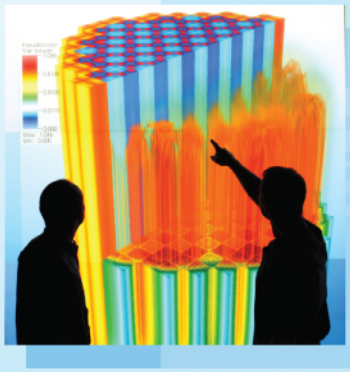
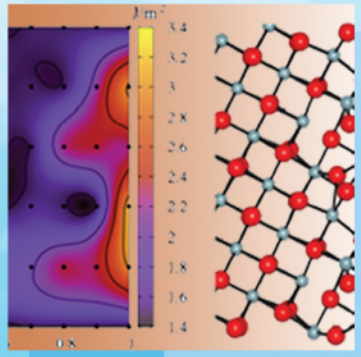
CASL-U-2014-0099-000

Power uprates
and plant life extension



Engineering design
and analysis

Science-enabling
high performance
computing



Fundamental science

Plant operational data

Consortium for Advanced Simulation of LWRs

Overview of the Consortium for the Advanced Simulation of Light Water Reactors (CASL)

Joel Kulesza, Fausto Franceschini
Westinghouse Electric Company, LLC

Tom Evans, Jess Gehin
Oak Ridge National Laboratory

April 17, 2014

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

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Paper A133

Outline

- Background & Relevance
- Goals
- Technical Focus Areas & Core Partners
- Resources
- Progress-to-Date (Examples: AP1000 ZPPT & SHIFT)
- Future Work
- Summary

Background

- Established in July 2010
- U. S. Department of Energy (DOE) Energy Innovation Hub
  - Innovation Hub Derives From Past Successful Major Collaborations
    - Manhattan Project, Bell Labs, etc.
- 5 Year Program, $25M / Year in Funding
  - Possibility of Extension to “Phase 2” – An Additional 5 Years
- Consortium is Centered at Oak Ridge National Laboratory
  - Six Technical Focus Area Teams
  - Ten Core Partners
- Focused on Modeling Physics within the Reactor Vessel
  - Neutronics, T-H, Chemistry, and Fuel & Structural Material Performance
  - Virtual Environment for Reactor Applications - Core Simulator (VERA-CS)
- Aimed at Improved Understanding of “Challenge Problems”

Relevance

- Advances Analytical State-of-the-Art
  - Advanced Modeling & Simulation Engineering Tools: Transport & Data Methods
  - Massive, Integrated, Software Project Development Methodology
  - Technical Project Collaboration Methods
- Fully-Coupled Analysis Toolset
  - Coupling & Modularity Leads to Portable Data
- Multi-Scale & Multi-Physics
  - Macroscopic & Microscopic Phenomena can be Considered Simultaneously
- Open Publication
- Periodic Generally-Available Releases of Tools
- Reactor Dosimetry Community Can Provide Validation
  - “Bridge the Gap” Between the Core & the Plant

Goals

- Addressing Contemporary Challenges for LWRs
  - Improve Economics (Operation & Power Uprate) and Safety
  - Provide Understanding for “Challenge Problem” Solutions
    - Normal Operation
    - Accident Conditions
    - Plant Lifetime Extension
  - Progress Towards Solutions and Better Understanding Validates Progress
- Developing and Applying Modern Virtual Reactor Technology
  - Traditional Reactor Design is Iterative, Decoupled, and Labor-Intensive
  - Leads to Overly Conservative Assumptions in Design
- Technical Community Engagement through Simulation
  - End Result Must be Usable by Nuclear Energy Community
- Developing New Collaboration Methods
  - Large, Geographically-Dispersed, Team – A Common Challenge

Challenge Problems

	Challenge Problem	Power Uprate	Higher Burnup	Life Extension	Safety
Operational Challenge Problems	CRUD-Induced Power Shift	X	X		X
	CRUD-Induced Localized Corrosion	X	X		X
	Grid-to-Rod Fretting Failure		X		X
	Pellet-Clad Interaction	X	X		X
	Fuel Assembly Distortion	X	X		X
Safety Challenge Problems	Departure from Nucleate Boiling	X			X
	Cladding Integrity during Loss of Coolant Accidents	X	X		X
	Cladding Integrity during Reactivity Insertion Accidents	X	X		X
	Reactor Vessel Integrity	X		X	X
	Reactor Internals Integrity	X		X	X

