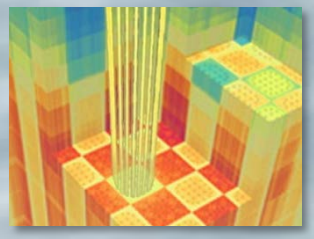
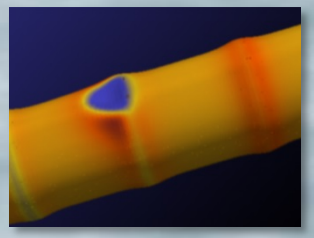
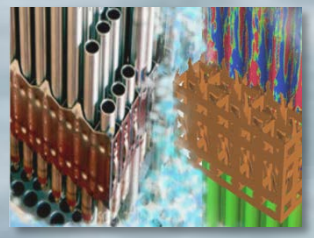
CASL Status

CASL Joint Industry Council / Science Council Meeting

Oak Ridge National Laboratory
October 11, 2016







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

U.S. DEPARTMENT OF ENERGY

Changes in CASL Organization

- Physics Integration (PHI)
  - Tom Downar (UM) takes over as Deputy Focus Area Lead

Tom Downar

- VMA Focus Area split into AMA and VVI
  - Change made to emphasize the focus on application with a distinct applications focus area.
  - VVI clearly identifies the role of developing VUQ methodologies and tools and integrating of the V&V activities across CASL.

Fausto Franceschini Andrew Godfrey

- Advanced Modeling Applications (AMA)
  - Fausto Franceschini (Westinghouse) Lead
  - Andrew Godfrey (ORNL) Deputy
- Verification and Validation Implementation (VVI)
  - Chris Jones (Sandia) Lead
  - Brian Williams (LANL) Deputy

Chris Jones

Brian Williams

All FY16 DOE-reportable milestones Completed on Schedule

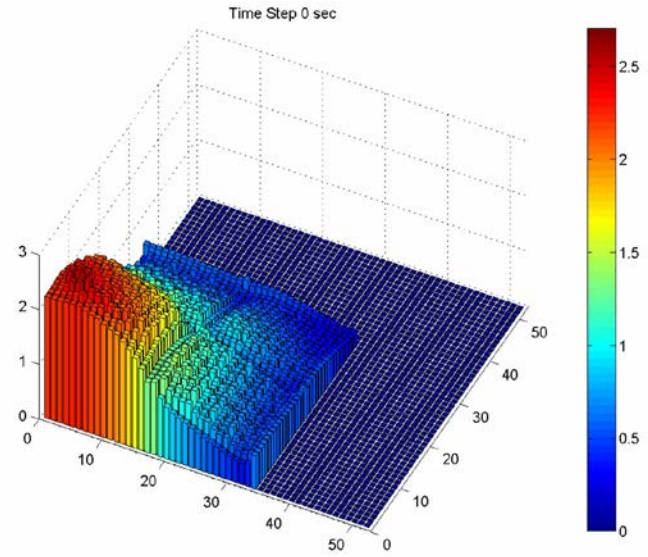
Milestone ID	Milestone Description	Finish Date	Status
FY16.CASL.001	Develop and test subchannel thermal hydraulics to support modeling of BWR operating conditions	January 2016	Completed On Time
FY16.CASL.002	Demonstrate Uncertainty Quantification and Data Assimilation for Watts Bar Unit 1 Cycle 1	March 2016	Completed On Time
FY16.CASL.003	Identify fuel performance capabilities needed for analysis of Reactivity Insertion Accidents (RIA) and complete initial implementation	May 2016	Completed On Time
FY16.CASL.004	Initiate VERA working group by holding first meeting	April 2016	Completed On Time
FY16.CASL.005	Complete VERA integrated Verification and Validation (V&V) requirements and planning and update V&V manuals for individual codes	June 2016	Completed On Time
FY16.CASL.006	Define post CASL sustainability strategy	July 2016	Completed On Time
FY16.CASL.007	Demonstrate VERA Core Simulator performance improvements	August 2016	Completed On Time
FY16.CASL.008	Implement VERA transient capability with internal heat conduction feedback for PWRs for analysis of Reactivity Insertion Accidents (RIA)	September 2016	Completed On Time
FY16.CASL.009	Demonstrate DNB analysis methods using CFD for Non-Mixing Vane and V5H grid spacers	September 2016	Completed On Time
FY16.CASL.010	Assess the analysis capability for core-wide PWR Pellet-Clad Interaction (PCI) screening and demonstrate detailed 3-D analysis on selected subregion	September 2016	Completed On Time
FY16.CASL.011	Qualify CFD-based PWR Crud Induced Localized Corrosion (CILC) capability to identify high-risk fuel rods	September 2016	Completed On Time

CASL has Presence at ANS PHYSOR 2016 Conference

- PHYSOR is the American Nuclear Society semi-annual international topical meeting on Reactor Physics
- Conference held May 1-5, 2016 in Sun Valley, Idaho
- CASL authored 18 papers at the meeting covering topics such as:
  - VERA Benchmarking with Nuclear Plant Data
  - Assessment of Pellet Clad Interaction
  - Westinghouse AP1000® Modeling
  - Radiation Transport methods and cross section processing
- CASL and its research were cited in some way in 14 papers not written by CASL authors indicating a significant impact on work of others

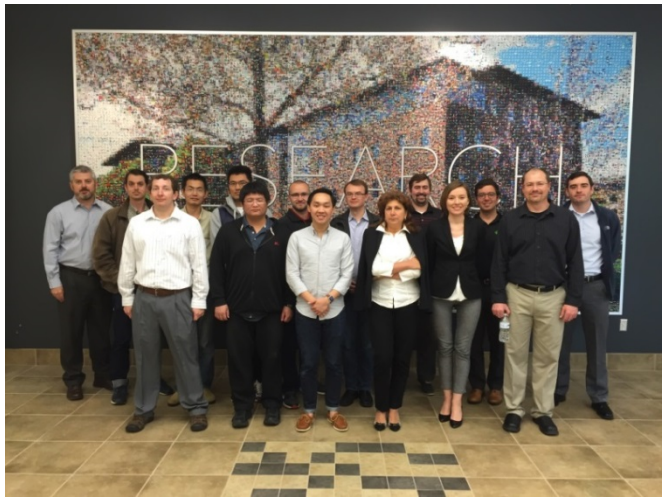
CASL-Seoul National University Collaboration Continuing

- CASL and Seoul National University Collaborating under a US-Republic of Korea International Nuclear Energy Research Initiative (I-NERI) project.
- The 5th meeting on the INERI collaboration was held in Sun Valley, ID during the PHYSOR 2016 conference:
  - 24 participants from Oak Ridge National Lab., University of Michigan, MIT, SNU and Ulsan National Institute of Science and Technology (UNIST)
  - 12 presentations for research collaboration and discussion including high-fidelity static and transient core simulation, and enhancement of deterministic and Monte Carlo core simulation methodologies
  - Reviewed the current progress of research and collaboration and discussed additional collaborations to resolve common technical issues



CASL Provides Training to University of Illinois Students and Exelon Staff

- Training was held at the University of Illinois-Urbana-Champaign (UIUC) May 16-17, 2016
  - 9 Participants from Exelon and UIUC
  - Instructors from ORNL, Idaho National Lab, University of Michigan and Core Physics were on hand to conduct the training
- The training supported Pellet-Cladding Interaction (PCI) modeling of Byron and/or Braidwood Pressurized Water Reactors (PWR) with Virtual Environment for Reactor Applications – Core Simulator (VERA-CS) coupled to Bison Fuel Performance Code
  - Codes were successfully installed and running on iForge cluster at National Center for Supercomputing Applications (NCSA)

