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MELCOR

MELCOR Code Assessment Program Non-LWR High-Level Overview

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Overview

High level overview by reactor type of:

- Existing models/capabilities
- Active or future code development

Non-LWRs:

- HTGR (PBR and PMR),
- FHR,
- MSR,
- SFR, and
- HPR

Conclusions

High Temperature Gas-Cooled Reactor (Pebble Bed and Prismatic)

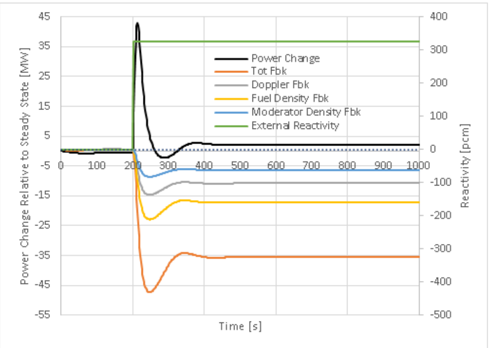
HTGR (PBR/PMR) Existing Models/Capabilities

Thermal hydraulics and heat transfer

- Matrix (MX) and reflector (RF) components
- Core conduction
  - Intracell (FU/MX)
  - Intercell
    - Effective conductivity
    - Conduction geometry
  - Radial Boundary (COR to HS)
- Core convection
  - Pebble Nusselt number correlation
  - MX and RF heat transfer resistance
  - Packed bed flow resistance
- Graphite steam and air oxidation
- Point reactor kinetics

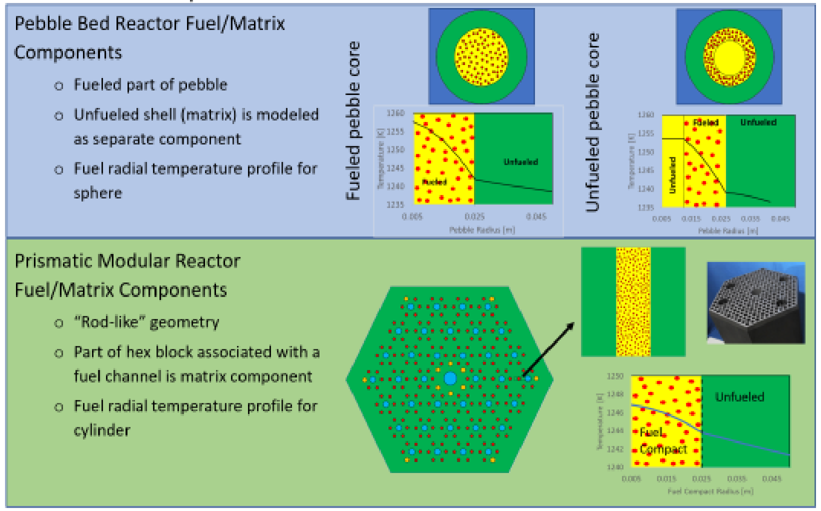
Radionuclide transport and release

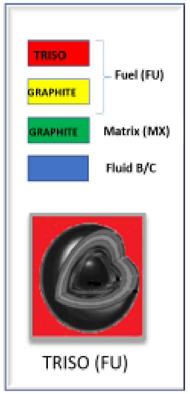
- Diffusional fission product release model
- Graphite dust generation and transport



