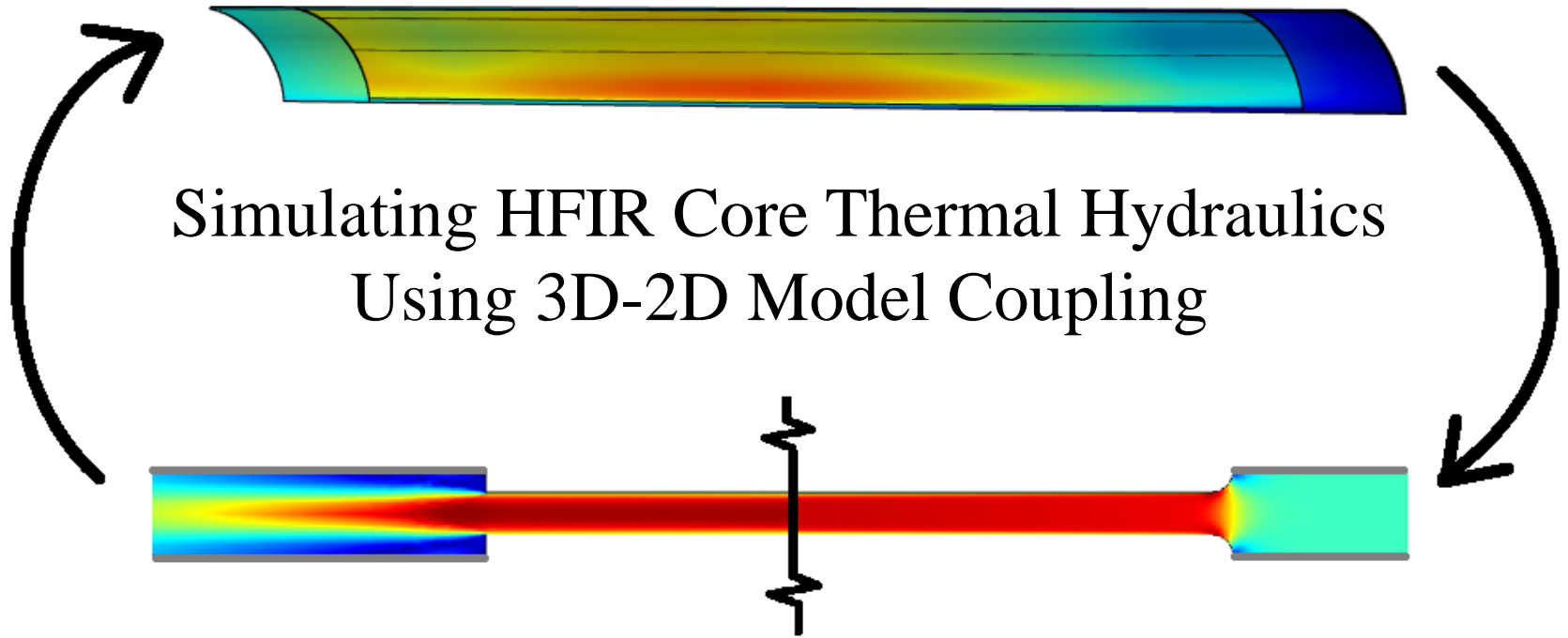




Simulating HFIR Core Thermal Hydraulics Using 3D-2D Model Coupling



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