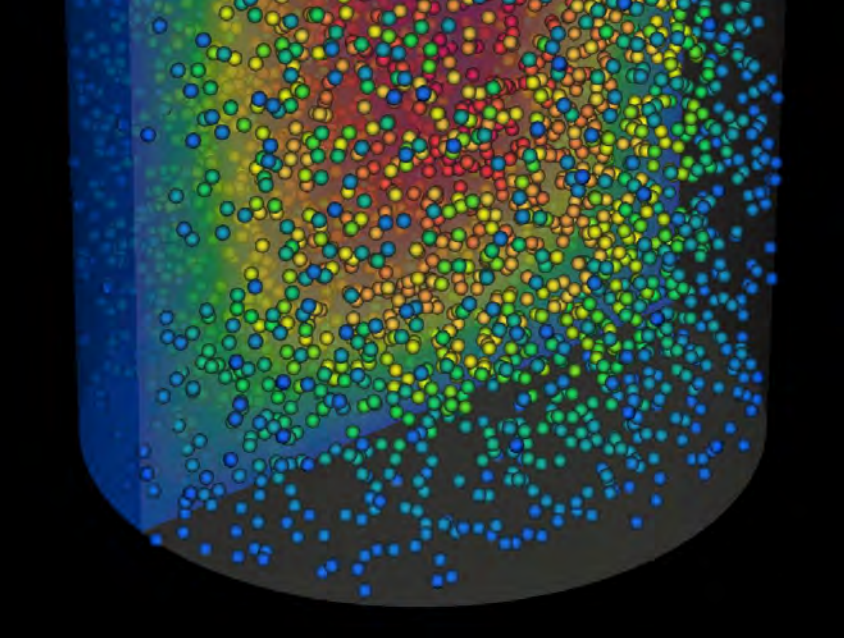
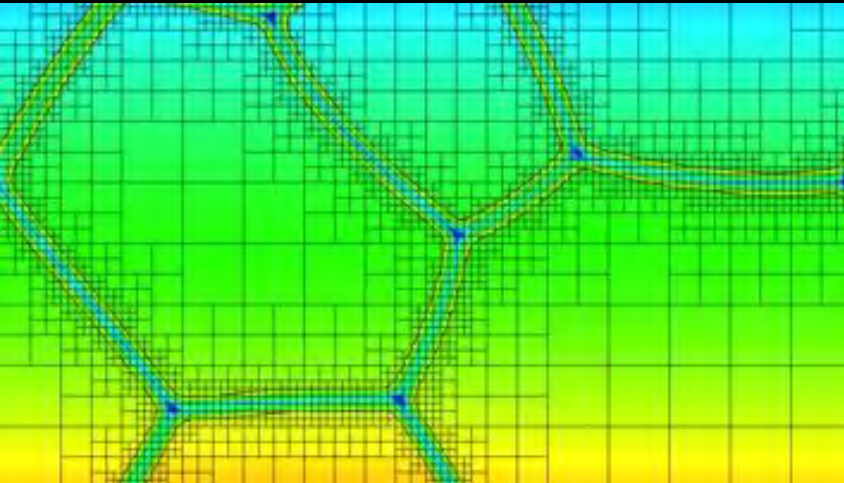




Cody Permann, Ph.D.
Computational Frameworks
Department Manager

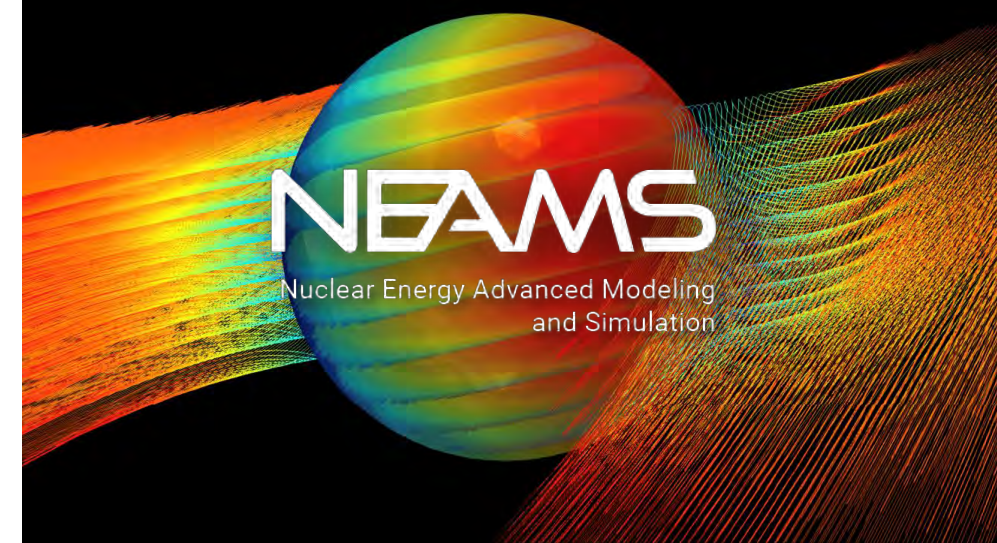


**Accelerating nuclear energy
deployment using MOOSE-based
simulation tools.**

NEAMS Program

www.neams.inl.gov

- Nuclear Energy Advanced Modeling & Simulation
- DOE-NE led program across several national labs: INL, ANL, ORNL, LANL
- Both LWR and non-LWR advanced reactor designs
- Divided into 5 technical areas:
 - Fuel Performance
 - Reactor Physics
 - Thermal Hydraulics
 - Structural Materials & Chemistry
 - Multiphysics Application
- Primarily leveraging MOOSE framework for software development

