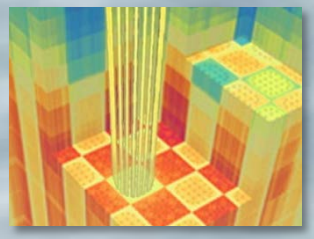
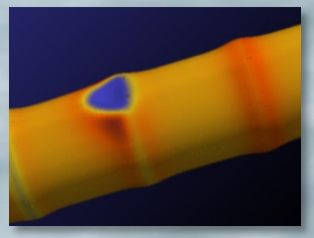
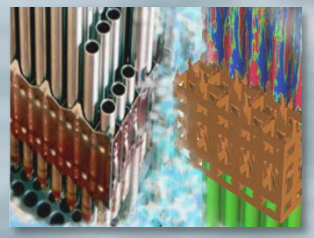
VERA-CS Applications Update

Andrew Godfrey
Oak Ridge National Laboratory

Industry Council Meeting
April 12, 2016

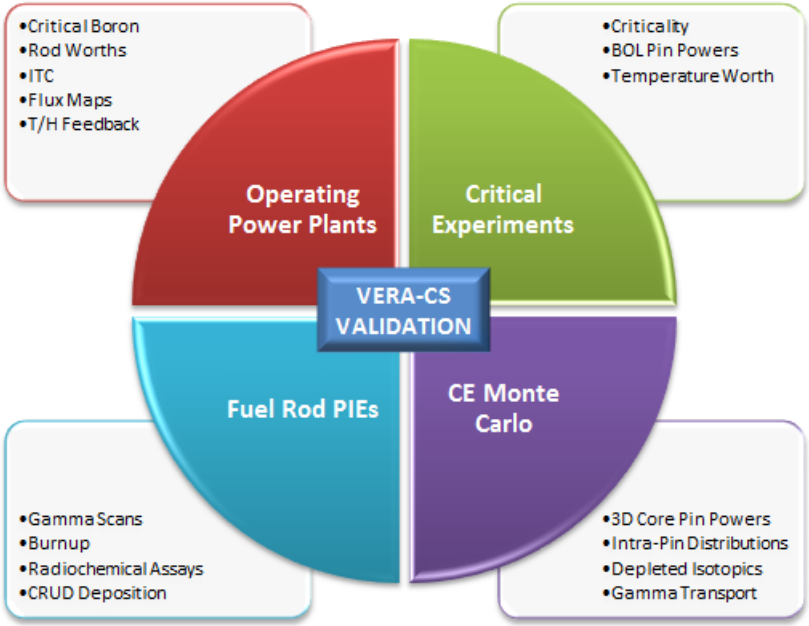
The Consortium for Advanced Simulation of LWRs
A DOE Energy Innovation Hub

CASL-U-2016-1083-000

U.S. DEPARTMENT OF ENERGY

Objective

- Update on recent and near-term applications of the VERA core simulator
  - MPACT 2D lattice physics comparisons
  - MPACT+CTF+ORIGEN 3D core comparisons
- Represents operating reactor benchmarking, validation, and testing
- Key component of the VERA-CS validation plan
- Increased focus on output processing and usability



Continued Expansion of Application Scope

Contents

- Watts Bar Nuclear 1 Activities
- Watts Bar Nuclear 2 Startup
- AP1000® First Cycle
- Krško Nuclear Power Plant

- VERAView Demo

Watts Bar Nuclear Plant – Tennessee Valley Authority

Watts Bar Nuclear Unit 1 (WBN1)

- Cycles 1-12 successfully simulated in 2015
- Stand-alone BISON calculations performed using VERA-CS pin power histories
- Core follow calculations are being repeated
  - Much improved BISON fuel temperatures
  - Many code enhancements/bug fixes
  - Demonstrate new performance enhancements
  - Provide new restart files for Cycle 7 CIPS work
- Performing Cycle 12 startup analysis
- Adding Cycles 13 and 14 (current)

