Verification and Validation of COMSOL Multiphysics to Support HFIR Applications
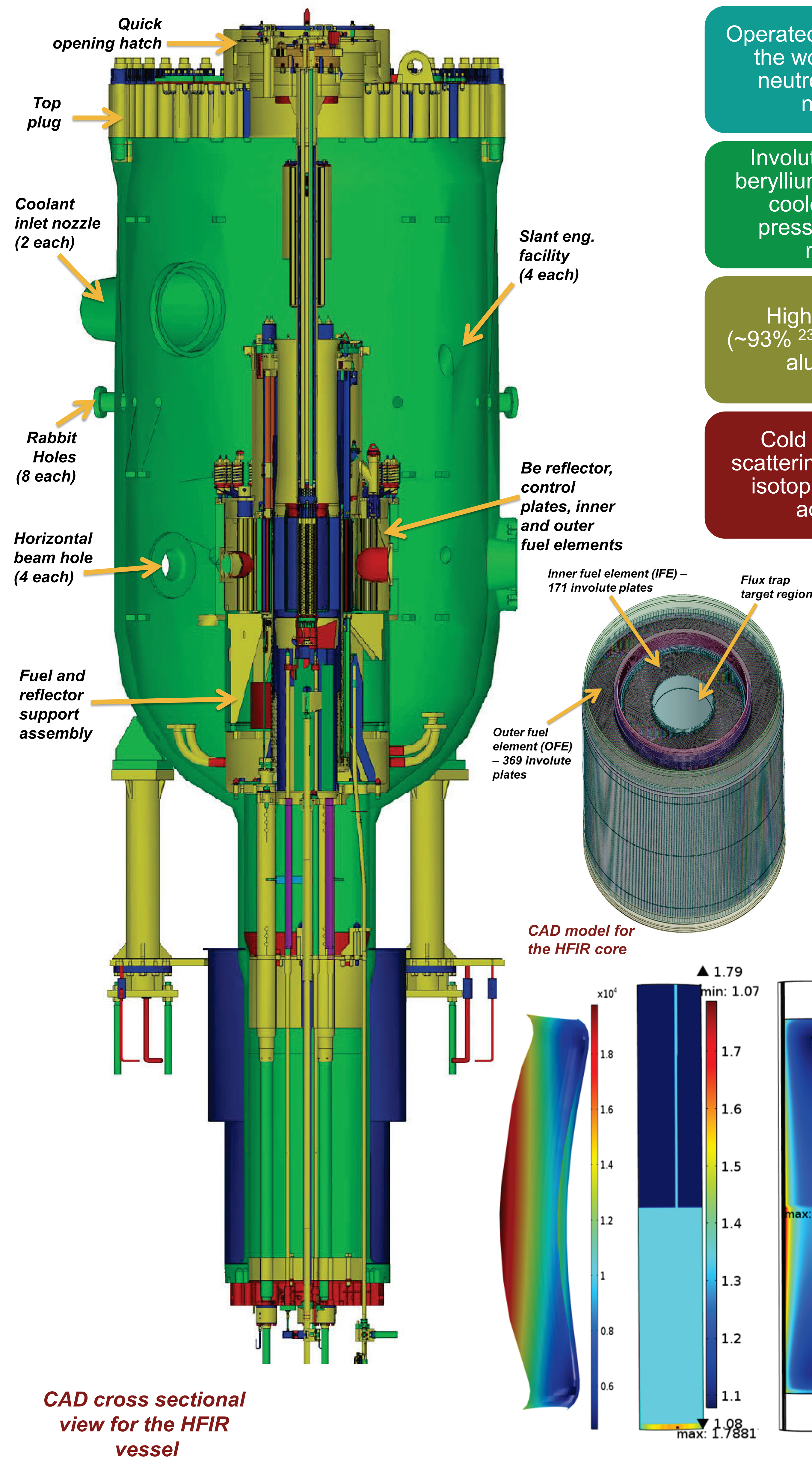
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U.S. DEPARTMENT OF ENERGY
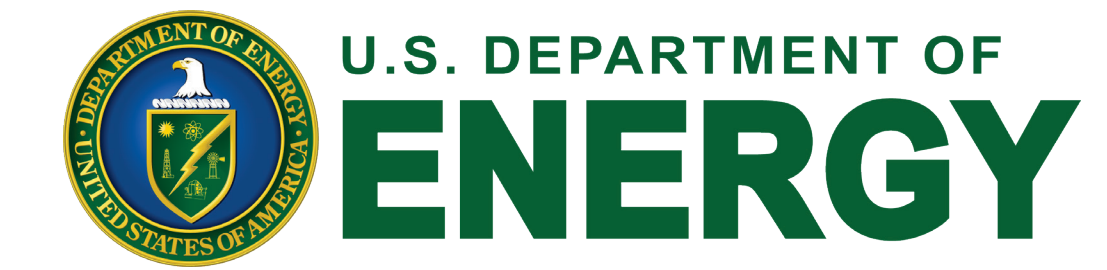
High Flux Isotope Reactor (HFIR)

