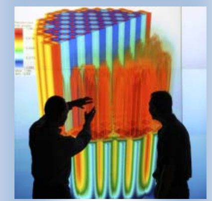

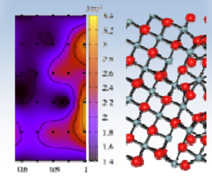

CASL: The Consortium for Advanced Simulation of Light Water Reactors

A DOE Energy Innovation Hub for Modeling & Simulation of Nuclear Reactors

Doug Kothe
Director, CASL

Director of Science, Oak Ridge Leadership Computing Facility
Oak Ridge National Laboratory

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CASL
Consortium for Advanced Simulation of LWRs

Outline

- CASL overview
- CASL virtual reactor development & application
- CASL science program
- Q&A

CASL delivers industry solutions with a focused plan having measurable milestones requiring M&S innovation in key science challenges

What is a DOE Energy Innovation Hub?
(as documented)

- Target problems in areas presenting the most critical barriers to achieving national climate and energy goals that have heretofore proven the most resistant to solution via the normal R&D enterprise
- Represent a new structure, modeled after research entities likes the Manhattan Project (nuclear weapons), Lincoln Lab at MIT (radar), and AT&T Bell Labs (transistor)
- Consistent with Brookings Institution's recommendations for "Energy Discovery-Innovation Institutes" (early 2009)
  - "…new research paradigms are necessary, we believe, that better leverage the unique capacity of America's research" - Dr. Jim Duderstadt, President Emeritus, University of Michigan
- Focuses on a single topic, with work spanning the gamut, from basic research through engineering development to partnering with industry in commercialization
- Large, highly integrated and collaborative creative teams working to solve priority technology challenges
- Embrace both the goals of understanding and use, without erecting barriers between basic and applied research

The CASL Team: A unique lab-university-industry partnership with a remarkable set of assets

Core partners

Oak Ridge
National Laboratory

Electric Power
Research Institute

Idaho National Laboratory

Los Alamos National Laboratory

Massachusetts Institute
of Technology

North Carolina State University

Sandia National Laboratories

Tennessee Valley Authority

University of Michigan

Westinghouse Electric Company

Building on longstanding, productive relationships and collaborations to forge a close, cohesive, and interdependent team that is fully committed to a well-defined plan of action

Individual contributors

ASCOMP GmbH
CD-adapco, Inc.
City University of New York
Florida State University
Imperial College London
Rensselaer Polytechnic Institute
Southern States Energy Board
Texas A&M University
University of Florida
University of Tennessee
University of Wisconsin
Worcester Polytechnic Institute

CASL vision: Create a virtual reactor (VR) for *predictive* simulation of LWRs

Leverage

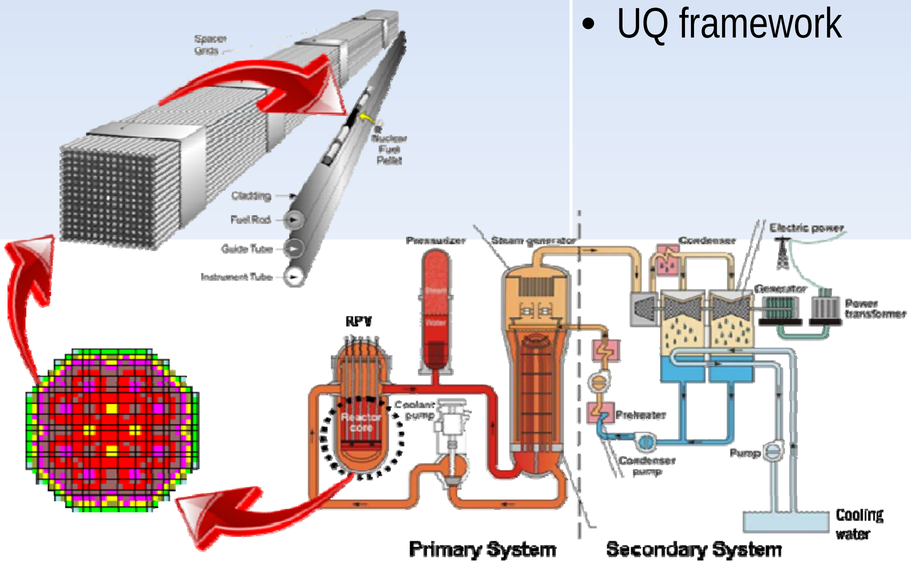
- Current state-of-the-art neutronics, thermal-fluid, structural, and fuel performance applications
- Existing systems and safety analysis simulation tools

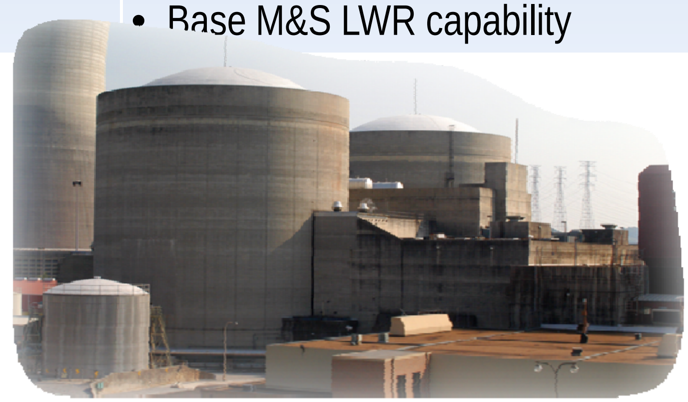
Develop

- New requirements-driven physical models
- Efficient, tightly-coupled multi-scale/multi-physics algorithms and software with quantifiable accuracy
- Improved systems and safety analysis tools
- UQ framework

Deliver

- An unprecedented predictive simulation tool for simulation of physical reactors
- Architected for platform portability ranging from desktops to DOE's leadership-class and advanced architecture systems (large user base)
- Validation basis against 60% of existing U.S. reactor fleet (PWRs), using data from TVA reactors
- Base M&S LWR capability





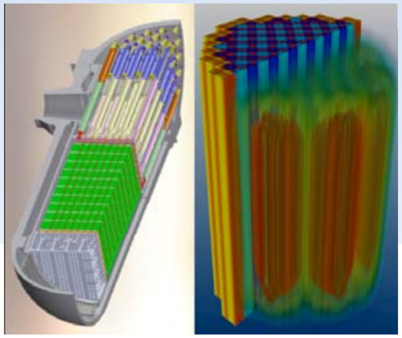
CASL mission: Develop and apply the VR to address 3 critical performance goals for nuclear power

1 Reduce capital and operating costs per unit energy by:

- Power uprates
- Lifetime extension

2 Reduce nuclear waste volume generated by enabling higher fuel burnups

3 Enhance nuclear safety by enabling high-fidelity predictive capability for component and system performance from beginning of life through failure



Each reactor performance improvement goal brings benefits and concerns

Power uprates

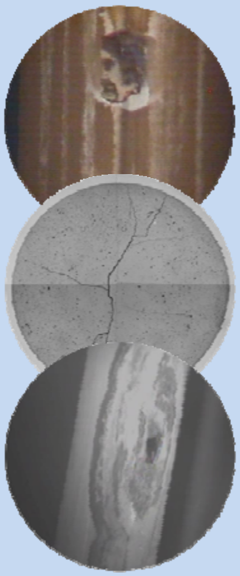
- 5–7 GWe delivered at ~20% of new reactor cost
- Advances in M&S needed to enable further uprates (up to 20 GWe)
- Key concerns:
  - Damage to structures, systems, and components (SSC)
  - Fuel and steam generator integrity
  - Violation of safety limits

Lifetime extension

- Reduces cost of electricity
- Essentially expands existing nuclear power fleet
- Requires ability to predict SSC degradation
- Key concerns:
  - Effects of increased radiation and aging on integrity of reactor vessel and internals
  - Ex-vessel performance (effects of aging on containment and piping)

Higher burnup

- Supports reduction in amount of used nuclear fuel
- Supports uprates by avoiding need for additional fuel
- Key concerns:
  - Cladding integrity
  - Fretting
  - Corrosion/ CRUD
  - Hydriding
  - Creep
  - Fuel-cladding mechanical interactions



CASL targets key limiting phenomena that are barriers to improved reactor performance

	Power uprate	High burnup	Life extension
Operational "Challenge Problems"			
CRUD-Induced Power Shift (CIPS)	×	×	
CRUD-Induced Localized Corrosion (CILC)	×	×	
Grid-to-Rod Fretting Failure (GTRF)		×	
Pellet Clad Interaction (PCI)	×	×	
Fuel Assembly Distortion (FAD)	×	×	
Safety "Challenge Problems"			
Departure from Nucleate Boiling (DNB)	×		
Cladding Integrity during Loss of Coolant Accidents (LOCA)	×	×	
Cladding Integrity during Reactivity Insertion Accidents (RIA)	×	×	
Reactor Vessel Integrity	×		×
Reactor Internals Integrity	×		×

CASL scope: Develop and apply the VR to assess fuel design, operation, and safety criteria

Near-term priorities (years 1–5)

- Deliver improved predictive simulation of PWR core, internals, and vessel
  - Couple VR to evolving out-of-vessel simulation capability
  - Maintain applicability to other NPP types
- Execute work in 5 technical focus areas to:
  - Equip the VR with necessary physical models and multiphysics integrators
  - Build the VR with a comprehensive, usable, and extensible software system
  - Validate and assess the VR models with self-consistent quantified uncertainties

Longer-term priorities (years 6–10)

- Expand activities to include structures, systems, and components beyond the reactor vessel
- Established a focused effort on BWRs and SMRs
- Continue focus on delivering a useful VR to:
  - Reactor designers
  - NPP operators
  - Nuclear regulators
  - New generation of nuclear energy professionals

Focus on challenge problem solutions

A comprehensive set of milestones is defined to drive solution of the challenge problems

Industry challenges and needs

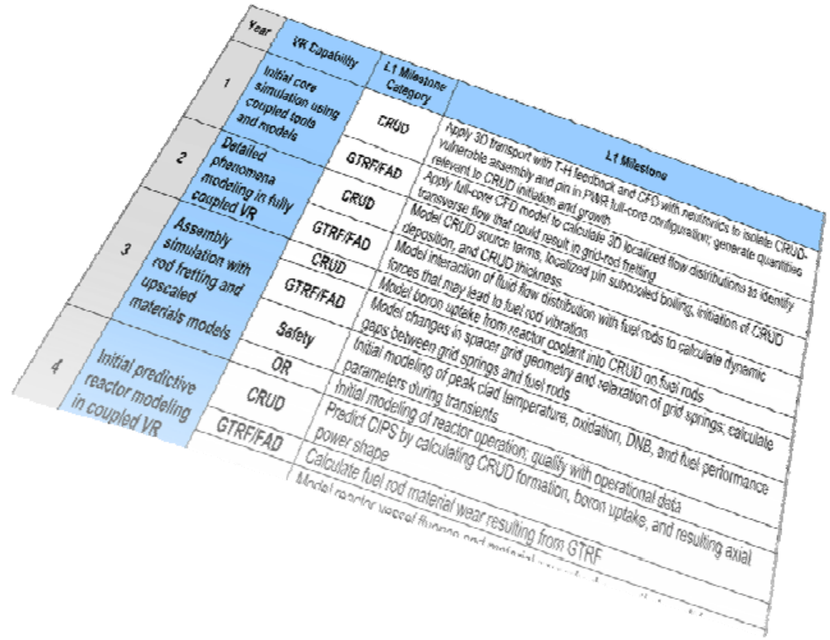
Challenge problems

L1 Milestones in 6 challenge categories

- CRUD
- Grid-to-rod fretting (GTRF)/
  fuel assembly distortion (FAD)
- Operational reactor
- Safety
- Lifetime extension
- Advanced fuels

L2 Milestones
Discipline-oriented focus areas

L3 Milestones
Projects



Year	VR Capability	L1 Milestone Category	L1 Milestone
1	Initial core simulation using coupled tools and models	CRUD	Apply 3D transport with T-H feedback and CFD with neutronics to isolate CRUD-vulnerable assembly and pin in PWR full-core configuration; generate quantities relevant to CRUD initiation and growth
		GTRF/FAD	Apply full-core CFD model to calculate 3D localized flow distributions to identify transverse flow that could result in grid-rod fretting
2	Detailed phenomena modeling in fully coupled VR	CRUD	Model CRUD source terms, localized pin subcooled boiling, initiation of CRUD deposition, and CRUD thickness
		GTRF/FAD	Model interaction of fluid flow distribution with fuel rods to calculate dynamic forces that may lead to fuel rod vibration
3	Assembly simulation with rod fretting and upscaled materials models	CRUD	Model boron uptake from reactor coolant into CRUD on fuel rods
		GTRF/FAD	Model changes in spacer grid geometry and relaxation of grid springs; calculate gaps between grid springs and fuel rods
		Safety	Initial modeling of peak clad temperature, oxidation, DNB, and fuel performance parameters during transients
		OR	Initial modeling of reactor operation; qualify with operational data
4	Initial predictive reactor modeling in coupled VR	CRUD	Predict CIPS by calculating CRUD formation, boron uptake, and resulting axial power shape
		GTRF/FAD	Calculate fuel rod material wear resulting from GTRF
			Model [illegible]

CASL milestones provide an aggressive yet attainable path to success

Approach to each challenge problem

CRUD formation: A significant barrier
to increasing power output in existing reactors

Milestone category	CRUD
Limiting phenomena	CRUD-induced Power Shift (CIPS), CRUD-induced Localized Corrosion (CILC)

Level 1 milestone map

Year 1	Apply 3D transport with T-H feedback and CFD with neutronics to isolate CRUD-vulnerable assembly and pin in PWR full-core configuration; generate boundary conditions relevant to CRUD initiation and growth
Year 2	Model CRUD source terms, localized pin subcooled boiling, initiation of CRUD deposition, and CRUD thickness
Year 3	Model boron uptake from reactor coolant into CRUD on fuel rods
Year 4	Predict CIPS by calculating CRUD formation, boron uptake, and resulting axial power shape
Year 5	Simulation insight into CRUD formation and CIPS mitigation: Where and how will CRUD form and how can we anticipate and mitigate it?

