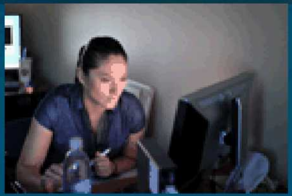
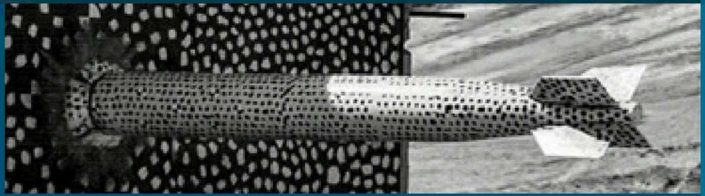
SAND2019-15329PE

MELCOR for Non-LWRs:
Severe Accident Analysis, Mechanistic Source Term Generation, and Risked-Informed Decision Making





Joint Committee on Nuclear Risk Management

December, 2019, Sandia National Laboratories

PRESENTED BY

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DEVELOPED BY

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MELCOR Applications - Severe Accident Analysis & Mechanistic Source Term

NRC ACRS position letter on advanced reactor computer code evaluations with reference to source term calculations:

- "…the staff will rely on their own code MELCOR"
- "Staff identified…MELCOR, that can perform reactor severe accident progression and source term analysis"

NRC Non-LWR Vision and Strategy, Volume 3 (Computer Code Development Plans for Severe Accident Progression, Source Term, and Consequence Analysis)

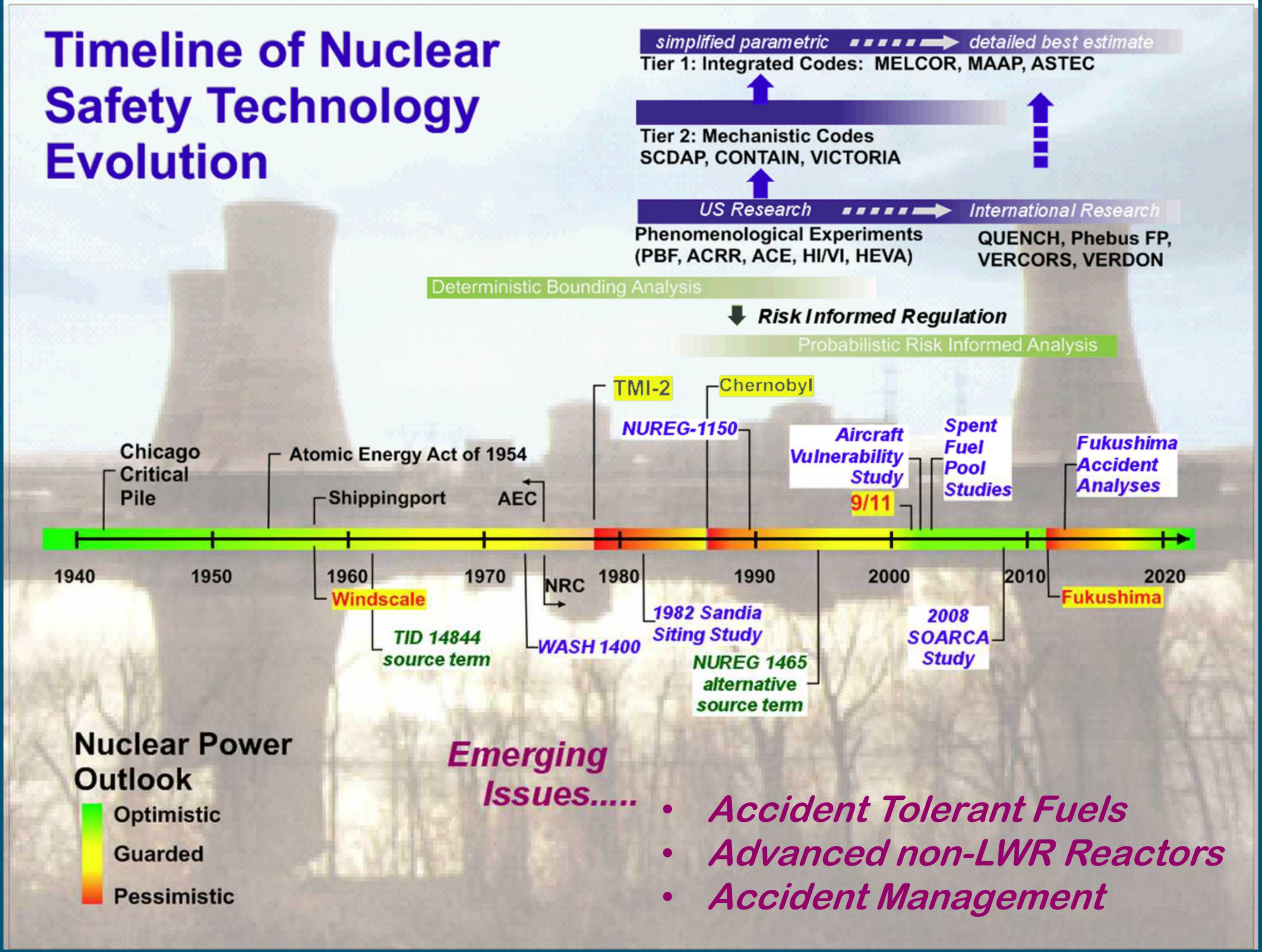
- SNL, ORNL, and NRC collaborated to build evaluation models (EM) for each non-LWR technology
- Regulatory Guide 1.203, "Transient and Accident Analysis Methods", an EM is:

