# Integration of Bison with VERA

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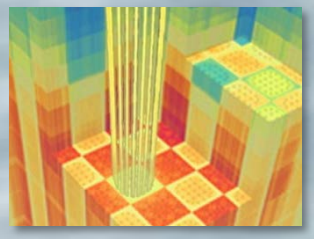
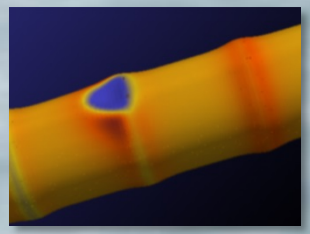
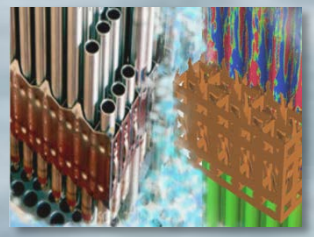
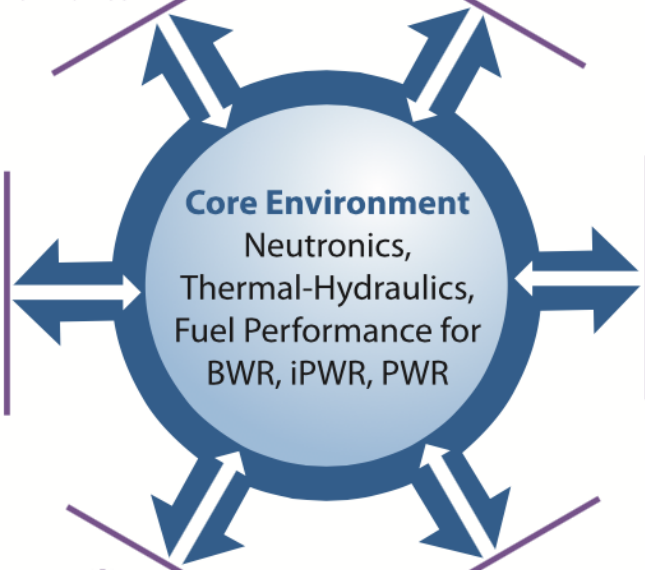




# Challenge Problems

**Pellet-Clad Interation (PCI)**
Predict core wide PCI margin and missing pellet surface PCI for BWR, iPWR, PWR
*Neutronics, Thermal-Hydraulics, Fuel/Cladding Performance*

**CRUD**
Predict CRUD thickness, boron uptake, and impact on power and cladding corrosion for iPWR, PWR
*Neutronics, Thermal-Hydraulics, Fluid Flow (CFD), Chemistry*

**Cladding Integrity Reactivity Insertion Accident**
Predict pellet-clad mechanical interaction for BWR, iPWR, PWR
*Reactor Kinetics, Transient Fuel/Cladding Performance*