The CASL milestone plan focuses the VR development

CASL organization: Key personnel

Board of Directors
Ernest Moniz, Chairman

U.S. Department of Energy

Chief Strategy Officer for Licensing/ Implementation
Mario Carelli

Director: Doug Kothe
Deputy: Ronaldo Szilard
Chief Scientist: Paul Turinsky

Partnership/Alliance Management
TBD

Operations
Becky Verastegui

Materials Performance and Optimization
Chris Stanek
Sid Yip

Virtual Reactor Integration
John Turner
Randy Summers
Rich Martineau

Advanced Modeling Applications
Jess Gehin
Zeses Karoutas

Models and Numerical Methods
Bill Martin
Ed Dendy

Validation and Uncertainty Quantification
Jim Stewart
Dan Cacuci

Councils

Science
John Ahearne, Chairman

Industry
John Gaertner, Chairman

Education
John Gilligan, Chairman

Commercialization
Chairman TBD

Communications, Policy, and Economic Development
Ken Nemeth, Chairman

Staff in the CASL executive and focus area leadership roles make up the 17 key personnel

CASL's technical focus areas will execute the plan

MPO
Materials Performance and Optimization
Chris Stanek, Lead

Sid Yip, Deputy


- Upscaling (CMPM)
- Fuel microstructure
- Clad/internals microstructure
- Corrosion
- CRUD deposition
- Failure modes

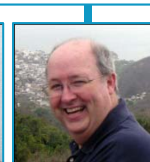
MNM
Models and Numerical Methods
Bill Martin, Lead

Ed Dendy, Deputy


- Radiation transport
- Thermal hydraulics

VRI
Virtual Reactor Integration
John Turner, Lead

Randy Summers, Rich Martineau, Deputies


- Coupled multi- physics environment
- VR simulation suite
- Coupled mechanics

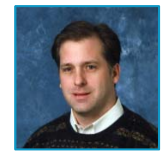
VUQ
Validation and Uncertainty Quantification
Jim Stewart, Lead

Dan Cacuci, Deputy


- V&V and calibration through data assimilation
- Sensitivity analysis and uncertainty quantification

AMA
Advanced Modeling Applications
Jess Gehin, Lead

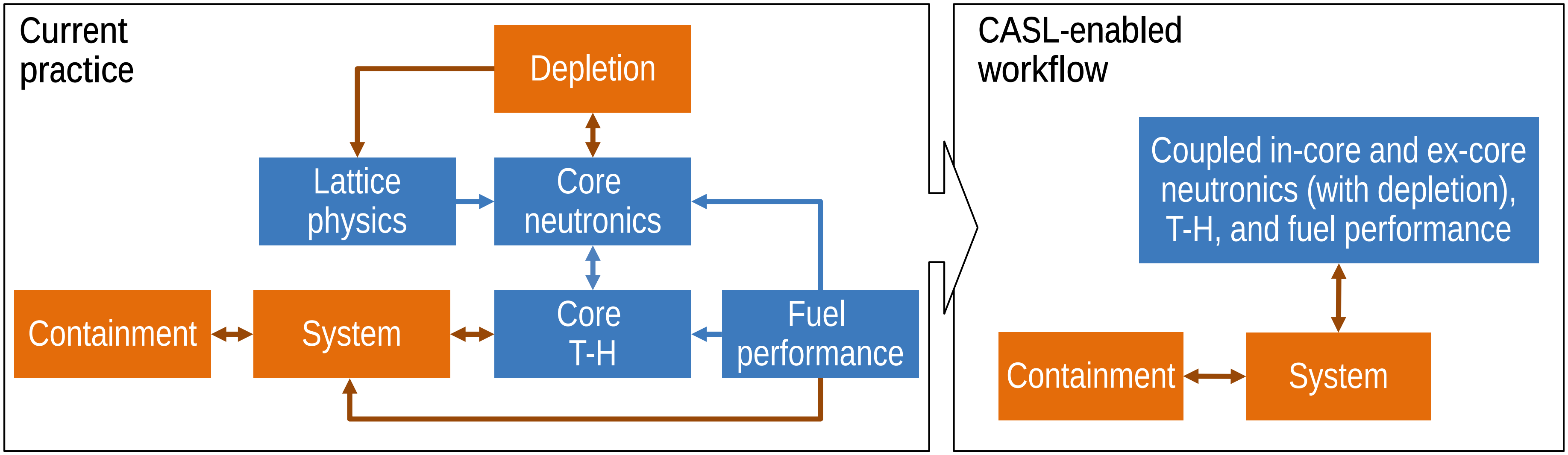
Zeses Karoutas, Deputy

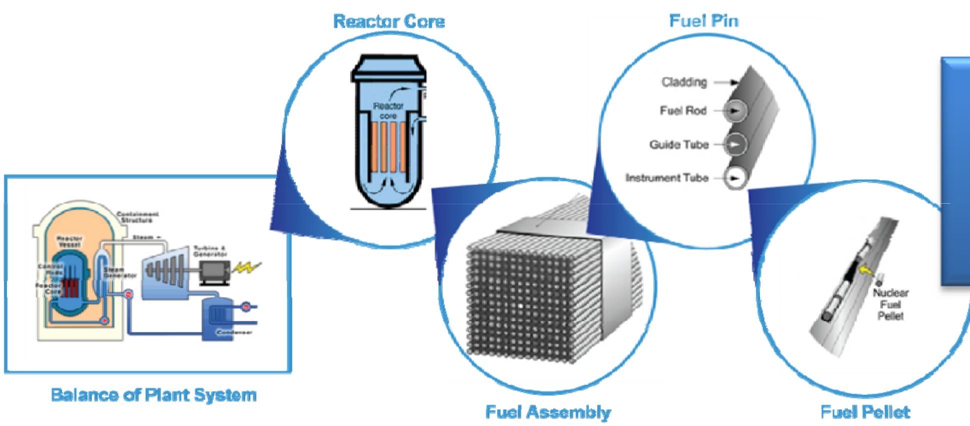



- VR requirements
- VR physical reactor qualification
- Challenge problem application
- VR validation
- NRC engagement

18 integrated and interdependent projects

The CASL Virtual Reactor is at the heart of the plan and is the science and technology integrator

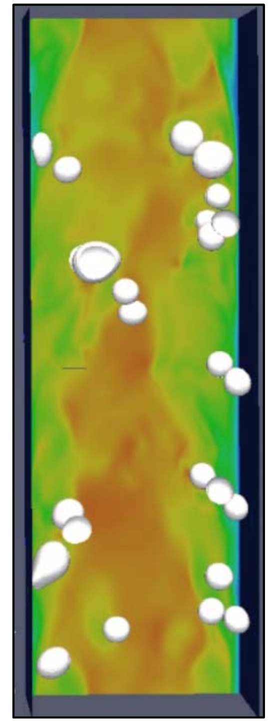


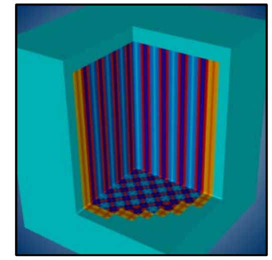


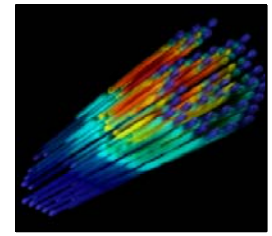
Suite of advanced yet usable M&S tools and methods, integrated within a common software infrastructure for predictive simulation of LWRs

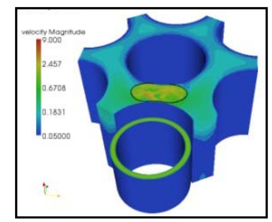
The CASL VR has a mature starting point

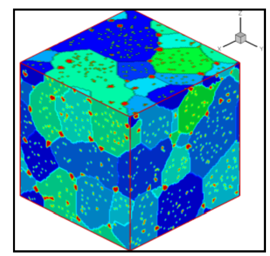
- Building on existing capability to deliver versatile tools
  - Initial focus on PWRs
  - Extensible to other reactor types
- Implemented as a component-based architecture integrating current and legacy workflows and capabilities
  - **Includes tools used to design and license the U.S. PWR fleet**
- An evolving state-of-the-art software design and ecosystem
  - Designed to exploit advanced computing platforms
  - Full coupling of all relevant physical processes
  - Integrated high-fidelity CFD, transport, and mechanics incorporated into the workflows of designers
  - Advanced methods for understanding sensitivities and propagating uncertainties

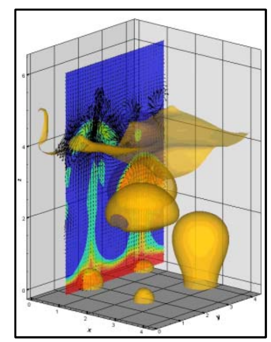




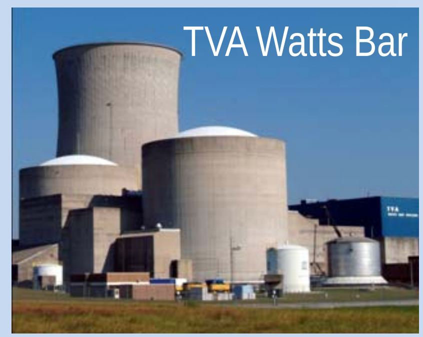








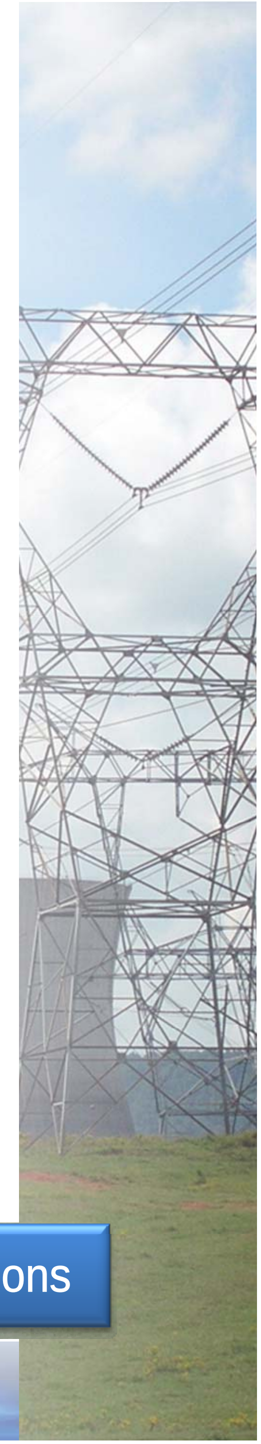
CASL possesses the key elements required for success

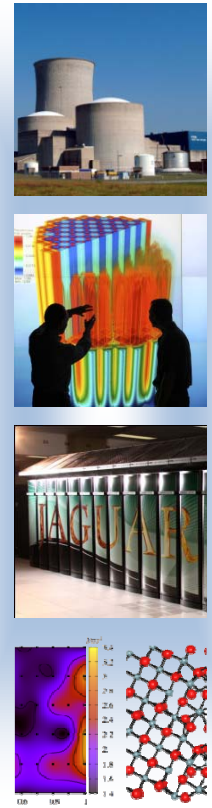
Physical reactors	• 3 Westinghouse PWRs at Sequoyah and Watts Bar, operated by TVA
NRC engagement	• Existing MOU between NRC Office of Regulatory Research and EPRI • CSO: Develop strategy for NRC engagement; AMA focus area Project 5: Execute strategy
Education, Training, and Outreach (ETO) Program	• Comprehensive engagement with students, faculty, and practicing scientists, engineers, and regulators • Leverage EPRI's structured technology transfer approach
Validation  ORNL HFIR  INL ATR	• One entire focus area dedicated to validation and UQ • Extensive reactor design information and test and operational data • Data validation needs and sources identified: Integral and separate-effects tests, PIE of used fuels, plant and in-core diagnostics, in- and out-of-pile testing of prototypic fuels  TVA Watts Bar  Westinghouse CRUD Facility
Virtual Office, Community, and Computing (VOCC)	• Integration and application of latest and emerging technologies to build an extended "virtual one roof"