  "the calculational framework for evaluating the behavior of the reactor system during a postulated transient or design-basis accident. As such, the EM may include one or more computer programs, special models, and all other information needed to apply the calculational framework to a specific event."
- Leverage SCALE (ORNL), MELCOR (SNL), and MACCS (SNL)
  - SCALE for reactor physics,
  - MELCOR for integral plant response including radionuclide transport, and
  - MACCS for off-site consequences

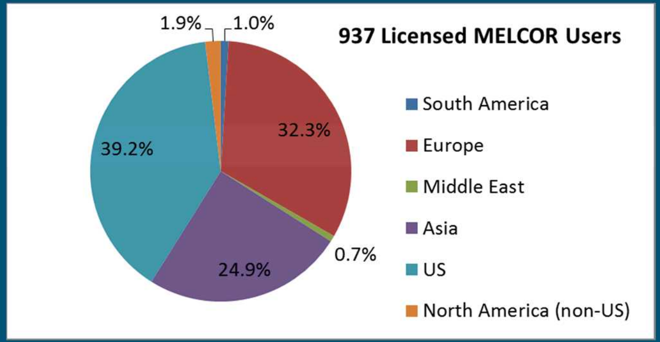
MELCOR transient/accident analyses must be informed with initial conditions, boundary conditions, and model inputs

A SCALE/MELCOR interface is required, but there is precedent (LWR and spent fuel pool analyses)

MELCOR History



- Began in 1982 shortly after TMI-2
- Replaced Source Term Code Package
- Systems-level approach to modeling
- Emphasis on "best-estimate"
- Repository of knowledge
- Global standard (used by 31+ nations)
  - Users' groups (AMUG & EMUG)
  - Annual CSARP/MCAP meetings



- Used by USNRC, USDOE & US industry
- Used for naval reactors (US/UK)
- Evolves to meet regulatory needs

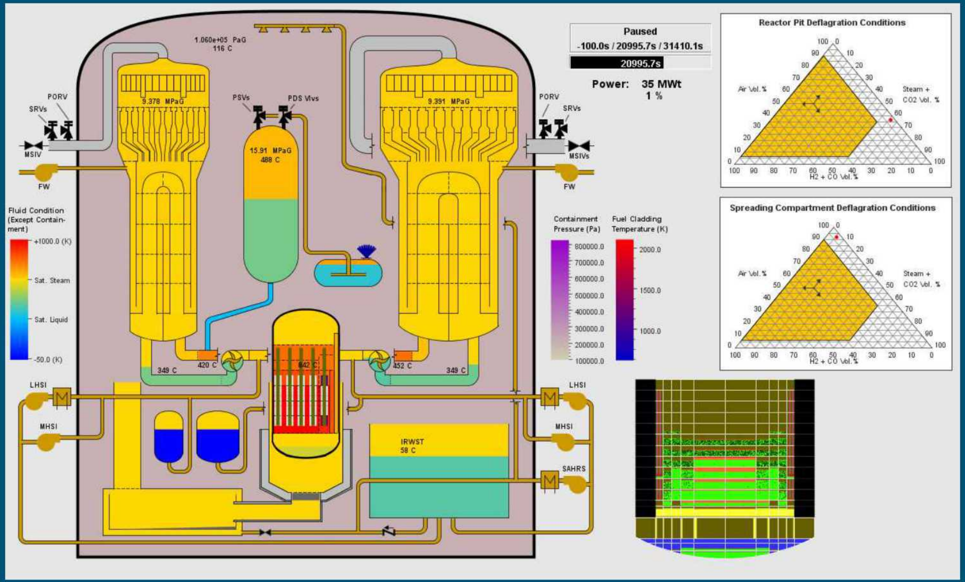
MELCOR Application Areas

Nuclear Reactor System Applications

Accident Analysis
- LWR sustainability (accidents, ATF)
- Accident forensics (Fukushima, TMI)
- Probabilistic risk assessment
- Experimental, naval, SMR, advanced

Regulatory
- License amendments
- Risk-informed regulation
- Design certification
- Vulnerability studies

