



# YRA poster session - July 25 2019

July 2019

*Changing the World's Energy Future*

Paolo Balestra, Sebastian Schunert, Gerhard Strydom, R. Carlsen, S. R. Sen,  
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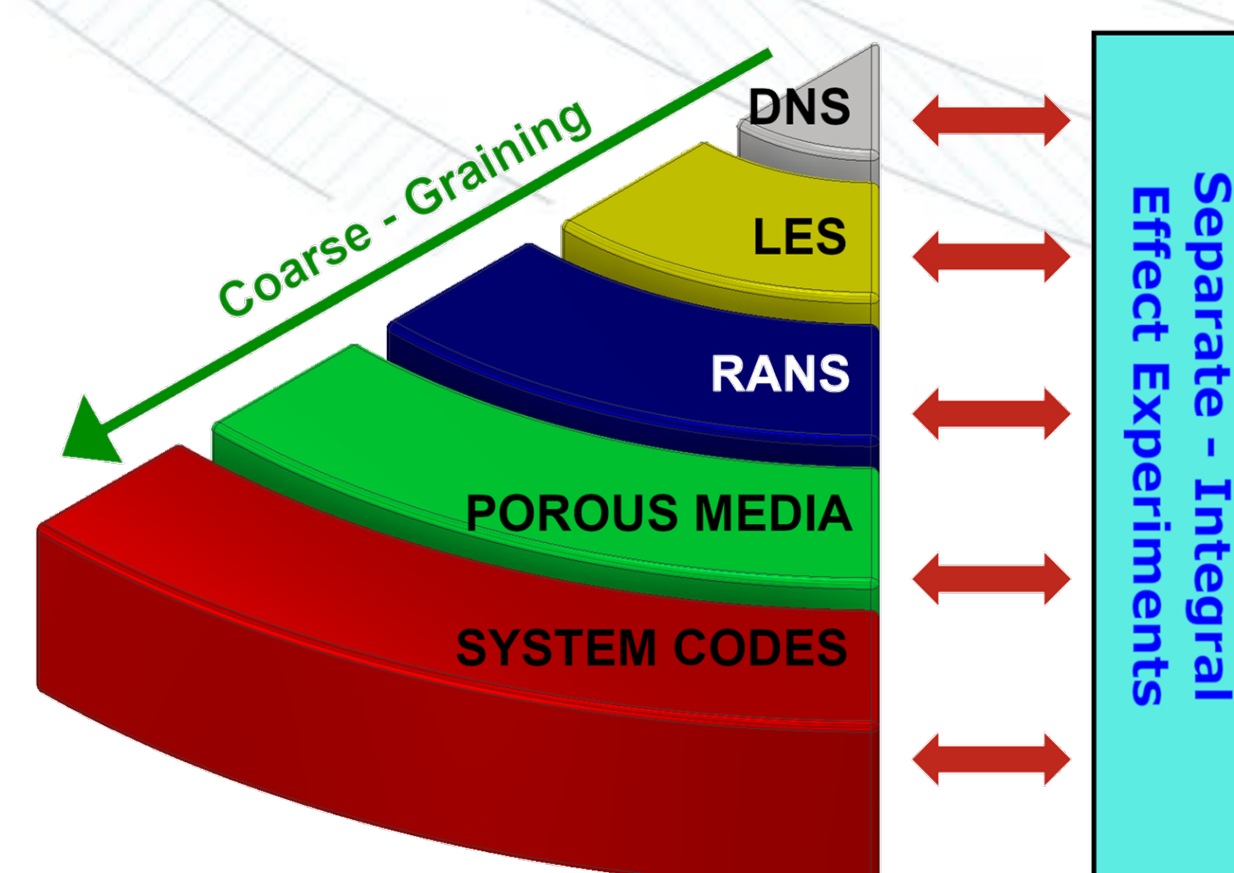
# Pronghorn: A MOOSE Based TH Tool for Advanced Reactor Concepts

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Reactor Systems Design and Analysis, Nuclear Engineering Methods Development

## Pronghorn history & activities



- NEK5000
- STARCCM+
- Pronghorn
- RELAP5-3D
- RELAP-7



## Pronghorn under the hood

Governing Equations, Approach #1: Two-Phases with Compressible Flow Phase and a Stationary Solid Phase

### Conservation of Mass

$$\frac{\partial \alpha \rho}{\partial t} + \nabla \cdot (\alpha \rho \vec{u}) = 0$$