CASL will apply a remarkable set of assets

- A U.S. team focused on U.S. leadership in nuclear energy
  - Carefully picked to leverage and pair partner strengths
  - A distinguished record of LWR regulatory and design accomplishments
- Industry partners are embedded to assure relevance and focus
  - Representing the entire U.S. nuclear industry landscape: Vendors, owner-operators, R&D for nuclear utilities
- Implements a new paradigm: University-industry-lab leadership balance
- Unparalleled collective institutional knowledge and nuclear science and engineering talent
  - The lead DOE laboratories in science, nuclear energy, and national security
  - Preeminent university nuclear engineering programs (Core + contributing partners: 7 of top 10 nuclear engineering programs)
  - Intimately connecting key science challenges to the nuclear energy enterprise: Unmatched expertise in materials science, chemistry, nuclear engineering, and multi-scale/multi-physics computational science
- Leaders in HPC (top 3 systems) and computational science (production codes)

Executing a clear, milestone-driven technical strategy for real-world NPP solutions





Consortium for Advanced Simulation of LWRs

CASL Interfaces

Ronaldo Szilard
Deputy Director, CASL
Director, LWR Sustainability Program
Director, Nuclear Science and Engineering Division
Idaho National Laboratory

Critical elements for integration of M&S into nuclear energy decisions

Acceptance by user community	• Address real problems in a manner that is more cost-effective than current technology • Meet needs of utility owner-operators, reactor vendors, fuel suppliers, engineering providers, and national laboratories
Acceptance by regulatory authority	• Address issues that could impact public safety • Deliver accurate and verifiable results
Acceptance of outcomes by public	• Provide outcomes that ensure high levels of plant safety and performance

The CASL team has unique capabilities for identifying, understanding, and solving nuclear reactor safety and performance issues

CASL challenge problems
Based on real-world industry experience and goals

- Industry goals will challenge fuel and plant performance:
  - Power uprates
  - Higher burnup
  - Life extension
- We evaluated detailed safety, operating, and design criteria to determine key phenomena that limit reactor performance
- Challenge problems tackle these key phenomena

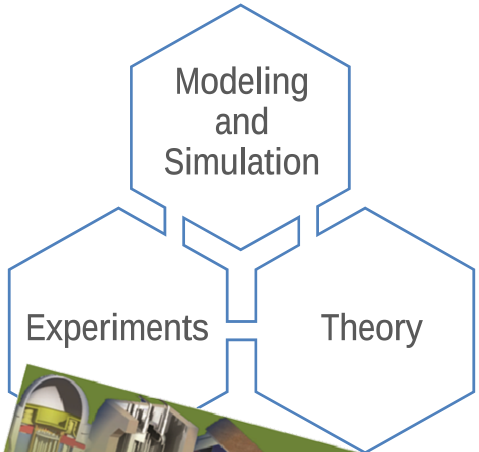
Core CASL objective:
Develop advanced M&S methods and investigate new fuel designs to address challenge problems

CASL evaluated safety, operating, and design aspects to develop the set of challenge problems

Safety	Operating	Design
• DNB safety limit • Reactivity coefficients • Shutdown margin • Enrichment • Internal gas pressure • PCMI • RIA fragmentation • Non-LOCA runaway oxidation • LOCA: PCT, oxidation, H release, long-term cooling • Seismic loads • Holddown force • Criticality	• DNB operating limit • LHGR limit • PCI • Coolant activity • Gap activity • Source term • Control rod drop time • RIA fuel failure limit	• Crud deposition • Stress/strain/fatigue • Oxidation • Hydride concentration • Transport loads • Fretting wear • Clad diameter increase • Cladding elongation • Radial peaking factor • 3D peaking factor • Cladding stability

Source: *Fuel Safety Criteria in NEA Member Countries,* NEA/CSNI/R(2003)10

CASL will take advantage of its strategic position in the nuclear enterprise to drive innovation



DOE-NE

- Integrate with existing programs: LWR-S, NEAMS, FCR&D, etc.
- Exploit computational and other developments

NNSA ASC Program

- Make use of methods, data, and HPC infrastructure developed for NNSA laboratories and applications

Industry

- Capitalize on engagement of industry partners to accelerate delivery of real-world solutions
- Conduct a broad industrial outreach program

DOE-SC

- Leverage EFRCs led by CASL partners to attack challenge problems
- Exploit models, tools, and other resources (e.g., SciDAC program)
- Build on current R&D activities to extend knowledge base

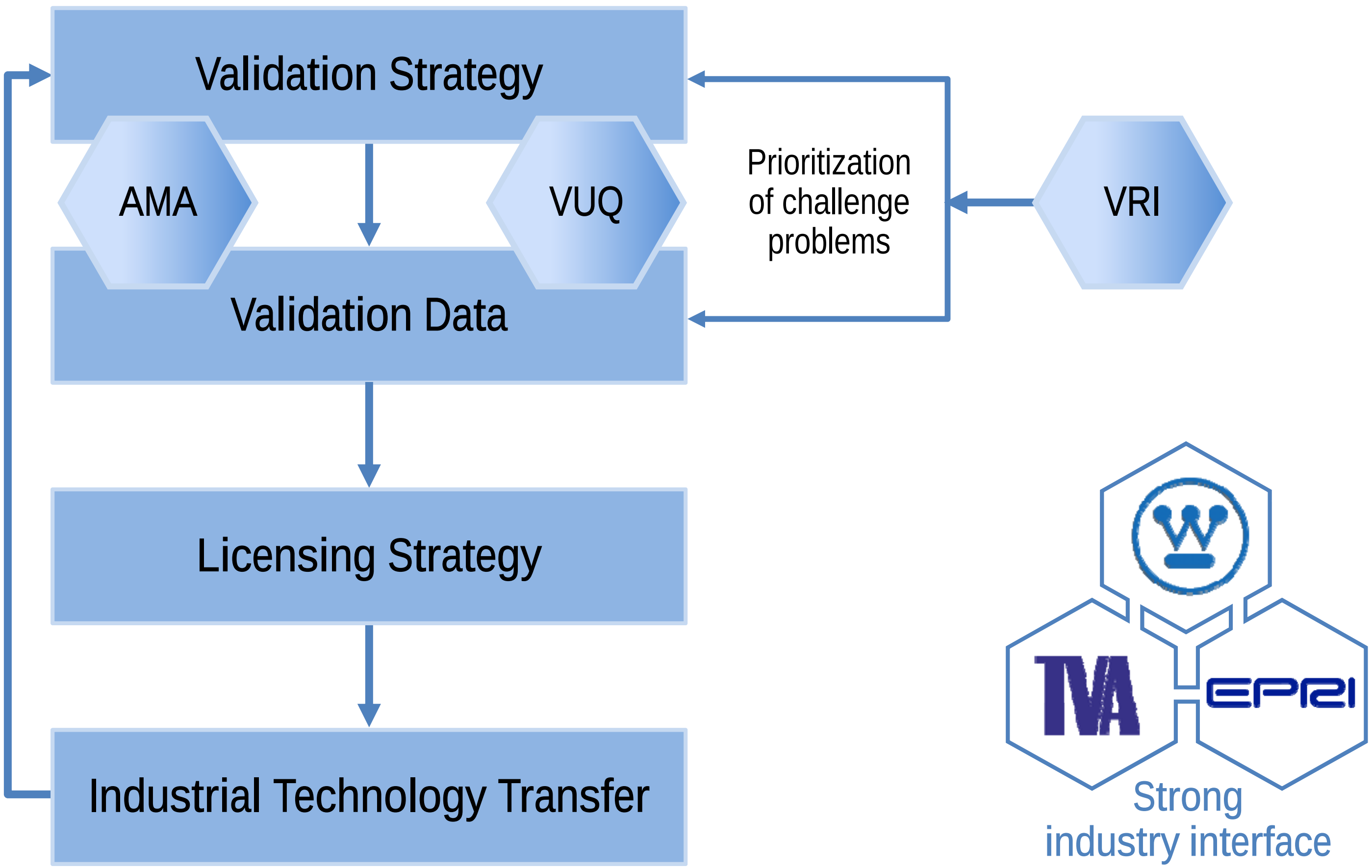
Regulatory authority

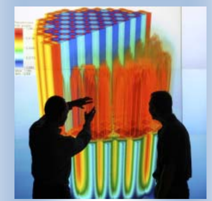
- Build on existing relationships to ensure acceptance of CASL VR

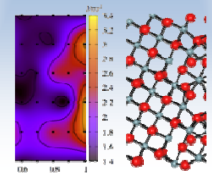
International programs

- Coordinate and make use of relevant data from international sources for validation

CASL has developed a structured approach to validation, licensing, and technology transfer







Advanced Modeling Applications

Jess Gehin
AMA Lead, CASL
Oak Ridge National Laboratory

Zeses Karoutas
AMA Petuty Lead, CASL
Westinghouse

CASL
Consortium for Advanced Simulation of LWRs

Advanced Modeling Application (AMA) Focus Area

Driving development of VR to support real-world users and applications

Objectives:

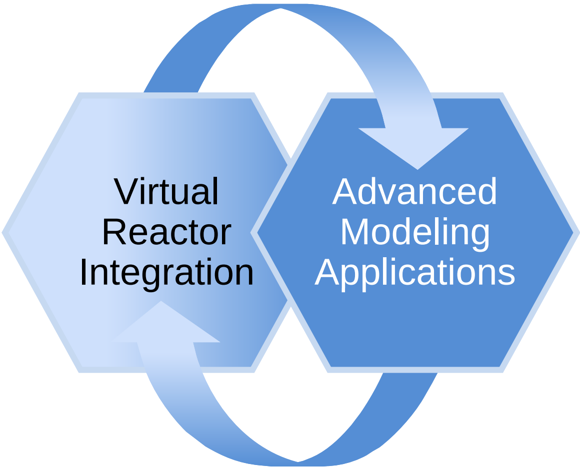
- Ensure that CASL VR meets user needs and requirements by setting requirements and assessing VR
- Support development of VR that meets user needs by directly engaging users in:
  - Setting VR modeling requirements and assessment
  - Performing VR validation
  - Performing VR qualification with physical TVA reactor data
  - Developing challenge problems and applications
  - Supporting NRC engagement

AMA will drive the VR development to meet the application needs to support industry applications for power uprates and life extension

AMA has strong connection to VRI and industry use of VR

- Enabling strong AMA/VRI collaboration, as needed for successful VR development:
  - Leadership co-location at CASL
  - Interaction with VRI via weekly meetings, code evaluation meetings, and day-to-day interactions at CASL
- Supporting demonstration in engineering environment
  - Key elements of AMA located on application/use site “test stands”
  - Coordination with CASL via on-line meetings, video conference, and project-specific messaging rooms
  - Physical reactor applications at TVA’s Watts Bar and Sequoyah nuclear plants