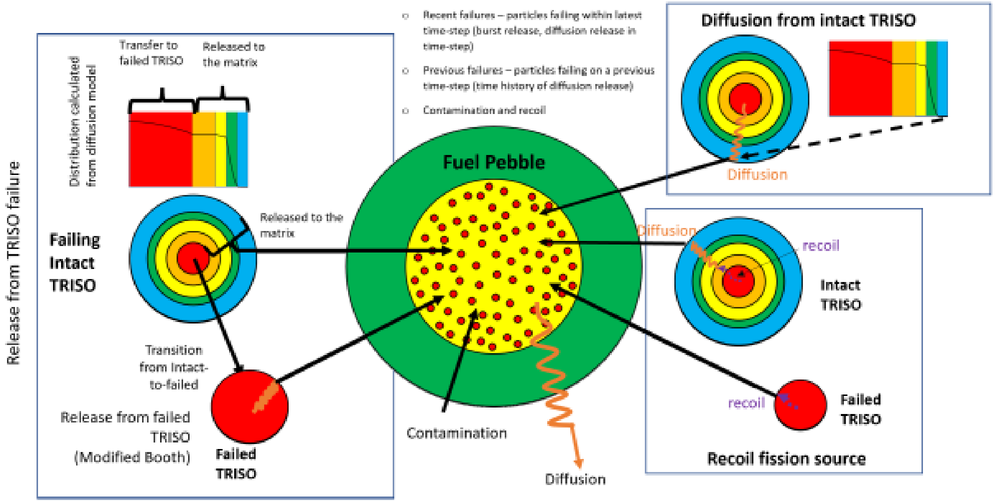
$$K^* = K_{empty} + \left[C_1 + C_2\frac{1-\varepsilon}{Re} + C_3\left(\frac{1-\varepsilon}{Re}\right)^{C_4}\right]\frac{(1-\varepsilon)L}{\varepsilon D_p} \qquad Re = \frac{\rho v \varepsilon D_p}{\mu}$$

Correlation	C_1	C_2	C_3	C_4
Ergun (original)	3.5	300.	0.0	-
Modified Ergun (smooth)	3.6	360.	0.0	-
Modified Ergun (rough)	8.0	360.	0.0	-
Achenbach	1.75	320.	20.0	0.4





Sub-component model for zonal diffusion of radionuclides through TRISO particle



HTGR (PBR/PMR) Active/Future Development

RF and MX component support rule revision

- Previously, MX could not support RF above and RF could not support MX above (core/reflector axial boundaries)
- Now, RF can transmit load to/through MX and vice-versa (ultimately to underlying SS)
- Backwards compatibility

Core radial conduction parameters

- Intercell component-wise radial conduction model derives a notion of radial conduction area as the common radial ring interfacial boundary area scaled by a component volume fraction
- New/revised COR SC1507 for limited parameterization of component volume fraction

RF component geometry flag

- RF can be “cylindrical” or “flat plate” geometry, and this definition factors into RF-side intercell conduction logic
- RF geometry plays a role in RF component convection as well

