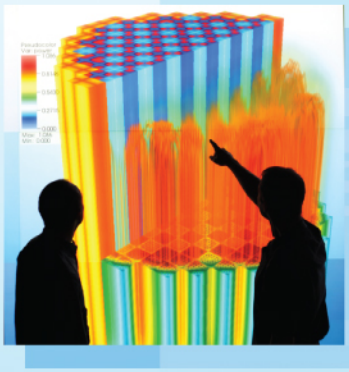
Power uprates
and plant life extension

CASL-U-2014-0103-000

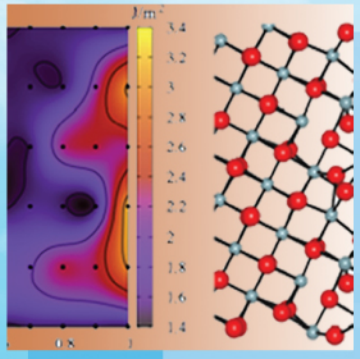
Consortium for Advanced Simulation of LWRs



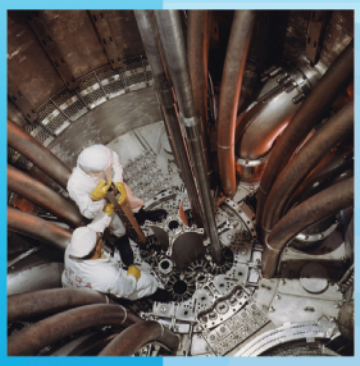
Engineering design
and analysis

CASL Overview to Dr. Ellen Williams, Senior Advisor, Office of the Secretary of Energy, Department of Energy

Science-enabling
high performance
computing



Fundamental science



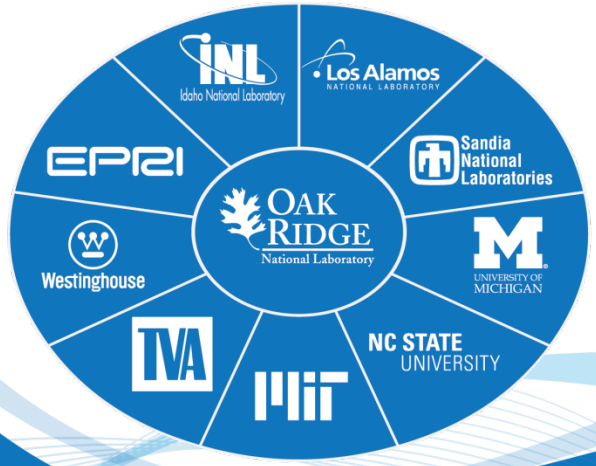
Plant operational data

Jess Gehin
Oak Ridge National Laboratory

June 13, 2014

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

The Consortium for the Advanced Simulation of Light Water Reactors



Dr. Jess C. Gehin

June 13, 2014

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

CASL-U-2014-0103-000

CASL
Consortium for Advanced Simulation of LWRs

CASL

A DOE Energy Innovation Hub in the Office of Nuclear Energy

- First Introduced by Secretary in the President's FY2010 Budget

- A Different Approach
  - "Multi-disciplinary, highly collaborative teams ideally working under one roof to solve priority technology challenges" – *Steven Chu*
  - "Create a research atmosphere with a fierce sense of urgency to deliver solutions." – *Kristina Johnson*
  - Characteristics
    - Leadership – Outstanding, independent, scientific leadership
    - Management – "Light" federal touch
    - Focus – Deliver technologies that can change the U.S. "energy game"

Mission

Provide leading edge modeling and simulation capabilities to improve the performance of currently operating Light Water Reactors

Vision

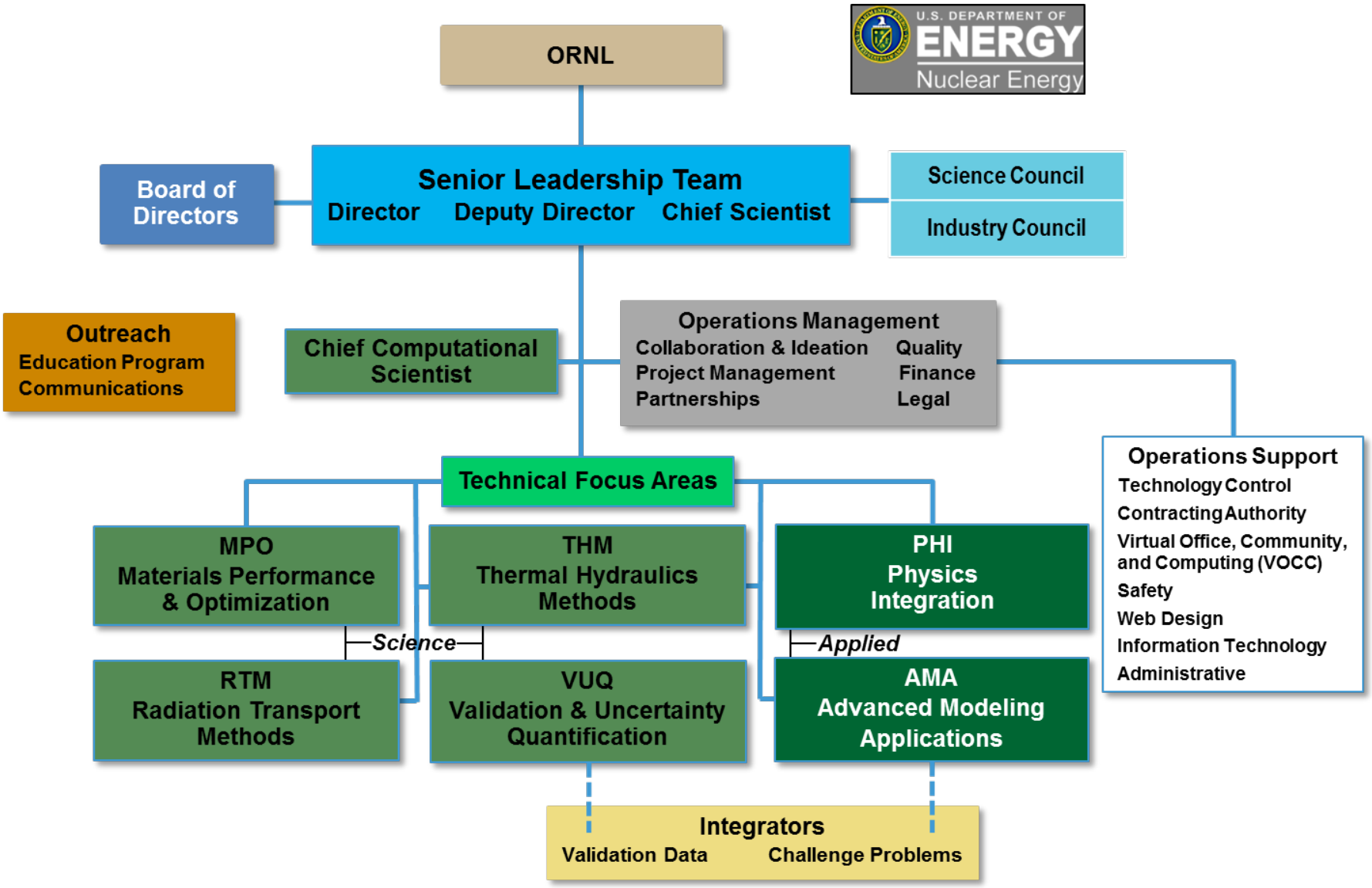
Predict, with confidence, the performance and assured safety of nuclear reactors, through comprehensive, science-based modeling and simulation technology that is deployed and applied broadly within the U.S. nuclear energy industry

