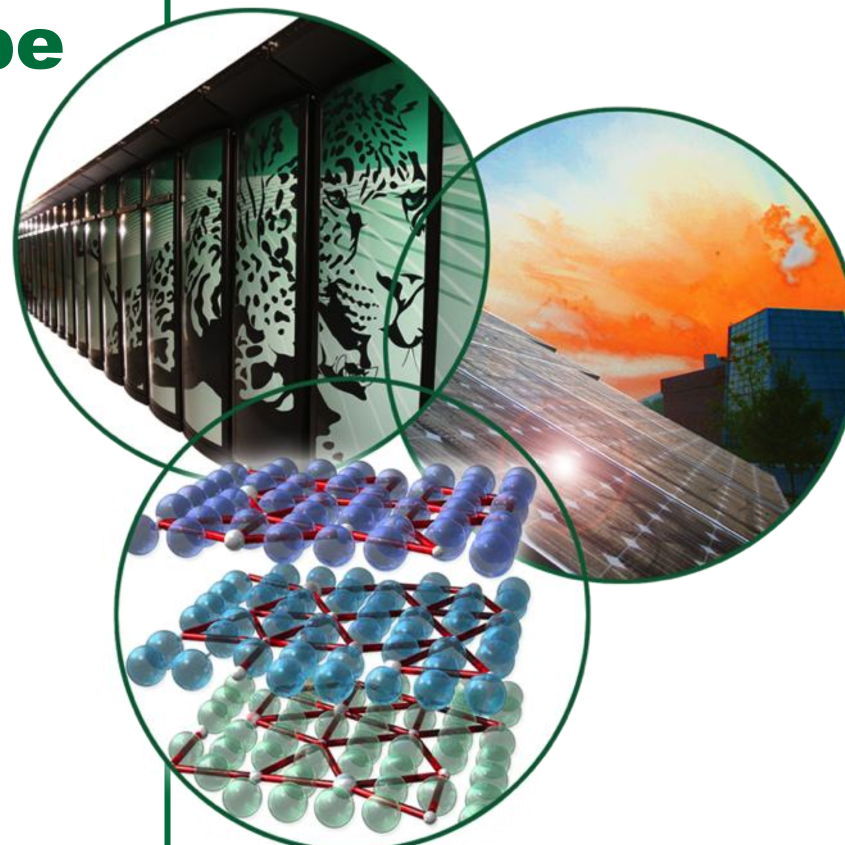
COMSOL Simulations for Steady State Thermal Hydraulics Analyses of ORNL's High Flux Isotope Reactor (HFIR)

COMSOL CONFERENCE BOSTON 2012



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U.S. DEPARTMENT OF ENERGY

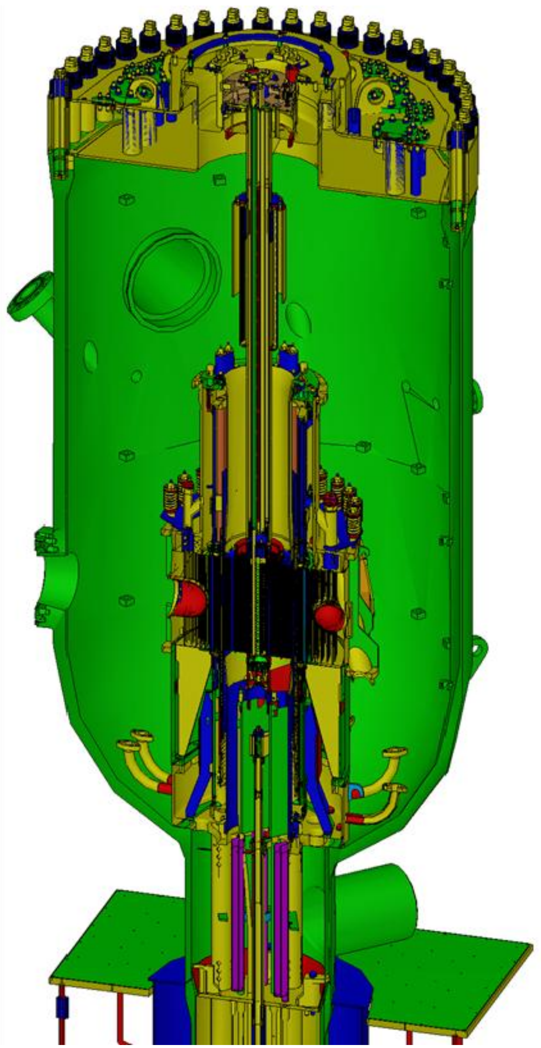
RNSD Reactor and Nuclear Systems Division

HFIR

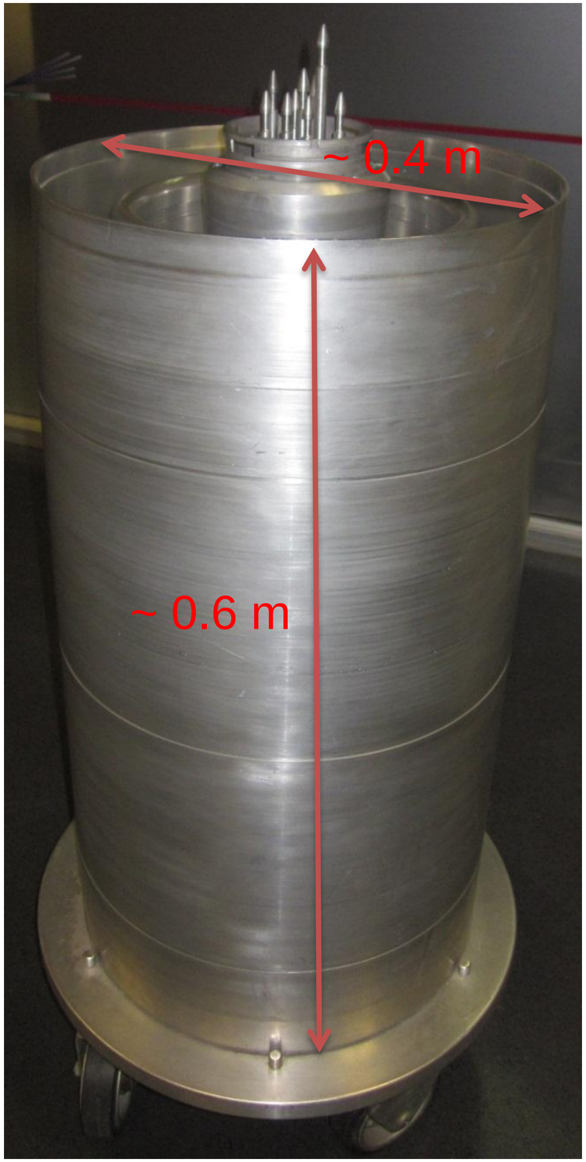
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

