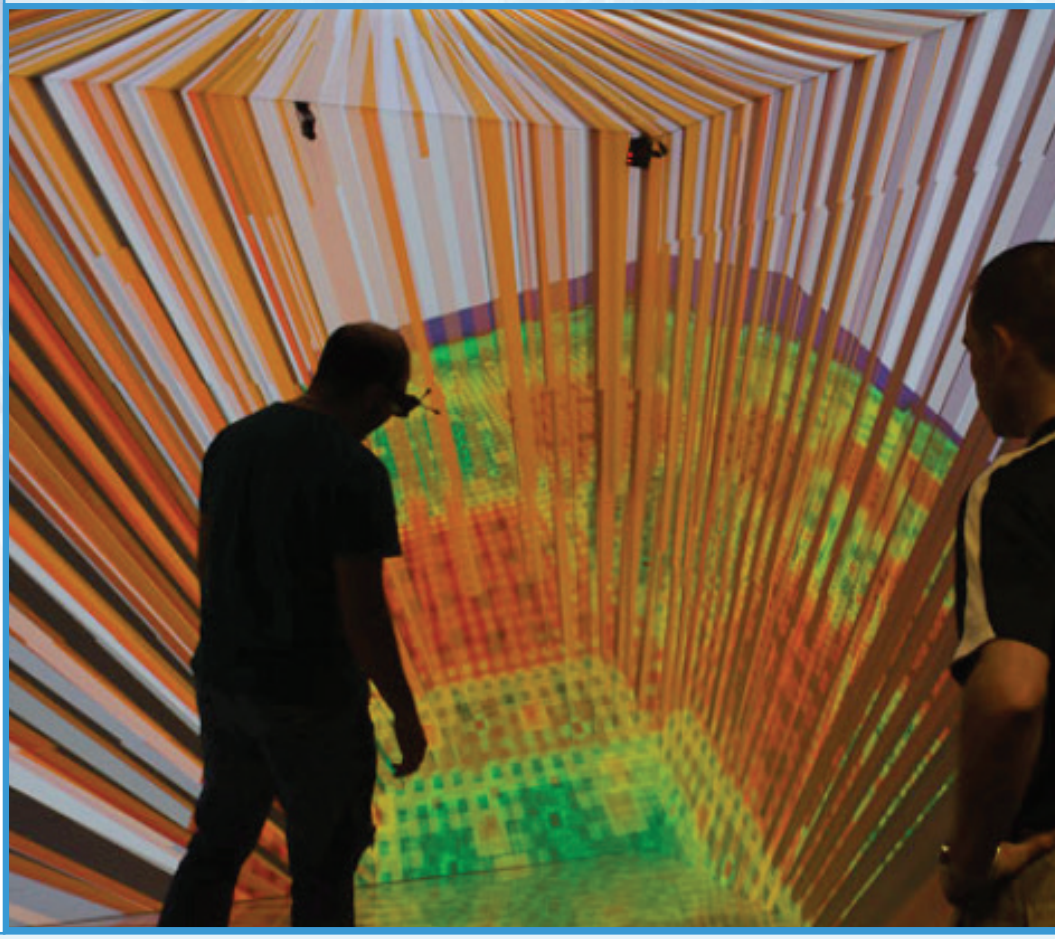
A DOE Energy Innovation Hub

Improving reactor performance with predictive science-based simulation technology that harnesses world-class computational power



3D visualizations allow a physical walk-through of the top 20% of high-powered rods in a pressurized water reactor core. Details revealed provide insight into factors affecting core performance and aging. (Image courtesy of Tom Evans, ORNL).

Consortium for Advanced Simulation of Light Water Reactors

The Consortium for Advanced Simulation of Light Water Reactors (CASL) was established by the US Department of Energy in 2010 to advance modeling and simulation capabilities for nuclear reactors. CASL's mission is to provide computational capabilities that will make it possible to more accurately predict the behavior of phenomena that define the operational and safety performance of light water reactors (LWRs). In January 2015, the Department of Energy approved a second five-year phase for CASL, expanding its research and development activities through fiscal year 2019.

Through CASL, experts from national laboratories, universities, and industry are developing and deploying the Virtual Environment for Reactor Applications (VERA), a "virtual reactor" that can accurately simulate the physical processes taking place in a reactor at previously unattainable levels of detail. These processes include neutron transport, thermal hydraulics, nuclear fuel performance, corrosion, and surface chemistry. VERA incorporates science-based models, state-of-the-art numerical methods, modern computational science and engineering practices, uncertainty quantification and sensitivity analysis, and validation against data from operating reactors, experiments, and other sources to replicate these physical processes and to model their interactions.