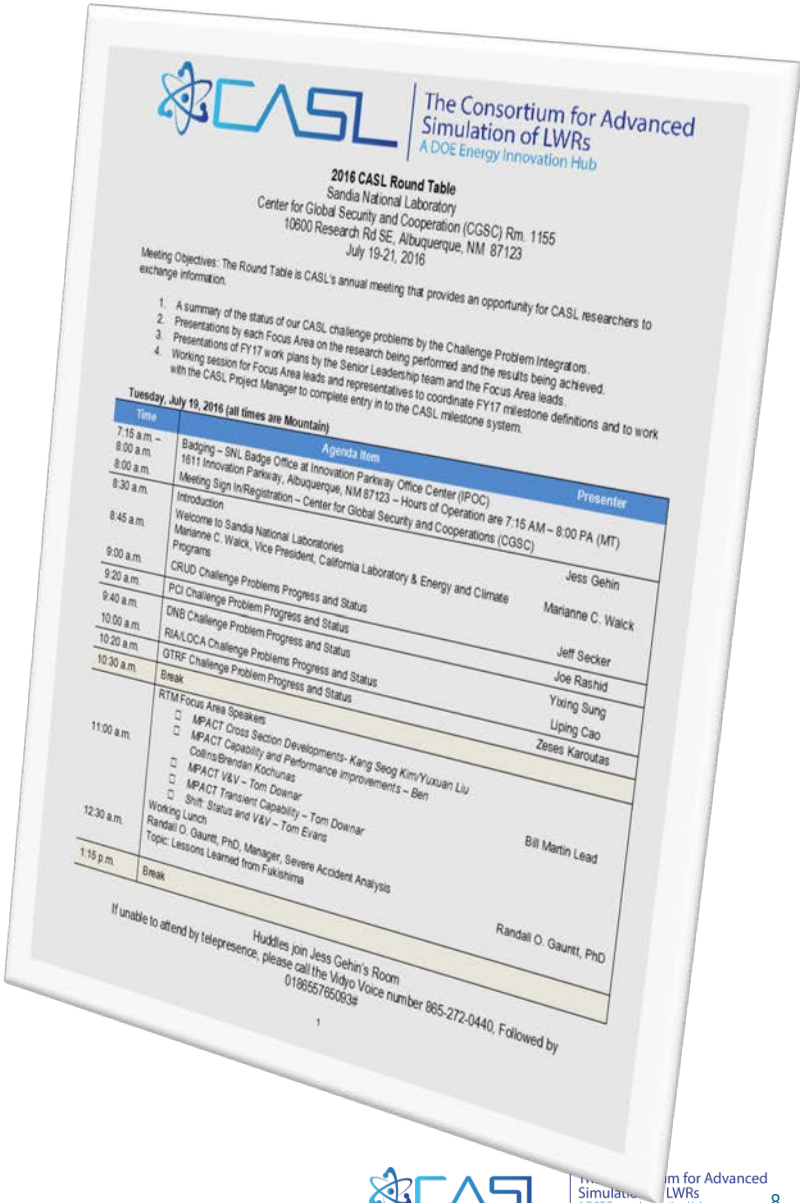


CASL Institute at ORNL

- CASL and ORNL hosted 30 students and industry professionals for a two week (June 20 – July 1, 2016) training and information workshop at ORNL.
- Lectures from multiple CASL partners educated participants about the Virtual Environment for Reactor Applications (VERA) and the CASL Challenge Problems.
- The participants were engaged with hands-on use of VERA and a team project that involved solving a real-world problem.
- Participants received a CASL VERA certificate after successfully completing the institute and meeting certification requirements through the team project.

CASL Annual Meeting – Round Table

- Provides for CASL wide interaction on review of on-going work and planning for next year.
- Summary of the status of our CASL challenge problems by the Challenge Problem Integrators.
- Presentations by each Focus Area on the research being performed and the results being achieved.
- Presentations of FY17 work plans by the Senior Leadership team and the Focus Area leads.
- Working session for Focus Area leads and representatives to coordinate FY17 milestone definitions.



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

2016 CASL Round Table
Sandia National Laboratory
Center for Global Security and Cooperation (CGSC) Rm. 1155
10600 Research Rd SE, Albuquerque, NM 87123
July 19-21, 2016

Meeting Objectives: The Round Table is CASL's annual meeting that provides an opportunity for CASL researchers to exchange information.

1. A summary of the status of our CASL challenge problems by the Challenge Problem Integrators.
2. Presentations by each Focus Area on the research being performed and the results being achieved.
3. Presentations of FY17 work plans by the Senior Leadership team and the Focus Area leads.
4. Working session for Focus Area leads and representatives to coordinate FY17 milestone definitions and to work with the CASL Project Manager to complete entry in to the CASL milestone system.

Tuesday, July 19, 2016 (all times are Mountain)

Time	Agenda Item	Presenter
7:15 a.m. – 8:00 a.m.	Badging – SNL Badge Office at Innovation Parkway Office Center (IPOC) 1611 Innovation Parkway, Albuquerque, NM 87123 – Hours of Operation are 7:15 AM – 8:00 PA (MT)	
8:00 a.m.	Meeting Sign In/Registration – Center for Global Security and Cooperations (CGSC)	
8:30 a.m.	Introduction	Jess Gehin
8:45 a.m.	Welcome to Sandia National Laboratories Marianne C. Walck, Vice President, California Laboratory & Energy and Climate Programs	Marianne C. Walck
9:00 a.m.	CRUD Challenge Problems Progress and Status	Jeff Secker
9:20 a.m.	PCI Challenge Problem Progress and Status	Joe Rashid
9:40 a.m.	DNB Challenge Problem Progress and Status	Yixing Sung
10:00 a.m.	RIA/LOCA Challenge Problems Progress and Status	Uping Cao
10:20 a.m.	GTRF Challenge Problem Progress and Status	Zeses Karoutas
10:30 a.m.	Break	
11:00 a.m.	RTM Focus Area Speakers ☐ MPACT Cross Section Developments- Kang Seog Kim/Yuxuan Liu ☐ MPACT Capability and Performance improvements – Ben Collins/Brendan Kochunas ☐ MPACT V&V – Tom Downar ☐ MPACT Transient Capability – Tom Downar ☐ Shift: Status and V&V – Tom Evans	Bill Martin Lead
12:30 a.m.	Working Lunch Randall O. Gaunt, PhD, Manager, Severe Accident Analysis Topic: Lessons Learned from Fukishima	Randall O. Gaunt, PhD
1:15 p.m.	Break	

If unable to attend by telepresence, please call the Vidyo Voice number 865-272-0440, Followed by Huddles join Jess Gehin's Room 018655765093#

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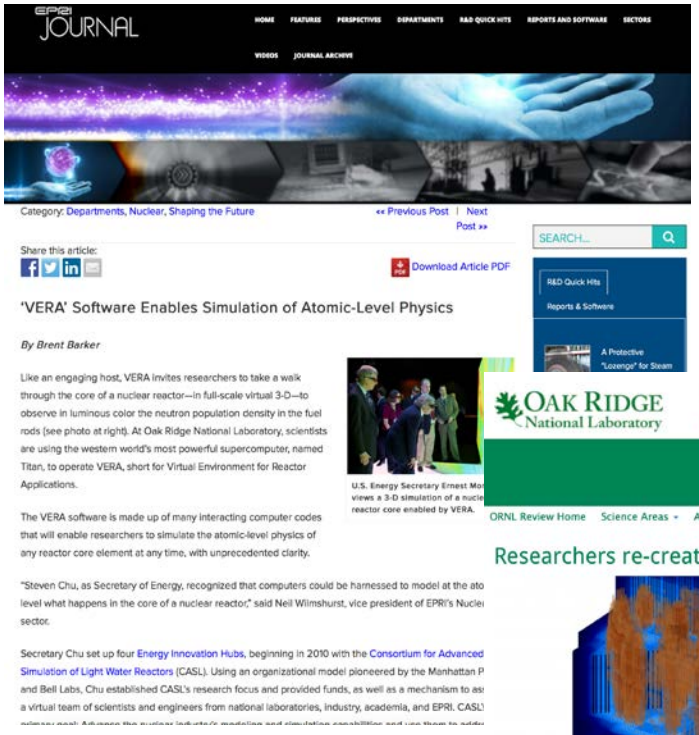
Congratulations Scott Palmtag!
2016 CASL Knight