Goals

1. Develop and Effectively Apply Modern Virtual Reactor Technology
2. Provide More Understanding of Safety Margins While Addressing Operational and Design Challenges
3. Engage the Nuclear Energy Community Through Modeling and Simulation
4. Deploy New Partnership and Collaboration Paradigms`

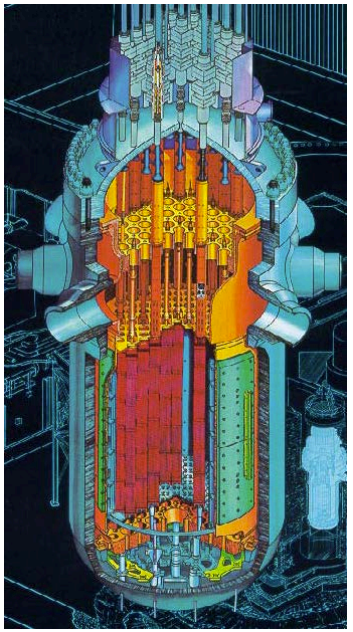
CASL Partners

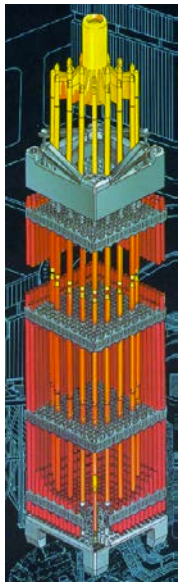
CASL Organization



Nuclear Energy Drivers and Payoffs for M&S technology

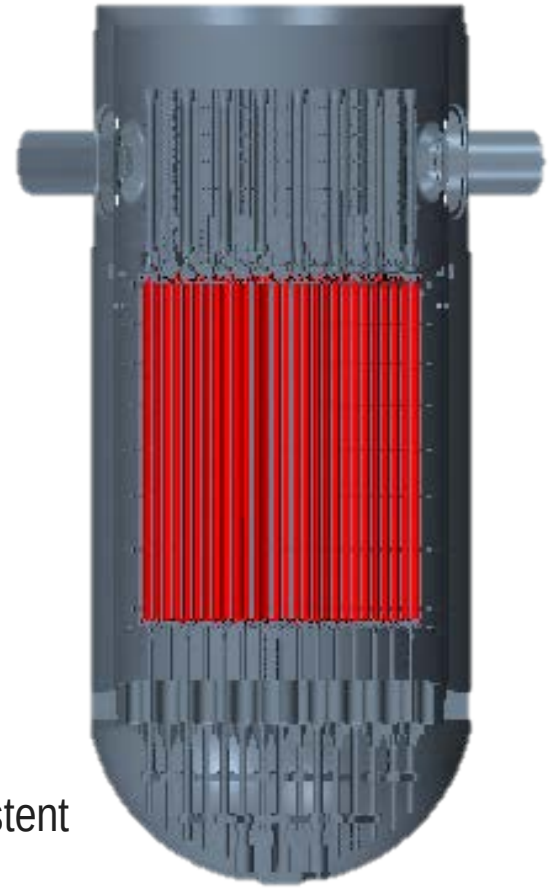
- Extend licenses of existing fleet (to 60 years and beyond)
  - Understand material degradation to reduce inspection & replacements
- Up-rate power of existing fleet (strive for another 5-10 GWe)
  - Address power-limiting operational & design basis accident scenarios
- Inform flexible nuclear power plant operations
  - Load follow maneuvering & coolant chemistry to enhance reliability
- Design and deploy accident tolerant fuel (integrity of cladding)
  - Concept refinement, test planning, assessment of safety margins
- Margin quantification, recovery, tradeoff
  - Plant parameters, fuel hardware, reload flexibility, regulatory changes
- Resolve advanced reactor design & regulatory challenges
  - Support Gen III+ reactors under construction (AP1000), refine SMR designs
- Fuel cycle cost savings
  - More economical core loadings and fuel designs
- Used fuel disposition
  - Inform spent fuel pools, interim storage, and repository decisions





