Modeling Research Reactor Fuel Plate Hotspots with COMSOL's Thin Layer and Thermal Contact Features

Michael J. Richards[1], Arthur E. Ruggles[1], James D. Freels[2]

[1]The University of Tennessee, [2]Oak Ridge National Laboratory

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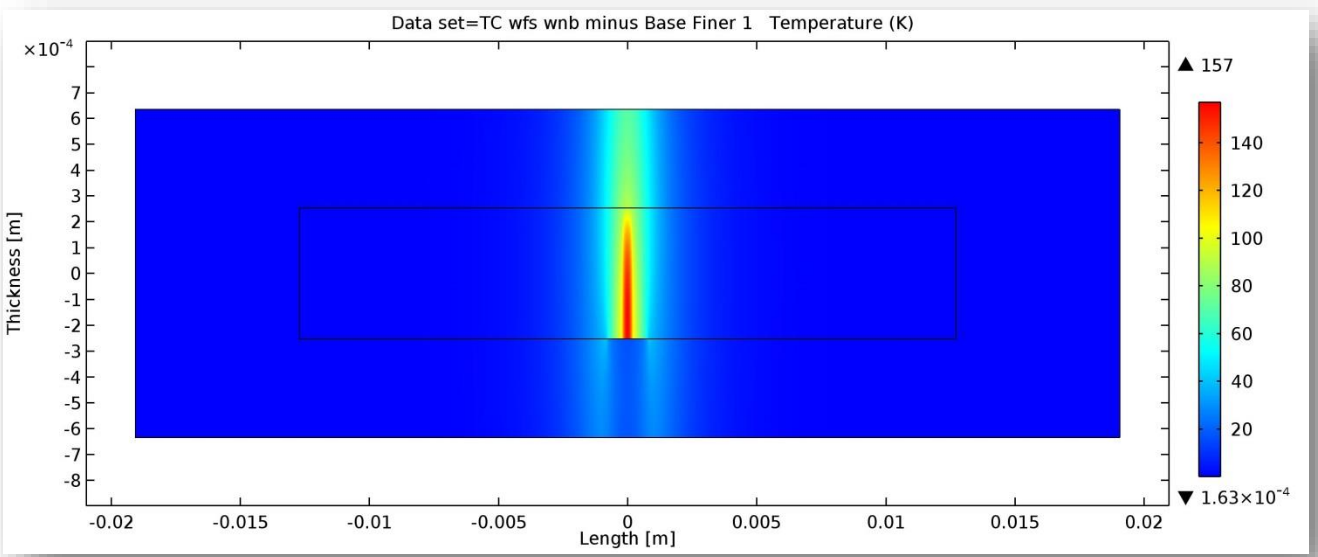
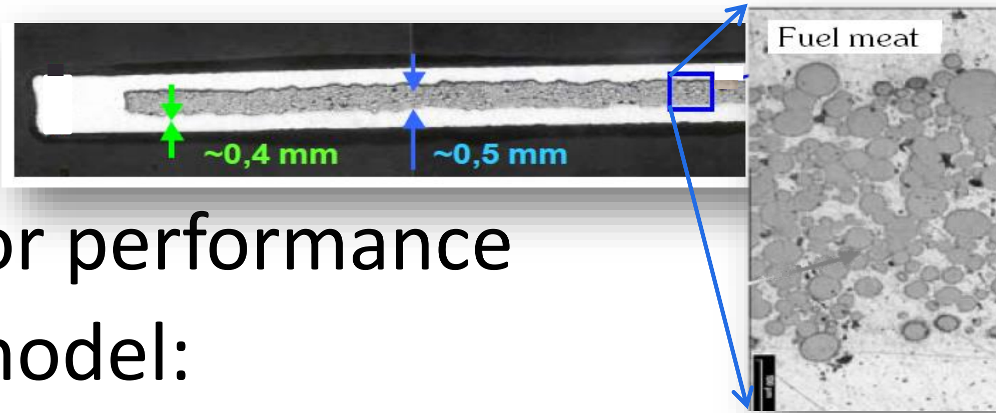