Quick opening hatch

Top plug

Coolant inlet nozzle (2 each)

Rabbit Holes (8 each)

Horizontal beam hole (4 each)

Fuel and reflector support assembly

Slant eng. facility (4 each)

Be reflector, control plates, inner and outer fuel elements

Inner fuel element (IFE) – 171 involute plates

Flux trap target region

Outer fuel element (OFE) – 369 involute plates

CAD model for the HFIR core

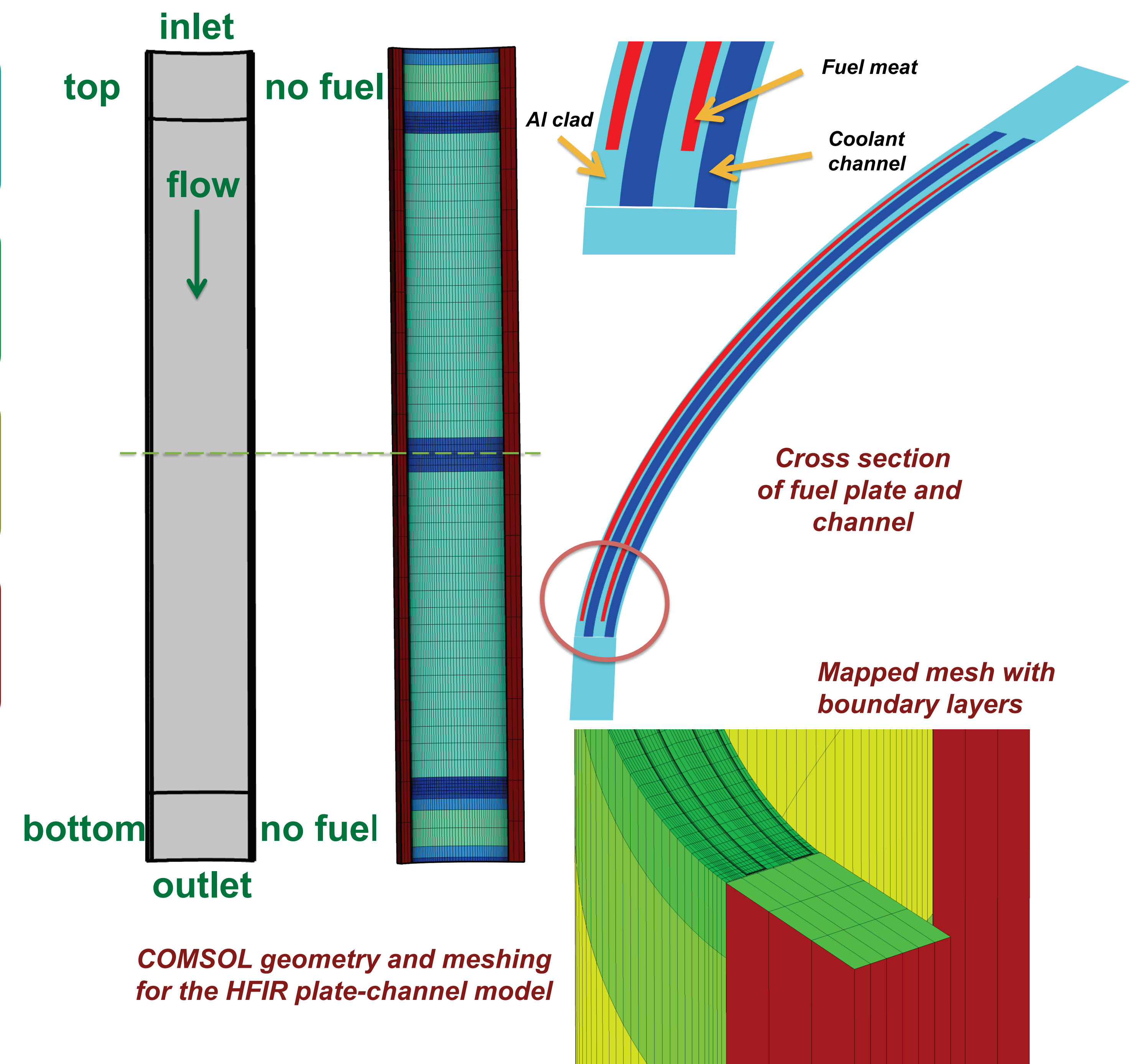*CAD cross sectional view for the HFIR vessel*
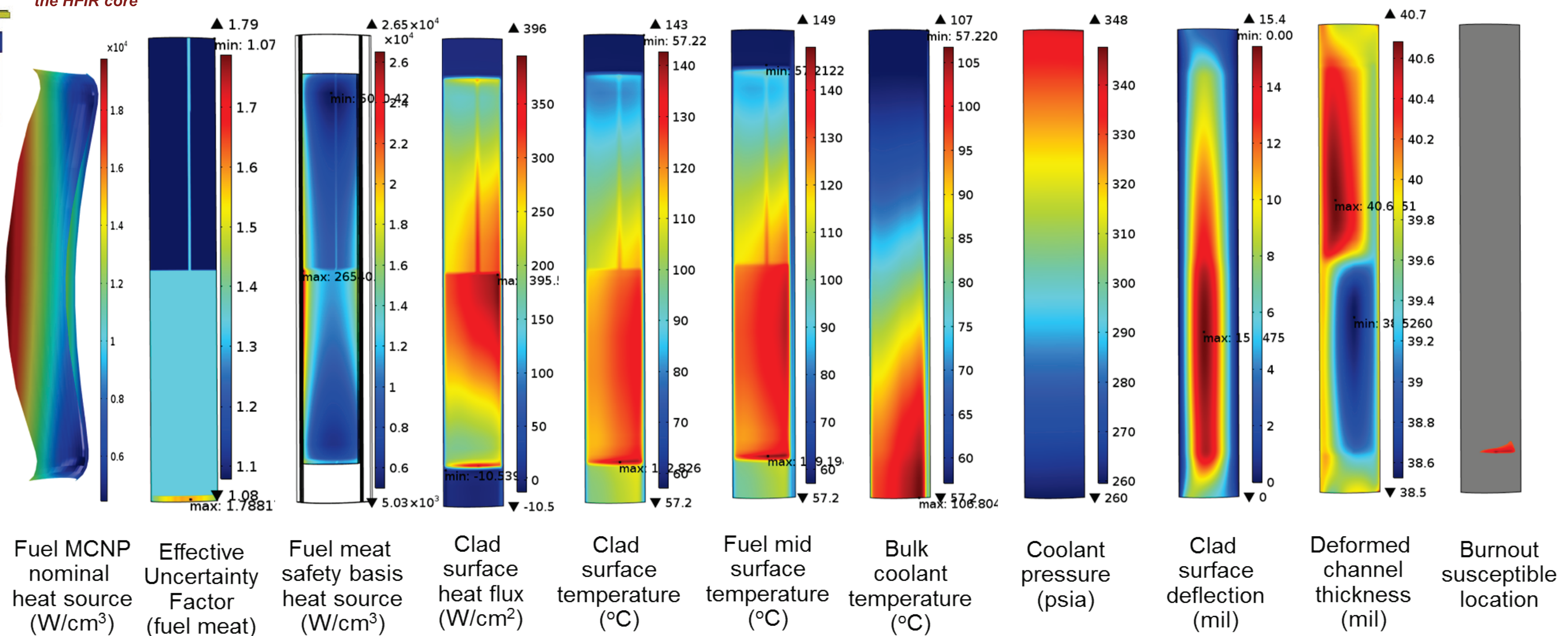
COMSOL Thermal-Hydraulics Models for the HFIR Core
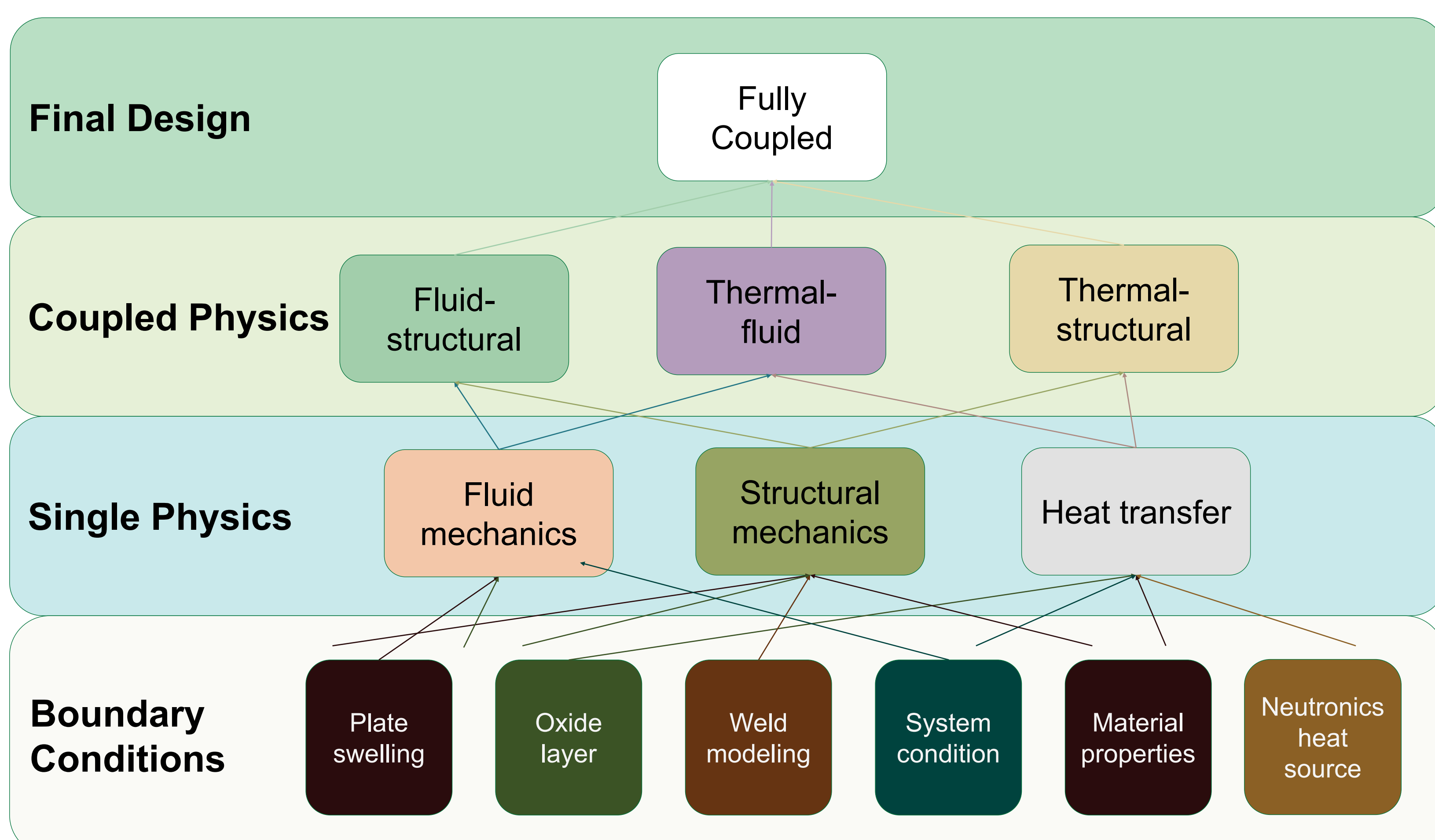
Operated since 1966 with one of the world's highest thermal neutron fluxes ~2.5 × 10^{15} neutrons/(cm^2-s)

