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Consortium for Advanced Simulation of LWRs

FY-2014 Results - and Their Importance

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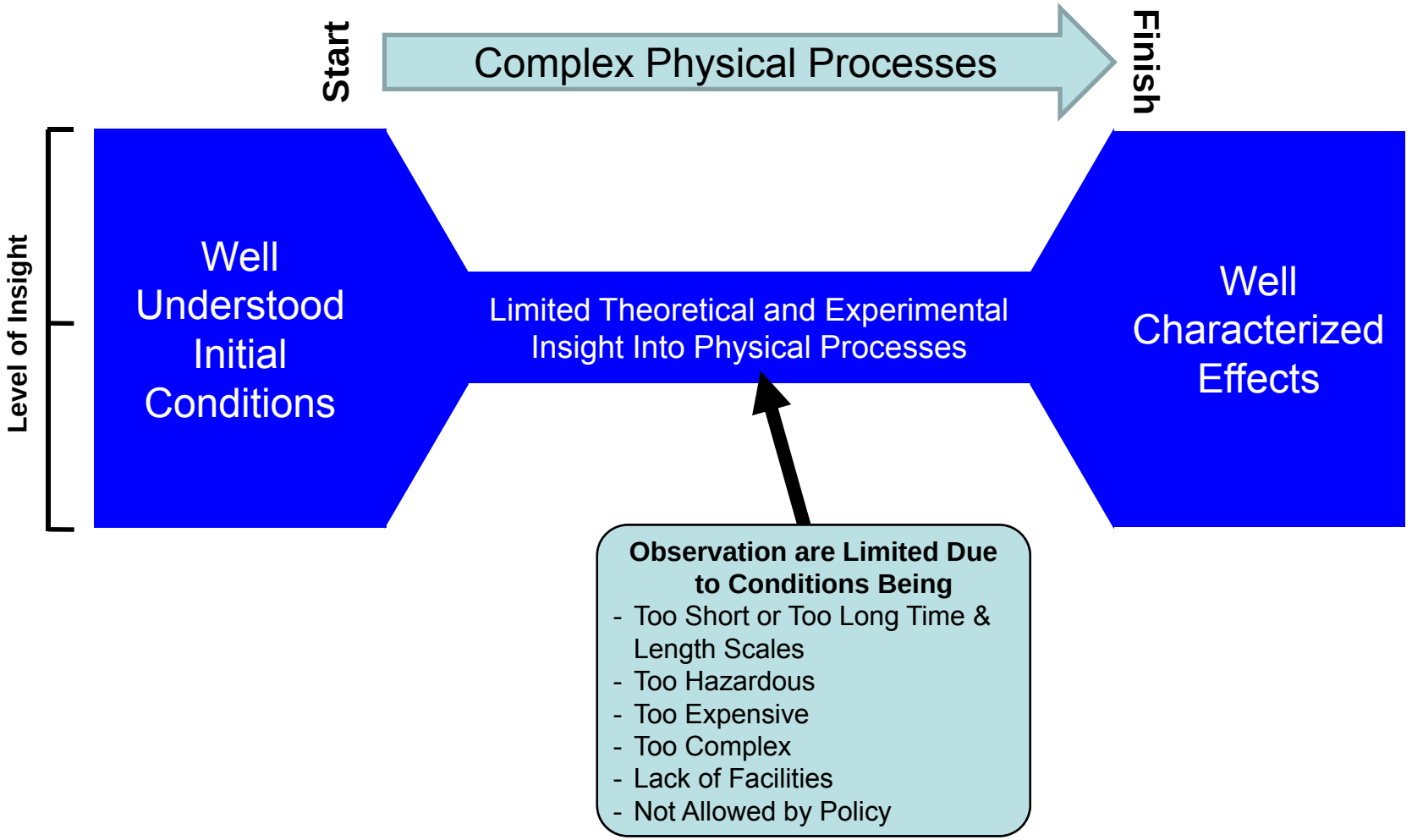
Understanding Complex Physical Processes