CASL Scope: Develop and apply a "Virtual Reactor" to assess fuel design, operation, and safety criteria

- Deliver improved predictive simulation of PWR core, internals, and vessel
  - Couple Virtual Reactor to evolving out-of-vessel simulation capability
  - Maintain applicability to other NPP types
- Execute work in six technical focus areas to:
  - Equip the Virtual Reactor with necessary physical models and multiphysics integrators
  - Build the Virtual Reactor with a comprehensive, usable, and extensible software system
  - Validate and assess the Virtual Reactor models with self-consistent quantified uncertainties

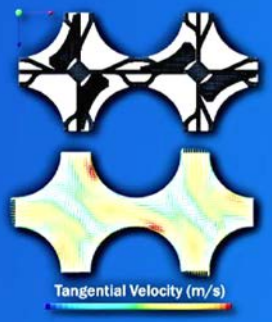


Focus on Addressing Challenge Problems to Drive Development and Demonstration

CASL Challenge Problems

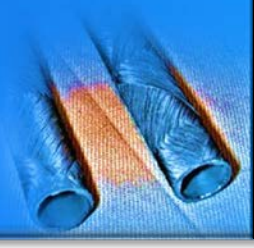
Key safety-relevant reactor phenomena that limit performance

Departure from Nucleate Boiling



Cladding Integrity

- During LOCA
- During reactivity insertion accidents
- Use of advanced materials to improve cladding performance



Safety Related Challenge Problems

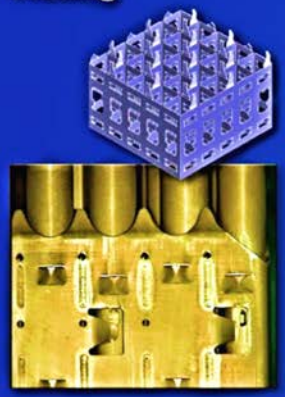
CASL is committed to delivering simulation capabilities for

- Advancing the understanding of key reactor phenomena
- Improving performance in today's commercial power reactors
- Evaluating new fuel designs to further enhance safety margin

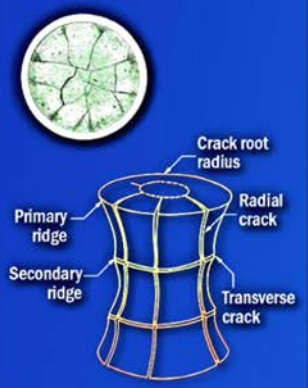
Crud

- Deposition
- Axial offset anomaly
- Hot spots

Grid-to-Rod Fretting



Pellet-Clad Interaction



Operational Challenge Problems

CASL Status and Looking Forward

- ✓ Year 1: Build the foundation
- ✓ Year 2: Advance the science basis of the M&S technology components
  - ◆ Guided by challenge problem requirements baselined against industry capabilities
- ✓ Year 3: Assess, refine, integrate, and beta test the M&S technology components within the multi-physics Virtual Reactor environment
  - ◆ Perform initial verification and validation (V&V), sensitivity analysis (SA), and uncertainty quantification (UQ) analyses
- ✓ Year 4: Harden for robustness & efficiency and deploy & apply the coupled multi-physics Virtual Reactor technology for broader assessment and continuous improvement
  - ◆ Prepare for possible 5-year renewal that leverages development to date
- ✓ Year 5: Continue maturation of the multi-physics Virtual Reactor technology thru increased breadth and depth of testing and application offered by a general release
  - ◆ Self-sustaining technology deployment (release/support) and evolution plan in place