CASL-U-2015-0206-000

VERA Benchmarking Results for Watts Bar Nuclear Plant Unit 1 Cycles 1-12

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June 30, 2015

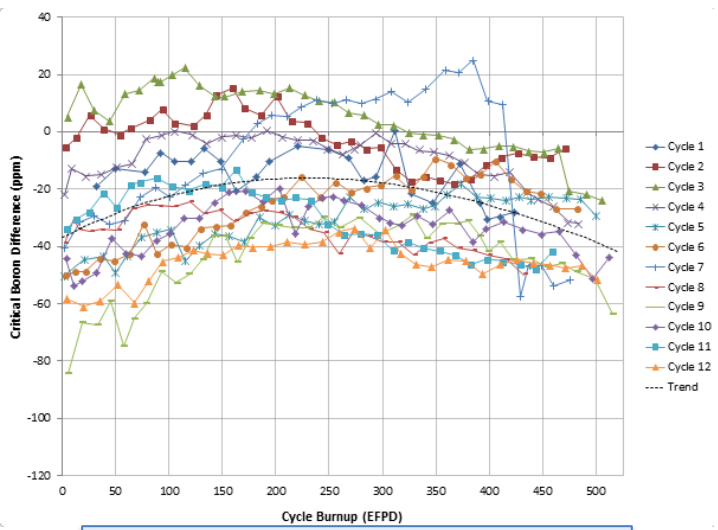
U.S. DEPARTMENT OF ENERGY | Nuclear Energy

http://www.casl.gov/docs/CASL-U-2015-0206-000.pdf

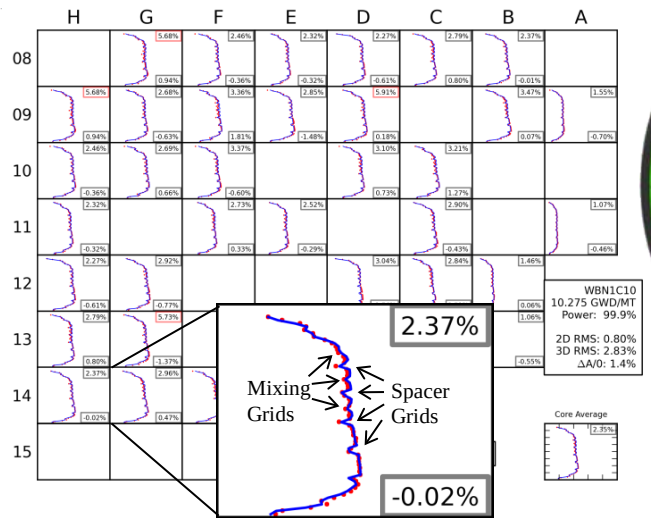
WBN1 Cycles 1-12 Benchmark

Godfrey, et. al, 2015

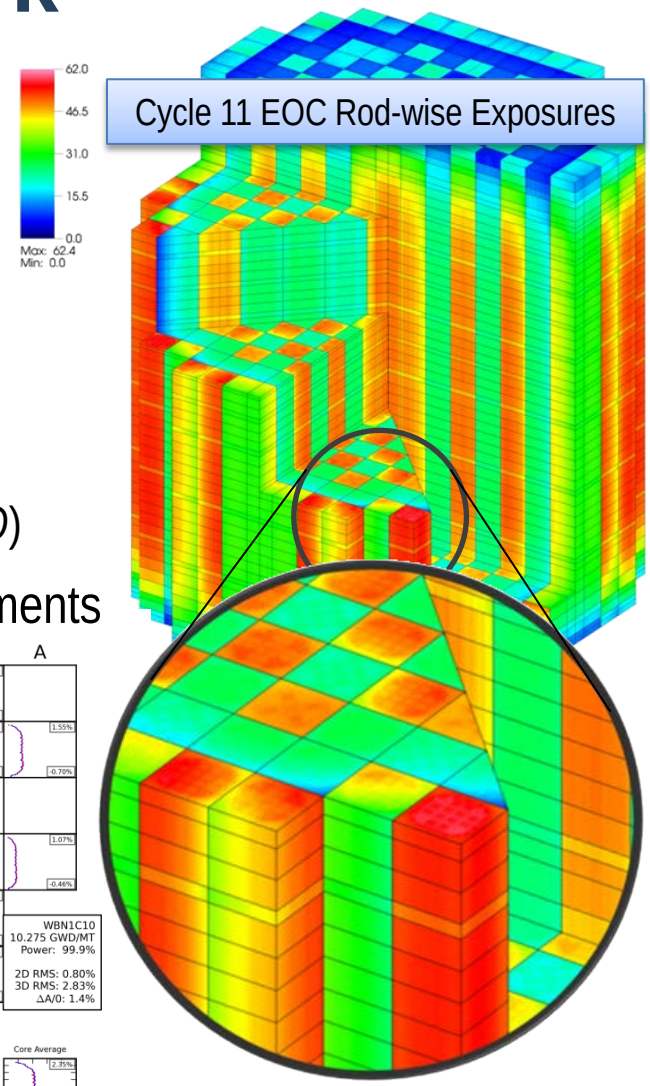
- VERA used to model 18 years of operation
  - MPACT+CTF+ORIGEN w/BISON fuel temperatures
- Measured data provided by TVA for benchmarking
  - Zero Power Physics Tests results (*~2% error in rod worth*)
  - Critical boron concentrations (*-24 ppm bias*)
  - In-core power distributions (*2% radial, ~4% total error, ~1% AO*)
- Good agreement with measured data, but room for improvements