VR releases

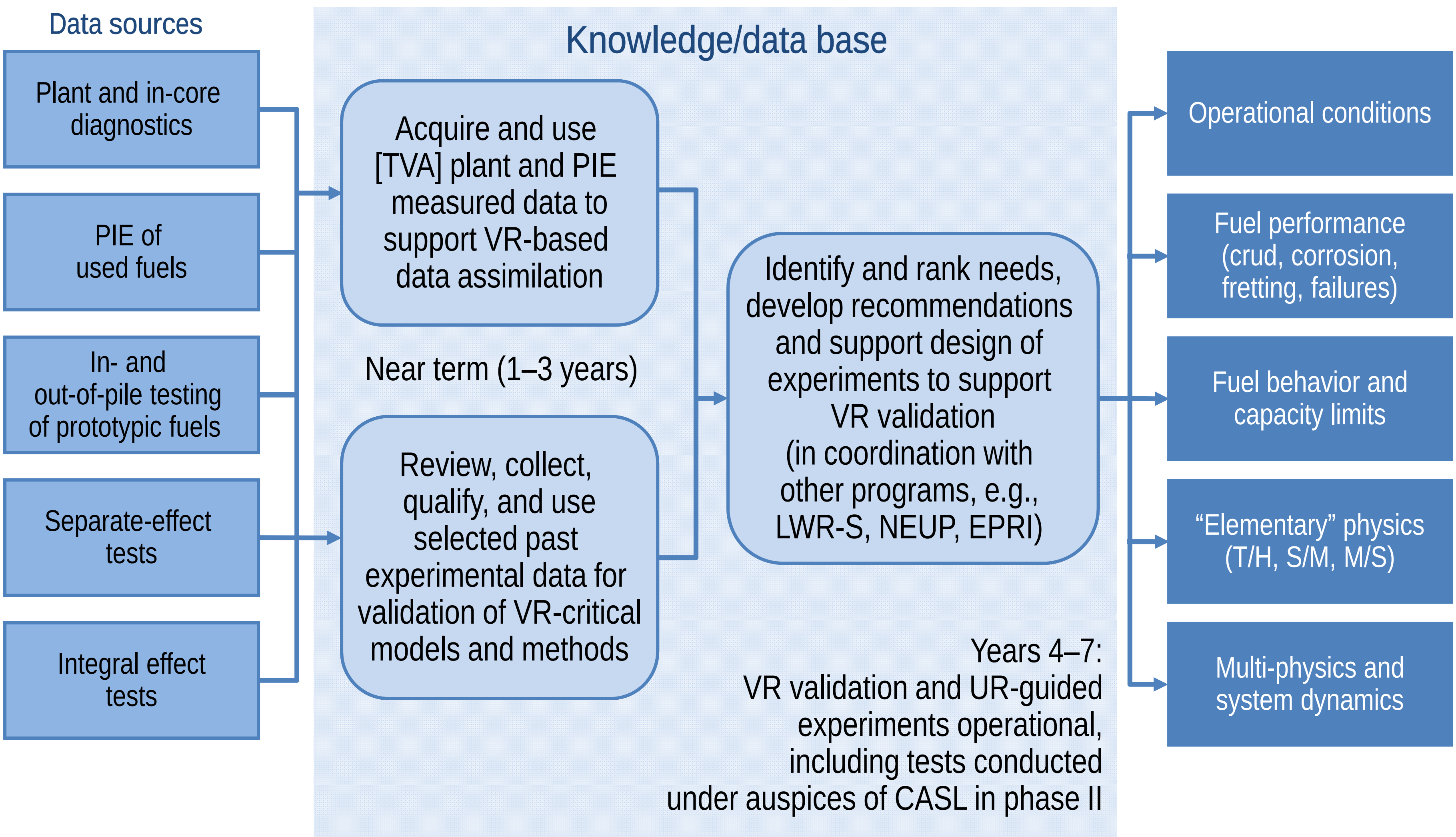


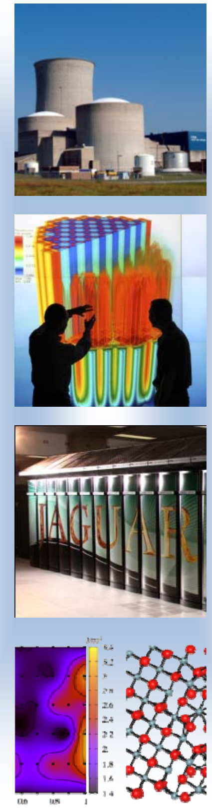
VR requirements and priorities
VR assessment of capabilities
VR qualification with physical reactor data and validation

Industry test stands

Westinghouse	EPRI
• Pittsburgh: Reload engineering and advanced fuels • Columbia: Fuel performance	• Charlotte: Industry interface • Palo Alto: Fuel management research

Validation data support plan (AMA Project 4)





Virtual Reactor Integration

John Turner
VRI Lead, CASL
Oak Ridge National Laboratory

Randy Summers
VRI Deputy Lead, CASL
Sandia National Laboratories

Rich Martineau
VRI Deputy Lead, CASL
Idaho National Laboratoy

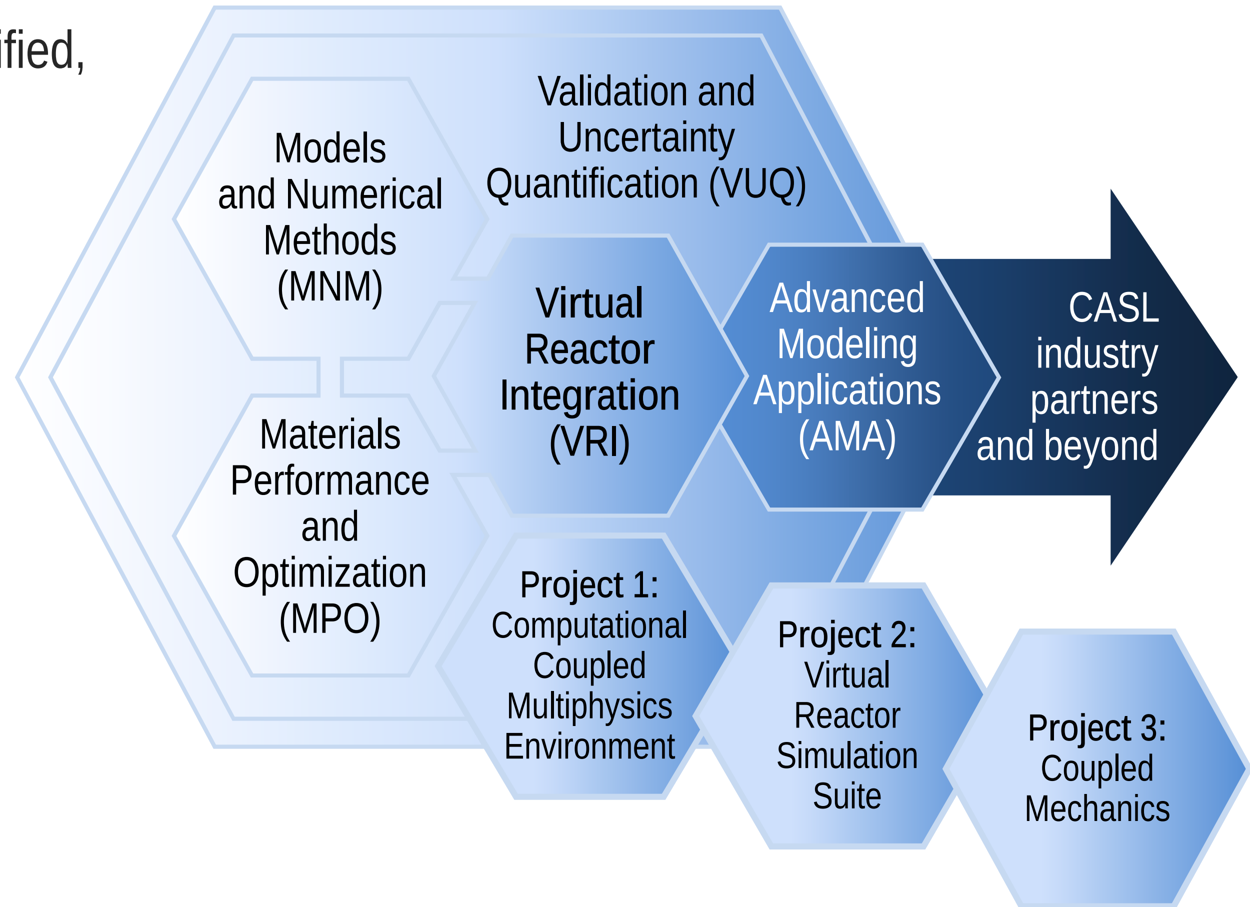
CASL
Consortium for Advanced Simulation of LWRs

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

The Virtual Reactor Integration Focus Area is the conduit between science and design/engineering

VRI will deliver

- A suite of robust, verified, and usable tools
- Within a common multi-physics environment
- To simulate phenomena within nuclear reactor vessels
- With quantified uncertainties



Three VRI projects combine to deliver the CASL VR capability

Computational Coupled Multiphysics Environment

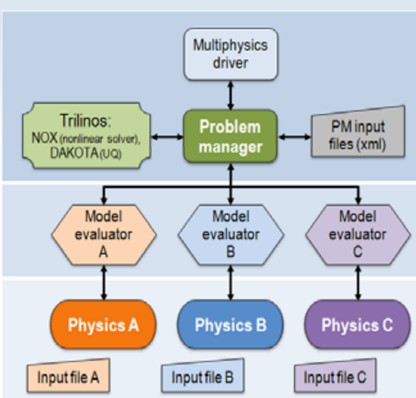
- Development of Lightweight Integrating Multiphysics Environment (LIME)
- Workflow and usability
- Meshing and mesh management
  - Leverage activities such as NEAMS ECT

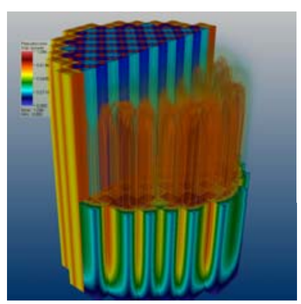
Virtual Reactor Simulation Suite

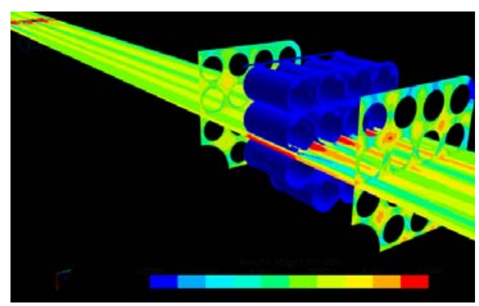
- Integrate existing and evolving capabilities:
  - Fuel performance
  - Chemistry
  - Neutronics
  - Thermal-hydraulics (T-H)
  - Structural mechanics
- Closely coordinate with VUQ
- Couple to reactor system simulation

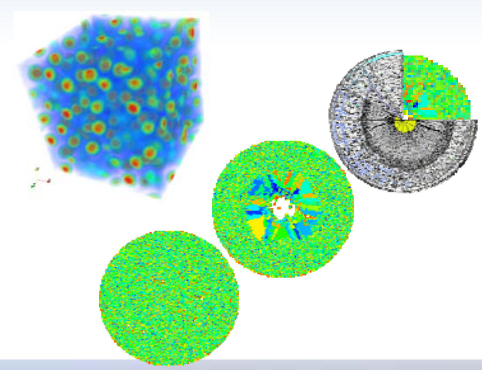
Coupled Mechanics

- Fuel performance
  - Leverage efforts such as BISON (INL) and AMP (NEAMS)
- Assembly dynamics and reactor internals
  - T-H and structural response of assembly components and reactor internals
- Chemistry and materials models









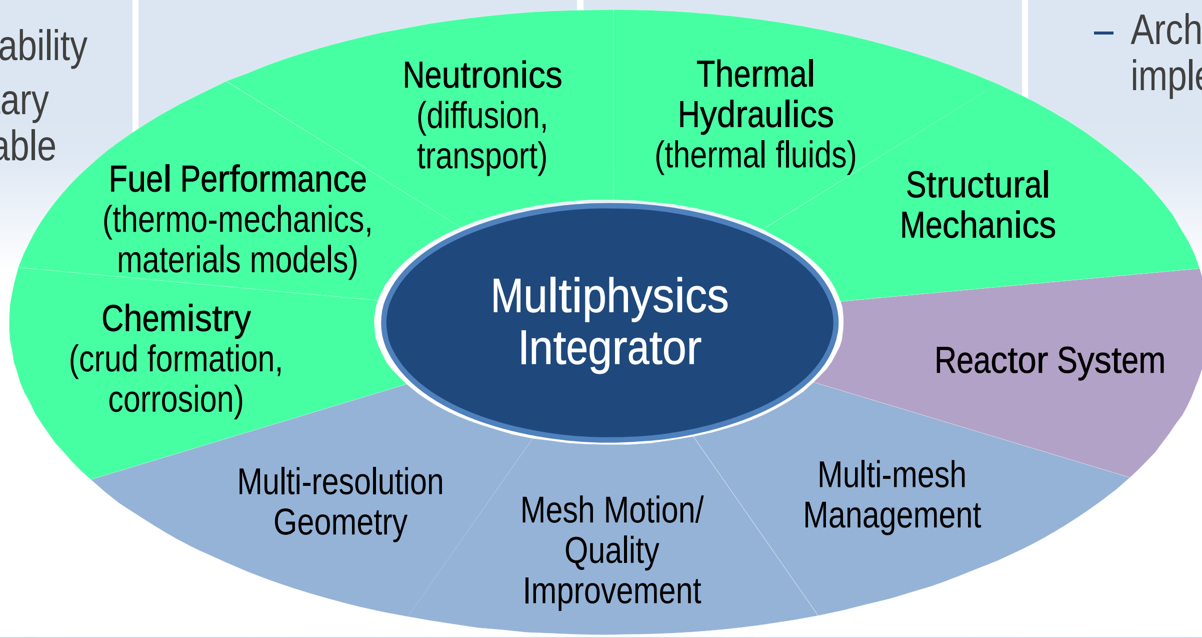
The CASL Virtual Reactor:
A code system for scalable simulation of nuclear reactor core behavior

