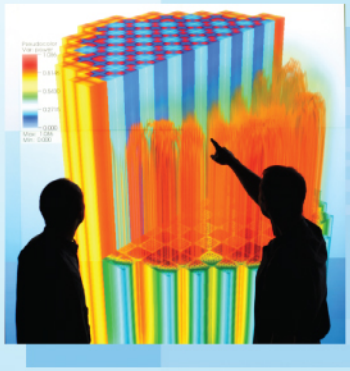
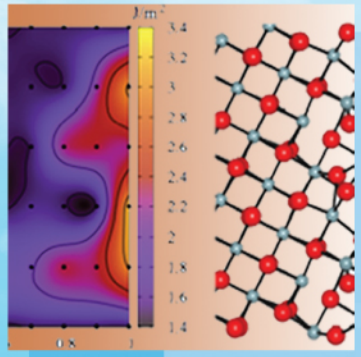
CASL-U-2014-0355-000

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

Nuclear Energy Institute (NEI) Summit Presentation

University-Industry-Laboratory Partnerships: Gauging Effectiveness

Douglas Kothe, CASL Director

Oak Ridge National Laboratory

February 26, 2014

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

CASL-U-2014-0355-000

University-Industry-Laboratory Partnerships
Gauging Effectiveness

CASL: The Consortium for Advanced Simulation of Light Water Reactors
A DOE Energy Innovation Hub

Douglas B. Kothe

Oak Ridge National Laboratory

Director, CASL

9th Nuclear Energy R&D Summit

Nuclear Energy Institute

Washington, D.C.

February 26, 2014

CASL Background

- What is CASL doing?
  - *Create* an advanced coupled multi-physics "virtual reactor" technology by adapting existing and developing new modeling and simulation (M&S) tools
  - *Effectively apply* the virtual reactor technology to provide more understanding of safety margins while addressing selected operational and design challenges of operational light water reactors
- Why?
  - Improve the performance and energy output of existing nuclear reactors by focusing on important industry defined challenge problems
  - M&S technology has long been a mainstay in the nuclear industry (vendors, owner/operators), helping to inform consequential operational and safety decisions codes daily. Current nuclear industry M&S technology, though continuously improved, has failed to capitalize on the benefits that more precise predictive capability and fundamental understanding offer
- Why do this in the Hub R&D business model?
  - Solution requires clear deliverables & products promoted by Hub R&D approach ("fierce sense of urgency")
  - Public-private partnership essential for adaptation, application, and "useful and usable" deployment of advanced M&S technologies under development at DOE national labs and universities to nuclear enterprise
- What is working?
  - Several elements have proven effective: partnerships, industry pull, technology deployment, clear deliverables and plans, effective and agile project management, 5-year time horizon, S&T guidance/review

Strong Dependency on Modeling and Simulation

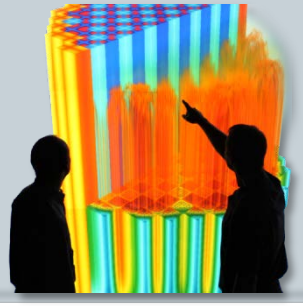
Need to assure nuclear safety but limited by inability to perform full-scale experimental mockups due to cost, safety & feasibility [1% power derating translates to $(5-10)M annual loss of revenue for 1 GWe unit]

Need to minimize economic uncertainty associated with new product introduction (e.g. fuel) by employing precise predictions [1% error in core reactivity has $4M annual fuel cycle cost impact for 1 GWe unit]

CASL's Charter

Mission is to 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 M&S technology deployed and applied broadly by the U.S. nuclear energy industry*
Goals	• Develop and effectively apply modern virtual reactor technology • Provide more understanding of safety margins while addressing operational and design challenges • Engage the nuclear energy community through M&S • Deploy new partnership and collaboration paradigms
Strategies	• Virtual Environment for Reactor Applications (VERA) • Industry Challenge Problems • Technology Delivery • Targeted, Enabling R&D • Education and Training • Collaboration and Ideation



Scope

- Address, through new insights afforded by advanced M&S technology, key nuclear energy industry challenges
  - ✓ furthering power uprates
  - ✓ higher fuel burnup
  - ✓ lifetime extension

  while providing higher confidence in enhanced nuclear safety
- Focus on performance of pressurized water reactor core, vessel, and in-vessel components to provide greatest impact within 5 years