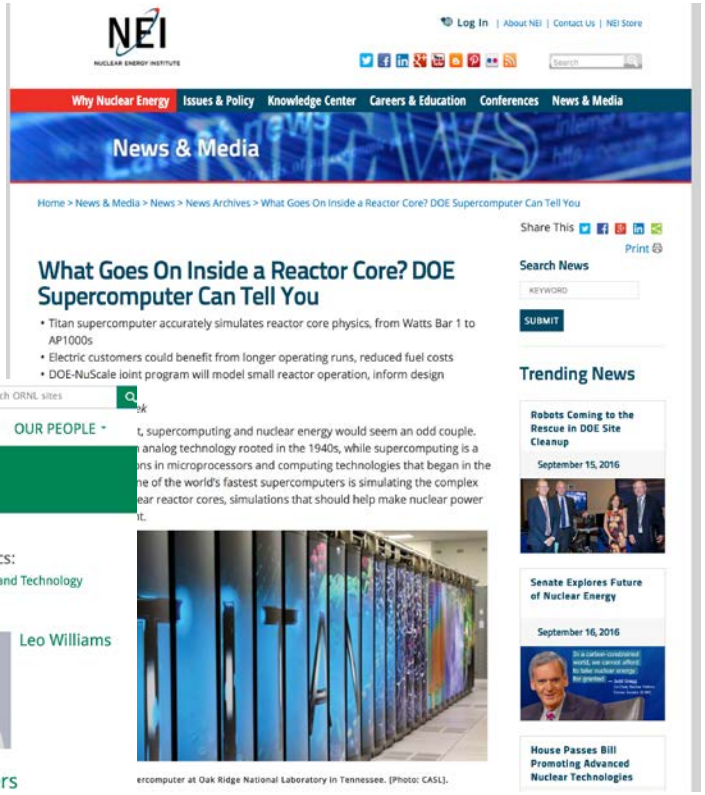
For Recognition of Outstanding Leadership in the Development of VERA-CS

Congratulations Annalisa Manera!
2016 CASL Directors Award

For Exceptional Leadership and Enthusiastically Stepping Forward to Accept Responsibility for Key Milestones on the CILC Challenge Problem

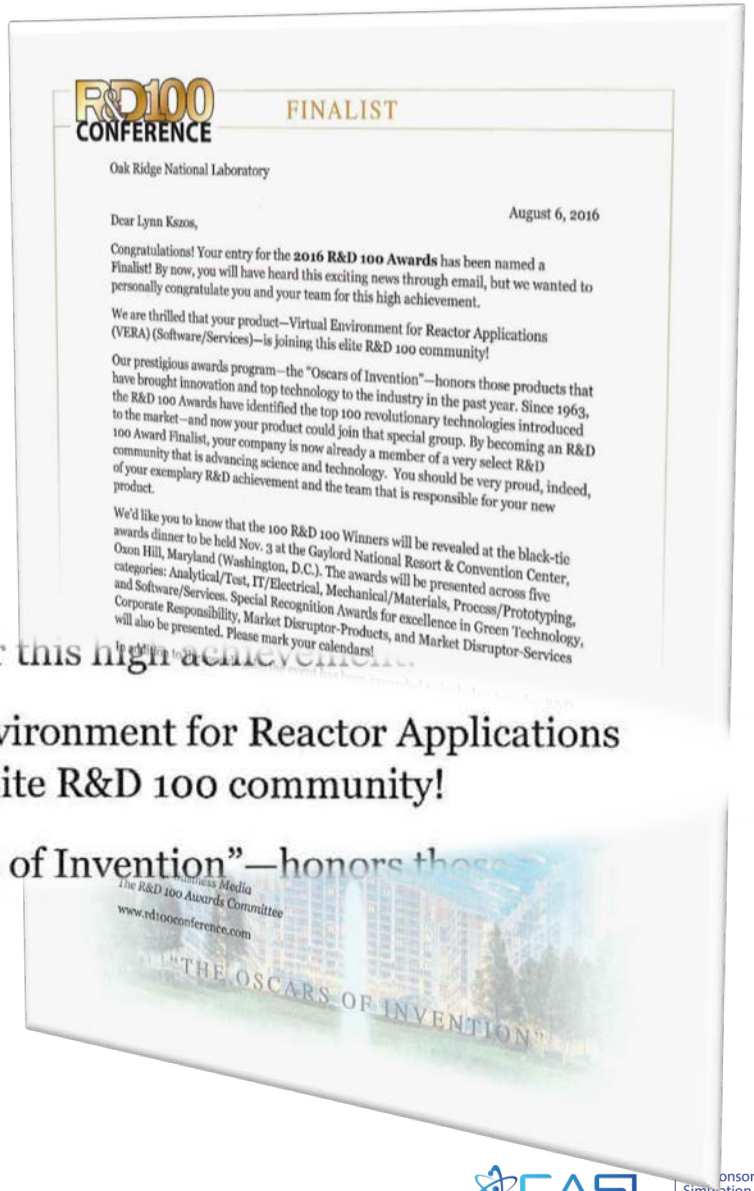
Web Articles Provide Visiblity on CASL's Research





VERA selected as a finalist for an R&D100 Award

R&D 100 2016 R&D 100 Awards



R&D100 CONFERENCE FINALIST

Oak Ridge National Laboratory

August 6, 2016

Dear Lynn Kszos,

Congratulations! Your entry for the **2016 R&D 100 Awards** has been named a Finalist! By now, you will have heard this exciting news through email, but we wanted to personally congratulate you and your team for this high achievement.

We are thrilled that your product—Virtual Environment for Reactor Applications (VERA) (Software/Services)—is joining this elite R&D 100 community!

Our prestigious awards program—the "Oscars of Invention"—honors those products that have brought innovation and top technology to the industry in the past year. Since 1963, the R&D 100 Awards have identified the top 100 revolutionary technologies introduced to the market—and now your product could join that special group. By becoming an R&D 100 Award Finalist, your company is now already a member of a very select R&D community that is advancing science and technology. You should be very proud, indeed, of your exemplary R&D achievement and the team that is responsible for your new product.

We'd like you to know that the 100 R&D 100 Winners will be revealed at the black-tie awards dinner to be held Nov. 3 at the Gaylord National Resort & Convention Center, Oxon Hill, Maryland (Washington, D.C.). The awards will be presented across five categories: Analytical/Test, IT/Electrical, Mechanical/Materials, Process/Prototyping, and Software/Services. Special Recognition Awards for excellence in Green Technology, Corporate Responsibility, Market Disruptor-Products, and Market Disruptor-Services will also be presented. Please mark your calendars!

congratulate you and your team for this high achievement.

We are thrilled that your product—Virtual Environment for Reactor Applications (VERA) (Software/Services)—is joining this elite R&D 100 community!

Our prestigious awards program—the "Oscars of Invention"—honors those

The R&D 100 Awards Committee

www.rd100conference.com

"THE OSCARS OF INVENTION"

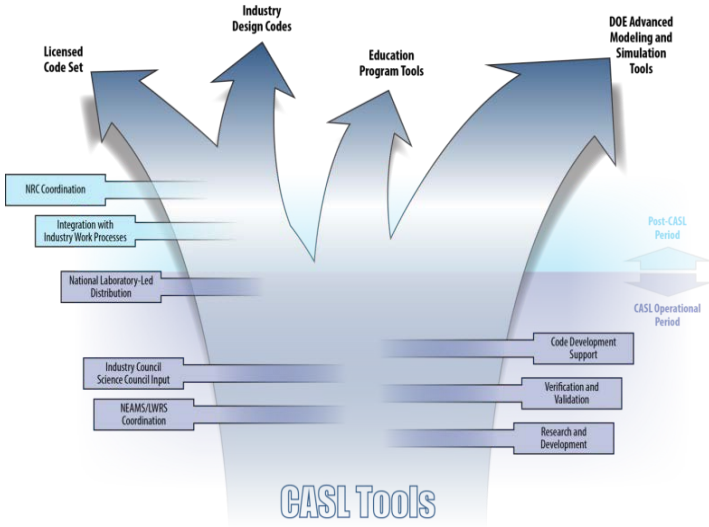
CASL Noted in Secretary Moniz's Testimony

- CASL noted in Secretary Moniz's testimony to the Senate Energy & Water Development Hearing on the Future of Nuclear Power on September 14, 2016.

"We have been successful in improving modeling and simulation to enhance the performance of currently operating light water reactors through the Consortium for Advanced Simulation of Light Water Reactors (CASL), one of the Department's Energy Innovation Hubs, and a program I was honored to serve as the Chairman of the Board for its first two years."

Post-CASL Strategy – What's Next for CASL?