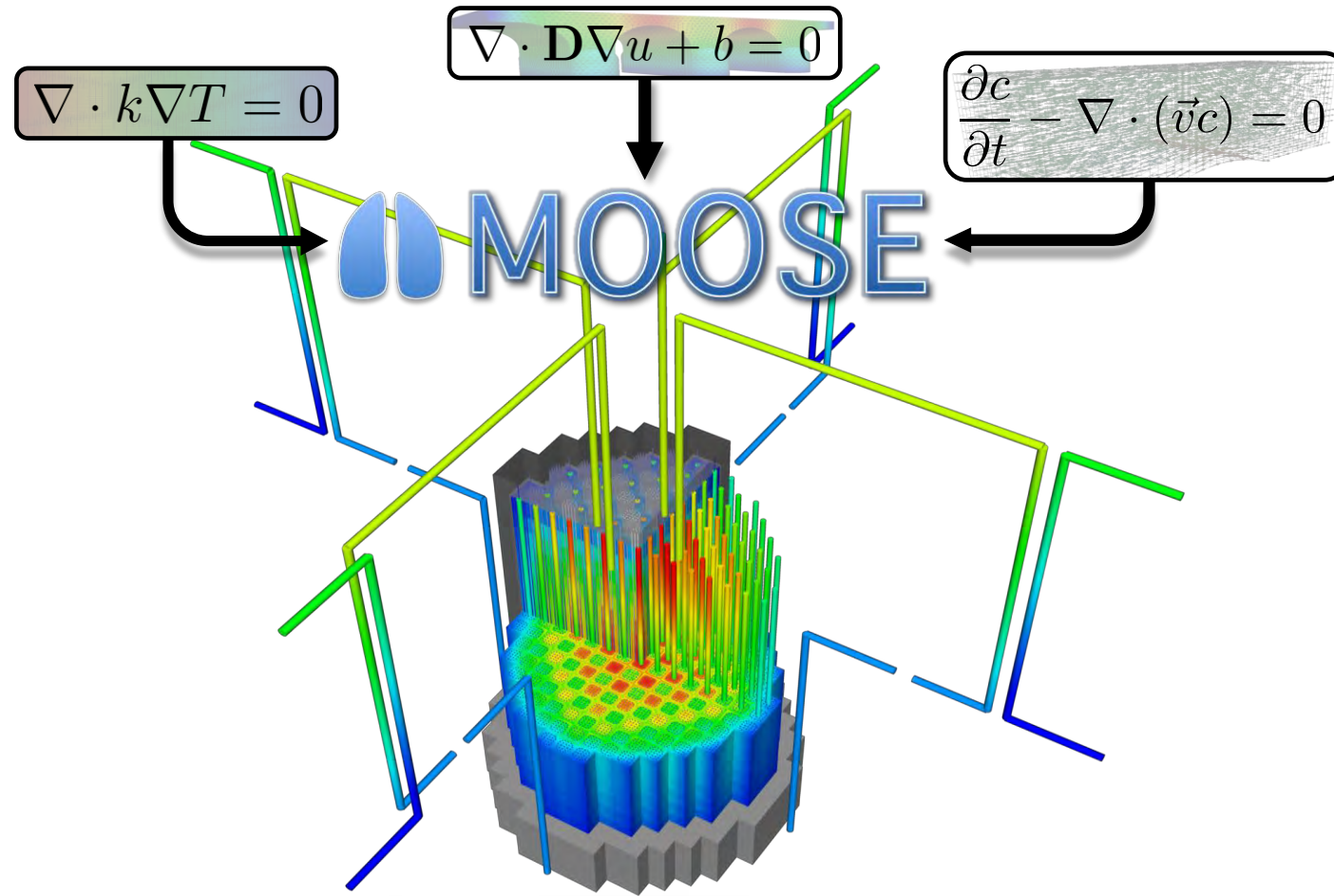


U.S. DEPARTMENT OF
ENERGY

Office of
NUCLEAR ENERGY



MOOSE Accelerates Development of High-Fidelity Modeling and Simulation Tools



What is MOOSE?

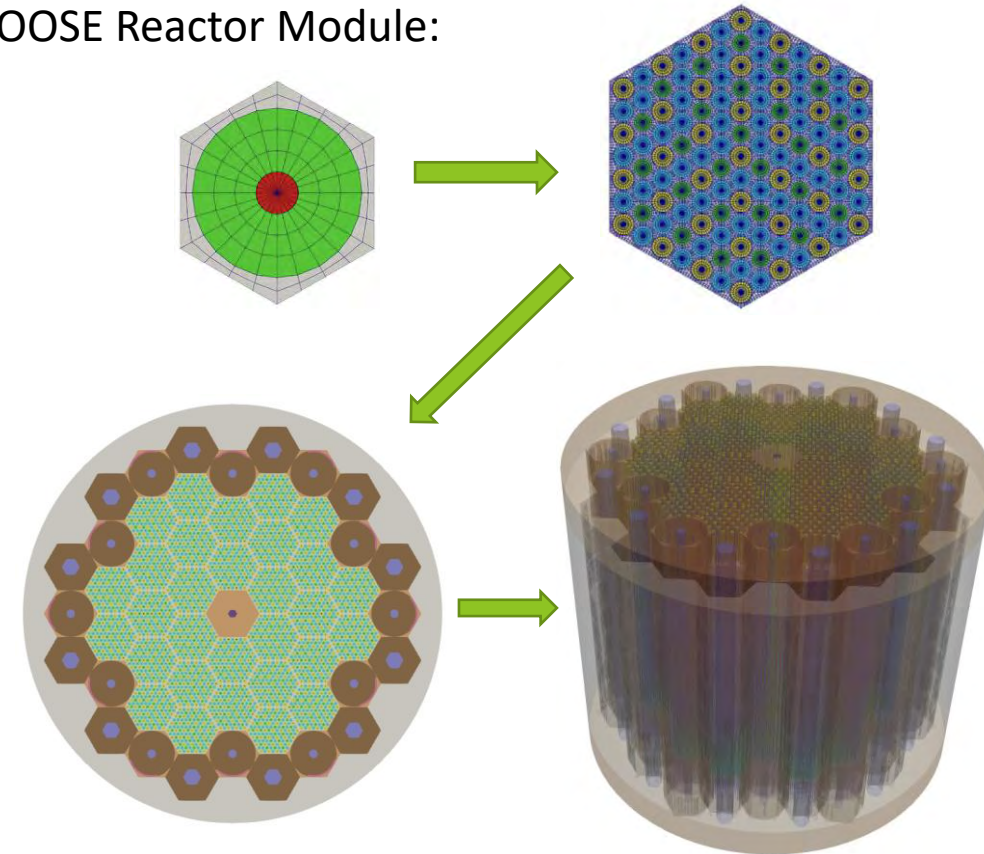
- Multiphysics
- Complete Platform
- Open-source
- Massively Parallel
- Flexible
- Extendable

mooseframework.org

MOOSE Physics Modules – All Open Source!

- Chemical Reactions
- Contact
- Electromagnetics
- Fluid Properties
- Fluid Structure Interaction (FSI)
- Function Expansion Tools
- Geochemistry
- Heat Conduction
- Level Set
- Navier Stokes
- Peridynamics
- Phase Field
- Porous Flow
- Ray Tracing/Particle Tracking
- rDG
- Reactor
- Stochastic Tools
- Subchannel
- Tensor (solid) Mechanics
- Thermal Hydraulics
- XFEM

MOOSE Reactor Module:



Building a mesh with the Reactor module [1]

