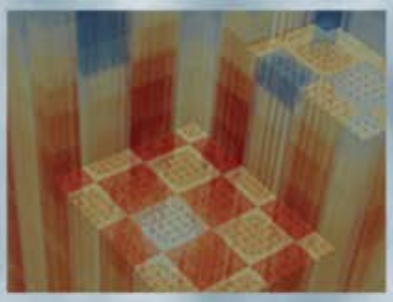
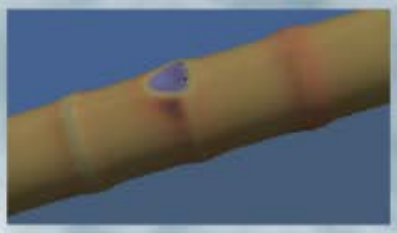
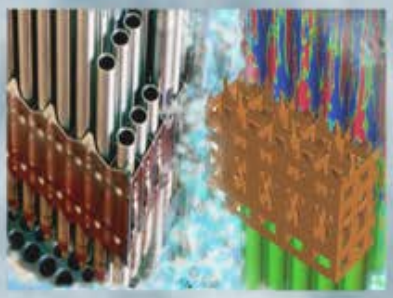
CASL-U-2015-0200-000

Electric Power Research Institute (EPRI) Workshop on High Performance Computing and Modeling Simulation







Heather Feldman, Brenden Mervin
Electric Power Research Insititute (EPRI)

October 15-16, 2014

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

ELECTRIC POWER RESEARCH INSTITUTE

AGENDA

WORKSHOP ON HIGH PERFORMANCE COMPUTING AND MODELING & SIMULATION

"Overcoming Barriers to Enable the Electric Power Industry to Realize the Benefits of High Performance Computing and Modeling & Simulation"

October 15-16, 2014 • EPRI Charlotte (Building 1 Rm 305)

WEDNESDAY, OCTOBER 15, 2014		
TIME	**TOPIC**	**PRESENTER**
7:30 a.m.	Continental Breakfast	
8:00 a.m.	Welcome and Overview of EPRI's HPC Initiative	***Heather Feldman (EPRI)***
8:30 a.m.	From Edison to Cray: An Industrial Cultural Revolution	***Rick Arthur (GE Global Research)***
9:15 a.m.	Break	
9:30 a.m.	Panel Discussion – Overcoming Barriers	***Rick Arthur (GE Global Research)*** ***Ashok Krishnamurthy (RENCI)***
10:45 a.m.	Break	
11:00 a.m.	Panel Discussion – Working with National Labs	***Suzy Tichenor (ORNL)*** ***John Grosh (LLNL)*** ***Eric Whiting (INL)***
12:00 p.m.	Lunch	
1:00 p.m.	On-line Transient Stability Analysis using High Performance Computing	***Liang Min (LLNL)***
1:45 p.m.	EPRI's Applications of HPC	
	• MAAP/Python and MACCS	***Rick Wachowiak (EPRI)*** ***Ken Canavan (EPRI)***
	• CASL Modeling & Simulation for High-Performance Computing Applications	***Brenden Mervin (EPRI)***
	• BOA Parameter Optimization Using Dakota	***Dan Wells (EPRI)***
	• Computational Electromagnetics for Power Utility Applications	***Alfonso Tarditi (EPRI)***
	• Computational Fluid Dynamics Studies in Environmental Controls	***Cassie Shaban (EPRI)***
4:30 p.m.	Round Table Discussion	***All***
5:00 p.m.	Adjourn	

Together . . . Shaping the Future of Electricity

WORKSHOP ON HIGH PERFORMANCE COMPUTING AND MODELING & SIMULATION

October 15-16, 2014 • EPRI Charlotte (Building 1 Rm 305)

THURSDAY, OCTOBER 16, 2014		
TIME	**TOPIC**	**PRESENTER**
7:30 a.m.	Continental Breakfast	
8:00 a.m.	Welcome	***Heather Feldman (EPRI)***
8:15 a.m.	Deep Dive of Hardware	***Mark Berrill (ORNL)***
9:00 a.m.	Introduction to Multiprocessing Programming	***Steve Smith (LLNL)***
9:45 a.m.	Break	
10:00 a.m.	Introduction to GPU Computing	***Steve Rohm (NVIDIA)*** ***Bill Veenhuis (NVIDIA)***
10:45 a.m.	Profiling, Tracing, and Identifying Bottlenecks in Parallel Codes	***Mark Berrill (ORNL)***
11:30 a.m.	Round Table and Wrap Up	***All***
12:00 p.m.	Lunch	
1:30 p.m.	Tour of UNC Charlotte's Research Computing Facility	***Chuck Price (UNC Charlotte)***
3:00 p.m.	**Adjourn**	

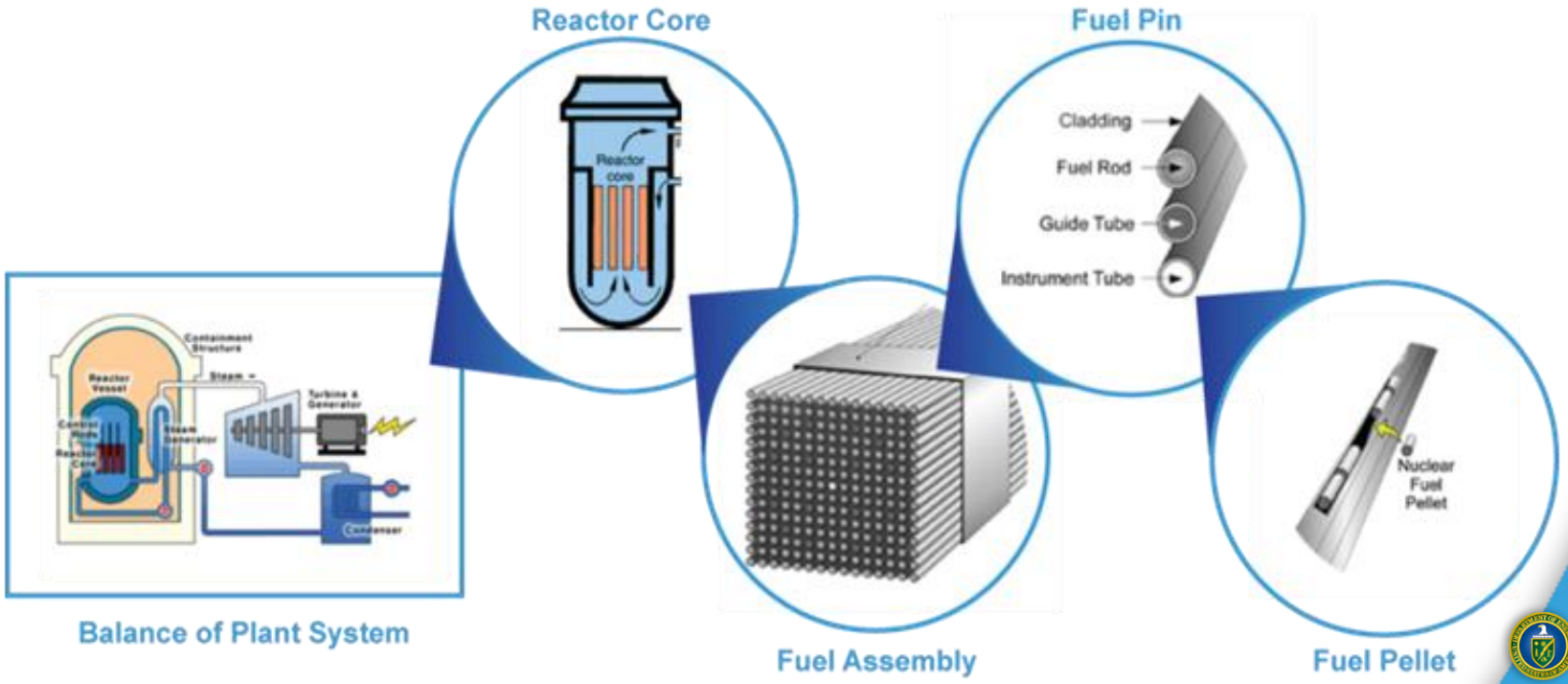
CASL Modeling & Simulation for High-Performance Computing Applications

October 15, 2014

Brenden Mervin

Overview

- CASL
  - Codes
  - Applications
  - Examples
- Test Stands
  - Westinghouse
  - EPRI
  - TVA



CASL: The Consortium for Advanced Simulation of Light Water Reactors

CASL will apply existing modeling and simulation (M&S) capabilities and develop advanced capabilities to create a usable environment for predictive simulation of light water reactors.