418 critical boron comparisons



183 in-core flux maps



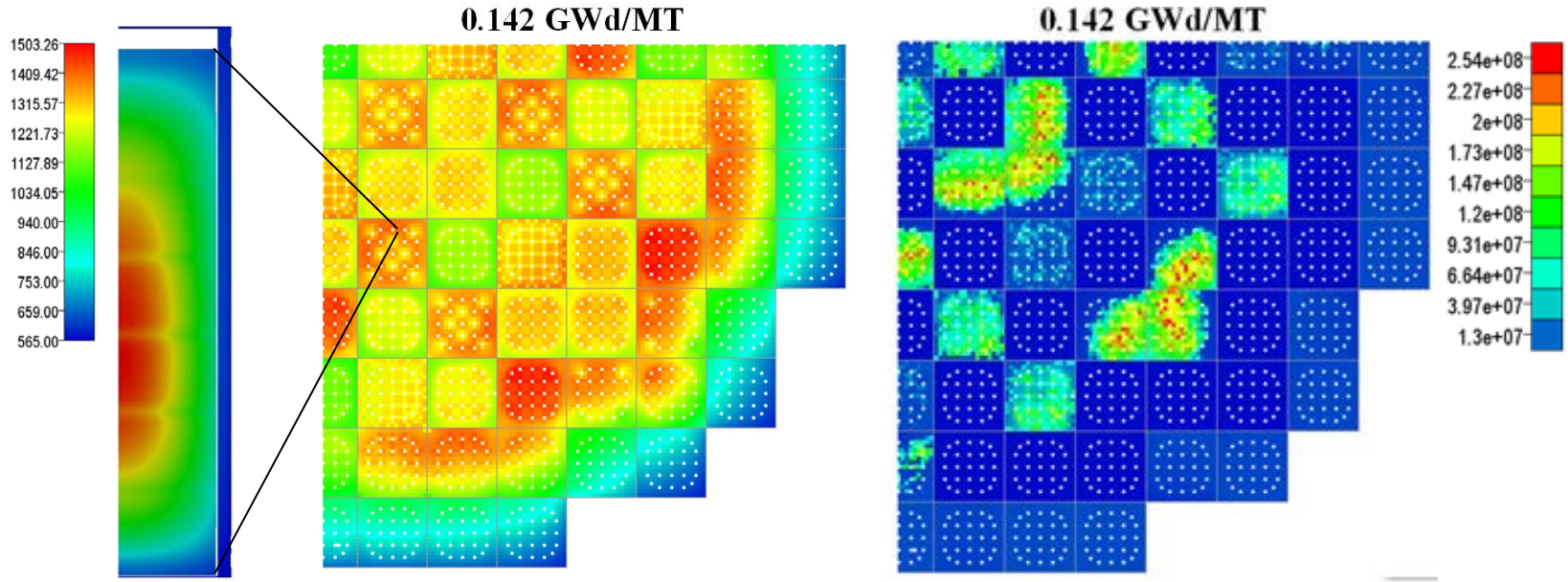
Cycle 11 EOC Rod-wise Exposures

Results published at PHYSOR 2016

Whole-Core Fuel Rod Performance

Stimpson (ORNL)