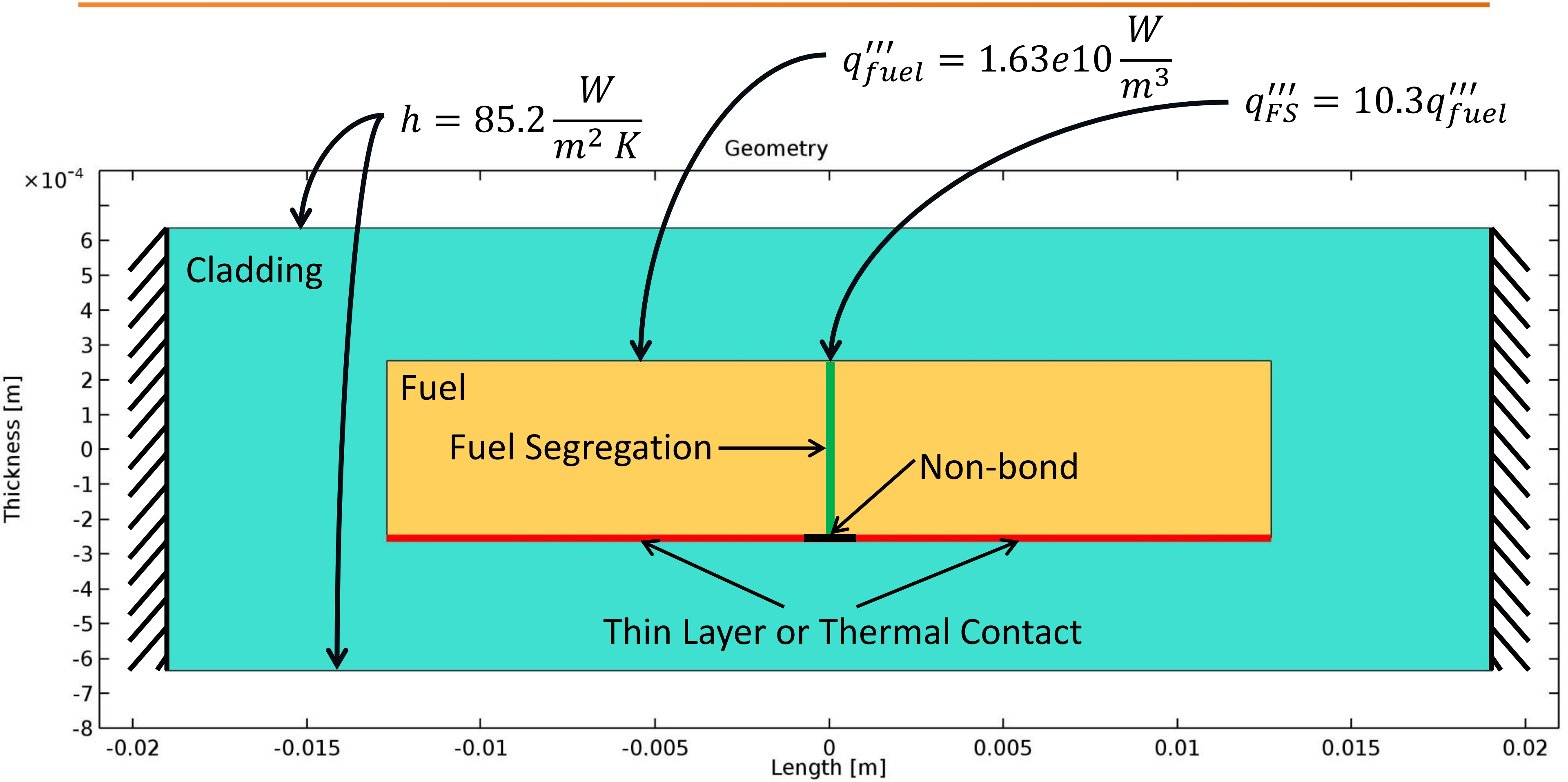
Introduction

- Many research reactors use plate fuel
- Fuel defects from manufacture cause hotspots
  - Fuel Segregations
  - Non-bonds