CASL partners are from national labs, universities and industry.

CASL consists of 6 technical "focus areas":

- Materials Performance
- Thermal Hydraulics
- Neutronics
- Validation/Uncertainty
- Model Applications
- Virtual Reactor development

Can an advanced "Virtual Reactor" be developed and applied to proactively address critical performance goals for nuclear power?

1

Reduce capital and operating costs per unit energy by:

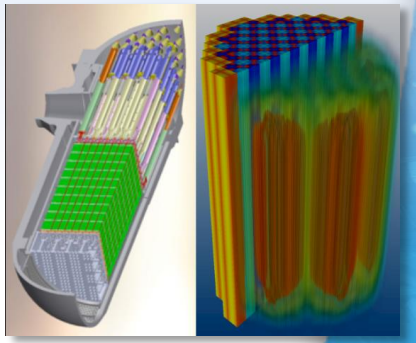
- Power uprates
- Lifetime extension

2

Reduce nuclear waste volume generated by enabling higher fuel burnups

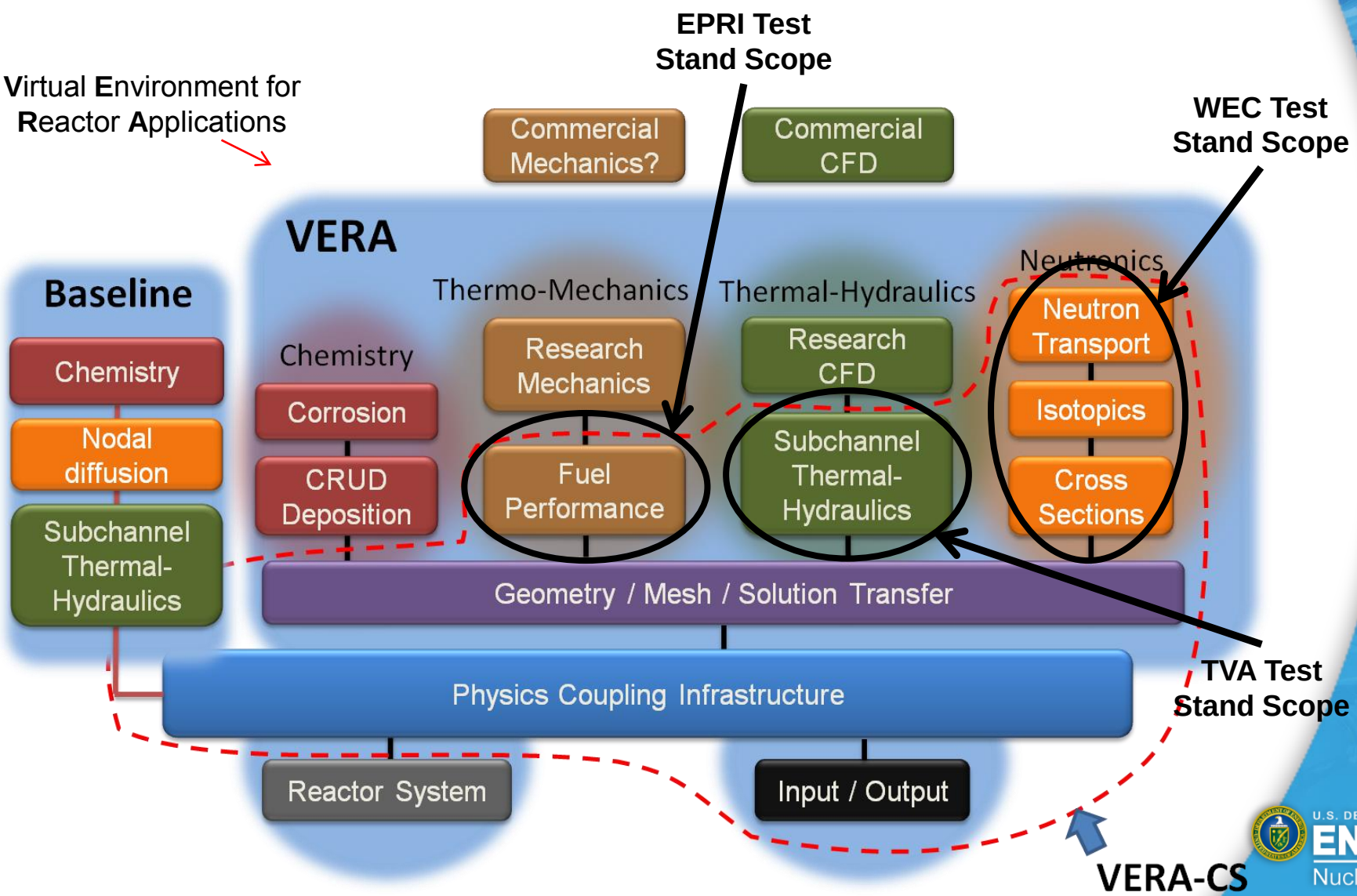
3

Assure nuclear safety by enabling high-fidelity predictive capability for component and system performance from beginning of life through failure