- Flexible coupling of physics components
- Toolkit of components
  - Not a single executable
  - Both legacy and new capability
  - Both proprietary and distributable

- Attention to usability
- Rigorous software processes
- Fundamental focus on V&V and UQ

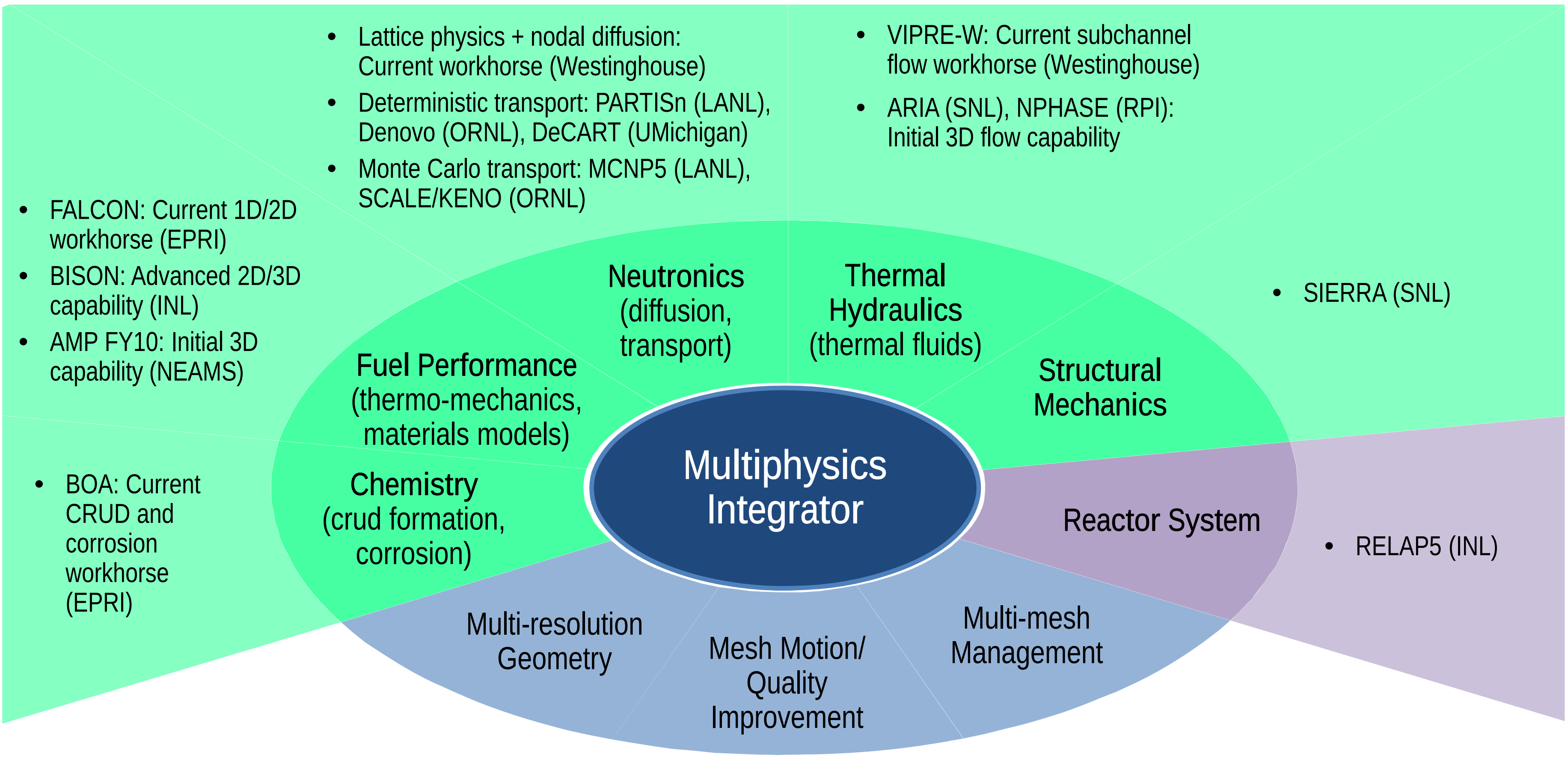
- Development guided by relevant challenge problems
- Broad applicability

- Scalable from high-end workstation to existing and future HPC platforms
  - Diversity of models, approximations, algorithms
  - Architecture-aware implementations

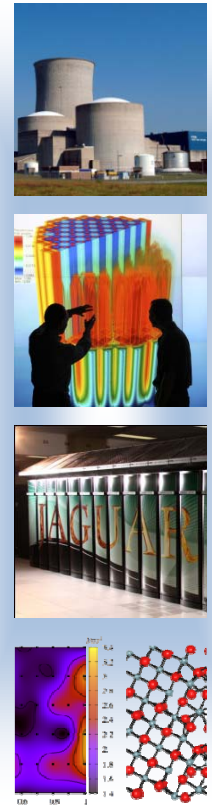


CASL

The CASL VR builds on a foundation of mature, validated, and widely used software



- CASL developers have delivered code for production (not just research)
  - ORNL and LANL codes account for almost 80% of RSICC distributions since 2005



Science Program

Paul Turinsky
Chief Scientist, CASL
Professor of Nuclear Engineering,
North Carolina State University

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Outline

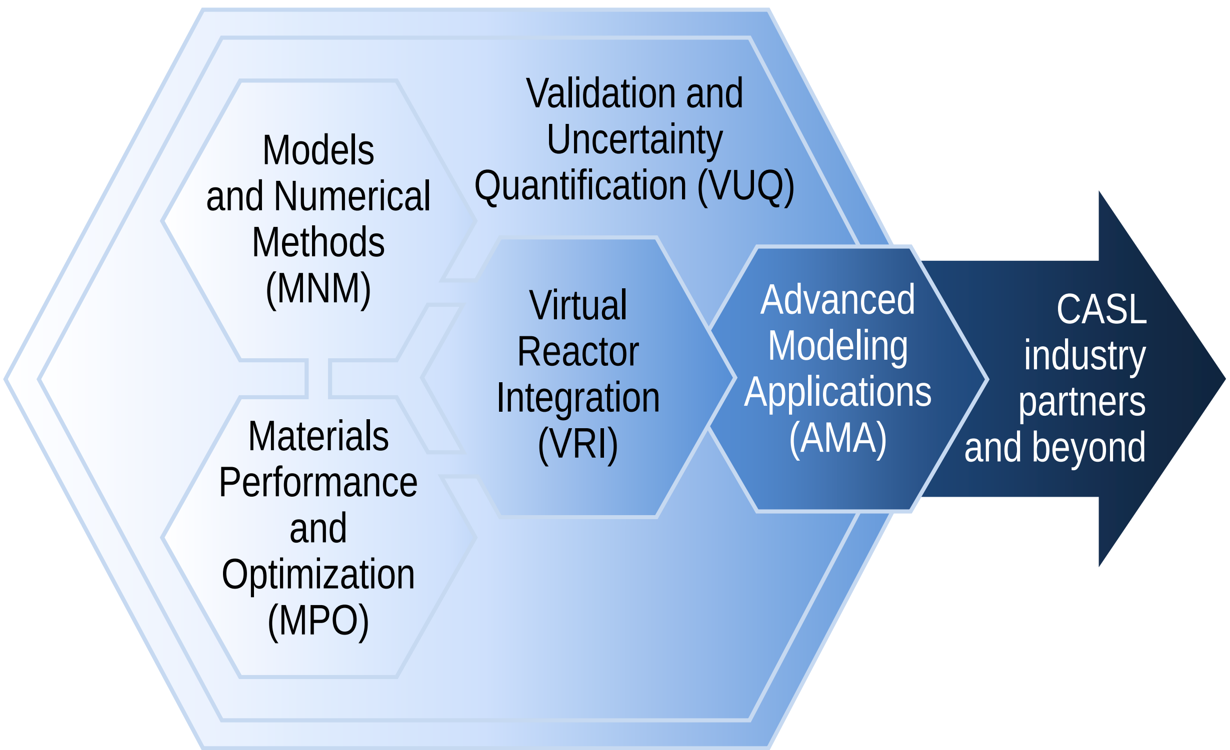
- Drivers for science-based modeling
- Overviews of science focus areas
  - Materials Performance and Optimization (MPO)
  - Modeling and Numerical Methods (MNM)
  - Validation and Uncertainty Quantification (VUQ)

Drivers for defining science program

Industry-defined challenge problems established capabilities required of VR (L1 milestones)	**Sensitivity/UQ contributors** to limiting system/ structure/component performance helped guide areas of emphasis	**Ability to validate** the M&S capability being developed was considered