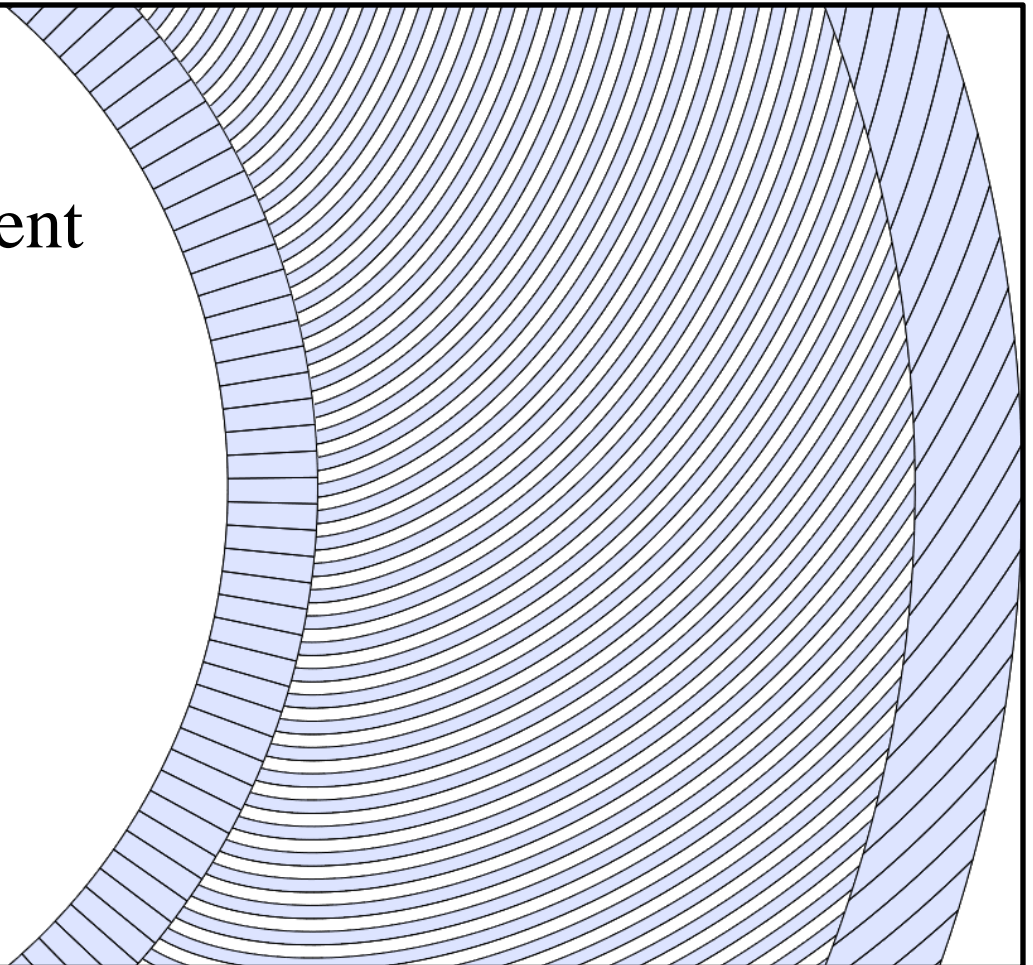
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Fuel Plate Geometry