- A Post-CASL Strategy was developed to identify steps that need to be taken over the next three years to prepare for post-CASL transition
- The strategy was a CASL FY16 DOE Reportable milestone with a scheduled delivery date of July 31, 2016
- Includes industry support through a VERA working group that was established this year
- R&D will be performed in an integrated CASL/NEAMS Nuclear Mod/Sim Program beginning in 2020



FY17 Planning - DOE-reportable milestones

Milestone ID	Milestone Description	Finish Date
FY17.CASL.001	Develop and deliver nuclear cross section data library supporting Pressurized Water Reactor (PWR) and Boilding Water Reactor (BWR) designs	Feb-17
FY17.CASL.002	Prepare and release update to VERA to the Radiation Shielding Information Computational Center (RSICC) for distribution outside of CASL	Feb-17
FY17.CASL.003	Perform core design and Crud Induced Induced Power Shift (CIPS) analysis of a future core design and compare to industry risk analysis	Mar-17
FY17.CASL.004	Complete and document Watts Bar Nuclear Unit 2 Startup Analysis	Mar-17
FY17.CASL.005	Complete and demonstrate VERA with cores simulator coupled with Monte Carlo ex-core transport capabilty	Apr-17
FY17.CASL.006	Complete and document assessment of VERA against the Verification and Validation Plan	Jun-17
FY17.CASL.007	Establish solution-verified Computational Fluid Dynamics (CFD) model of Westinghouse 5 x 5 bundle for Departure from Nucleate Boiling (DNB) validation studies	Jul-17
FY7.CASL.008	Complete and demonstrate improved VERA CRUD Induced Power Shift (CIPS) capabilties	Aug-17
FY17.CASL.009	Develop, Demonstrate, and Assess advancec Computational Fluid Dynamics (CFD) Based Capabilty for Prediction of Departure from Nucleate Boiling (DNB)	Sep-17
FY17.CASL.010	Complete benchmarking of BISON against Loss of Coolant Accident experiments.	Sep-17
FY17.CASL.011	Complete and document CASL research and development on grid-to-rod fretting (GTRF) challenge problem	Sep-17

DOE NE CASL and NEAMS Collaboration

CASL

- The CASL and NEAMS leadership teams met with Deputy Assistant Secretary Shane Johnson and program federal managers DOE at DOE Headquarters in Germantown, MD on August 17, 2016.
- The goal of the meeting was to provide an opportunity to discuss, highlight and plan collaboration and engagement between the CASL and NEAMS programs including ongoing collaboration and proposed future collaborations.
- Other objectives included:
  - Discuss common needs between the programs such as staff availability, computing resources, and connections to other DOE offices and programs.
  - Consider coordination opportunities to provide modeling and simulation capabilities to support other DOE/NE programs.
  - Discuss collaborative development of an integrated, comprehensive advanced modeling and simulation program that could be implemented after CASL has completed its 10 year operation period.

NEAMS
NUCLEAR ENERGY ADVANCED MODELING & SIMULATION PROGRAM

CASL

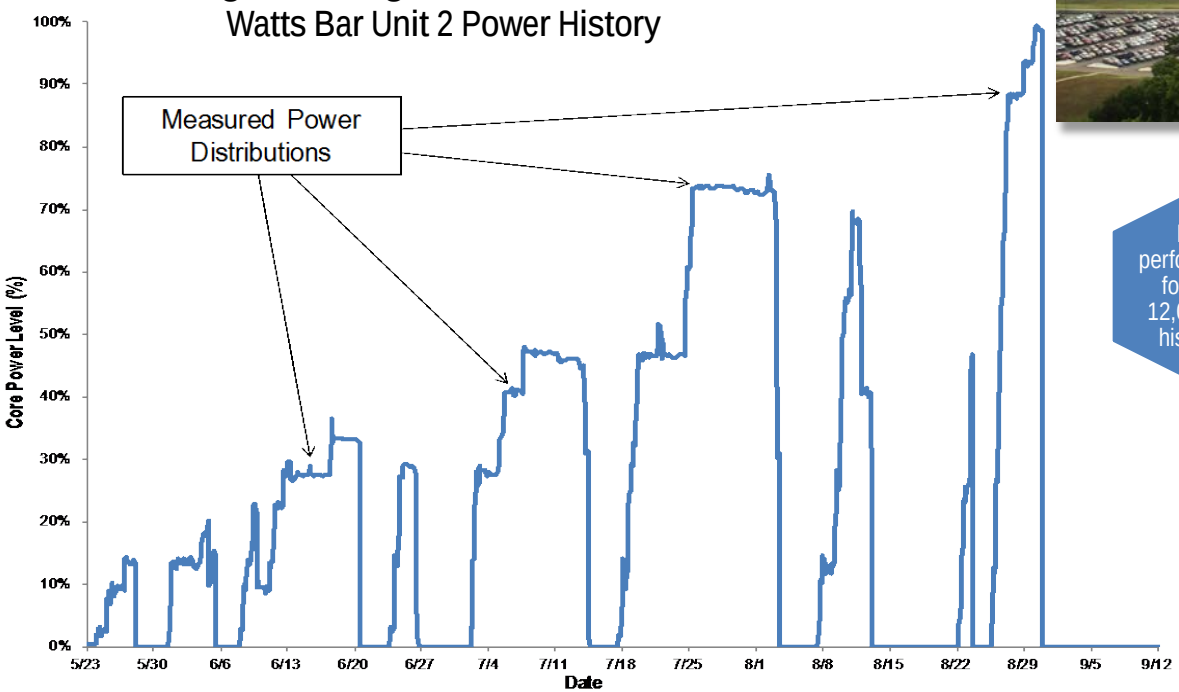
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

CASL is Modeling Watts Bar Unit 2 Startup and Power Ascension

- Watts Bar Unit 2 initial criticality was on May 23, 2016

  December 2015 – Fuel Load
  May 23, 2016 – Initial criticality
  June 3, 2016 – On the power grid
  June – August 2016 – Power Ascension Testing
  August 30, 2016 – Reactor trip from 99% power (transformer fire)
  October 2016 – Full power operation

- VERA results have already been important for informing Westinghouse and TVA evaluations



Over 10,000 coupled nuclear/T-H iterations

Transient Isotopics in over two million regions

Fuel performance for over 12,000 rod histories

Direct in-core self-powered detector response

Frequent comparisons to plant measure-ments

Explicit shutdown decay of radioactive fission products

Largest simulation by CASL to date – done in nearly real-time

CASL Milestone Demonstrate Significant VERA Performance Improvements

- CASL submitted a milestone report to DOE which describes the performance improvements made to the Virtual Environment for Reactor Applications Core Simulator (VERA-CS) during FY16.
- The goal of this work was to reduce the VERA-CS run-times so a complete cycle depletion could be run with 1,000 cores overnight (i.e., the “1,000 core depletion” criterion). This goal was set by CASL industry partners so they could achieve reasonable turnaround on medium-sized computer clusters.
- The results presented in this report show a code speed-up by a factor of 5, which successfully satisfies the goal set by industry.

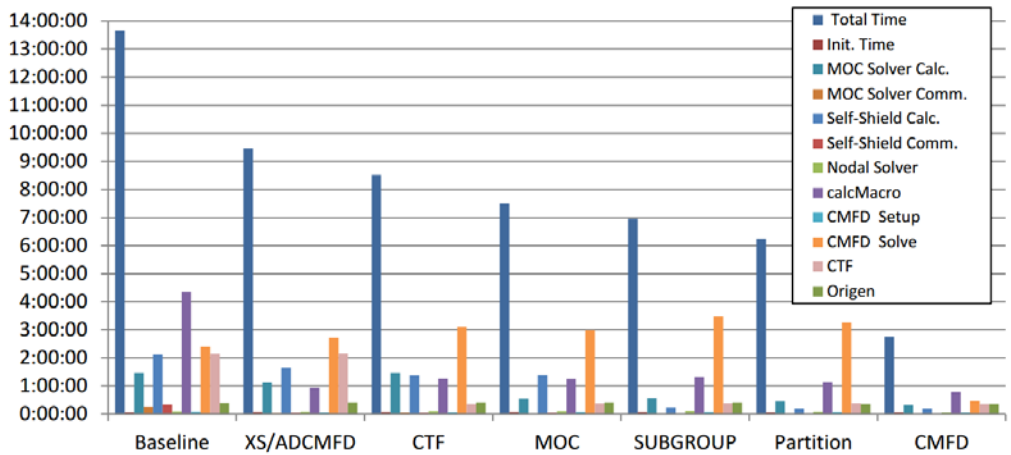


Figure 17. Progression of speedup for cycle depletion case.

