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

Lesson’s Learned for Molten Salt Reactor Development

Dr. Jess C. Gehin  
CASL Director

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Innovation – Learning from Bell Labs

• Per Jon Gertner: “Innovation defined the lengthy and wholesale transformation of an idea into a technological product (or process) meant for widespread practical use.”

• This cannot be performed by a single group. Needs:
  – Discovery
  – Turning discovery into invention
  – Turning invention into a product
  – Implementing the product

• Hence, a connection from scientists, engineers, product development, and deployment

• Bell Labs did this all within their own company
  – Discovery, research, engineering, and product use under “one roof”
What is a DOE Energy Innovation Hub?

• Target problems in areas presenting the most critical barriers to achieving national climate and energy goals

• Represent a new structure, modeled after research entities like the Manhattan Project and AT&T Bell Labs

• Focus 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
  – Bring together the top talent across the R&D enterprise (gov, academia, industry, non-profits) to become a world-leading R&D center in its topical area

For more info: http://energy.gov/science-innovation/innovation/hubs
Advanced modeling and simulation based on rapid growth in computing is tool for nuclear innovation

http://en.wikipedia.org/wiki/TOP500
Attributes Sought by DOE for the Energy Innovation Hub for Modeling & Simulation of Nuclear Reactors

• **Utilize existing** advanced modeling and simulation capabilities developed in other programs within DOE and other agencies

• **Apply them** through a new multi-physics environment and develop capabilities **as appropriate**

• **Adapt the new tools** into the current and future culture of nuclear engineers and produce a multi-physics environment to be used by a wide range of practitioners **to conduct predictive simulations**

• Have a **clear mission that focuses and drives R&D**

• Use **data from real physical operation reactors to validate** the virtual reactor

• Lead organization with **strong scientific leadership** and a clearly defined central location (“one roof” plan)
Nuclear Energy Drivers and Payoffs for M&S technology

• Extend licenses of existing fleet (to 60 years and beyond)
  – Understand material degradation to reduce inspection & replacements

• Up-rate power of existing fleet
  – Address power-limiting operational & design basis accident scenarios

• Inform flexible nuclear power plant operations
  – Load follow maneuvering & coolant chemistry to enhance reliability

• Design and deploy accident tolerant fuel (integrity of cladding)
  – Concept refinement, test planning, assessment of safety margins

• Margin quantification, recovery, tradeoff
  – Plant parameters, fuel hardware, reload flexibility, regulatory changes

• Resolve advanced reactor design & regulatory challenges
  – Support Gen III+ reactors under construction (AP1000), refine SMR design

• Fuel cycle cost savings
  – More economical core loadings and fuel designs

• Used fuel disposition
  – Inform spent fuel pools, interim storage, and repository decisions
The Consortium for the Advanced Simulation of Light Water Reactors - An Energy Innovation Hub

• Established by Former DOE Energy Secretary Steven Chu
• Modeled after the scientific management characteristics of AT&T Bell Labs:
  – Addressing critical problems
  – Combines basic and applied research with engineering
  – Integrated team to take discovery to application
• 10 year focused R&D effort (2010–2019)

“Multi-disciplinary, highly collaborative teams ideally working under one roof to solve priority technology challenges”
– Steven Chu

CASL MISSION
Provide leading-edge modeling and simulation (M&S) capabilities to improve the performance of currently operating and future light water reactors (LWR’s)
CASL is a National Laboratory, Industry, University Partnership

International Collaborators

CASL Founding Partners

CASL Contributing Partners

Core Physics, Inc.

ANATECH

ASCOMP

CD-adapco

Core Physics, Inc.