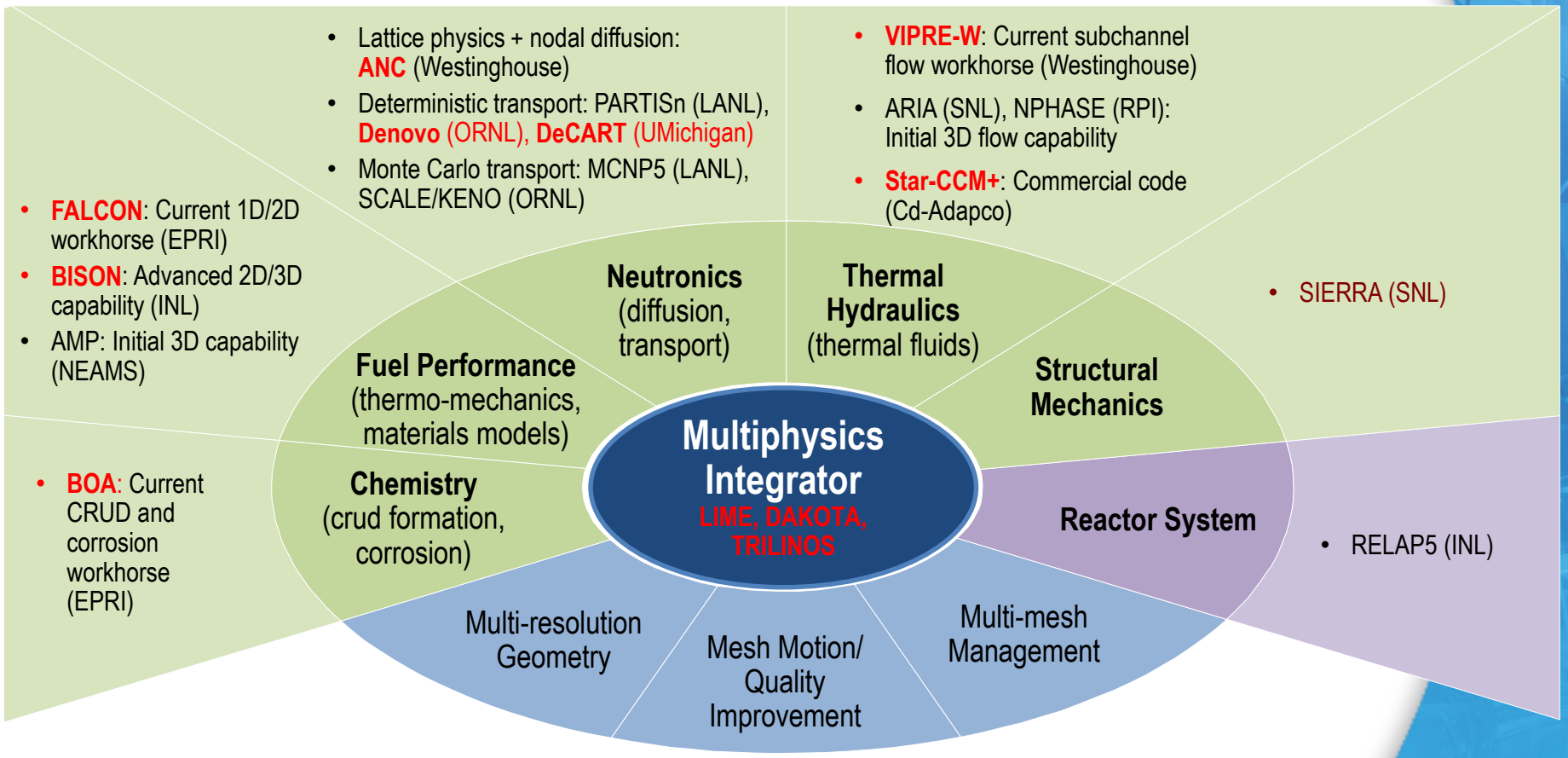


CASL Overview

VERA: Virtual Environment for Reactor Applications

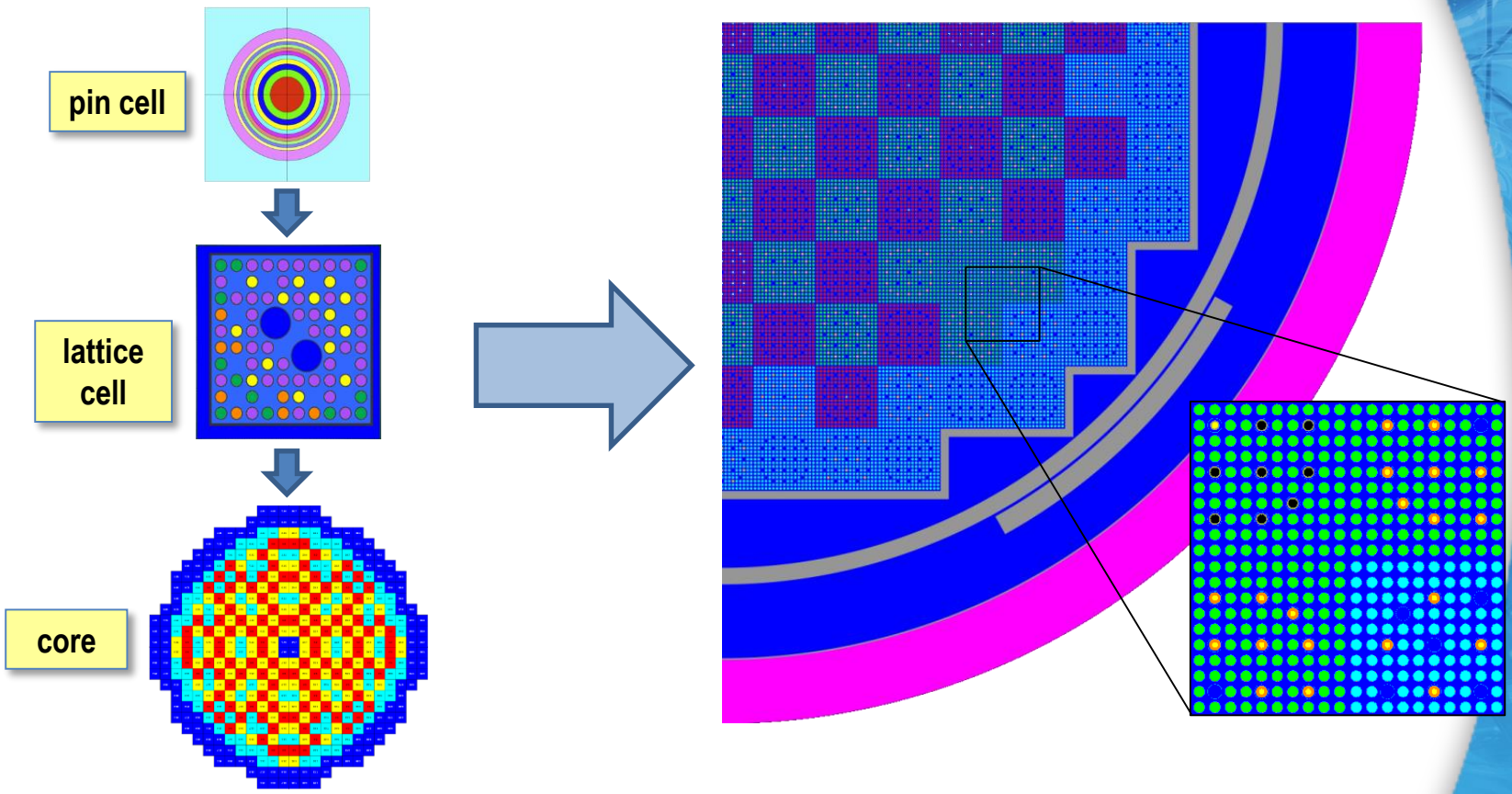


CASL Overview
Code Suite



Examples from Radiation Transport

Goal: High-Fidelity Simulations
Neutron Transport Example



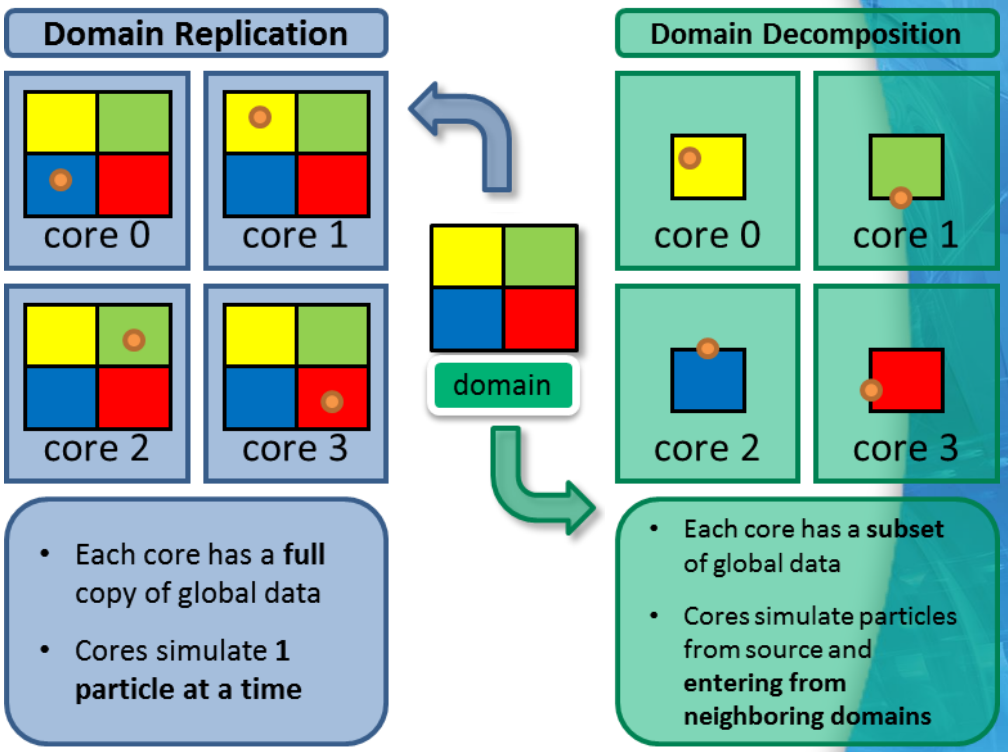
- Replace traditional step-by-step approach with high-fidelity fully-coupled approach

HPC-Enabled Neutron Transport
Stochastic (Monte Carlo) Approach

- PWR Core problem

193	(assemblies/core)
× 264	(rods/assembly)
× 4	(radial bins/rod)
× 4	(azimuthal bins/rod)
× 24	(axial bins/rod)
× 200	(energy groups)

= 3.91×10^9 tally bins	



- 10^9 tally bins in fuel is too much information to store on every processor
  - Represents approximately 16 GB of information per processor