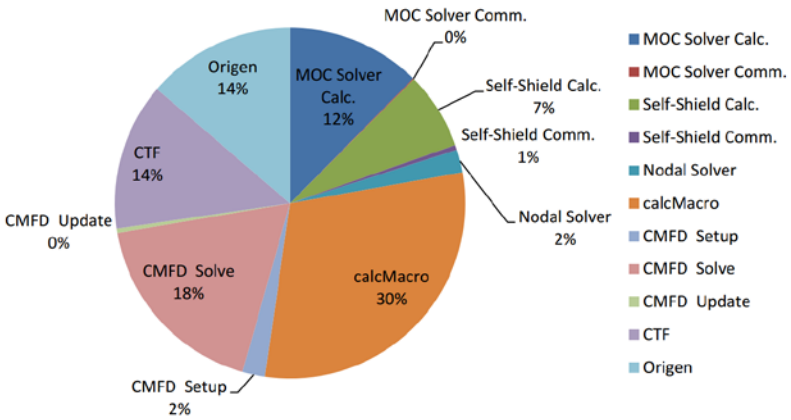
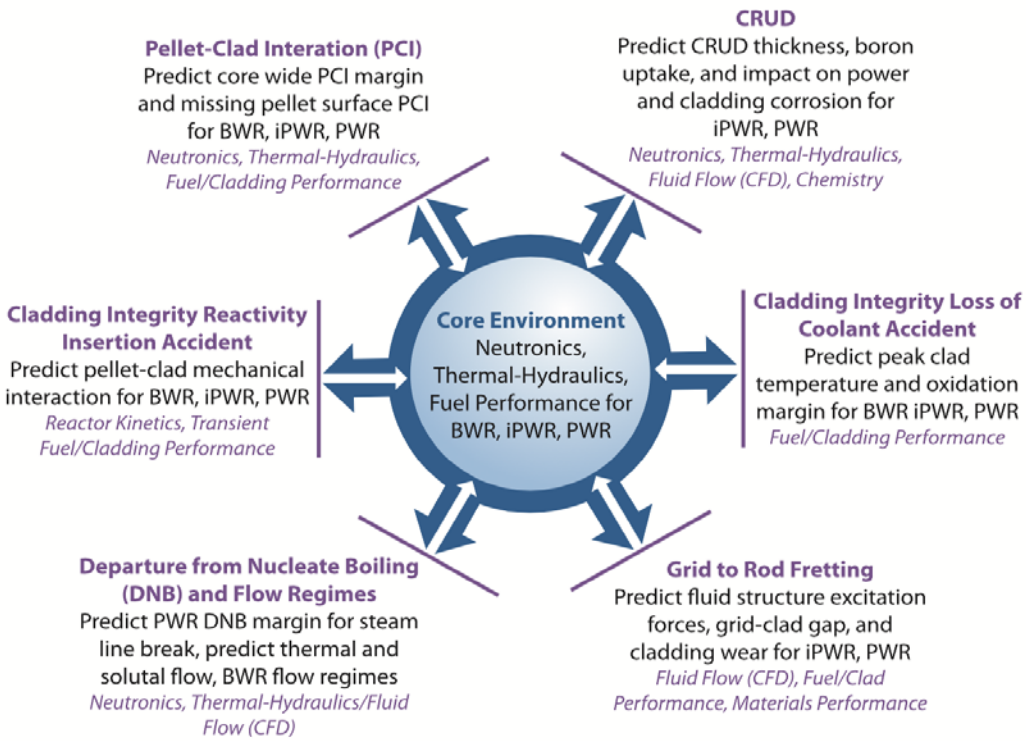


Figure 18. Final fraction of run-time for cycle depletion.

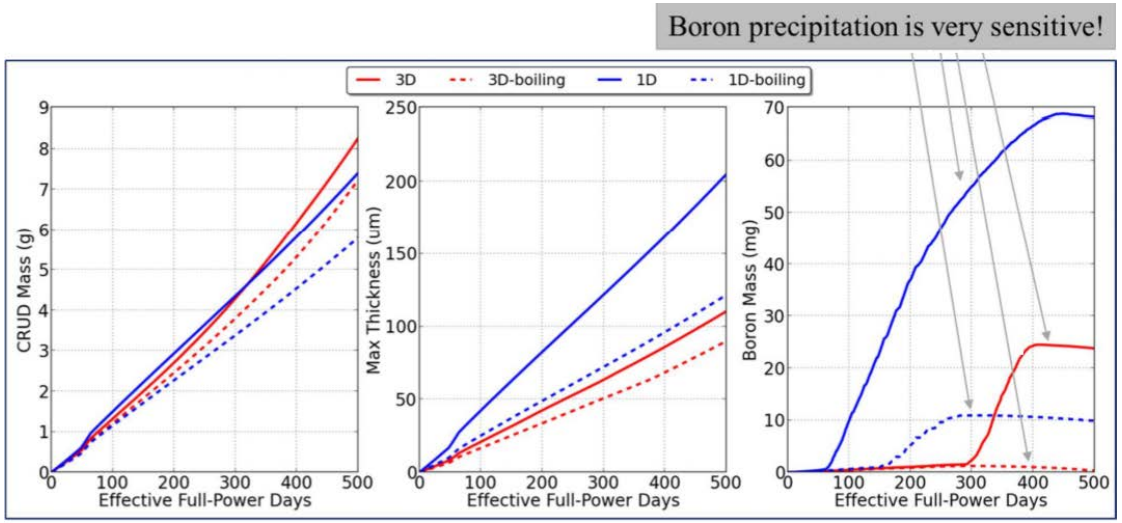
Challenge Problems Progress

- The following Challenge Problems are being focused upon in FY16:
  - CRUD Induced Power Shift (CIPS) and CRUD Induced Localized Corrosion (CILC)
  - Pellet-Clad Mechanical Interaction (PCMI)
  - Departure from Nuclear Boiling (DNB)
  - Transient behavior during Reactivity Insertion Accident (RIA)



Two-Phase CFD/Subchannel Comparison and Assessment of the MAMBA CRUD Deposition Models

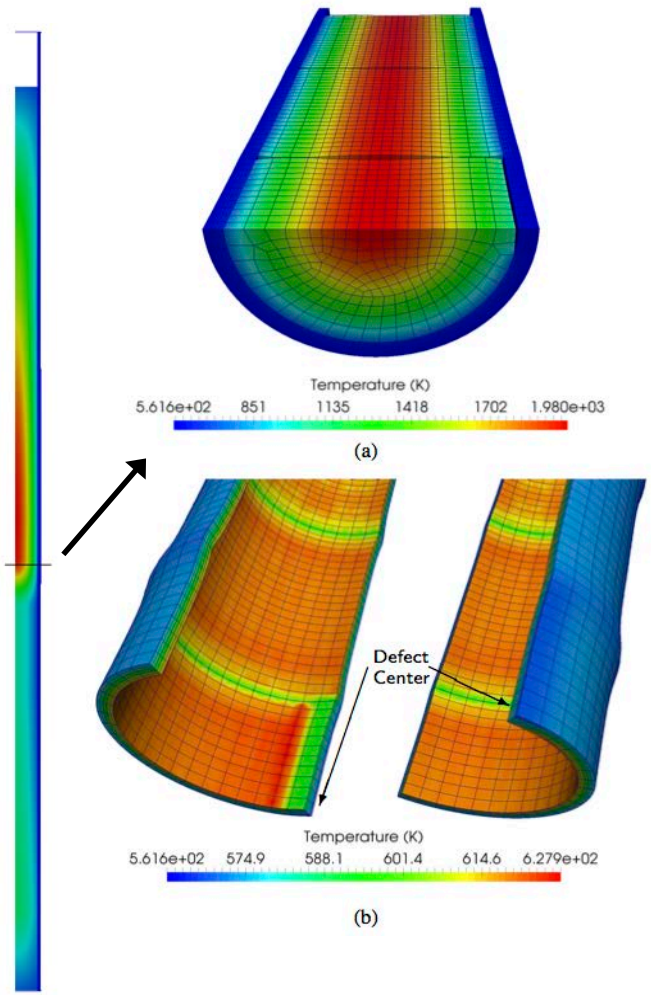
- CASL completed a level 2 milestone which completed significant improvements to the MAMBA -3D coupling with the computational fluid dynamics software STAR-CCM+.
- Quantified the difference between STAR-CCM+ and CTF under subcooled nucleate boiling conditions (wall temperature, wall heat flux and turbulent kinetic energy, grid effects)
- Quantified the difference between MAMBA-3D and MAMBA-1D under subcooled nucleate boiling conditions (CRUD mass and thickness, boron mass)
- The progress made in this milestone has advanced the predictive capabilities and functionality of coupled MAMBA-3D as well as inform future development coupled MAMBA/CTF