### Balance of Momentum

$$\frac{\partial \alpha \rho \vec{u}}{\partial t} + \nabla \cdot (\alpha \rho \vec{u} \otimes \vec{u} + p \mathbf{I}) = p_i \nabla \alpha + \nabla \cdot (\alpha \mu_{eff} \nabla \vec{u}) + \alpha(1 - \alpha) K_m (\vec{u}_s - \vec{u})$$

### Conservation of Total Energy

$$\frac{\partial \alpha \rho E}{\partial t} + \nabla \cdot (\alpha \rho \vec{u} H) = p_i \vec{u}_i \cdot \nabla \alpha - \nabla \cdot (\alpha \vec{q}) + \alpha \rho Q + \alpha(1 - \alpha) K_e (T_s - T) + \vec{u} \cdot (\alpha \rho \vec{g})$$

### Solid Phase Energy Balance

$$(1 - \alpha) \rho_s c_{v,s} \frac{\partial T_s}{\partial t} = \nabla \cdot [(1 - \alpha) \vec{q}_s] + (1 - \alpha) \rho_s Q_s - \alpha(1 - \alpha) K_e (T_s - T)$$

Governing Equations, Approach #2: Thermally Expansive, Nearly Incompressible (liquid) Flow Phase and a Stationary Solid Phase

### Conservation of Mass

$$\frac{\partial \alpha \rho}{\partial t} + \nabla \cdot (\alpha \rho \vec{u}) = 0$$

### Balance of Momentum

$$\alpha \rho \frac{D \vec{u}}{Dt} = -\alpha \nabla p + \nabla \cdot (\mu_{eff} \alpha \nabla \vec{u}) - \alpha(1 - \alpha) K_m \vec{u} + \alpha \rho \vec{g}$$

### Liquid Phase Energy Balance

$$\alpha \rho c_p \left( \frac{\partial T}{\partial t} + \nabla T \cdot \vec{u} \right) = (p - p_i) \vec{u} \cdot \nabla \alpha + \nabla \cdot (\alpha k_{eff} \nabla T) + \alpha \rho Q + \alpha(1 - \alpha) K_e (T_s - T)$$

### Solid Phase Energy Balance

$$(1 - \alpha) \rho_s c_{v,s} \frac{\partial T_s}{\partial t} = \nabla \cdot [(1 - \alpha) \vec{q}_s] + (1 - \alpha) \rho_s Q_s - \alpha(1 - \alpha) K_e (T_s - T)$$

Legacy Governing Equations, Approach #3: Porous flow approximation. Reproduces legacy THERMIX approach.

### Conservation of Mass

$$\epsilon \frac{\partial \rho}{\partial t} + \nabla \cdot \left[ \frac{\epsilon^2}{W} (-\nabla P + \rho_f \vec{g}) \right] = 0$$