- Fuel rod power histories extracted from VERA-CS results for Cycles 1-3
- BISON input generated automatically for each rod
- BISON results post-processed back onto VERA-CS geometry
- Progress toward whole-core multi-physics coupling and analyses with VERA-CS



Maximum Centerline Fuel Temperature (K)

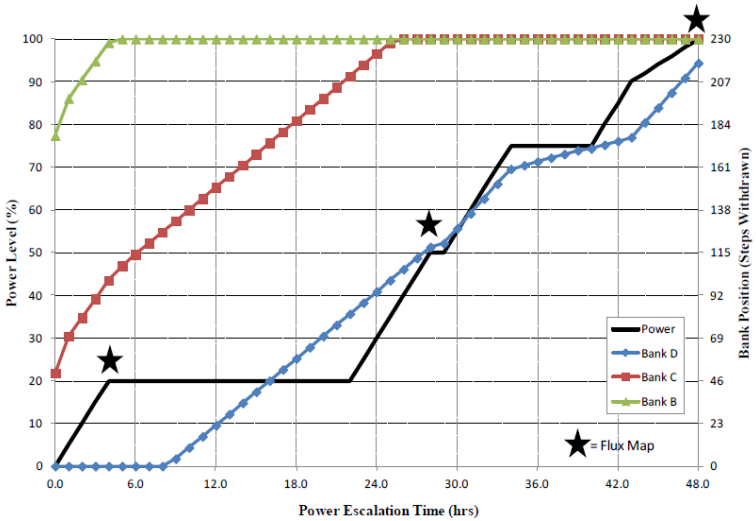
Maximum Clad Hoop Stress (Pa)

Core-Wide Fuel Performance Results for WBN1

WBN1C12 Power Escalation Calculations

Godfrey (ORNL); Cunningham, Ritchie (TVA)

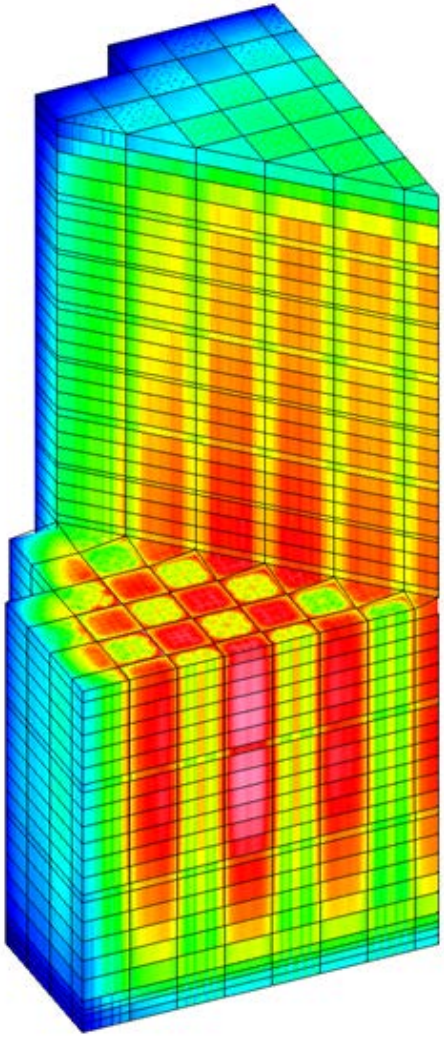
- Benchmark of startup procedure to support WBN2
- Currently performing hourly power maneuver calculations for validation of:
  - Transient xenon
  - Short-term depletion
  - Fuel temperature tables
  - Computation requirements (~200 cases)
- Benchmarking against measured data:
  - Critical boron concentrations vs. power
  - Flux maps at multiple testing plateaus
- Testing shutdown decay capabilities for planned reactor trips
- Preliminary results looking good:
  - Flux map errors consistent with HFP BOC results
  - Reactivity bias fairly constant as a function of power level
- Final results reported later



Watts Bar Nuclear Unit 2 (WBN2)

Godfrey, Gentry, Collins (ORNL); Cunningham, Ritchie (TVA), Franceschini (WEC)