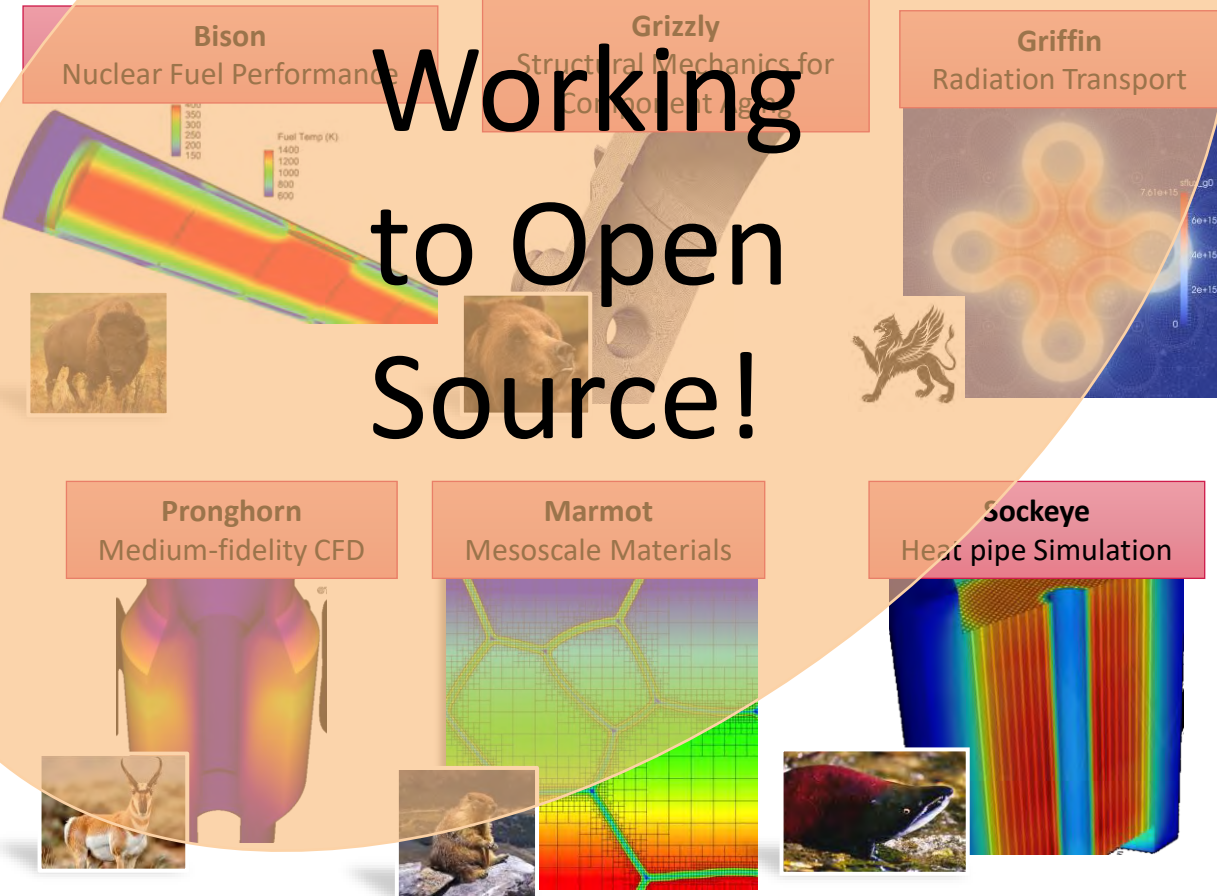
4 1. Shemon, Emily, Yinbin Miao, Shikhar Kumar, Kun Mo, Yeon Sang Jung, Aaron Oaks, Scott Richards, Guillaume Giudicelli, Logan Harbour, and Roy Stogner. "MOOSE Reactor Module: An Open-Source Capability for Meshing Nuclear Reactor Geometries." *Nuclear Science and Engineering* (2023): 1-25.

Accelerating Advanced Reactor Deployment

NEAMS

Accelerating Advanced Fission Reactor Deployment

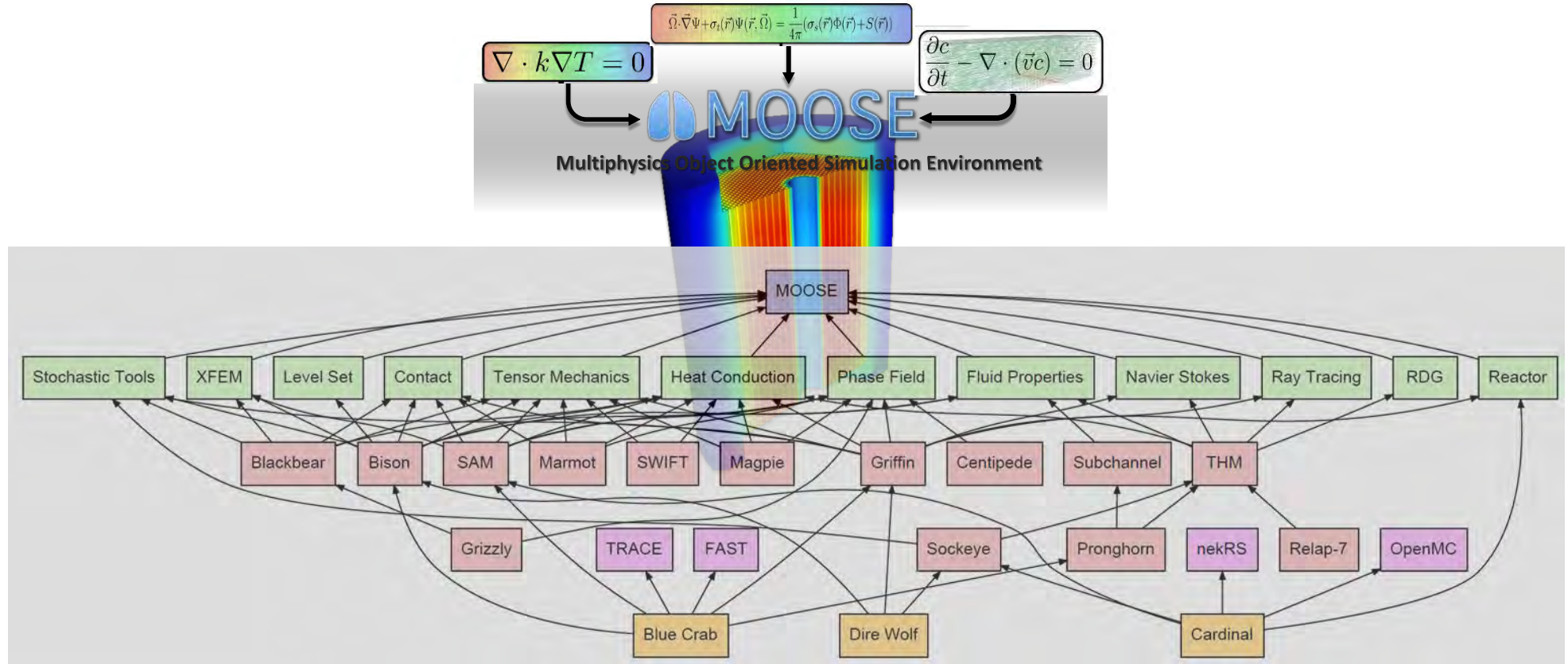
Working
to Open
Source!



Open-Source Nuclear Technologies Research

- Fission:
 - BlackBear – Structural Material Degredation
 - Kuglepy – PBR Serpent file generator
- Fusion:
 - TMAP8 – Tritium Migration Program
 - SALAMANDER - Software for Advanced Large-scale Analysis of Magnetic confinement for Numerical Design, Engineering & Research
 - UKAEA Applications!