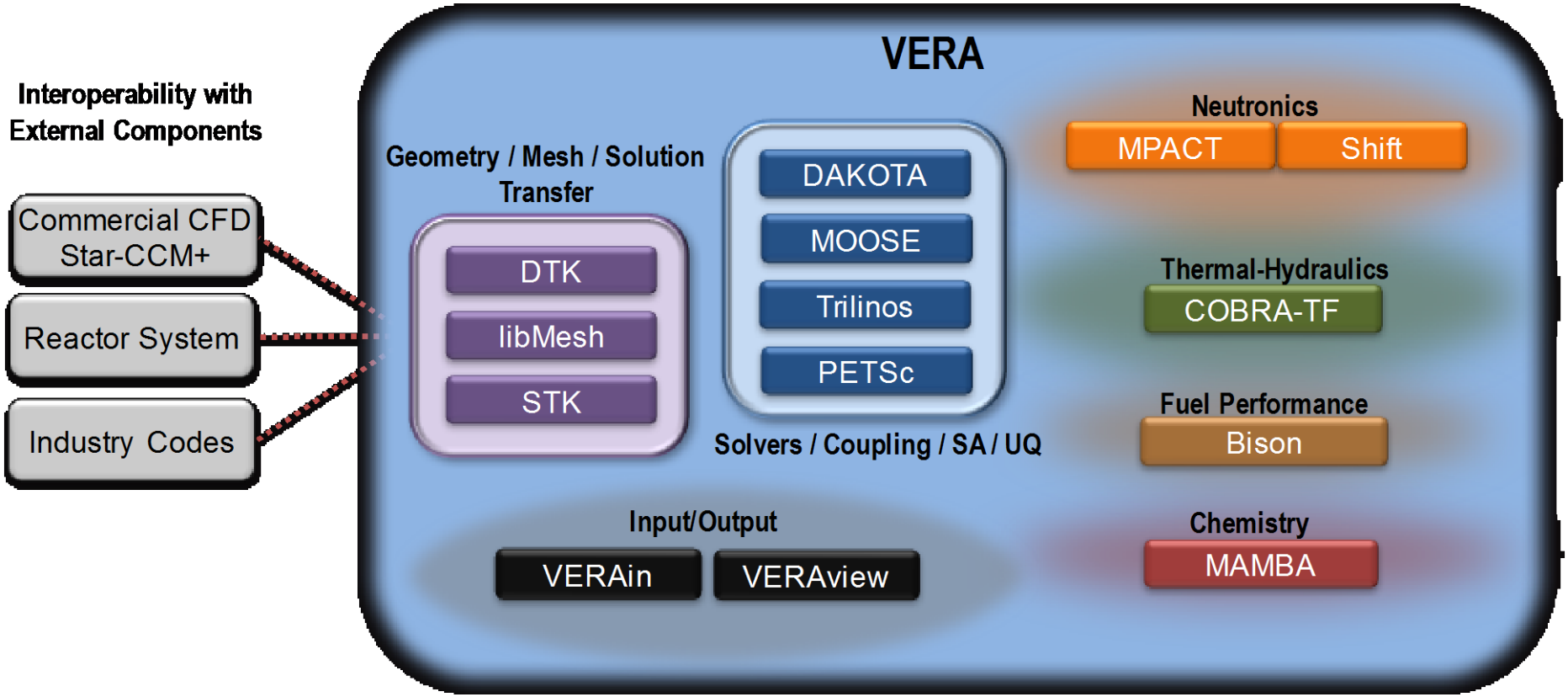



**Cladding Integrity Loss of Coolant Accident**
Predict peak clad temperature and oxidation margin for BWR iPWR, PWR
*Fuel/Cladding Performance*

**Departure from Nucleate Boiling (DNB) and Flow Regimes**
Predict PWR DNB margin for steam line break, predict thermal and solutal flow, BWR flow regimes
*Neutronics, Thermal-Hydraulics/Fluid Flow (CFD)*

**Grid to Rod Fretting**
Predict fluid structure excitation forces, grid-clad gap, and cladding wear for iPWR, PWR
*Fluid Flow (CFD), Fuel/Clad Performance, Materials Performance*

# Virtual Environment for Reactor Applications (VERA)




The “Core Simulator” consists of MPACT, COBRA-TF, and MAMBA

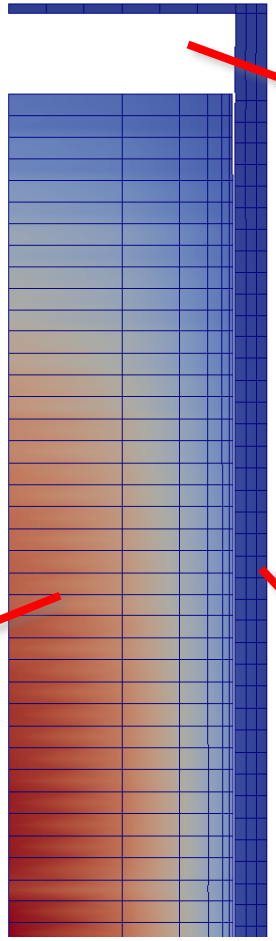
# Bison Fuel Performance Code

## General Capabilities

- Built upon the MOOSE framework
- Fully-coupled thermomechanics (2D or 3D)
- Steady and transient operation

## $UO_2$ Fuel Models

- Discrete or smeared pellets
- Conductivity: f(T, BU)
- Volumetric heat generation (fission)
- Thermal expansion
- Relocation
- Densification
- Fission product swelling (solid, gaseous)
- Fission gas release