Top-down driven, nimble research plan

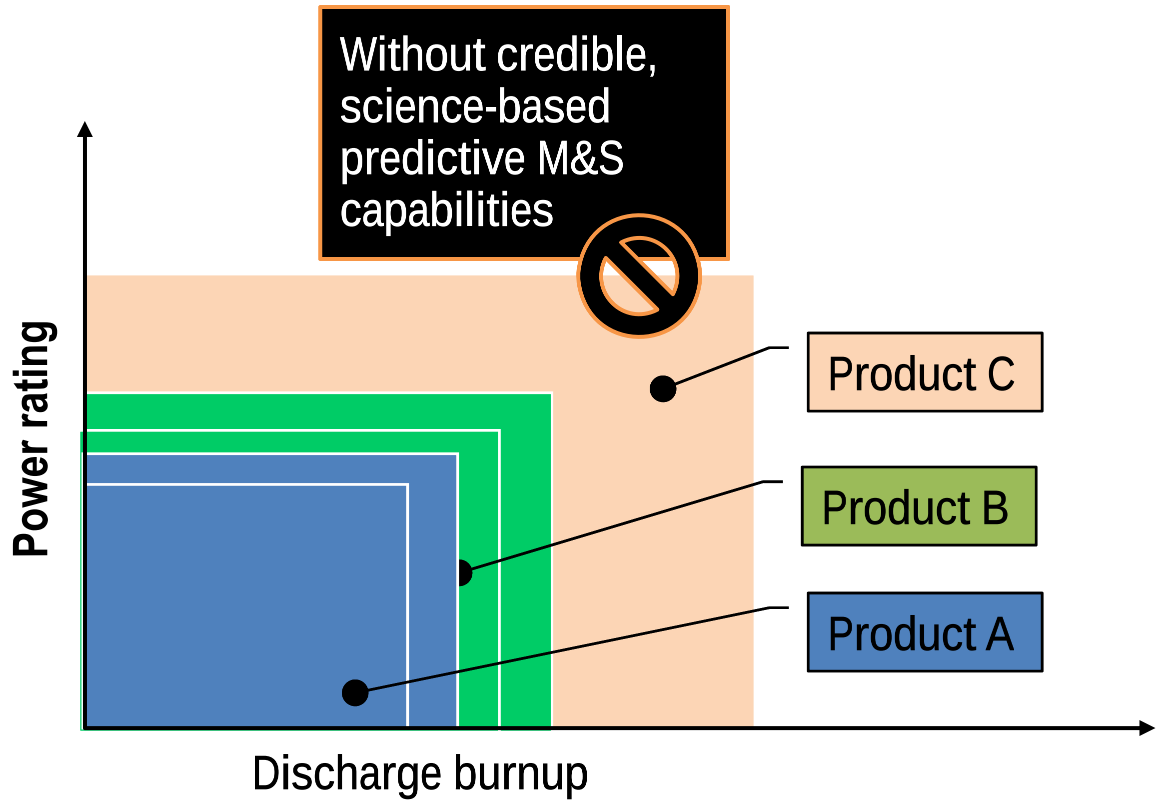
Drivers Lead to Defining Focus Areas



VUQ is all encompassing

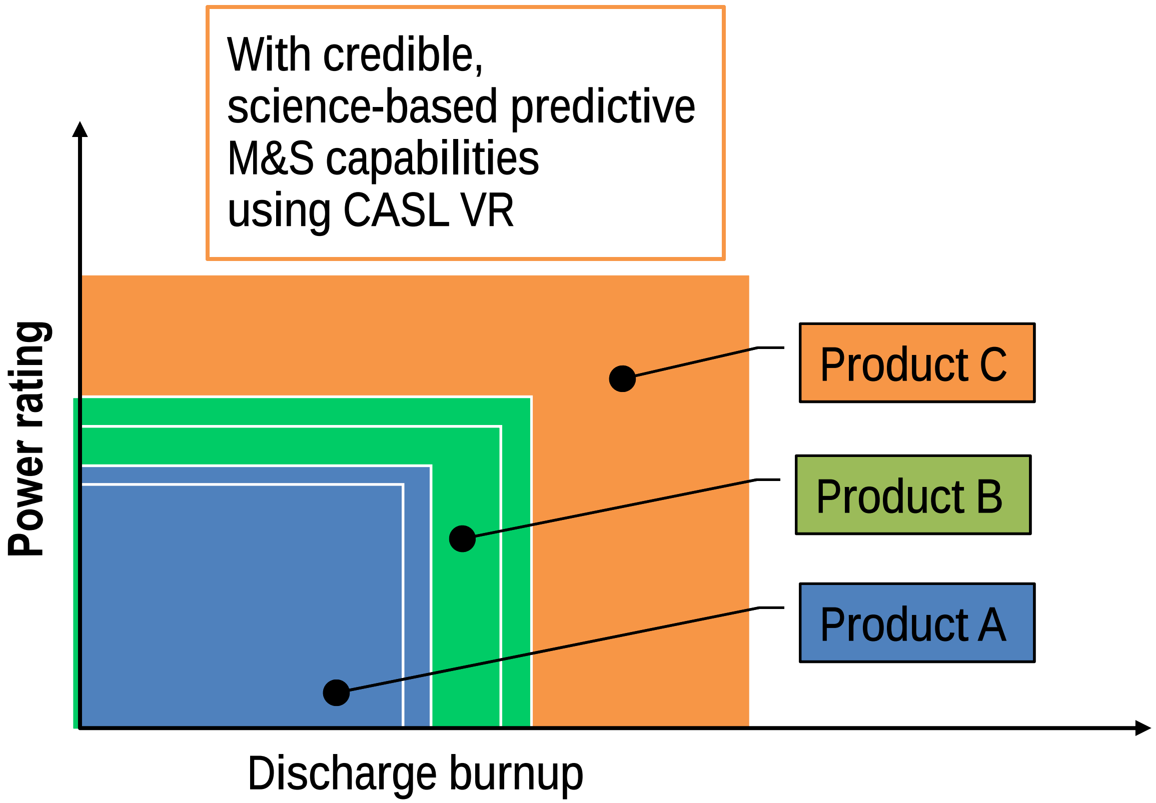
Focus areas integration is absolutely necessary

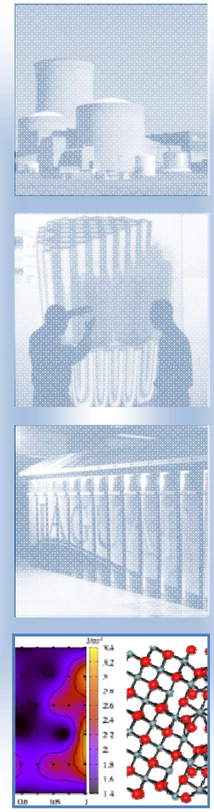
Current M&S capability
Limited by demonstration basis used for validation



CASL science objective

Enabling stretched performance of current products and more timely introduction of new enhanced products





Materials Performance and Optimization (MPO)

Chris Stanek
MPO Lead, CASL
Los Alamos National Laboratory

Sidney Yip
MPO Deputy Lead, CASL
Massachusetts Institute of Technology

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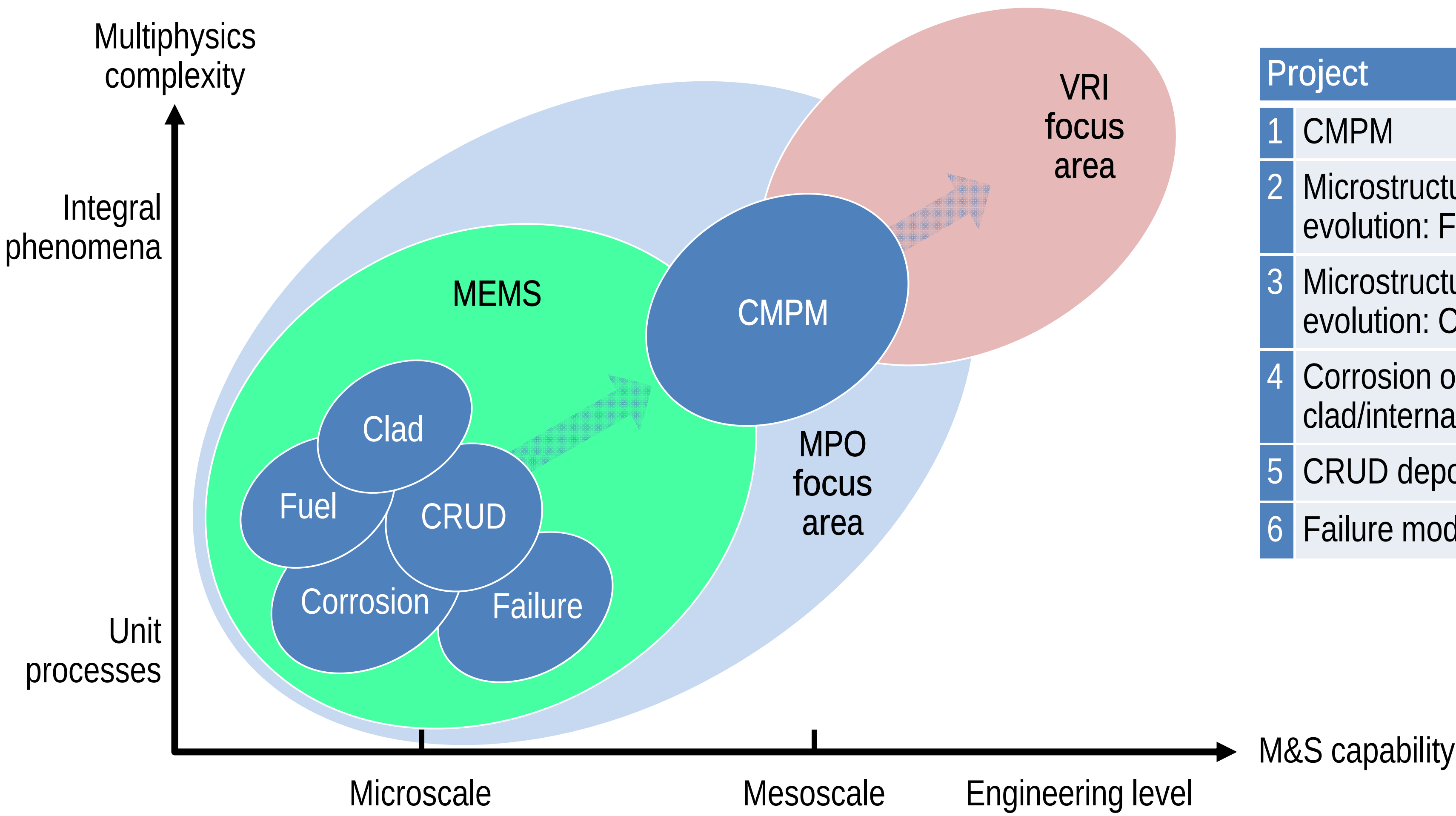
MPO objective: Deliver multiphysics-multiscale materials models to enable CASL mission in addressing power uprates, higher burnup, and life extension

- Implement a mesoscale model (Comprehensive Materials Performance Model - CMPM) to couple microstructure evolution modeling and simulation (MEMS) to Virtual Reactor Integration (VRI)

- Leverage cooperation with EFRCs to develop physics, mechanics and chemistry models of microstructural evolution M&S (MEMS) for input to CMPM

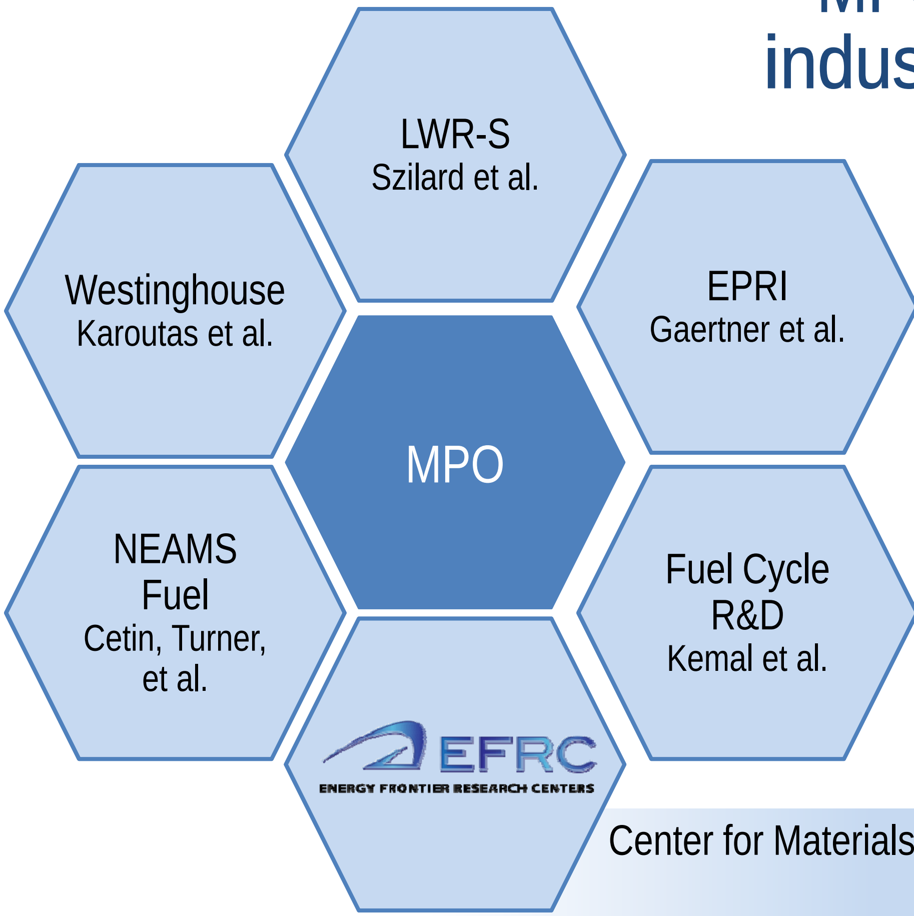
Innovation for optimization
of fuel and vessel materials

MPO science innovation is micro-meso coupling in both complexity of physical phenomena and modeling and simulation capability



Project	
1	CMPM
2	Microstructure evolution: Fuel
3	Microstructure evolution: Clad
4	Corrosion of clad/internals
5	CRUD deposition
6	Failure modes

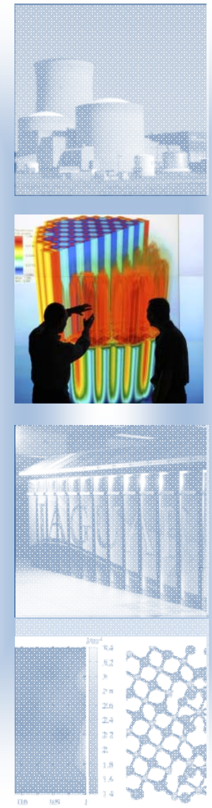
MPO will leverage existing DOE, industry, and university programs



Center for Materials Science of Nuclear Fuel
INL/NCState/UF/FSU

Extreme Environmental Tolerant Materials via Atomic Scale Control of Interfaces
LANL/MIT

Center for Defect Physics of Structural Materials
ORNL



Models and Numerical Methods (MNM)

Bill Martin
MNM Lead, CASL
University of Michigan

Ed Dendy
MNM Deputy Lead, CASL
Los Alamos National Laboratory

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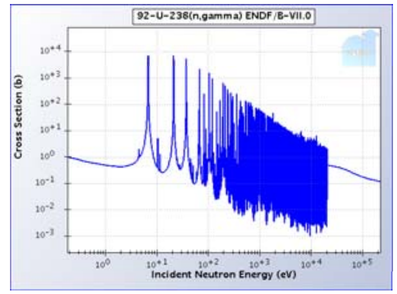
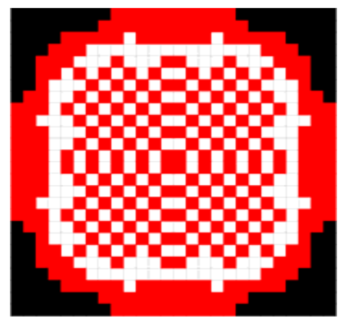
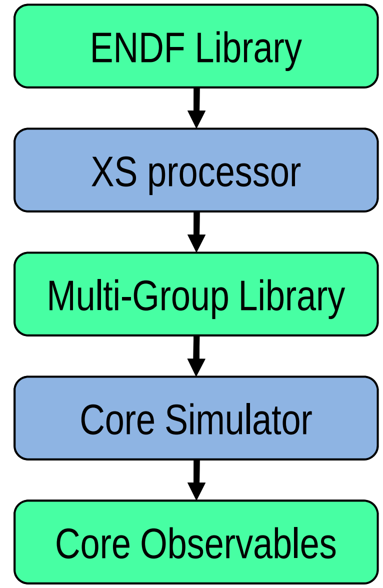
Desired MNM nuclear power industry capabilities:
MNM objective

