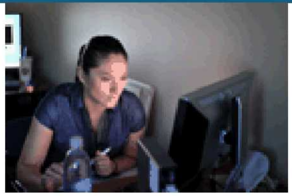
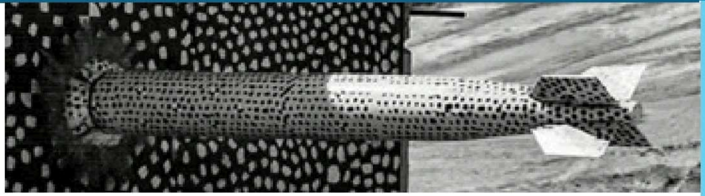
SAND2020-9209PE

SCALE/MELCOR Non-LWR Accident Progression and Source Term Analysis





SCALE/MELCOR Team

Cooperative Severe Accident Research Program

September 2, 2020

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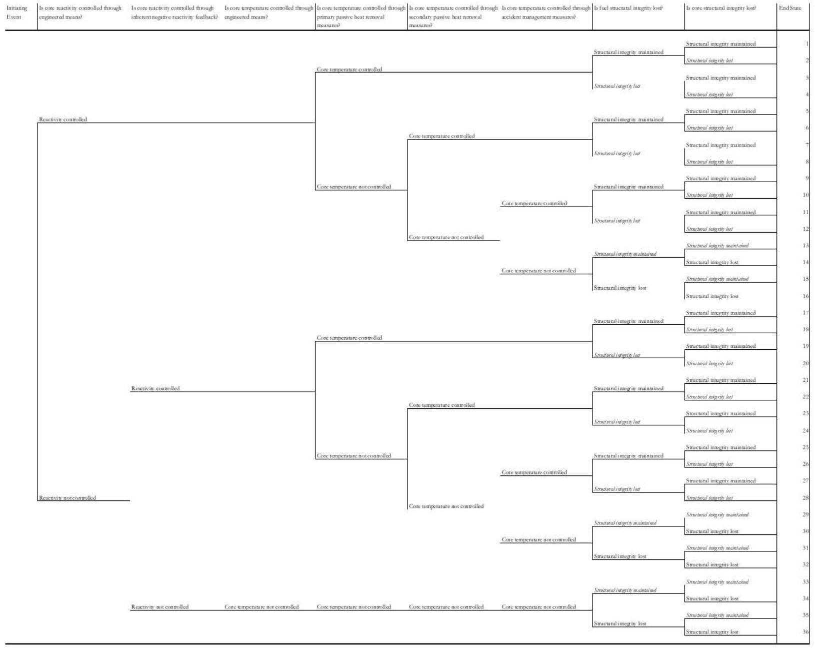
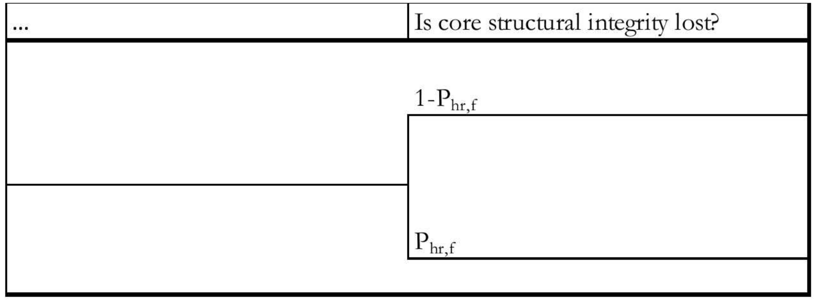
Challenges for Advanced Reactor Safety Technology

- Advanced nuclear technologies dominated by passive safety systems
- Traditional risk significantly influenced by random failure of components in active safety systems
  - External events could be treated as a systematic process leading to multiple failures at once
- Advanced reactors will be robust to random failure
  - Likelihood of passive safety systems randomly failing quite low
- Risk profile for advanced reactors most likely not dominated by internal events
  - External events - seismic, high winds, flooding, etc.
- PRA methods have largely grown up to tease apart complex interaction of active components
- How does one assess “reliability” of a passive system in relevant portion of risk profile?
- Will greatly expand use and scope of traditional mod/sim for reactor systems