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

inlet
top   no fuel
flow
bottom   no fuel
outlet

Fuel meat
Al clad
Coolant channel

Cross section of fuel plate and channel

Mapped mesh with boundary layers

COMSOL geometry and meshing for the HFIR plate-channel model

COMSOL Results for the HFIR HEU Inner Fuel Element under Hypothetical Safety Basis Conditions

Fuel MCNP nominal heat source (W/cm³)

Effective Uncertainty Factor (fuel meat)

Fuel meat safety basis heat source (W/cm³)

Clad surface heat flux (W/cm²)

Clad surface temperature (°C)

Fuel mid surface temperature (°C)

Bulk coolant temperature (°C)

Coolant pressure (psia)

Clad surface deflection (mil)

Deformed channel thickness (mil)

Burnout susceptible location

Hierarchy of Verification and Validation (V&V)

Final Design — Fully Coupled

Coupled Physics — Fluid-structural, Thermal-fluid, Thermal-structural

Single Physics — Fluid mechanics, Structural mechanics, Heat transfer

Boundary Conditions — Plate swelling, Oxide layer, Weld modeling, System condition, Material properties, Neutronics heat source

Select V&V Problems for HFIR

Physics	Validation comparison
HFIR system	HFIR plant data
Fuel swelling	Advanced Test Reactor (ATR) data
Oxidation	American Nuclear Society (SNS) data
Structural attachment	HFIR plate pull test data
Heat transfer	Analytic solution of heat transfer
Fluid mechanics	National Advisory Committee for Aeronautics (NACA) experiments
Structural mechanics	Analytic solution of plate deflection
Fluid-thermal	STAR-CCM+ comparison, Gambill & Bundy
Fluid-structural	Smissaert experiments
Thermal-structural	Cheverton Kelly