# Improving Nuclear Safety through Multiphysics Modeling and Simulations

OAK RIDGE National Laboratory

RNSD Reactor and Nuclear Systems Division
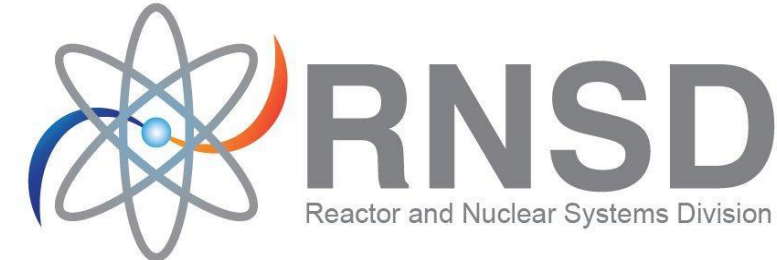
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HFIR

U.S. DEPARTMENT OF ENERGY
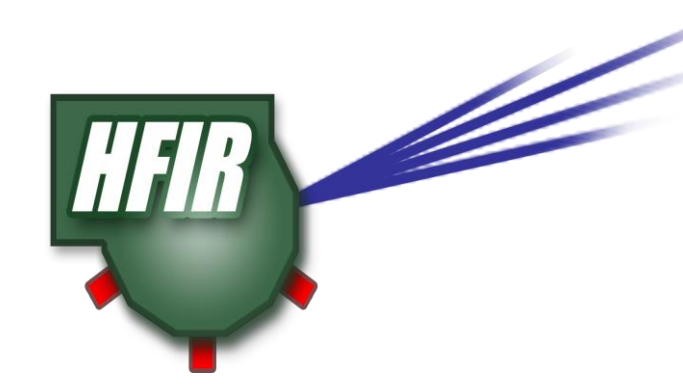
## High Flux Isotope Reactor (HFIR)