- Hotspots limit reactor performance
- Improving hotspot model:
  - Improves safety analysis of existing fuels
  - Aids in qualification of new fuels
- This works focuses on developing a better non-bond model

Simplified, 2D Fuel Plate Model

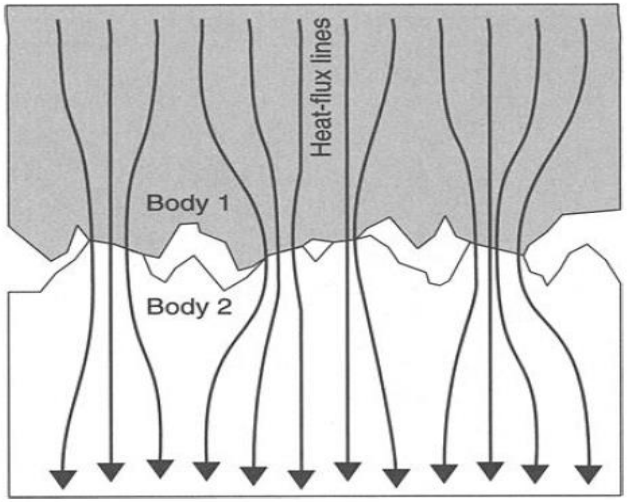


COMSOL's Thin Layer Boundary

- Thin layer (TL) and Thermal Contact (TC) boundaries can be used to reduce meshing requirements of very small features
- TL is modeled mathematically as:
  - $\boldsymbol{n}_d \cdot \boldsymbol{q}_d = k_s \frac{T_u - T_d}{d_s}$
    - The *d* and *u* subscripts indicate the "down" and "up" side of the boundary, representing coincident nodes on either side of the boundary
- The altered boundary (bottom of fuel) should mimic unaltered boundary when $k_s = k$

COMSOL's Thermal Contact Boundary

- Thermal Contact (TC) mathematical model:
  - $\boldsymbol{n}_d \cdot \boldsymbol{q}_d = h_c(T_u - T_d)$, with
    - $h_c = 1.54 k_c \frac{m_{asp}}{\sigma_{asp}} \left(\frac{\sqrt{2}p}{m_{asp}E'}\right)^{0.94}$

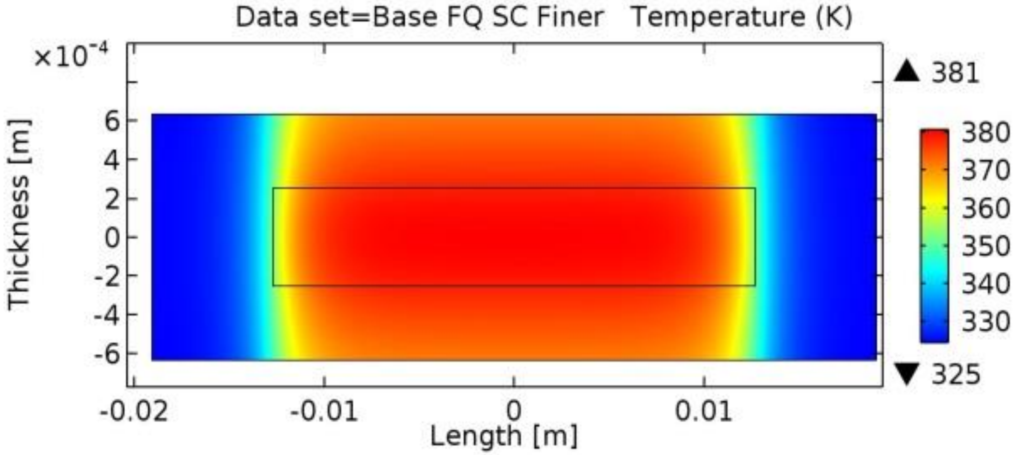


- Rearranging produces
  - $q_{tc} = C_{tc}\, k_c \frac{T_u - T_d}{\sigma_{asp}}$, with
    - $C_{tc} = 1.54\, m_{asp}^{0.06} \left(\frac{\sqrt{2}p}{E'}\right)^{0.94}$
- By selecting *m*, *p*, and *E'* so C_{tc}=1 and k_c=*k*, the altered boundary should mimic the unaltered boundary