Fluoride High Temperature Reactor

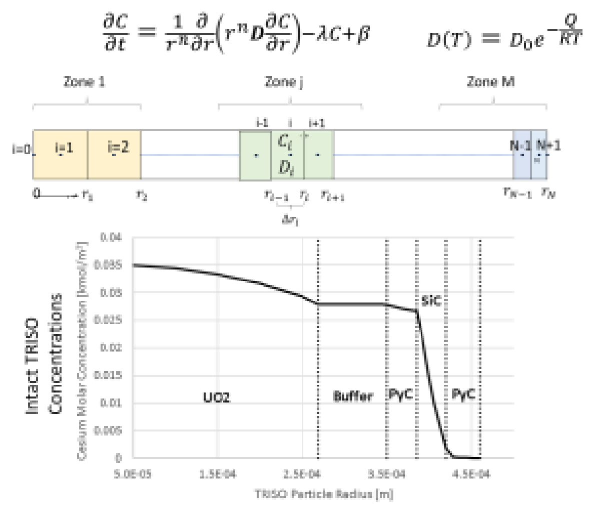
FHR Existing Models/Capabilities

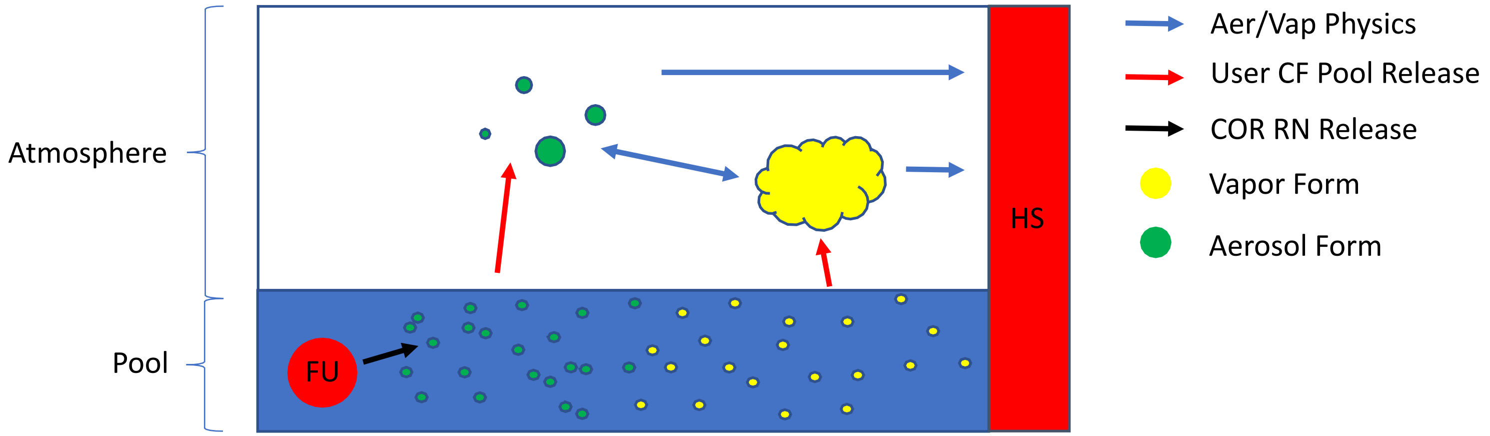
Thermal hydraulics and heat transfer

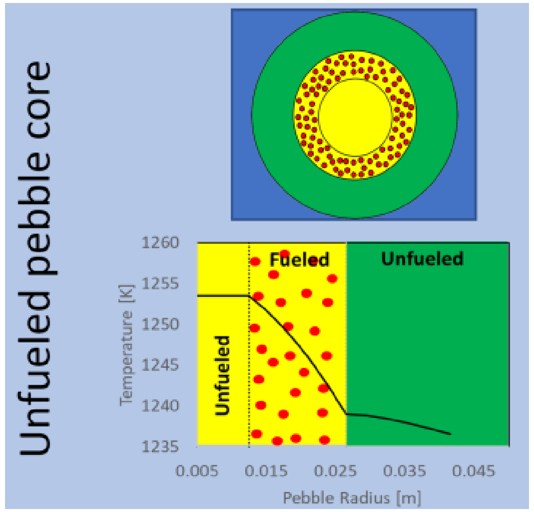
- Several of the same models applicable to HTGR (PBR in particular)
- Zehner-Schlunder-Bauer effective conductivity models' radiation component
- FLiBe properties/EOS (condensable hydrodynamic material)

Radionuclide transport and release

- Diffusional fission product release model compatible with alternative (fueled shell) pebble fuel element
- Control-function pool release with conventional built-in radionuclide forms, or
- Generalized radionuclide transport and retention (GRTR) framework







FHR Active/Future Development

Issues mentioned for PBR/PMR may or may not apply to FHRs

Generalized radionuclide transport and release framework and ORIGEN/MELCOR integration

- Radionuclide forms in pool, release from pool, chemistry and radionuclide retention, etc.
- ORIGEN/MELCOR may impact the chemistry of the problem

Multiple condensable fluids (CVH/EOS) – Other than FLiBe in secondary or tertiary loops