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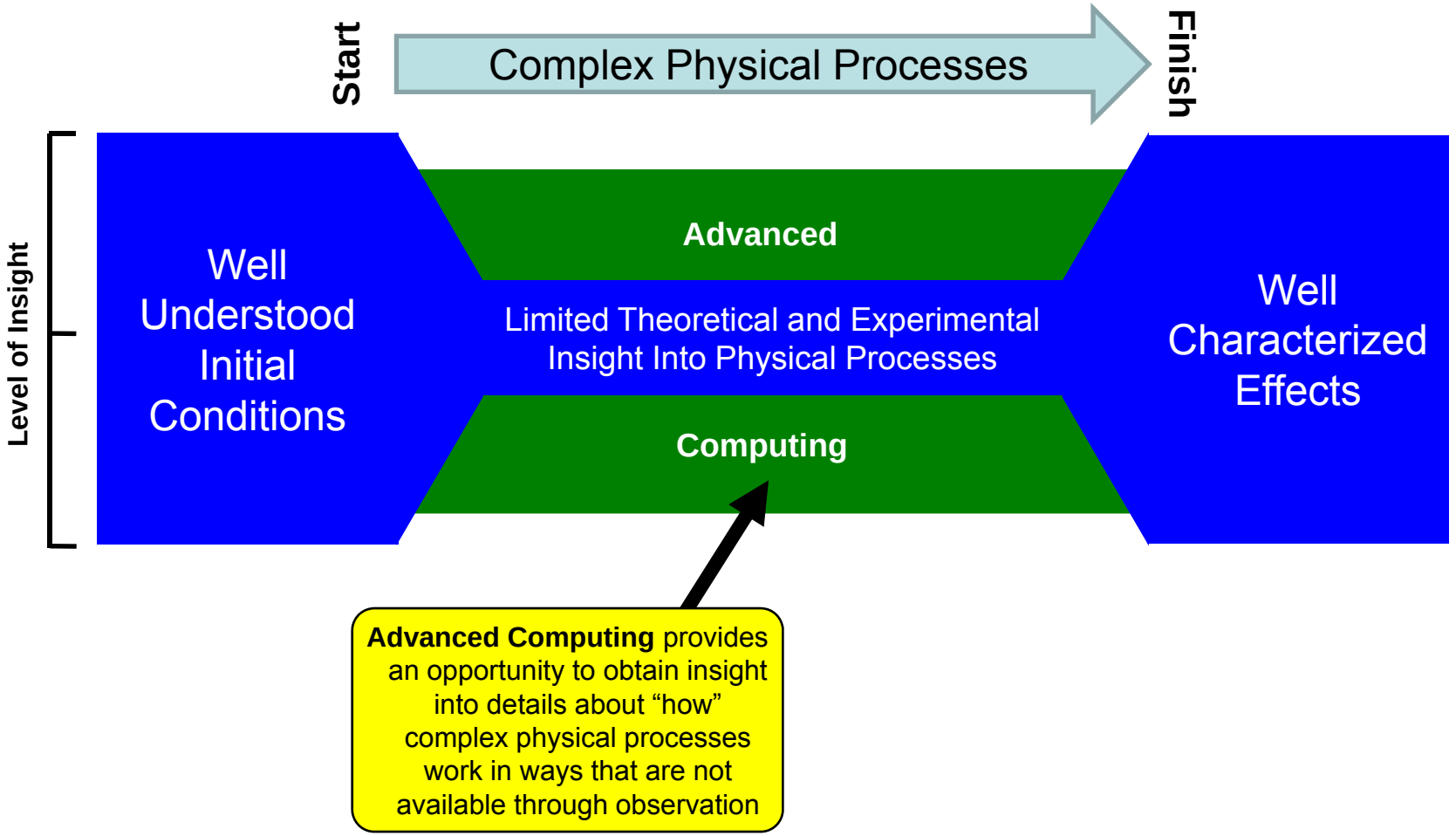
The Value of Adding of Modeling and Simulation



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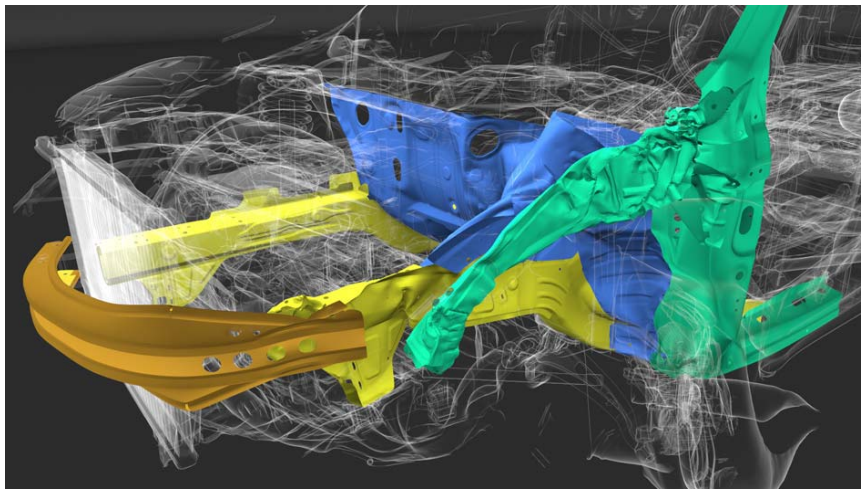
For Example – Automotive Crash Testing



Credit: http://www.rtt.ag/en/work/references/advanced-study-of-crash-test-simulations

Modeling and Simulation Results Provides the Ability to:

- Stop/slow time
- Make parts translucent
- Quantify parameters of interest
- Create a detailed understanding of “how” things happened during the crash

Verification, validation, and uncertainty quantification is always critical

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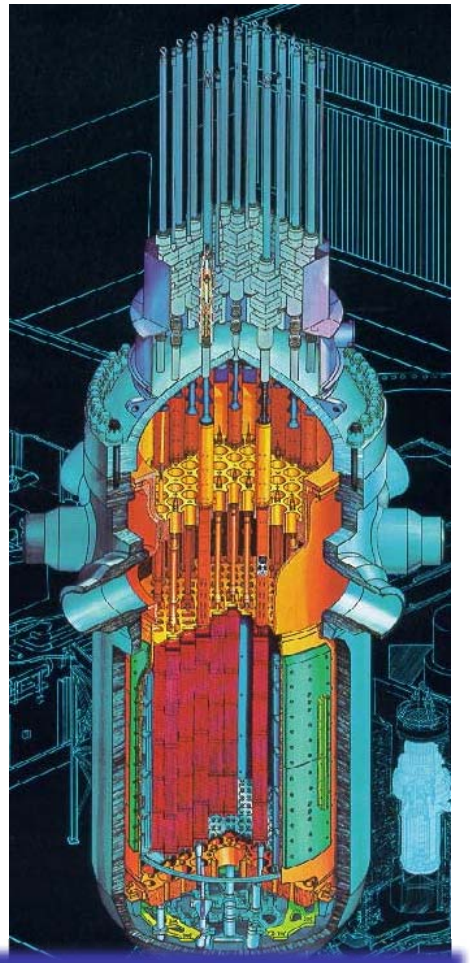
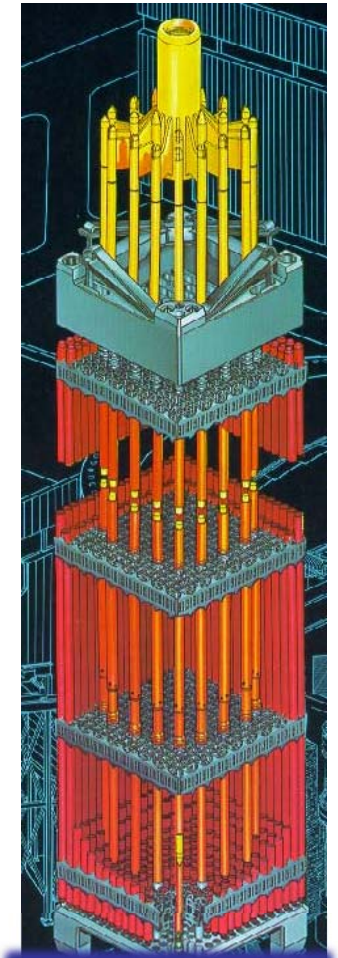
In Many Ways, Simulation of PWR is Even More Challenging