Quick opening hatch
Top plug
Coolant inlet nozzle (2 each)
Slant eng. facility (4 each)
Rabbit holes (8 each)
Be reflector, control plates, inner and outer fuel elements
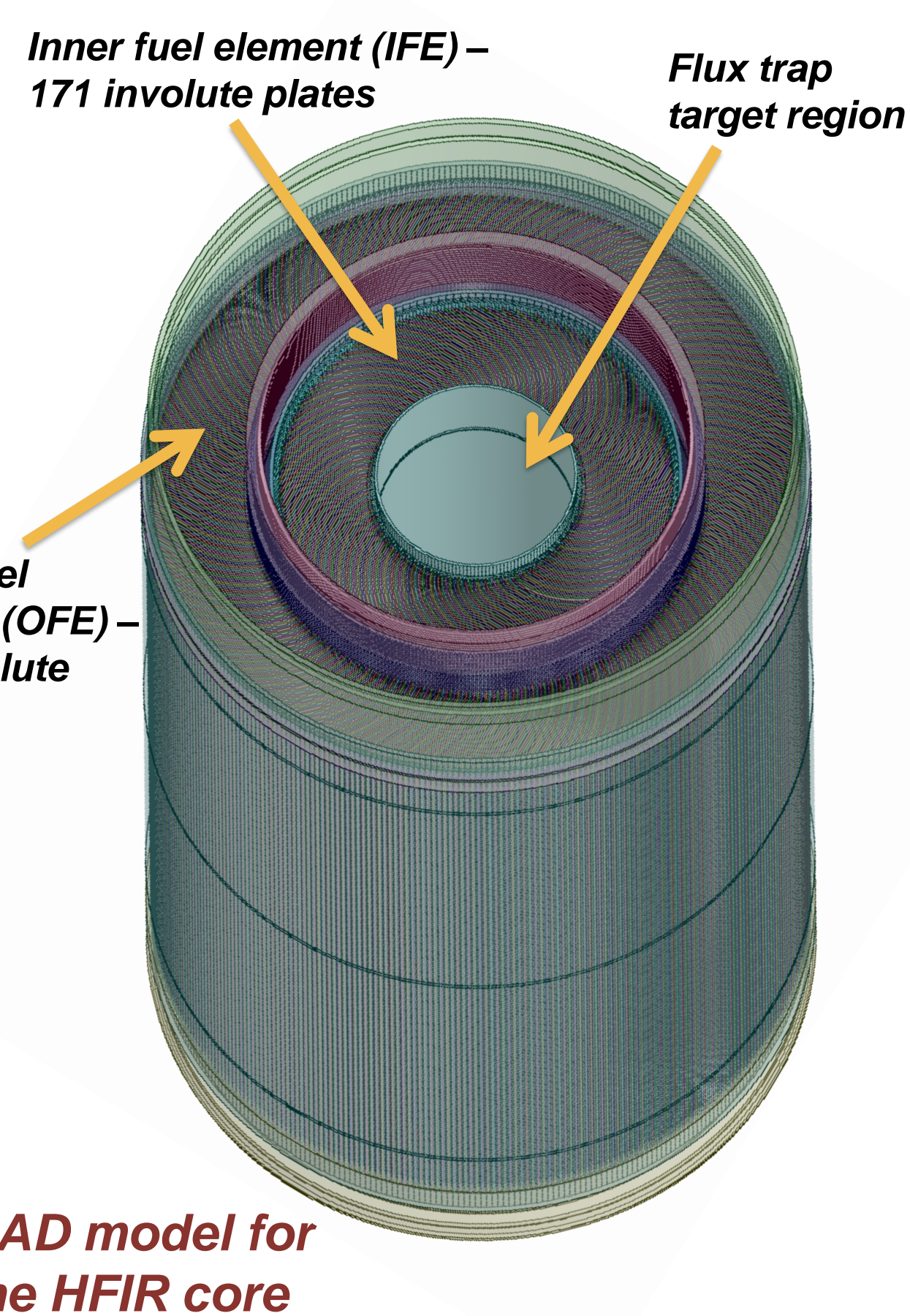Horizontal beam hole (4 each)
Fuel and reflector support assembly
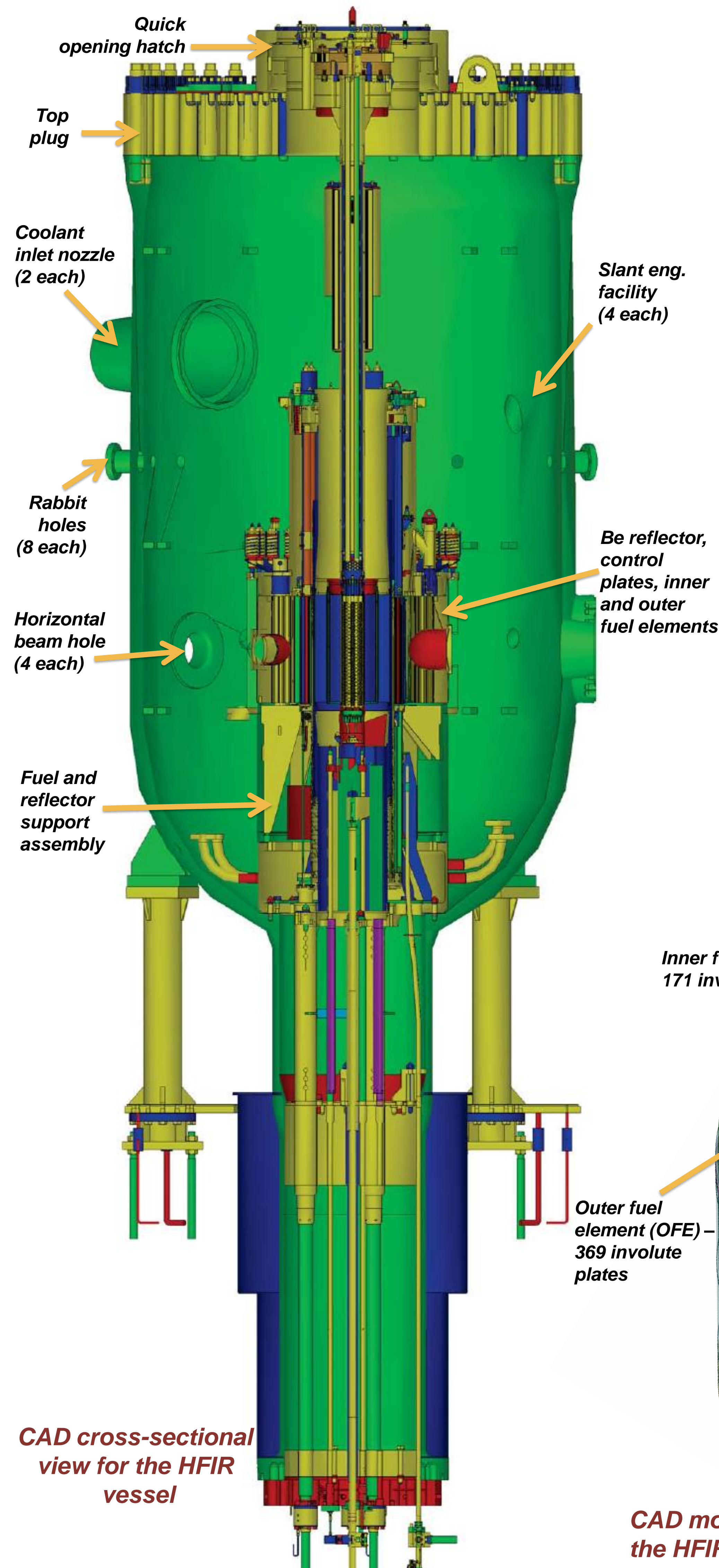
*CAD cross-sectional view for the HFIR vessel*