Effective conductivity model – Pebble bed in molten salt

Molten Salt Reactor

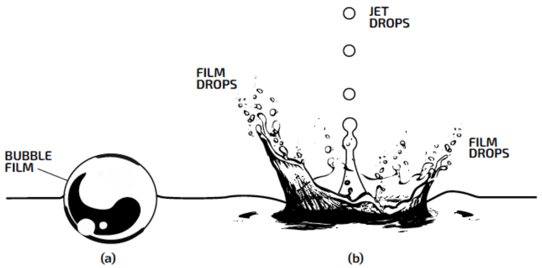
MSR Existing Models/Capabilities

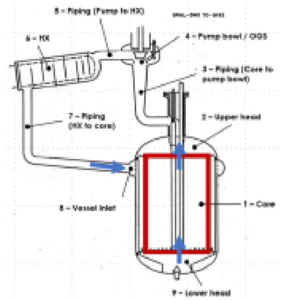
Thermal hydraulics and heat transfer

- FLiBe properties/EOS (condensable hydrodynamic material) to include treatment for salt freezing
- CVH package fluid fuel/core – power magnitude and distribution
- Fluid fuel point reactor kinetics model (delayed neutron precursor drift)

Radionuclide transport and release

- Control-function pool release with conventional built-in radionuclide forms, or
- GRTR framework
- Ability to initialize and/or source in (over an initialization period) all RN classes, forms, etc.





A – In-Vessel DNP gain by fission
B – In-Vessel DNP loss by decay and flow
C – Ex-Vessel DNP gain by Ex-Vessel DNP flow
D – Ex-Vessel DNP gain by In-Vessel DNP flow
E – Ex-Vessel DNP loss by decay, flow

Fission inside core

- Neutrons generated and moderated
- DNPs generated

DNPs that do not decay in core-region flow into loop

- Decay in loop or advect back into core-region

$$\frac{dP(t)}{dt} = \left(\frac{\rho(t)-\bar{\beta}}{\Lambda}\right)P(t) + \sum_{i=1}^{6}\lambda_i C_i^c + S_0$$

$$\frac{dC_i^c(t)}{dt} = \left(\frac{\beta_i}{\Lambda}\right)P(t) - \left(\lambda_i + {}^{1}/_{\tau_c}\right)C_i^c(t) + \left(\frac{V_L}{\tau_L V_C}\right)C_i^L(t-\tau_L), \quad for\ i = 1\ldots6$$

$$\frac{dC_i^L(t)}{dt} = \left(\frac{V_C}{\tau_C V_L}\right)C_i^c(t) - \left(\lambda_i + {}^{1}/_{\tau_L}\right)C_i^L(t), \quad for\ i = 1\ldots6$$

$$\bar{\beta} = \beta - \left(\frac{\Lambda}{P(t)}\right)\sum_{i=1}^{6}\lambda_i C_i^L(t)$$

** DNP = Delayed Neutron Precursor

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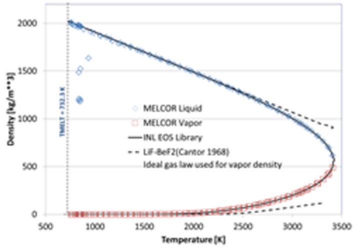
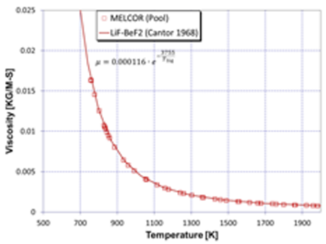
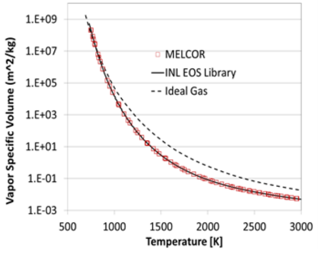
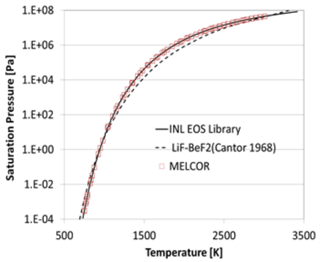
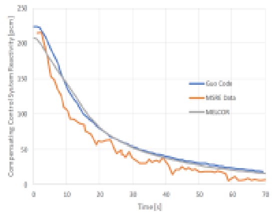
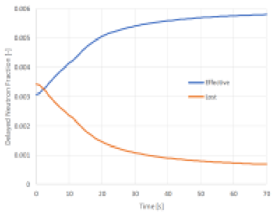