reactor vessel and internals



17x17 fuel assembly

Core
- 11.1' diameter x 12' high
- 193 fuel assemblies
- 107.7 tons of UO_2 (~3-5% U_{235})

Fuel Assemblies
- 17x17 pin lattice (14.3 mm pitch)
- 204 pins per assembly

Fuel Pins
- ~300-400 pellets stacked within 12' high x 0.61 mm thick Zr-4 cladding tube

Fuel Pellets
- 9.29 mm diameter x ~10.0 mm high

Fuel Temperatures
- 4140° F (max centerline)
- 657° F (max clad surface)

~51,000 fuel pins and over 16M fuel pellets in the core of a PWR!

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CASL Started by Asking Industry to Identify Their Challenge Problems

Improve Industry's Ability to Address Performance & Safety Challenge Problems

TVA's Watts Bar #1

PCI*
- Predict Core Wide PCI Margin with **PEREGRINE2D**
- Zoom in and Predict MPS PCI leaker with **PEREGRINE3D**

CRUD*
- **CIPS:** Predict Boron Uptake with **MAMBA2D and COBRA-TF**
- **CILC**: Predict Crud thk & corrosion with **MAMBA3D and HYDRA-TH**

VERA-CS*
Insilico-MPACT/ COBRA-TF/PEREGRINE
(full depletion for all rods in core)

RIA*
• Predict PCMI Margin using **MPACT** and **PEREGRINE2D**

LOCA*
•Predict PCT – Oxidation Margin using **PEREGRINE2D** & System Code **RELAP5 or W COBRA-TRAC**

DNB*
- Predict DNB Margin for RIA with **MPACT** and **COBRA-TF**
- Predict Mixing & DNB with CFD using **STAR/HYDRA-TH**

GTRF*
- Predict Minimum GTRF Margin in Core using **PEREGRINE2D** – grid to rod gap, **STAR/HYDRA-TH** excitation force

For Each Challenge Problem Apply DAKOTA using Coupled Tools for UQ

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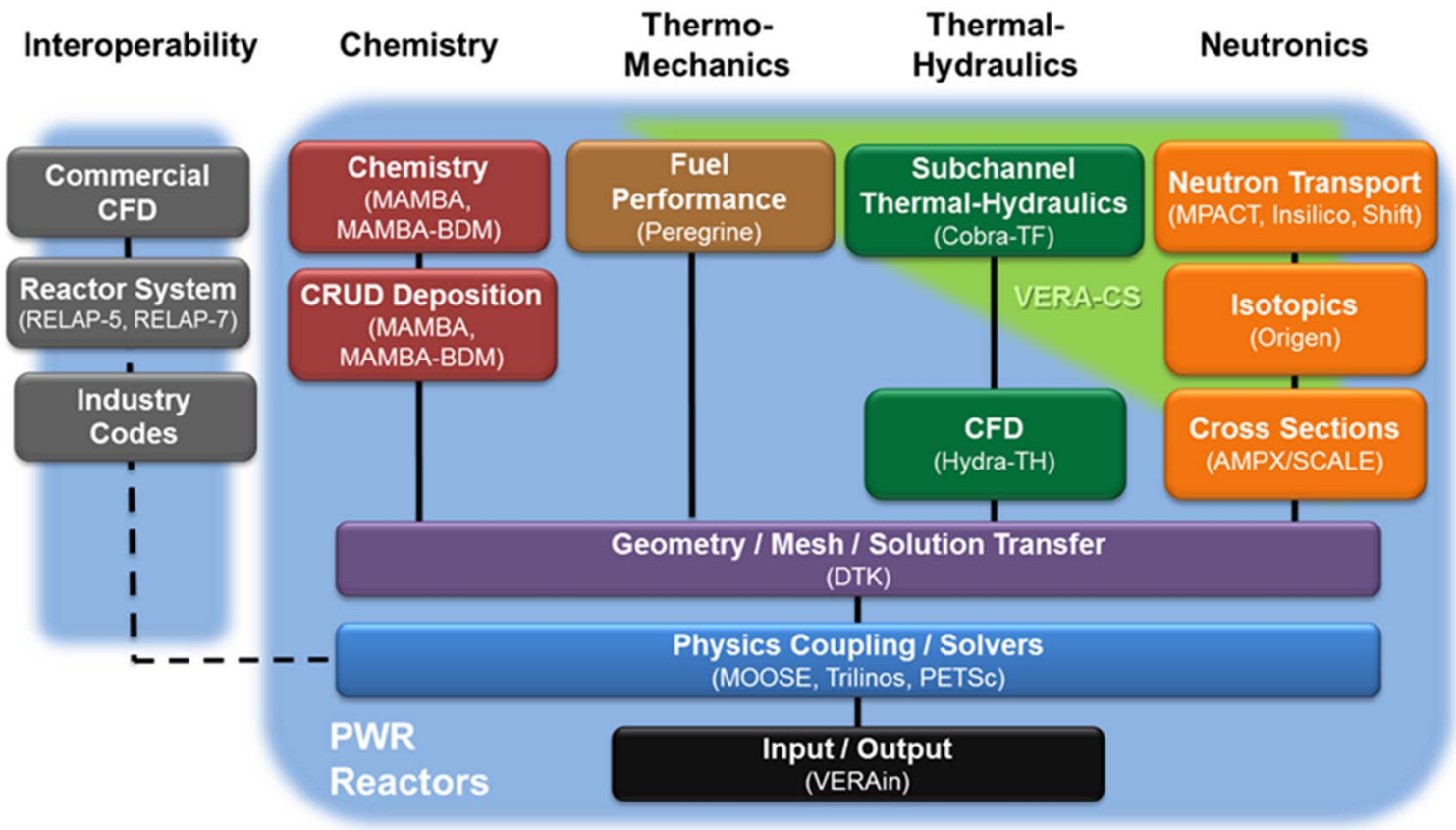
That Information Led to the Creation of a Modular and Flexible Architecture