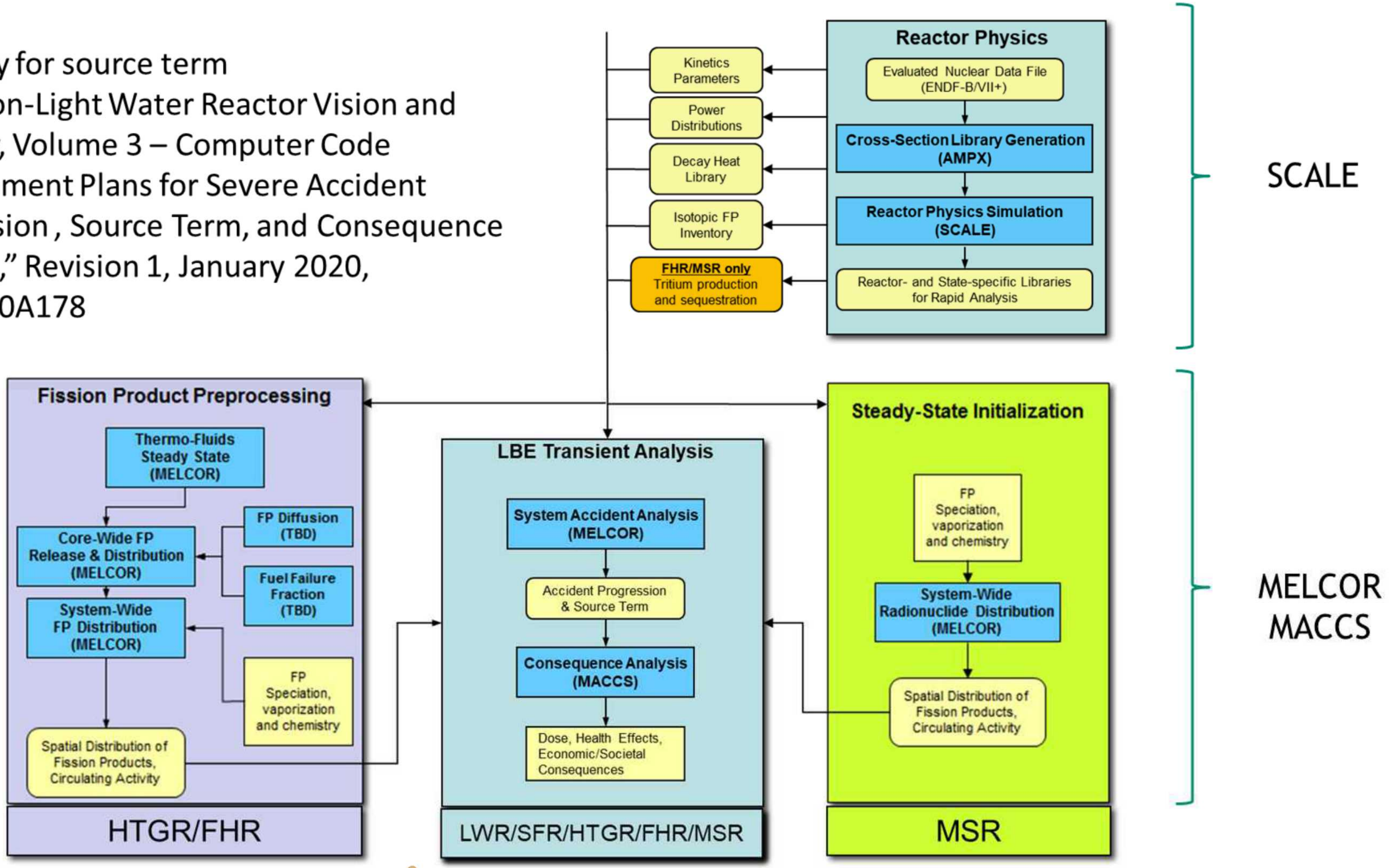


Non-LWR Evaluation Model

Evaluation Model and Suite of Codes

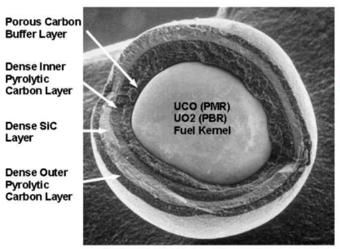
Code strategy for source term

"NRC Non-Light Water Reactor Vision and Strategy, Volume 3 – Computer Code Development Plans for Severe Accident Progression , Source Term, and Consequence Analysis," Revision 1, January 2020, ML20030A178