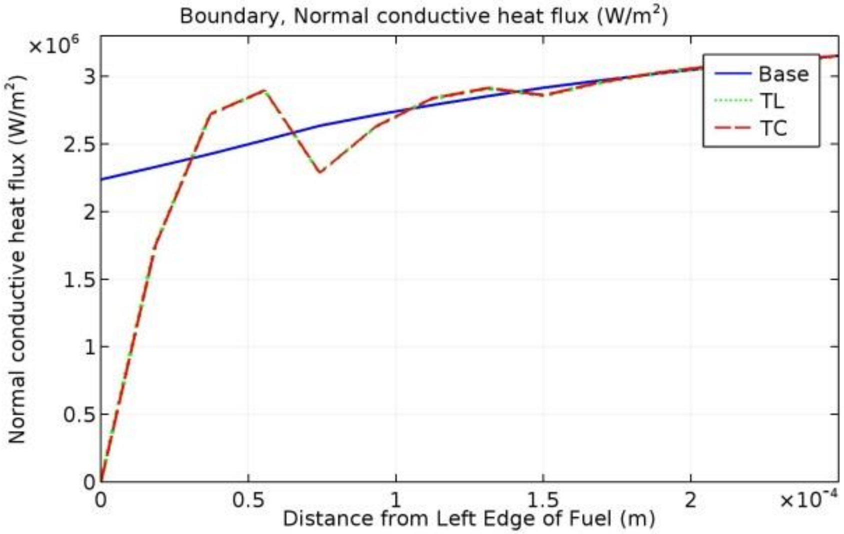
Cases Examined

- No non-bonds, No Fuel Segregations (FS)
  - Altered boundaries mimic unaltered boundary for the entire length of boundary
- Non-bonds included, No FS
  - Geometric non-bond with standard FEM technique
  - TL: adiabatic non-bond with a function for k_s
    - $k_s = k \notin$ non-bond; $k_s = 0 \in$ non-bond
  - TC: non-bond with a similar function for $\frac{p}{E'}$
- FS included, No non-bonds
- Both non-bonds and FS included

No non-bonds, No FS



All 3 models (Base, TL & TC) temperature results are visually indistinguishable

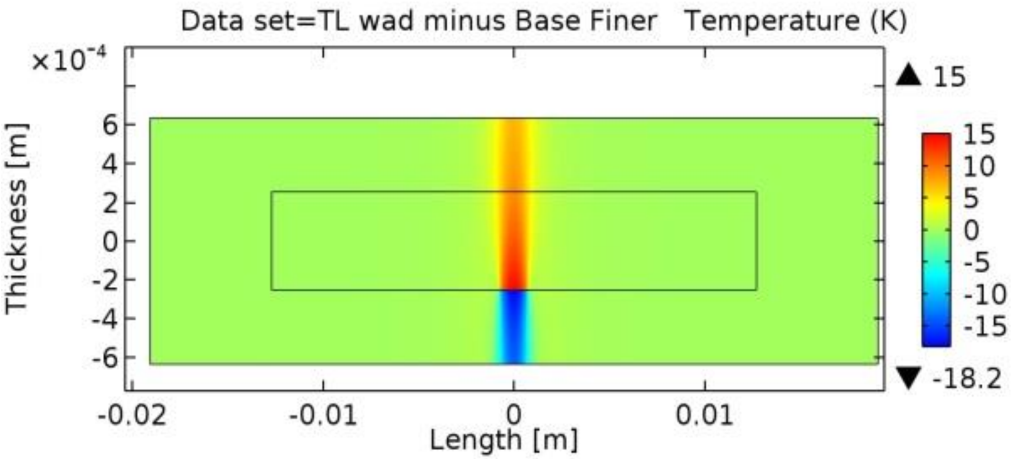


Normal heat flux along the modified boundary shows oscillations at the edge in both TL and TC compared to the base model