- Collaboration between TVA, WEC, and ORNL to predict and follow the startup of WBN2 with VERA-CS
  - First US reactor to come online in 20 years
  - Criticality and commercial operation this year
- Use of new fixed in-core detectors models
- Criticality and physics test results predicted on 3/1
  - Generally agreement within acceptance criteria of all tests
- Performed comparisons between VERA-CS, SHIFT, and Westinghouse nodal methods
- OLCF providing new allocation of over 5M core-hours to support simulation of power escalation and testing "real time"



Fission rate distribution in WBN2

Most complex time-dependent simulation performed by VERA-CS to date

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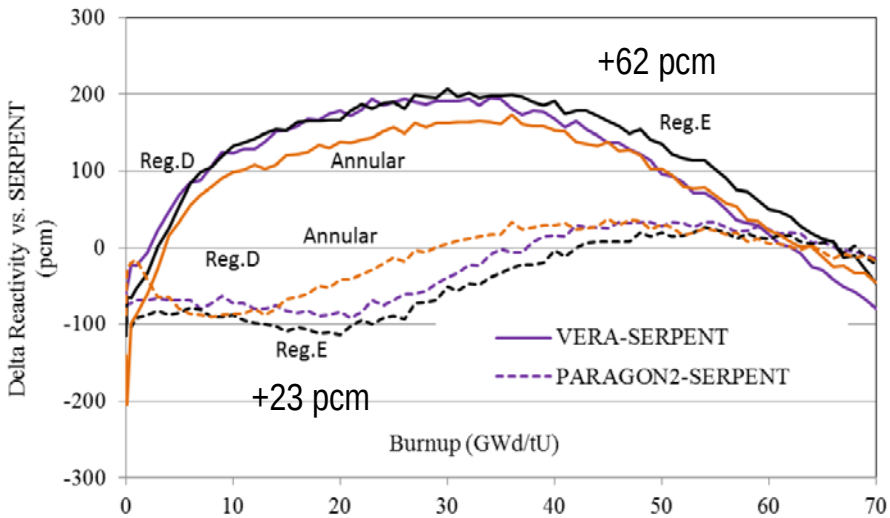
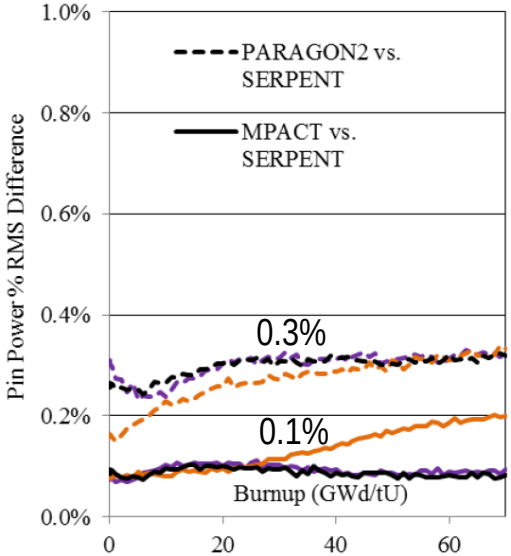
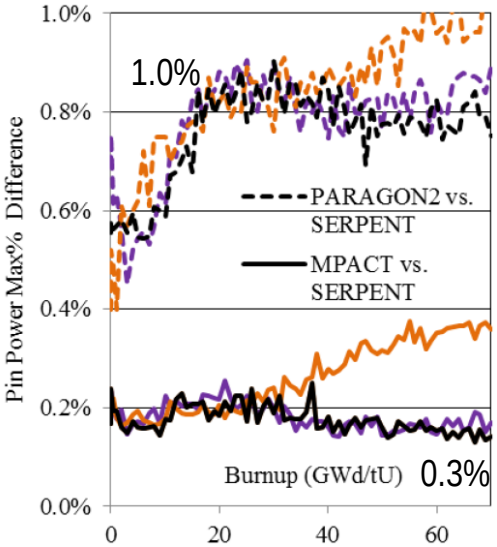
AP1000 Fuel Lattice Depletion Benchmark

Franceschini (WEC), Gentry, Godfrey (ORNL)

- Serpent continuous energy Monte Carlo depletion for MPACT validation
  - Substitution for measured data since none is available yet
- Seven of the most dominate lattice types of the AP1000 were analyzed (public versions)
- PARAGON2 (latest WEC lattice physics) included in comparison
- All codes compared very well with the Serpent, with some minor biases