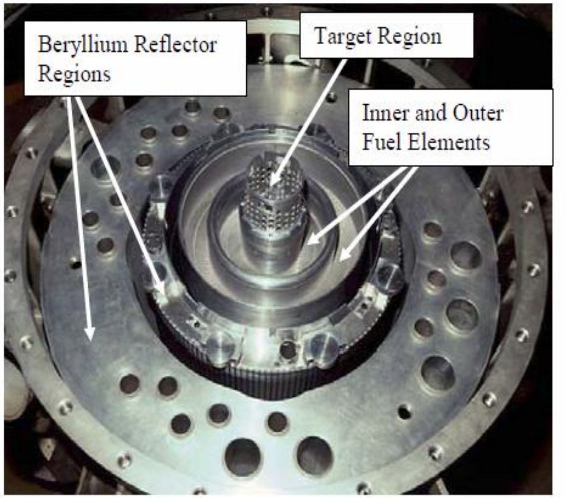
HFIR is a Multi-Purpose High-Performance Research Reactor

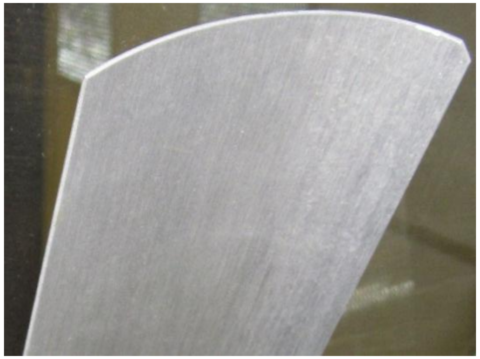
- Operated since 1966 with one of the world's highest thermal neutron fluxes ~$2.5x10^{15}$ neutrons/(cm^2-s)
- Involute-shaped fuel plates, beryllium reflected, light water-cooled and –moderated, pressurized, flux-trap type research reactor
- Highly enriched uranium (~93% $^{235}U/U$) fuel embedded in aluminum-6061 clad
- Cold and thermal neutron scattering, materials irradiation, isotope production, neutron activation analysis

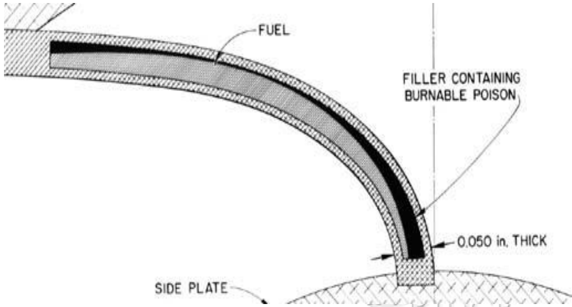


The HFIR Core





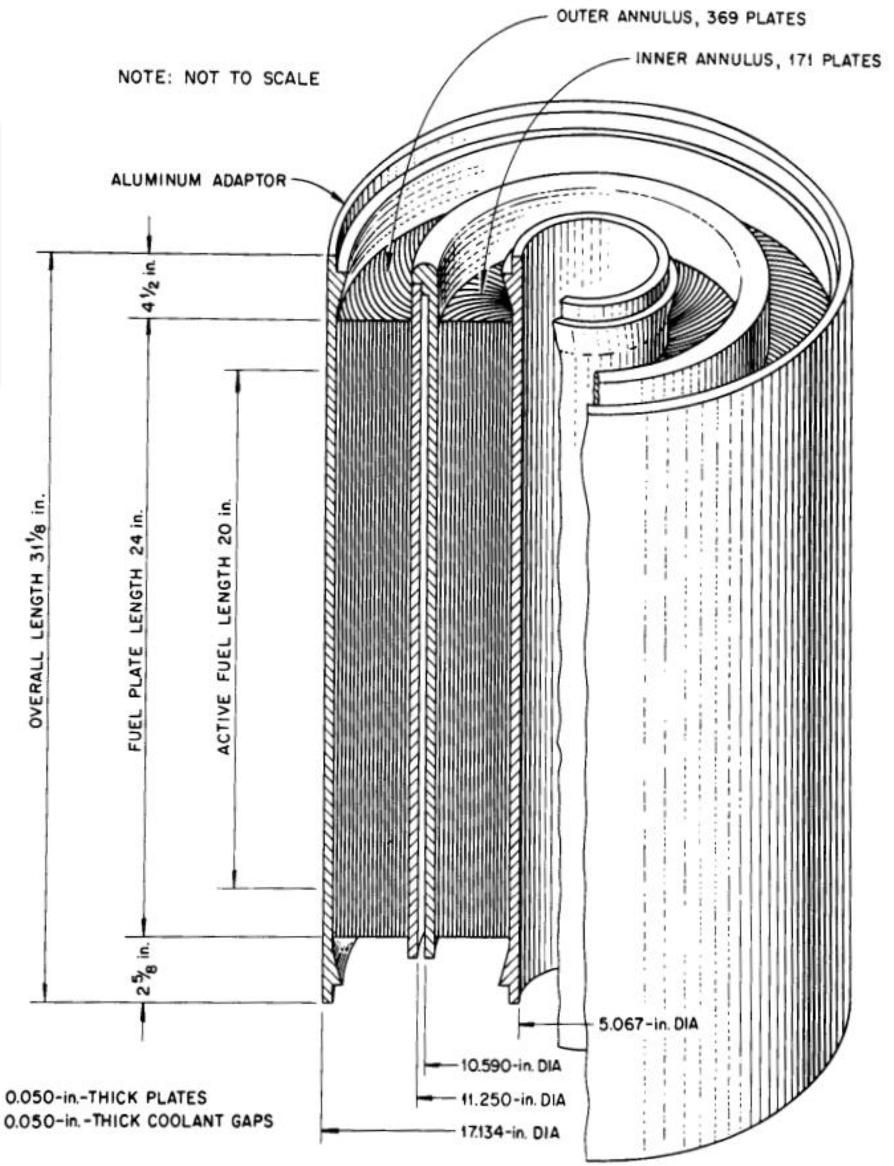




Physics of Interest for HFIR LEU Safety Analyses

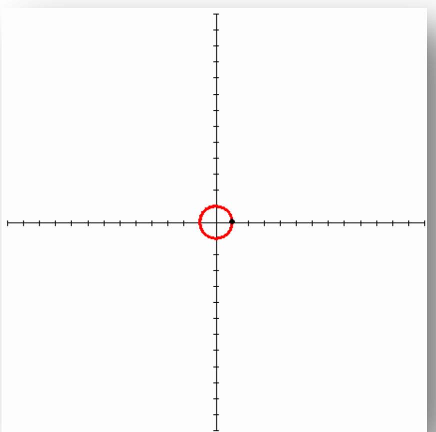
Reactor Physics | Turbulent Flows | Conjugate Heat Transfer | Thermal Structural Interaction (TSI) | Fluid Structural Interaction (FSI)