	Grid		
Domain	Fine	Finer	Extra Fine
Fuel	0.0759%	0.0217%	0.0107%
Whole Model	0.0000%	0.0000%	0.0000%

Base model shows no error in energy balance, TL and TC show identical errors, as shown above

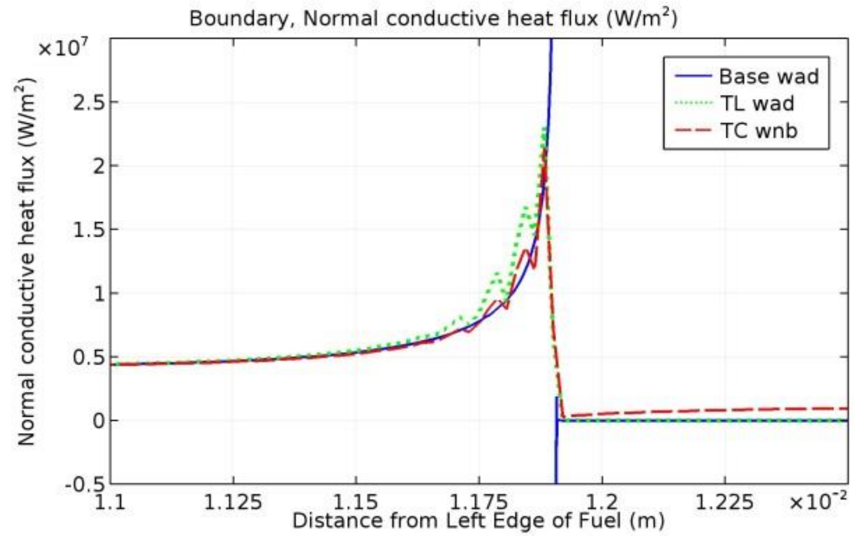
Non-bonds included, No FS



Temperature increase caused by an adiabatic non-bond

	Base wad	TL wad	TC wnb
max	393	393	390
increase	14.4	15	11.6

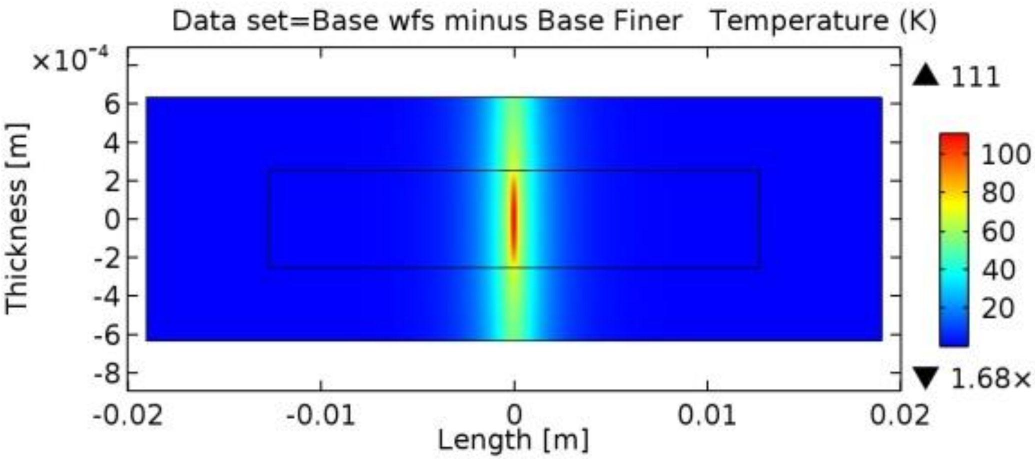
Maximum temperature and temperature increase caused by the inclusion of a non-bond (wad) in the 3 models