Scientific Output thru Year 3

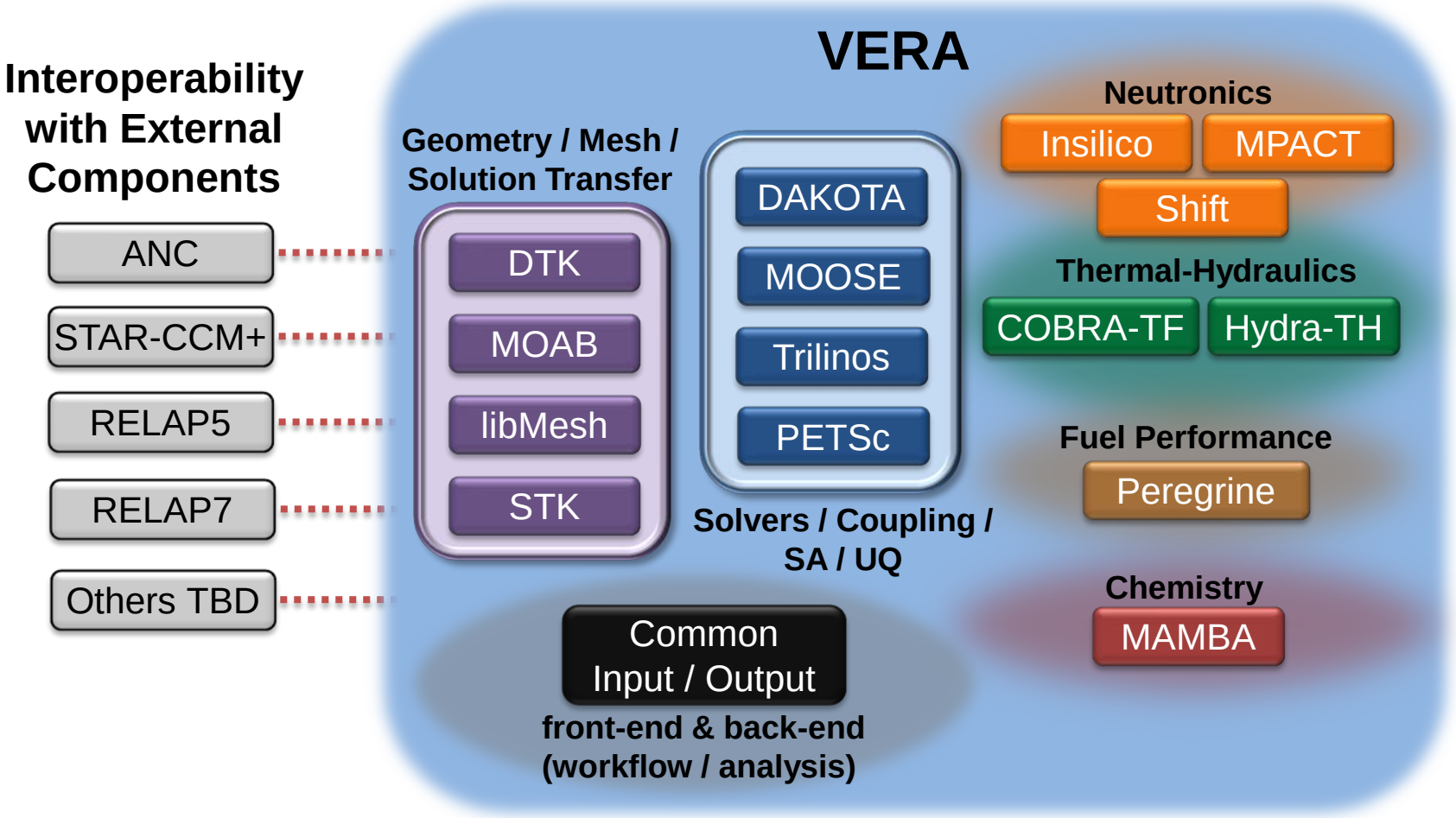
- Virtual Reactor M&S technology integrated, under active development and assessment, and deployed for beta testing
- 81+ journal articles
- 328 conference papers
- 28 technical reports
- 51+ invited talks
- 382 milestone reports
- 216 programmatic reports

CASL supports a range of reactor core physics and spatial scales

- Neutron transport/Cross Sections
  - Spatial scale: fuel pellet to fuel rod to fuel assembly to full core
  - Components: Insilico, Shift (ORNL), MPACT (UMich)
- Single-phase and multi-phase thermal hydraulics
  - Subchannel spatial scale: fuel assembly to full core
  - CFD Spatial scale: fuel sub-assembly (3x3 rods) to fuel assembly (17x17 rods)
  - Components: COBRA-TF (PSU), Hydra-TH (LANL)
- Nuclear fuel behavior and performance
  - 2D R-Z Spatial scale: fuel rods to full core
  - Unstructured-mesh 3D spatial scale: fuel pellet to fuel sub-assy (3x3 rods)
  - Component: PEREGRINE (INL)
- Coolant chemistry and CRUD deposition/buildup
  - Spatial scale: fuel pellet to fuel rods to fuel sub-assembly
  - Components: MAMBA (LANL), MAMBA-BDM (MIT)

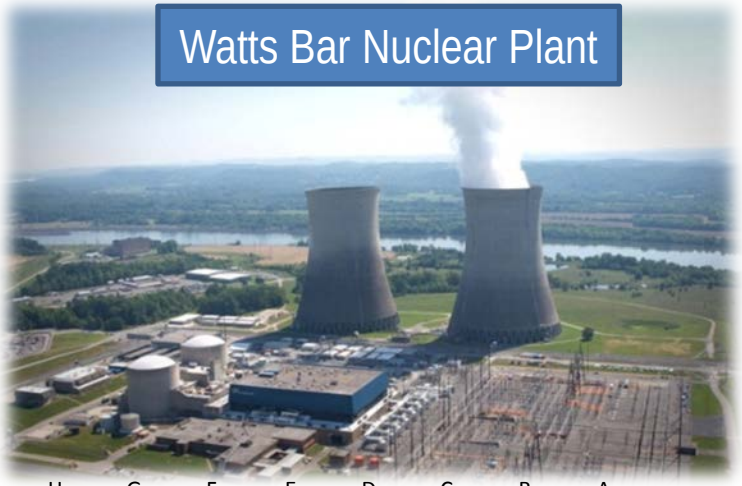
Virtual Environment for Reactor Applications (VERA)

Planned Components



CASL Modeling Comparisons to Plant Measurements: Zero Power Physics Tests

- TVA's Watts Bar Nuclear Unit 1 is CASL's "physical" reactor
- Recently modeled the zero power physics tests performed at start up of the reactor (Cycle 1)
- Zero Power Physics Tests are performed at the startup of each operation cycle to confirm the the core had been loaded correctly and that control rod worth meets safety requirements
- Goal of analysis is to predict critical configurations, control rod worth, differential boron absorber worth and isothermal temperature coefficients.