- <u>**Unique features for HFIR modeling**</u>
  - **Multi-physics problem**
  - **Non-uniform spatial heat source distribution inside the fuel plates (fuel, mixture, clad, radial and axial variation)**
  - **Nonlinear material property variation (~f(T))**
  - **Very narrow flow channels**
    - **High aspect ratio = H/t = 24 inch/0.05 inch = 480**
  - **Desired high level of accuracy and fidelity because of impacts on nuclear safety**

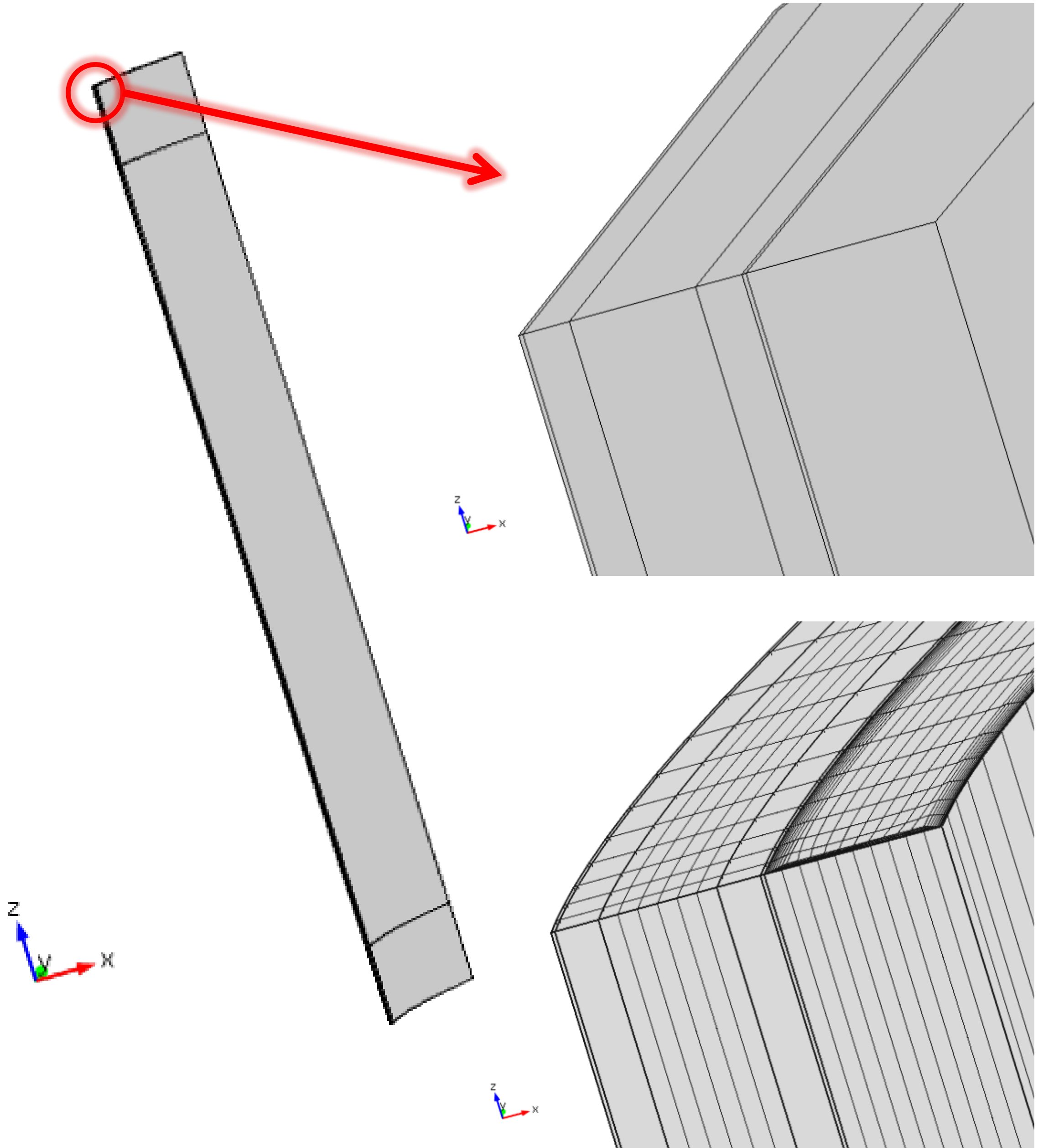


Parametric Geometry and Mapped Meshing

$$
\begin{aligned}
x(s) &= R_{b_i}\left[sin(s) - s \cdot cos(s)\right], \\
y(s) &= R_{b_i}\left[cos(s) + s \cdot sin(s)\right], \quad \text{where} \\
\theta_{\min} &\leq s \leq \theta_{\max}, \\
R_{b_i} &= \text{base radius of the involute, and} \\
\theta_{\min} &= \text{angle for the starting point of the involute, and} \\
\theta_{\max} &= \text{angle for the end point of the involute.}
\end{aligned}
$$