Technical Focus Areas

1. Advanced Modeling Applications (AMA)
   - Links Development & Full-Scale Validation, Sets Requirements
2. Physics Integration (PHI)
   - Assemblies Models, Methods, and Data
3. Radiation Transport Methods (RTM)
   - Develops Neutron Transport Simulation Tools - VERA
     - 3D Full-core Discrete Ordinates (S_N) Transport
     - Pin-homogenized Simplified P_N (SP_N) Transport
     - Pin-resolved 2D MOC Transport/1D Diffusion (or Transport)
     - Path Toward Hybrid Monte Carlo
4. Materials Performance and Optimization (MPO)
   - Models Fuel, Clad, and Structural Material Behavior
5. Validation and Uncertainty Quantification (VUQ)
   - Assigns Uncertainties to Improve Margins
6. Thermal-Hydraulics Methods (THM)

Core Partners

Over 20 Other Contributors…

Resources

- Computational
  - Allocation of Time on Titan – 300,000 Cores, 19,000 GPUs
  - HPC at various institutions (e.g. INL Fission)
  - Industry Partner Clusters – ~500 Cores
- Collaborative
  - Virtual Office Community and Computing (VOCC) Laboratory at ORNL
  - Personal Videoteleconferencing Software & Hardware
- Experimental
  - Fundamental Research in Support of Basic Physics Models
    - Individual Calculational Component Verification & Validation
  - Operational Reactor Data to Support Fully-Coupled Analysis
    - Whole Analysis Suite Verification & Validation

Progress-to-Date: Overall Roadmap

Capability	Year 1	Year 2	Year 3	Year 4	Year 5
Neutron Transport	• Full core 3D homogeneous pin cell Sn transport • Full core 2D/1D resolved pin cell MOC transport with T-H coupling	• Full-core 3D homogeneous pin cell Sn transport with T-H coupling	• Full-core 3D pin-resolved (Sn, MOC) transport • Initial transient 3D (Sn, MOC) transport capability	• Full-core 3D pin-resolved (Sn, MOC) transport with T-H coupling • Initial 3D hybrid MC transport	• Transient full-core 3D pin-resolved (Sn, MOC) transport with T-H coupling • Full-core 3D hybrid MC transport with T-H coupling
Thermal Fluids with Conjugate Heat Transfer	• Subchannel legacy and commercial CFD • Continuum & ITM multiphase benchmarks	• Next-generation sub-cooled boiling capability • Subgrid single-phase models informed by ITM	• Next-generation multiphase flow capability • Subgrid multiphase models informed by ITM	• Evaluate multiphase flow capability • Improved numerical methods & coupling	• Refined multiphase flow capability • Targeted methods & coupling advances
Fuel & Clad Performance	• 1.5D legacy capability • Phenomenological models & properties	• Initial fuel mesoscale models for FG release, swelling, μ-structural evolution • Initial corrosion models	• Clad mesoscale μ-structural evolution • Fuel chemistry evolution	• Clad corrosion & refined μ-structural evolution • SCC & fatigue crack propagation	• Full upscale model for fuel performance and life extension predictions
Coolant Chemistry	• Legacy capability	• CRUD source terms & growth model	• Boron uptake in CRUD	• CRUD formation	• CRUD formation & induced corrosion
Structural Thermo Mechanics	• Assess and integrate existing capability	• Loosely coupled structural vibrations • Initial radiation creep & hardening models	• Fully coupled structural vibration for fretting	• Implicit nonlinear fretting • Improved radiation damage models	• Formally assessed structural vibration capability
Physics Coupling	• Legacy coupled via LIME • Subchannel transport & single-phase CFD	• Homogeneous cell transport & CFD • Initial FSI	• Improved FSI • Homogeneous cell transport, CFD, fuel, & chemistry	• Pin-resolved transport & CFD	• Full-core transport, CFD, fuel, chemistry, mechanics • Core + physical plant
Validation and Uncertainty Quantification	• DAKOTA for scoping UQ	• Time-dependent DA for parameters and responses • Model V&V procedures and initial databases	• Sensitivity and UQ for coupled components • Model V&V tools for selected modules	• DA with reduced-order modeling • Model V&V tools for selected coupled modules	• High-order DA including errors and uncertainties • Model V&V tools for coupled VERA system

