Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
Oak Ridge National Laboratory

Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives

Hearing on Department of Energy (DOE) Innovation Hubs

June 17, 2015

Chairman Weber, Ranking Member Grayson, and Members of the Subcommittee, I am pleased to appear before you today.

My name is Jess Gehin. I am the Director of the Consortium for Advanced Simulation of Light Water Reactors (CASL), a DOE Energy Innovative Hub consisting of 10 core founding partner institutions and lead by Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. It is an honor to provide testimony on the Hub integrated research approach and progress towards of our research and development goals.

Summary

Energy Innovation Hubs bring together teams of top scientists and engineers from academia, industry, and government to collaborate and overcome critical known barriers to achieving national climate and energy goals that have proven resistant to solution via the normal R&D enterprise. Hubs apply a research model inspired by AT&T Bell Labs and the Manhattan Project that resulted in a tremendous number of innovations that helped win the Second World War. More specifically, Hubs focus on a single topic, with the objective of rapidly bridging the gaps between basic research, engineering development, and commercialization through a close partnership with industry. To achieve this goal, the Hubs necessarily consist of large, highly integrated and collaborative creative teams working to solve priority technology challenges.

In July 2010, the Consortium for Advanced Simulation of Light Water Reactors (CASL) was the first Hub established by the Department of Energy. CASL is focused on innovations in commercial nuclear power generation, specifically the modeling and simulation (M&S) of nuclear reactors. CASL's vision is to *predict, with confidence, the performance of nuclear reactors through comprehensive, science-based M&S technology that is deployed and applied broadly throughout the nuclear energy industry to enhance safety, reliability, and economics*. CASL is bringing innovation to the nuclear energy enterprise by helping it capitalize on advancements in computing over the past few decades and is helping retain and strengthen U.S. leadership in two DOE mission areas: high performance computing-enabled M&S and nuclear energy. CASL implements several key Hub management elements: clear deliverables and products that solve industry issues driven by a well-defined yet dynamic plan; a strategy of delivering prototype products early and often; and targeted

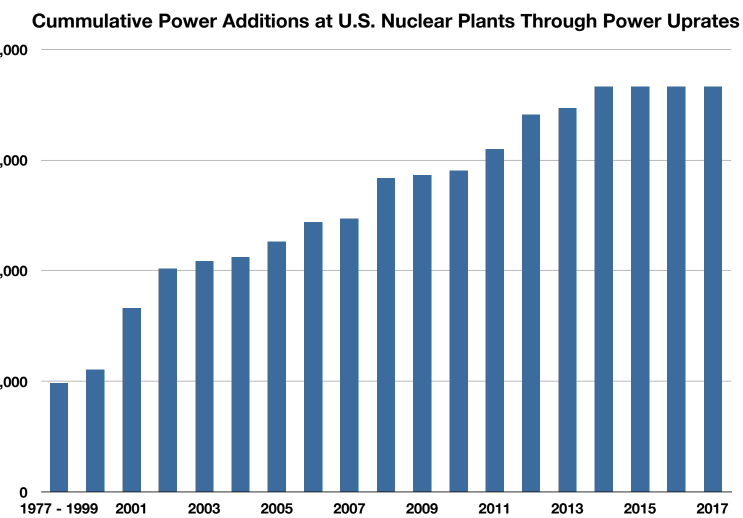
customers and users. CASL is currently completing the fifth year of its first five-year term (Phase 1); in January 2015, DOE approved a second five-year term for CASL (Phase 2).

CASL's R&D supports the U.S. energy mission by targeting technical challenges that have been carefully and collaboratively selected as significant, current industrial challenges where M&S can provide meaningful advancements. This is the CASL "Challenge Problems" approach to addressing phenomena that industry is spending hundreds of millions of dollars to address (through resolution or avoidance). In this approach CASL has identified industry Challenge Problems that can help achieve nuclear reactor power uprates, life extensions, and higher fuel utilization. In order to achieve this, CASL is developing a *virtual reactor* called the Virtual Environment for Reactor Applications (VERA).