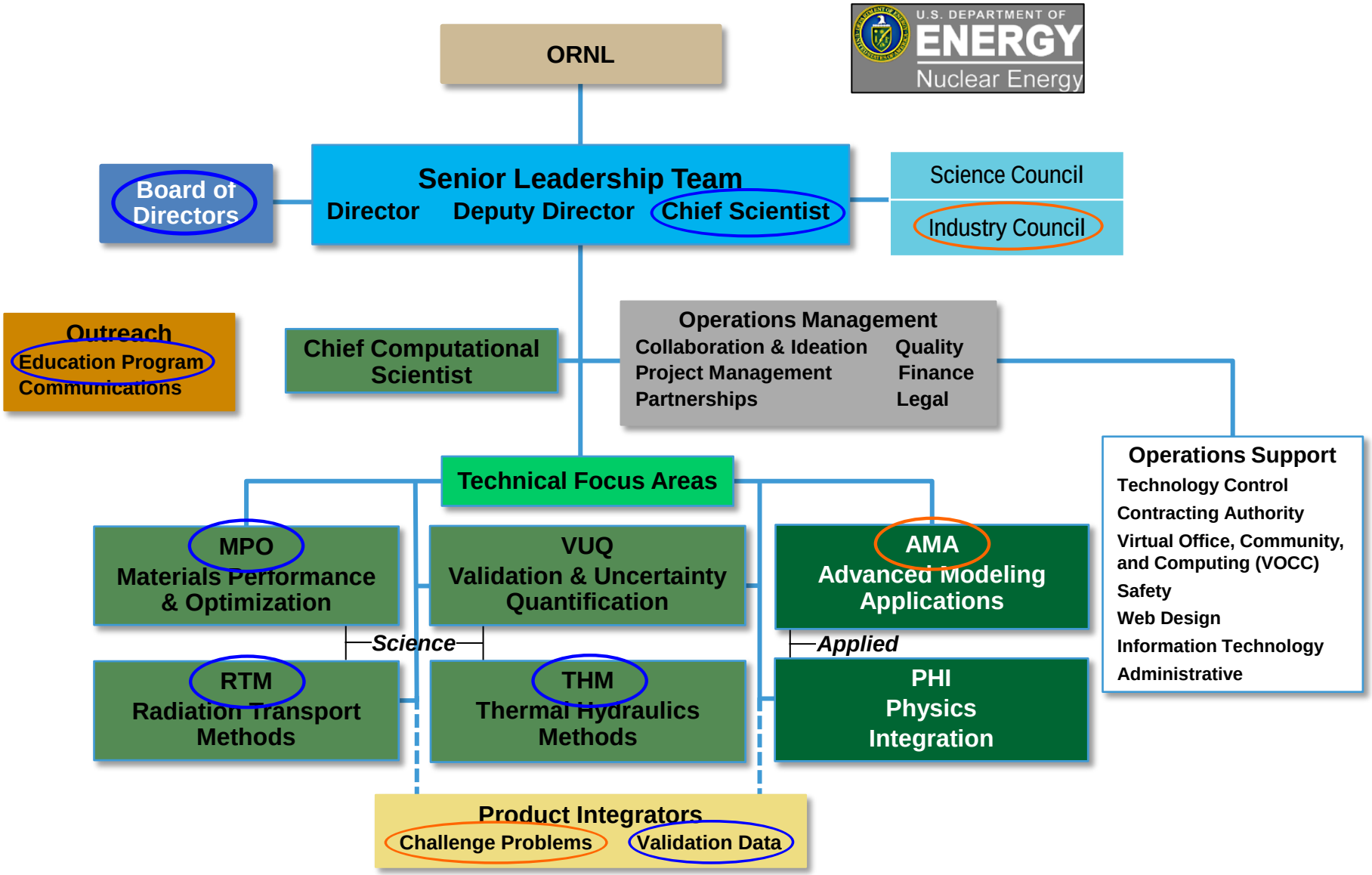
CASL Components

US team with a remarkable set of assets – Address tough industry challenges that matter – Urgent and compelling plan

Collaborate creatively – Target and foster innovation - Deliver industry solutions with predictive simulation

CASL Organization

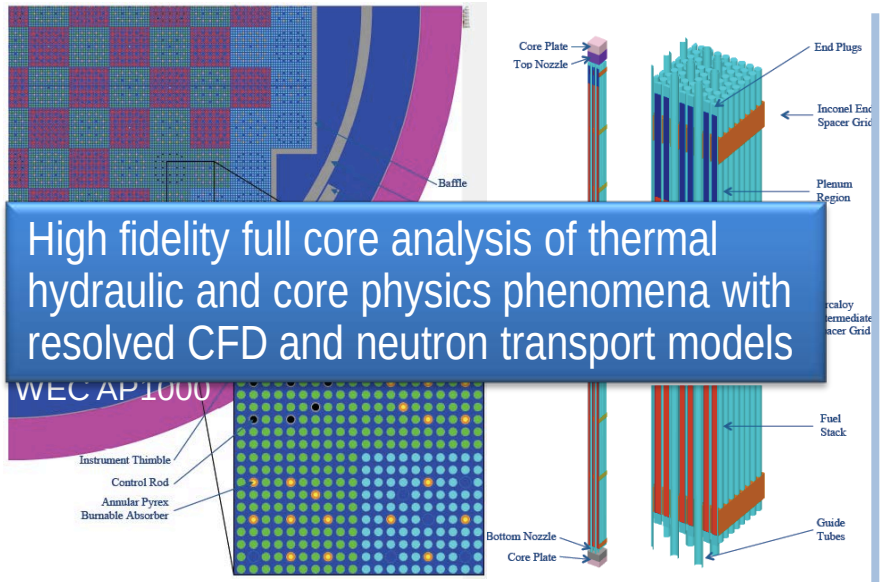
A diverse multi-institutional leadership team leads to informed decision making