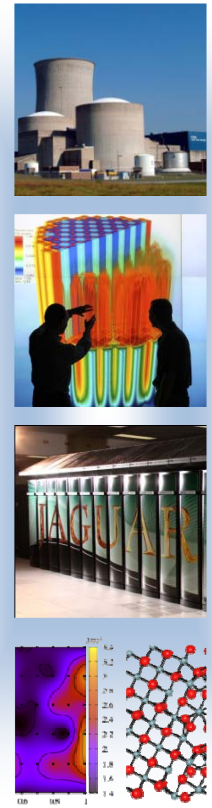
Radiation transport	• Fully resolved capability to determine heat deposition rates and isotopic evolution for generalized geometries using deterministic and stochastic methods
Thermal-hydraulics	• Fully resolved CFD based multiphase flow and conjugate heat transfer capability for complex flow geometries and heat transfer surfaces with reduced dependences on closure relationships
Numerical methods	• Methodologies in support of models' implementation and multiphysics integration on parallel architectures







Improved predictive capability to foster improved product performance



Validation and Uncertainty Quantification (VUQ) Focus Area

Jim Stewart
VUQ Lead, CASL
Sandia National Laboratories

Dan Cacuci
VUQ Deputy Lead, CASL
North Carolina State University

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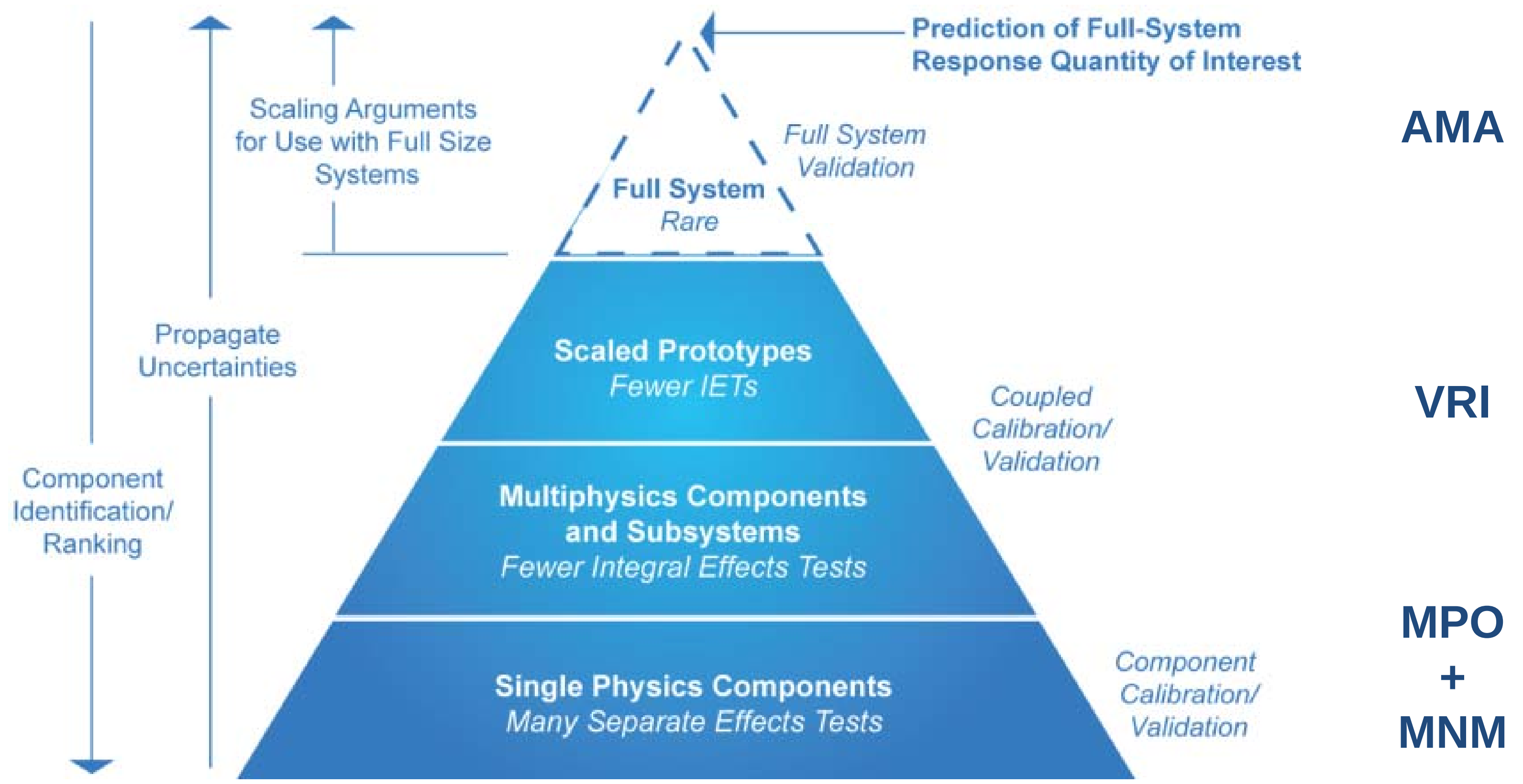
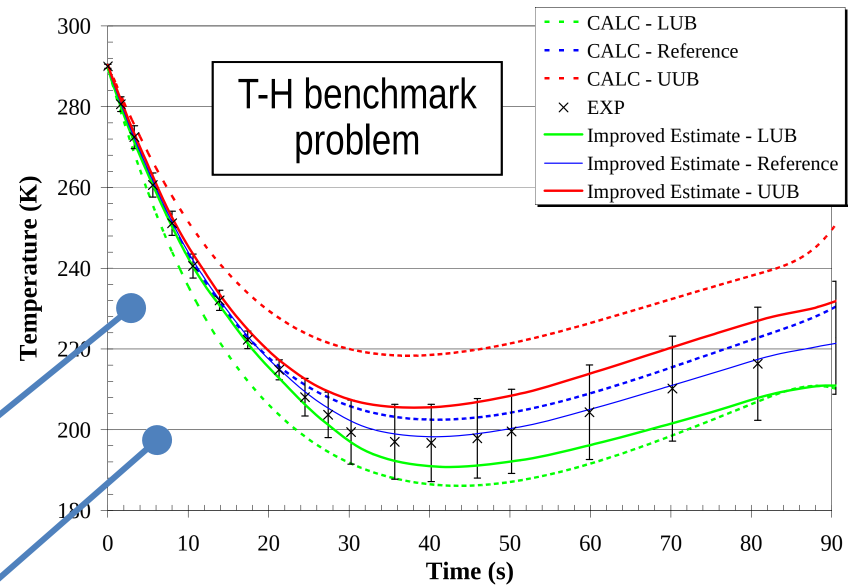
The validation hierarchy integrates all CASL Focus Areas, executed in a bottom-up and top-down way



VUQ objective:
Develop and deploy state-of-the-art VUQ capabilities for the nuclear power industry

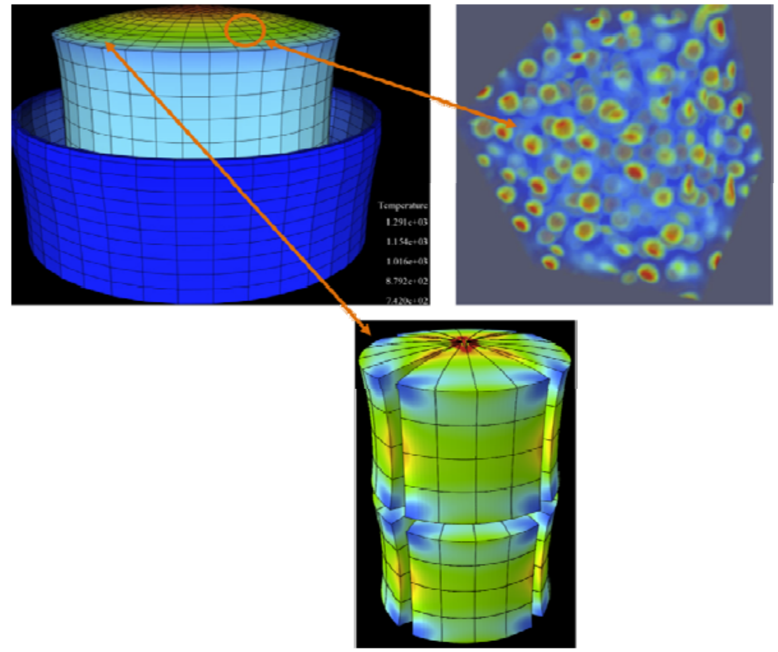
- Develop new methods across capability areas
  - Innovation and performance
    - ➢ Advanced algorithms and software
    - ➢ Integrated in VR



VUQ capability areas:
- Verification
- Validation
- Calibration through data assimilation
- Sensitivity analysis
- Discretization error analysis and control
- Uncertainty quantification

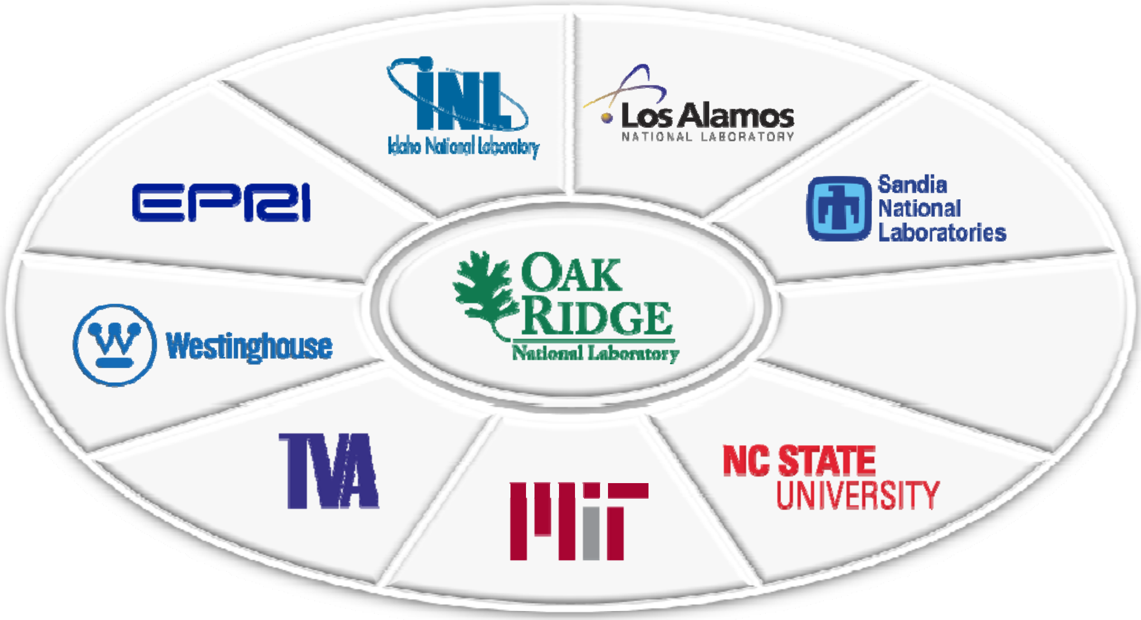
Enabling informed R&D, design, and operational decision making

CASL legacy:
A preeminent computational science institute for nuclear energy



- CASL VR: Advanced M&S environment for predictive simulation of LWRs
  - Operating on current and future leadership-class computers
  - Deployed by industry (software “test stands” at EPRI and Westinghouse)
- Advanced M&S capabilities:
  - Advances in HPC algorithms and methods
  - Validated tools for advancing reactor design
- Fundamental science advances documented in peer-reviewed publications
- Innovations that contribute to U.S. economic competitiveness
- Highly skilled work force with education and training needed:
  - To sustain and enhance today’s nuclear power plants
  - To deliver next-generation systems

Supplemental Material



The CASL challenge problems drive VR requirements and define L1 milestones

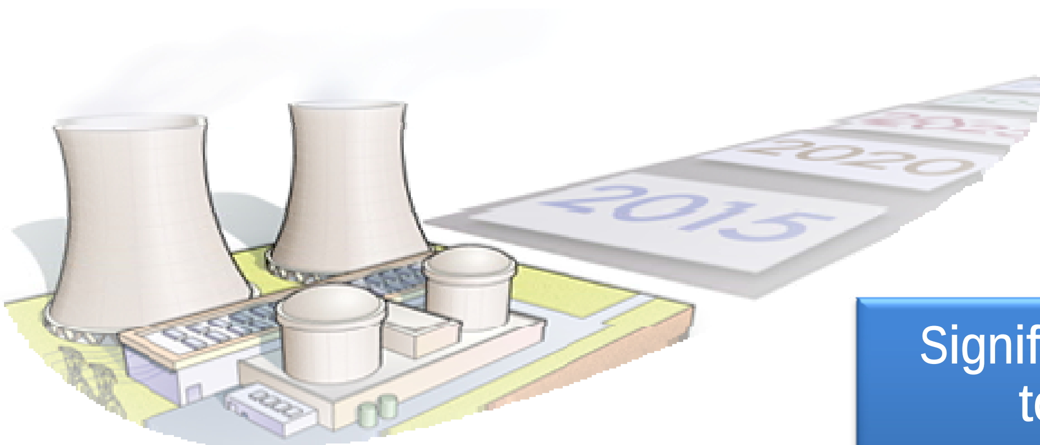
- Each challenge problem carries a unique set of functional science and engineering requirements
- CASL activities have been prioritized to meet these requirements
  - Priority placed on 6 problems
  - Selected aspects of 4 problems to be addressed