Oak Ridge National Laboratory (ORNL) supercomputer, Titan, rated in 2014 as the leading HPC facility in the western world, supports CASL computational needs. (Image courtesy of ORNL)

CASL Achievements to Date

CASL is meeting milestones established by a well-defined yet flexible plan and delivering technologies that address industry issues. VERA has been deployed through "test stands" (prototype installations in actual engineering and design environments) and used to match actual startup and operations data for a Generation 2 reactor on the grid (the Tennessee Valley Authority's Watts Bar Unit 1) and to predict startup data for a Generation 3+ reactor design, the Westinghouse AP1000®, that is the basis for eight reactors now under construction. The CASL team is working to ensure that a subset of VERA, the VERA Core Simulator, can follow operational reactors through depletion, power maneuvering, and fueling cycles.

The models, methods, data, and understanding developed by CASL are being applied to create "useful and usable" tools to help the nuclear industry address three critical areas of performance for nuclear power plants (NPPs): (1) reducing capital and operating costs per unit of energy by enabling power uprates for existing NPPs and by increasing the rated powers and lifetimes of next-generation NPPs; (2) reducing nuclear waste volume generated by enabling higher fuel burnup, and (3) enhancing nuclear safety by enabling high-fidelity predictive capability for component performance through the onset of failure.

Innovations, Deployed Technologies, and an Effective Public-Private Partnership

- Integrated, goal-oriented, productive team spanning a geographically dispersed, heterogeneous set of organizations (national labs, universities, industry)
- Demonstrated, industry-reviewed predictions of reactor core behavior at previously unattainable levels of physical and geometric fidelity
- Multi-physics modeling and simulation of nuclear materials, corrosion chemistry, and fluids revealing insights that support enhanced operational maneuvering
- New fluid dynamics, chemistry, and materials modeling technologies that can resolve 3D reactor/fuel geometries via High Performance Computer oriented, advanced solution methodologies, for realistic nuclear fuel performance assessments
- Designer and researcher access to VERA's broad multi-physics simulation capabilities through a common "industry-friendly" interface for analyzing reactor operations

CASL Mission

Provide coupled, high-fidelity, usable capabilities needed to predict behaviors of light water reactor operational and safety performance-defining phenomena

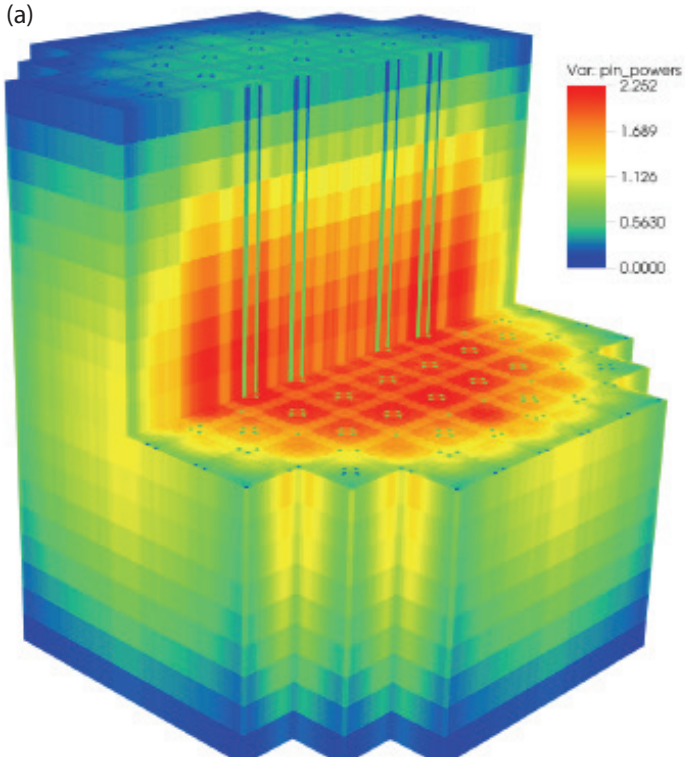
Strategic Goals

1. Develop and effectively apply modern virtual reactor technology (CASL's Virtual Environment for Reactor Applications: VERA)
2. Address design, operational and safety challenges for light water reactors (CASL Challenge Problems)
3. Engage the nuclear energy community through modeling and simulation
4. Deploy new partnership and collaboration paradigms

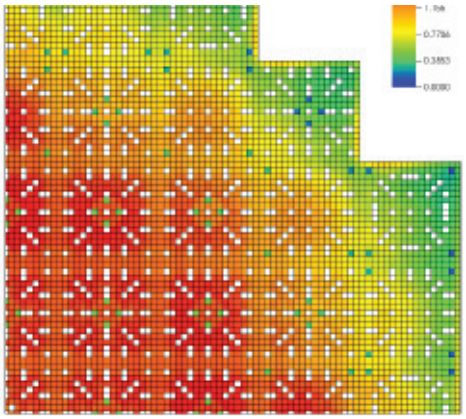
Illustration of VERA-CS Application to Integral Pressurized Water Reactor (iPWR) Small Modular Reactor (SMR)

The CASL VERA-CS is being used to model a four-year iPWR SMR cycle. The work has progressed to the 3D quarter-core calculations illustrated below: a) the 3D relative pin power distribution with a cutout section revealing the interior; b) the relative pin power distribution at the mid-axial plane; c) the core loading plan developed in the study associated with the power distributions.