Serving as Lead or Deputy Lead: **university**, **industry**

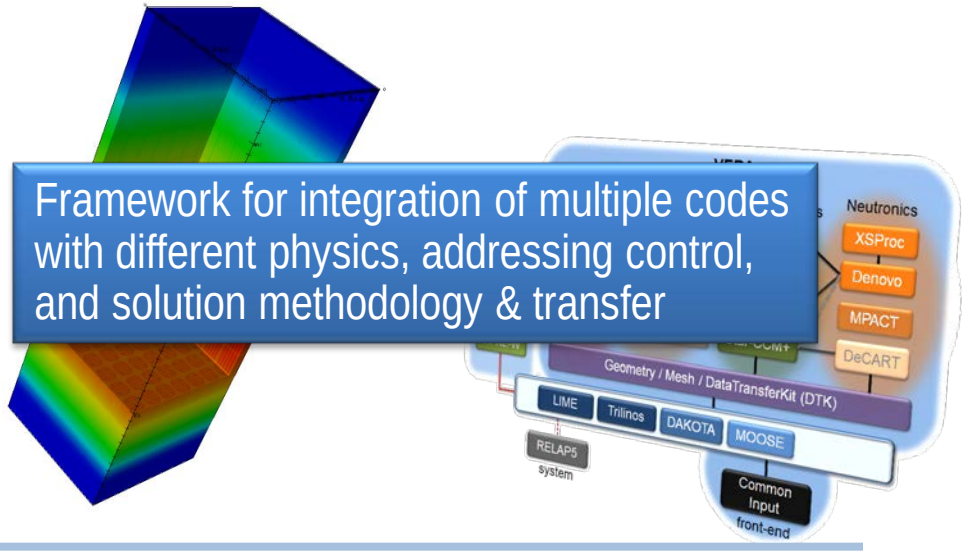
CASL Innovations

Advanced Modeling Applications



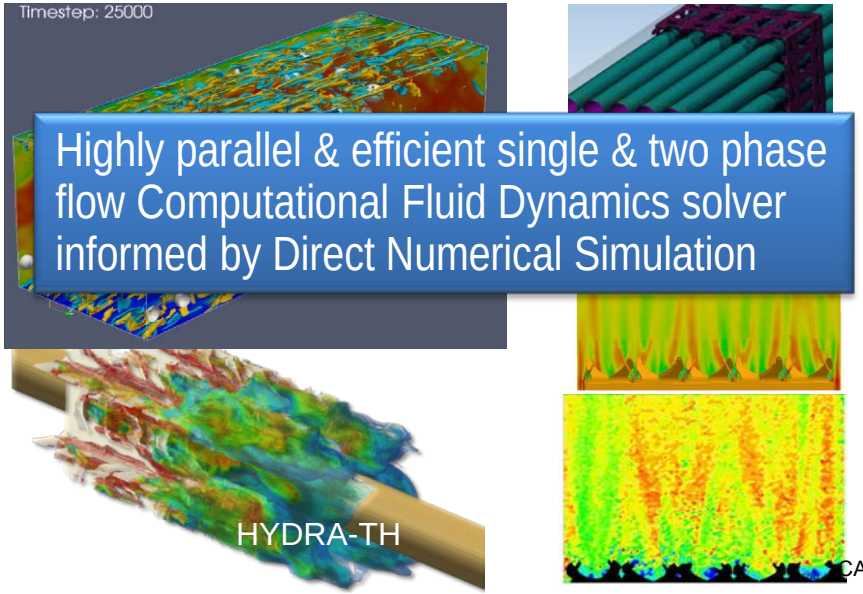
High fidelity full core analysis of thermal hydraulic and core physics phenomena with resolved CFD and neutron transport models

Physics Integration



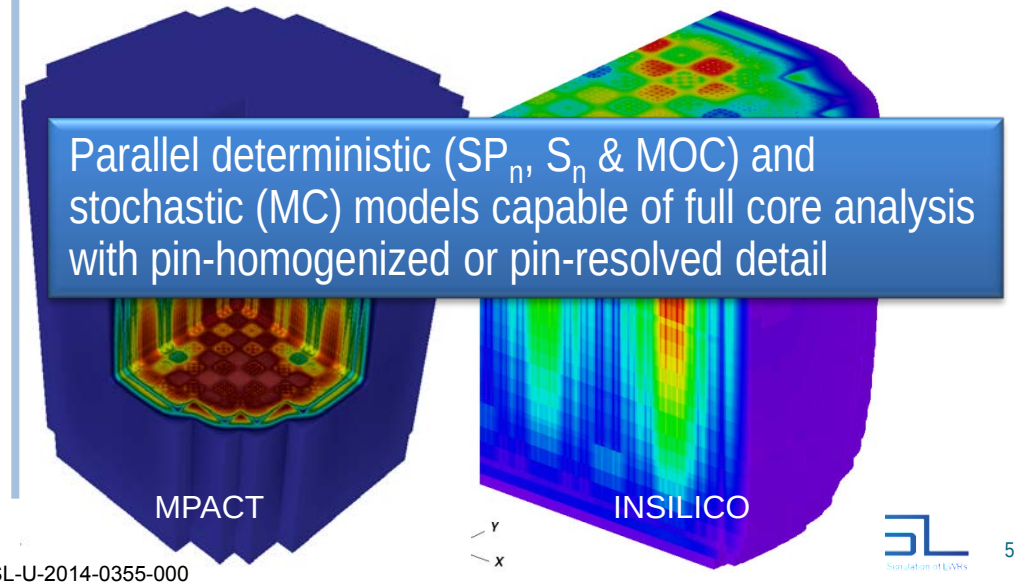
Framework for integration of multiple codes with different physics, addressing control, and solution methodology & transfer

Thermal Hydraulic Methods



Highly parallel & efficient single & two phase flow Computational Fluid Dynamics solver informed by Direct Numerical Simulation

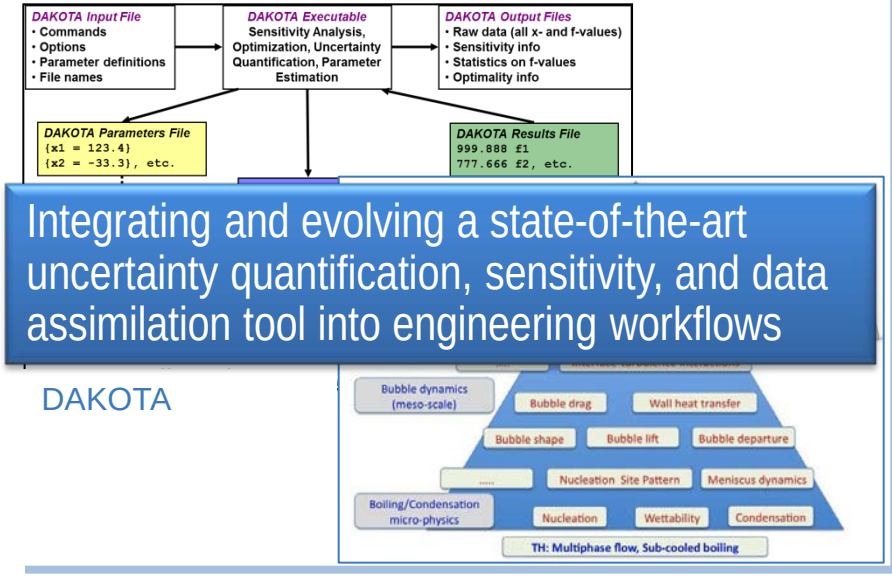
Radiation Transport Methods



Parallel deterministic (SP_n, S_n & MOC) and stochastic (MC) models capable of full core analysis with pin-homogenized or pin-resolved detail