Virtual Environment for Reactor Applications (VERA)



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Overall FY-2014 Was a Busy Year for CASL

- **Demonstration of neutronics coupled to thermal-hydraulics for a full-core scenario using VERA.**
  - *Target: September 2013 – Completed in December 2013*
- **VERA Deployment for EPRI Test Stand on PCI**
  - *Target: December 2013 – Completed on Time*
- **PWR Full Core 2D Depletion Capability with Pin Resolved Transport**
  - *Target: December 2013 – Completed on Time*
- **User Guidelines and Best Practices for CASL UQ Analysis using DAKOTA**
  - *Target: March 2014 – Completed on Time*
- **Experience with use of VERA in Industry Test Stands**
  - *Target: March 2014 – Completed on Time*
- **Assessment of CASL Engineering Wear Model Against Experimental Fretting Measurements**
  - *Target: June 2014 – Completed on Time*
- **Assess Peregrine as a 3D Fuel Performance Model for the PCI Challenge Problem**
  - *Target: July 2014 – Completed on Time*
- **Demonstrate integrated VERA-CS for the PCI Challenge Problem**
  - *Target: August 2014 – Completed on Time*
- **Demonstration of Integrated DA/UQ for VERA-CS on a Core Physics Progression Problem**
  - *Target: August 2014 – Completed on Time*
- **Single Phase Validation of Hydra-TH for Fuel Applications**
  - *Target: August 2014 – Completed on Time*
- **Implementation of Operational Reactor Depletion Analysis Capability with TH Feedback**
  - *Target: September 2014 – Completed on Time*
- **Demonstration of Coupled CFD and Crud/Corrosion Chemistry for a Fuel Sub-region**
  - *Target: September 2014 – Completed on Time*
- **Demonstration of Atomistically-informed Multiscale Zr Alloy Deformation Models in Peregrine for Normal Operation and Accident Scenarios**
  - *Target: September 2014 – Completed on Time*

In addition, CASL internally tracked about 100 other L2, L3, & L4 milestones

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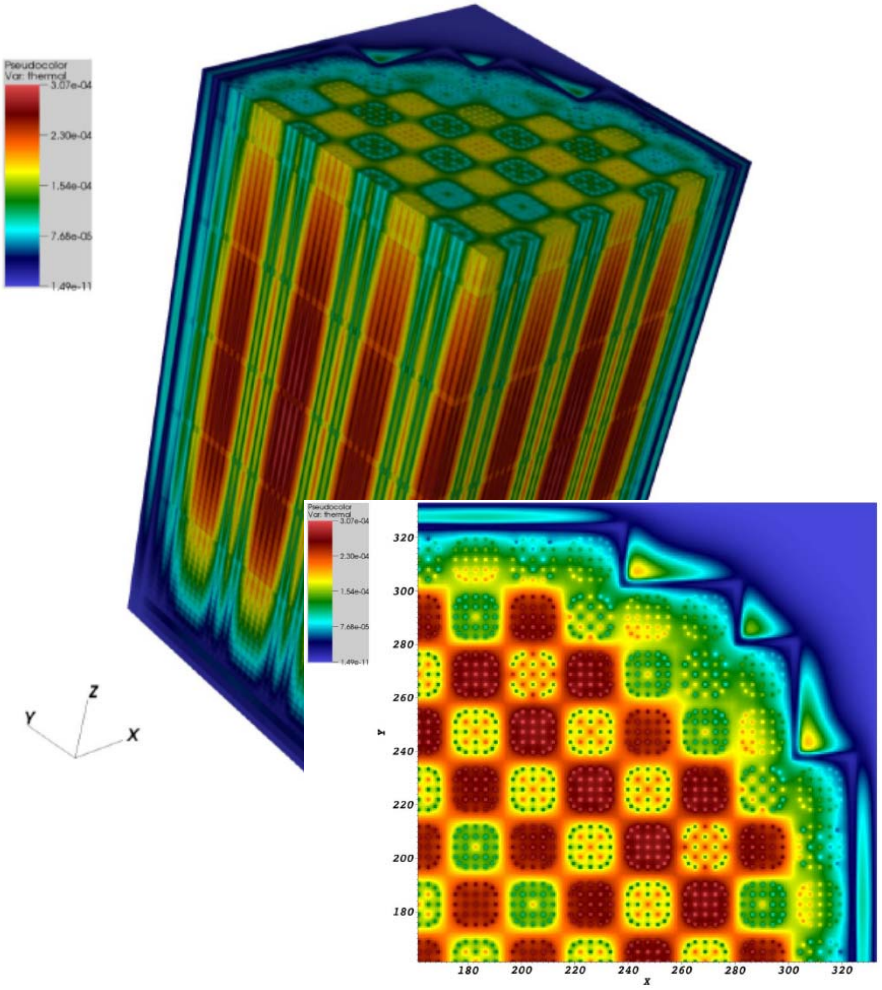
Demonstration of the VERA Core Simulator (VERA-CS)