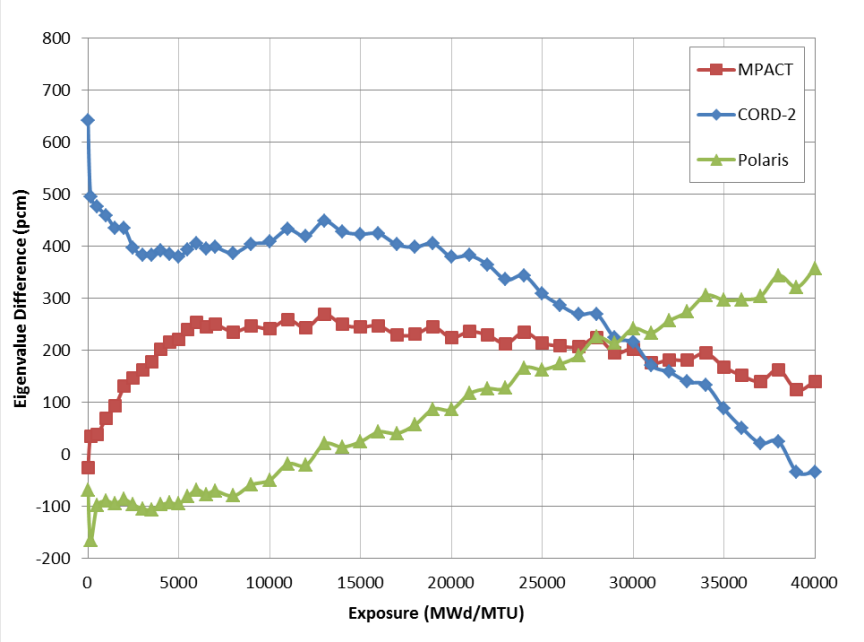
Results published at PHYSOR 2016

Depletion accuracy comparable to MC methods

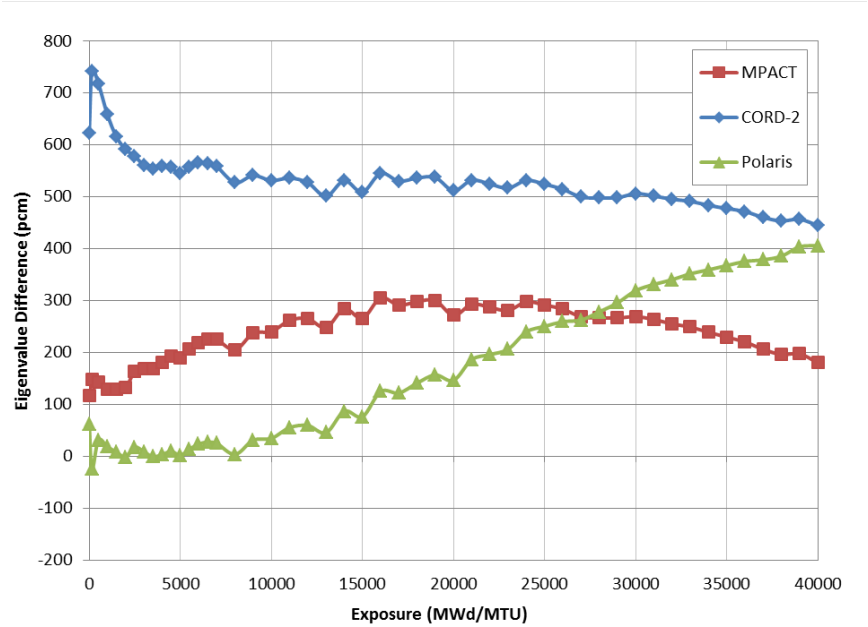
Krško Cycle 1 Fuel Lattice Benchmark

Godfrey, Jessee (ORNL), Kromar (JSI), Franceschini (WEC)

- Serpent continuous energy Monte Carlo depletion for MPACT validation
- Poisoned and unpoisened 16x16 lattice
- CORD-2 (JSI licensed neutronics methods) included in comparison
- SCALE 6.2 LWR lattice physics code Polaris included as well