Comparison of integral CRUD characteristics predicted by MAMBA-1D and -3D for boundary conditions provided by both single- and two-phase STAR-CCM+ models; 150% power

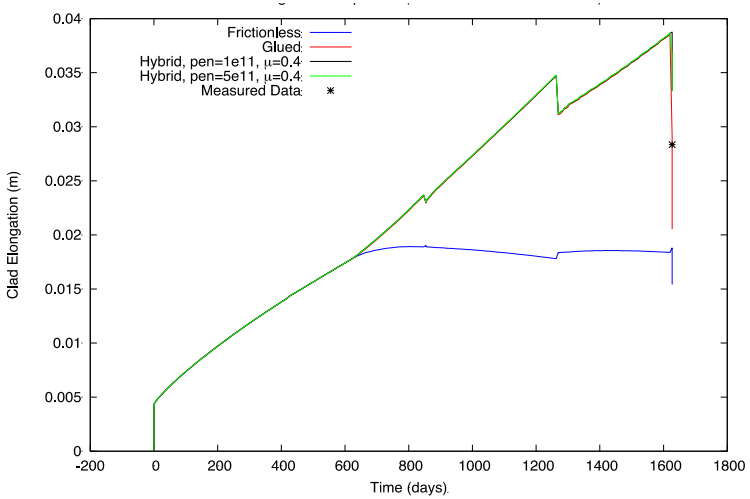
Enhanced Coupling Between BISON 2D and 3D Models

- Efficient modeling of local effects requires:
  - Global model of full fuel rod (2D for efficiency)
  - Local submodel (3D for accuracy)
  - Transfer of boundary conditions
- Recent enhancements permit variable transfer from 2D-RZ model to prescribe boundary conditions on 3D submodel
  - Global scalar variables
    - Fission gas released
    - Plenum gas temperature and volume
  - Field variables
    - Displacements at submodel ends (providing relative motion between fuel and clad)
    - Cladding temperature beyond submodel region

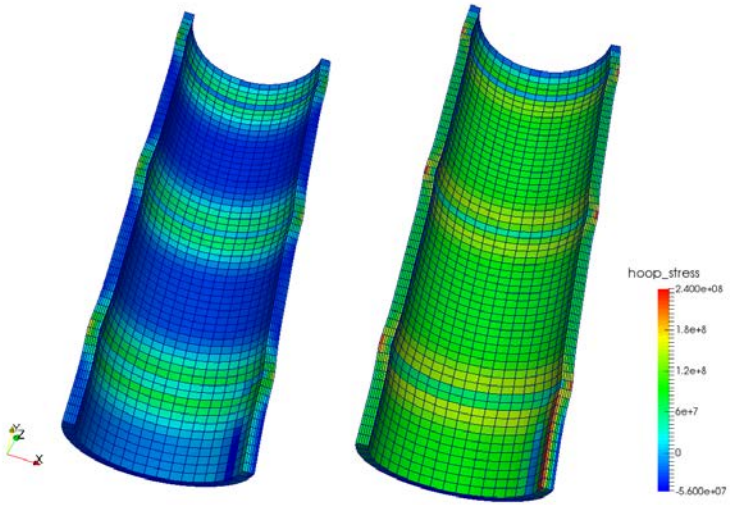


BISON Improvements for Frictional Contact in 2D and 3D

- A new hybrid frictional contact formulation including a slip damper have been implemented in BISON
- Multiple test cases and example problems demonstrate significant improvements in code robustness.
- Further refinements, verification and validation are still needed and will be undertaken in the next fiscal year.



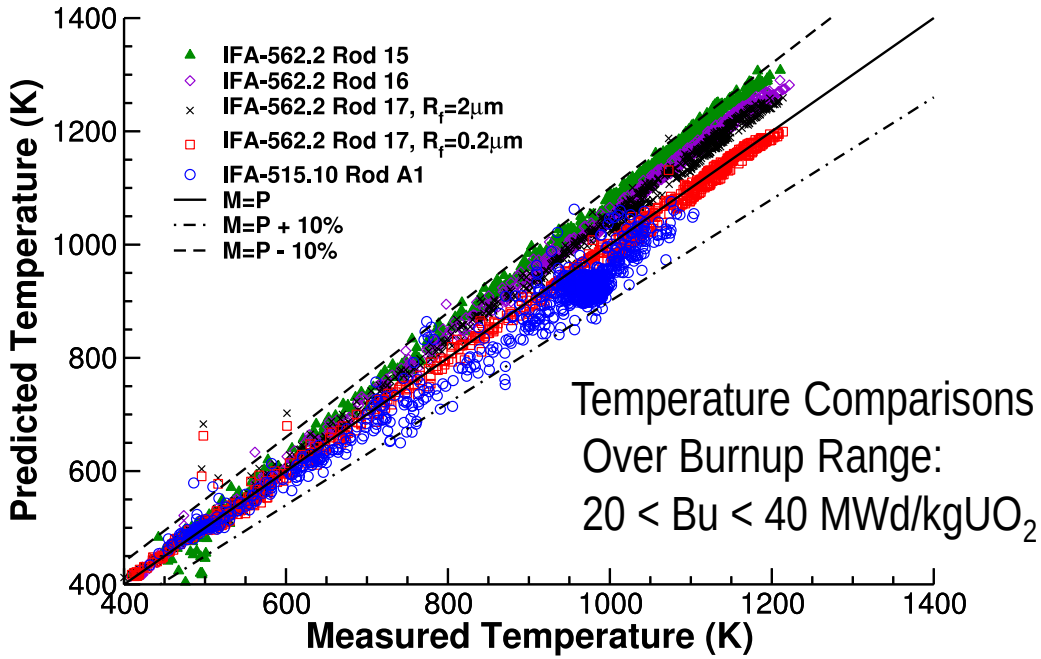
Clad elongation comparisons for a commercial fuel rod



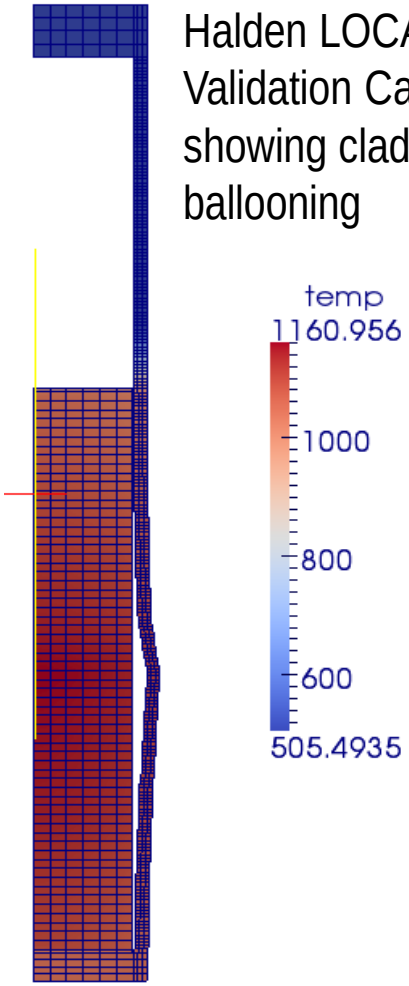
Comparison of hoop stress with frictionless (left) and frictional (right) contact for clad surrounding a defective fuel pellet

BISON Verification and Validation: Status and Plans

- V&V Plan completed March 31, 2016 to satisfy Milestone L3:FMC.PCI.P12.03
- Outlines both current status and future plans
- Motivated by CASL Challenge Problems (PCI, LOCA, RIA) and prior LWR validation experience



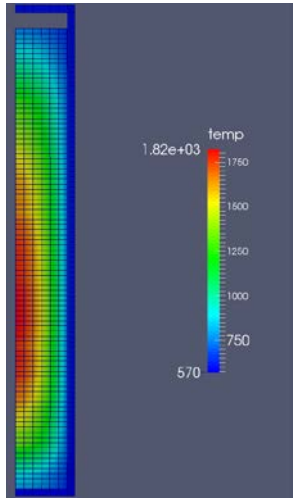
Temperature Comparisons Over Burnup Range: 20 < Bu < 40 MWd/kgUO_2