MOOSE Framework Ecosystem for Non-LWR Analysis



HTGR

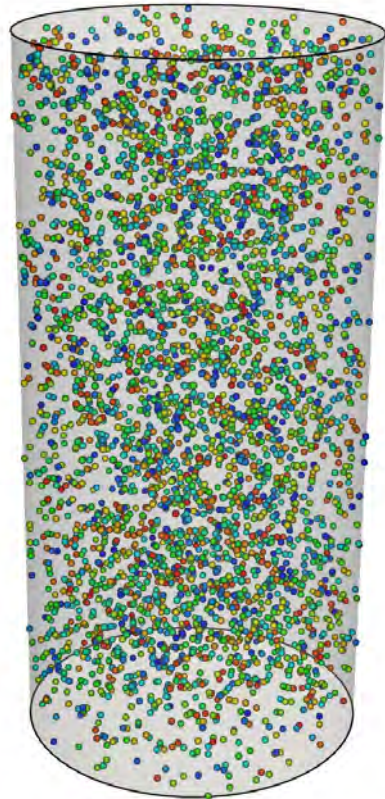
FHR

MSR

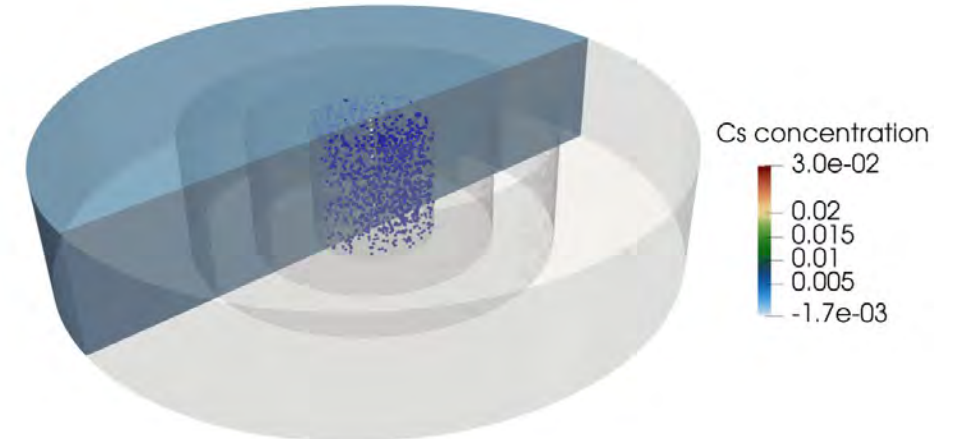
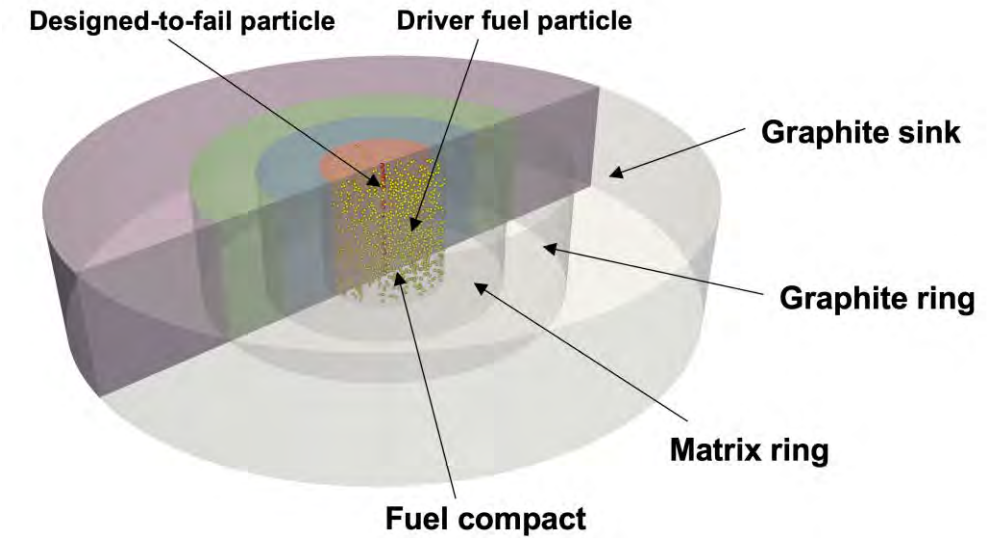
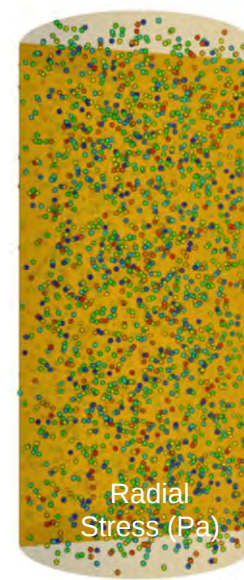
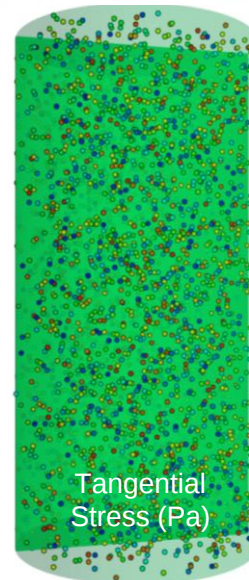
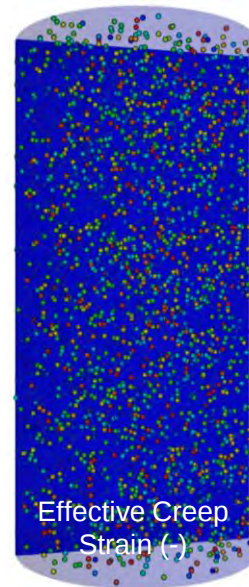
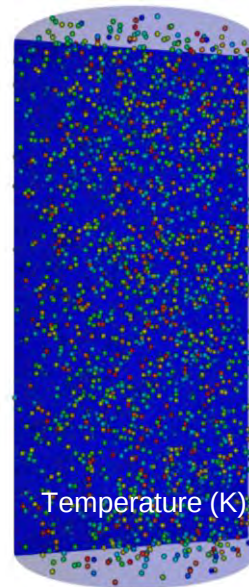
Microreactor

LMFR

AGR TRISO compact modeling

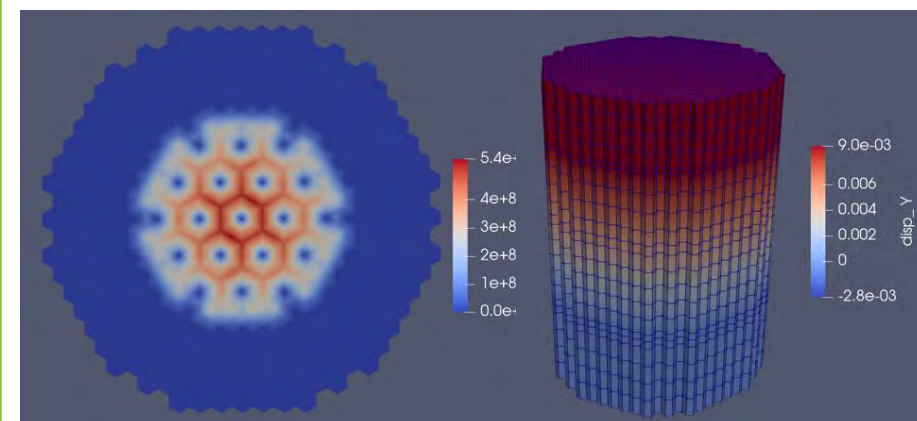
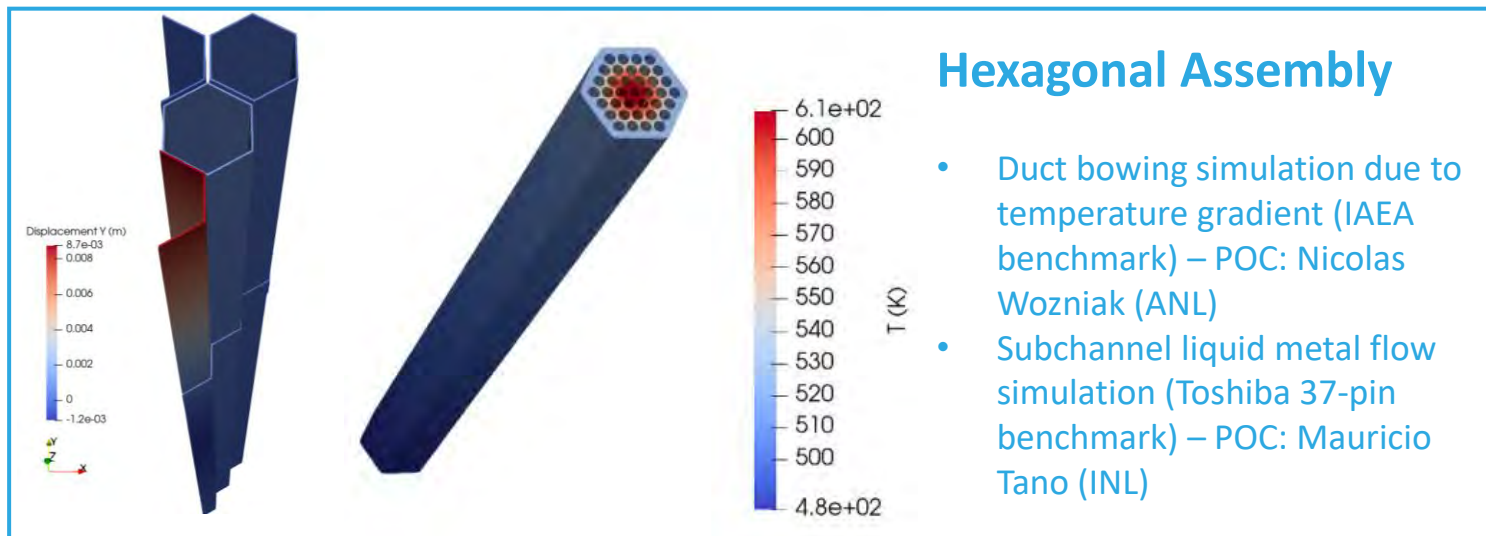