Operated since 1966 with one of the world's highest thermal neutron fluxes ~2.5 × 10$^{15}$ neutrons/(cm$^2$-s )

Involute-shaped fuel plates, beryllium-reflected, light-water-cooled and -moderated, pressurized, flux-trap-type research reactor
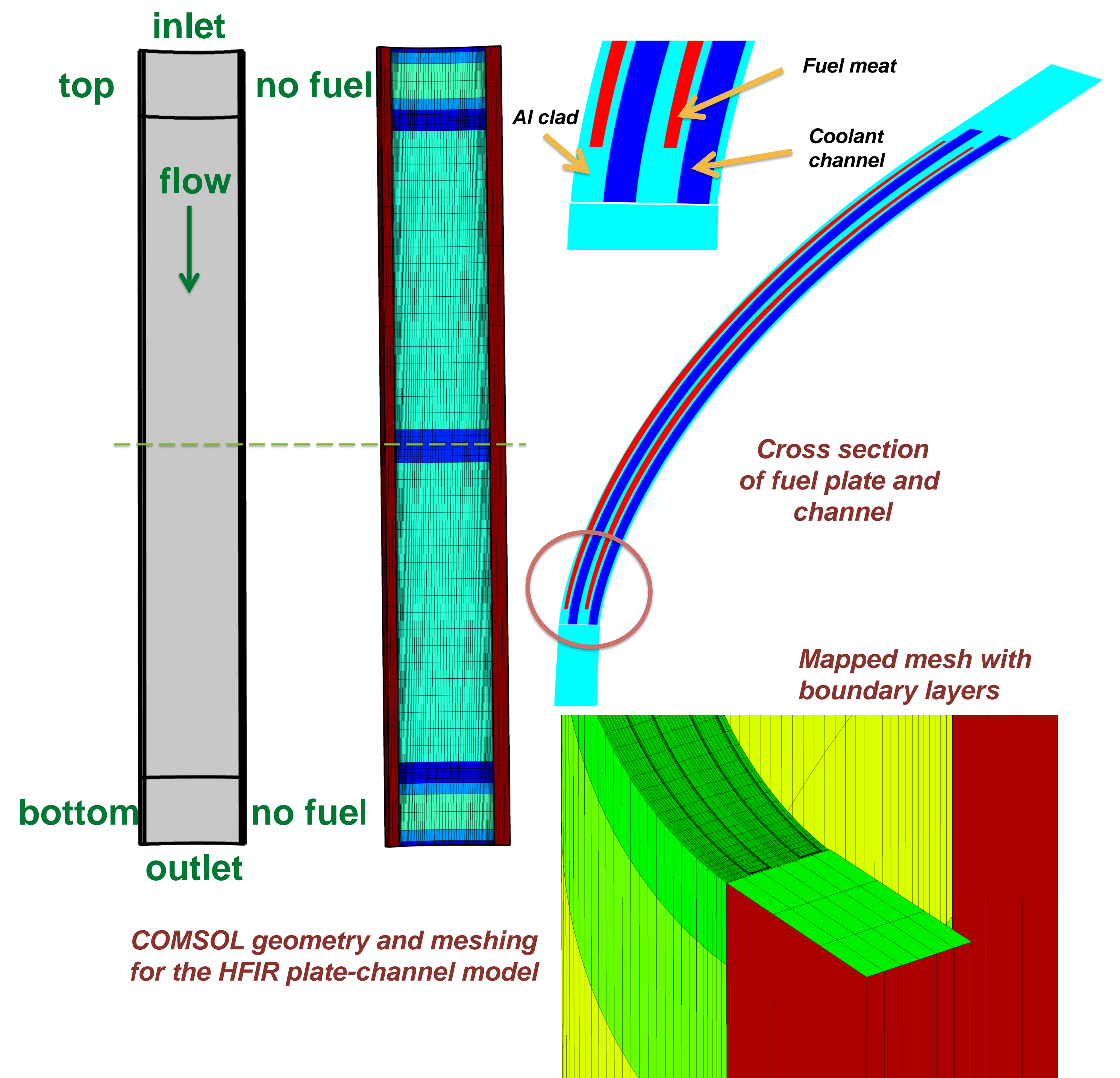
Highly enriched uranium (~93% $^{235}$U/U) fuel embedded in aluminum-6061 clad

