Nuclear Energy Advanced Modeling and Simulation (NEAMS)

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Nuclear Energy Can Benefit from Modeling and Simulation in the Near, Mid, and Long Terms

Time (* Dates Approximate)
2010 2020 2040

Near-Term
- Power Uprates
- Higher Burnups
- Deployment of Gen III+ Reactors
- NGNP

Mid-Term
- Small Modular Reactors
- License Extensions
- Gen IV Reactors

Long-Term
- Closed Fuel Cycle
- Waste Repository

New means of improved understanding nuclear energy issues

Modeling and simulation has become a peer to theory and experiment to develop science insight
NEAMS and the Energy Innovation Hub Will Play Important Roles

- NE-5 Fuel Cycle R&D
  - Used Fuel Disposition
  - Separations
  - Safeguards

- NE-7 Adv Reactor Concepts R&D
  - Fuels
  - LWRS
  - SMR
  - NGNP

- Improved U.S. Utilization of Nuclear Energy
- M&S Capabilities
- M&S Oversight

Nuclear Energy Advanced Modeling and Simulation (NEAMS)

Apply NEAMS Delivered Capabilities

Supplement NEAMS Delivered Capabilities
National Goals for Nuclear Energy Technology Development

- Decrease costs
- Improve performance
- Increase pace of deployment
- Enhance innovation
- Responsively deal with nuclear waste
- Promote non-proliferation

We need to go beyond traditional “test-based” approach to understanding nuclear energy

- Very successful for over last 40 years – current fleet is very safe and performs well
- However, test-based approach is:
  - Very slow
  - Very costly
  - Very hard to optimize

Development, deployment and use of advanced modeling and simulation will:

- Provide a new means of obtaining science-based insight that will
  - Increase the pace of innovation
  - Reduce costs by eliminating unnecessary margins
  - Optimize operations
  - Reduce uncertainty and risk
We call on DOE, perhaps in collaboration with other countries, to establish a major project for the modeling, analysis, and simulation of commercial nuclear energy systems.

High-fidelity (science-based) integrated simulations must form the core of design efforts, allowing for rapid prototyping that minimizes the need to experiment.

Modeling and simulation The 2003 study emphasized the need for greater analytic capability to explore different nuclear fuel cycle scenarios based on realistic cost estimates and engineering data acquired at the process development unit scale. The DOE program has moved in this direction but much remains to be done.

An advanced modeling and simulation effort can lead to better understanding of nuclear energy systems and has the potential to resolve longstanding uncertainties associated with the deployment of these systems.
NEAMS Builds on the Success of ASCI & SciDAC

- **Important Lessons from ASCI**
  - **Vision** – Have a clear and compelling vision of the mission, and develop a comprehensive program to create new capabilities
  - **Leadership** – Headquarters need a “team of rivals” at the national laboratories for leadership of the program
  - **Partnership** – Success requires the best from universities, industry and national laboratories
  - **Endurance** – Accomplishing the ambitious goals will take time and funding. But it must deliver increasing capabilities “early and often”

ASCI History Available at https://asc.llnl.gov/asc_history/Delivering_Insight_ASCI.pdf
Enabling a Shift to a Modern Science Based Approach

**Traditional Science Approach**
- Theory drives design of Experiments
- Experiments provide discoveries to drive Theory
- Empirically based modeling and simulation heavily dependent on staying close to experimental basis

**Addition of Science Based Modeling and Simulation**
- Science (1st principles) based modeling and simulation used to extrapolate and predict beyond tested states
- Can quickly confirm or disprove Theory hypotheses
- Improve experiments by predicting "areas of interest" and expected results
Why Step Up to New Methods of Gaining Insight?