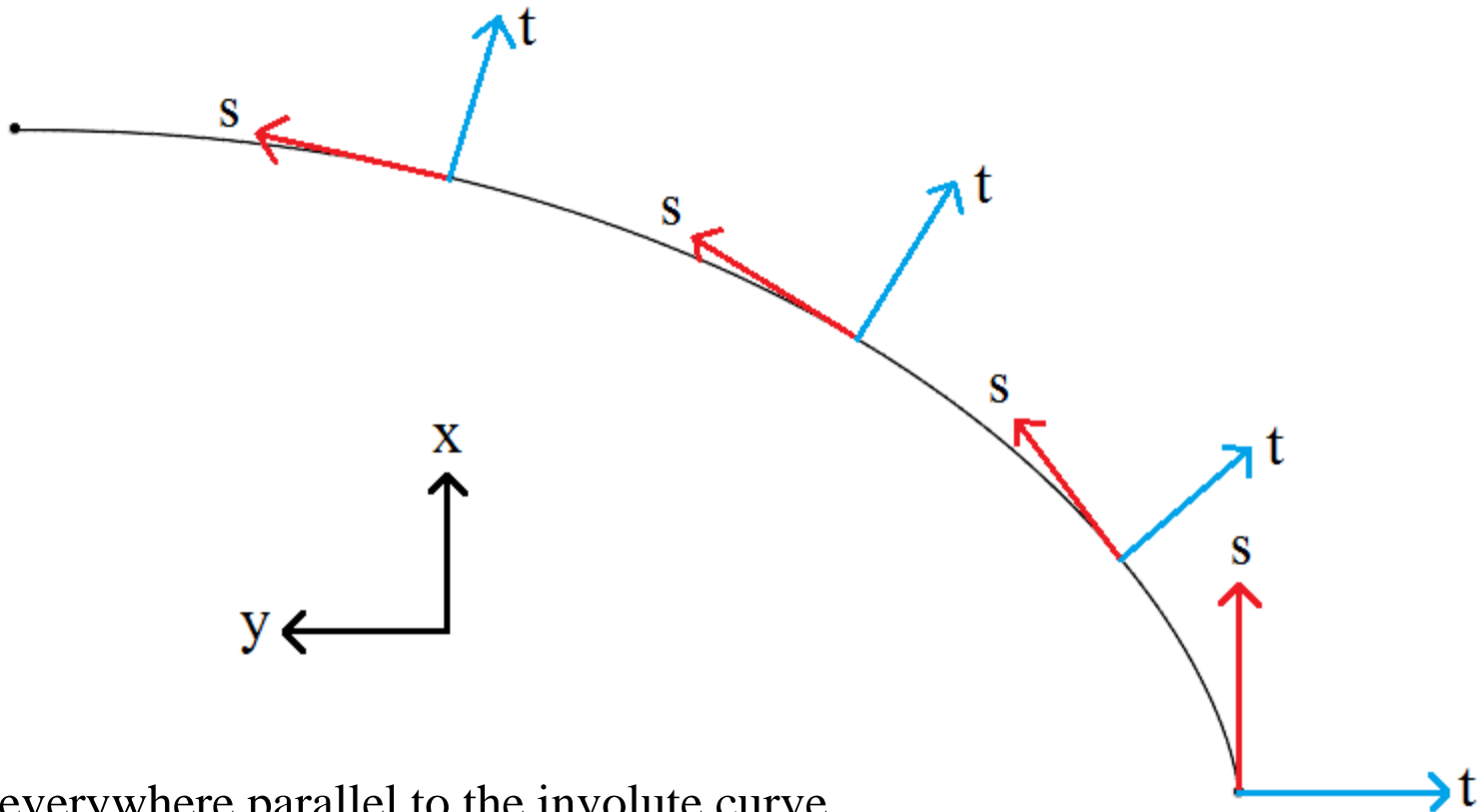
- 171 involute fuel plates in inner element
- Governed by the parametric equation:

$$x = r_b \left[\cos \theta + \left(\theta + \frac{t}{r_b} \right) \sin \theta \right]$$

$$y = r_b \left[\sin \theta - \left(\theta + \frac{t}{r_b} \right) \cos \theta \right]$$



Involute Coordinate System



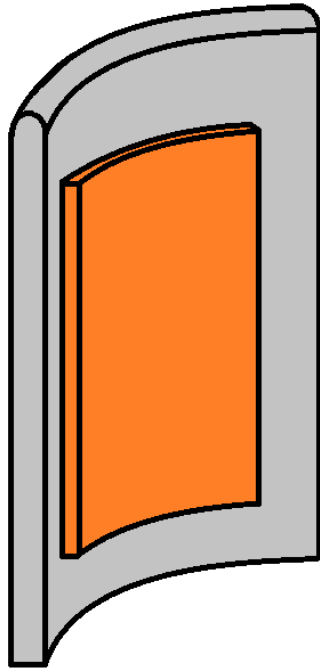
s is everywhere parallel to the involute curve
 t is everywhere perpendicular