Today & On-Track

Progress-to-Date: Example – AP1000 ZPPT

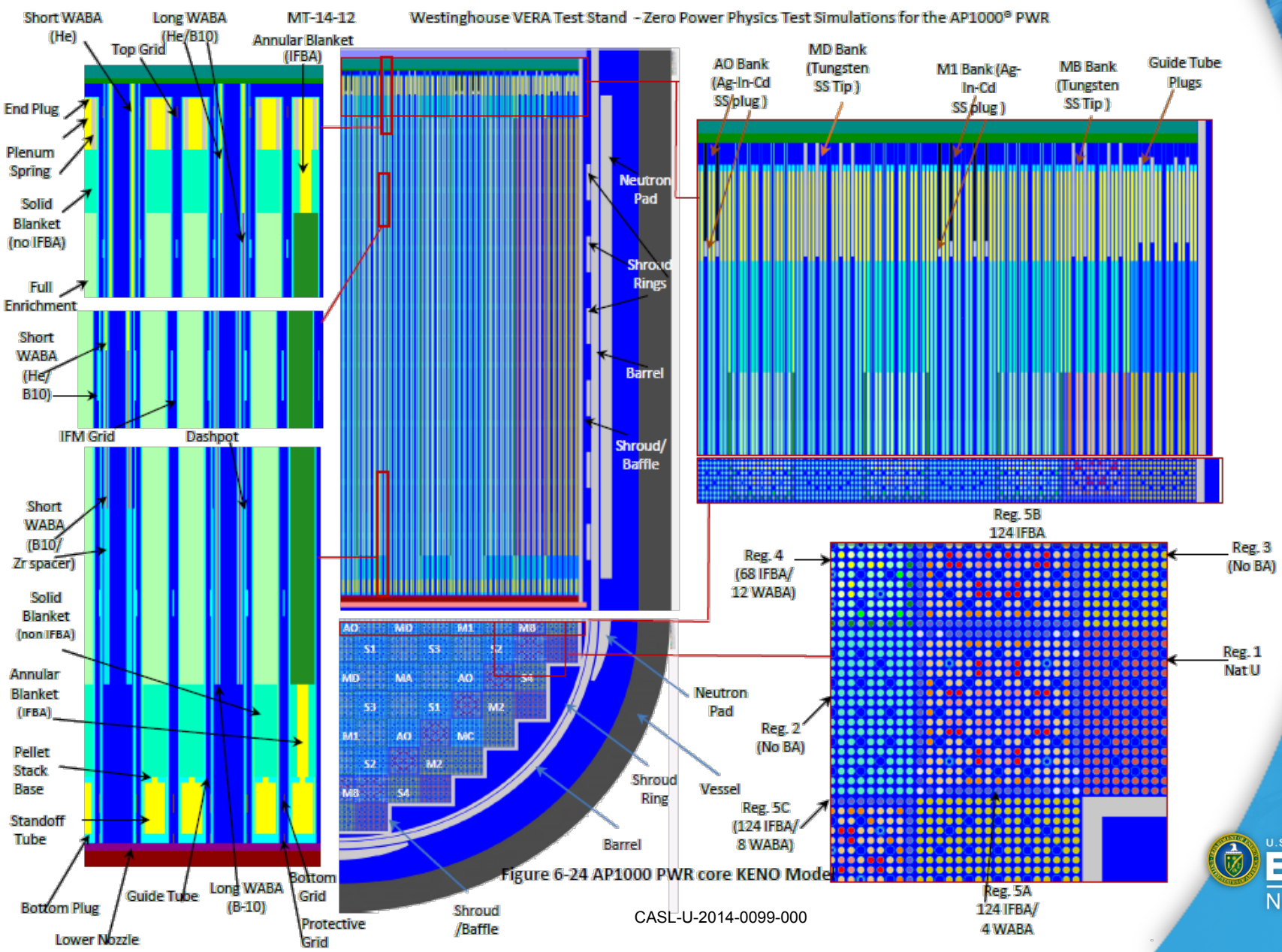
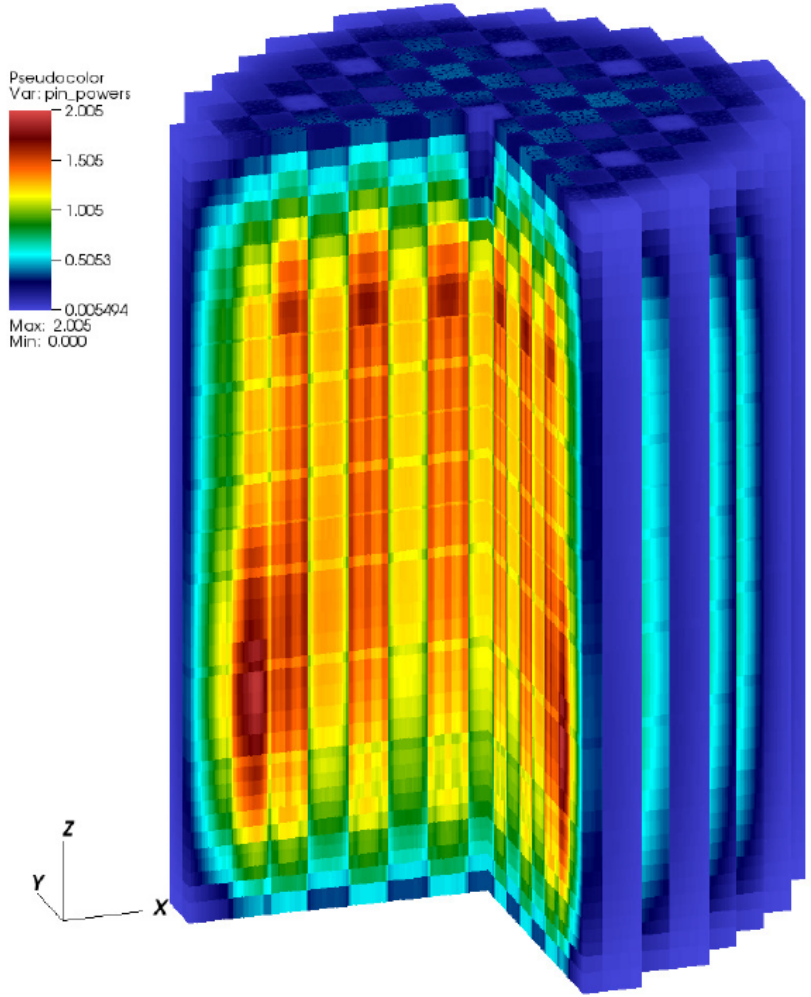