Commercial
- Analysis and design scoping calculations
- Training simulators

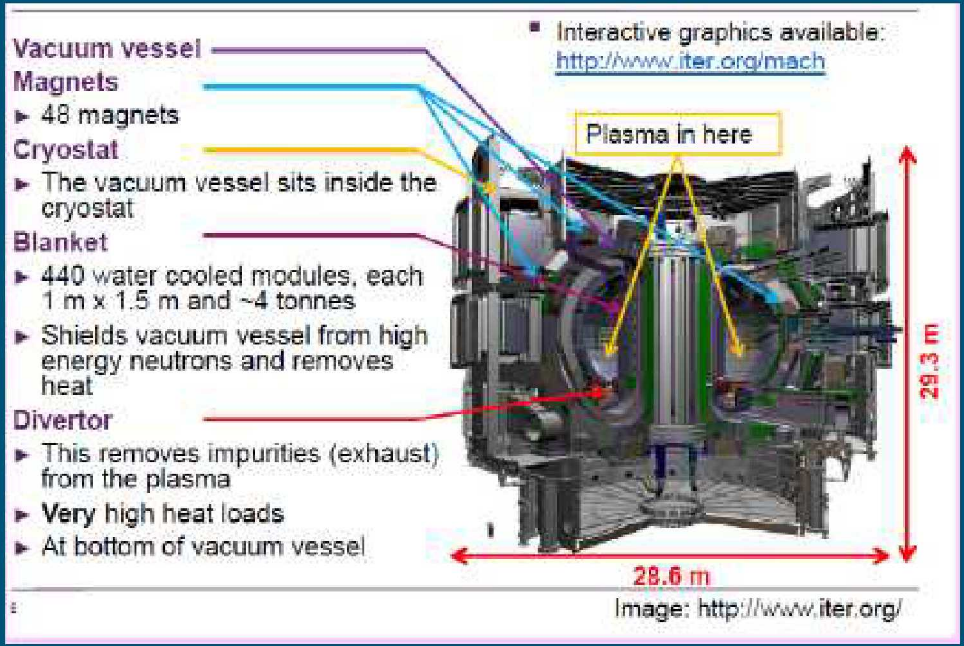


Non-Reactor Applications

Fusion
- Neutron beam injectors
- Li loop LOFA transient analysis
- ITER cryostat modeling
- He-cooled pebble test blanket (H^3)

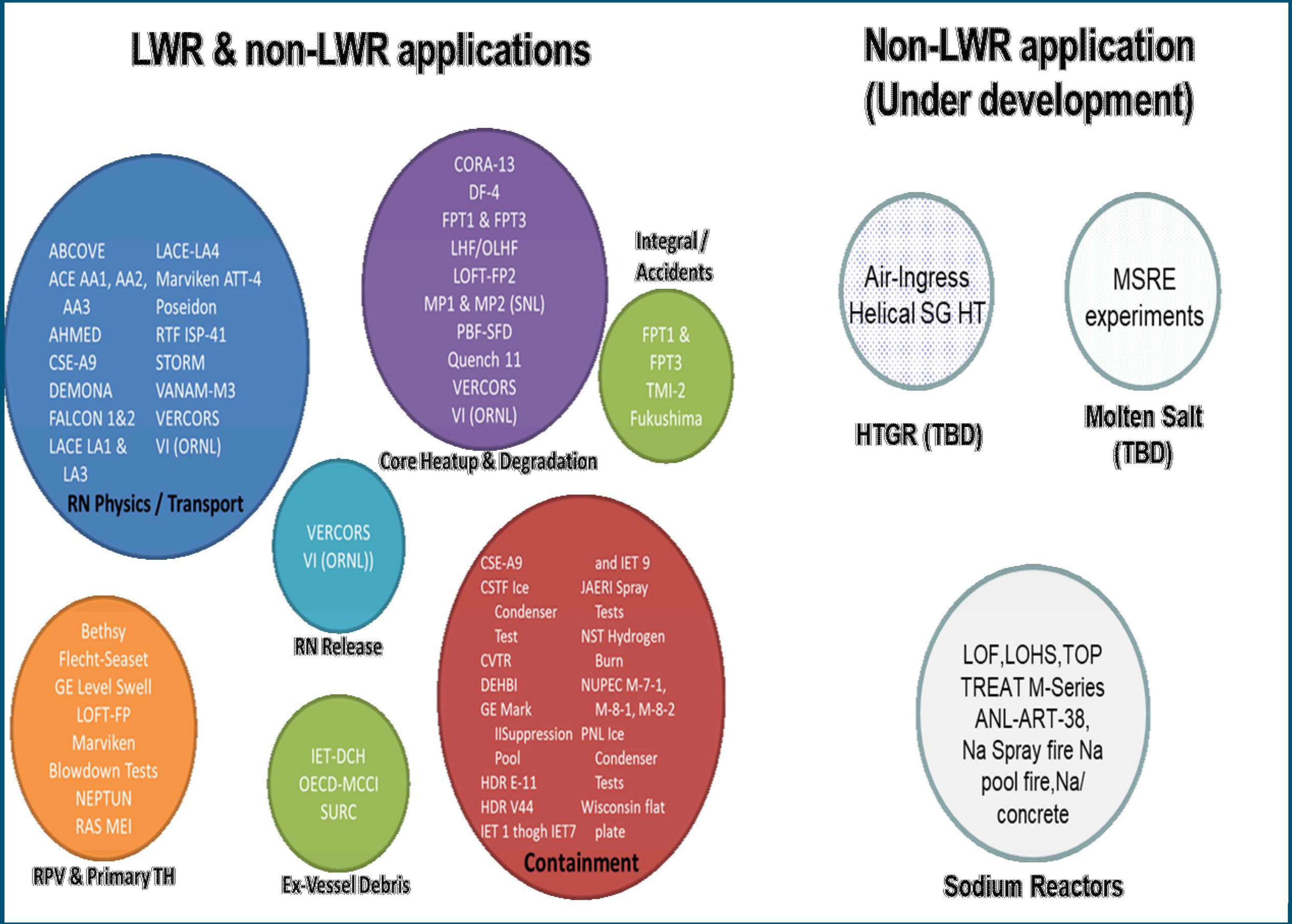
Spent Fuel
- Risk studies
- Multi-unit accidents
- Dry storage

Non-nuclear Facilities
- Leak path factor calculations
- DOE safety toolbox code
- DOE nuclear facilities (Pantex, Hanford, Los Alamos, Savannah River Site)