Model Coupling

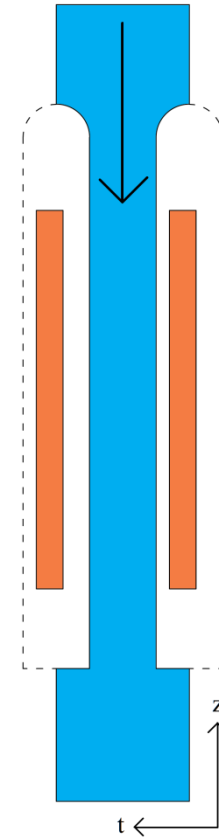
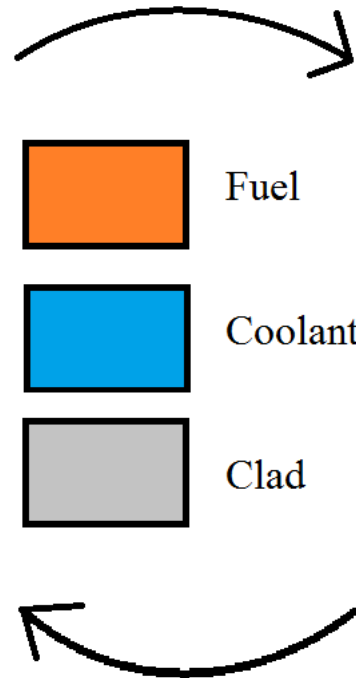
- Domain is split into two sub-domains:
 - 3D fuel plate (modeled explicitly)
 - 2D coolant channel slice (approximate)
- Division creates an interdimensional interface between domains of inconsistent dimensions.
- Model coupling is used to collect, format, and pass variables across this interface.

The Domains

3D Fuel Plate



2D Coolant Channel



Solid-to-Coolant Coupling

- 3D model to 2D model
 - Pass surface temperature values (2D surfaces) to coolant boundaries (1D lines)
 - Surface Temperatures ($T(s,z)$) are averaged in the s -coordinate in the solid domain and passed as a function of axial position ($T(z)$) to the coolant domain:

$$\bar{T}_{surf}(z_{coolant}) = \frac{1}{\Delta s} \int_s T_{surf}(s, z_{plate}) ds$$

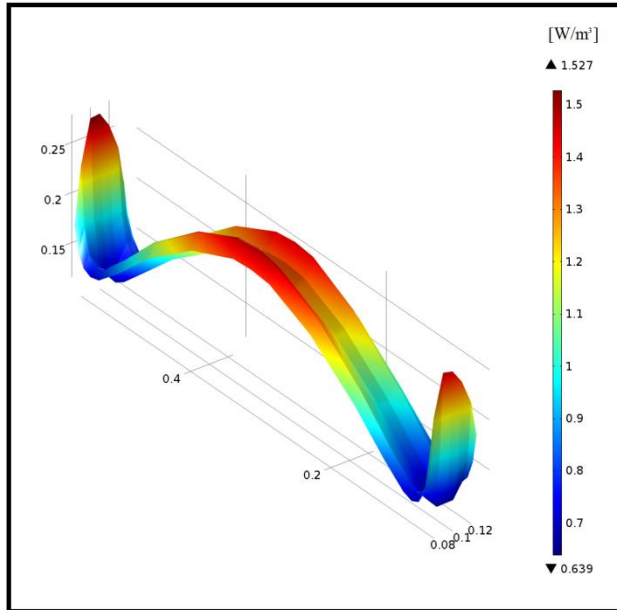
Coolant-to-Solid Coupling

- 2D model to 3D model
 - Pass bulk temperature values (1D variable) to clad boundaries (2D surfaces)
 - Bulk temperatures are computed across the width of the coolant channel in the t -direction and passed as a function of axial position to the solid domain:

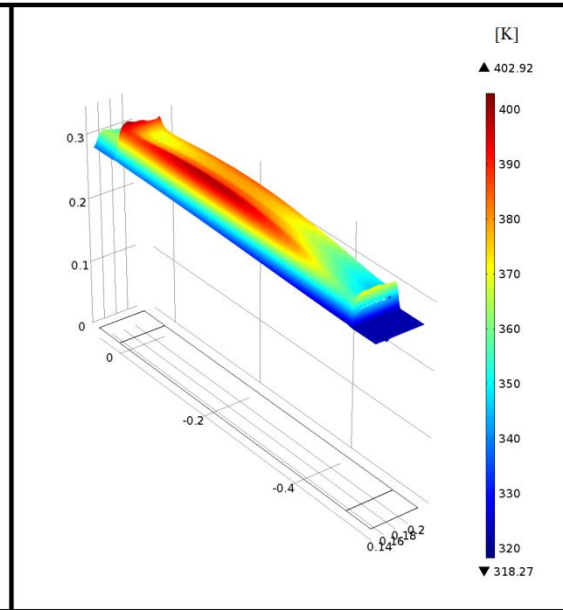
$$T_B(z_{plate}) = \frac{\int_t \rho u c_p T dt \Big|_{(t, z_{coolant})}}{\int_t \rho u c_p dt \Big|_{(t, z_{coolant})}}$$

Solution Comparisons

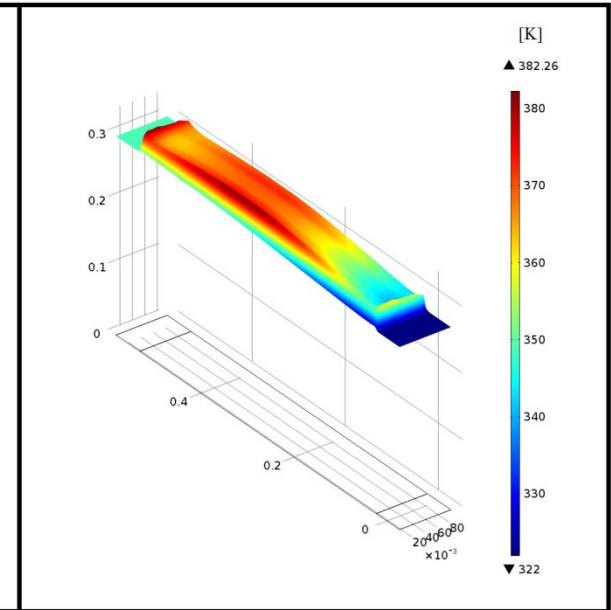
LEU Fuel Power Distribution



Full 3D COMSOL Comparison Model



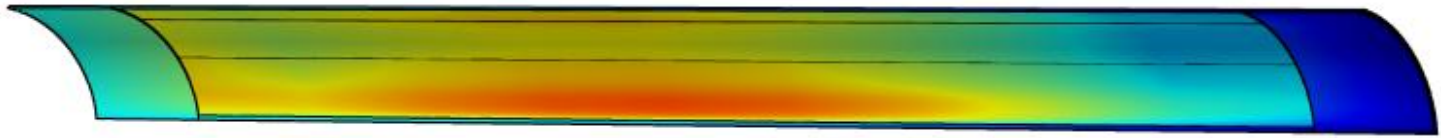
Coupled COMSOL Model



Degrees of Freedom (million)	Total: ~3.5 Clad: ~1.0 Coolant: ~2.5	Total: ~2.2 Clad: ~1.2 Coolant: ~1.0
Solution Time	~72 hours	~6 hours

Conclusion

- Close qualitative agreement
- Temperature discrepancy is largely due to smoothing effect of averaged values
 - Loss of peaks and valleys
 - Can be regained through manipulation of bulk temperatures as a function of local surface temperature and average surface temperature
- An efficient, reliable, and accurate alternative to explicitly modeling the entire domain (full 3D)
 - Potential for modeling more fuel plates at once and thus expanding the model's periodicity. Useful for the analysis of localized disturbances such as fuel defects and flow blockages



Questions?