Introduction

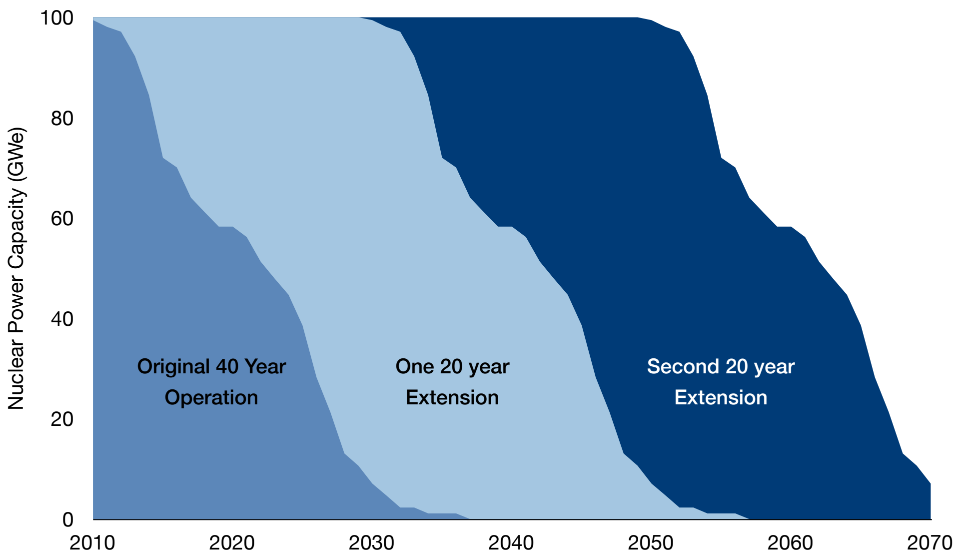
Nuclear power plants are the largest clean-air energy source in the U.S. As the U.S. moves toward a clean-energy economy, nuclear energy must continue to be a part of the energy mix. Yet many challenges remain for nuclear energy—both for the existing U.S. fleet as well as for new reactors; improvements must be made in economics and performance. The future of the commercial nuclear power industry hinges upon furthering power uprates, realizing higher fuel burnup, and operating the existing plants for longer lifetimes—all while providing higher confidence in assured nuclear safety for both the current fleet and the next generation of nuclear power technology.

As illustrated in the figures below, large gains in U.S nuclear energy production can be provided through marginal increases in operation and life extension. The first figure provides the cumulative increases in nuclear power generation achieved through improved operations resulting in the addition of approximately 7,000 MWe, or roughly the equivalent of seven nuclear power plants. CASL's modeling and simulation is focused on physical phenomena that currently limit plant power output; higher fidelity understanding of these phenomena has the potential to facilitate generation of more power using these plants.



Nuclear energy generation additions (in MWe) at U.S. nuclear power plants through power uprates (increases in licensed operating powers) (source of data: U.S. NRC).

Similarly, the next figure illustrates the positive impact resulting from extending the lifetime of the U.S. nuclear power fleet. The originally licensed lifetime was conservatively set at 40 years; through industry and government research, many plants have received approval for an additional 20 years, extending our national investment into clean energy, low-cost nuclear power generation benefits past 2040. The figure also shows a profile that represents the expanded benefit through 2060 resulting from a subsequent 20-year life extension. One part of enabling this is to ensure that reactor life-limiting components can meet their design requirements. For example, the reactor vessel that contains the reactor core is a critical component that cannot be replaced. CASL, working with DOE's Light Water Reactor Sustainability Program, is developing capabilities to understand the performance of reactor vessels for extended plant lifetimes, providing valuable information to support the continued operations of our reactor fleet.



Nuclear energy capacity profiles in United States for original plant 40 year licenses and profiles assuming all existing plants receive a 20 year extension to 60 years and a subsequent 20 year license extension to 80 years (assumes 100 GWe fleet, no additional power uprates or premature plant shutdowns) (source of data: U.S. NRC).

CASL Organization and Management

CASL's unique partnership of universities, DOE national laboratories, and industry possesses unparalleled institutional knowledge, nuclear science and engineering talent, computational science leadership, and LWR design and regulatory accomplishments. The CASL team includes renowned nuclear research universities, extensive expertise and facilities in nuclear sciences and in modeling and simulation at our national laboratories and industry, which provides combined reactor operating experience of thousands of reactor operating cycles, with data and design experience supporting the application and validation of CASL's VERA.

Oak Ridge National Laboratory is CASL's lead institution for CASL, with the following additional Founding Partners:

- 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

The Hub approach specifically provides a unique opportunity for researchers, scientists, and engineers from across this broad set of organizations to directly work together more closely than is typical of government research projects.

CASL's integrated research model is based on establishing an organization with the best and brightest researchers with a clear and agile research plan. The primary features of this integrated model are:

- Central, integrated management working predominately from a single location at ORNL: Director with full line authority and accountability for all aspects of CASL; Deputy Director to drive program planning, performance and assessment; Chief Scientist to drive science-based elements; experienced Focus Area Leads and Deputies with responsibility for the core science and engineering elements;

- Strong science, engineering, applications, and design leadership;

- A virtual one-roof approach utilizing widespread implementation of state-of-the-art collaboration technology;

- Well-informed and timely decision-making and program integration;

- Independent oversight and review via an external Board of Directors (BOD) advising on annual performance goals, tactical and strategic plans, and performance metrics and Science and Industry Councils for external oversight, review, and advisory functions;

- Integrated project management across CASL for scope/schedule/budget planning and tracking and an integrated Operations and Management Support team providing clear leadership for environment, safety, and health; partnerships and intellectual Property management; finance and procurement; quality; and security;

CASL's work is identified, constructed, planned, and executed within period durations of six-month known as Plans of Record (PoRs). Planning and working in these six month periods allows managed change that is dynamic and responsive to approved change while still meeting, or exceeding, commitments made at the onset of the PoR. This is consistent with modern agile project management philosophies and has been highly effective.