MELCOR Capabilities and Validation

Extensive Validation Basis



Integral plant response accident analysis code

Multi-physics modeling

- Thermal-hydraulic response
- Core heat-up, degradation, and relocation
- Core-concrete interactions
- Hydrogen production, transport, combustion
- Fission product release and transport

Extensively validated

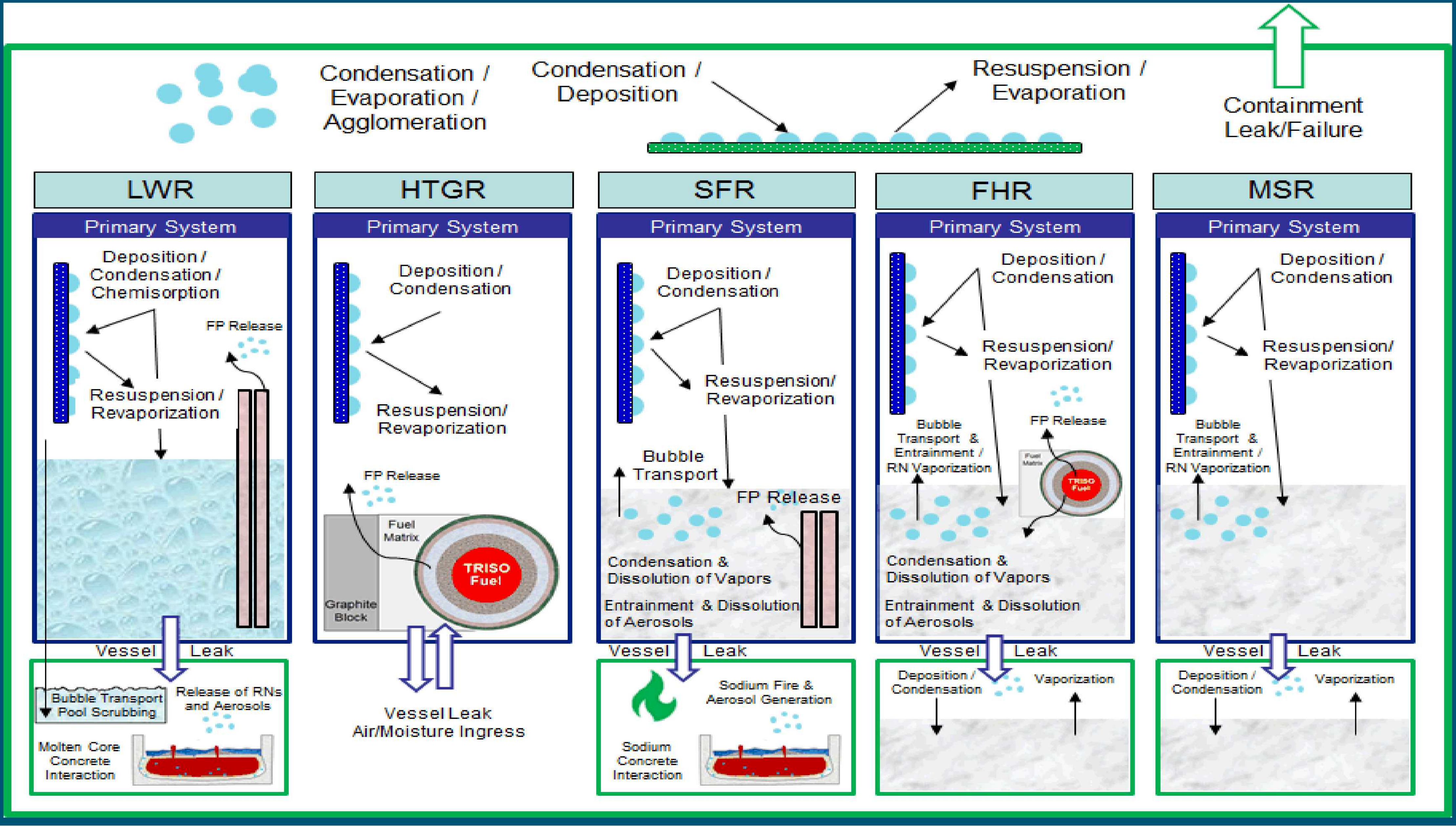
- Separate effects tests
- Integral tests
- International Standard Problems
- Actual reactor accidents

Facilitates uncertainty assessment

- Fast-running
- Reliable and robust
- User access to modeling parameters'

Non-LWR development since 2005

MELCOR as a Generalized Modeling Tool for Non-LWR Technology



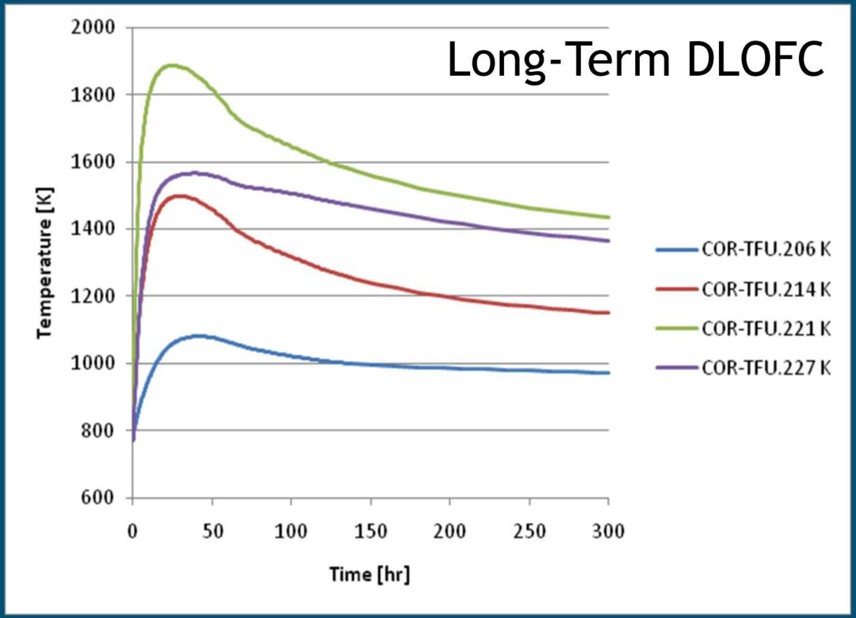
MELCOR High Temperature Gas-Cooled Reactor Modeling Capabilities