## Gap/Plenum Behavior

- Gap heat transfer
- Mechanical contact
- Plenum pressure as a function of: gas volume (mechanics), gas mixture (FGR), gas temperature

## Modified Zr4 Cladding Models

- Thermal and irradiation creep
- Thermal expansion
- Axial growth
- Plasticity

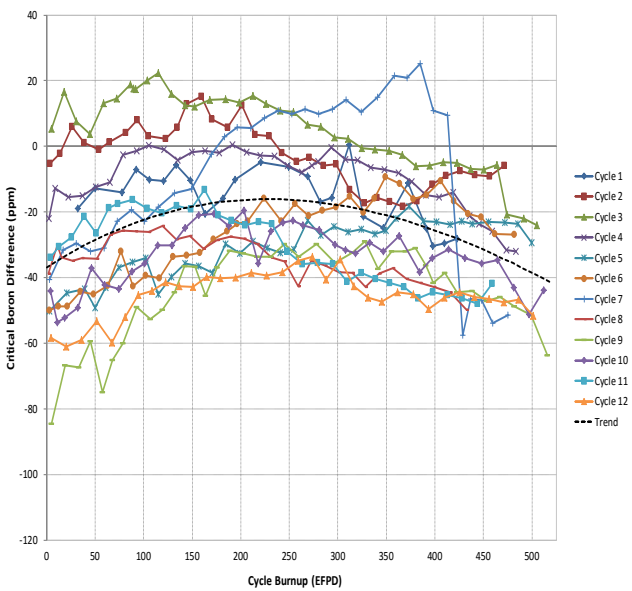
# Drivers: for Bison integration with VERA

- **Traditional use fuel performance code**
  - EPRI and Areva test stands
  - Load follow operation at Exelon
- **PCI scoping tool for nominal operation**
  - Half of the PCI Challenge Problem (identify pins of interest)
  - Load-follow and optimization of power ramping
- **Time-dependent sources and BCs for transients**
  - For high-resolution fuel performance analysis of particular pins
  - RIA and LOCA Challenge Problems
- **Improve accuracy of VERA for nominal operation**
  - Westinghouse and Areva test stands
  - Quantify error in neglecting all of the in-rod physics

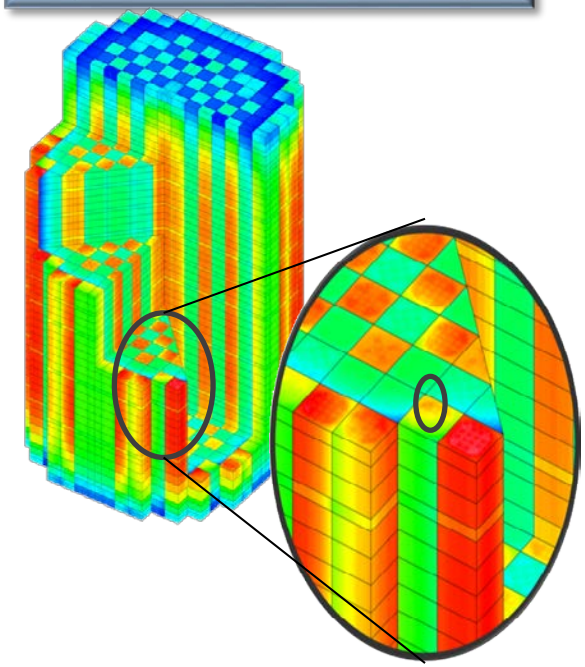
# Providing fuel performance modeling

- **Traditional use fuel performance code**
  - Simplify the use of Bison for standard LWRs modeled with VERA