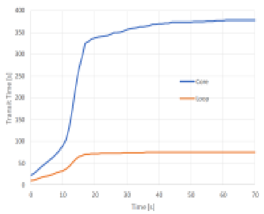








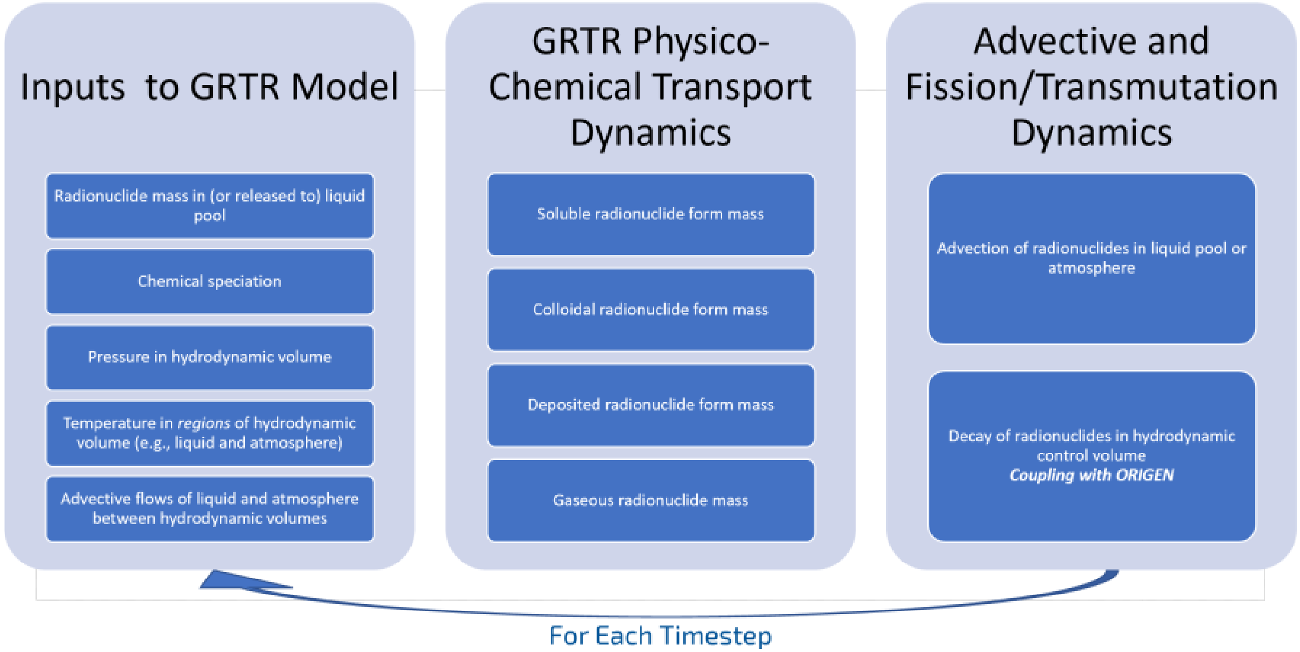




MSR Active/Future Development

Generalized radionuclide transport and retention framework and ORIGEN/MELCOR integration

- Work in progress
- Concerned with physico-chemical forms and their dynamics
  - Pool release (solubility, vapor pressure)
  - Insoluble forms and deposition
  - Various mass transport mechanisms



HS surface heat transfer with atmosphere

- Useful in salt spill accident scenarios
- Mitigate time-step thrashing (HS/CVH coupling)
- Place a physical realizability limit on allowable heat transfer with atmosphere considering all HS surfaces in a CV

Multiple condensable fluids (CVH/EOS)

