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Modeling Internal Material Melting

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Modeling Internal Material Melting

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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

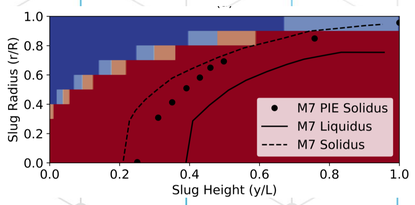

Figure from INL/EXT-19-55892 Rev. 1

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**

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

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

Example of range melting constant material properties:

$$\Gamma_S = \frac{k_s}{c_s}$$

$$\Gamma_M = \frac{k_m \Delta T_m}{H + c_m \Delta T_m}$$

$$\Gamma_L = \frac{k_l}{c_l}$$

$$S_S = 0$$

$$S_M = 0$$

$$S_L = \frac{\Delta T_m}{c_l}(k_m c_l - k_l c_m) - \frac{k_l}{c_l} H$$

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