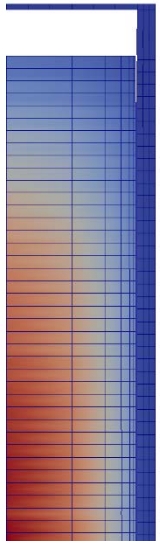
Model Multiple Cycles




Select Pin of Interest



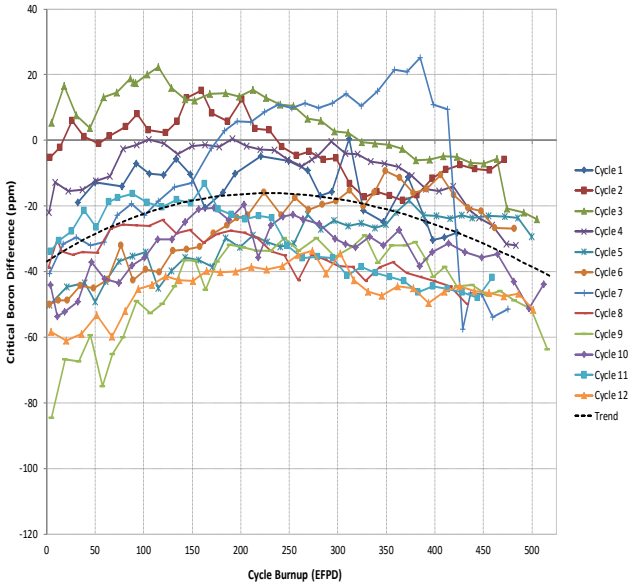
Run Bison for that Pin



# Enabling core-wide fuel analysis

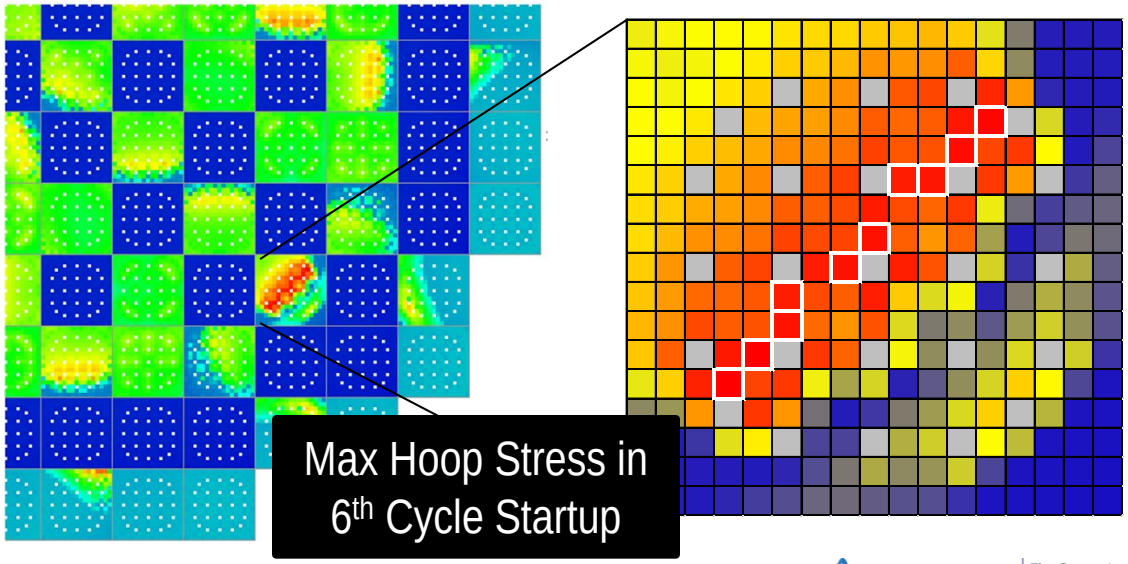
- **Traditional use fuel performance code**
  - Simplify the use of Bison for standard LWRs modeled with VERA
- **PCI scoping tool for nominal operation**
  - Simplify core-wide analysis of fuel performance using VERA