Understanding of Complex Physical Process

Start

Limited Insight Gained from Theory, Experiments and Empirical Based Modeling and Simulation

Well Understood Initial Conditions

Limited Theoretical and Experimental Insight Into Physical Processes

Well Characterized Effects

Finish

Understanding Limited Due To Conditions Being
- Too Small
- Too Hazardous
- Too Long
- Too Far Away
- Too Expensive
- Too Complex
- Lack of Facilities
- Not Allowed by Policy

Level of Possible Insight
Supplements Theory and Experiment to Explain “How” Things Happened

Understanding of Complex Physical Processes

Start
Improved Insight by Adding Science (1st Principles) Based Advance Modeling and Simulation to Theory and Experiments

Level of Possible Insight
Well Understood Initial Conditions

Advanced Science Based
Limited Theoretical and Experimental Insight Into Physical Processes

Modeling and Simulation

Well Characterized Effects

Finish
It is Important to Note That Advanced Modeling and Simulation Does Not Replace the Need for Theory or Experiments
What Does Simulation for Discovery Look Like?

- 3D
- Integrated System
- Science Based Behaviors
- 217 Pin Fast Reactor
  Thermal Hydraulics
  2.1 Billion Finite Elements
  Up to 100,000 Processors on ANL BG/P
- Highly Resolved (Cublt)
- Advanced Visualization (Vizlt)
- High Performance Parallel Computing
Advanced Modeling and Simulation has become an Essential Part of NE R&D

- **R&D Objective 1** – Develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors.

- **R&D Objective 2** – Develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals.

- **R&D Objective 3** – Develop sustainable nuclear fuel cycles.

- **R&D Objective 4** – Understand and minimize the risks of nuclear proliferation and terrorism.
Prominent in the Recent NE Report to Congress

- Advanced Modeling and Simulation Tools – Conduct R&D needed to create a new set of modeling and simulation capabilities that will be used to better understand the safety performance of the aging reactor fleet. These tools will be fully three-dimensional, high-resolution, modeling integrated systems based on first-principle physics. To accomplish this, the modeling and simulation capabilities will have to be run on modern, highly parallel processing computer architectures.
Roadmap Modeling and Simulation Deliverables

■ R&D Objective 1
  - 2014 – State of the art predictive reactor core analysis capability
  - 2019 – Performance models developed to enable applications for reactor life extensions
  - 2019 – Fully-coupled safety analysis tools validated and issued to industry

■ R&D Objective 2
  - 2015 – Complete 3-D high fidelity reactor core simulator
  - 2015 – Demonstrate advanced modeling and simulation tool for SMR plant design, performance, and safety validation

■ R&D Objective 3
  - 2015 – Development of a framework for advanced computational models for disposal system performance

■ R&D Objective 4
  - 2020 – Test fully integrated advanced material measurement and information analysis systems
Vision

To rapidly create and deploy “science-based” verified and validated modeling and simulation capabilities essential for the design, implementation, and operation of future nuclear energy systems with the goal of improving U.S. energy security.
Anatomy of a Generic Program to Build Advanced Modeling and Simulation Capabilities

Note: An advanced modeling and simulation program does not have to build all of the elements. However, it must ensure that all of the elements exist and are integrated in order to build advanced capabilities.
**Integrated Performance and Safety Codes (IPSC)**

- Continuum level codes that will predict the performance and safety of nuclear energy systems technologies
- Attributes include 3D, science based physics, high resolution, integrated systems
- Large code teams (~25 people)
- Single “center of gravity”
- Long-term commitment (~10 years)
- Codes “born” with verification, validation and uncertainty quantification
- Using interoperability frameworks and modern software development techniques and tools

**Program Support Elements**

- Develop crosscutting (i.e. more than one IPSC) required capabilities
  - Fundamental Methods and Models
  - Verification, Validation and Uncertainty Quantification
  - Interoperability frameworks
  - Enabling Computational Technologies
- Provide a single NEAMS point of contact for crosscutting requirements (e.g. experimental data, computer technologies)
- Smaller, more diverse teams to include laboratories, universities and industries.
- Shorter timelines
NEAMS Will Deliver . . .

- Continuously increasing capability for predictive simulation of the performance and safety of:
  - Nuclear reactors
  - Fuels
  - Safeguarded Separations
  - Waste Forms in a Repository Environment

- These capabilities will be flexible so they can be applied to different types of nuclear energy technologies

- NEAMS will implement a comprehensive approach that ensures that new capabilities are fully developed and “born” with appropriate verification, validation and uncertainty quantification.