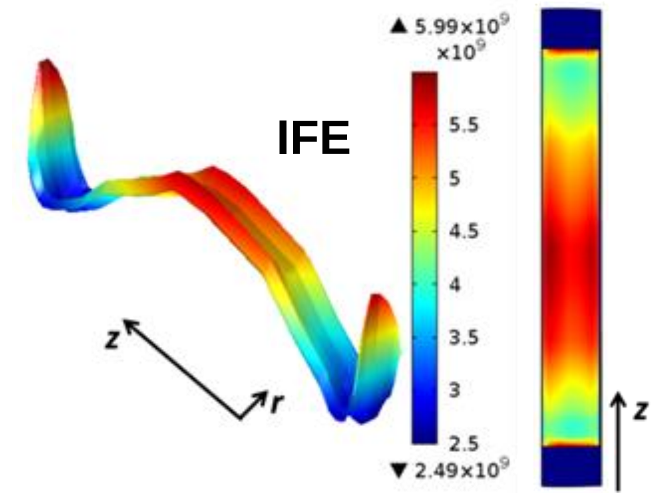


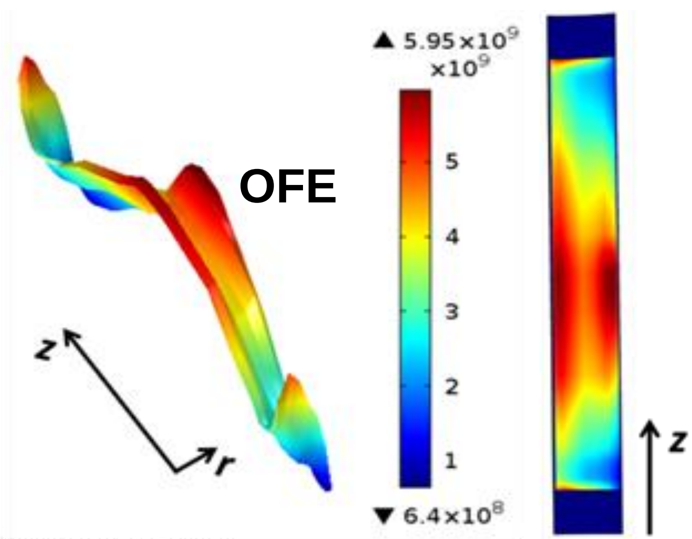
Equation of the involute of a circle



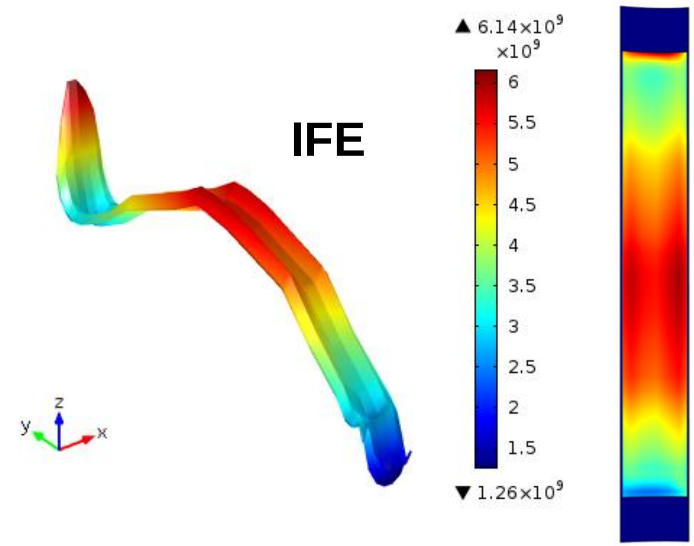
Volumetric Heat Source Distributions

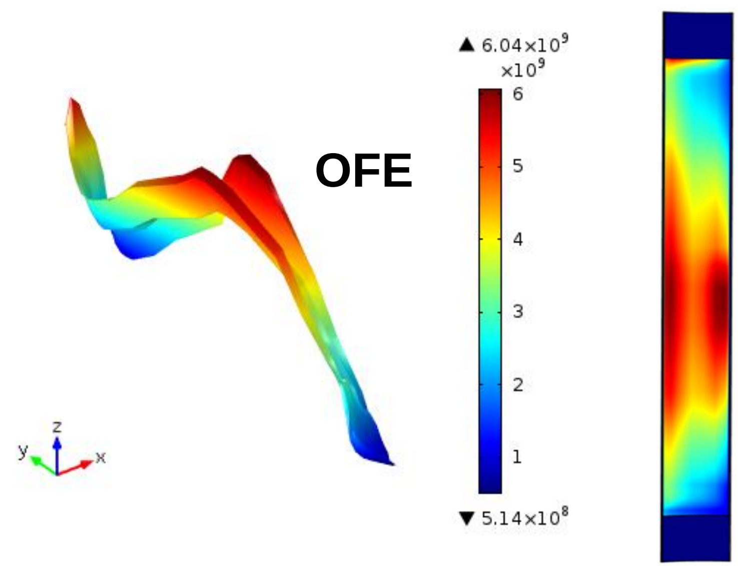
Axially Non-Contoured Fuel Plates