- **FY13.CASL.011**
  - Demonstrated the modeling of a full Pressurized Water Reactor (PWR) core with a multiphysics coupling of neutronics (including cross section and neutron transport) and thermal-hydraulics
- **Importance**
  - Pin and sub-channel resolved core simulator that will be used to generate detailed understanding of conditions for the on-set of operational performance and safety issues

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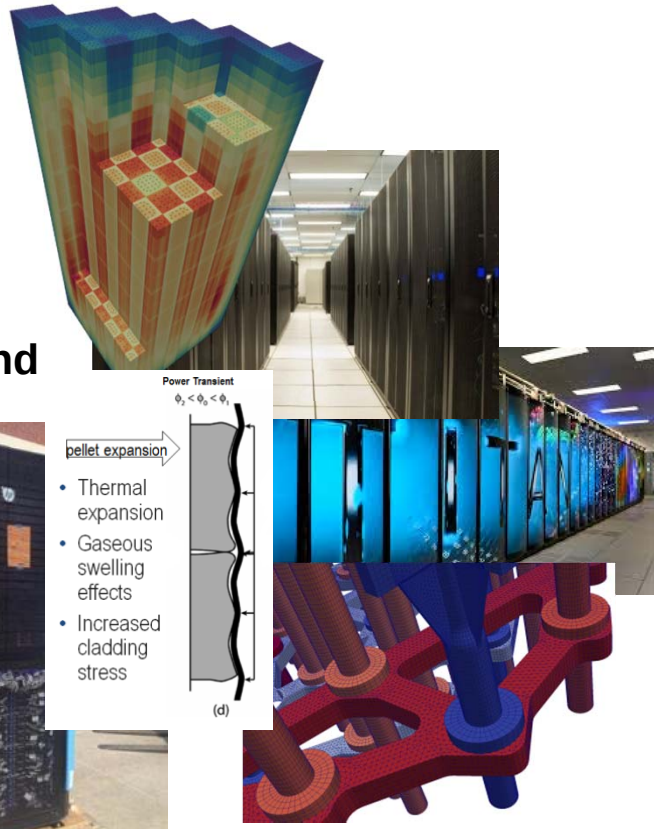
Report on Test Stands Experience

Westinghouse Test Stand



EPRI Test Stand

TVA Test Stand

- **FY14.CASL.004**
  - Milestone reports the experiences setting up computational “Test Stands”
  - Test Stands then used by industry partners for their own defined problems
- **Importance**
  - Demonstrates CASL’s commitment to deployment of its tools to industry users
  - Developed lessons learned and best practices for future deployments of CASL modsim tools into industry environments

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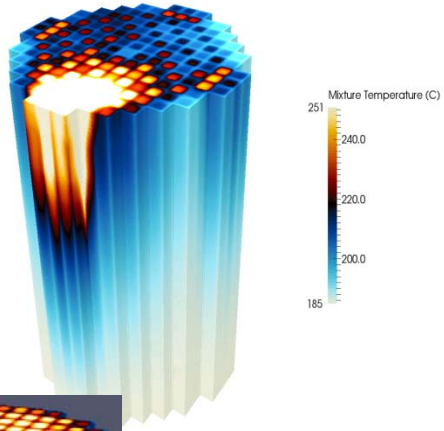
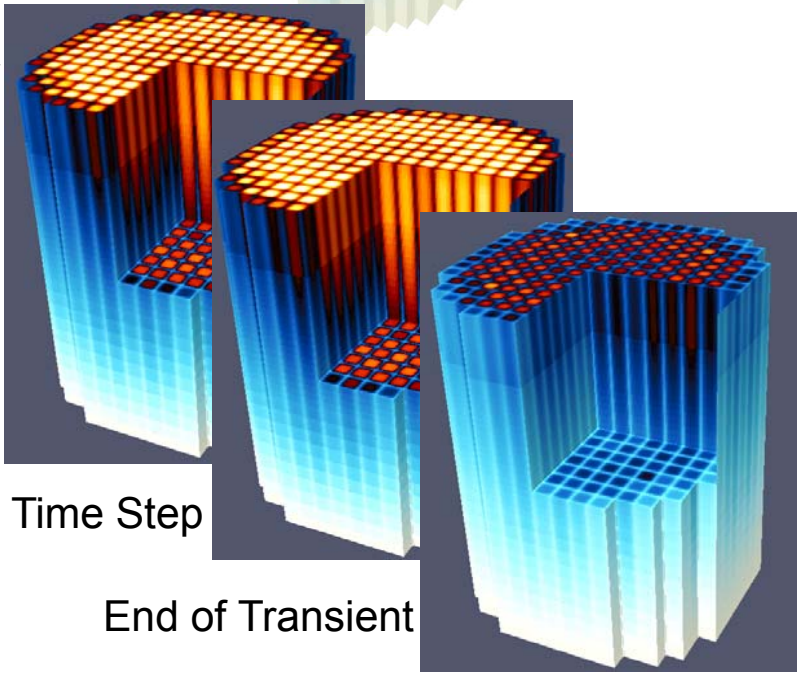
Application of VERA Thermal Hydraulics to Accident Conditions