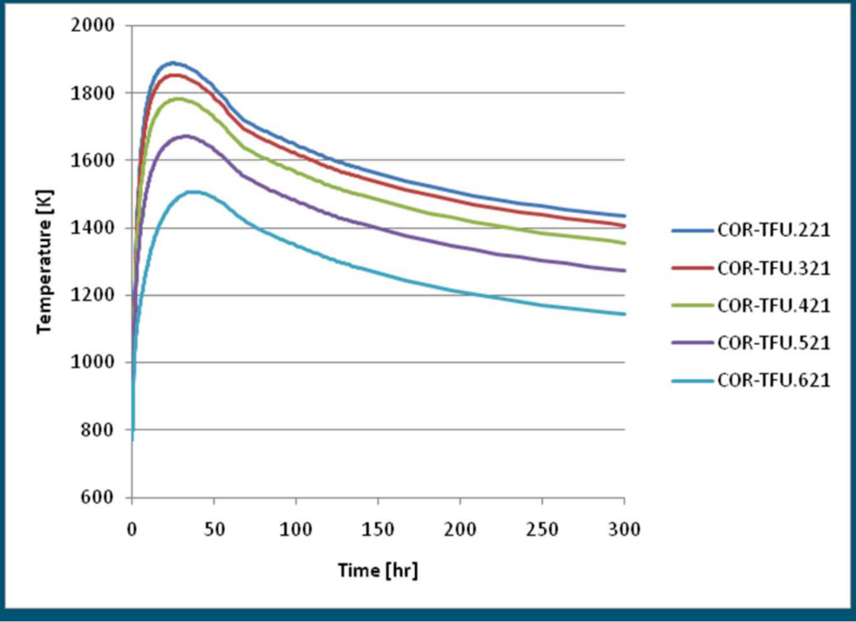
HTGR modeling capabilities added over the past decade or more
- Prismatic type
- Pebble bed type

Current efforts focused on integral plant response analyses:
- Point kinetics for ATWS-type analyses
- Thermal hydraulic assessment of PLOFC/DLOFC scenarios
- Fission product diffusion/transport/release and graphite dust transport

Fission product transport/release and graphite dust transport:
- Accelerated steady-state to calculate a thermal steady-state
- Steady-state diffusion calculation
- Steady-state fission product and graphite dust transport calculation
- Transient accident calculation