Input and Data Requirements

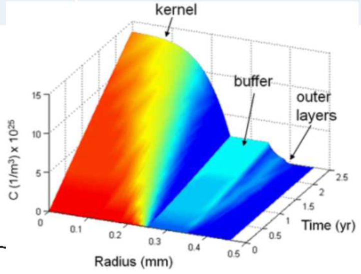
Input Data	HTGR	SFR	MSR	FHR
FP Inventory	SCALE	SCALE	SCALE	SCALE
FP diffusion coefficients (D) and release	Experiments (e.g., AGR) and analysis (e.g., DOE tools)	Experiments		Experiments (e.g., AGR) and analysis (e.g., DOE tools)
Core power shape	Radial/Axial profiles (e.g., SCALE)	Radial/Axial profiles (e.g., SCALE)	Radial/Axial profiles (e.g., SCALE)	Radial/Axial profiles (e.g., SCALE)
Fuel failure	Experiments/other codes (e.g., DOE tools)	Experiments/other codes (e.g., DOE tools)		Experiments/other codes (e.g., DOE tools)
Dust generation & FP transport	Experiments, historical data and other code (e.g., DOE tools)			
FP release under air/water ingress & interaction w/ graphite	Experiments			
Kinetics parameters and reactivity feedback coefficients	Experiments/other codes (e.g., SCALE)	Experiments/other codes (e.g., SCALE)	Experiments/other codes (e.g., SCALE)	Experiments/other codes (e.g., SCALE)
Equilibrium constants for release from pool and vapor pressure data		Experiments/other codes (e.g., DOE tools)	Experiments/other codes (e.g., DOE tools)	Experiments/other codes (e.g., DOE tools)



$$\frac{\partial C}{\partial t} = \frac{1}{r^m}\frac{\partial}{\partial r}\left(r^m D \frac{\partial C}{\partial r}\right) - \lambda C + S$$