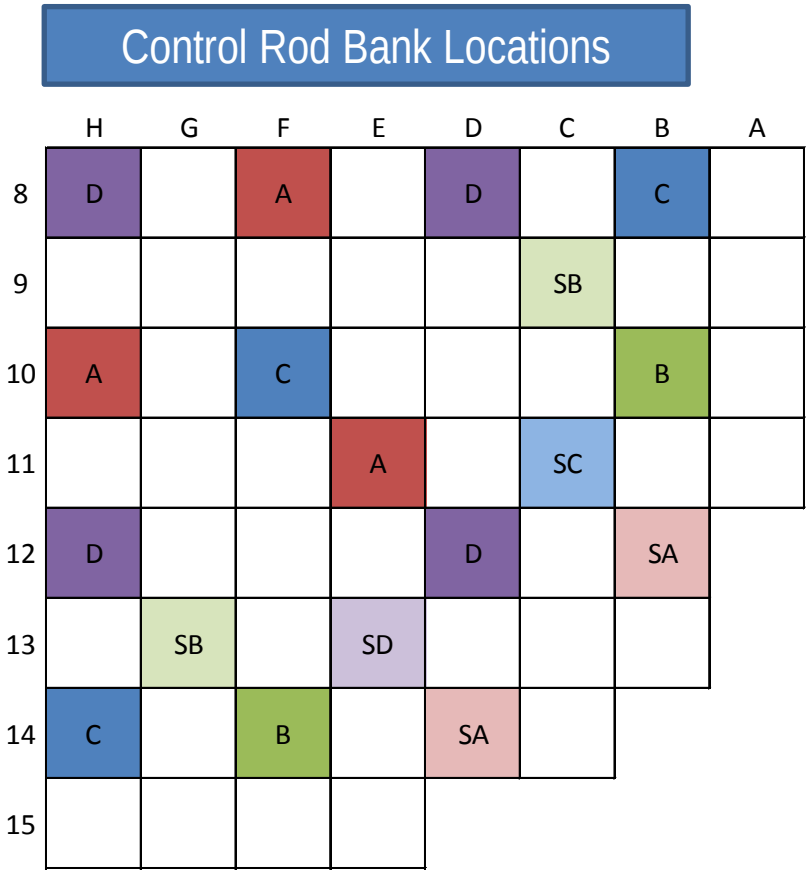


	H	G	F	E	D	C	B	A
8	2.1	2.6 20	2.1	2.6 20	2.1	2.6 20	2.1	3.1 12
9	2.6 20	2.1	2.6 24	2.1	2.6 20	2.1	3.1 24	3.1
10	2.1	2.6 24	2.1	2.6 20	2.1	2.6 16	2.1	3.1 8
11	2.6 20	2.1	2.6 20	2.1	2.6 20	2.1	3.1 16	3.1
12	2.1	2.6 20	2.1	2.6 20	2.6	2.6 24	3.1	
13	2.6 20	2.1	2.6 16	2.1	2.6 24	3.1 12	3.1	
14	2.1	3.1 24	2.1	3.1 16	3.1	3.1		
15	3.1 12	3.1	3.1 8	3.1	Enrichment Number of Pyrex Rods			

Cycle 1 Core Loading

VERA (CASL) Results for Watts Bar Unit 1 Startup Critical Configurations

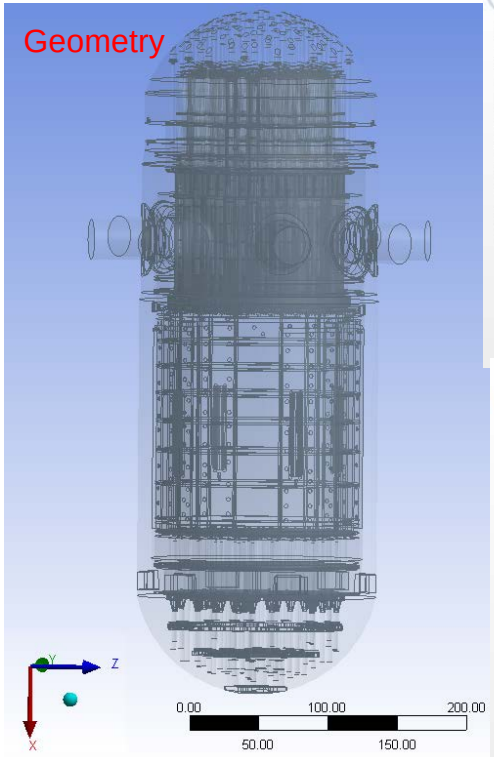
Critical Configuration	VERA k-eff	Difference (pcm)
Initial	1.00122	122
ARO	1.00157	157
Bank D In	1.00084	84
Bank C In	1.00094	94
Bank B In	1.00081	81
Bank A In	1.00092	92
Bank SD In*	1.00073	73
Bank SC In*	1.00071	71
Bank SB In	1.00100	100
Bank SA In	1.00070	70
Average	**1.00094**	**94**
St. Deviation	**0.00027**	**27**

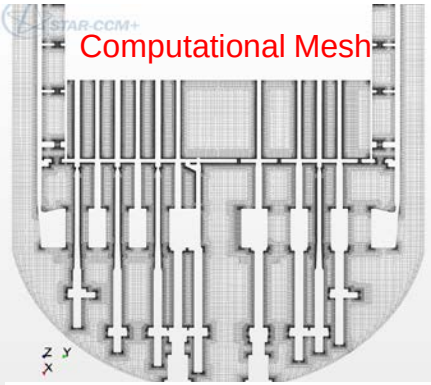


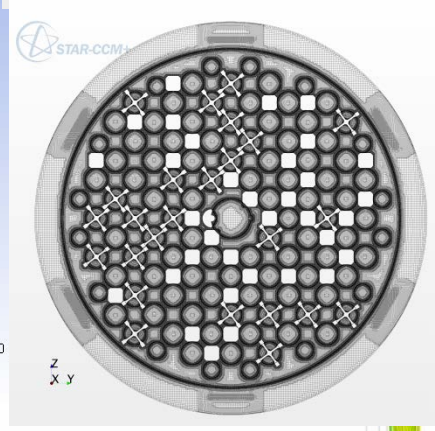
Excellent Agreement with Plant Conditions (keff = 1)