Requisite capabilities for accident analyses and MST generation installed

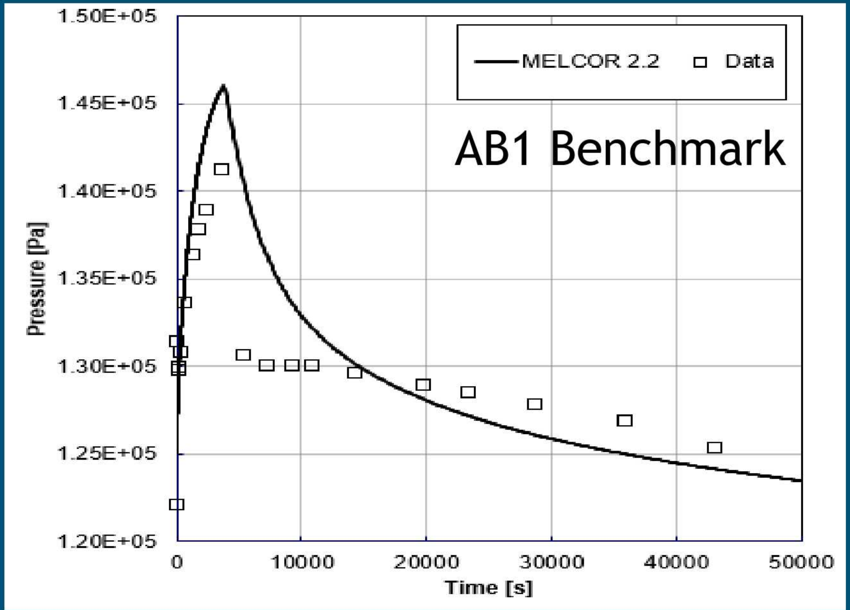




MELCOR Sodium Fast Reactor Modeling Capabilities

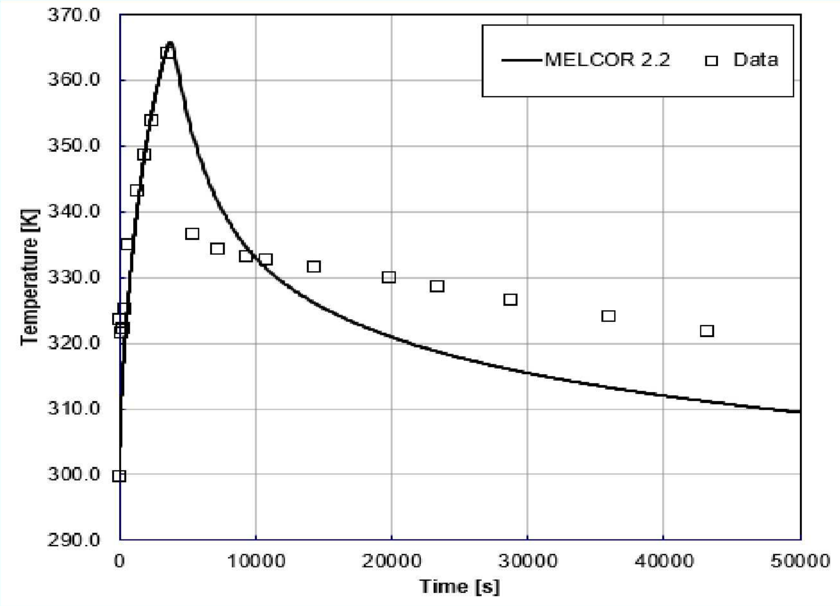
SFR modeling capabilities focused on containment phenomena

- Sodium as a working fluid
- Sodium and water in same calculation
- Spray fires
- Pool fires
- Atmospheric chemistry
- Benchmarking activity
  - Aerosol Behavior Code Validation and Evaluation (ABCOVE) experiments
  - Investigated nuclear aerosol behavior for LMFBRs



ABCOVE tests

- AB1 – Sodium pool fire ; sodium aerosols in dry containment vessel
- AB5 – Sodium spray ; sodium aerosols
- AB6 – Sodium spray fire ; sodium aerosols ; NaI aerosols for fission products



Initial focus on sodium fires due to role in challenging containment integrity

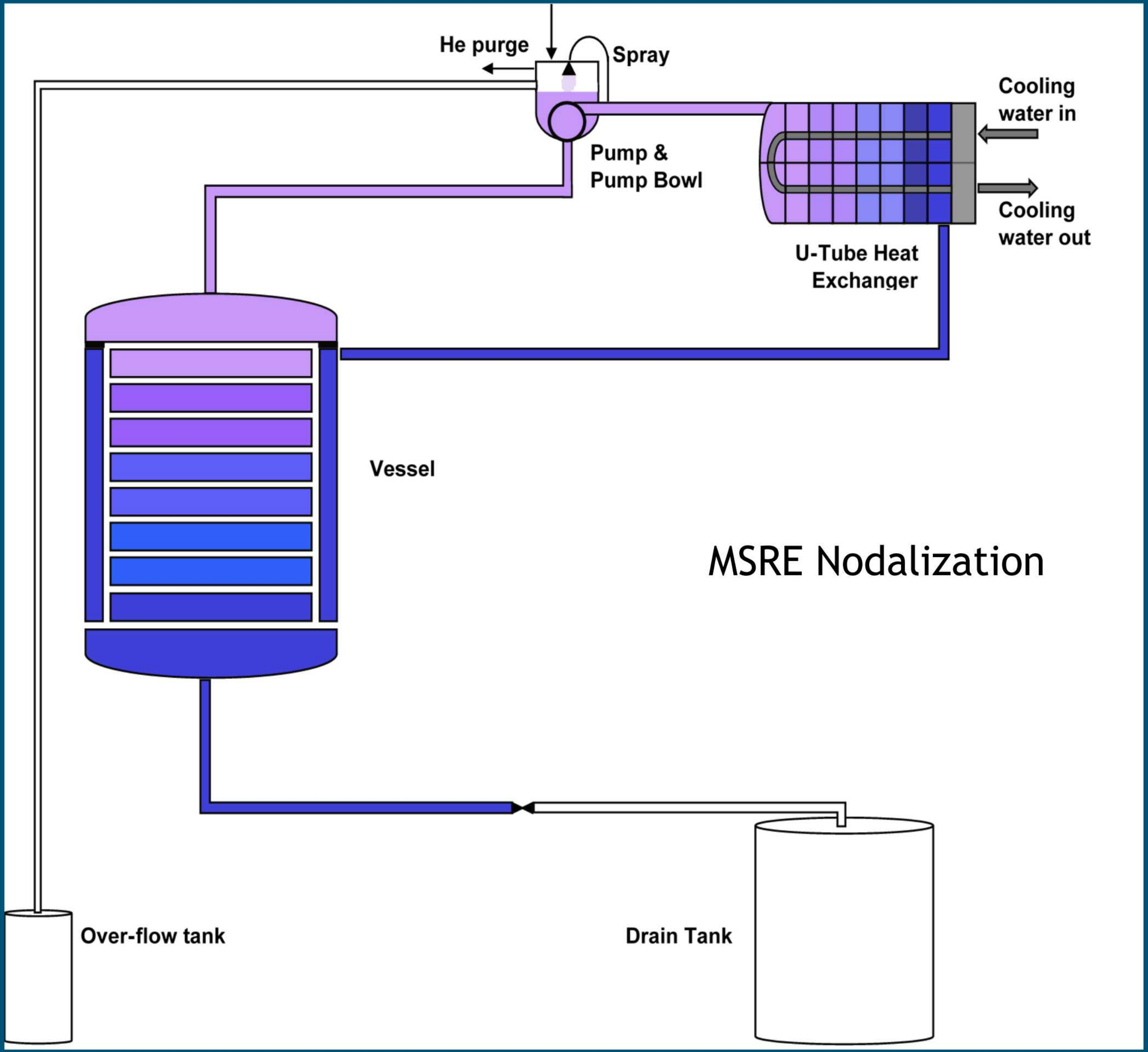
MELCOR Molten Salt Reactor Modeling Capabilities