Figure 6-24 AP1000 PWR core KENO Model

Progress-to-Date: Example – AP1000 ZPPT



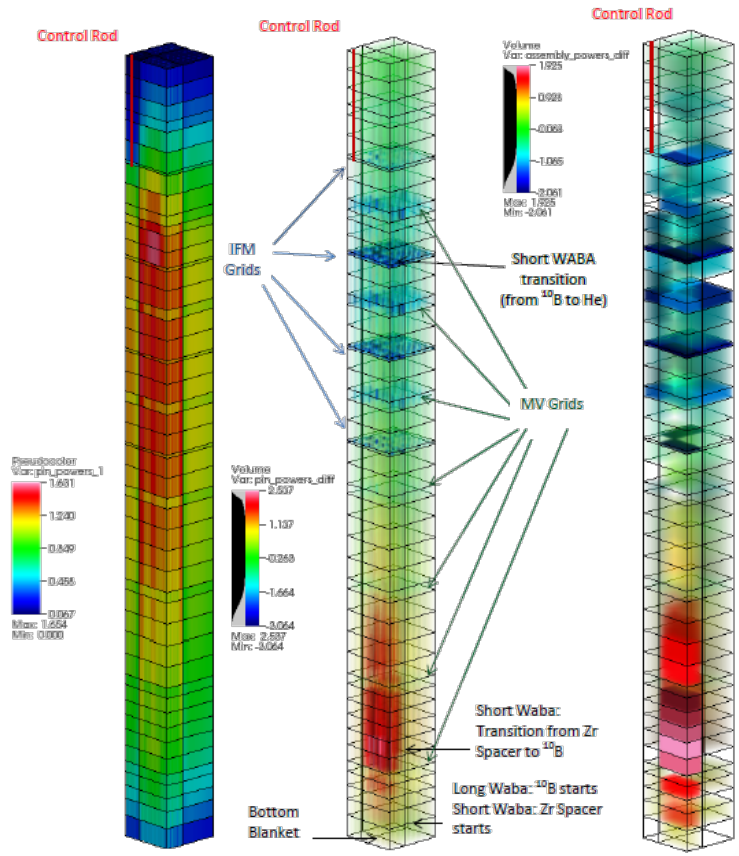


Figure 6-22 3D 3x3 power (left), delta power VERA-KENO (by cell: middle, by axial node: right)

Calculational Benchmark Effort: 235,000 Core-Hours

Progress-to-Date: Example – AP1000 ZPPT

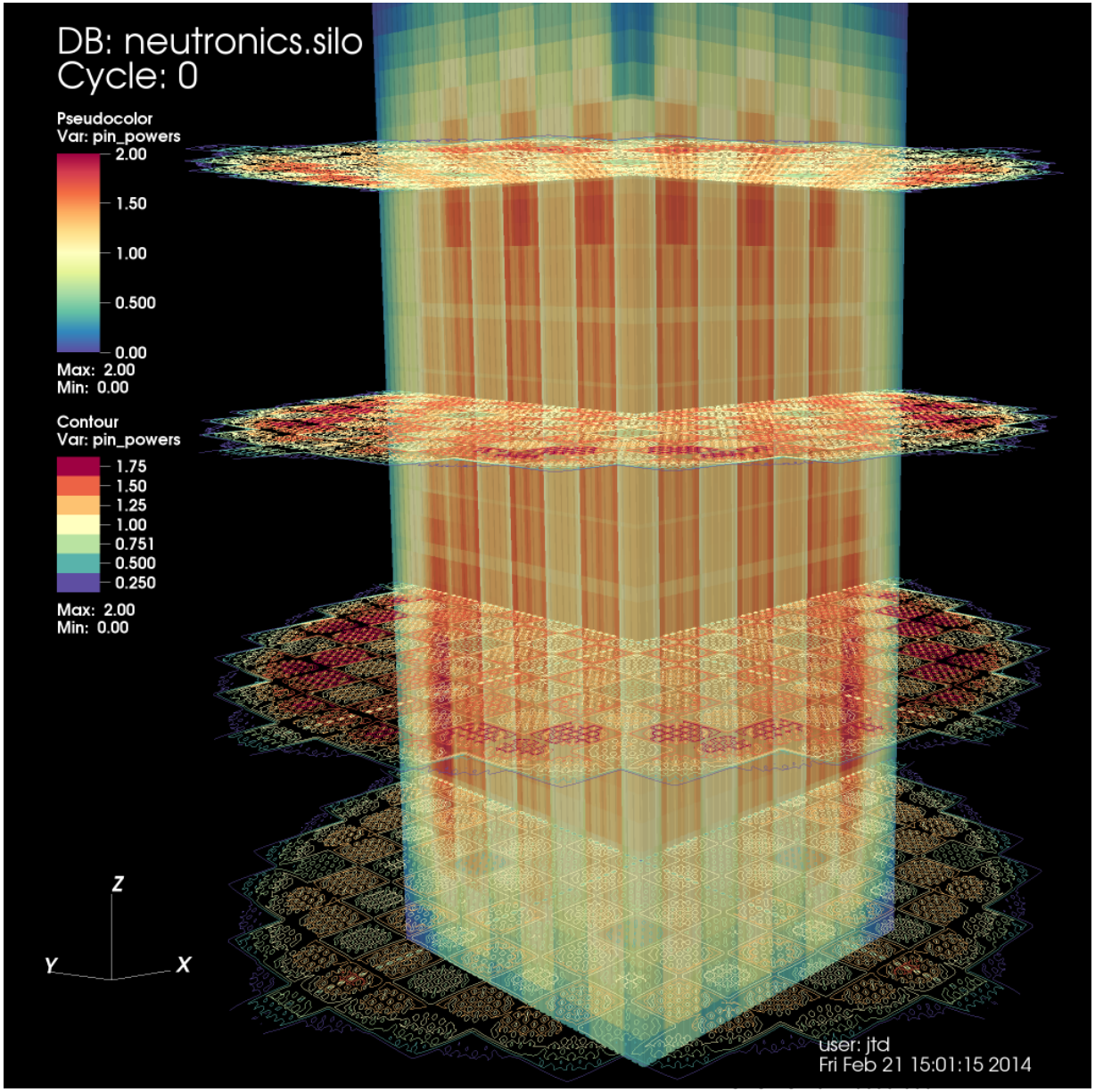
	KENO	VERA	VERA-KENO
All rods out start-up critical boron	1313 ppm	1310 ppm	-3 ppm (-32 pcm)