Large Break Loss of Coolant Accident



Coolant Temperature

Reactivity Insertion Accident



Initial

DNBR Time Step

End of Transient

- **F&14.CASL.007**
  - Milestone reported the use of the COBRA-TH codes by Westinghouse to understand their potential applicability to simulate reactor accident conditions
  - Also the use of Hydra-TF for fine grain turbulence and single phase subassembly mixing
- **Importance**
  - Showed the use of CASL tools to simulate transient, accident conditions
  - Also, demonstrated the use of CASL tools by industry expert users

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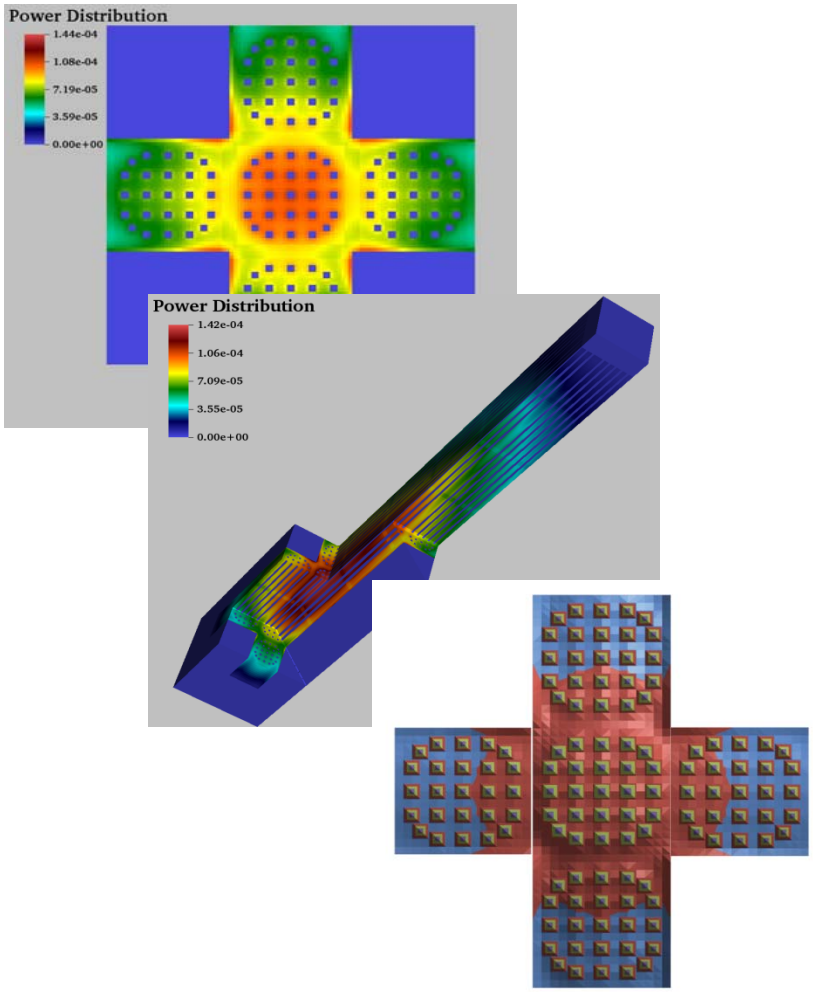
Simulating Pellet Clad Interface (PCI)



FY14.CASL.008

- Demonstrated integrated VERA-CS for the PCI challenge problem
- Performed multiple assembly simulation of coupled CTF/Insilico/BISON-CASL that computes figures of merit for PCI analysis.

Importance

- Required runtime coupling of neurtronics, thermal hydraulics, and fuel performance codes
- Tool to be used to develop improved understanding of PCI, which is often a limiting factor for reactor power ramp-up and load following