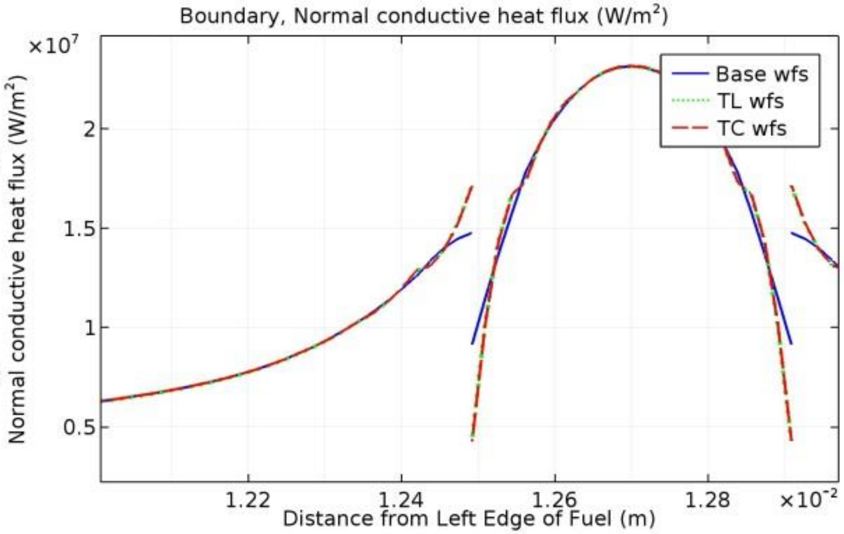
Normal heat flux along the modified boundary shows oscillations across the non-bond in both TL and TC compared to the base model

- Introduction of a non-bond does not change the energy balance errors in TL and TC, however including a geometric non-bond causes a 0.062% error in energy balance for the base model (that remains constant for both Finer and Extra Fine grids)

FS included, No non-bonds



Temperature increase caused by a FS

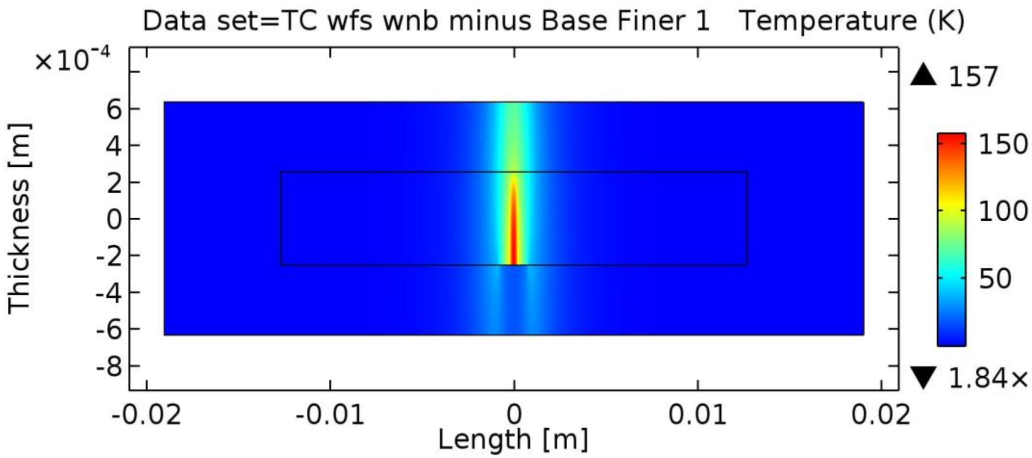


Normal heat flux along the modified boundary showing oscillations experienced by TL and TC with the introduction of a simulated fuel segregation along the modified boundary

	Grid	
Domain	Finer	Extra Fine
Fuel Segregation (FS)	-0.229%	-0.122%
Fuel + FS	0.019%	0.010%
Whole Model	0.000%	0.000%

Base model shows no error in energy balance, TL and TC show identical errors shown above