Cold and thermal neutron scattering, materials irradiation, isotope production, neutron activation analysis



Inner fuel element (IFE) – 171 involute plates
Flux trap target region
Outer fuel element (OFE) – 369 involute plates

*CAD model for the HFIR core*

## COMSOL Thermal-Hydraulics Models for the HFIR Core



inlet
top — no fuel
flow
bottom — no fuel
outlet

Fuel meat
Al clad
Coolant channel

*Cross section of fuel plate and channel*

*COMSOL geometry and meshing for the HFIR plate-channel model*

*Mapped mesh with boundary layers*

## Transformational Challenge Reactor (TCR)
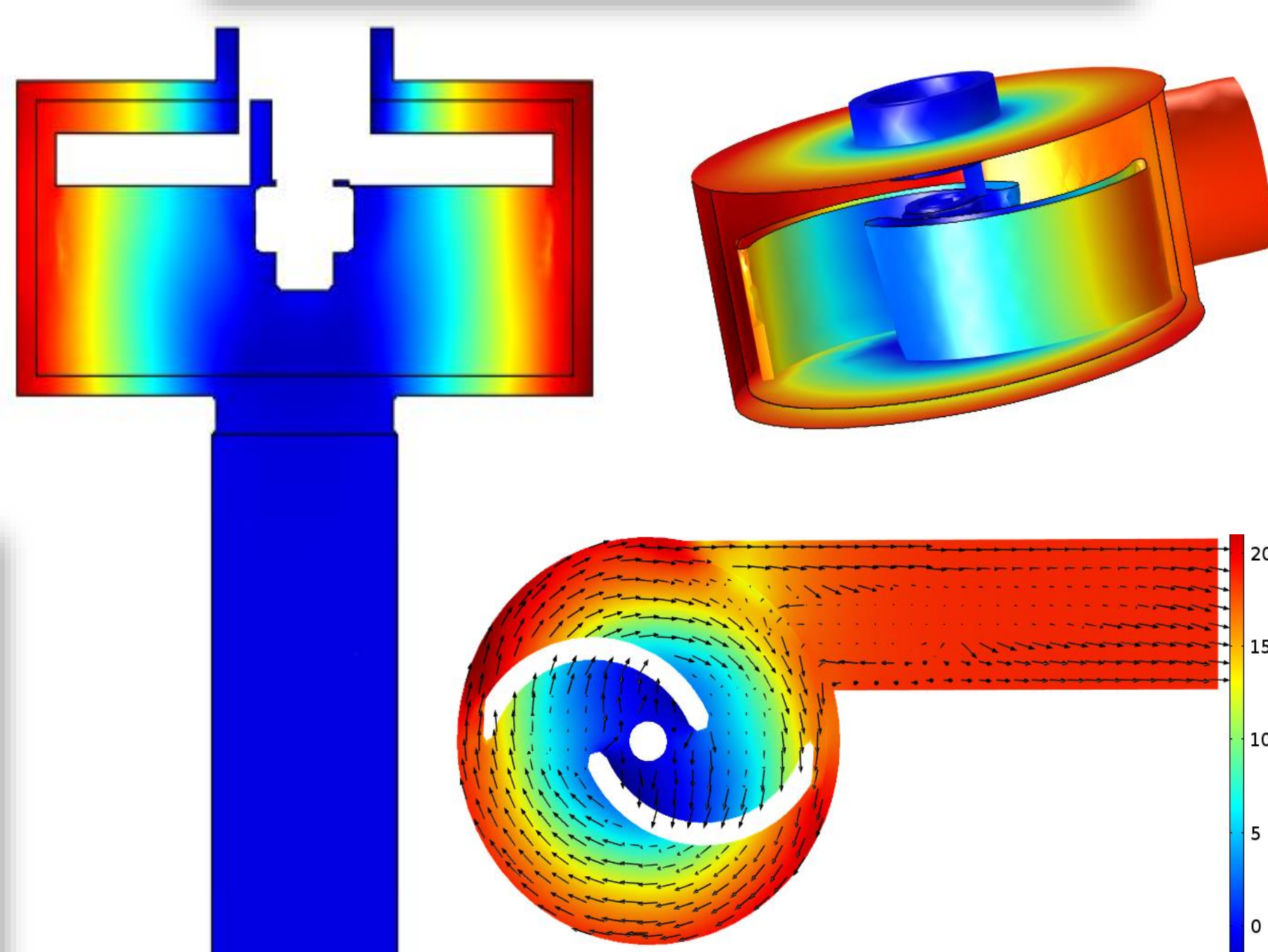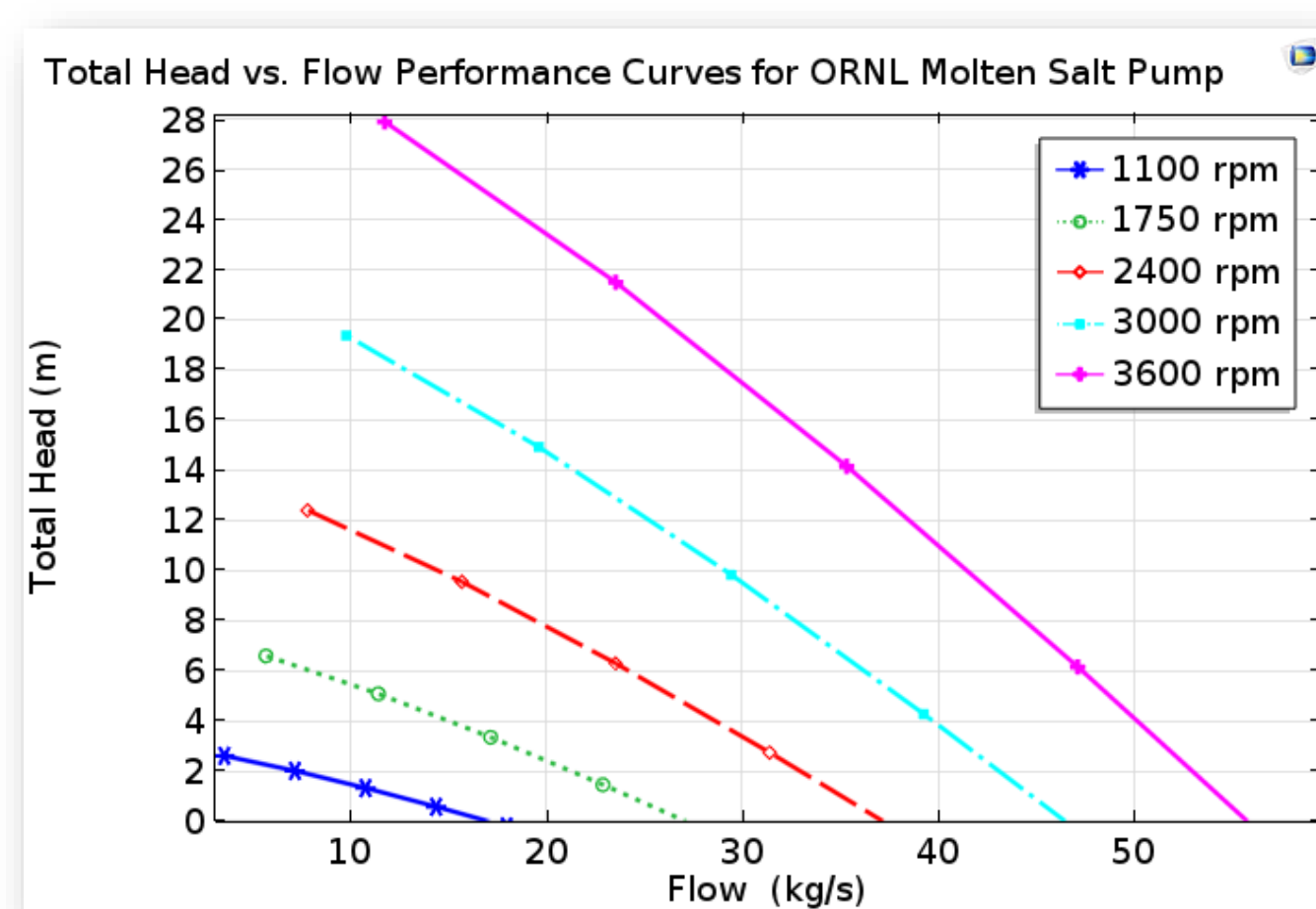