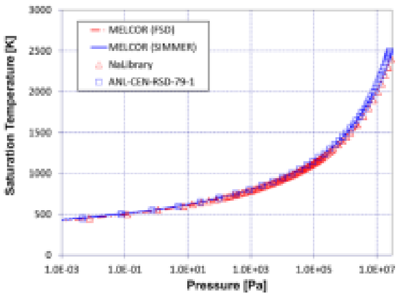
- Other than FLiBe in secondary or tertiary loops
- New CVH/EOS fluids, e.g. chloride salts

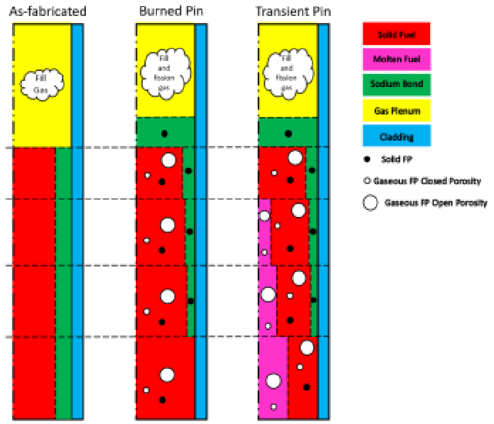
Sodium Fast Reactor

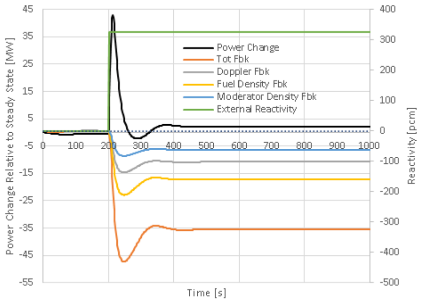
SFR Existing Models/Capabilities

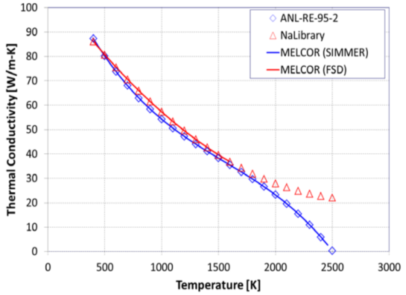
Thermal hydraulics and heat transfer

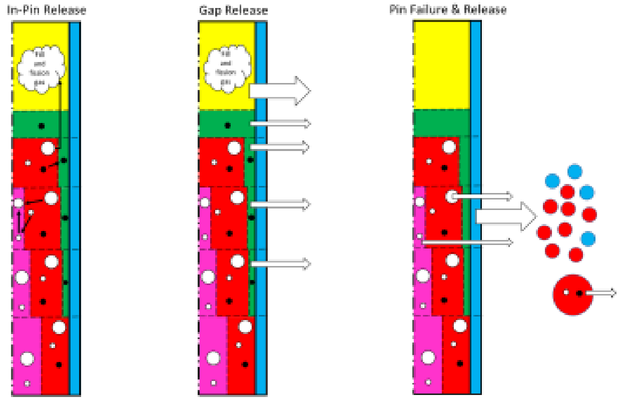
- Metal FU properties, CL and CN primary materials, sodium bond gap
- Sodium properties/EOS (condensable hydrodynamic material)
- Pin and pin plenum fission gas dynamics/transport
- In-pin molten (contiguous) cavity formation/pressurization
- Point reactor kinetics model
- Fuel failure and degradation
  - Candling/blockage,
  - Particulate debris, and
  - Molten pool models
- Ex-vessel (spray fire, pool fire, atmospheric chemistry)