Fuel compact containing 4,000 TRISO particles randomly generated from an MC simulation.



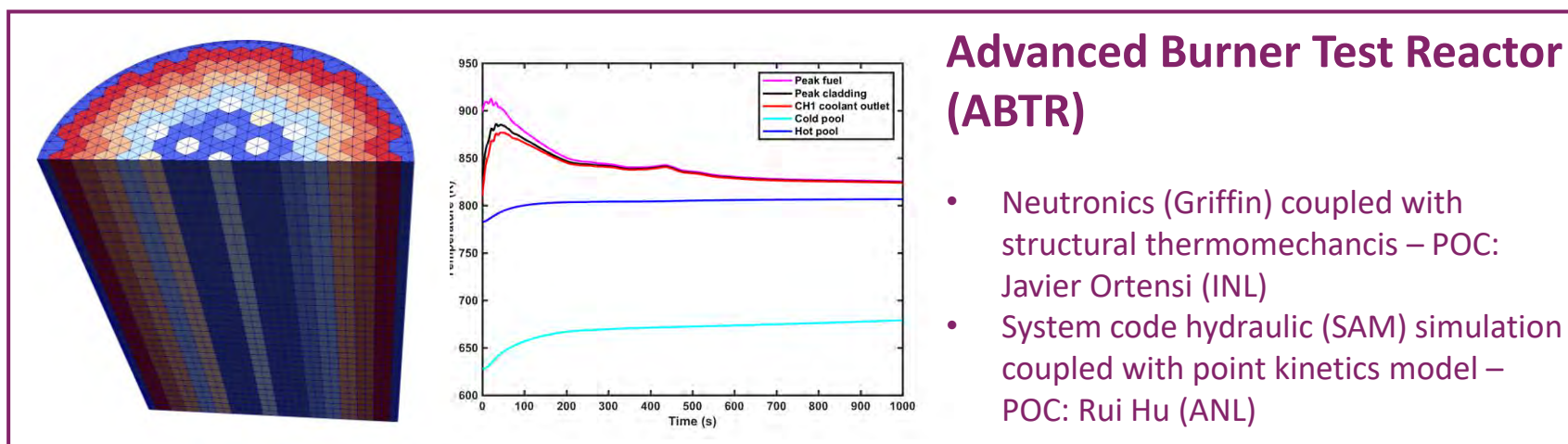
Irradiate fuel containing 20 uranium oxycarbide (UCO) designed-to-fail (DTF) fuel particles that will provide a known source of fission products for subsequent transport through compact matrix and structural graphite materials.

Reactor Use Case: SFR

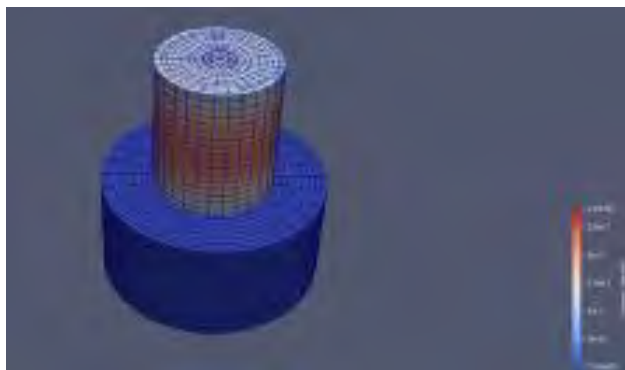


Versatile Test Reactor (VTR)

- Fully-coupled feedback model between neutronics, conduction, hydraulics, and structural expansion
- Codes coupled: Griffin, Bison, and SAM
- POC: Nicolas Martin (INL)

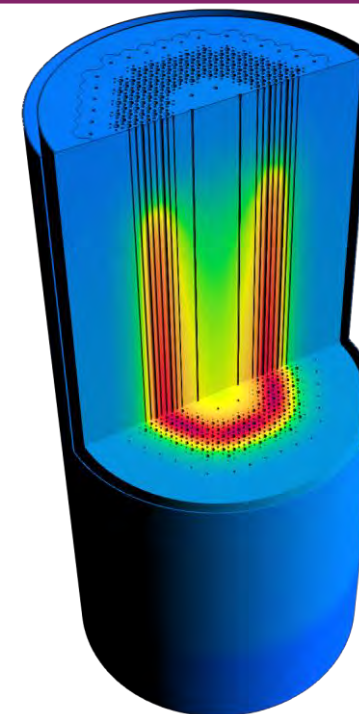
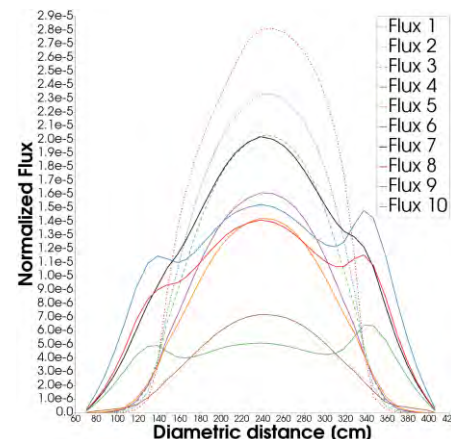
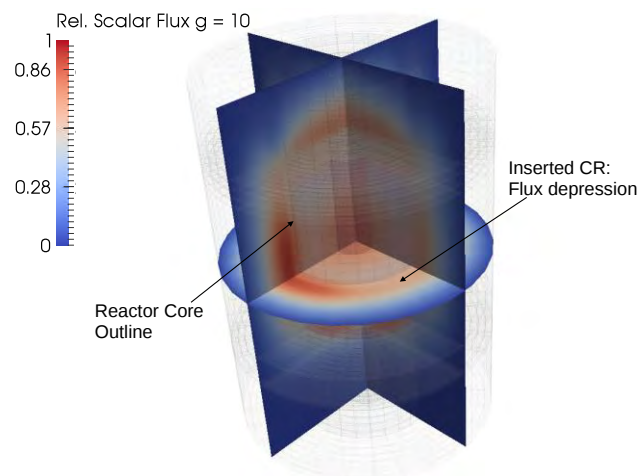


