



Modeling Internal Material Melting

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Changing the World's Energy Future

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Internal melting is *not* surface melting



Known applications:

- Zero gravity melting
- Internal heating causing melting

Apply to BISON’s M7 TREAT Assessment:

- BISON is state-of-the-art nuclear fuel performance code
- M7 experiment has internal heating causing melting
- Improve results by properly accounting for heat of fusion

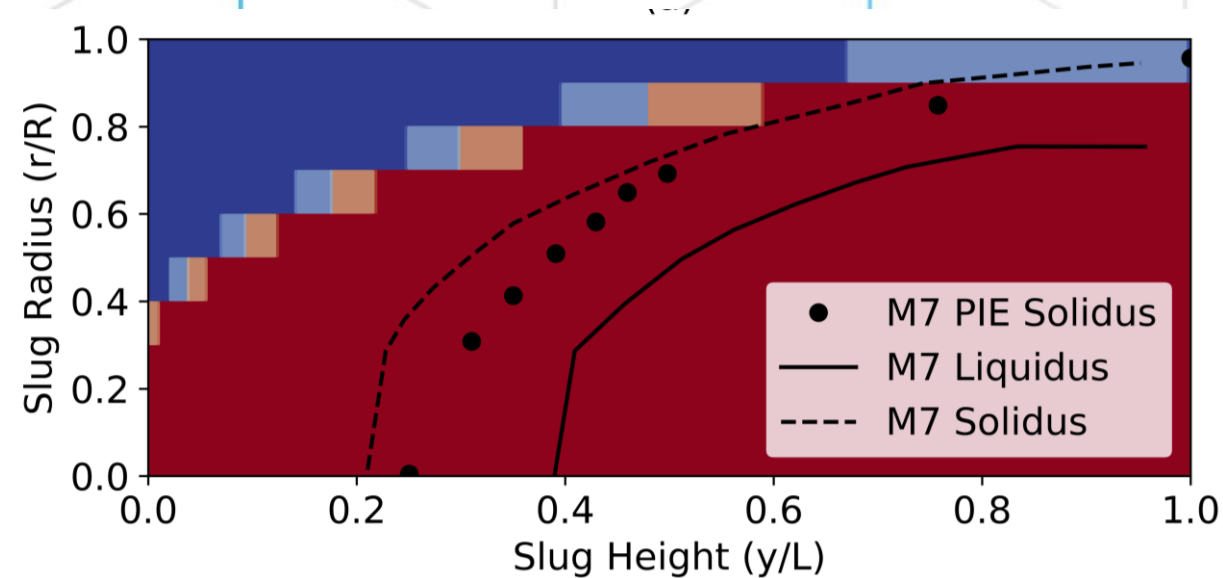


Figure from INL/EXT-19-55892 Rev. 1

Code Additions

Class Name	Documented	Regression Tests	Reason	Merged
General Info	✓	MOOSE Doc Builds	Explain enthalpy approach	MOOSE Ready
Enthalpy-Conduction	✓	✓	$-\nabla^2(\Gamma(E)E)$	MOOSE Ready
Enthalpy-Time-Derivative	✓	✓	$\frac{\partial}{\partial t}(\rho E)$	MOOSE Ready
EnthalpyFix-TemperatureBC	✓	✓	Temperature Dirichlet converted to enthalpy Dirichlet	MOOSE Ready
UPuZrState-Change	✓	✓	Metallic fuel solidus and liquidus temperatures	BISON ✓
Addition to UPuZrThermal	✓	✓	New liquid thermal conductivity model approximation	BISON ✓

All classes are available as both standard and automatic differentiation

Final Piece: Temperature-dependent material properties complicate enthalpy material property calculation. Two options considered:

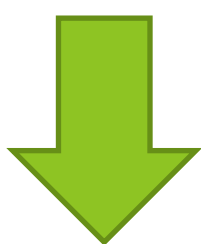
1. Manually convert each temperature-dependent material to enthalpy forms
 - More code additions duplicating existing dependent material codes
 - Must be able to integrate dependent material properties
2. Material converter with moving enthalpy reference using existing dependent material codes
 - Change in enthalpy is computed each timestep, where new reference enthalpy is updated each timestep end
 - Dependent material properties approximated by constant average properties at reference enthalpy and new enthalpy

Novel Approach: Enthalpy

Use enthalpy form of heat conduction governing equation:

- Enthalpy continues to change during phase change
- Uses new material properties formed from thermal conductivity and specific heat properties

$$\frac{\partial}{\partial t}(\rho E) = -\nabla \cdot \vec{q} + \dot{q}$$



$$\frac{\partial}{\partial t}(\rho E) = -\nabla^2(\Gamma(E)E) - \nabla^2(S(E)) + \dot{q}$$

Example of range melting constant material properties:

$$\begin{aligned}\Gamma_S &= \frac{k_S}{c_S} \\ \Gamma_M &= \frac{k_m \Delta T_m}{H + c_m \Delta T_m} \\ \Gamma_L &= \frac{k_l}{c_l} \\ S_S &= 0 \\ S_M &= 0 \\ S_L &= \frac{\Delta T_m}{c_l} (k_m c_l - k_l c_m) - \frac{k_l}{c_l} H\end{aligned}$$

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