Unpoisoned Fuel Lattice



Fuel Lattice with Pyrex Absorber

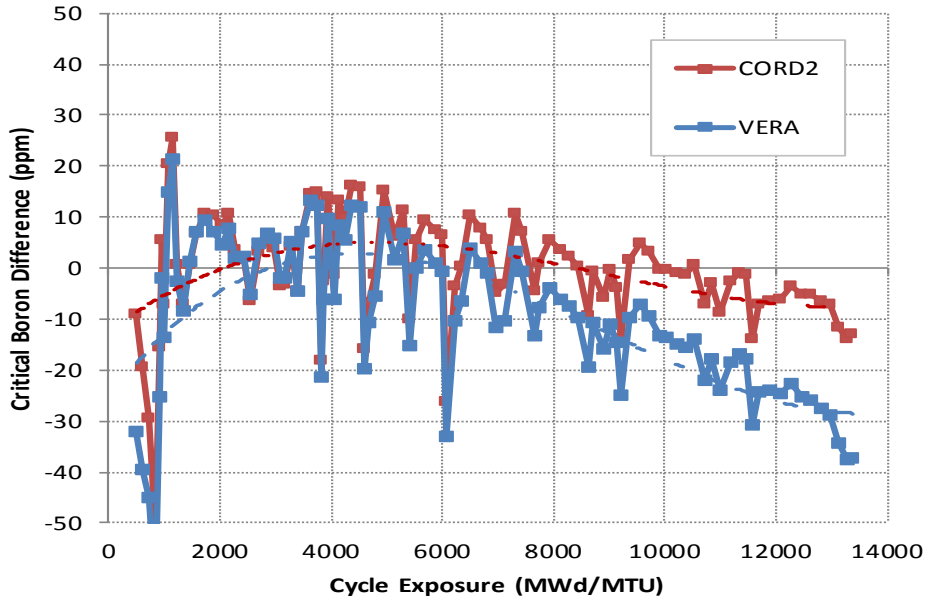
Depletion accuracy comparable to MC methods

Results published at PHYSOR 2016

Krško Cycle 1 Benchmark

Godfrey (ORNL), Kromar (JSI), Franceschini (WEC)

- Cycle 1 depletion results compared to measured data
  - Critical boron concentrations
  - 'Measured' assembly power distribution
- CORD-2 (JSI licensed neutronics methods) included in comparison



VERA-Meas

-1.3%	-0.5%	-0.1%	-0.3%	-0.1%	-2.0%	0.5%
-0.5%	-0.9%	-0.8%	0.1%	-0.9%	-1.2%	1.0%
-0.1%	-0.6%	0.1%	0.2%	-0.1%	0.4%	
-0.3%	-0.3%	0.0%	0.3%	-0.3%	1.2%	
-0.1%	-0.7%	0.5%	0.7%	1.5%		
-2.0%	-1.2%	0.9%	1.5%			
0.5%	1.3%					

RMS = 0.9%

CORD2-Meas

-4.2%	-2.7%	-1.5%	0.2%	0.5%	-0.4%	1.7%
-2.7%	-2.9%	-1.1%	-0.2%	0.2%	-0.4%	0.7%
-1.3%	-0.8%	-0.4%	0.8%	0.6%	-0.3%	
0.2%	-0.5%	0.7%	0.8%	0.4%	0.5%	
0.4%	0.5%	1.2%	1.3%	-0.1%		
-0.3%	-0.2%	0.4%	0.8%			
1.8%	1.2%					

RMS = 1.1%

Cycle Exposure MWd/MTU	Root Mean Square (RMS) Difference		Maximum Absolute Difference		Difference in Maximum Power	
	CORD-2	VERA	CORD-2	VERA	CORD-2	VERA
Average	0.8%	0.8%	3.2%	2.1%	-1.4%	-0.9%
St. Dev.	0.1%	0.1%	0.7%	0.2%	1.5%	0.3%

