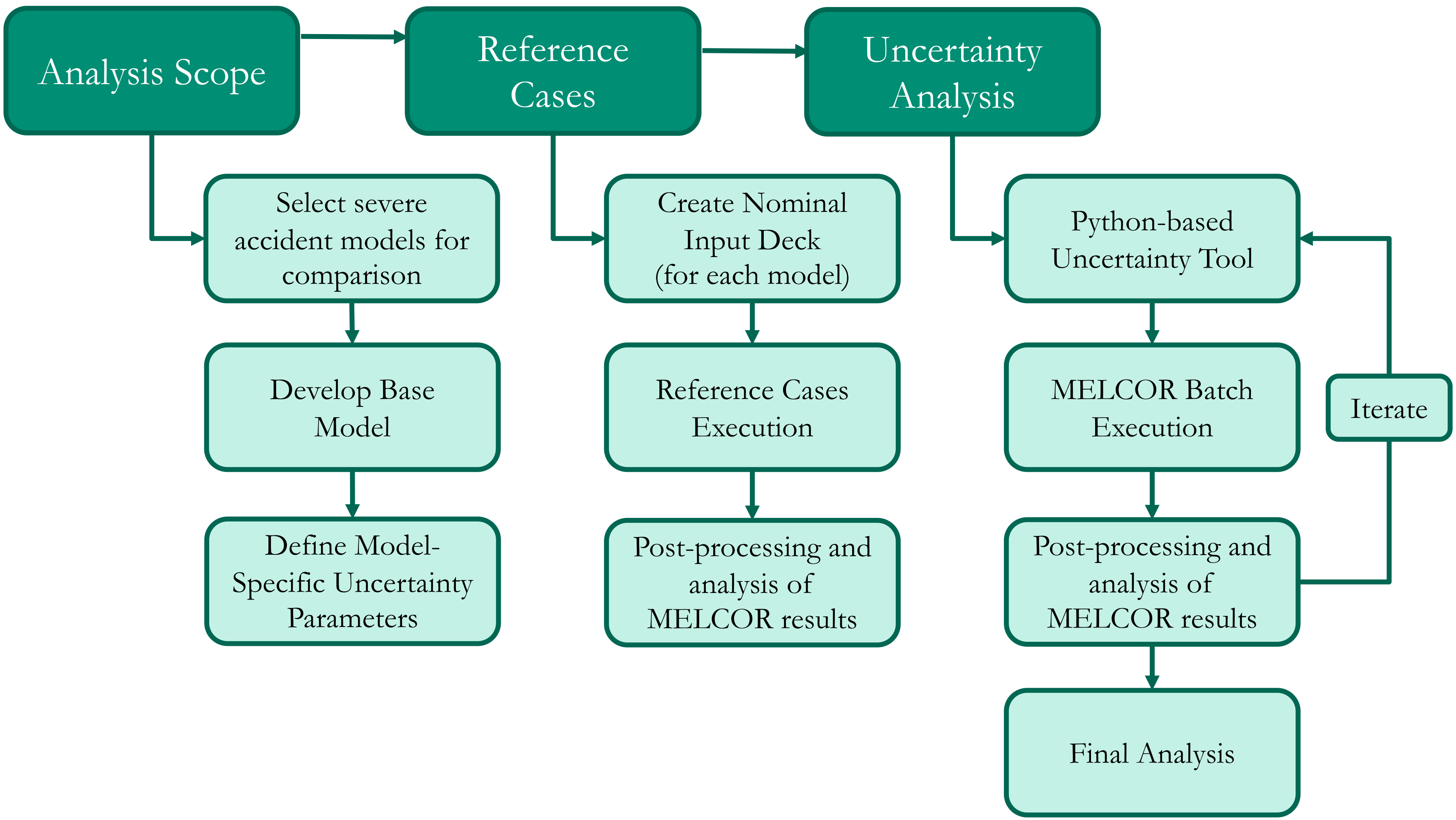
Correlation

- Identification of unknown correlations between input parameters and FOMs or multiple FOMs.
- Comparison of known/unknown correlations between each model

Clustering

- Identification of result clustering within each model's distribution
- Identification of cluster differences between models (cluster "existence", "location", and "size").

Analysis Workflow



Uncertain Parameters

Input Record	Description	Units	Distribution	Parameter Options		Reference
				Interactive Materials Model	Eutectics Model	
Material Interaction Model						
Material Interaction Model Activation	This analysis involves a comparison of the interactive materials and eutectics models available in MELCOR	-	-	Interactive Materials Model Activate	Eutectics Model Activate	-
MP_PRC: ZRO2-INT, UO2-INT	Interactive materials model reduced liquefactions temperatures for ZRO2-INT and UO2-INT	K	Uniform	2230.0-2728.0	-	Informed by SOARCA (3σ)
Candling Models						
COR _SC: 1131(2)	Molten Material Holdup Parameters: Maximum ZrO2 temperature permitted to hold up molten Zr in CL.	K	Uniform	2100-2540	2100-2540	Informed by SOARCA (min-max)
COR _SC: 1141(2)	Core Melt Breakthrough Candling Parameters: Maximum melt flow rate per unit width after breakthrough	kg m/s	Uniform	0.1-2.0	0.1-2.0	Informed by SOARCA (min-max)
Fuel Rod Failure Models						
COR_ROD	Rod Collapse Model	-	Discrete Uniform	Active (0), Disabled (1)	Active (0), Disabled (1)	-
COR_CCT: DRZRMN	Component Critical Minimum Thicknesses	m	Uniform	0.0-0.00015	0.0-0.00015	
COR_SC: 1132(1)	Core Component Failure Parameters: Temperature to which oxidized fuel rods can stand in the absence of unoxidized Zr in the cladding.	K	Uniform	2230.0-2728.0	2230.0-2728.0	Informed by SOARCA (3σ)
Debris Quenching and Dryout Models						
COR_EDR: DHYPD, DHYPB (Active Core)	Particulate debris equivalent diameter in the active core region	m	Uniform	0.005-0.015	0.005-0.015	Engineering judgement
COR_EDR: DHYPD, DHYPB (Lower Plenum)	Particulate debris equivalent diameter in the lower plenum	m	Uniform	0.0001-0.005	0.0001-0.005	Engineering judgement
COR_LP: HDBH2O	Heat transfer coefficient of falling debris	W/m^2K	Uniform	100.0-4000.0	100.0-4000.0	Engineering judgement
COR_LP: VFALL	Velocity of falling debris	m/s	Correlated to particulate debris diameter in the lower plenum	-	-	Engineering judgement
COR _SC: 1244 (3)	Debris Dryout Heat Flux Correlation: Minimum Debris Porosity	-	Uniform	0.15-0.4	0.15-0.4	Engineering judgement
COR_TST: IMPLZDM	Lipinski zero-dimensional dryout heat flux flag	-	Discrete Uniform	Active (0), Disabled (1)	Active (0), Disabled (1)	-
Numerical Uncertainty						
CVH_SC: 4422 (2)	A random number seed that varies the t/h solution matrix to include and evaluate numerical model variance importance . A value of 0.0 indicates that MELCOR will generate a random number seed based on the system clock time.	-	Uniform	1-1e6	1-1e6	-

Acknowledgements

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