HPC-Enabled Neutron Transport
Deterministic Approach

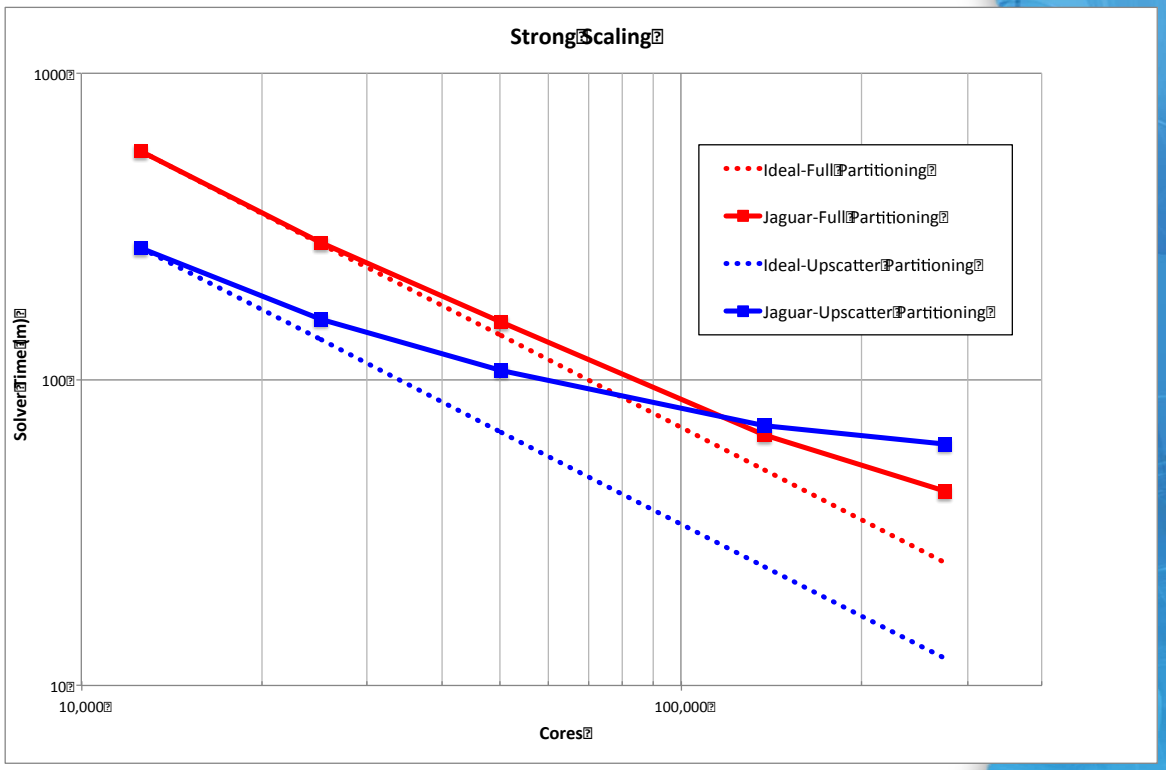
- Looking to solve for neutron angular flux, $\varphi\left(\vec{r}, \vec{\Omega}, E\right)$

70000	(radial locations)
× 500	(axial elevations)
× 8	(angles)
× 250	(energy groups)

= 10^{10}	unknowns

- The unknowns alone represent ~80 GB of data

PWR900 Scaling on Jaguar XK6 (2012)



Full partitioning scales well to 275,000 cores

- Assuming linear scaling on 275,000 processors:
  - In parallel: 40 minutes
  - In serial: **21 years**

Westinghouse Test Stand

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Westinghouse Test Stand – Zero Power Physics Test Simulations for the AP1000® PWR

2D

- Single Lattice (20 types)
- Multi Lattice (Unrodded and Rodded)
- Core with Reflector (Various Reflectors)

3D Assembly

- Single Assembly (7 types)
- Multi Assembly (Partial Rod Insertion)

3D Core

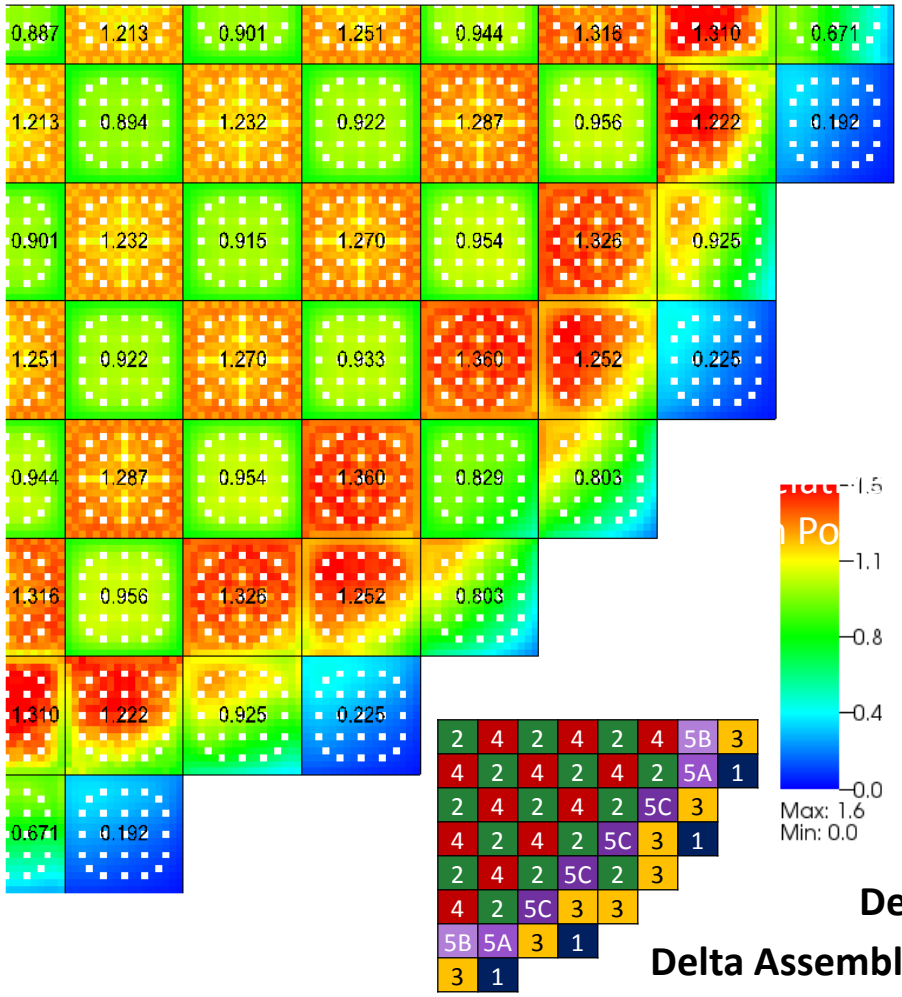
- HZP Critical Boron
- Rod Worth (11 Banks)
- Boron Worth

Using VERA with SP_N 3D neutronics capabilities (via Insilico)

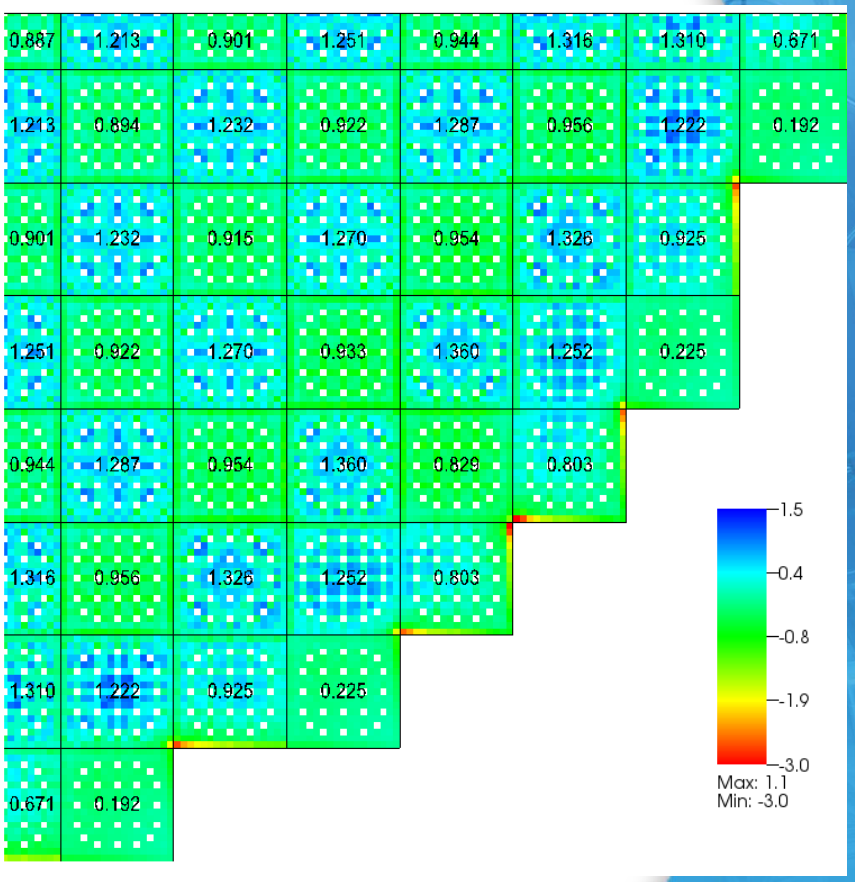
Westinghouse Test Stand Results

Power Distribution Results (from WEC)

Pin Power Distribution



Delta **Pin** Power x100 (VERA-KENO)