Reactor Use Case: HTGR



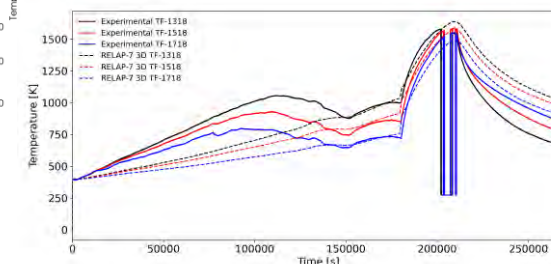
High-Temperature Reactor (HTR-10)

- Steady-state benchmarks with different control rod positions
- Neutronics (Griffin) with heat conduction (MOOSE)
- POC: Javier Ortensi (INL)



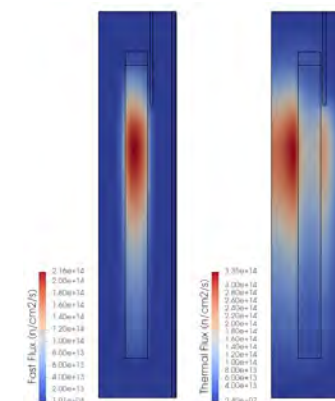
High-Temperature Test Facility (HTTF)

- Coupled heat conduction with system hydraulics
- Steady-state and transient simulations
- POC: Lise Charlot (INL)



Pebble-Bed Modular Reactor (PBMR400)

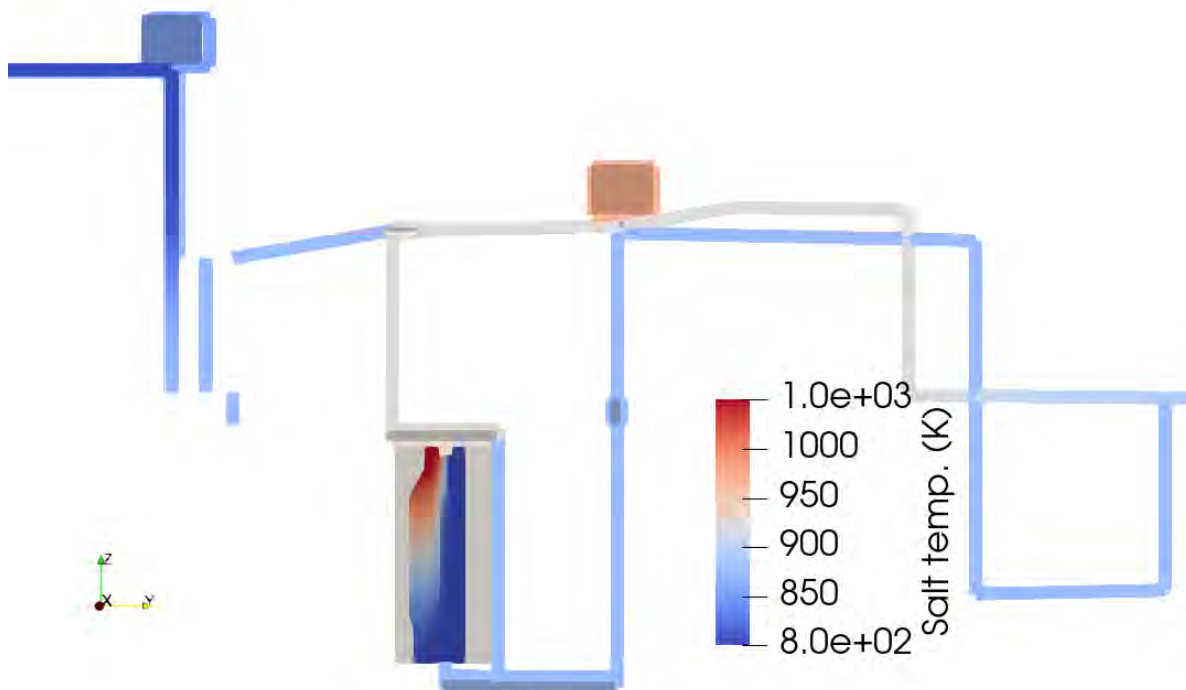
- Coupled neutronics (Griffin) with thermal hydraulics (Pronghorn)
- Multiscale modeling: core-pebble-particle
- Steady-state and transient simulations
- POC: Paolo Balestra (INL)



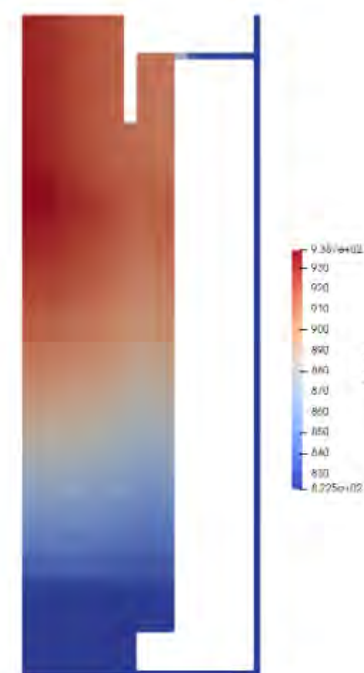
Reactor Use Case: FHR

Mk-I FHR

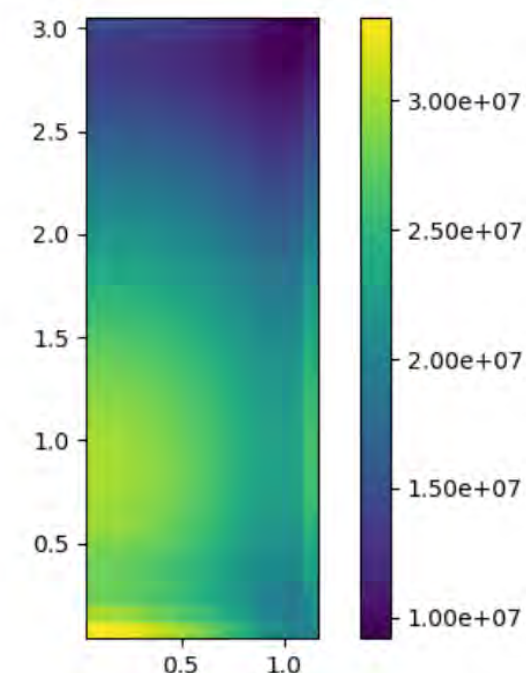
- Coupled core neutronics (Griffin) with core thermal hydraulics (Pronghorn) with plant hydraulics (SAM)
- Steady-state and transient simulations
- POC: Guillaume Giudicelli (INL)



Fluid temperature [K]



Power density [W/m³]