Challenge Problem	Description	Relevance
CRUD	CIPS: Deviation in axial power shape caused by CRUD deposition in high power density regions with subcooled boiling. CILC: Clad corrosion and failure due to CRUD deposition	Power uprates yield higher power density and an increased potential for CRUD growth, axial power offsets, and clad failures
GTRF	Clad failure due to flow vibration-induced rod-spring interactions amplified by irradiation-induced grid spacer growth and spring relaxation	Power uprates and burnup increase potential for fretting failures, the leading cause of fuel failures in PWRs
Internals Lifetime (LE)	Damage to internals packages caused by thermal fatigue, mechanical fatigue, radiation damage, and stress corrosion cracking.	Replacement cost of internals is high, making lifetime extension fees economically attractive
DNB (Safety)	Local clad surface dryout causing dramatic reduction in heat transfer capability during certain accident transients (e.g., overpower and low coolant flow)	Power uprates require improved quantification of margins for DNB limits
FAD	Distortion or component structural failure due to excessive axial forces caused by radiation-induced swelling	Power uprates and increased burnups may increase fuel distortions and alter core power distributions and fuel handling scenarios
Advanced Fuel Forms (AF, Safety, GTRF)	Examination of new cladding material, fuel material, and fuel pin geometries.	New fuel forms will enable power uprates, higher fuel burnups, and lower fuel cycle costs than can be achieved by incremental modifications of current fuel forms, i.e., zirconium alloy cladding, UO_2 fuel pellet, and cylindrical geometry
LOCA (Safety)	Numerous fuel failure modes resulting in fission product	Realistic LOCA

Life extension driven by economic decision on ability to continue to operate the plant

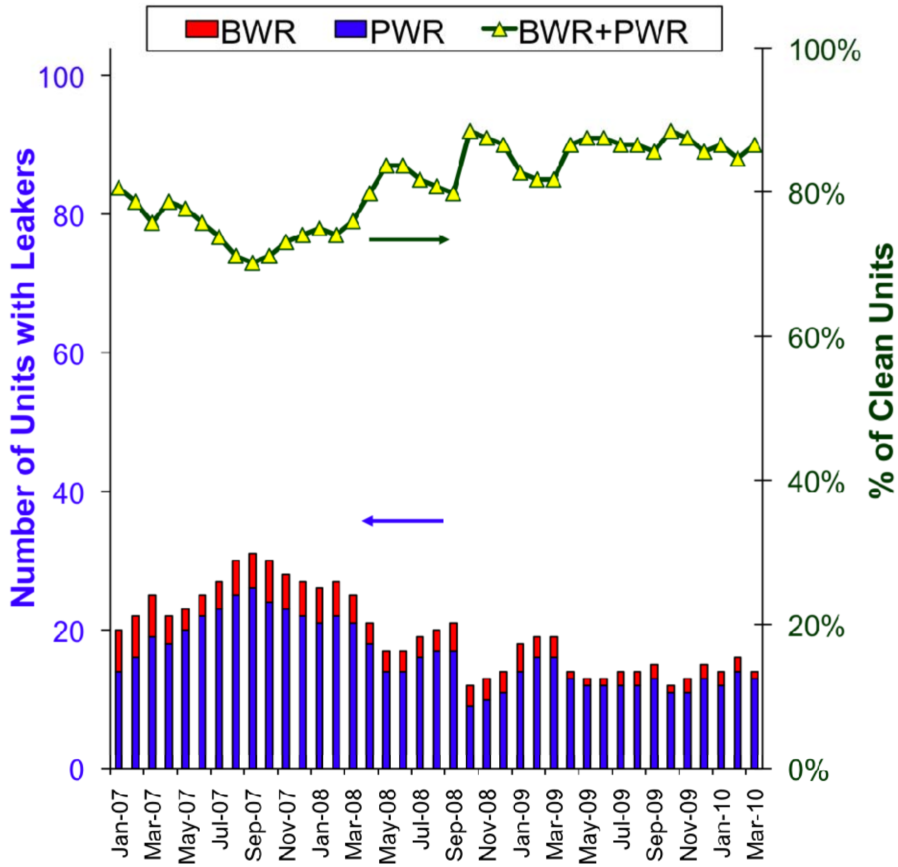
Key technical elements for basis of license renewal and life extension:

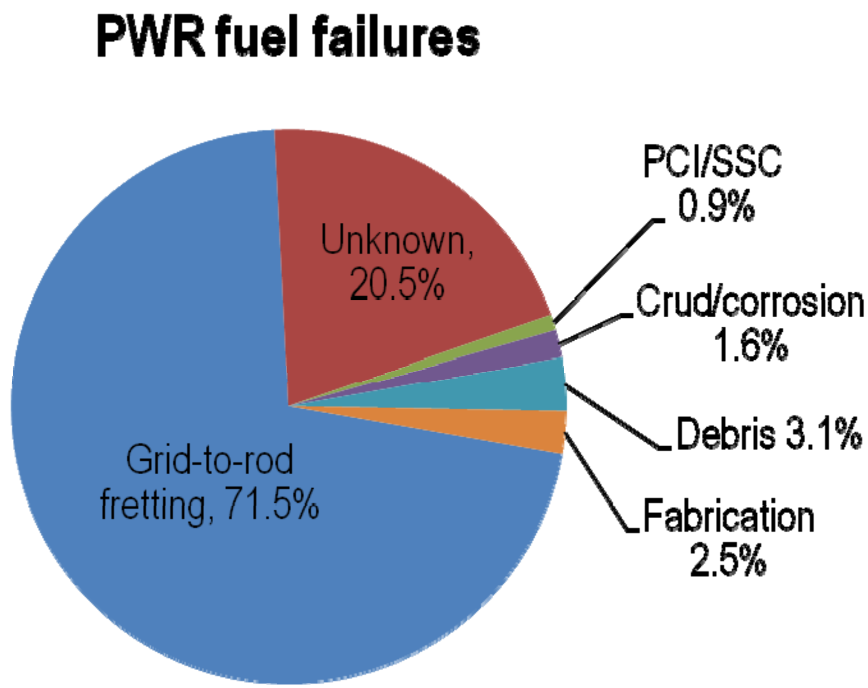
- Identify and quantify potential “life limiting” issues
- Structures, systems, and components aging and life-cycle management
- Opportunities for modernization and power uprates
- Enabling technology (e.g., analysis methods/simulation capability)



Significant financial decisions
to support operation
beyond 60 years
are expected in 2014–2019

Current fuel performance issues provide insights for further power uprates and increased fuel burnups





CASL VR M&S capability will permit proactive evaluation to enable critical performance enhancements

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Ken Nemeth
(Secretary and Executive Director, SSEB)

Leadership roles represent the full range of CASL's capabilities

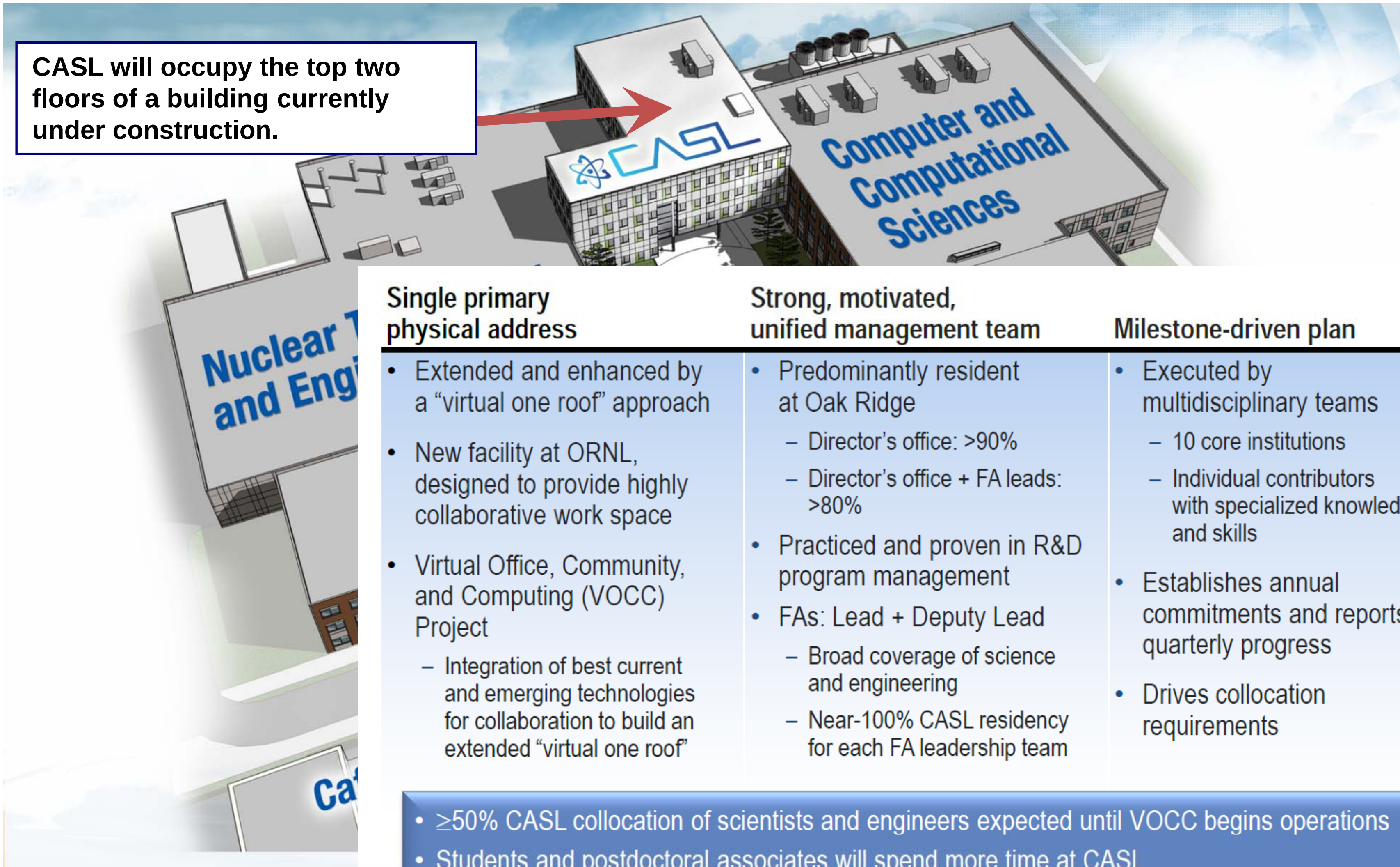
CASL administration

Director	ORNL
Deputy Director	INL
Chair, Board of Directors	MIT
Chief Scientist	NCSU
Chair, Education Council	NCSU
Chief Strategy Officer for Licensing/Implementation	Westinghouse
Chair, Industry Council	EPRI
Physical Reactor Operations	TVA

CASL focus areas

Materials Performance and Optimization	Lead: LANL Deputy lead: MIT
Models and Numerical Methods	Lead: Michigan Deputy lead: LANL
Virtual Reactor Integration	Lead: ORNL Deputy lead: INL Deputy lead: SNL
Validation and Uncertainty Quantification	Lead: SNL Deputy lead: NCSU
Advanced Modeling Applications	Lead: ORNL Deputy lead: Westinghouse

CASL's "one roof" approach



Single primary physical address	Strong, motivated, unified management team	Milestone-driven plan
• Extended and enhanced by a "virtual one roof" approach • New facility at ORNL, designed to provide highly collaborative work space • Virtual Office, Community, and Computing (VOCC) Project – Integration of best current and emerging technologies for collaboration to build an extended "virtual one roof"	• Predominantly resident at Oak Ridge – Director's office: >90% – Director's office + FA leads: >80% • Practiced and proven in R&D program management • FAs: Lead + Deputy Lead – Broad coverage of science and engineering – Near-100% CASL residency for each FA leadership team	• Executed by multidisciplinary teams – 10 core institutions – Individual contributors with specialized knowledge and skills • Establishes annual commitments and reports quarterly progress • Drives collocation requirements

- ≥50% CASL collocation of scientists and engineers expected until VOCC begins operations
- Students and postdoctoral associates will spend more time at CASL