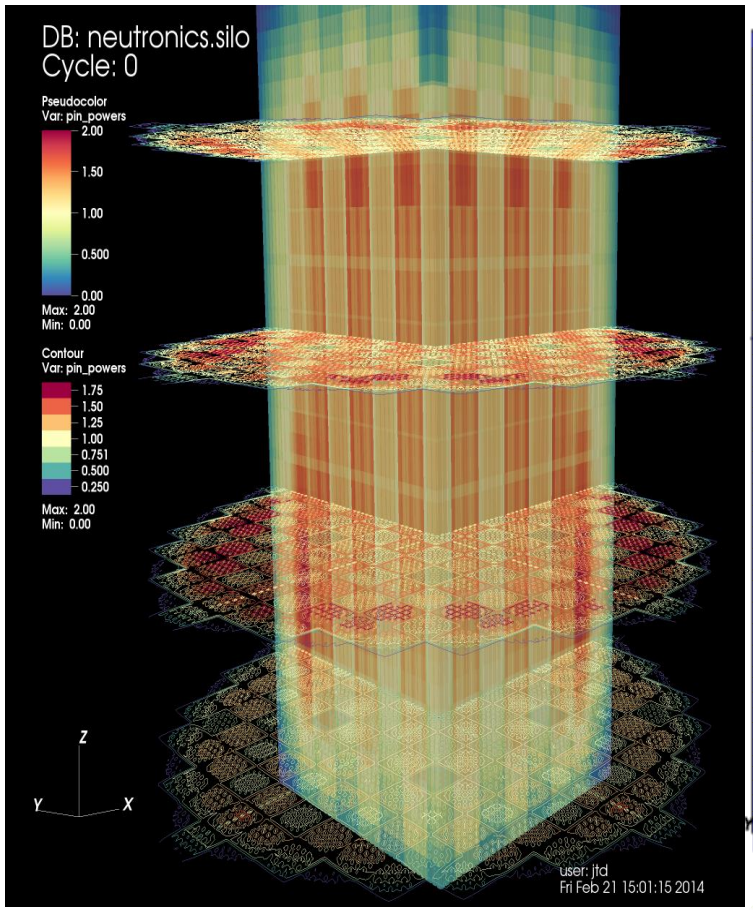
Delta k-eff : 0±1 pcm

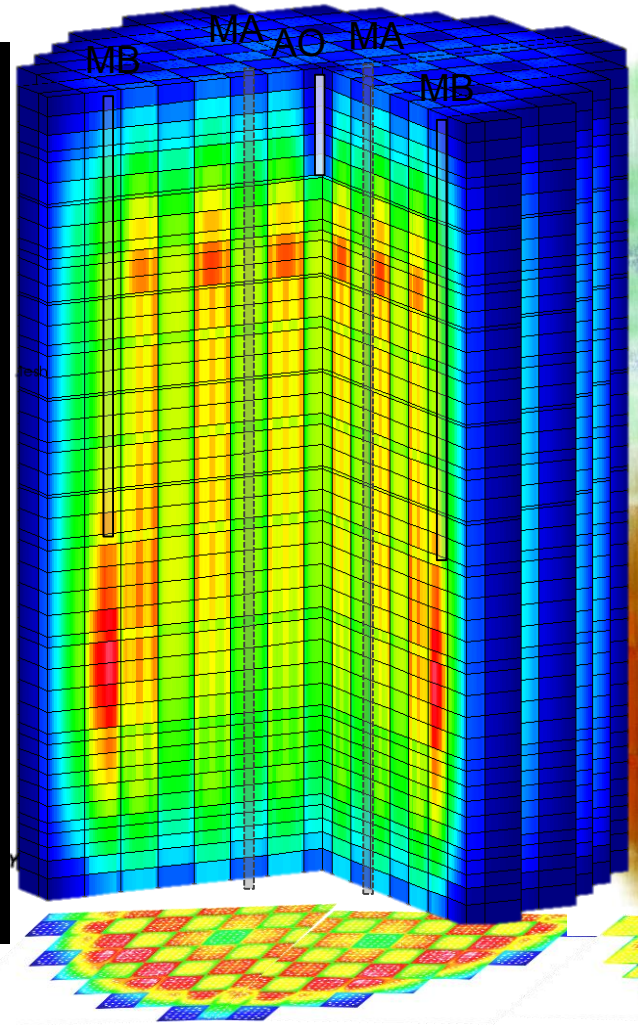
Delta Assembly Power RMS/Max: <0.3/0.4%

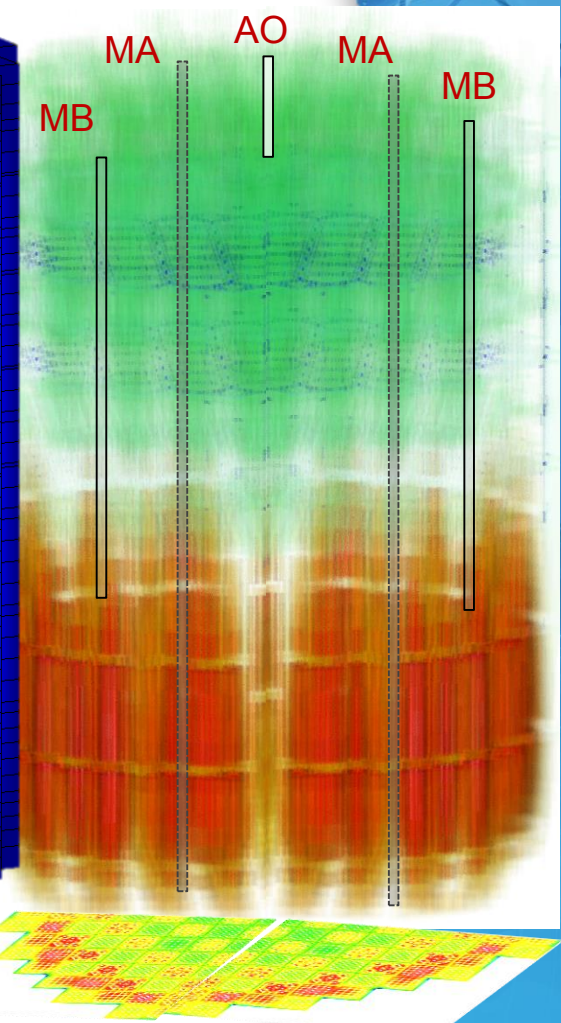
Delta Pin Power RMS/Max: 0.4/3.0 %

3D Core Power Distribution (AO and M-Banks Inserted)

3D Core ΔPower 100x(VERA-SHIFT)







Δk-eff = -81 +/- 2 pcm Hot Spot ΔP = 1% ΔAO = -0.9%

RMS ΔP = 1.2% Max ΔP = 5.9%

Computational Resources

	KENO (SHIFT for 3D Core)					VERA-CS SP_5P_3 23g				
	Particles (x10^9)	Pin Unc. %	Cores #	Wall Time	Core Hours	Cores #	Cells #	Core Hours	Wall Time	Memory
2D Lattice	1.1	0.02	312	~3.5h	1K	12	324	0.2	~1 min	<96 GB
3x3 Lattice	3	0.04	300	~10h	3K	12	3K	0.4	~2 min	<96 GB
2D Core	25	0.06	300	~6d	43K	144	86K	13	~5 min	<512 GB
3D Assembly	17.5	0.08	240	~3d	17K	64	0.2M	32	30 min	<512 GB
3D 3x3 Assembly	25	~0.1	180	~6d	26K	144	1.5M	96	40 min	<1.2 TB
3D Core (Eigenvalue)	25	0.38	180	6.5d	28K	320	6M	0.5K	100 min	<4 TB
3D Core (Pin Power)	1,000	<1%?	232K	5.5h	1.3M	4,096	24M	2.3K	34 min	<32TB