CASL Research Goals and Progress

To complete its mission and realize its vision, CASL has four strategic goals:

- Address design, operational, and safety challenges for LWRs;
- Develop and effectively apply modern virtual reactor technology;
- Engage the nuclear energy community through modeling and simulation; and
- Deploy new partnership and collaboration paradigms.

In order to achieve these strategic goals, in its first five years (Phase 1), CASL has developed a M&S capability called the Virtual Environment for Reactor Applications (VERA) that integrates simulation capabilities of key physical phenomena in a nuclear reactor core: neutronics, thermal-hydraulics, chemistry, and nuclear fuel performance. VERA provides for a higher fidelity and resolution for modeling the reactor core and vessel systems of a nuclear reactor than is currently available in industry. This capability, combined with modern uncertainty quantification approaches, is focused on helping to address key industry challenges related to pressurized water reactor (PWR) core performance in normal and accident conditions. VERA has been deployed to early adopters through CASL Test Stands, to be discussed in more detail below.

Key CASL's accomplishments and initiatives include:

- A successful, comprehensive Hub development environment has been created and supports a large team of researchers working on developing, testing, and deploying the VERA virtual reactor;
- The computational methods and computer codes representing all of the key physics to be included in VERA (neutronics, fuel performance, fluid flow/heat transfer, and chemistry) have undergone their initial development and have been integrated into the software;
- VERA has been applied to simulate several nuclear power plants, including several operating cycles of the Watts Bar Nuclear Plant where results have been compared with measured plant data and showed a high degree of consistency;
- Coupling of physics software components and models have been performed with initial applications to the corrosion product deposition challenge problems based both on high-resolution localized deposition prediction and detailed three-dimensional core modeling;
- Early deployment of VERA to industry engineering environments has been performed through CASL Test Stands:
    - As part of a Westinghouse Test Stand, the startup of the AP1000® reactor has been simulated in very high detail and used within Westinghouse to confirm their engineering calculations;
    - The Electric Power Research Institute has assessed the use of the VERA for analyzing fuel performance using their industry guidelines;
    - The Tennessee Valley Authority is using VERA to simulate coolant flow within the Watts Bar Unit 1 reactor vessel;
- In Phase 2, CASL is expanding VERA to encompass the design extents of the existing and currently envisioned commercial nuclear fleet by including options for simulation of Boiling

Water Reactors (BWRs) and Small Modular Reactors (SMRs), and through the addition of features supporting simulation of additional operating conditions;

- In Phase 2, CASL is planning for the long-term sustainability of the Hub technology through broad deployment of VERA throughout the industrial and academic communities.

The research performed by CASL is well disseminated throughout the scientific community through technical reports, conference presentations and proceedings, seminars, and peer-reviewed journal publications. To date more than 113 journal articles, 360 conference papers, 118 invited talks, and 500 technical reports have been created documenting our research, many of which are available on the CASL website (www.casl.gov).

Transferring CASL Technology and Knowledge to the Private Sector

A key metric of the success of the development of M&S capabilities is deployment to the end user. While Phase 1 was focused on innovation and on developing capabilities to address Challenge Problems, a sizable effort went into understanding stakeholder requirements, educating future VERA users, and deploying CASL technologies to end users. In Phase 2, CASL is placing heavy focus on deployment and outreach through the addition of a new Technology Deployment and Outreach (TDO) activity. TDO is chartered to ensure the continued flow of CASL technology to the nuclear energy community, with a particular focus on the commercial power industry and U.S. universities. To achieve a wide deployment, TDO will work in four primary areas: long-term sustainability of CASL technology, outreach, test stand deployments, and VERA release and support.

Test Stands serve as a primary mechanism for early deployment of CASL-developed technology to key stakeholders, including the private sector. They also provide direct stakeholder feedback on VERA usability and capability and permit additional demonstrations of CASL-developed capabilities on applications that are not directly addressed as part of the CASL development effort. The first Test Stands were executed with the CASL industry partners (EPRI, TVA, and Westinghouse) that represent a broad spectrum of industry stakeholders; thus, these partners provided an ideal initial environment to demonstrate and evaluate VERA. Additional, external Test Stands (outside the CASL partnership) are being planned. Test Stand hosts generally reported very positive experiences. For example, "Westinghouse reported, "…the results already obtained, and those to come in the future now that the codes have been deployed on the Westinghouse cluster, [are] viewed by Westinghouse as possessing extremely high value." Similarly, the Test Stands with EPRI and TVA have provided highly valuable feedback to guide CASL's research.