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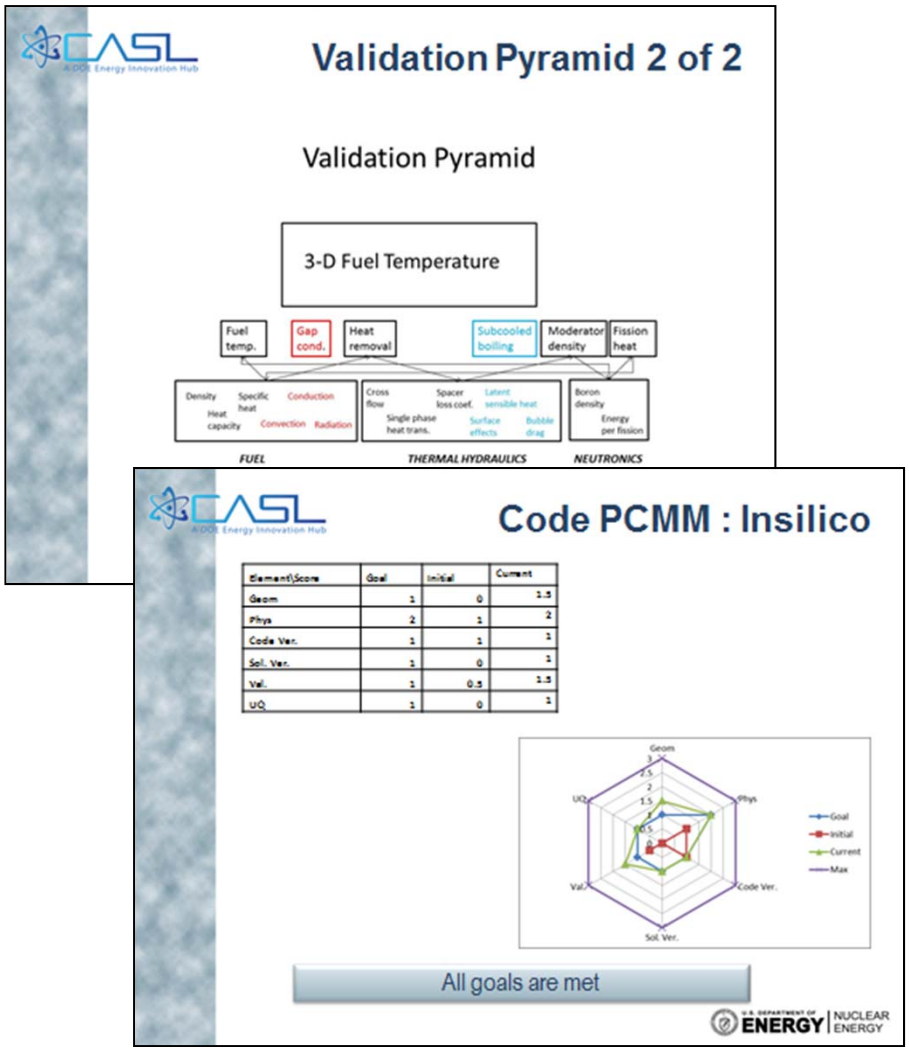
End to End Implementation of Verification and Validation Processes



- **FY14.CASL.009**
  - Demonstration of integrated Data Analysis/Uncertainty Quantification (DA/UQ) for VERA-CS on a core physics progression problem
- **Importance**
  - First demonstration by CASL of the full process of verification, validation, and uncertainty quantification using the Predictive Capability Maturity Model (PCMM)
  - Clarified the details of the process and the resources people, experimental data, computational) needed to execute

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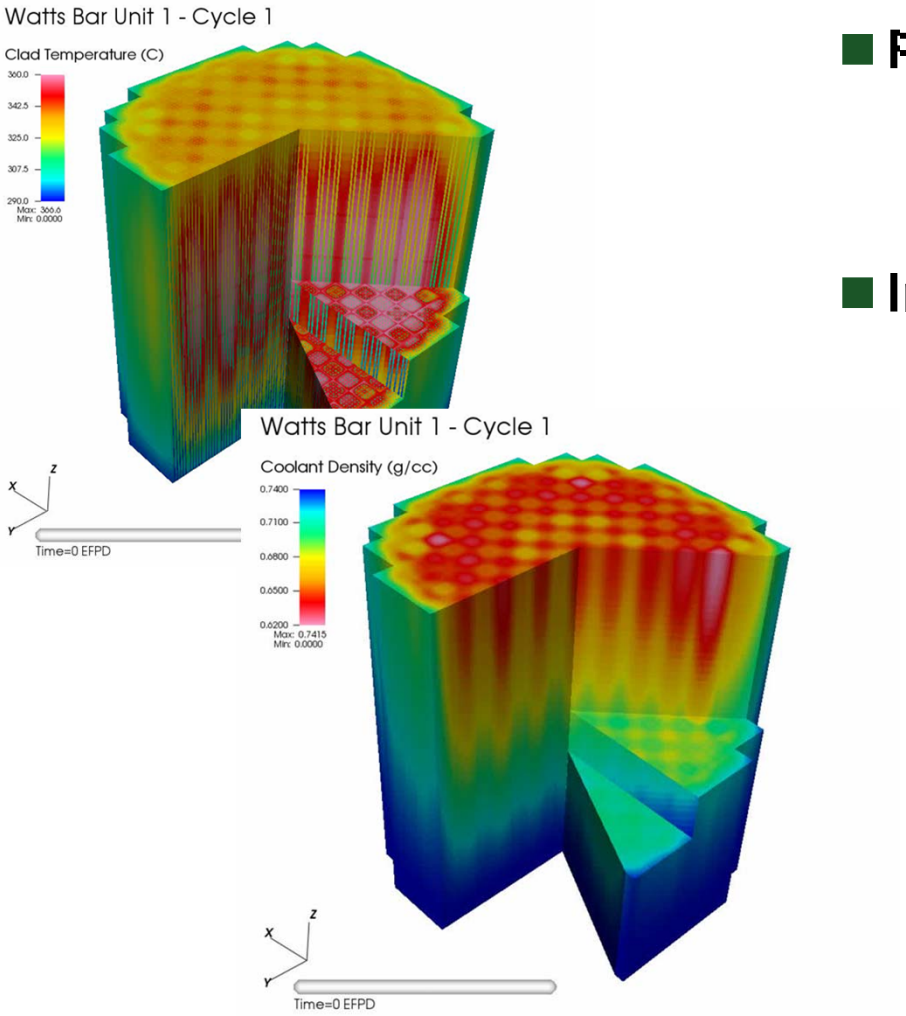
Implementation of Depletion in MPACT Neutron Transport Code



- **FY14.CASL.011**
  - Implementation of operational reactor depletion analysis capability with thermal-hydraulics feedback
- **Importance**
  - MPACT is being developed primarily by the University of Michigan
  - Uses Methods of Characterization (MOC) to resolve neutron transport for circular fuel pins
  - With depletion, VERA-CS is now able to load follow operational reactors. Watts Bar 1 data comparison (boron concentration) excellent.