Results published at PHYSOR 2016

Upcoming Tasks

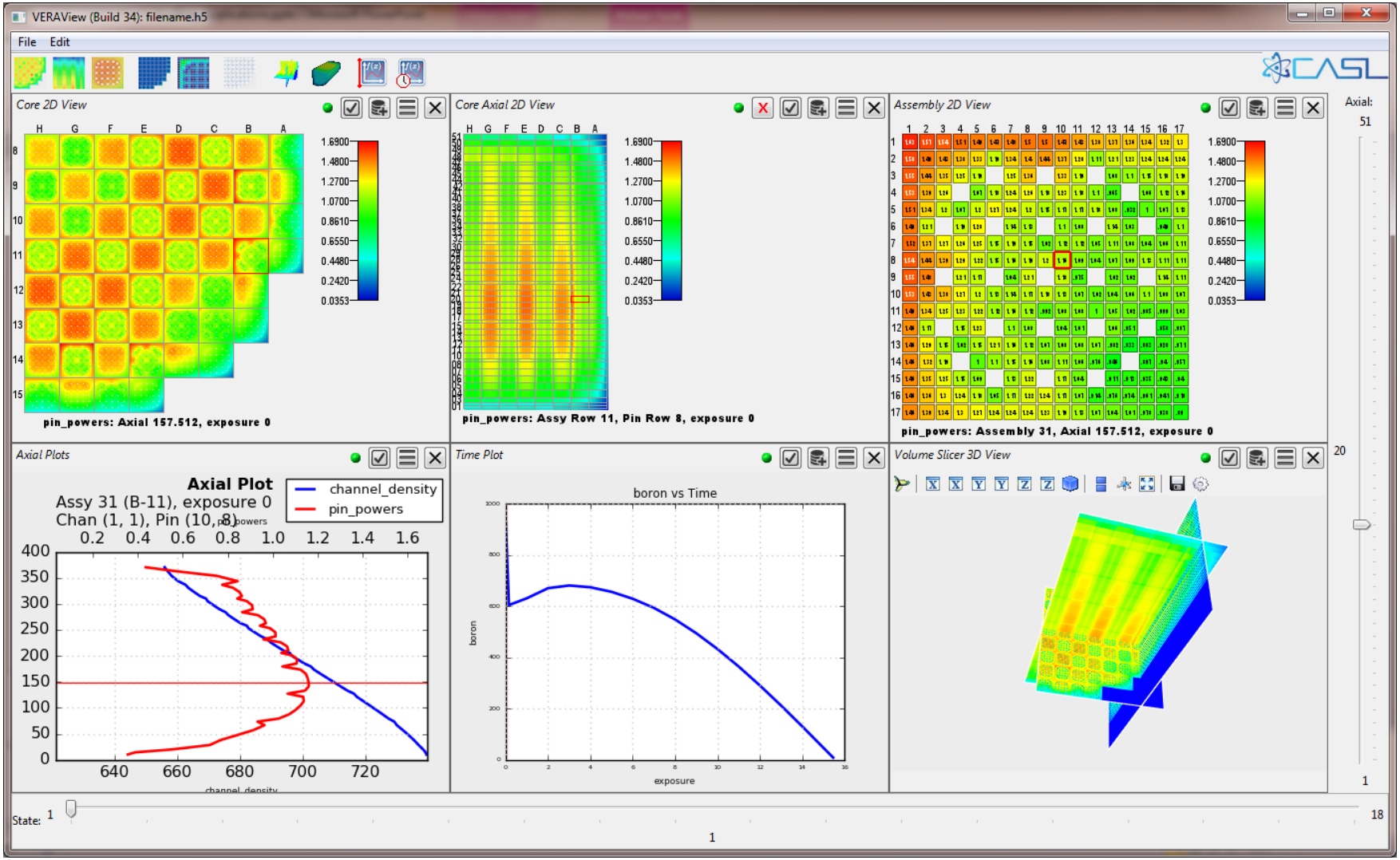
- WBN1 Cycles 13 and 14+
  - Start comparisons of 610 level flux map data
- WBN2 Startup and Power Escalation
- Krško Cycles 2+
- Test Stand support (Westinghouse, Areva)
- Further collaboration with interested utilities

VERAView

Lee, Godfrey (ORNL)

- VERA-CS generates a large amount of fuel rod and channel data
- CASL is primarily focused on VERA's multi-physics capabilities, but recognizes the need for users to interrogate results
- VERAView developed as a prototype graphical interface to simply visualize VERA output
- Python-based open source software that can be used to visualize any reactor-based data

VERAView Demo



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