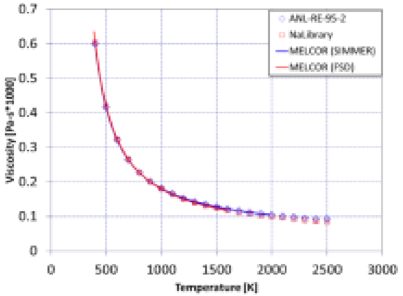


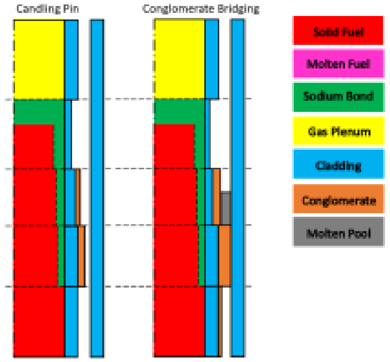




Radionuclide transport and release

- Initialize fuel, sodium bond gap, and pin plena gaseous/solid inventory
- In-pin fission gas dynamics (closed/open porosity, solid to molten, release)
- Control-function pool release with conventional built-in radionuclide forms, or
- GRTR framework





SFR Active/Future Development

More detailed fuel pin mechanics and fission gas dynamics model(s) for pre-transient and transient

- System of algebraic expressions to predict fuel/clad stress/strain
- More detailed pin failure logic
- Core degradation modeling benchmark(s) and subsequent improvements

Generalized radionuclide transport and release framework and ORIGEN/MELCOR integration

COR heat transfer limitation/relaxation – physical realizability limit on COR/CVH heat transfer

Multiple condensable fluids (CVH/EOS) - Other than sodium in secondary or tertiary loops

Improved and expanded ex-vessel modeling

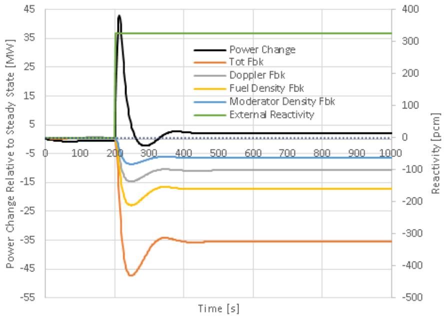
- Sodium/limestone ablation (SLAM) model (MCCI for SFRs)
- Spray/pool fire model modifications