CASL Innovations

Validation & Uncertainty Quantification



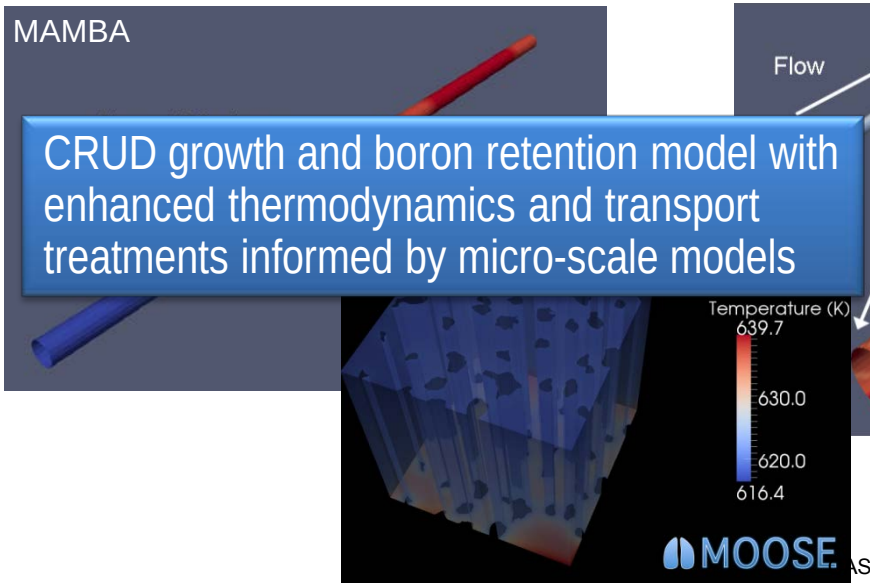
Integrating and evolving a state-of-the-art uncertainty quantification, sensitivity, and data assimilation tool into engineering workflows

DAKOTA

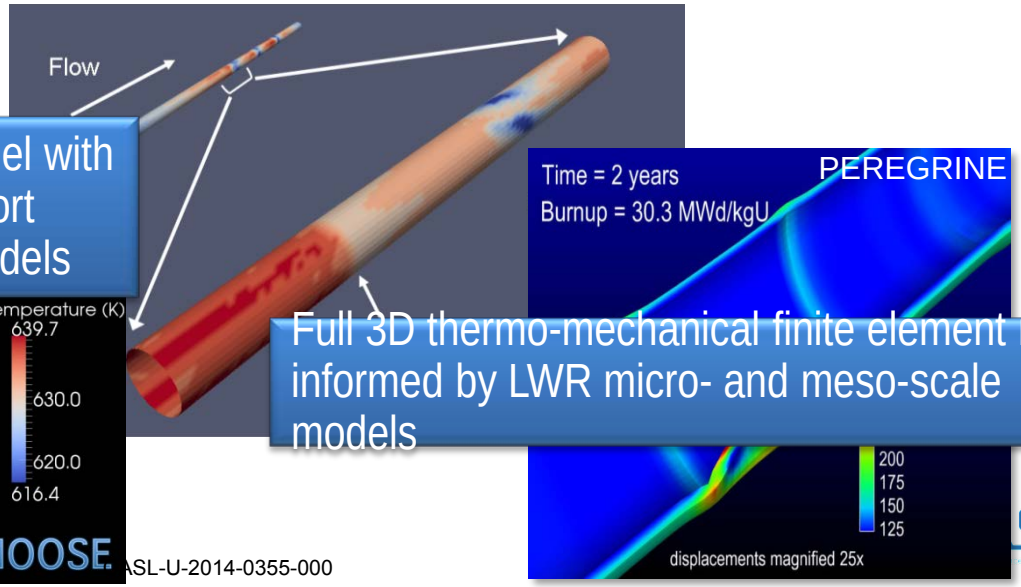
VOCC

Bringing together local ("physical") and geographically distributed ("virtual") contributors in a meaningful and productive way

Materials Performance and Optimization



CRUD growth and boron retention model with enhanced thermodynamics and transport treatments informed by micro-scale models



Full 3D thermo-mechanical finite element model informed by LWR micro- and meso-scale models

Industry Council

Assure that CASL solutions are "used and useful" by industry and that CASL provides effective leadership advancing the M&S state-of-the-art.

Objectives and Strategies

- Early, continuous, and frequent interface and engagement of end-users and technology providers
- Critical review of CASL plans and products
- Optimum deployment and applications of periodic VERA releases
- Identification of strategic collaborations between industry and CASL Focus Areas

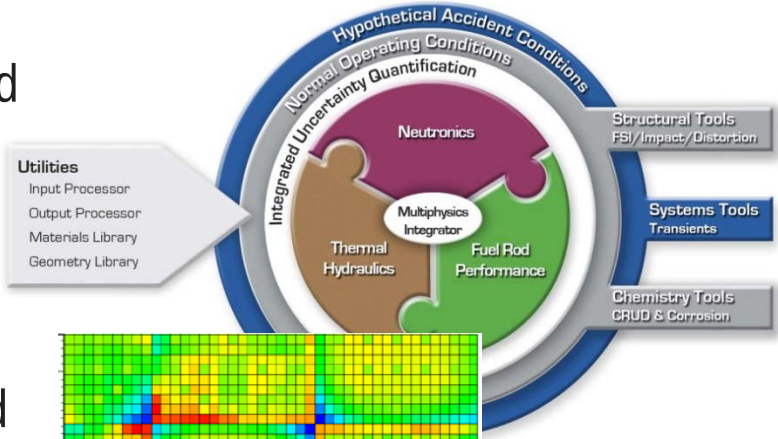
Outcomes and Impact

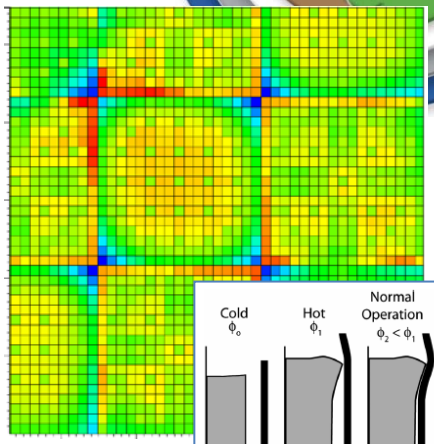
- CASL benefits from advice on technical requirements, schedules, commercialization strategies, and computer requirements
- Industry Council can influence the CASL product to be compatible with expected applications and can better prepare internal technical and business processes