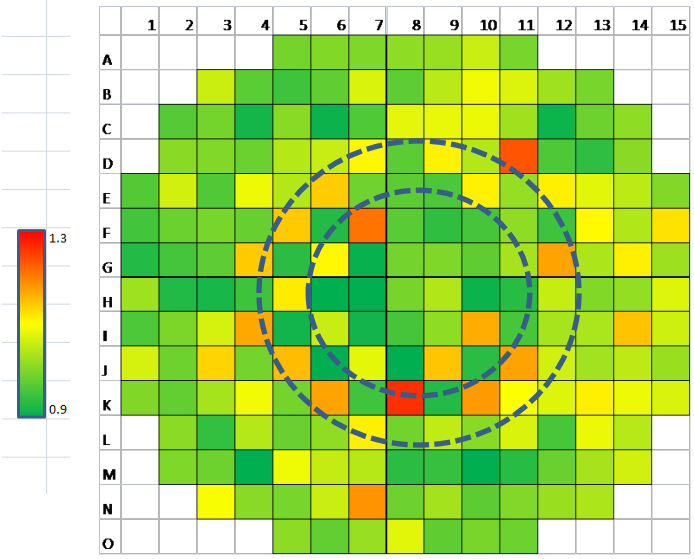
New Computational Fluid Dynamics (CFD) Model Developed for Watts Bar Reactor Vessel

- A new CAD (solid) model for the TVA Watts Bar whole Reactor Pressure Vessel (RPV) with most of the features of the geometry faithfully captured.
  - CFD mesh generated consists of 299 M hexahedral cells.
- Preliminary CFD results have uncovered interesting flow dynamics at the inlets of the fuel assemblies
  - The adjacent fuel assemblies with large flow rate difference in the marked area represent area of potential susceptibility to Grid To Rod Fretting (GTRF), which has been observed in plant operations
- Further investigations will proceed as part of the TVA Test Stand on CFD analysis of lower plenum flow anomalies