(a)

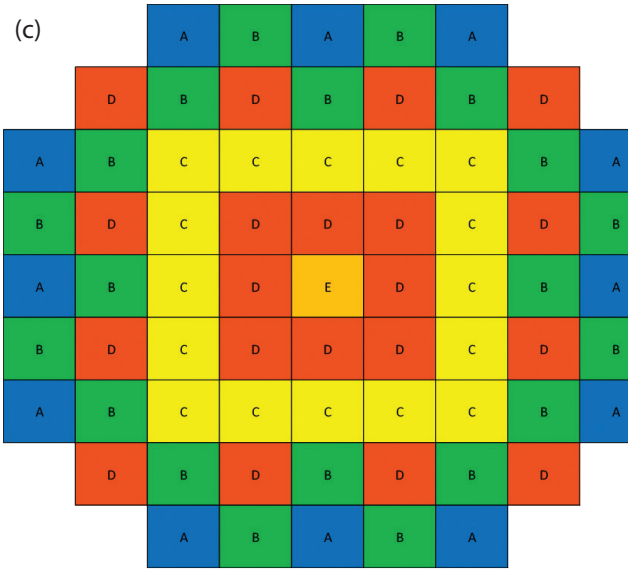


(b)



The white spaces in the image correspond to the pins that do not produce power (control rods and BPR pins).

(c)



Assembly Type	# Standard Fuel Pins	Standard Fuel Pin Enrichment	# Gd Fuel Pins	Wt% Gd
A	248	4.95	4	3
B	244	4.95	4	3
C	240	4.95	4	3
D	236	4.95	4	3
E	236	4.95	0	3

(Images courtesy of Kelly Kenner, Ivan Maldonado, University of Tennessee at Knoxville, Rose Montgomery, TVA, and Dudley Raine, B&W)

Achievements to Date
(FY 2010–FY 2014)

Year 1 . . .

- Technical roadmaps established for addressing high-priority Challenge Problems
- First high-resolution reactor core model for TVA Watts Bar plant
- First-of-a-kind three-dimensional (3D) assessment of fuel pellet-to-cladding interaction
- **VERA** founded with infrastructure and basic industry Core Simulator

Year 2 . . .

- Established methods for placing computer-based tools in industrial environments for real-life testing
- **VERA** produced neutronics simulation (prediction of changing neutron distribution in reactor core)

Year 3 . . .

- Expanded the neutronics capability to obtain unprecedented details on the movement of neutrons in a reactor core (demonstrated how to model the individual performance of thousands of fuel pins in an entire reactor)
- **VERA** internal release: Core neutronics + thermal hydraulics + fuel performance

Year 4 . . .

- Demonstrated application VERA tools to improve understanding of fuel-to-cladding interactions and the corrosion-induced power losses that result (reduding corrosion prevents power losses)
- **VERA** limited external release: Refinements to prior capabilities + corrosion and surface chemistry
- Completion and validation of VERA Core Simulator

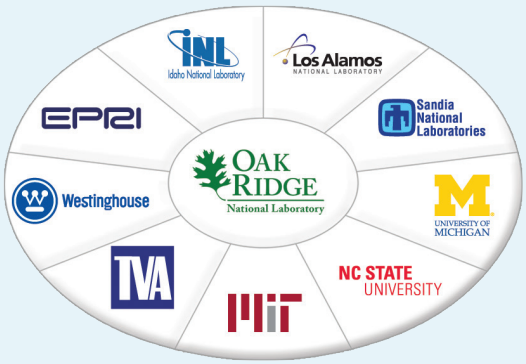
Year 5 . . .

- **VERA** broad external release: Validate VERA with data from Watts Bar Unit 1 operating cycles and demonstrate CRUD challenge problem capababilites

CASL-U-2014-0089-001

Key Goals for 5 Year Extension
(FY 2015–FY 2019)

1. In it's second five-year phase, CASL will deepen its research and development for simulation of PWRs and broaden its applications to SMRs and BWRs through:
   - Fuel performance under accident conditions →further enhance safety of plants
   - Chemical and corrosion interactions between materials and coolants →reduce corrosion for longer-life plants
   - Two-phase thermal hydraulics for operational and transient reactor scenarios →more efficient plant performance
   - Expand to other types of reactors and reactors of the future →achieve industry-wide performance improvements
2. Develop the VERA core simulator kinetics capabilities and improve computational performance and accuracy → maximize value
3. Establish a self-sustaining organization, drawing from the CASL Industry Council, that is dedicated to the advancement and industry-wide deployment of VERA technologies → establish sustainable support for VERA



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