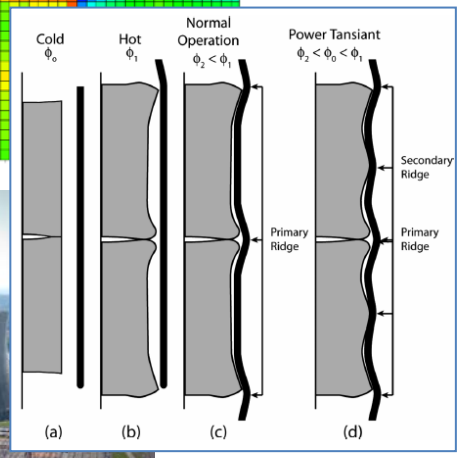
CASL Technology Deployment

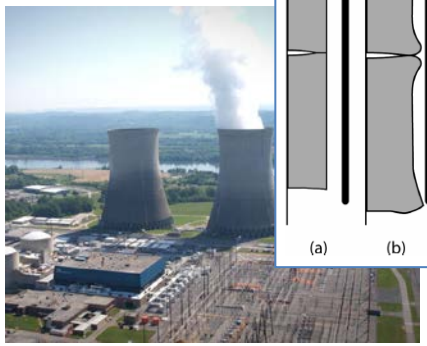
From Pilot Projects to Test Stands to Beta Releases to Broad Releases
Vision: independent organization chartered to release, support, evolve and apply CASL M&S technology (industry affiliates / users group)

- U.S. taxpayers investment in CASL will only be realized if its products are deployed beyond the labs and the core CASL team to the broader nuclear industry
- Pilot Projects: simulation applications of VERA outside of direct CASL scope yet of interest to 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 fuel performance (Peregrine) performance applications
  - TVA: Deployment planned for Mar 2014; focus currently targeted for lower plenum flow anomaly observed in many current operational reactors
- Currently evaluating options for evolving the Industry Council into a semi-independent organization







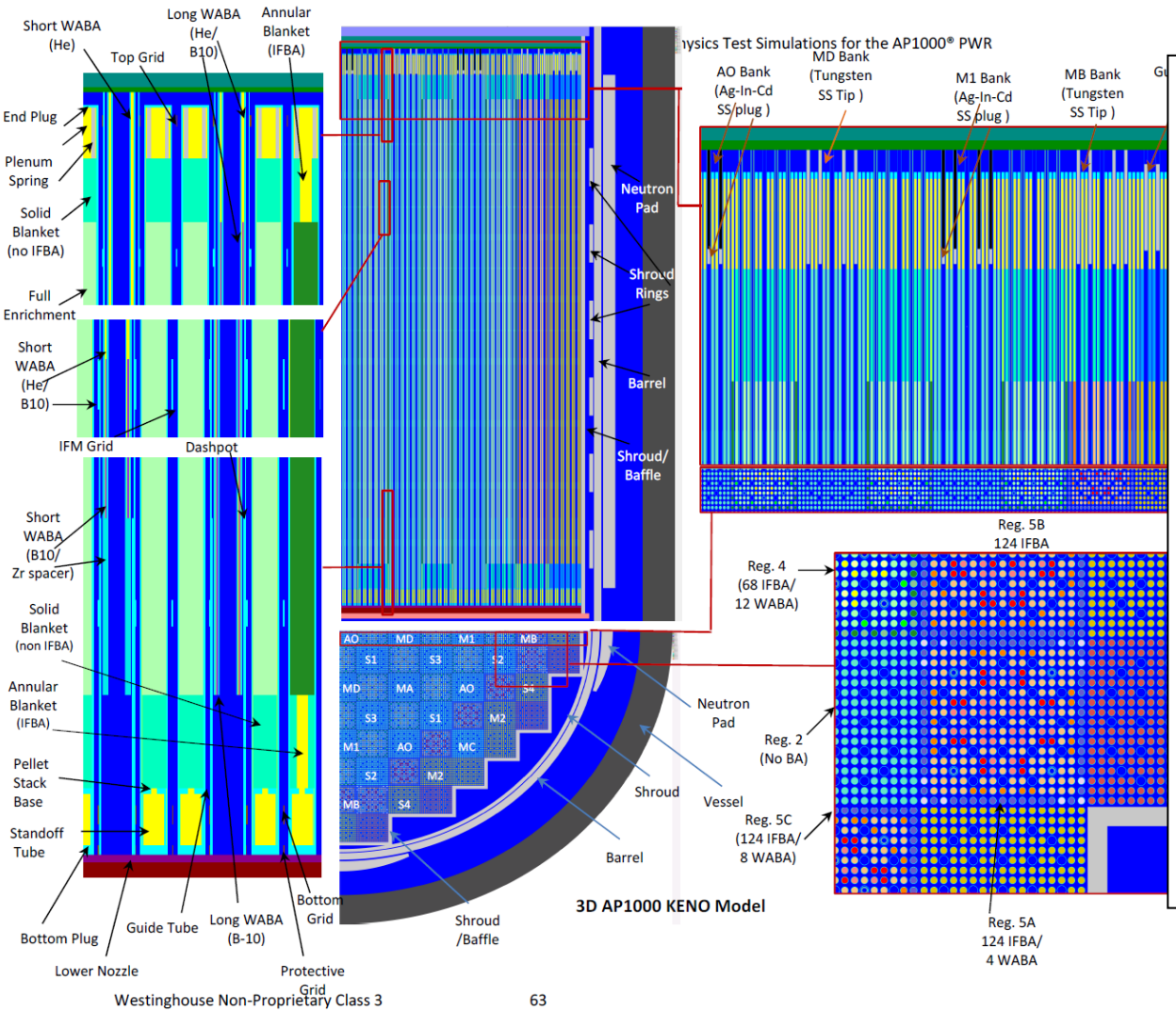


CASL Test Stand @ Westinghouse

- Westinghouse personnel “test driving” CASL technology
- CASL Core Simulator (VERA-CS) deployed and operational at Westinghouse
- Applied to the simulation of the AP1000® PWR start-up
  - Outstanding agreement with Monte-Carlo with much lower computational resources
  - High fidelity tool to investigate real-world simulation scenarios
- Provides framework for continuous technology improvement based on understanding of end user needs
- Goal-oriented collaboration that benefits the industry and the scientific community at large