Model Multiple Cycles




Run Bison for Every Pin

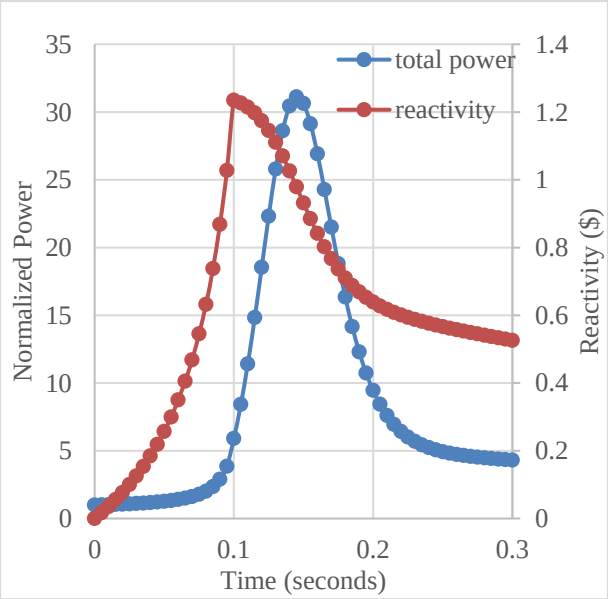
Select Pins of Interest



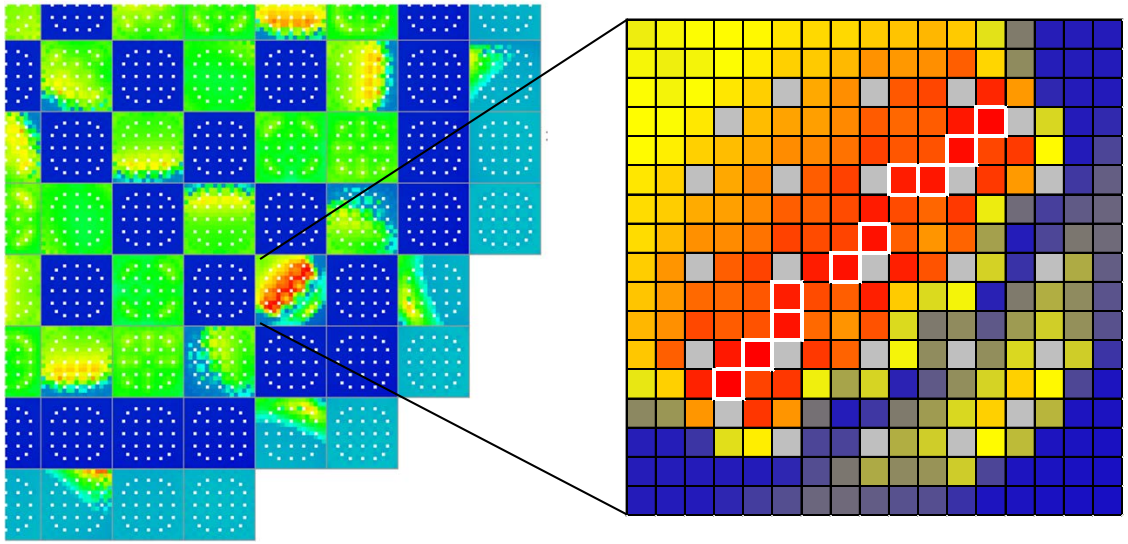
# Enabling transient core-wide fuel analysis

- **Traditional use fuel performance code**
- **PCI scoping tool for nominal operation**
- **Time-dependent sources and BCs for transients**
  - Simplify core-wide analysis of fuel performance using VERA

Model RIA/LOCA




Run Bison for Every Pin



Select Pins of Interest

# Meeting essential user-needs

- **Provide core-wide fuel performance analysis**
  - Traditional use fuel performance code
  - PCI scoping tool for nominal operation
  - Time-dependent sources and BCs for transients

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- **Provide core-wide fuel performance analysis**
  - Traditional use fuel performance code
  - PCI scoping tool for nominal operation
  - Time-dependent sources and BCs for transients
- **Simplify the use of Bison with VERA**
  - Model multiple cycles of operation
    - (Restart VERA to model a transient)
  - Generate Bison inputs for thousands of fuel rods
  - Execute thousands of Bison inputs
  - Generate VERAout from thousands of Bison outputs
  - Identify potentially limiting rods
  - Modify Bison input for high-resolution analysis
  - Perform high-resolution fuel performance analysis

# Meeting essential user-needs

- **Provide core-wide fuel performance analysis**
  - Traditional use fuel performance code
  - PCI scoping tool for nominal operation
  - Time-dependent sources and BCs for transients
- **Simplify the use of Bison with VERA**
  - Model multiple cycles of operation **VERA**
    - (Restart VERA to model a transient) **MPACT**
  - Generate Bison inputs for thousands of fuel rods **XML2MOOSE**
  - Execute thousands of Bison inputs **Bison**
  - Generate VERAout from thousands of Bison outputs **BisonPost**
  - Identify potentially limiting rods **VERAView**
  - Modify Bison input for high-resolution analysis
  - Perform high-resolution fuel performance analysis **Bison**