- Modeling and simulation capabilities that can be used to create scientific understanding, design, and license nuclear energy technologies for:
  - Sustainment of the current LWR fleet
  - Near term deployment of new advanced reactors
  - Innovative uses of nuclear energy
  - Proper disposal of waste
  - Closing the fuel cycle
NEAMS Users

Research and Development
- To make discoveries and obtain insight into the physical behavior of nuclear energy technologies (e.g. reactors, fuels, waste)

Technology Designers
- To conduct design studies for new nuclear energy technologies to understand performance, safety, and cost with the potential of a design of a system submitted for licensing.

Regulators
- To evaluate submitted designs and supporting analysis to determine if the technologies will meet the requirements to protect human health and the environment

Utilities & Operators
- To understand and optimize the operations of nuclear energy technologies
NEAMS Has Assembled the “A” Team of Labs, Universities and Industry

**Integrated Performance and Safety Codes**
- **Nuclear Fuels**
  - LANL – lead
  - ORNL
  - LLNL
  - INL
  - Texas A&M
  - UC Davis
  - Oklahoma State
- **Reactors**
  - ANL – lead
- **SafeSeps**
  - LANL – lead
  - ORNL
  - ANL
  - SUNY Stonybrook
- **Waste**
  - SNL – lead
  - LBNL
  - ANL

**Supporting Program Elements**
- **Fundamental Methods and Models**
  - PNNL – lead
  - SNL
  - ORNL
  - North Carolina State
  - Michigan
  - Nevada, Reno
  - Wisconsin
- **Verification, Validation and Uncertainty Quantification**
  - INL – lead
  - SNL
  - LANL
  - University of Idaho
- **Capability Transfer**
  - ORNL
  - ANL
  - IBM
- **Enabling Computational Technologies**
  - LLNL
The Elephant in the Room is an Important Part of the Answer

- The NE Modeling and Simulation Energy Innovation Hub

- What can we say?
  - At this point – we can talk about things from the workshop and the FOA.

- What we (specifically I) cannot say?
  - Anything about the applications or the substance of the review process
“The proposed Energy Innovation Hubs will take a very different approach – they will be multi-disciplinary, highly collaborative teams ideally working under one roof to solve priority technology challenges”

**Leadership**
- Outstanding scientist leaders who will have flexibility on a day-to-day basis to guide Hub activities

**Connection to NE R&D**
- Focused on a small range of important problems to maximize impact

**Funding**
- Lower ($25M per year for 5 years), but stable
Achieving the Promise of the Hub Requires a Mission Focus

Advanced Modeling and Simulation of the Operating Reactor
(aka “Virtual Reactor”)

Improved Scientific Understanding of Important Technology Issues

Data for validation from instrumented plant
Mutually Supportive Roles

**Clearly the Hub**
- Current LW Reactor Simulation
- Current LW Reactor Fuels
- Verification, Validation, and Uncertainty Quantification for the Above
- Enabling Computational Technology (frameworks and user environments) for the Above
- Capability Transfer
- Fundamental Methods and Models for the Above?

**Clearly NEAMS**
- Safeguards and Separations IPSC
- Waste and Repository IPSC
- Advanced Reactors IPSC
- Advanced Fuels IPSC
- Fundamental Methods and Models for the Above
- Verification, Validation, and Uncertainty Quantification for the Above
- Enabling Computational Technology (frameworks and user environments) for the Above

*Both are important, but neither are sufficient*
Putting it All Together
NEAMS + Hub Are Important for Success

NE Programs (use modeling and simulation)
- Power Uprates
- Deployment of Gen III+ Reactors
- Small Modular Reactors
- License Extensions
- Gen IV Reactors
- Closed Fuel Cycle
- Waste Repository

NE M&S Hub
NEAMS (Nuclear Energy Advanced Modeling & Simulation)
(existing model capabilities)

M&S Insights Needs
- Higher Burnups
- NGNP

M&S Capability
- Existing M&S Capabilities

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- 2010
- 2020
- 2040
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Requirements
- $s & Oversight

Capabilities
- M&S

$ s & Oversight

Requirements
- M&S