MSRE model based on available ORNL-TM-0728

- Currently available MELCOR version
- Could be used as demonstration of the MSR EM

System represented using generic MELCOR elements

- 1D core for now with 2D extension straightforward
  - 8 control volumes
  - No traditional solid core structures represented
- Graphite blocks (heat structures)
- Diversion and drain tanks connected to primary loop
- Core bypass (leakage flow)
- Primary loop (with heat structures for pipe walls)
- Fuel pump and pump bowl
  - Overflow tank
  - Pump spray with helium gas purge for salt clean-up
- Horizontal u-tube heat exchanger



MSRE Nodalization

MELCOR Molten Salt Reactor Modeling Capabilities

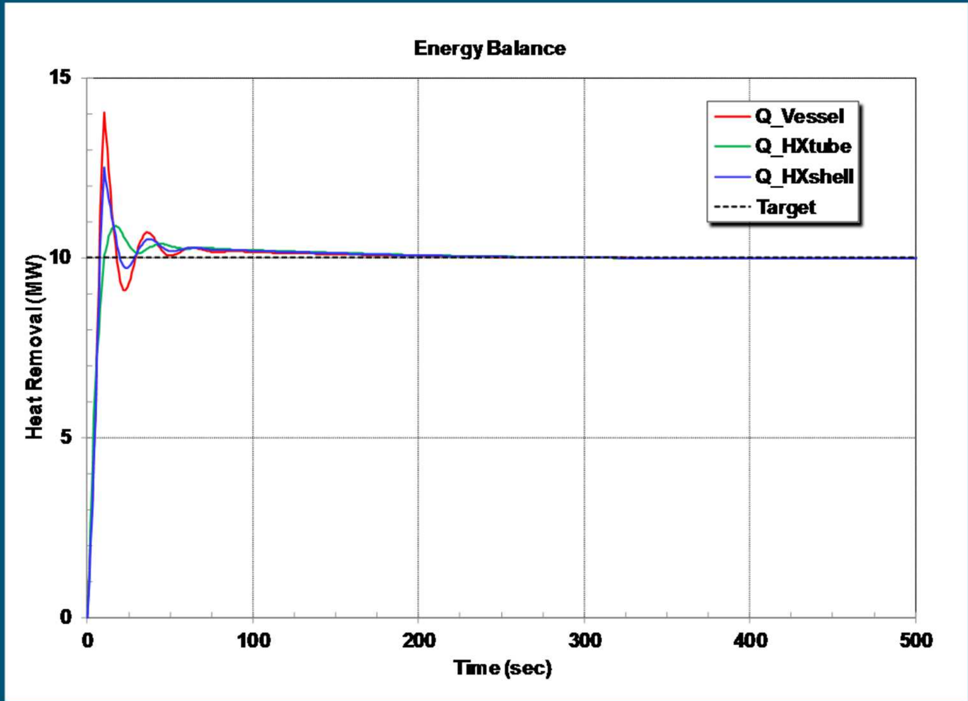
Successful benchmarking against MSRE

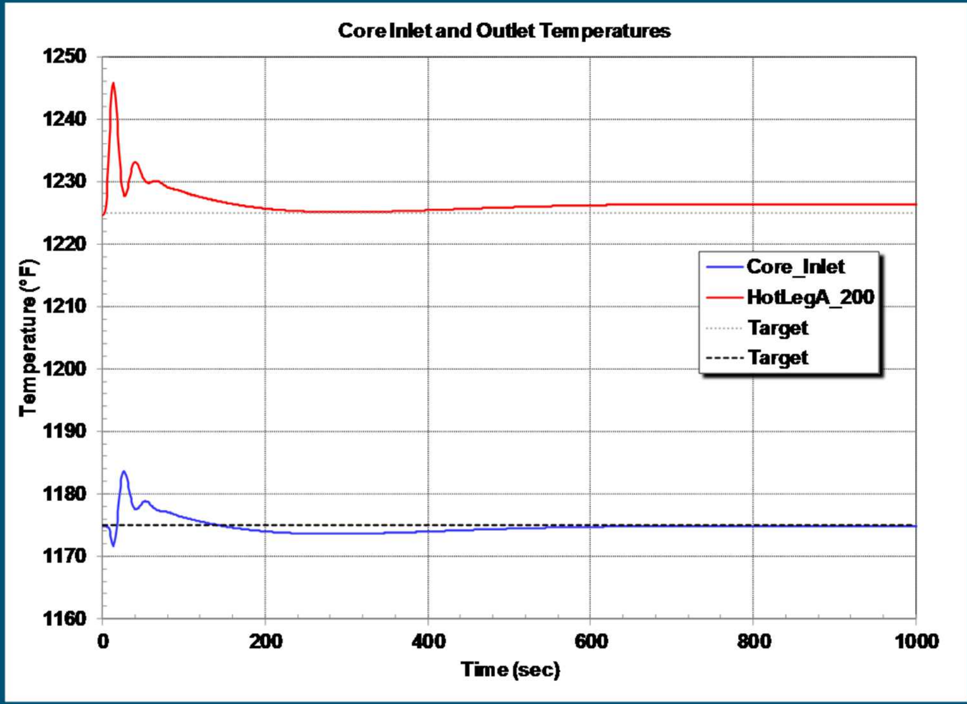
- Model achieves a steady-state
- Results compare well to nominal MSRE operating points (10 MW_{th}, T_{in}/T_{out} = 1175/1225 °F)