AP1000 core models generated with VERA-CS & KENO

AP1000 First Core



Westinghouse Non-Proprietary Class 3 63

VERA Input

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  12W -   8W  - -
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  -   AIC
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  -   AIC -   AIC -
  W   -   AIC -
  -   -

crd_bank
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  -  S1
  MD -  MA
  -  S3 -  S1
  M1 -  AO -  MC
  -  S2 -  M2 -
  MB -  S4 -
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```

<1,000 lines of input for VERA-CS vs. Million lines for KENO

Highlights of AP1000 Test Stand Results

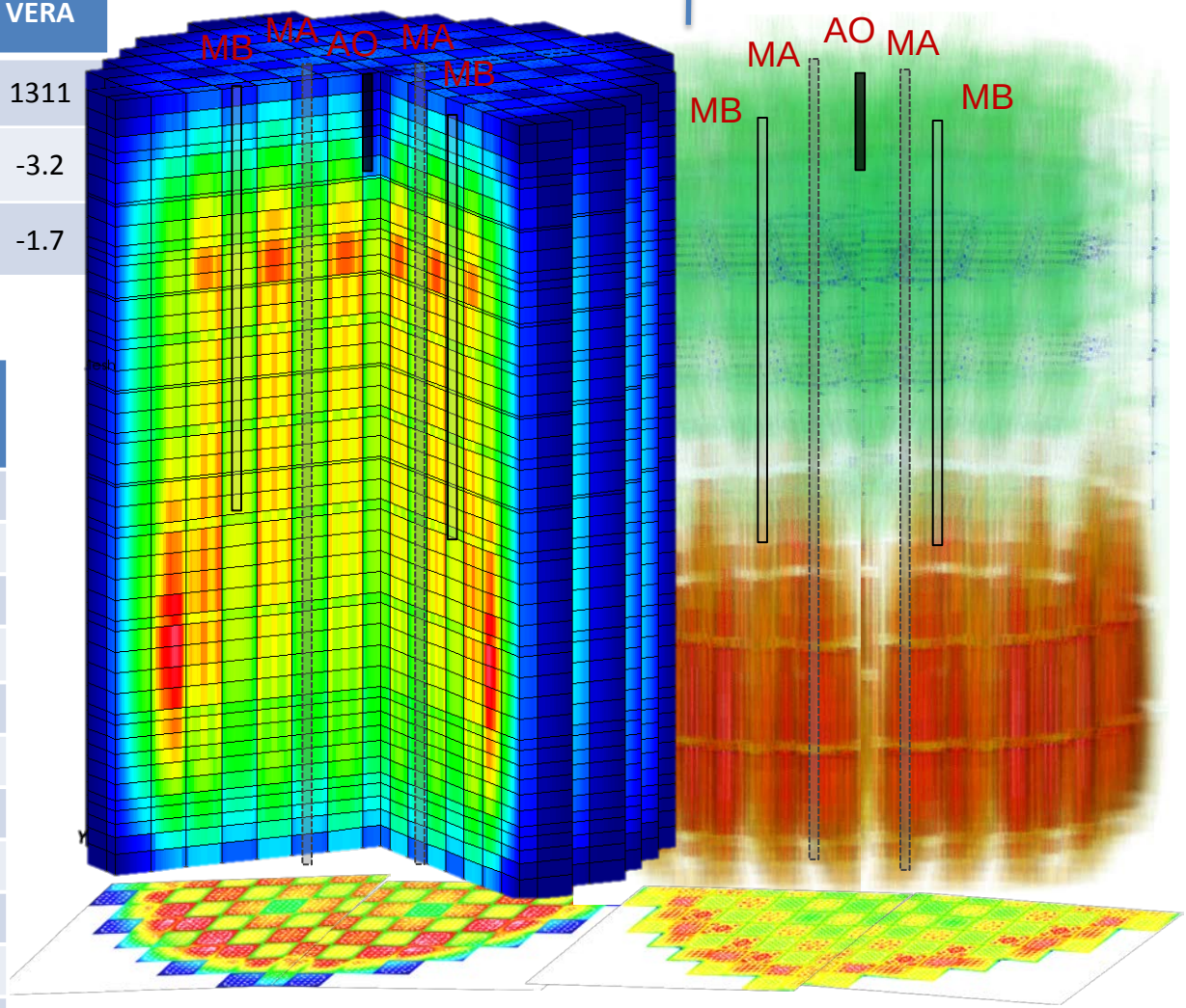
Start-up Boron and Reactivity Coefficients

	KENO	VERA
Critical Boron (ppm)	1314	1311
Isothermal Temperature Coefficient (pcm/F)	-2.7	-3.2
Doppler Temperature Coefficient	-1.6	-1.7

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

Power Distribution



Comparison with 3D Monte Carlo

Main Contributors: F. Franceschini (Westinghouse) and A. Godfrey (ORNL)