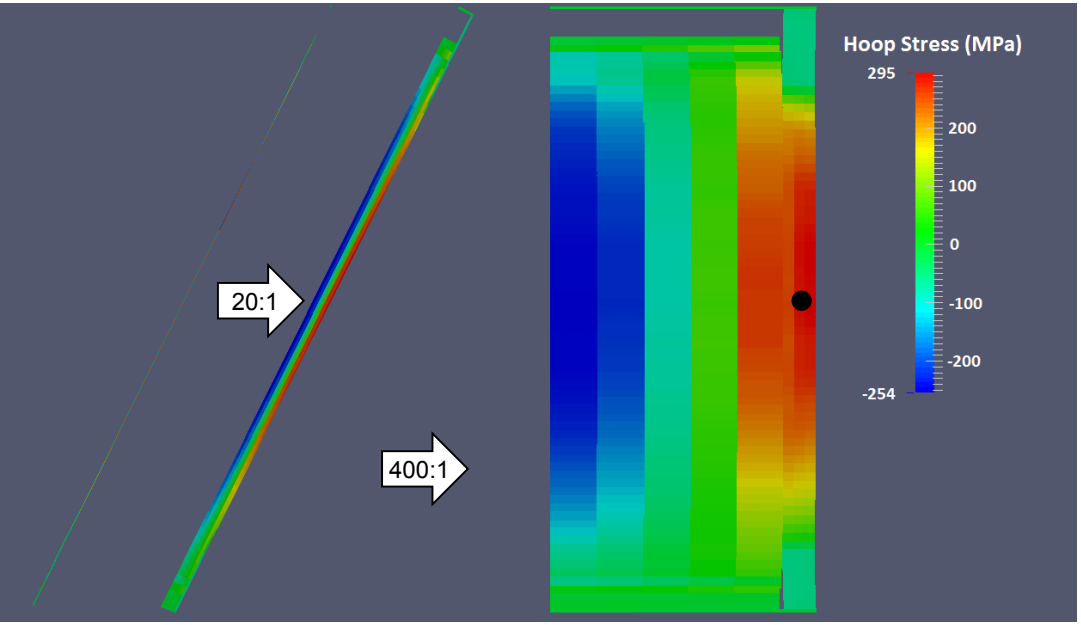
EPRI Test Stand

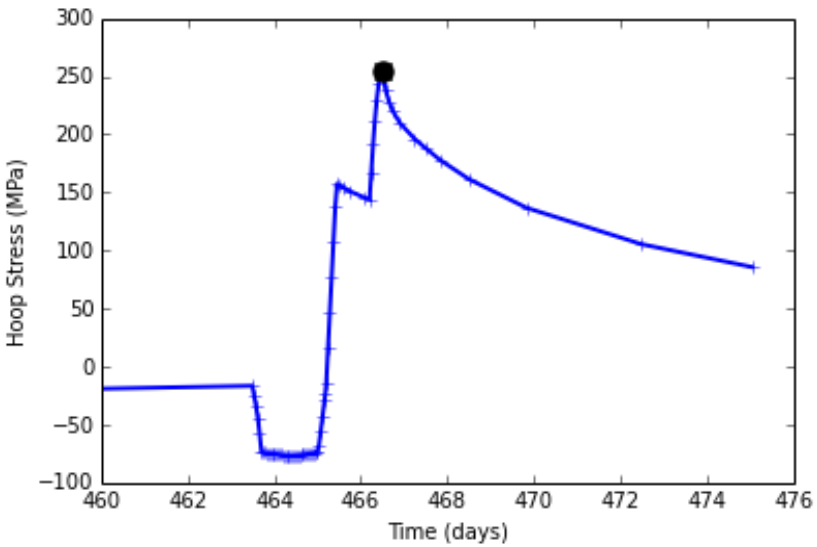
EPRI Test Stand
Thermo-Mechanical Analysis of Peregrine Fuel Performance Code

1. Thermal analysis of shortened rod with a flat axial profile
2. Single-cycle thermo-mechanical analysis of a full-length generic PWR fuel rod
3. Single-cycle thermo-mechanical analysis of a full-length generic PWR fuel rod with upscaled power history to force gap closure
4. Thermo-mechanical analysis with down power
5. Thermo-mechanical analysis with additional power ramp
6. Thermo-mechanical analysis with down power and 2nd cycle ramp
7. Thermo-mechanical analysis using proprietary reactor data

EPRI Test Stand
Pellet-Cladding Interaction (PCI)

2D FEM plot of the hoop stress for a full-length PWR fuel rod using aspect ratios of 1:1 (left), 20:1 (center), and 400:1 (right).



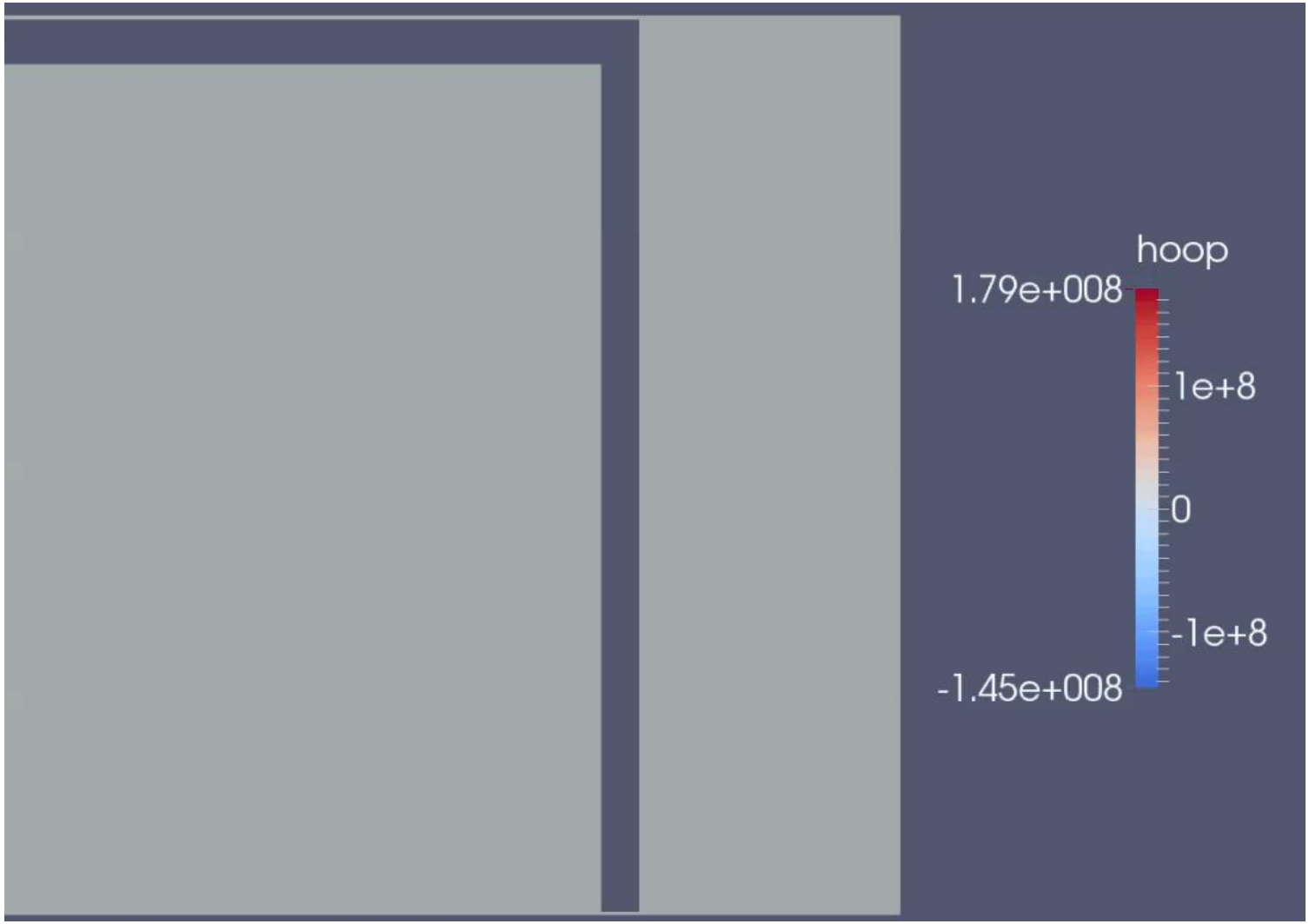


Inside cladding surface hoop stress predicted by Peregrine during second-cycle restart.