MDF Manufacturing Demonstration Facility

ORNL, in collaboration with BWXT, is developing design and technology to 3D print a nuclear reactor. COMSOL Multiphysics is one of the design tools on the project.

*3D printed Shelby Cobra at ORNL*

## Pump Performance Characterization for High-Temperature FLiNaK Molten Salt



Total Head vs. Flow Performance Curves for ORNL Molten Salt Pump
1100 rpm
1750 rpm
2400 rpm
3000 rpm
3600 rpm
Total Head (m)
Flow (kg/s)

*3D and 2D cut-plane pressure (psi) contours at 1750 rpm for 1 m/s pump discharge*

## Isotope Production and Irradiation Engineering



Heat deposition (n+fission products, prompt+capture photons, delayed alpha, beta and gammas)
Multilayer heat conduction
Highly nonlinear, burn up and T-dependent material properties
Pellet-pellet & pellet-clad mechanical interaction (contact physics)
Irradiation swelling and shrinkage
Thermal expansion, Thermal and Irradiation Creep
Gas gap heat transfer
• Fission (Xe, Kr) gas release, transport and mixing with the He fill gas
• Gap temperature jump and accommodation coefficient
• Solid spot conductance (surface roughness, plasticity and elasticity index)
• Radiative heat transfer
Oxide layer growth (chemistry, residence time, T)
Convective heat removal (turbulent flow and conjugate heat transfer)

not to scale

1.994 in.
Top of 1-in. hole
2.836 in.
Top end cap (Al 6061)
Top of 7-tube holder
3.663 in.
Upper spacer (SS 316)
Weld backing tube (Al 4047)
Dummy pellet (Al 6061)
2.250 in.
2.250 in.
NpO2/Al pellets (52 total)
2.250 in.
2.250 in.
HFIR core midplane
2.250 in.
2.250 in.
2.250 in.
3.248 in.
Dummy pellet (Al 6061)
Bottom of 7-tube holder
Lower spacer (SS 316)
3.810 in.
Bottom end cap (Al 6061)

Temperature (degc)
r-coordinate (mil)

$^{238}$Pu bare pellet test

*Irradiation of SiC clad*