SCALE

Experiments/Analysis



Distribution of Cs-137 in different layers as a function of time

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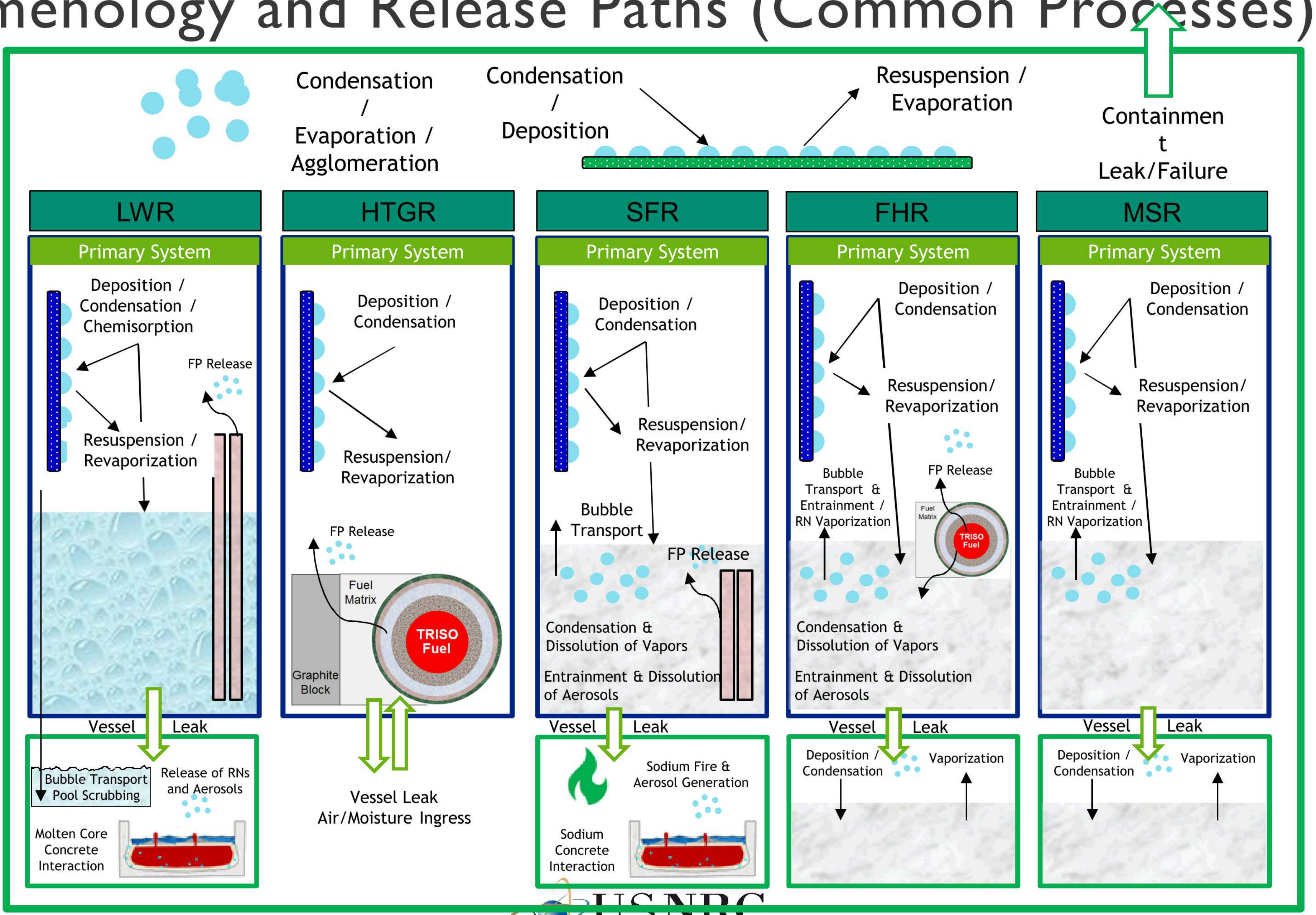
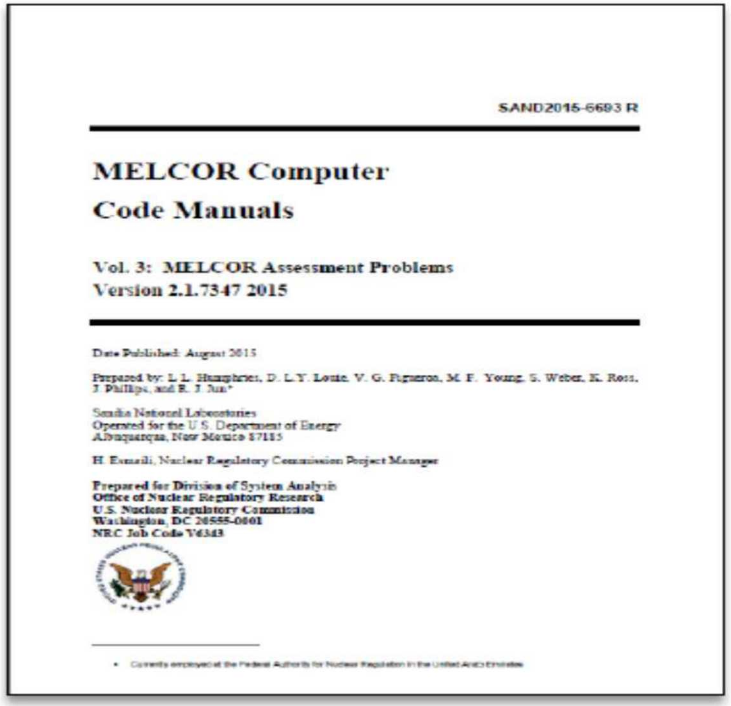
Phenomenology and Release Paths (Common Processes)