Initial efforts for FHR-type non-LWR underway

- Sample analysis based on PBMR-400 (HTGR) with FLiBe as the working fluid
- Error-free execution and physically sensible plant response

MSRE Steady-State





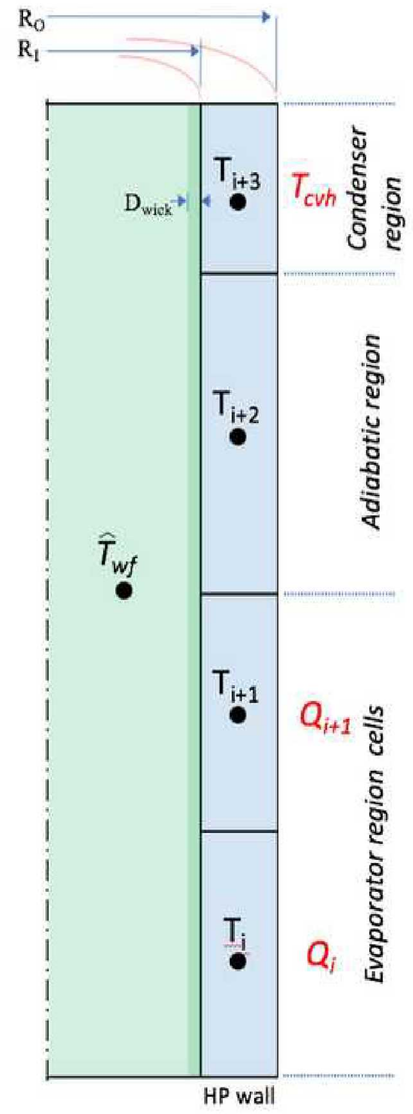
MELCOR Heat Pipe Reactor Modeling Capabilities

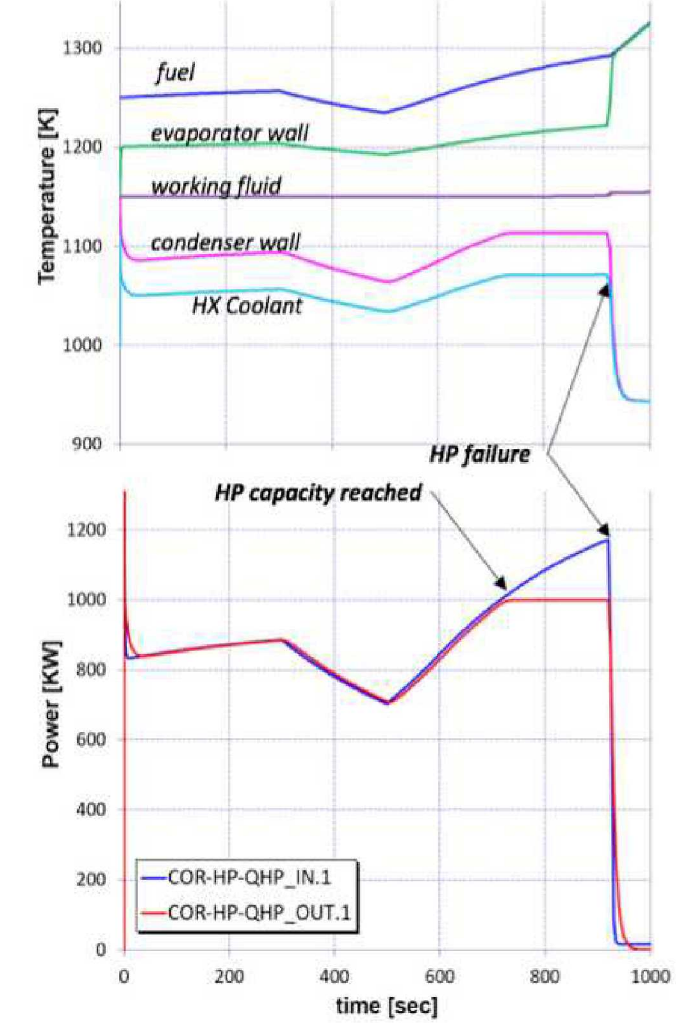
MELCOR HP modeling approach:

- Captures heat transfer, fuel to secondary coolant
  - Heat flux from fuel to HP evaporator region
  - HP condenser region an energy source to secondary
- Several HPR designs & geometric configurations
  - Introduces modeling challenges for MELCOR
  - Generically consider range of HPR configurations

MELCOR HP model

- HP geometry (wick diameter, wall radii)
- Evaporator, adiabatic, condenser regions
- Ability to track transient HP behavior
  - Temperatures of fuel, HP fluid, HP wall segments
  - Power input (from fuel) and output (to secondary)
  - Can predict failure, e.g. due to overloading
- Under active development
- Compatible with other MELCOR models





Illustrative output (temperatures and in/out power) from a slow transient of a simple HP test problem