The University of Texas at Austin

UT Knoxville

The University of Tennessee

Westinghouse

Idaho National Laboratory

Los Alamos National Laboratory

Sandia National Laboratories

EPRI

Oak Ridge National Laboratory

UC Davis

University of Michigan

University of Minnesota

University of Texas

William & Mary

The University of Tennessee

Oak Ridge National Laboratory

Global Nuclear Fuel

A Joint Venture of UT, Tennessee, Rensselaer, & Northeastern

The Consortium for Advanced Simulation of Light Water Reactors (CASL)
CASL Scope: Develop and apply a “Virtual Reactor” to assess fuel design, operation, and safety criteria

• Deliver improved predictive simulation of Light Water Reactors
  – Focus on fuels, vessel, internals
  – First five year focus on PWRs, broadened to BWR and Light Water Small Modular Reactors

• Equip the Virtual Reactor with necessary physical models and multiphysics integration
  – Build the Virtual Reactor with a comprehensive, usable, and extensible software system
  – Validate and assess the Virtual Reactor models with self-consistent quantified uncertainties

• Apply the virtual reactor to address challenges in reactor operations
Our Challenge Problems are Focused on Key Commercial Reactor Performance Areas

- **Pellet-Clad Interaction (PCI)**
  - Predict core wide PCI margin and missing pellet surface PCI for BWR, iPWR, PWR
  - Neutronics, Thermal-Hydraulics, Fuel/Cladding Performance

- **CRUD**
  - Predict CRUD thickness, boron uptake, and impact on power and cladding corrosion for iPWR, PWR
  - Neutronics, Thermal-Hydraulics, Fluid Flow (CFD), Chemistry

- **Cladding Integrity Reactivity Insertion Accident**
  - Predict pellet-clad mechanical interaction for BWR, iPWR, PWR
  - Reactor Kinetics, Transient Fuel/Cladding Performance

- **Core Environment**
  - Neutronics, Thermal-Hydraulics, Fuel Performance for BWR, iPWR, PWR

- **Cladding Integrity Loss of Coolant Accident**
  - Predict peak clad temperature and oxidation margin for BWR, iPWR, PWR
  - Fuel/Cladding Performance

- **Departure from Nucleate Boiling (DNB) and Flow Regimes**
  - Predict PWR DNB margin for steam line break, predict thermal and solutal flow, BWR flow regimes
  - Neutronics, Thermal-Hydraulics/Fluid Flow (CFD)

- **Grid to Rod Fretting**
  - Predict fluid structure excitation forces, grid-clad gap, and cladding wear for iPWR, PWR
  - Fluid Flow (CFD), Fuel/Cladding Performance, Materials Performance
Virtual Environment for Reactor Applications

- Physics components for reactor simulation and challenge problems
- Same or better spatial scales as current methods
- Direct multi-physics couplings between physics
- High attention to usability and parallel performance
CASL Tools Applied to Operating Plants - Watts Bar Nuclear Unit 1 Operation

- Operated by Tennessee Valley Authority
- Traditional four-loop Westinghouse PWR
- Began operation in 1996
- Currently in 14th fuel cycle
- 3459 MW\text{th} thermal power
- Unit 2 Critical on May 23, 2016
VERA Results: Watts Bar Unit 1

Cycle 11 Fuel Pin Power Distribution

Cycle 11 Coolant Density

183 power distribution comparisons

418 critical boron comparisons
CASL Challenge Problem: Watts Bar 1 Cycle 7 Predicted Crud Distribution

The Result is a Significant Improvement in Power Distribution
CASL is Modeling Watts Bar Unit 2 Startup and Power Ascension

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

Watts Bar Unit 2 Power History

- Measured Power Distributions

- 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 measurements
- Explicit shutdown decay of radioactive fission products
- Largest simulation by CASL to date – done in nearly real-time
Industry Highlights CASL’s Impact and Potential

“VERA is a game-changing technology. I expect that we will look back and say, ‘Wow, that technology really changed how we predict what is happening in a reactor.’” - Heather Feldman, a Program Manager in EPRI’s Nuclear sector.

http://eprijournal.com/seeing-deeply-into-a-nuclear-reactor/

CASL technology deployed at the industry proves beneficial for challenging simulation scenarios
Key Points Leading to CASL’s Success

- Built an exceptionally strong and talented team
- Clear deliverables that solve industry issues and are driven by a well-defined yet agile plan
- A true private-public partnership in management, leadership, and execution leveraging the strengths of each type of organization
- Defined customers and users, with “industry pull” ensured by industry partners and industry council
- Led by one institution with resource allocation 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
- Independent councils to review and advise on quality and relevance of S&T