Verification and Validation of Modeling



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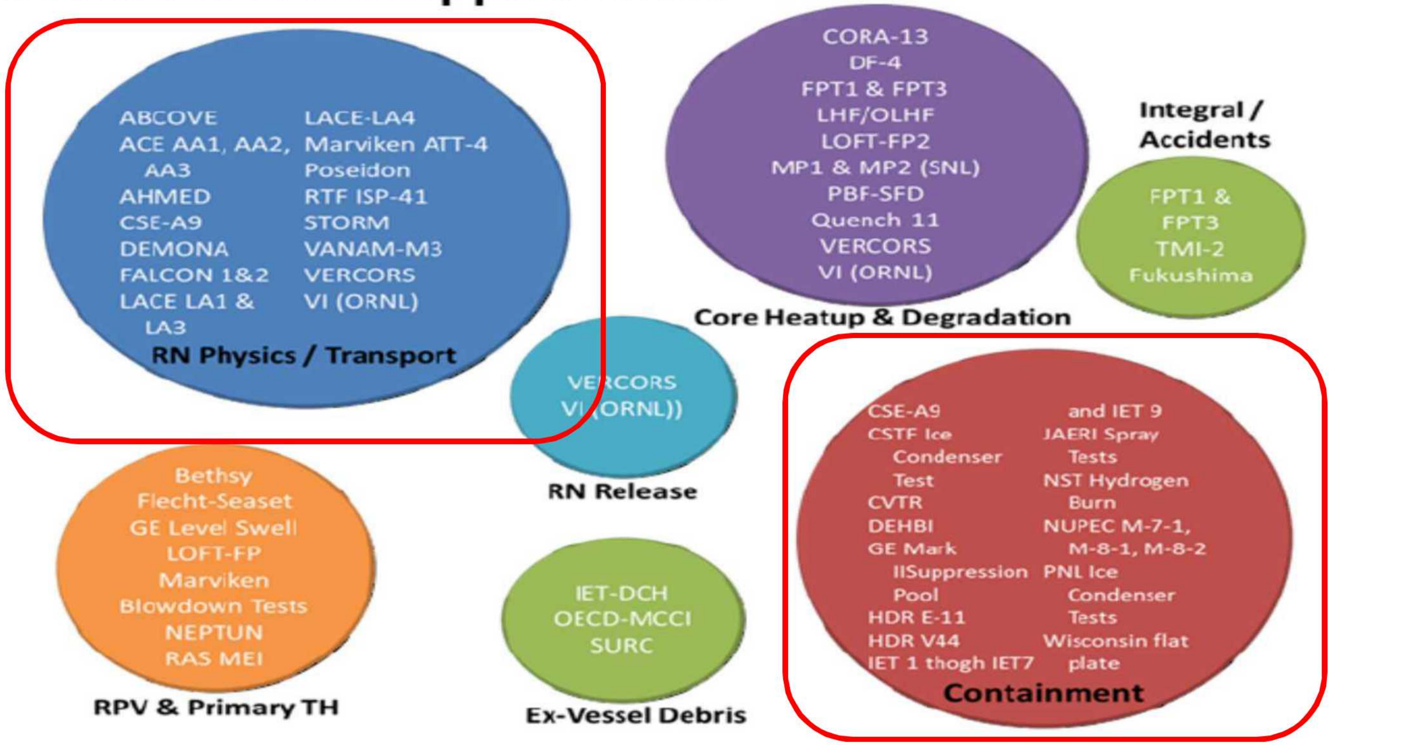
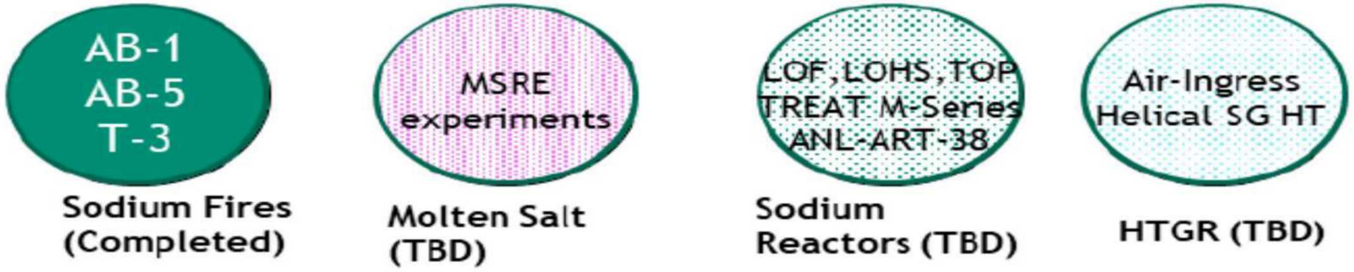
LWR & non-LWR applications



Specific to non-LWR application



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HTGR Development

Key Phenomenon	Importance	Existing Capabilities	Modeling Gaps
Modeling of TRISO fuels	Determining release of fission products from fuel and fuel material properties	• Analytic release model • Multi-zone diffusion model • Account for FP recoil, matrix contamination, and initial TRISO defects	• Current modeling uses UO2 material properties, needs to be extended to UCO (Development Items M2.1 and M2.2)
Heat Transfer in Graphite block (PMR)	Thermal response of fuel components and failure of TRISO fuel particles	• Tanaka-Chisaka effective radial conductivity	
Heat Transfer in fuel pebbles (PBR)	Thermal response of fuel components and failure of TRISO fuel particles	• Zehner-Schlunder-Bauer effective thermal conduction	
Reactivity temperature feedback coefficients.	Neutronics power feedback	• Point kinetics model • Reactivity coefficients specific to an application can be implemented via control functions	
Ability to model two-sided reflector component	Heat transfer from overheated core	• Two-sided reflector component	
Modeling graphite dust transport	Pathway for fission product transport and release	• All relevant mechanisms for graphite dust transport, deposition, and resuspension	
Graphite oxidation	Heat generation and release of combustible gases	• Graphite oxidation model and oxidation products	
Air/moisture Ingress modeling	Air/moisture ingress can lead to oxidation of the graphite structures and release of radionuclides	• Momentum exchange model	