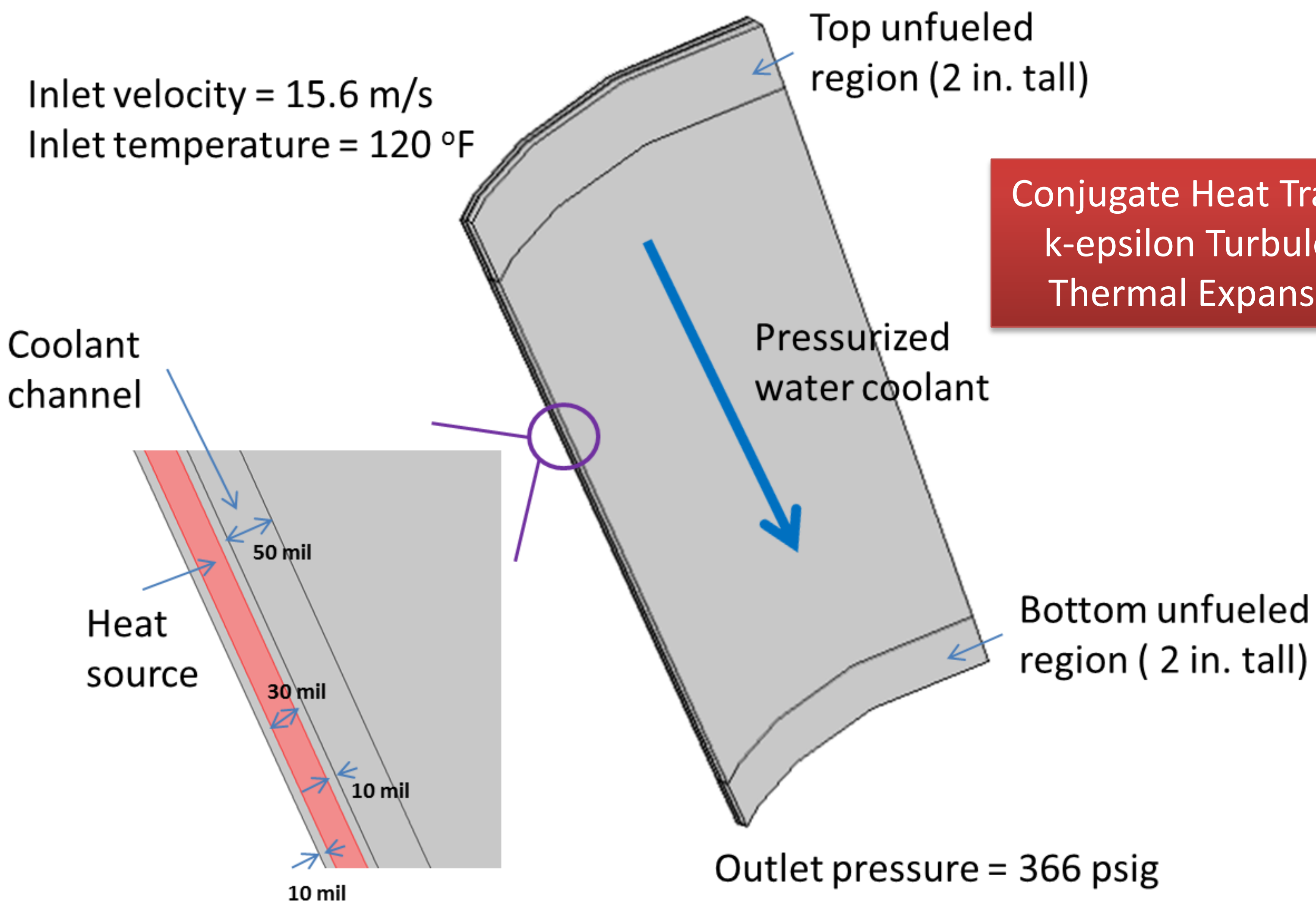


Axially Contoured Fuel Plates





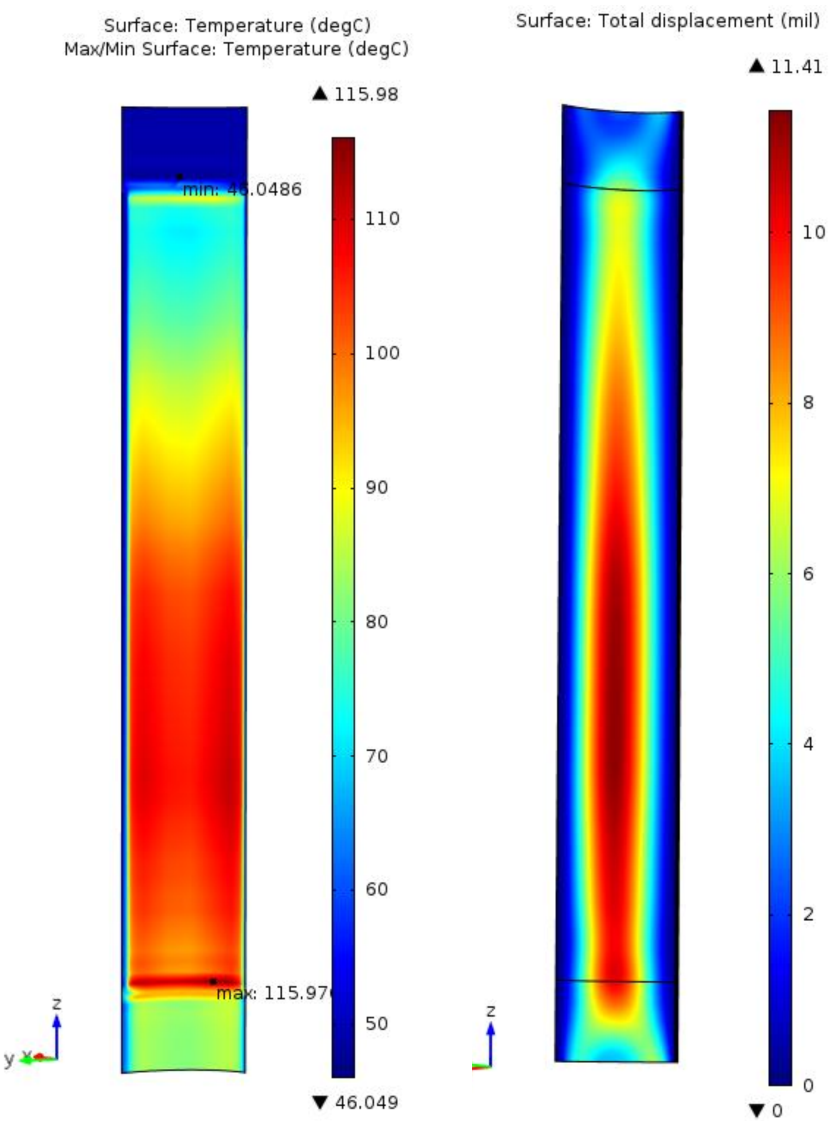
Simulation for Nominal Operation at the Beginning of Reactor Cycle



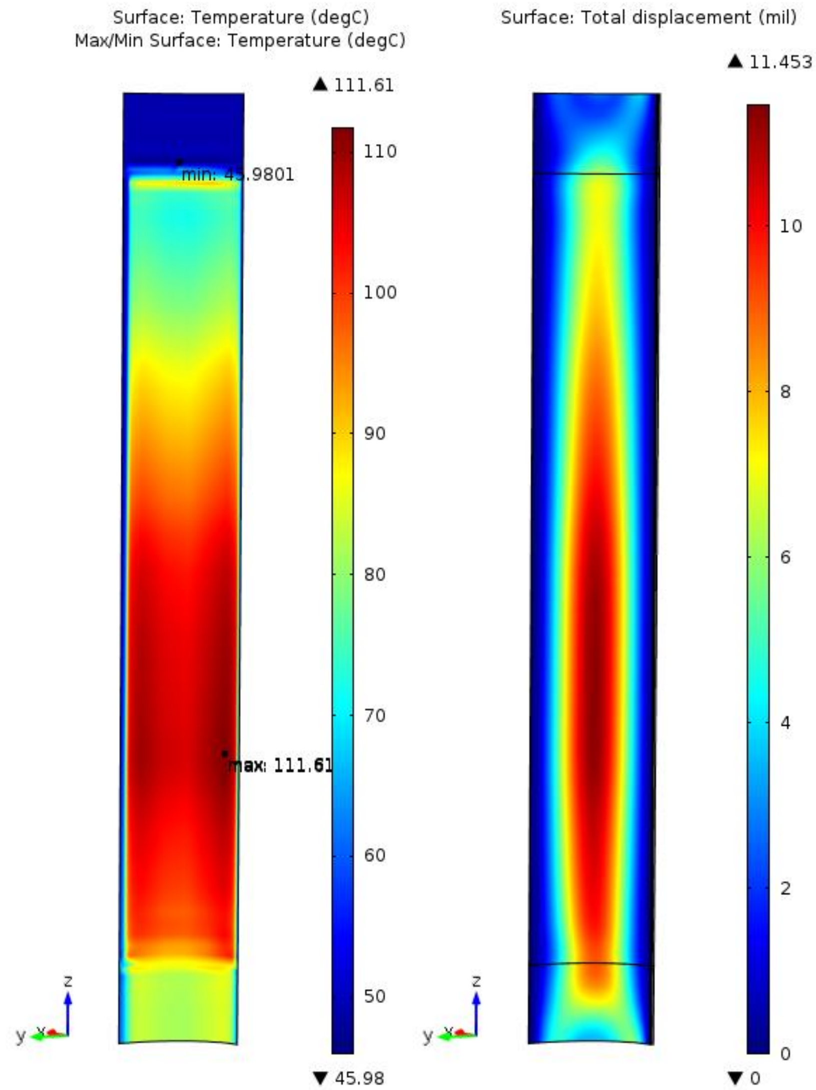
Conjugate Heat Transfer Physics
k-epsilon Turbulence Model
Thermal Expansion Physics