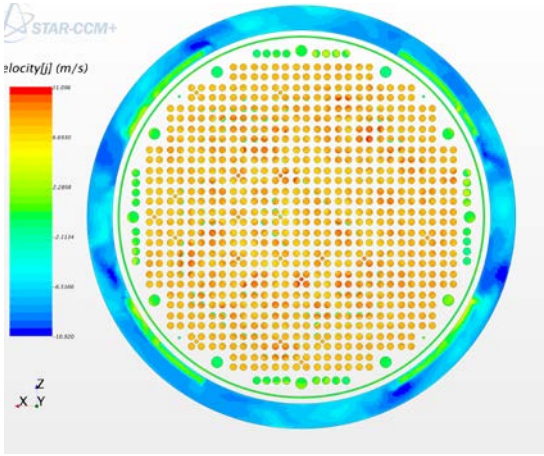




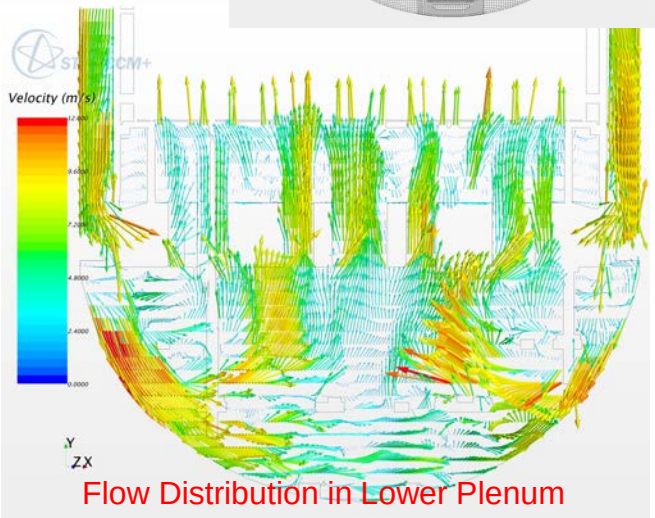




Normalized Flow Rate at fuel assembly inlets



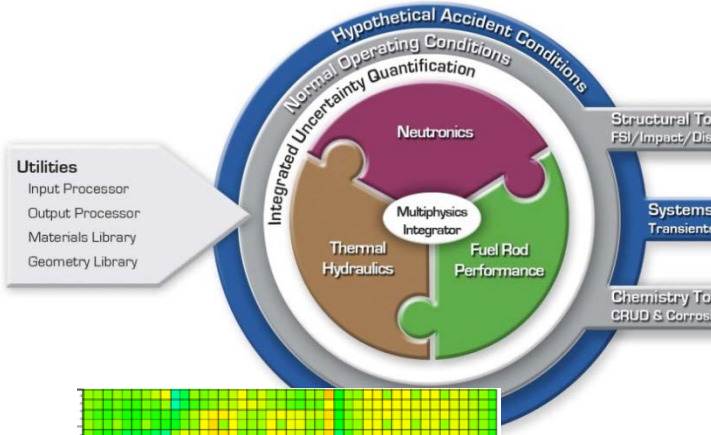
Flow Distribution at Core Plate

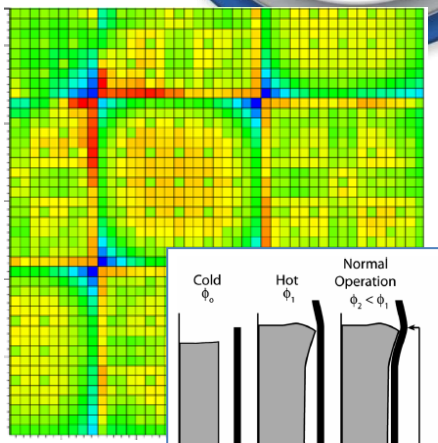


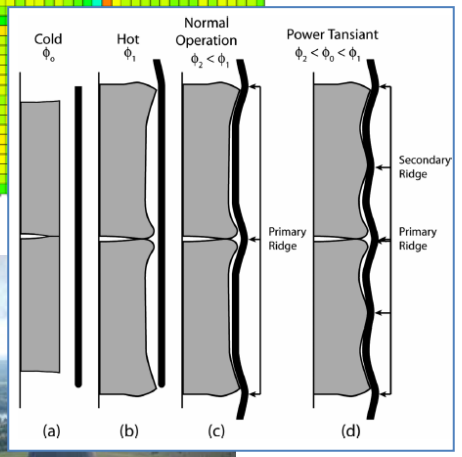
Flow Distribution in Lower Plenum

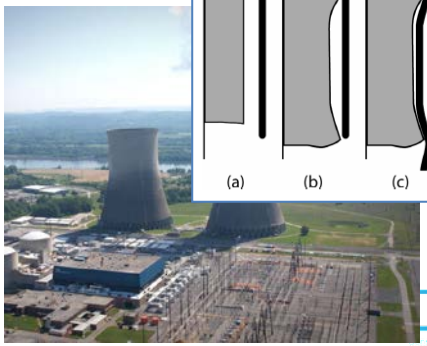
CASL Technology Deployment through Test Stands and Software Releases

- CASL is committed to ensuring its products are deployed to the broader nuclear industry
- **Test Stands:** Early deployment to industry for rapid and enhanced testing, use, and ultimate adoption of VERA to support real-world LWR applications
  - WEC: Deployment Mar 2013; focus on VERA simulation of AP1000 first core startup
  - EPRI: Deployment Nov 2013; new EPRI computing capabilities will be utilized to test VERA fuel (Peregrine) performance applications
  - TVA: Deployment Mar 2014; focus on lower plenum flow anomaly observed in many current operational reactors
- **Releases:** Regular distribution of VERA
  - 2010-2012: Internal CASL releases
  - 2013: First external release (limited)
  - 2014: Full VERA release planned









VERA Test Stand at Westinghouse

AP1000® Zero Power Physics Tests Simulation

- Purpose: Initial deployment of VERA-CS
  - Public report available
- Results: Excellent agreement with reference KENO results
  - Some differences in ITC & MTC

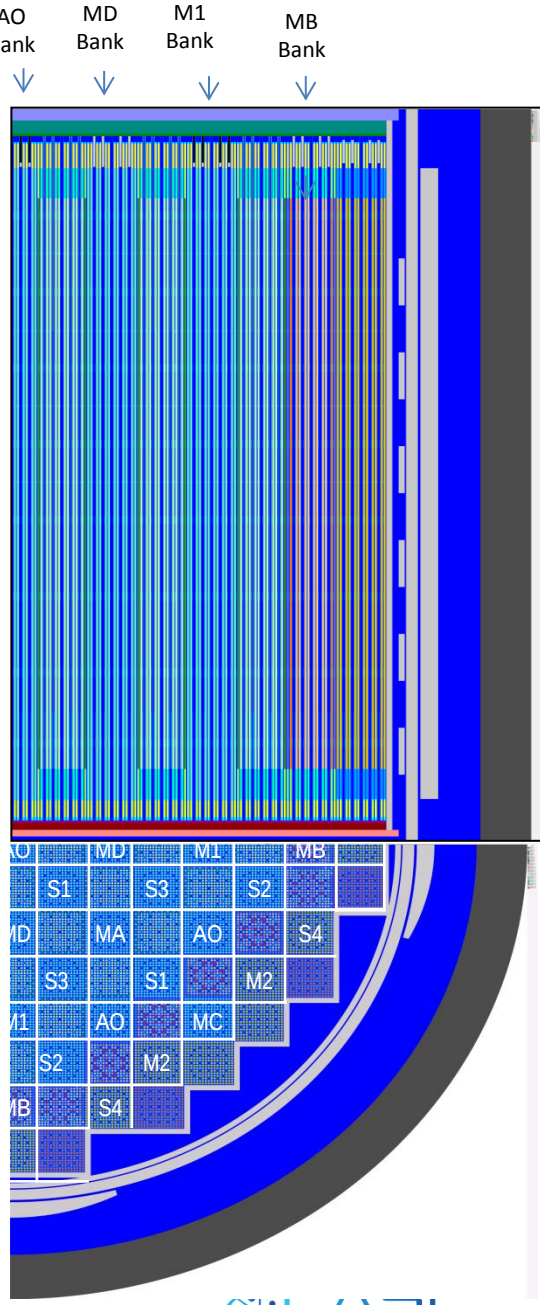
Start-up Boron and Reactivity Coefficients

	KENO	VERA
Critical Boron (ppm)	1314	1311
Isothermal Temp. Coeff. (pcm/F)	-2.7	-3.2
Doppler Temp. Coeff.	-1.6	-1.7
Moderator Temp. Coeff.	-1.1	-1.5