- Phoebe Usage Statistics
  - 400+ individual Peregrine simulations
  - 15,000+ core hours

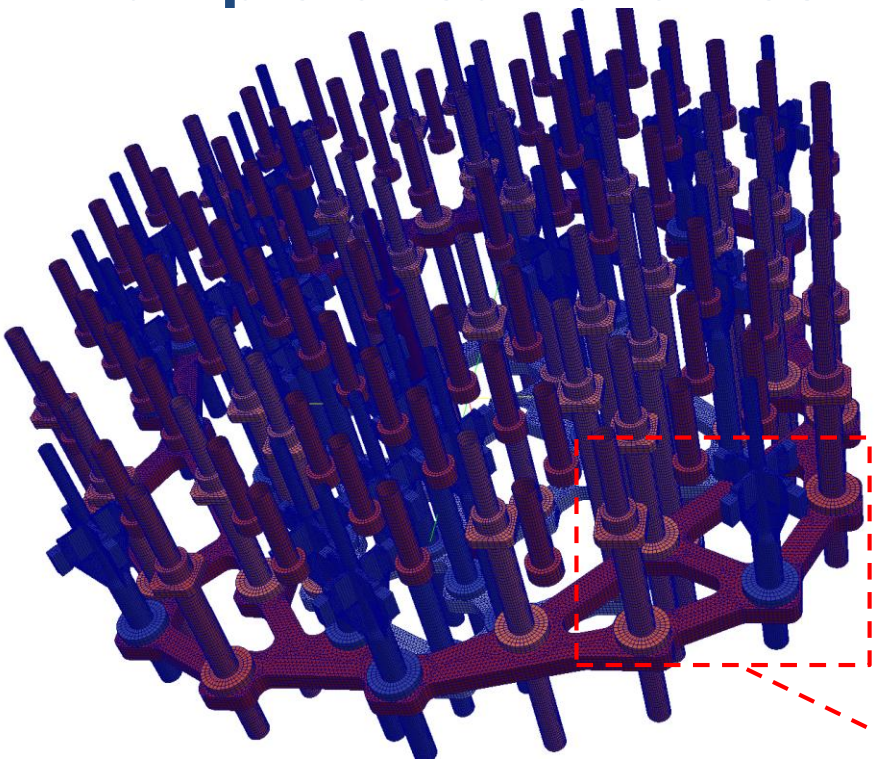
EPRI Test Stand

2D FEM animation of gap closure with hoop stress super-imposed

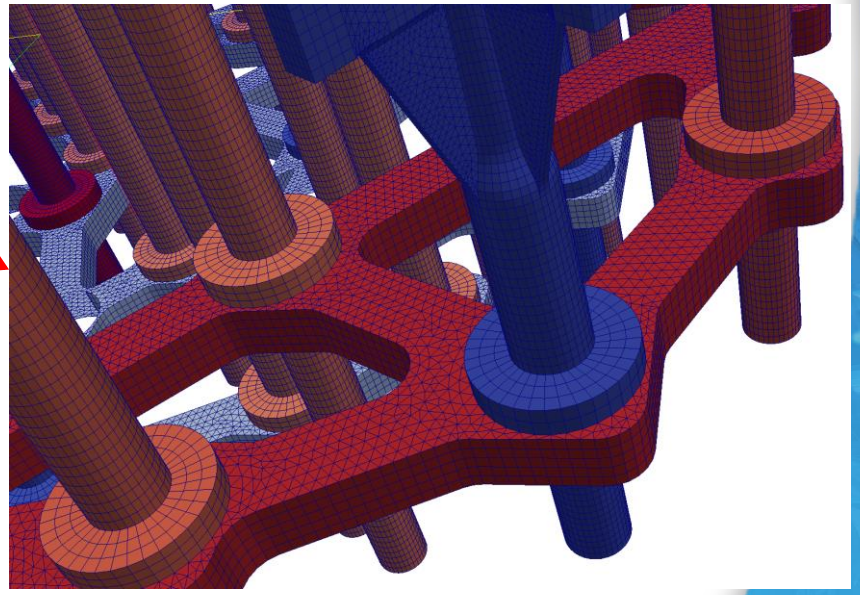


TVA Test Stand

Example of current mesh size being used

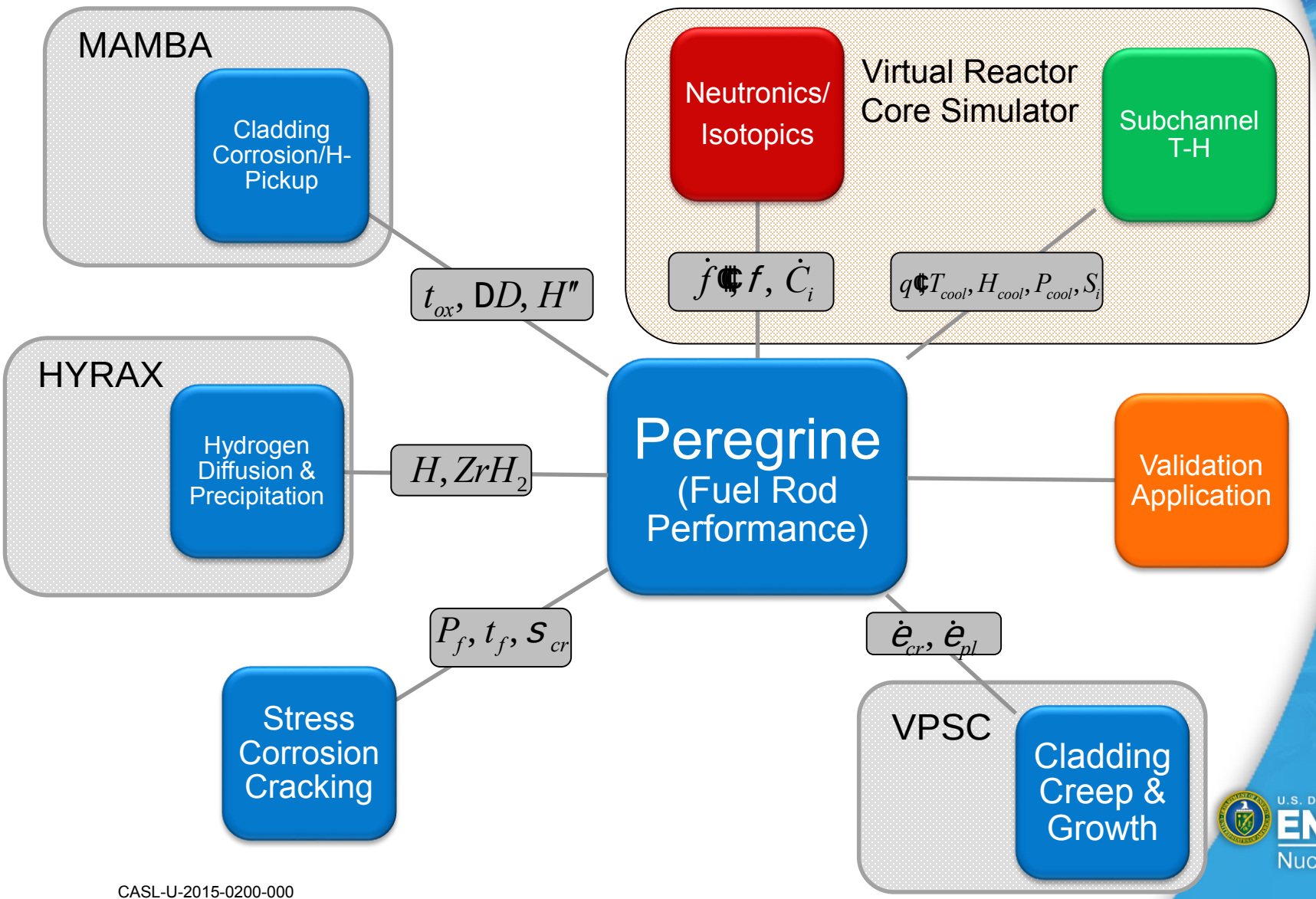


Mesh created by UT-C SimCenter



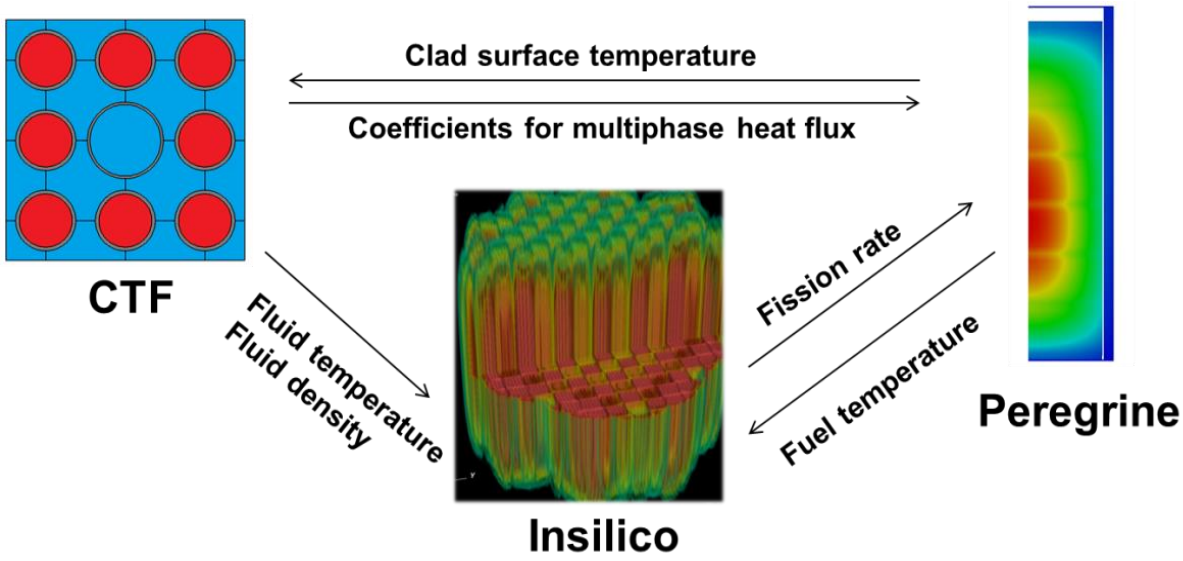
View of reactor lower internal structures