Note 1 mil = 0.001 in

Inner Fuel Element – Nominal Conditions

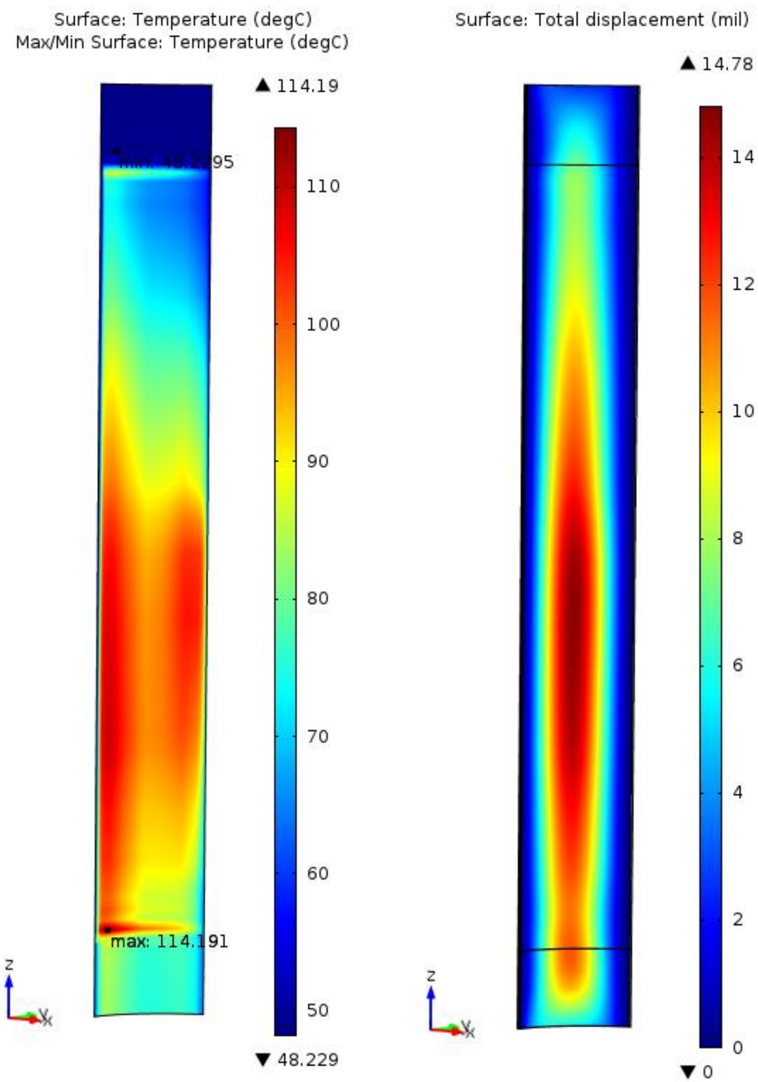


Axially Non-Contoured Fuel Plates

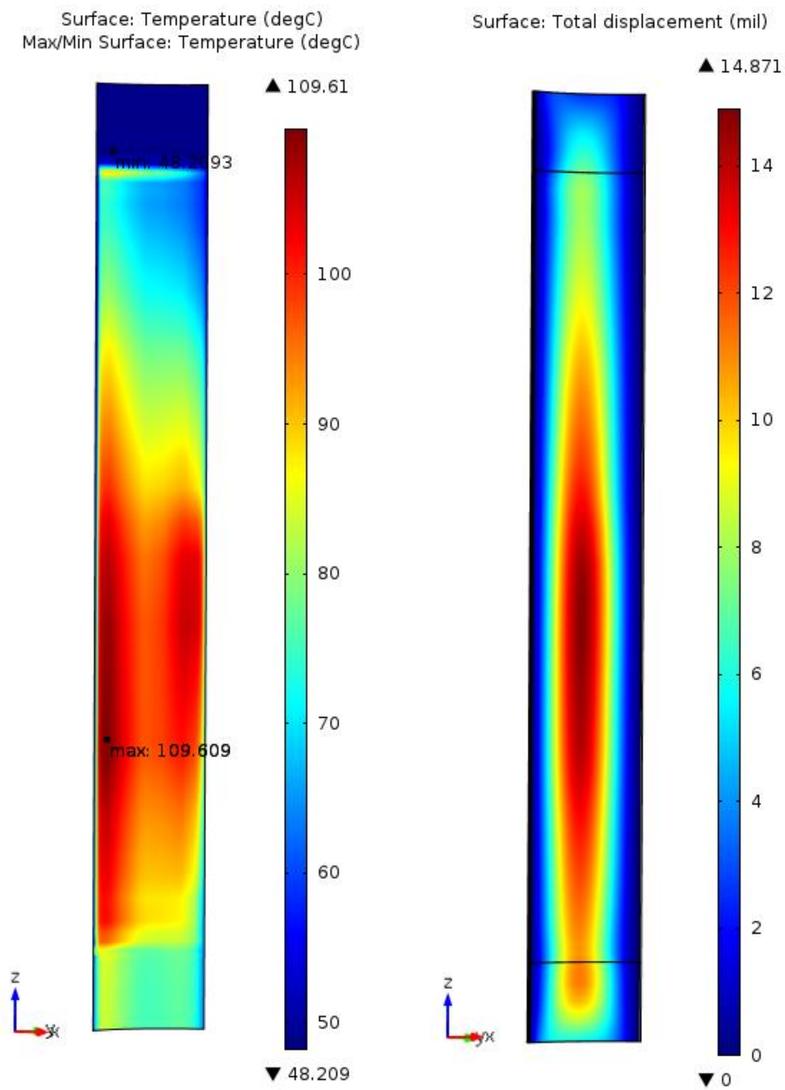


Axially Contoured Fuel Plates

Outer Fuel Element – Nominal Conditions



Axially Non-Contoured Fuel Plates



Axially Contoured Fuel Plates

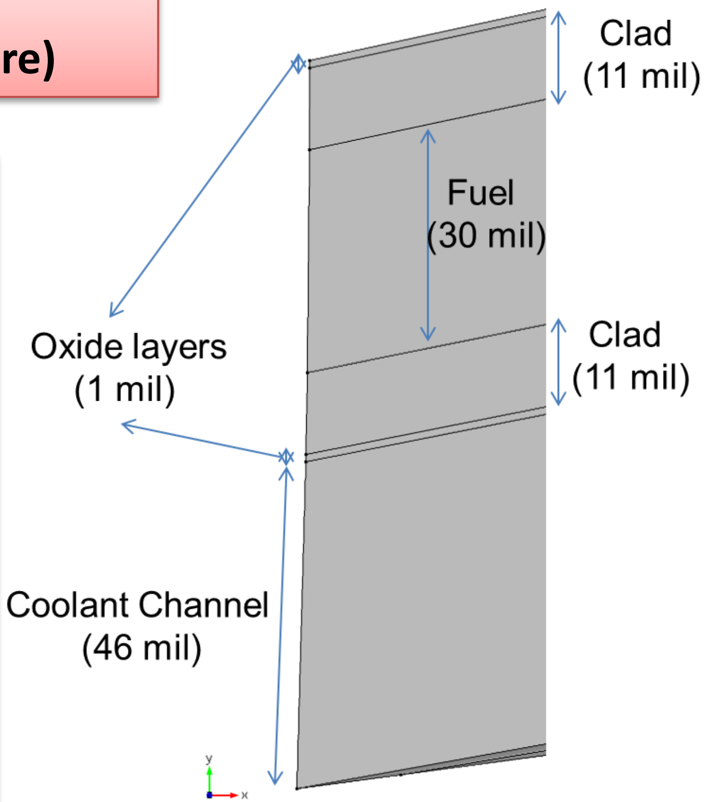
“Hot Channel” Safety Basis Cases at the Beginning Of Cycle

Conservative boundary conditions
(135 °F inlet temperature and 232.7 psia outlet pressure)

- U2 = Uncertainty in the fissile loading = **1.05**
- U3 = Uncertainty in the power density distribution = **1.199**
- U4 = Uncertainty in average fuel concentration in hot plate = **1.06**
- U18 = Fuel Segregration Flux Peaking = **1.1**