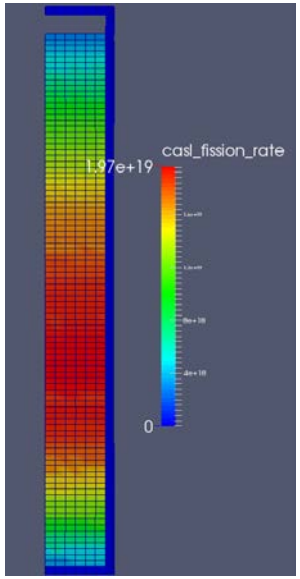


Halden LOCA Validation Case showing clad ballooning

Initial Capability VERA-CS+Bison for PCI Assessment Demonstrated

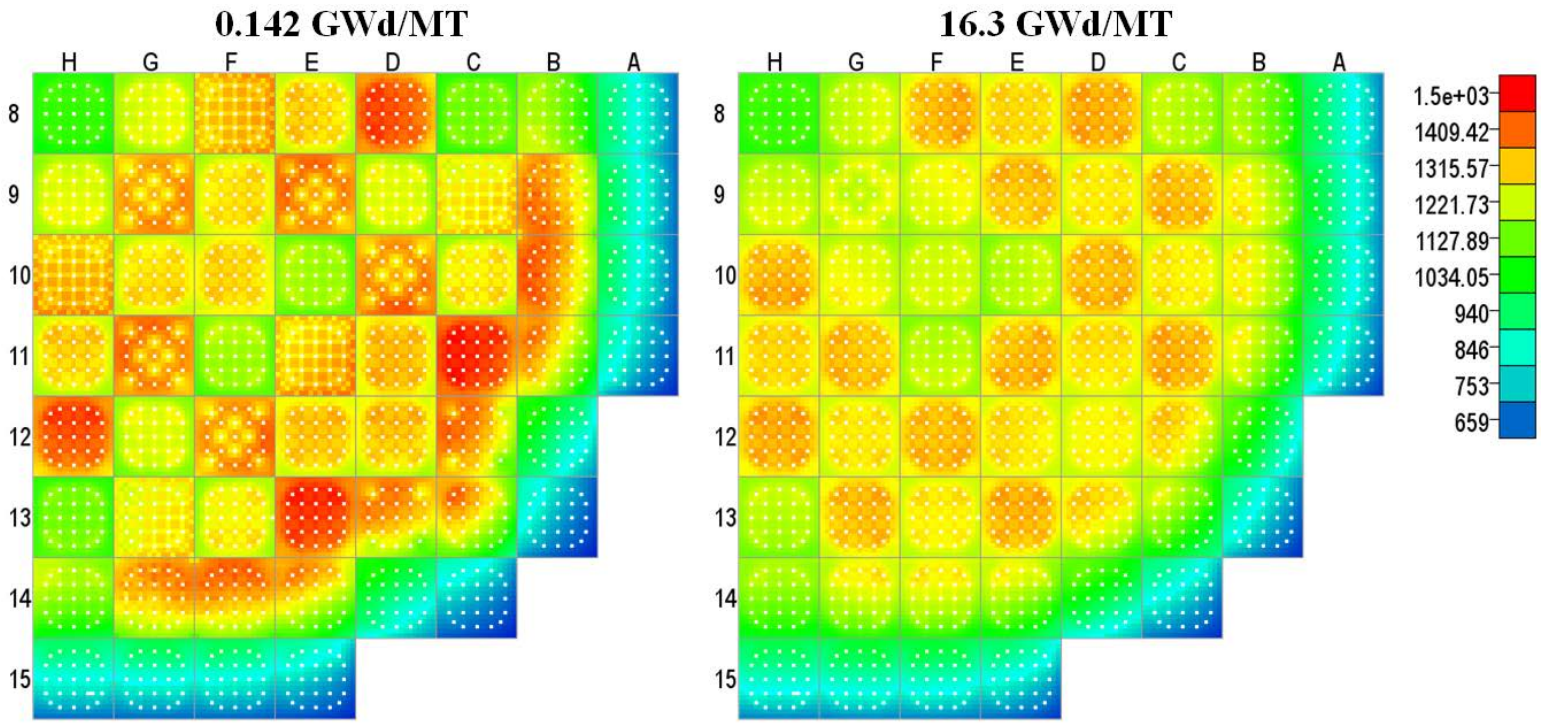
- Develop an initial “Inline” coupling mode between Virtual Environment for Reactor Applications – Core Simulator (VERA-CS) and Bison to assess Core-wide Pellet-Clad Interaction.
  - Allows for faster analysis of depletion with Bison.
- Capabilities:
  - Modification of solver structure to execute in this mode.
  - Processing of the VERA input to enable it.
  - Collection of the "PCI indicator" relevant data from all Bison pins
  - Outputting PCI Indicators to common HDF5 file for VERAView
  - Support for core symmetry options.
  - Improved accuracy: radial biasing and higher order element support.
  - Automated nightly updates of Bison.
- Successfully demonstrated time stepping algorithm for coupled simulations of mini-core test problem.





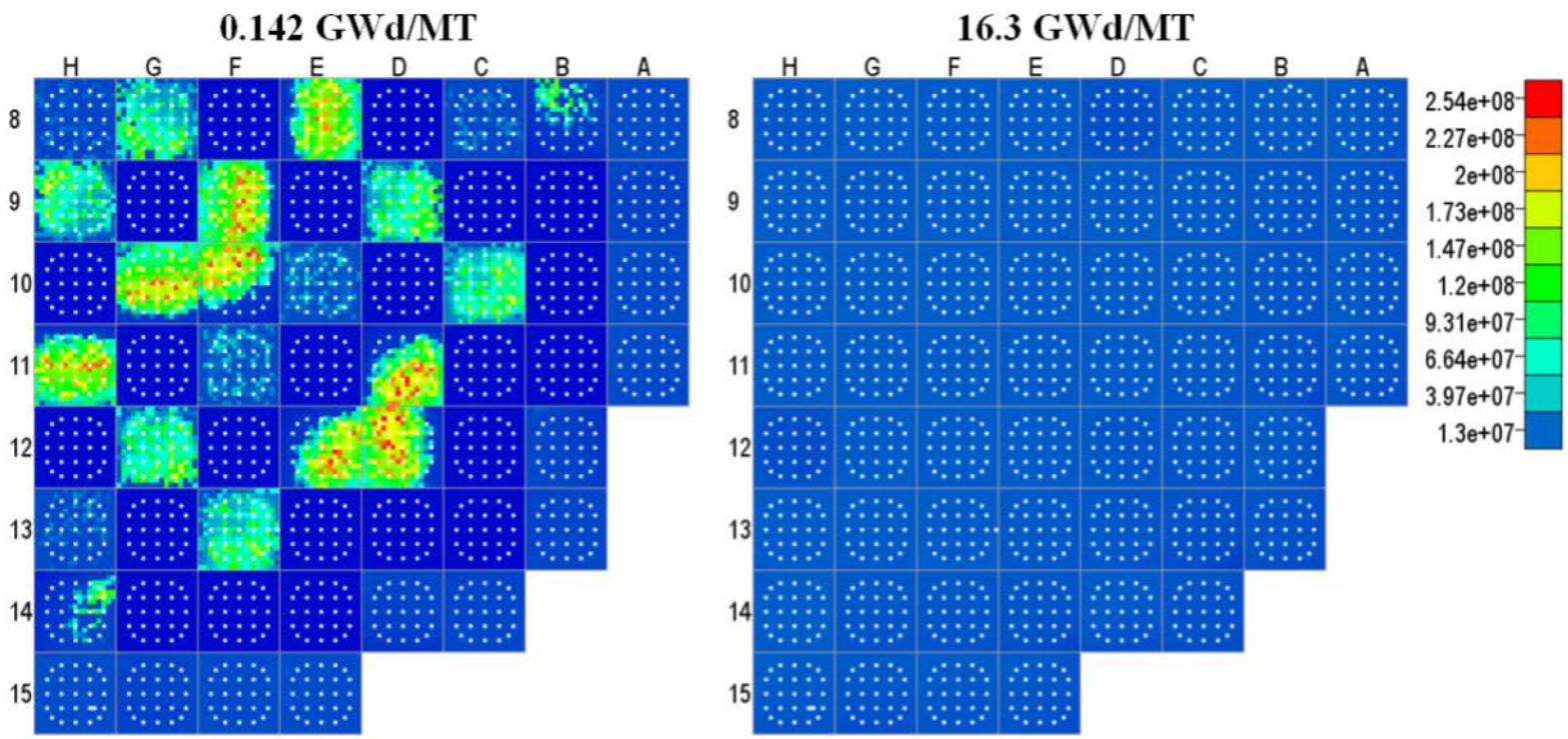
Watts Bar Unit 1 Cycle 2

Maximum Centerline Fuel Temperature (K)