Highlights of Results

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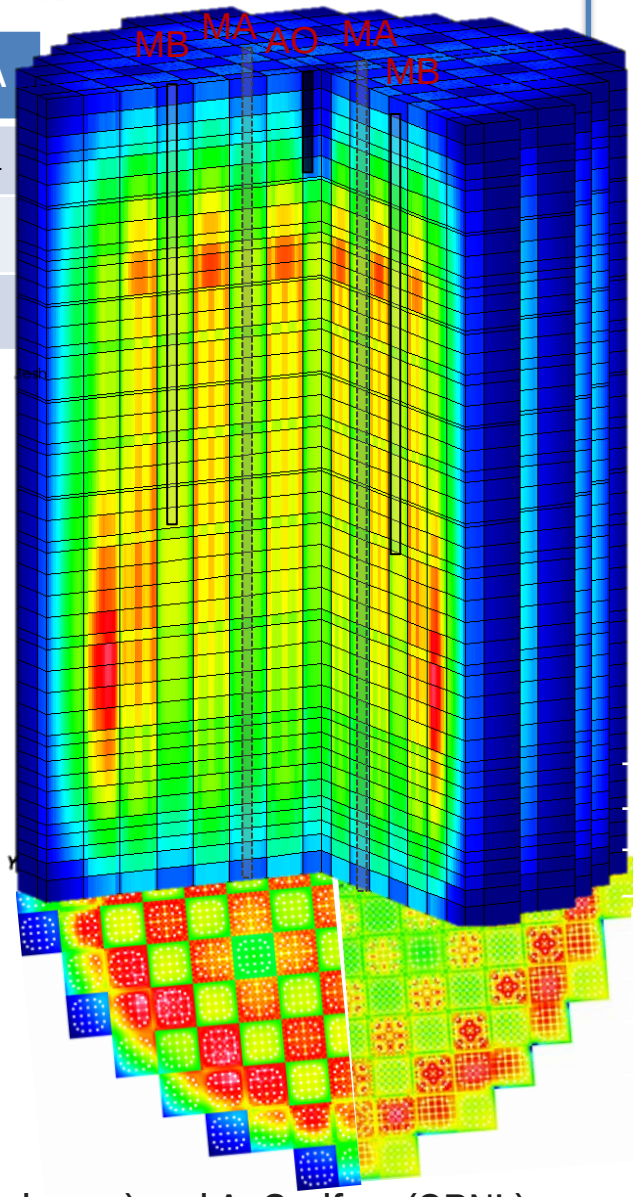
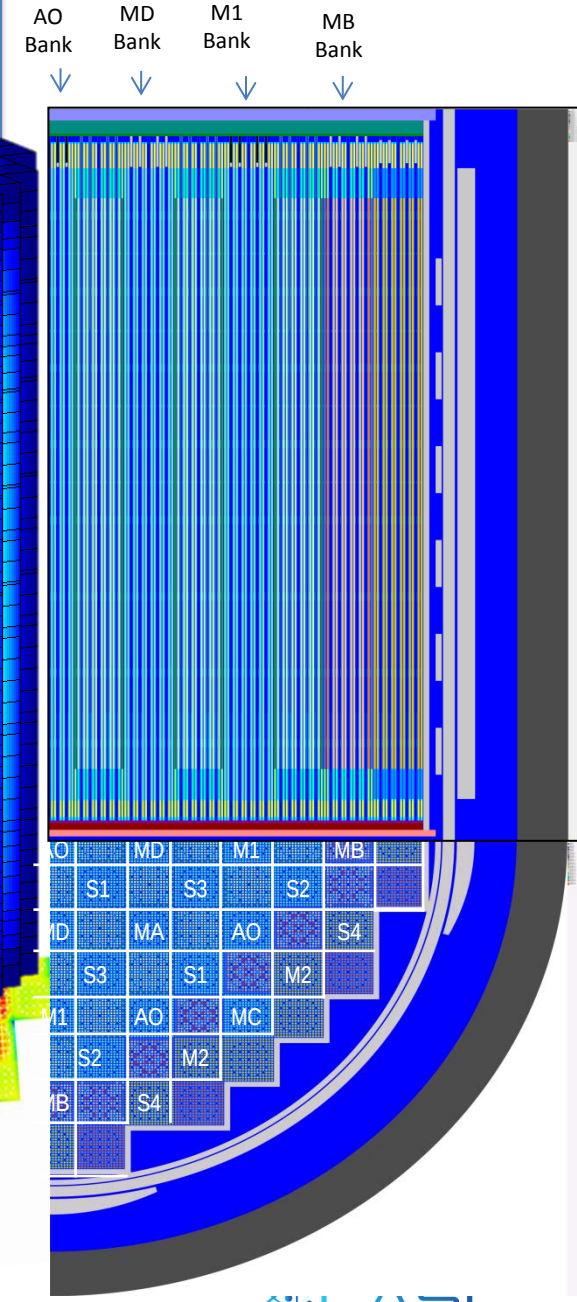


AP1000 Core KENO Model



Main Contributors: F. Franceschini (Westinghouse) and A. Godfrey (ORNL)

Benefits of the Consortium

TVA perspective

- The team brings together an integrated team of experts
  - Industry provides application-specific expertise and experience
  - National Labs and academia provide broad science expertise
- Approach provides a focused mission that is structured to ensure benefit to the entire domestic fleet
  - Mission to utilize nonproprietary codes and technologies helps to ensure broad benefit
- The Consortium has adopted a requirements-based problem solving approach for detailed, concrete goals with applications for all partners
- Focus on development of a versatile general tool (the virtual reactor) along with solutions and demonstrations for current industry issues provides immediate payoff with long-term benefits
  - Opportunity to dramatically advance understanding of reactor performance
  - Potential efficiency improvements; design tool for future; enhanced safety
- Early industry involvement is essential to successfully deploy products
  - Foster use of the products by industry
  - Create bridges from the DOE research island to industry mainland
  - Provide experience to ensure products can be licensed by NRC

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Navigate Transforming Landscape via CASL

EPRI Perspective on Potential Applications

Flexible Nuclear Plant Operation

- Gray control rods
- Flow induced vibration
- Flow accelerated corrosion

License Extension

- Higher burn up fuel
- Enhanced core design

Accident Tolerant Fuel

- Concept refinement
- Test Planning
- Margins

Power Up-rate

- Fuel modifications
- Safety margin assessment

CASL Test Stand - Potentials

- Peregrine validation
- Inform mods to Falcon
- Technical Challenges

Alpha tester (Test Stand) for software – a great opportunity for EPRI to see “under the hood” and provide constructive feedback to the CASL development team

Flexibility is needed when industry works with national labs and universities - the right topic / engagement with the right person at the right time is needed for successful engagements (win-win for EPRI and CASL)

CASL 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)