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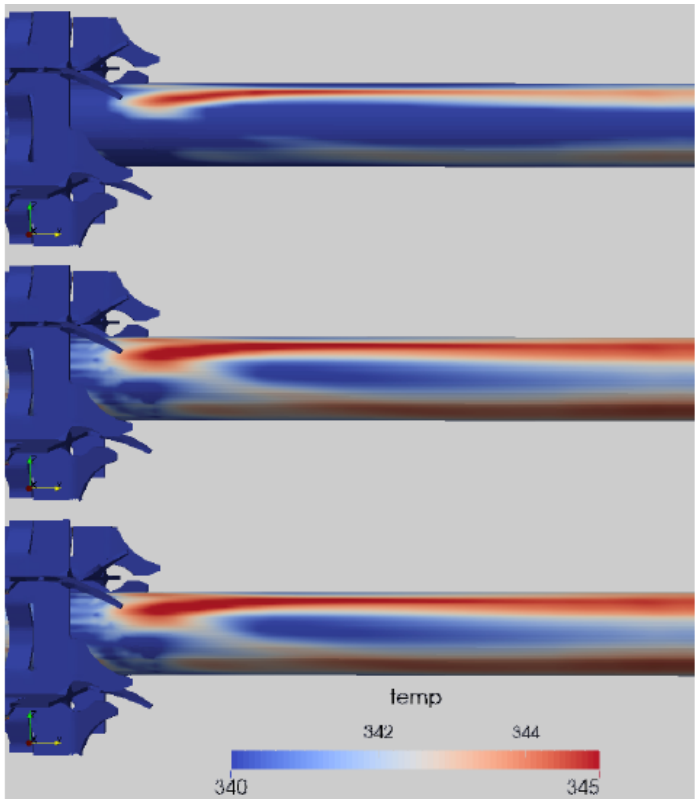
Coupled CFD and CRUD/Corrosion Chemistry



No Surface Chemistry

With Surface Chemistry

FY14.CASL.012

- Demonstration of Coupled Computational Fluid Dynamics (CFD) and CRUD/Corrosion Chemistry for a Fuel Sub-region

Importance

- CRUD is a fundamentally fuel pin level phenomena both axially and azimuthally
- This demonstration provides an initial capability that embeds surface chemistry with CFD to provide a detailed understanding of the impact of flow rates and turbulence on the formation (and erosion) of CRUD/Corrosion

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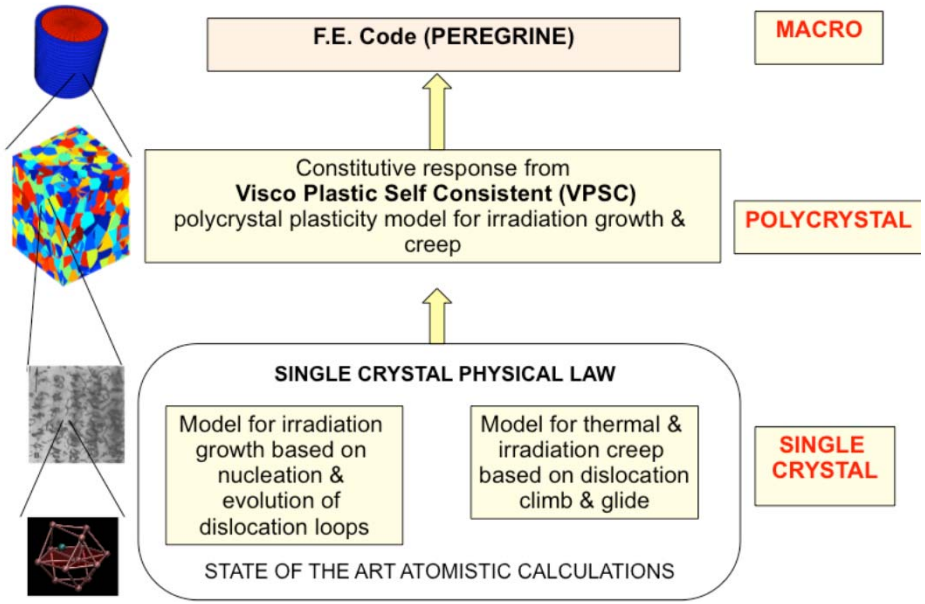
Implementation of Visco-Plastic Self-Consistent (VPSC) in BISON-CASL



- **FY14.CASL.013**
  - Demonstration of atomistically-informed multiscale Zr alloy deformation models in BISON-CASL for normal operations and accident conditions
- **Importance**
  - Implementation of VPSC in BISON-CASL (formerly known as Peregrine) so as to model important manufacturing details needed to understand how cladding shape evolves as influenced by radiation
  - Improved understanding will lead to better management of performance and safety margins

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FY-2014 Was an Important Year for CASL

- **CASL results this year build on a solid foundation**
- **VERA-CS maturing to the point of being ready for broad distribution in late FY-15**
- **Proactively assigned leadership roles to partners across the CASL organization**
- **Implemented an innovative mix of collaboration technologies and geographic co-location works to create a cohesive team**
- **Utilized sound program management practices**
- **In addition to all these accomplishments, CASL also completed their application for renewal to continue to Phase 2**
- **Phase 2 will focus on broadening and deepening Phase 1 deliverables**
- **They defined a new set of challenge problems**
  - Involving the CASL team, Industry Council, and other industry groups
  - These will be used to determine the future development of VERA
- **The DOE decision on renewal is pending**