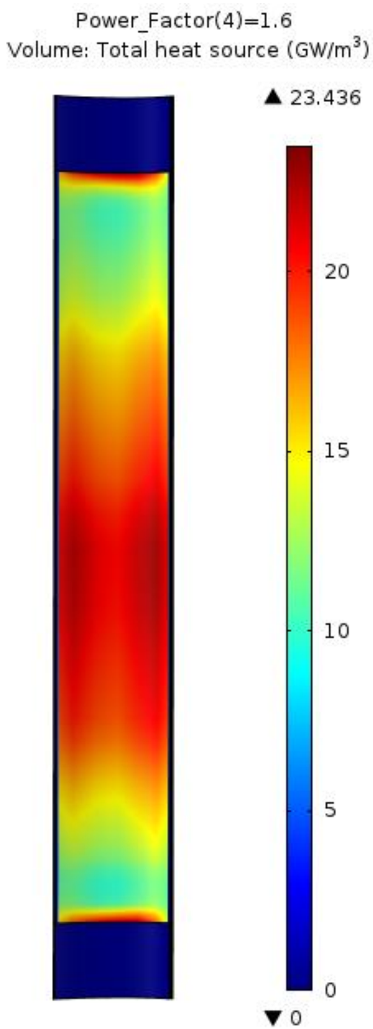
- Ueff = U2*U3*U4*U18 = **1.4679**

- Effective heat source =
  Ueff*PowerFactor*MCNP_Power

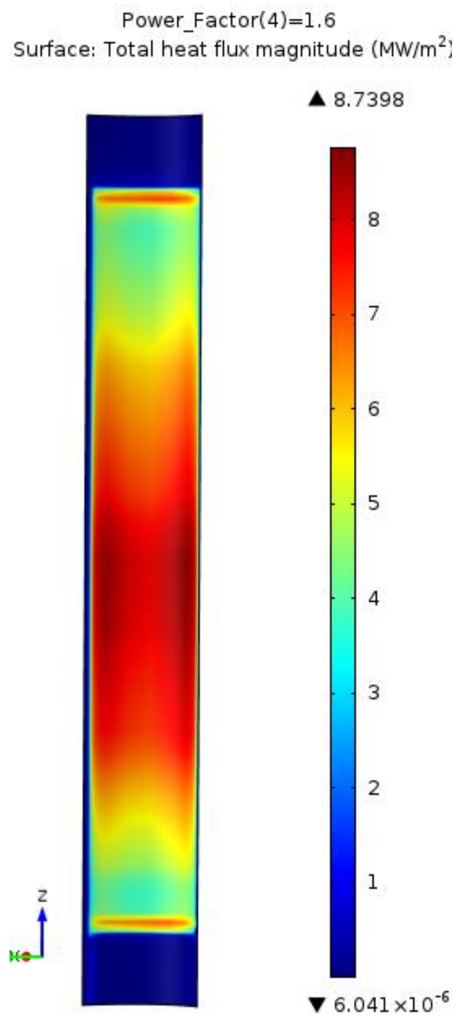


IFE, Axially Non-Contoured LEU Fuel

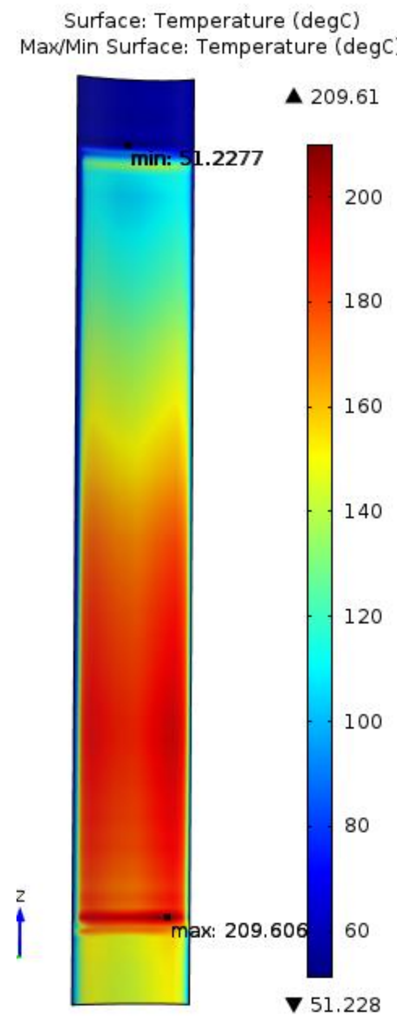
Power Factor = 1.6



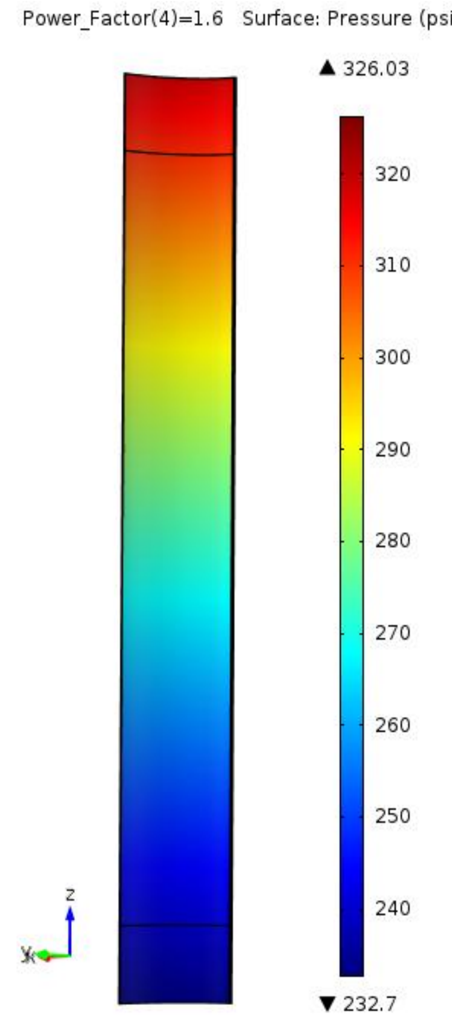
Heat Source (Q''')



Clad Heat Flux (q'')



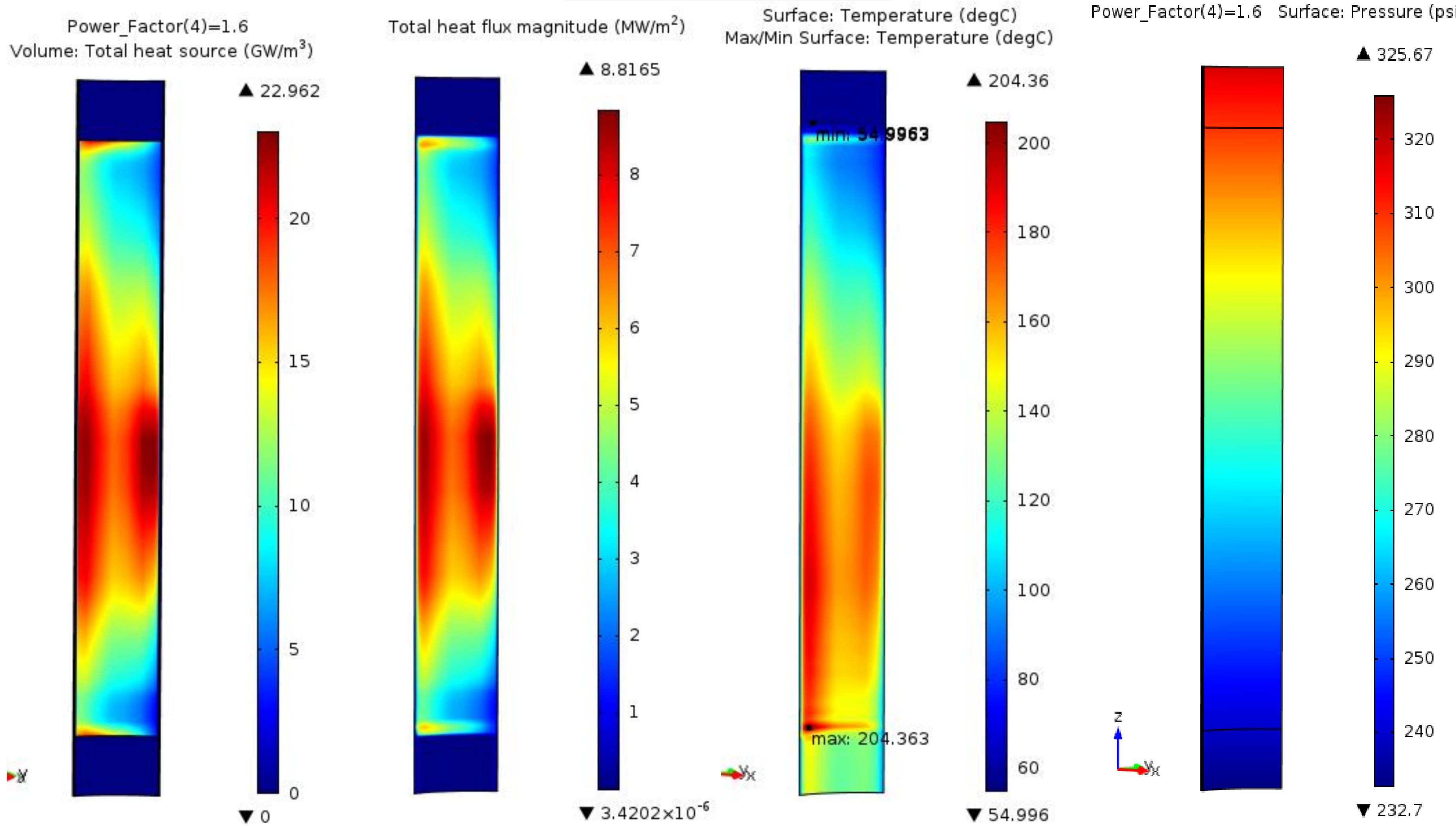
Clad Temperature (T)



Coolant Pressure (P)

OFE, Axially Non-Contoured LEU Fuel

Power Factor = 1.6



Heat Source (Q‴) | Clad Heat Flux (q″) | Clad Temperature (T) | Coolant Pressure (P)

Conclusions and Future Directions

- COMSOL Multiphysics is providing a robust platform to simulate HFIR fuel plates and coolant channels.
- Models developed for IFE and OFE are continually being advanced with a goal to simulate HFIR's safety basis conditions (or, worst possible conditions).
- Preliminary work is also underway to develop a one-dimensional HFIR system model with the primary/secondary piping loops, heat exchangers, pumps, valves and bends. This model is based on HFIR's existing RELAP5 models.
- Coupled CFD/SM models of IFE and OFE could later be coupled with the HFIR system model.
- Parallel and scalable solvers in COMSOL need to be improved and made easier to implement to allow significantly "bigger" HFIR simulations on leadership class computing clusters (e.g., Jaguar/Titan, Kraken etc.).

Thank you for your attention.