But there are so many 'codes' to learn…

# Meeting essential user-needs

- **Provide core-wide fuel performance analysis**
  - Traditional use fuel performance code
  - PCI scoping tool for nominal operation
  - Time-dependent sources and BCs for transients
- **Simplify the use of Bison with VERA**
  - Model multiple cycles of operation — **VERA**
    - (Restart VERA to model a transient) — **MPACT**
  - Generate Bison inputs for thousands of fuel rods — **XML2MOOSE**
  - Execute thousands of Bison inputs — **Bison**
  - Generate VERAout from thousands of Bison outputs — **BisonPost**
  - Identify potentially limiting rods — **VERAView**
  - Modify Bison input for high-resolution analysis
  - Perform high-resolution fuel performance analysis — **Bison**

But there are so many 'codes' to learn…

# Meeting essential user-needs

- **Provide core-wide fuel performance analysis**
  - Traditional use fuel performance code
  - PCI scoping tool for nominal operation
  - Time-dependent sources and BCs for transients
- **Simplify the use of Bison with VERA**
  - Model multiple cycles of operation (and a transient) **VERA**
    - Along with a Bison for every fuel pin
    - Generate VERAout for core simulator and every fuel pin
  - Identify potentially limiting rods **VERAView**
  - Modify Bison input for high-resolution analysis
  - Perform high-resolution fuel performance analysis **Bison**