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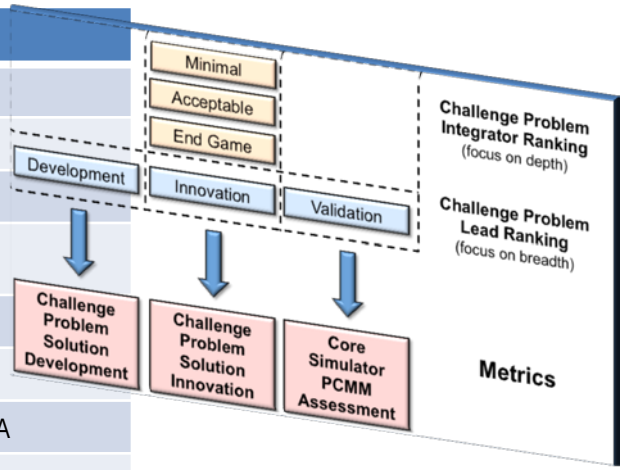
Effectiveness Metrics

Used to guide the CASL management and assess its performance

- CASL has defined Outcome and Performance Metrics (measured every Plan of Record)
  - *Outcome Metrics* that represent higher level metrics spanning organizational groups and lower lever performance measures (key performance indicators – map to strategic goals)
  - *Performance Metrics* that measure specific areas of performance and act as early indicators
    - Project management, student/university/industry engagement, infrastructure uptime, VERA development
- CASL also appeals to its Board and Council structure for measuring performance
  - *Industry Council* assesses CASL's technology (VERA) usefulness and usability
  - *Science Council* assesses CASL's quality of science and engineering and its ability to identify and adjust to new circumstances and effectively communicate with the technical community
  - *Board of Directors* assesses CASL's management performance – its ability to manage a vastly diverse team to deliver the planned technical scope on target, schedule and budget

Strategic Outcome	Metric
Address design, operational, and safety challenges for LWRs	Challenge Problem Solution Development
	Challenge Problem Solution Innovation
Develop and effectively apply modern virtual reactor technology	Challenge Problem PCMM Assessment
	Core Simulator PCMM Assessment
Engage nuclear community through modeling and simulation	Number of VERA licenses granted, open source downloads, & registered users
	Industry Council & User Group activity / membership
	Faculty, graduate and/or postdoctoral researchers utilizing and/or evolving VERA
Deploy new partnership and collaboration paradigms	VOCC Laboratory and technology availability/utilization
	Virtual collaboration endeavors leveraging or attributable to CASL VOCC technology



Elements of CASL's Approach That are Proving Effective

With continuous improvement drawing on feedback from customers/clients/users

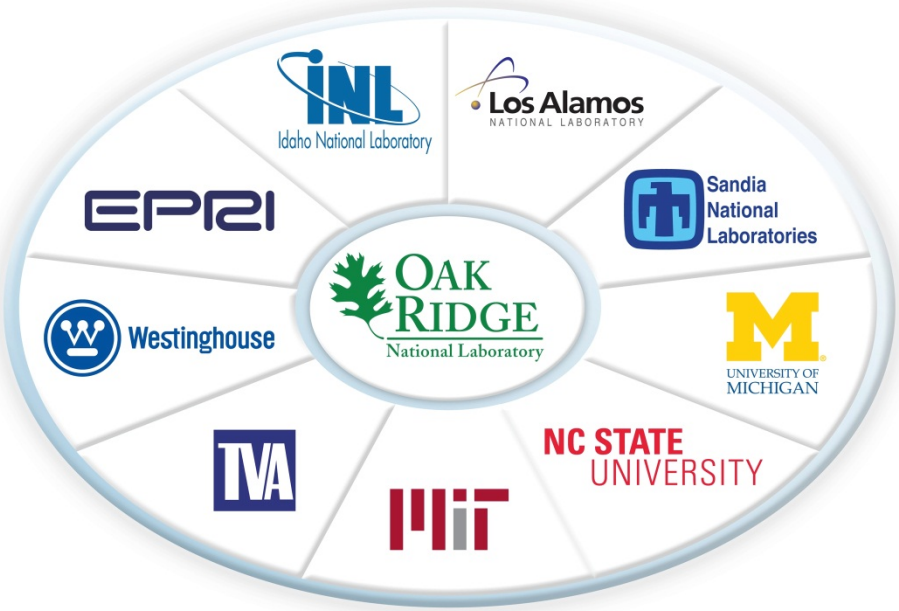
- ✓ *Clear deliverables that solve industry issues and are driven by a well-defined yet dynamic plan*
  - Commit to a hierarchical milestone plan with tangible deliverables; define products integrated across capabilities
- ✓ *A strategy of delivering prototype products early and often*
  - Early deployment of Hub's technology (VERA) into industrial environment for rapid and enhanced testing, use, and ultimate adoption to support real-world LWR applications
- ✓ *Defined customers and users, with "industry pull" ensured by an industry council*
  - Charter and engage Industry Council (IC) for early, continuous, and frequent interface and engagement of end-users and technology providers. Use the IC for critical review of CASL plans and products – want products to be "ours"
- ✓ *A true private-public partnership in management, leadership, and execution*
  - Engage the nuclear industry broadly (vendors, owners/operators, R&D) and at all levels of execution. Involve the best and brightest crucial for success & credibility using virtual collaboration technologies for daily interactions
- ✓ *A 5-year horizon for completion and funding with a renewal option for second 5 years*
  - 5-year period a must to attract and retain community leaders yet upon execution forces specific paths and decisions
- ✓ *Led by one institution with resource allocation authority and responsibility*
  - Not easy nor a guarantee of success but enables agility while assignment of clear authority and responsibility
  - DOE empowers lead institution and Hub leadership ("light federal touch") as long as execution and performance warrants
- ✓ *BOD providing oversight and advice on management, plan, and science & technology (S&T) strategy*
  - Not a useful body unless Hub leadership knows how to effectively utilize it; guidance of CASL BOD has been immeasurable
- ✓ *Independent councils to review and advise on quality and relevance of S&T*
  - Science Council - independent assessment of whether the scientific work planned and executed is of high quality and supports attaining CASL goals – motivates CASL leadership to more directly address problems with needed decisions

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

Questions?

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