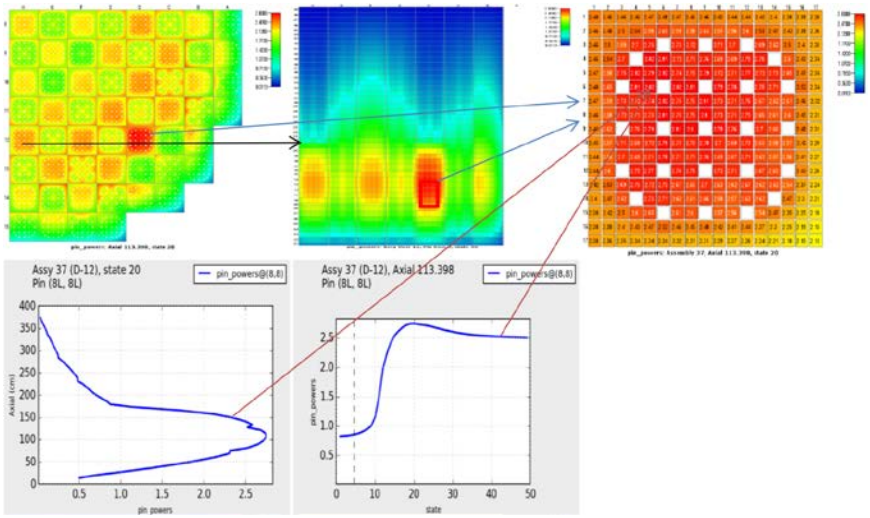
Watts Bar Unit 1 Cycle 2

Maximum Cladding Hoop Stress (Pa)



VERA Transient Capability Demonstrated

- CASL completed a level 2 milestone in which the focus of the work was to develop and implement the algorithms necessary to provide an efficient and accurate solution of the full core time-dependent transient calculations in MPACT.
- The work reported in this milestone report is a necessary step to achieve the capability in VERA-CS to perform full core Reactivity Insertion Accident (RIA) analysis as specified in the CASL RIA Challenge Problem Implementation Plan.
- The results confirmed the feasibility of performing VERA-CS transients for practical large-scale light water reactor problems.

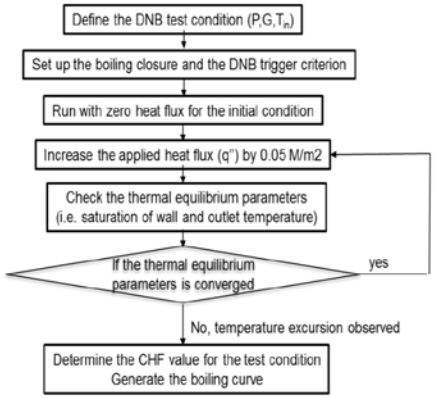


Sample VERAView Transient Output from MPACT

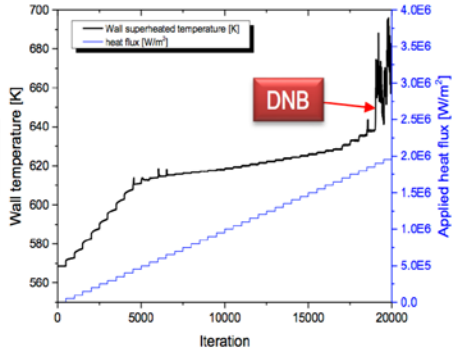
CFD-Based DNB Approach

- Development of improved DNB models for implementation into CFD codes.
- Supported by experiments and new data analysis techniques
- FY17 planned milestone on demonstration of CFD-based approach

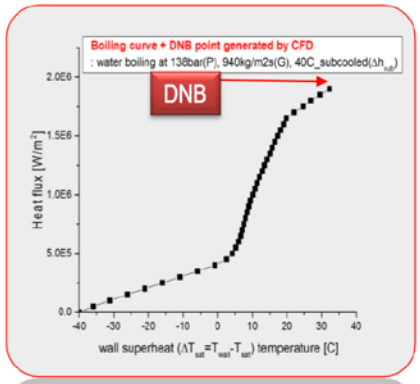
CFD methodology for DNB model

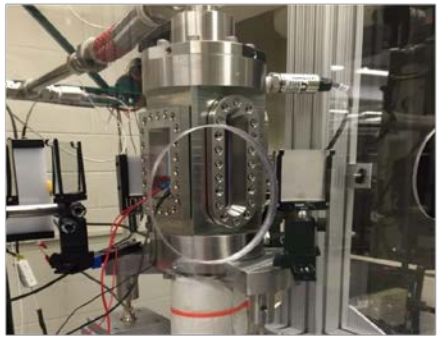


Wall temperature monitoring



Boiling curve with DNB point





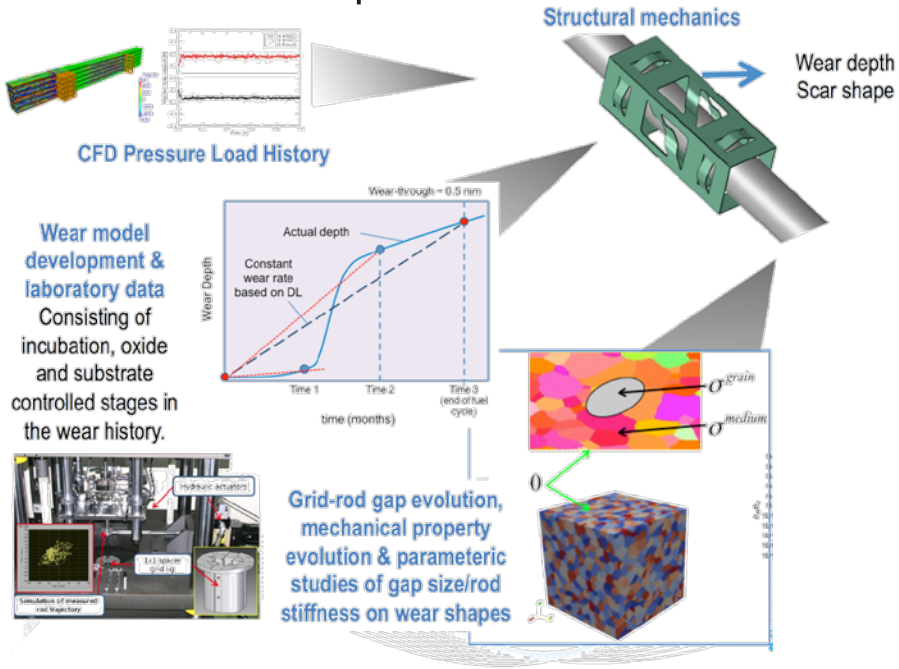
PEThER

- **Up to10 bars**
- Ambient temperature to saturation
- 400 to 1250 kg/m²/s
- **Up to CHF**
- **Synchronized IR and HSV**
- **Advanced post-processing algorithms**

Grid-to-Rod Fretting Challenge Problem Effort to be Completed in FY17

GTRF Challenge Problem

- Work performed over past 6 years:
  - CFD Simulations for Pressure Load
  - Development of a wear model
  - Experimental measurements of wear parameters
  - Evaluation of grid-to-rod gap evaluation
  - Structural mechanics approach to compute wear scare
- Multi-year effort on GTRF will be completed in FY17 with a demonstration of capability.



Priorities for FY17 (CASL L1 and Key L2 Milestones)

- Complete and demonstrate improved VERA CRUD Induced Power Shift (CIPS) capabilities
- Complete and document CASL research and development on grid-to-rod fretting (GTRF) challenge problem
- Develop, demonstrate, and assess advanced Computational Fluid Dynamics (CFD)based capability for prediction of Departure from Nucleate Boiling (DNB)
- Complete and demonstrate VERA with cores simulator coupled with Monte Carlo ex-core transport capability
- Advance fundamental research for multi-phase CFD (BWR flow regime closure relations)
- Advance RIA and LOCA fuel performance work - fundamental model development and benchmarking

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