### Balance Momentum

$$\epsilon \nabla P - \epsilon \rho_f \vec{g} + W \rho_f \vec{V} = 0$$

### Liquid Phase Energy Balance

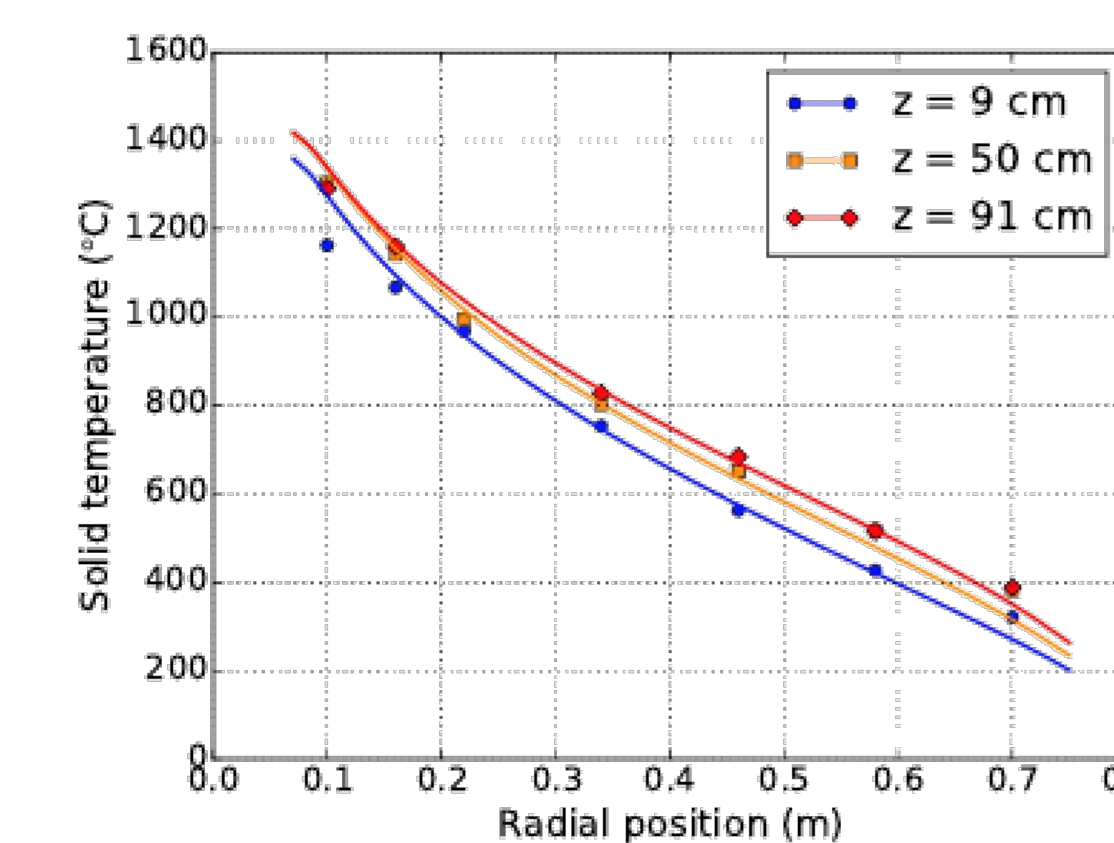
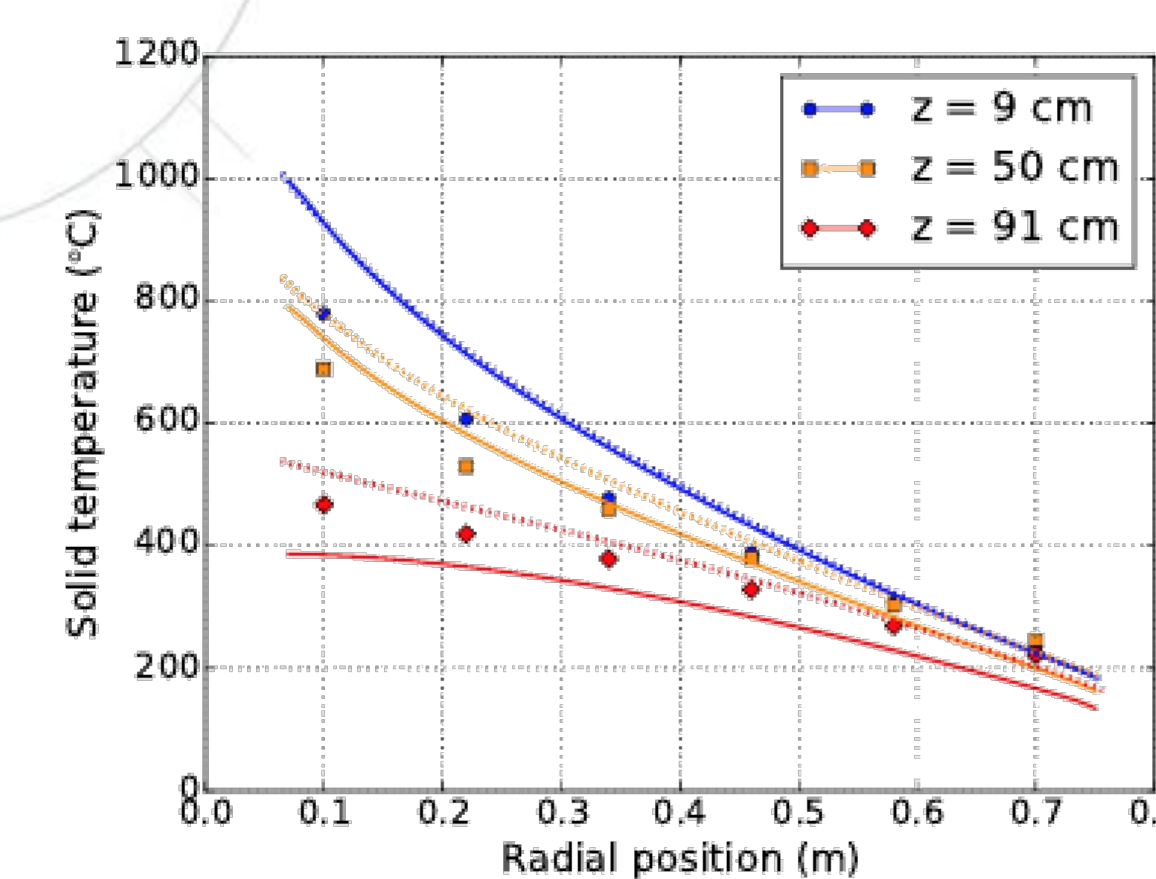
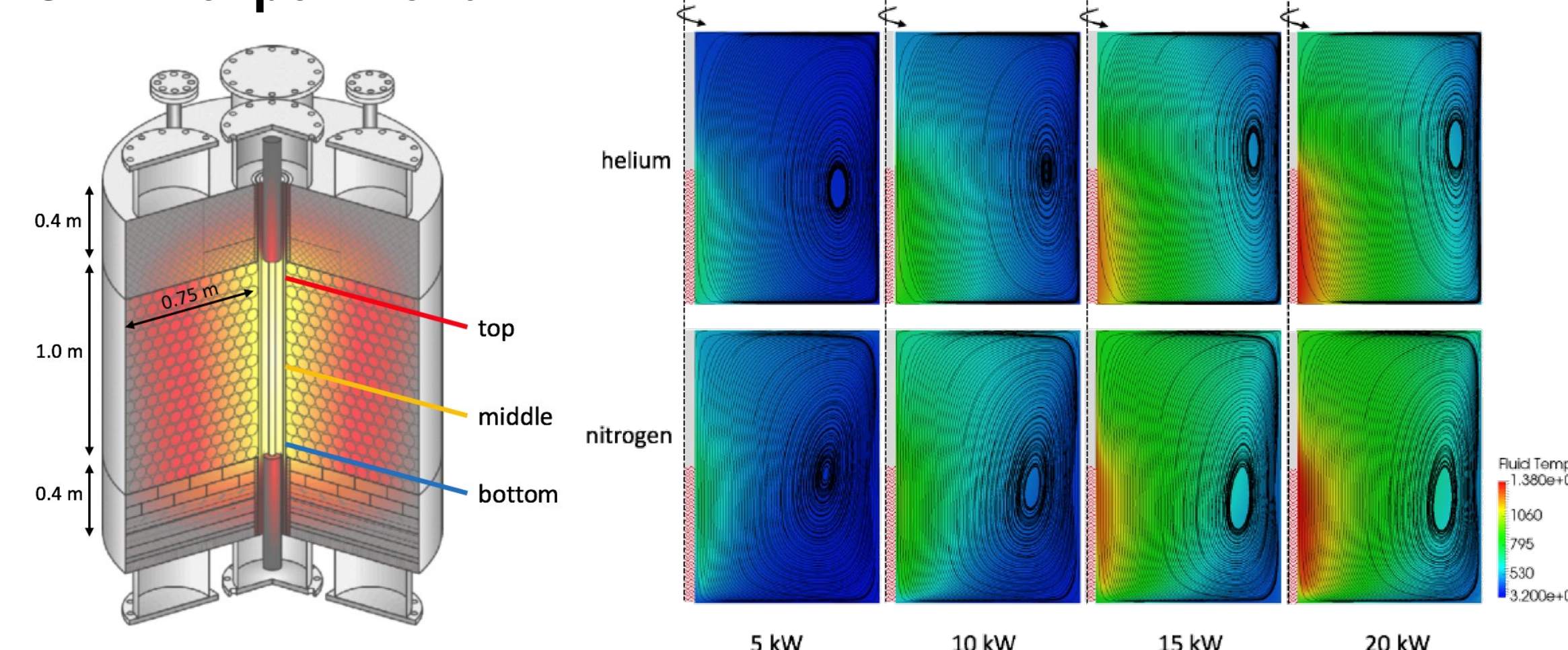
$$\epsilon \rho_f C_{p,f} \frac{\partial T_f}{\partial t} + \epsilon \rho_f C_{p,f} \vec{V} \cdot \nabla T_f - \nabla \cdot (\kappa_f \nabla T_f) + \alpha (T_f - T_s) + \dot{q}_f = 0$$

### Solid Phase Energy Balance

$$(1 - \epsilon) \rho_s C_{p,s} \frac{\partial T_s}{\partial t} - \nabla \cdot (\kappa_s \nabla T_s) + \alpha (T_s - T_f) + \dot{q}_s = 0$$

## Code Validation & Verification

- SANA experiment



- PBMR-400 benchmark