	KENO	VERA	VERA-KENO
Doppler Temperature Coefficient (DTC) pcm/F	-1.54 ± 0.03	-1.72	-0.18
Moderator Temperature Coefficient (MTC) pcm/F	-1.12 ± 0.04	-1.50	-0.38
Isothermal Temperature Coefficient (ITC) pcm/F	**-2.66±0.05**	**-3.22**	**-0.56**

		KENO	VERA-CS	
Bank	Material	Worth (pcm) ± 2 pcm	ΔWorth (pcm)	ΔWorth (%)
MA	Tungsten	258	-1	-0.5
MB	Tungsten	217	-5	-2.1
MC	Tungsten	188	-2	-1.1
MD	Tungsten	234	0	0.0
M1	Ag-In-Cd	651	-4	-0.6
M2	Ag-In-Cd	887	3	0.4
AO	Ag-In-Cd	1635	-4	-0.3
S1	Ag-In-Cd	1079	0	0.0
S2	Ag-In-Cd	1096	-9	-0.8
S3	Ag-In-Cd	1124	0	0.0
S4	Ag-In-Cd	580	-3	-0.4

AMA Milestone Report
CASL-U-2014-0012-001
March 2014

Progress-to-Date: Example – SHIFT



10^{12} Particles
230,000 Cores
4 Hours to Run

Future Work & Summary

- Continue to Execute "The Plan" – Proceed to Phase 2
  - Complete Development of Deterministic Transport Coupled Core Simulator
  - Continue and Expand Validation Basis Against Plant Measurements
  - Hybrid Monte Carlo to Support Numerical Validation
- Pursue Additional Partnership Opportunities
  - Broaden User Base
- Begin Identification of Other "Challenge Problems"
- Expand Modeling Capabilities – Ex-core and Ex-Vessel
  - Directly Benefits Reactor Dosimetry Community & CASL

Questions?

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More Information

http://www.casl.gov

Backup Slide: Watts Bar Cycle 1

	ID	KENO	SHIFT	Diff		Worth	Worth	Diff
1	ARO	1.00087	1.00103	16				
2	dbw	1.00324	1.00345	21		-9.44	-9.64	-0.20
3	MA	0.998258	0.998414	16		-261	-262	0.1%
4	MB	0.998669	0.998909	24		-220	-212	-3.7%
5	MC	0.998956	0.999148	19		-191	-188	-1.7%
6	MD	0.998496	0.998643	15		-238	-239	0.5%
7	M1	0.99435	0.994548	20		-655	-651	-0.6%
8	M2	0.992001	0.992185	18		-893	-891	-0.3%
9	AO	0.984609	0.984749	14		-1650	-1652	0.1%
10	S1	0.990103	0.9902	10		-1087	-1093	0.6%
11	S2	0.989935	0.990183	25		-1104	-1094	-0.8%
12	S3	0.98965	0.989739	9		-1133	-1140	0.6%
13	S4	0.995055	0.995295	24		-584	-576	-1.4%
Average				18		-8016	-7996	-0.2%
StDev				5				