Both non-bonds and FS included



Temperature increase caused by a FS coincident with a non-bond

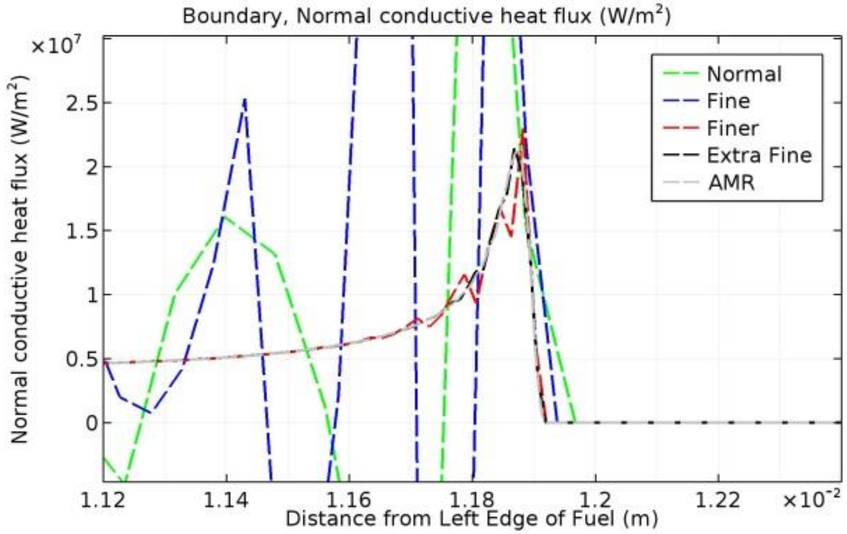
	Base	TL	TC
maximum	546	548	537
minus Base wfs	97.4	99.4	87
minus Base	167	169	157

Maximum temperature and temperature increase caused by the inclusion of a FS (wfs) and a non-bond in the 3 models

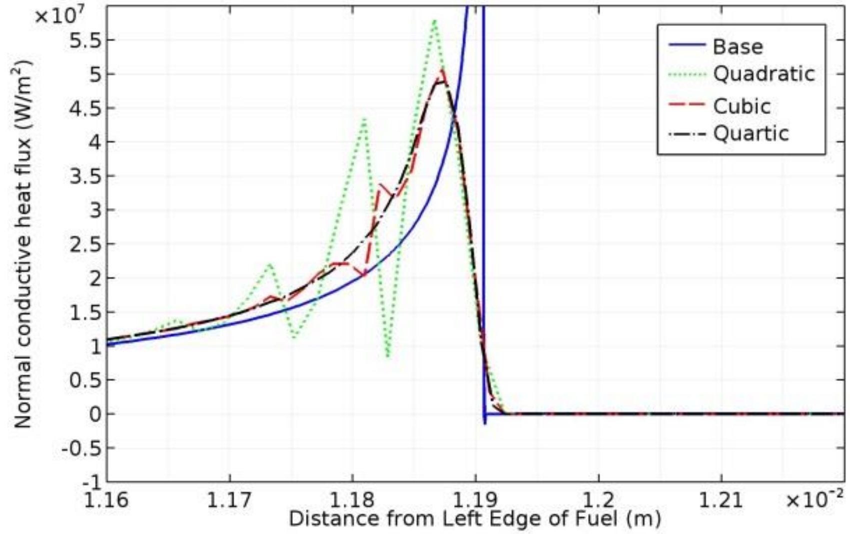
Grid	Finer	Extra Fine
Domain	Base	
Fuel Segregation (FS)	0.000%	0.000%
Fuel + FS	0.046%	0.046%
Whole Model	0.000%	0.000%
	TC	
Fuel Segregation (FS)	-0.055%	-0.030%
Fuel + FS	0.019%	0.010%
Whole Model	0.000%	0.000%
	TL	
Fuel Segregation (FS)	0.001%	0.000%
Fuel + FS	0.019%	0.010%
Whole Model	0.000%	0.000%

Energy balance errors for all 3 models with a FS and a non-bond

Mesh and Order Comparison



Effect of grid refinement on oscillations near discontinuity in thermal conductivity



Effect of element order on oscillations near discontinuity in thermal conductivity

- Additional cases were run to examine the effects of grid refinement and element order on oscillations near discontinuities

Discussion and Conclusion

- TC and TL both experience distortions in fluxes and temperatures relative to a traditional FEA model with a refined mesh
- Errors in energy balance are more severe with only a fuel segregation than in any other cases examined
- Refining the mesh on TC and TL, as well as increasing the element order reduce distortions
- Both thin layer and thermal contact modeling options are similar in performance
- Care must be exercised in mesh development to ensure flux distortions within the TL and TC boundary layer features are at acceptable levels

Questions?