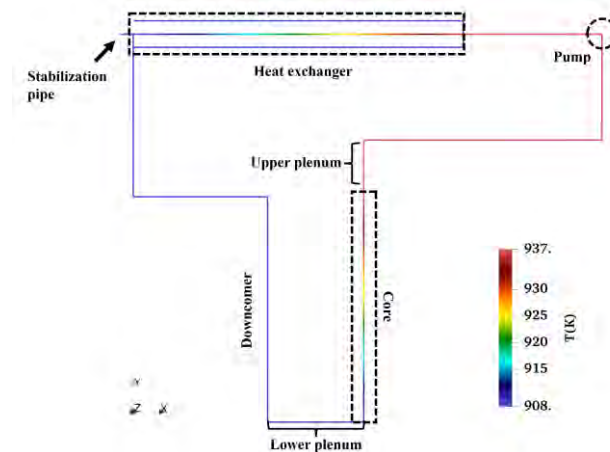
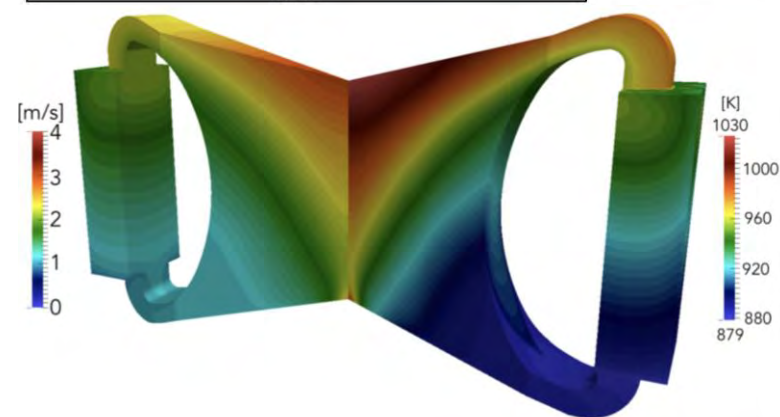
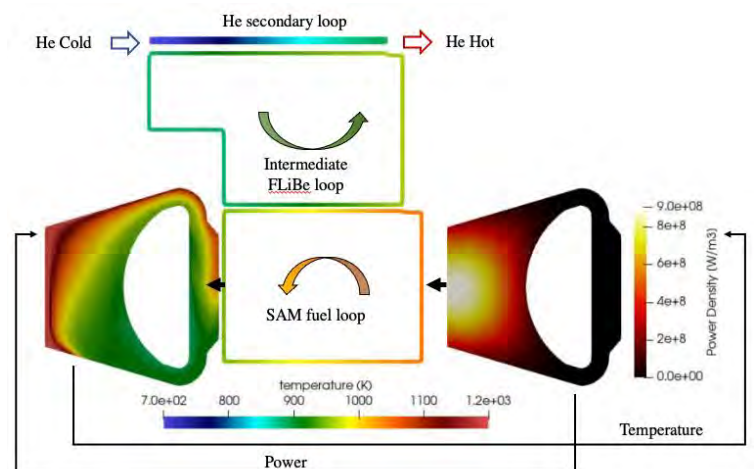
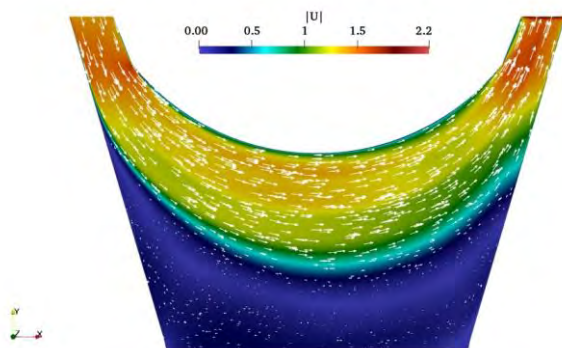
Generic Fluoride High-Temperature Reactor (gFHR)

- Equilibrium core calculation with pebble tracking
- Coupled neutronics (Griffin) with thermal hydraulics (Pronghorn)
- Steady-state and transient simulations
- POC: Sebastien Schunert and Javier Ortensi (INL)

Reactor Use Case: MSR

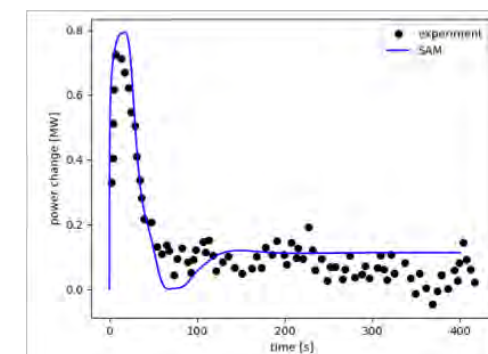
Molten Salt Fast Reactor (MSFR)

- Coupled core neutronics (Griffin) with core thermal hydraulics (Pronghorn) with plant hydraulics (SAM)
- Steady-state and transient simulations
- POC: Mauricio Tano (INL)



Molten Salt Reactor Experiment (MSRE)

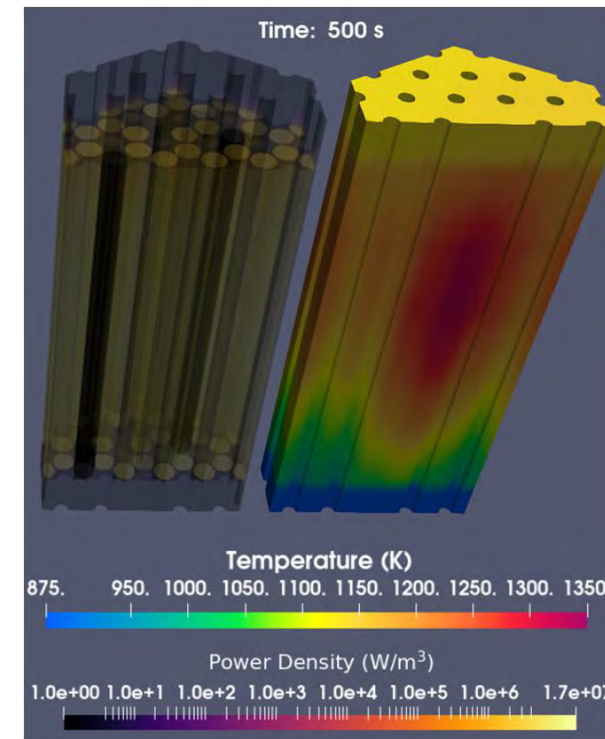
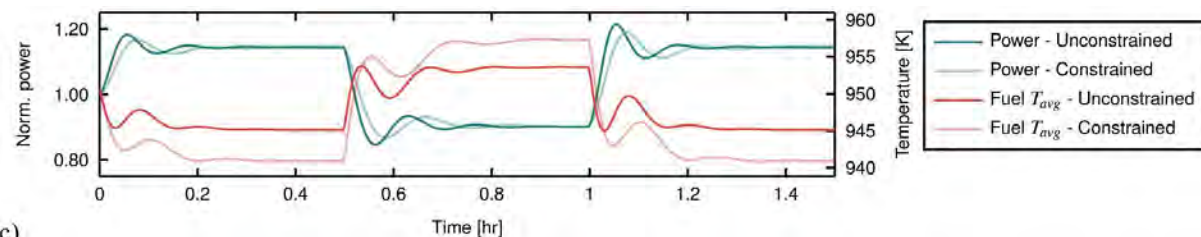
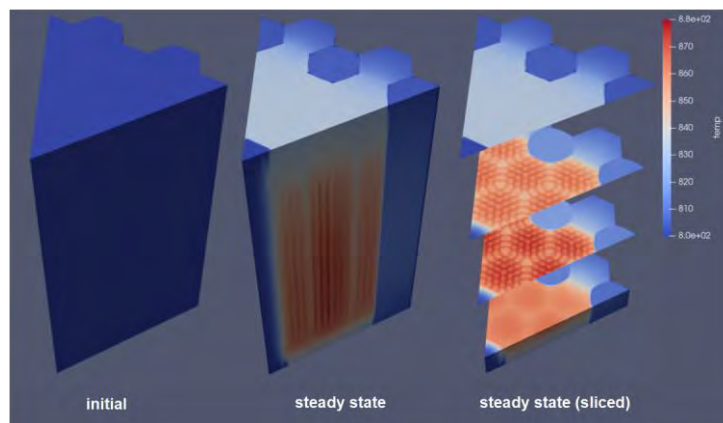
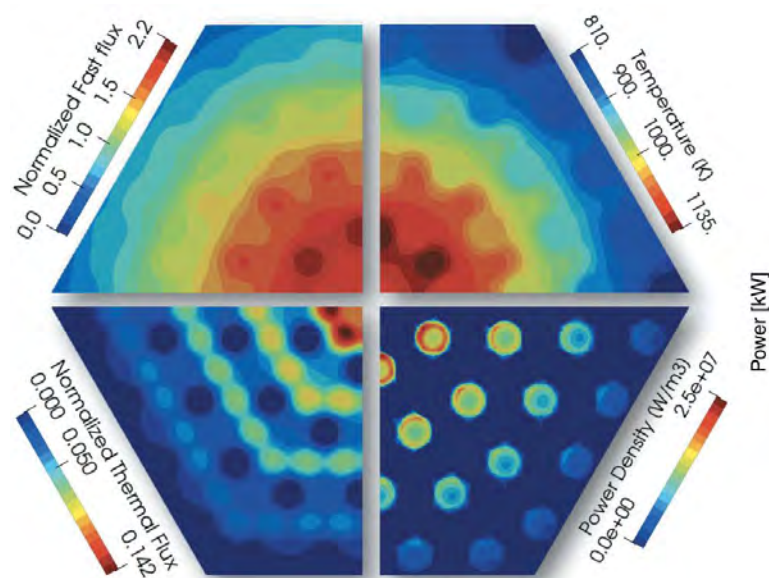
- Coupled systems hydraulics with point kinetics model (SAM)
- Steady-state and transient simulations
- Benchmarked against MSRE data
- POC: Rui Hu (INL)