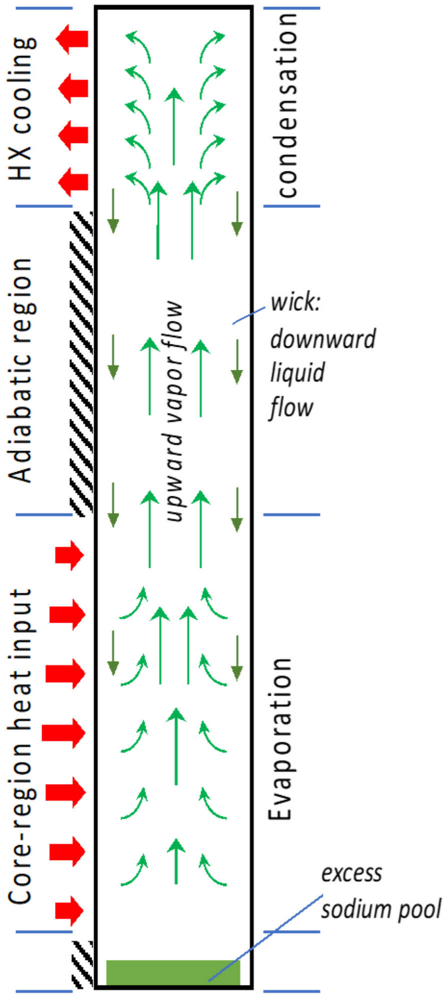
Heat Pipe Reactor

HPR Existing Models/Capabilities

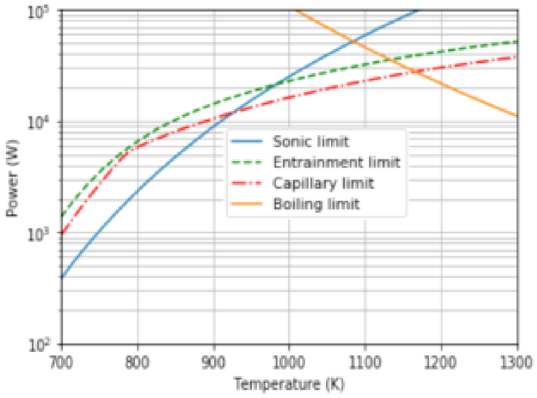
Thermal hydraulics and heat transfer

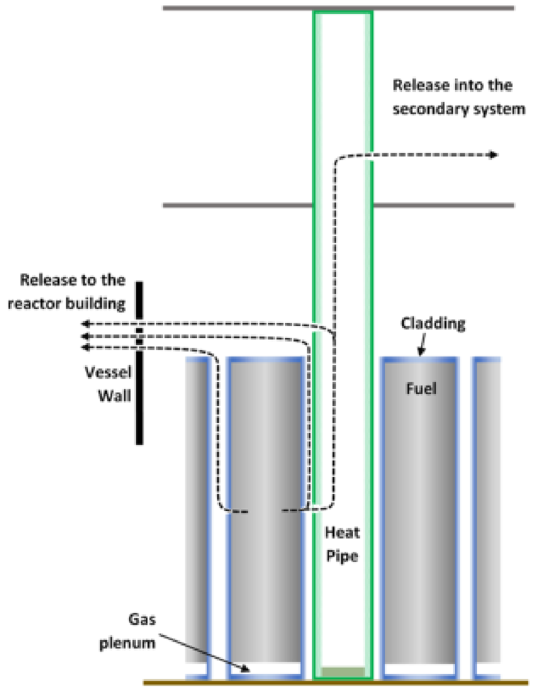
- HP component and heat pipe performance/response model(s)
- HP failure and operational limits
- Point reactor kinetics modeling
- User-defined heat transfer pathway capability

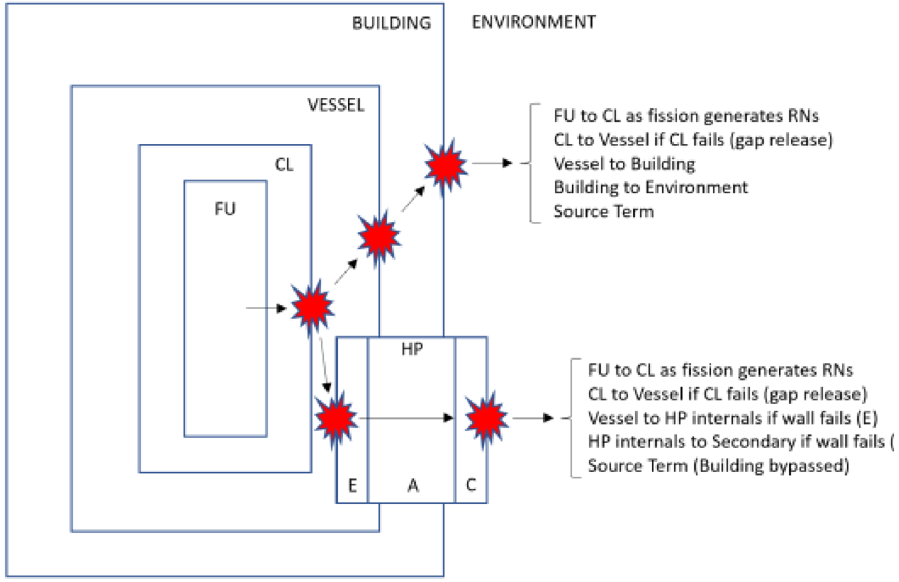




Radionuclide transport and release – Conventional built-in radionuclide forms/models or GRTR







HPR Active/Future Development

Multi-rod modeling extension for heat pipes – would help investigate hypothesized cascading HP failure

Horizontal heat pipes (currently only vertical)

Fission product release models

Conclusions

Gave a brief description of MELCOR models/capabilities for non-LWRs

- HTGR (PBR and PMR)
- FHR
- MSR
- SFR
- HPR

Code models/capabilities are sufficient to demonstrate source term calculations for each reactor type, and various development tasks are ongoing with several more coming soon

Various domestic and international code users are actively exercising non-LWR models/capabilities, and their findings are factoring into the development cycle in real time