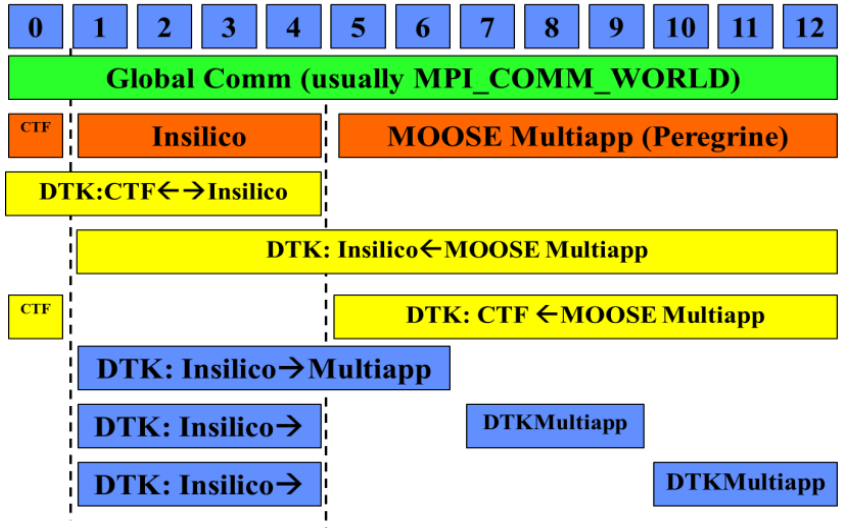
Multiphysics Coupling
Peregrine



Multiphysics Coupling

Neutronics, Thermal Hydraulics, and Fuel Performance

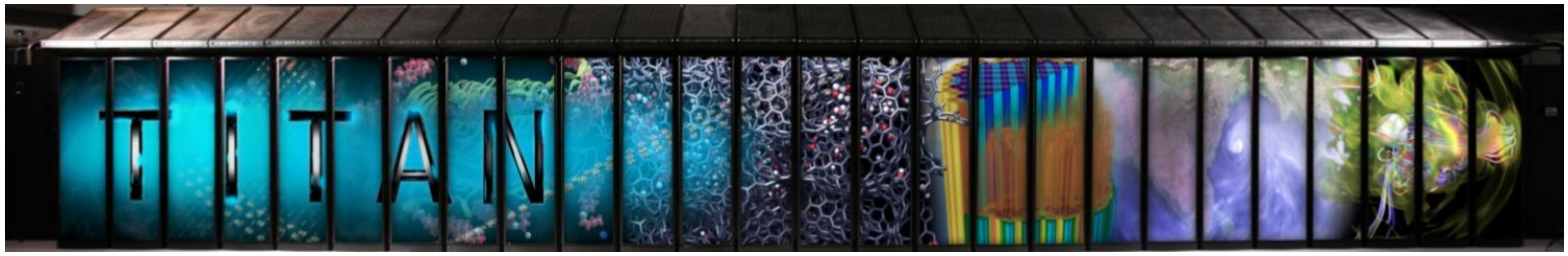




Acknowledgements

- Dennis Hussey, Steve Hess, Martin Pytel (EPRI)
- Robert Montgomery (PNNL)
- Fausto Franceschini, Zeses Karoutas (Westinghouse)
- Rose Montgomery (TVA)
- Doug Kothe, Scott Palmtag, Thomas Evans (ORNL)

Questions?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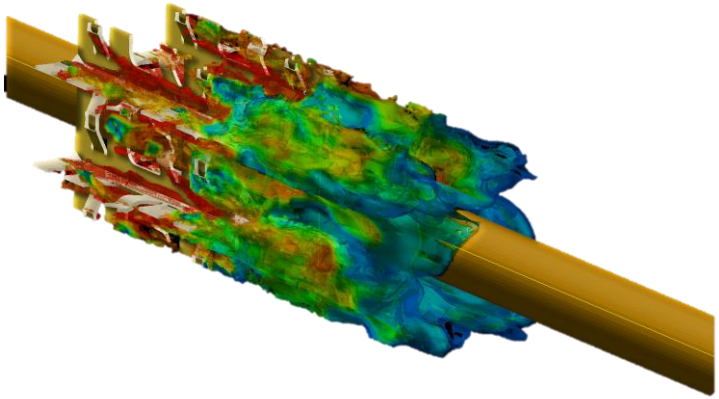

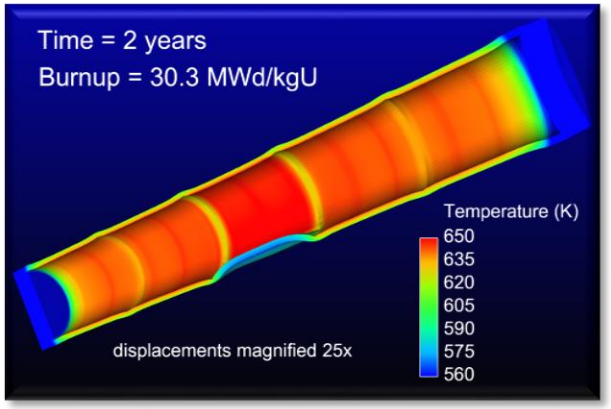
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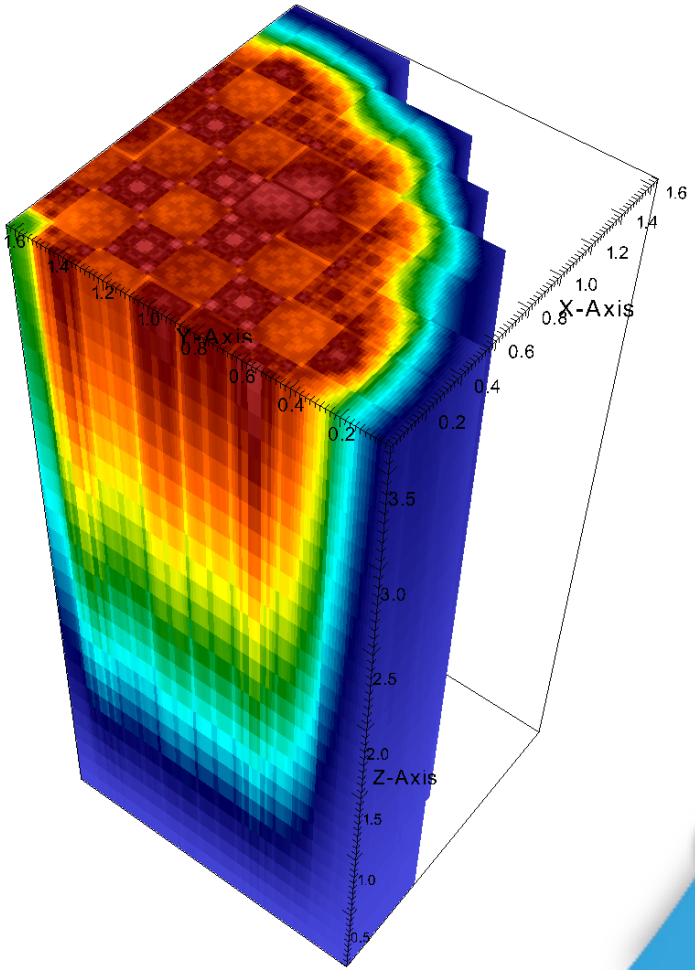
Burnup = 30.3 MWd/kgU
Temperature (K)
650
635
620
605
590
575
560
displacements magnified 25x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Y-Axis
Z-Axis