SFR/Heat Pipe Development

Key Phenomenon	Importance	Existing Capabilities	Modeling Gaps
Liquid Metal as Working Fluid	Modeling the liquid metal coolant heat transfer properties is essential in simulating the reactor response to accident conditions	Na equation of state (EOS) libraries already available to MELCOR.	• Ability to model sodium as the working fluid in some control volumes and water in others will be added (development Item M1.7) • Addition of Pb and Pb/Bi EOS/Properties (infrastructure developed under development item M1.7)
Sodium Fire & Sodium Concrete Interaction Modeling	Fire is a source of heat and provides a path for transport of sodium and fission products to the atmosphere. Concrete interaction important source of aerosols and possible combustible gases.	Sodium pool fire and spray fire models, as well as atmospheric chemistry models have already been added to the code.	• Addition of a hot gas layer model during sodium fires (development Item M1.6) • Add sodium concrete interactions (development Item M1.5)
Fission Product Speciation	Affects the release, vapor pressure, and chemical interactions of fission products.	MELCOR radionuclide classes organized by chemical similarities can be easily adapted for reactor application	• Determination of MELCOR class structures (development Item M1.3)
Fission Product Release Model	Determines distribution of fission products between the fuel and fission gas plenum.	MELCOR has a generic release model easily adapted for metallic fuel.	• Extension of existing modeling for FP release for metallic fuel (development Item M1.4)
Fuel Degradation Model	Degraded fuel components lead to release of fission products from the fission gas plenum as well as some fuel/clad material.	MELCOR has models for fuel components that can be extended to SFR application	• Extend MELCOR fuel component to capture melting fuel in fuel matrix • Model for cladding failure from eutectic penetration or molten fuel contact • Ejection of fuel/sodium from failed rod (Item M1.2)
Dissolution of RN and vaporization of dissolved species	Transport of radionuclides to and from the sodium pool and into the cover gas	Similar capability exists for molten corium pool (VANESA)	• Add models for dissolution and vaporization of dissolved species (development Item M1.3)
Bubble Transport/ partitioning between bubble & sodium pool	Transport of radionuclides directly to the atmosphere.	MELCOR's SPARC model might be leveraged, though modified significantly for this application	• Development of bubble transport model (development Item M1.3)
Heat Pipe Thermal Hydraulics & Failure	The heat pipe is the primary means of heat removal from fuel. Failure of the heat pipe determines the extent of core degradation and source term released from fuel.	Existing multi-rod model can be leveraged in calculating propagation of local heat pipe failure (development Item 1.8)	
Reactor kinetics	Calculate transient power feedback	Existing point kinetics and reactivity feedback model	• Evaluate neutronics parameters in the existing point kinetics model (development Item M1.9)

MSR Development

Key Phenomenon	Importance	Existing Capabilities	Modeling Gaps
Physical Properties	Fundamental to simulation of steady state temperature and flow distributions.	FLiBe EOS and properties already implemented in MELCOR.	Validation of properties (development items M3.1, M3.4 and M3.6)
Heat Transfer Coefficients	Transfer of heat to calculate heat loads to structural materials	Existing generic correlation forms	Implement and validation of heat transfer coefficients (development items M3.4 and M3.6)
Track the flow of gas through the molten salt	Important for calculating entrainment of fission products from molten salt (next item)	SPARC model for aerosol scrubbing in liquid pools exists in MELCOR	Molten Salt Model (MSM) (under current development)
Entrainment of contaminated molten salt droplets in the gas flow	The primary mechanism for such entrainment of droplets is of course the rupture of gas bubbles at the molten salt surface.	Similar capability exists for molten corium pool (VANESA)	Molten Salt Model (MSM) (under current development)
Vaporization of fission products from the molten salt.	Release of volatile fission products to cover gas.	Similar capability exists for molten corium pool (VANESA)	This phenomenon is described further in Appendix C and is part of Development Items M3.2 and M3.3 MSR