**"Inline" core simulation and fuel performance**

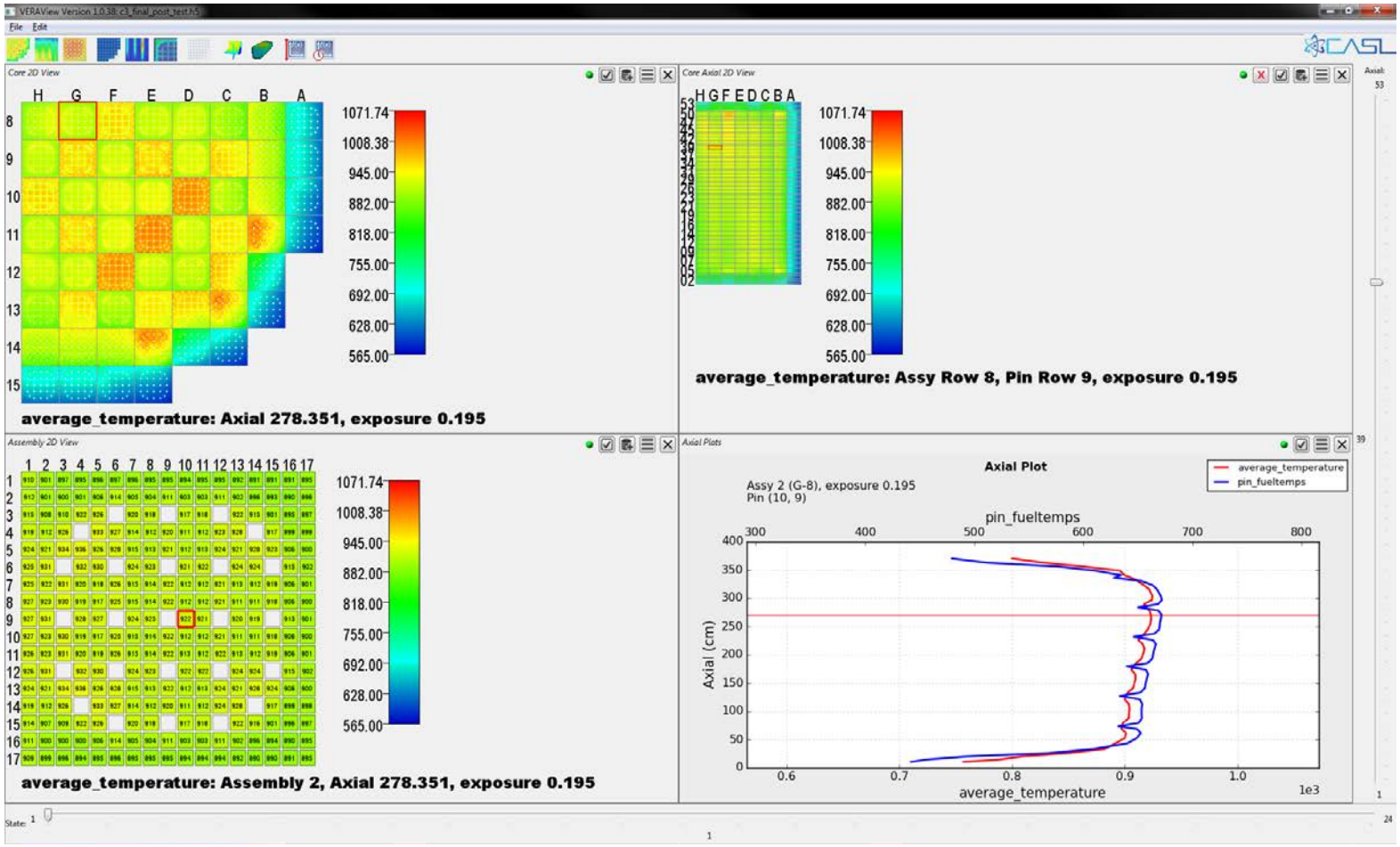
# Continuum of Integration with Bison

| Feature | Offline (VERA + Bison) | Inline (VERA -> Bison) |
|---|---|---|
| Coupling | One-way | One-way |
| Transfers | File I/O | In-memory |
| Execution Time | Fast | Fast |
| If a Bison pin cannot converge? | Remaining pins complete | Entire simulation fails |
| Hardware required | Moderate | Large |

But how accurate is the fuel model in the core-simulator?

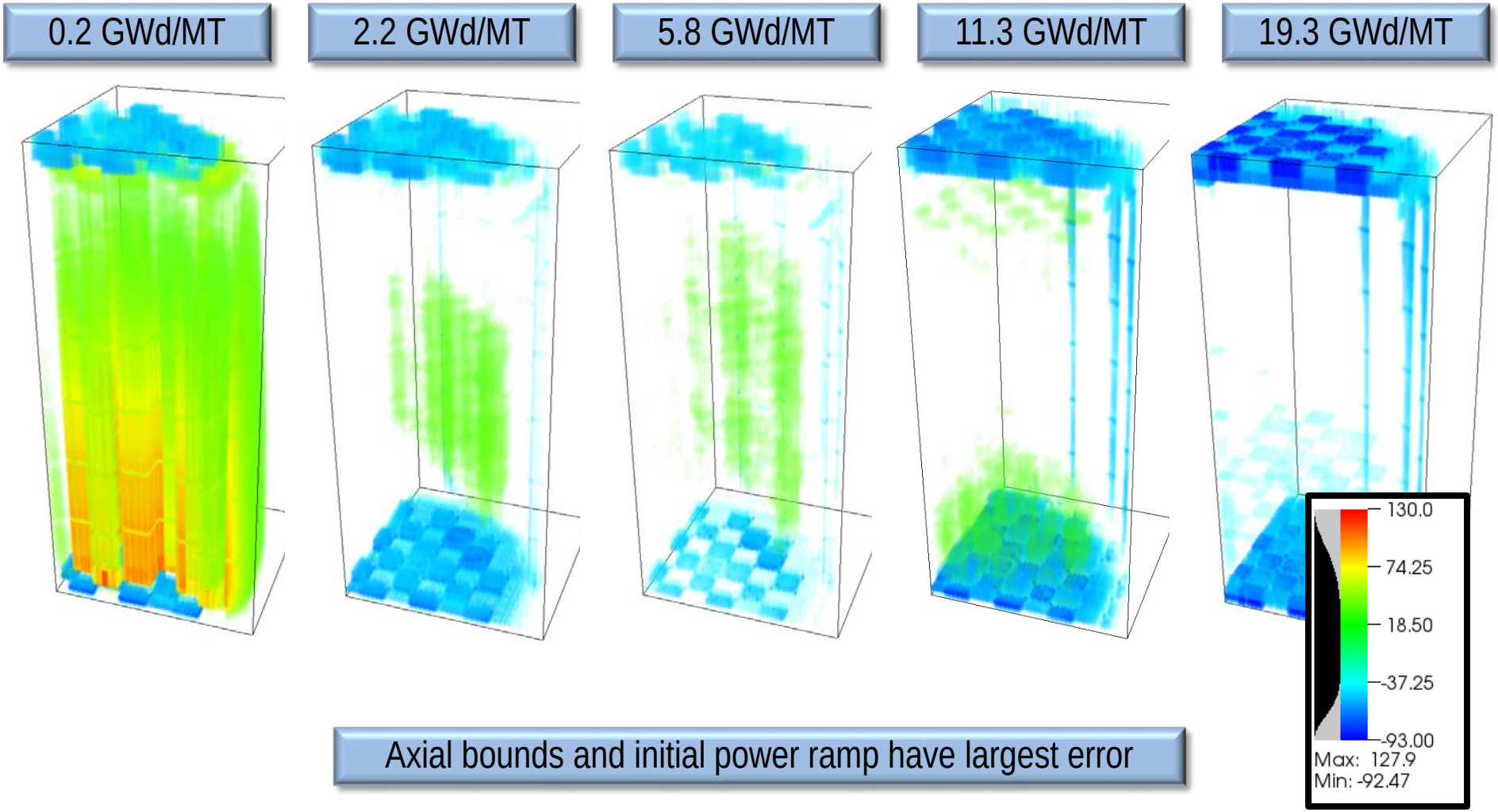
→ Ease-of-use and hardware requirements →