Control Rod Worth

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

KENO Model

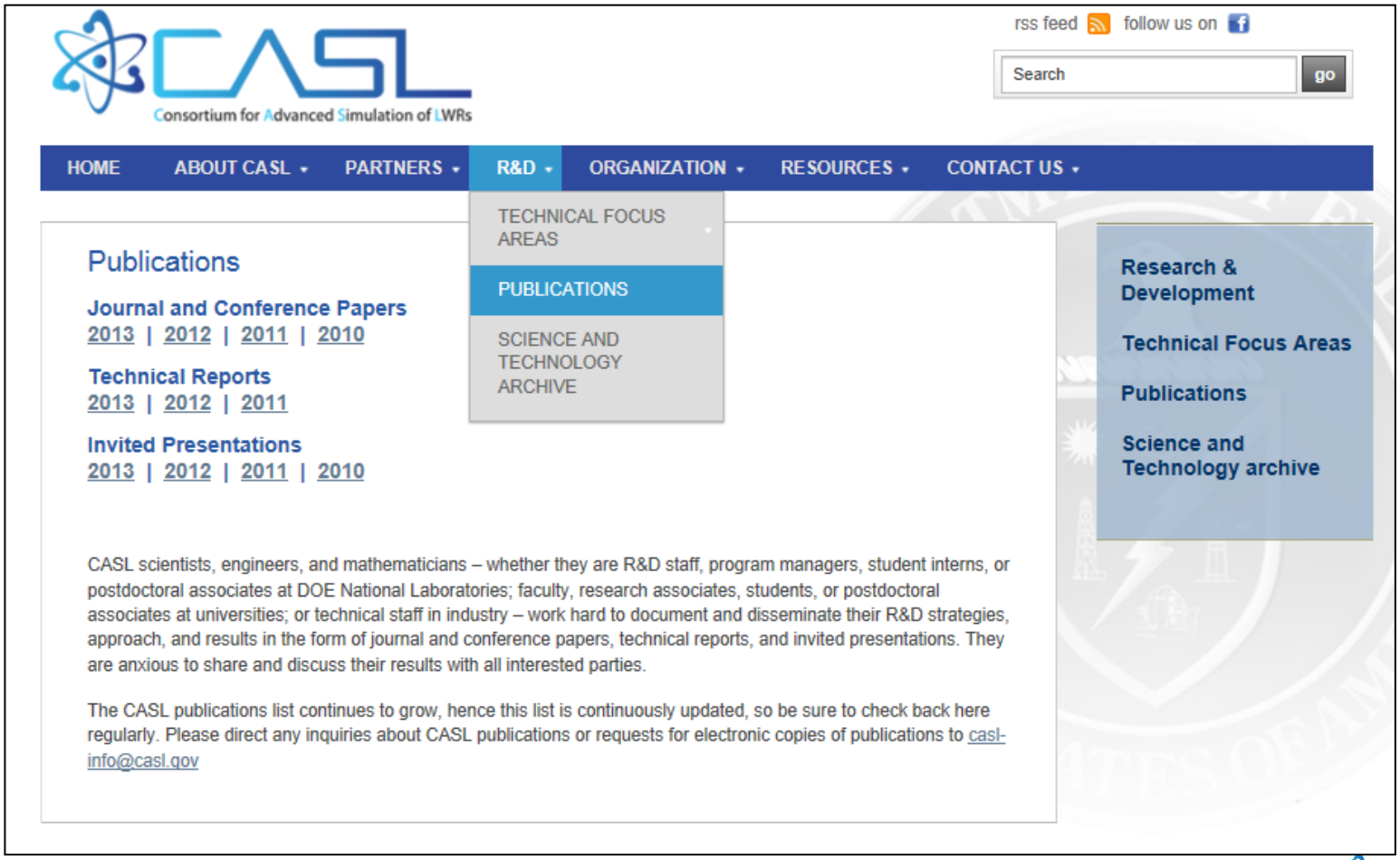


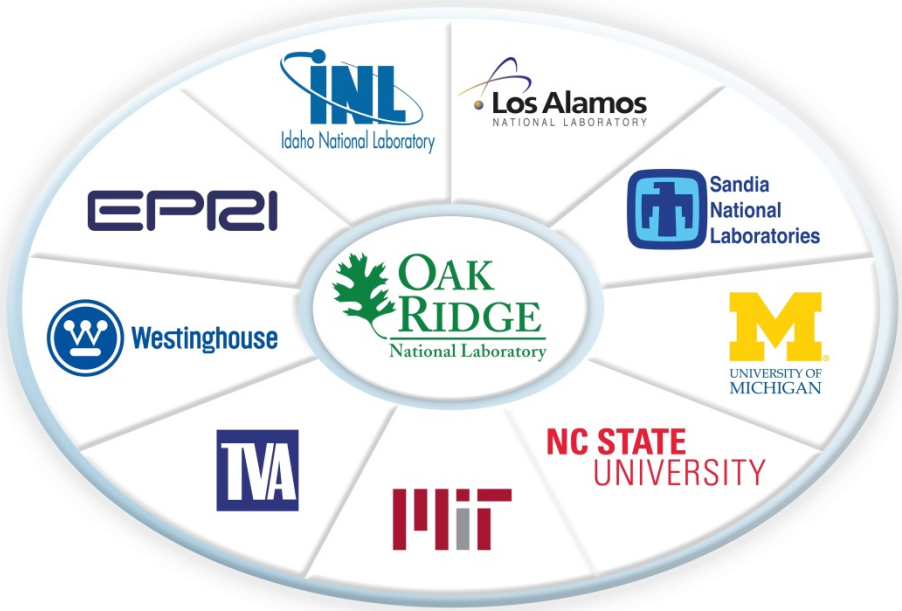
CASL Also Has an Education Program

- Facilitate transfer of CASL technology into the class room and to the nuclear industry
  - CASL Educational Modules
    - Cross-university offering of educational materials (Neutronics, Thermal Hydraulics, Fuel Performance, UQ)
  - CASL Webinar Series
  - CASL Graduate Student Summer Workshops (2011 – present)
  - CASL School (Summer 2015)
    - For graduate students and industry - intensive applications of CASL Education Modules
- Development of an "Educational/Production" version of VERA that is amenable to University instruction
  - Transparent user interface (in development)
  - Reasonable run times on student/utility assessable platforms
- Educating faculty to benefits of using VERA
- VERA training to industry (with Industry Council)

We are Making a Concerted Effort to Publish our Results Online

- http://www.casl.gov/
- Significantly more reports are available



Questions?

www.casl.gov or *info@casl.gov*