Reactor Use Case: Microreactor

Empire Design

- Coupled core neutronics (Griffin), heat pipe (Sockeye), and thermomechanics (Bison)
- Steady-state and transient simulations
- POC: Javier Ortensi(INL), Nicolast Stauff (ANL)



Generic Gas-cooled Microreactor (GC-MR)

- Neutronics (Griffin) coupled with system hydraulics (SAM) and thermomechanics (Bison)
- Steady state and transient capabilities
- POC: Nicolas Stauff (ANL)

mooseframework.org/virtual_test_bed

Virtual Test Bed (VTB)

- The VTB supports NRIC's mission of delivering successful demonstration and deployment of advanced nuclear energy

How?

- Library of Reference Model:** database of advanced multiphysics advanced reactor models that users can download, edit, and re-run
- Targeted Model Generation:** developing demonstration-relevant models (e.g., candidates for DOME/LOTUS) to accelerate safety evaluations
- Continuous Software QA:** linking repository to software development to avoid legacy issues while enabling rapid code development

VTB So Far

- 50+ models hosted (and counting): 20+ reactor designs, and 8 codes showcased
- Collaboration with NEAMS, industry, NRC, and academia
- Help accelerate timelines for DOE/NRC confirmatory analysis
- Accelerate development cycle for industry and academia

Reactor Demonstrations

Accelerate
Licensing
Evaluation
(NRC)

Accelerate
Authoriza-tion
Evaluation
(DOE)

Accelerate
Design
Maturation
(industry)

Targeted
Model
Generation

Library of
Reference
Models

Testing for
Agile Software
QA

Mission

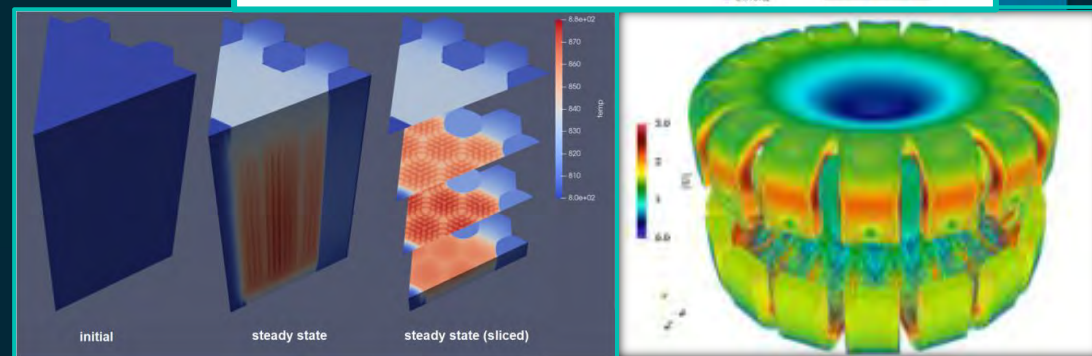
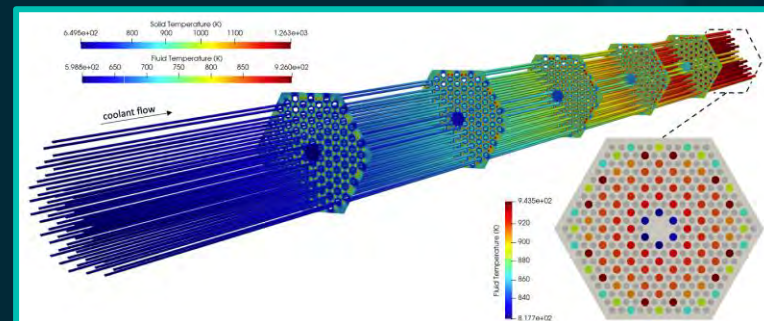
Mission

Scope

NRIC

VTB

VTB



VTB Model Tree

- 30+ distinct simulations
- 14 reactor designs
- 7 codes showcased

Codes Represented:

FY21

FY22

FY23 + Under Review

Griffin

Nek

Pronghorn

Sockeye

SAM

Bison

Cardinal

VTB Repo

MSR

HTGR

FHR

LMFR

MR

MSFR

MSRE

PBMR

MHTGR

HTTF

HTR10

TREAT

Mk1

Lat.

VTR

ABTR

HP-MR

GC-MR

SNAP8

Core neutr
+ TH steady
& transient

Griffin
Pronghorn

System steady
SAM

System transient
SAM

Core high-fidel. CFD

Nek

Core + system
neutr+TH

Griffin SAM
Pronghorn

Core depletion
+ species

Griffin

67 pebble
CFD

iNL Nek

Core neutr+
TH steady &
transient

Griffin
Pronghorn

System steady
SAM

System transient
SAM

System steady+
transient
SAM

TH+Struct
transient
RELAP7/THM

Core neutr
steady

Griffin

Assembly neutr+TH

Cardinal

Core neutr
steady

Griffin

TRISO fuel
perform.

Bison

Core neutr +
TH steady

Griffin
Pronghorn

Reflector
bypass
flow

Nek

Pulse
transient

Griffin
Bison

Core + system
neutr+TH

Griffin SAM
Pronghorn

System steady+
transient
SAM

Assembly neutr+TH
+ fuel

Griffin SAM
Bison

Sub-channel
TH

Pronghorn

LFR het.
neutronics

Griffin

Duct
bowing

MOOSE

3D Core
neutr +
TH + fuel

Griffin SAM
Bison

Core TH
transient

SAM

Core TH+struct.
steady

Sockeye
Bison

3D Core neutr
+ TH + Struc
transient

Sockeye Griffin
Bison

Assy Neutr +
TH + Struct
transient

Griffin SAM
Bison

2D Core
Neutr+
Structure

Griffin
Bison