# Evaluating core simulator fuel models




Axial bounds and grids have smaller depression than Bison

# Evaluating core simulator fuel models




Axial bounds and initial power ramp have largest error

# Improving the fuel models in VERA

- **Use Bison to create fuel temperature tables**
  - Generate Bison inputs from VERA
- **Add physics to fuel models**
  - Temperature tables -> 1D heat transfer -> 1D thermo-mechanics
  - Replicate material models from Bison
  - Bison informs effective models

Hi2Lo methods

- **Couple Bison directly with VERA**
  - Consistent Bison-MPACT-CTF solution at every depletion step

# Continuum of Integration with Bison

| Feature | Offline (VERA + Bison) | Inline (VERA -> Bison) | Coupled |
|---|---|---|---|
| Coupling | One-way | One-way | Consistent |
| Transfers | File I/O | In-memory | In-memory |
| Execution Time | Fast | Fast | Slow |
| If a Bison pin cannot converge? | Remaining pins complete | Entire simulation fails | Entire simulation fails |
| Hardware required | Moderate | Large | Large |

→ Ease-of-use and hardware requirements →

→ Fidelity of solution and software complexity →

# Milestones in FY17

- Integration and demonstration
  - Demonstration of load-follow with VERA-CS+Bison — PHI (Stimpson)
  - Demonstration of Tiamat for cycle depletion (PHI — PHI (Stimpson)
  - Bison modeling of impact of load following operation on PCI — FMC (Rashid)
  - Assess BISON for BWR fuel failure PCI analysis — FMC (Powers)
- Improving VERA fuel models
  - Creation of a 1D Bison-informed fuel model available to both MPACT and CTF — PHI (Collins)
  - Advancement of Bison-informed fuel model in VERA-CS — PHI (Toptan)
  - Hi2Lo and active subspace capability development and Dakota integration — VVI (Smith)
- Enabling faster and more robust Bison solutions
  - Develop BISON 1.5D Capability for LWR Fuel — FMC (Hales)
  - Continued contact improvements for PCI — FMC (Williamson)
  - Continued improvements in numerical/mechanical BISON models — FMC (Liu)
- Methods development for fully-coupled solutions
  - Investigation of time-integration strategies for fully-coupled Tiamat — PHI (Stimpson)
  - Checkpoint execution of Bison MultiApps — PHI (Permann)
- Verification and testing
  - Tiamat-like tests in MOOSE — PHI (Pawlowski)
  - Review of Bison usage in VERA — PHI (Gardner)
  - Migration of common utilities from MPACT and CTF into a common repository — PHI (Collins)
  - Verify and Validate 1.5D Capability — FMC (Hales)

Coordinated contributions from ORNL, INL, SNL, NCSU, and Anatech

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