In addition to engagement of the Industry Founding partners, CASL has developed a broad connection with private industry through the integration of more than 50 contributing partner organizations that support CASL's research. CASL also relies on an industry-led Industry Council with over 25 members from the nuclear energy and modeling and simulation industries to provide feedback and input to CASL. CASL also engages with the U.S. Nuclear Regulatory Commission (NRC), to inform them on our research. An education program has also been established to ensure that the next generation of engineering graduates with the knowledge needed to use VERA for real-world applications. This includes lectures, course materials, and CASL summer schools.

A CASL Intellectual Property Management Plan (IPMP) has been developed to establish guidelines for making CASL IP available to the US nuclear energy community, while protecting partner IP from inappropriate access and distribution. Non-disclosure agreements were executed that enable open sharing of information within the CASL partnership. Several classes of licenses are currently in use or under development to support distribution of CASL technology. A comprehensive export control review process has also been established to ensure that internal and external discussions about VERA development and release of the VERA software meet all applicable export control regulations.

Conclusion

Energy Innovation Hubs represent an effective research model that CASL has successfully implemented to connect basic and applied research to critical energy applications. Through the Hub model, CASL has efficiently tapped into the DOE's advanced computing strengths and nuclear energy research capabilities, taken advantage of the best and brightest of university researchers, and also been privy to decades of industry experience and expertise. This highly integrated, focused R&D partnership has demonstrated accomplishments at a rapid pace in its first five years, notably including successful deployments to several industry end users. Building on this success, CASL's second phase will expand its applications, achievements, and impact to a broader range of problems and through broader deployment and application. As the first Energy Innovation Hub, CASL has clearly demonstrated that this research model can be a very effective method to deliver targeted research and rapid solutions to address complex issues. Based on this experience, the CASL Hub approach represents a good model to be adopted for future public-private research consortia.

Summary of Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
June 17, 2015

The Consortium for Advanced Simulation of Light Water Reactors (CASL) was the first Hub established by the Department of Energy with a vision to *predict, with confidence, the performance of nuclear reactors through comprehensive, science-based modeling and simulation technology that is deployed and applied broadly throughout the nuclear energy industry to enhance safety, reliability, and economics.* The full testimony addresses the following questions:

1. What are the primary research and development goals of CASL? Since the hub was organized by DOE, what progress has been made towards those goals?

CASL has identified industry Challenge Problems that can help achieve nuclear reactor power uprates, life extensions, and higher fuel utilization. In order to achieve these strategic goals, CASL has developed an advanced modeling and simulation technology called the Virtual Environment for Reactor Applications (VERA) that integrates simulation capabilities of key physical phenomena in a nuclear reactor core. VERA has been rigorously assessed and applied model several nuclear plants including several operating cycles of TVA's Watts Bar Nuclear Plant and through CASL Test Stands deployed to industry.

2. How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

CASL's unique partnership of universities, DOE national laboratories, and industry possesses unparalleled institutional knowledge, nuclear science and engineering talent, computational science leadership, and LWR design and regulatory accomplishments. CASL's integrated research model is based on establishing an organization with the best and brightest researchers with a clear and agile research plan. CASL is bringing innovation to the nuclear energy enterprise and is helping retain and strengthen U.S. leadership in two DOE mission areas: high performance computing-enabled M&S and nuclear energy. CASL's integrated research model includes clear deliverables and products that solve industry issues as driven by a well-defined yet dynamic plan; a strategy of delivering prototype products early and often; and targeted customers and users.

3. How does the private sector interact with CASL? In what way does CASL prioritize technology transfer of technologies developed at the hub?

CASL includes private sector organizations as part of its research and development activities through its three Industry Founding Partners (Westinghouse Electric Company, Electric Power Research Institute, and TVA). In addition to engagement of the Industry Founding partners, CASL has developed a broad connection with private industry through the integration of more than 50 contributing partner organizations that support CASL's research. CASL also relies on an industry-led Industry Council with over 25 members to provide feedback and input to CASL. In Phase 2, CASL is placing heavy focus on deployment and outreach through the addition of a new Technology Deployment and Outreach (TDO) activity chartered to ensure the continued flow of CASL technology to the nuclear energy community, with a particular focus on the commercial power industry and U.S. universities. To achieve a wide deployment, TDO will work in four primary areas: long-term sustainability of CASL technology, outreach, test stand deployments, and VERA release and support. Technology transfer is prioritized to maximize impact to industry.

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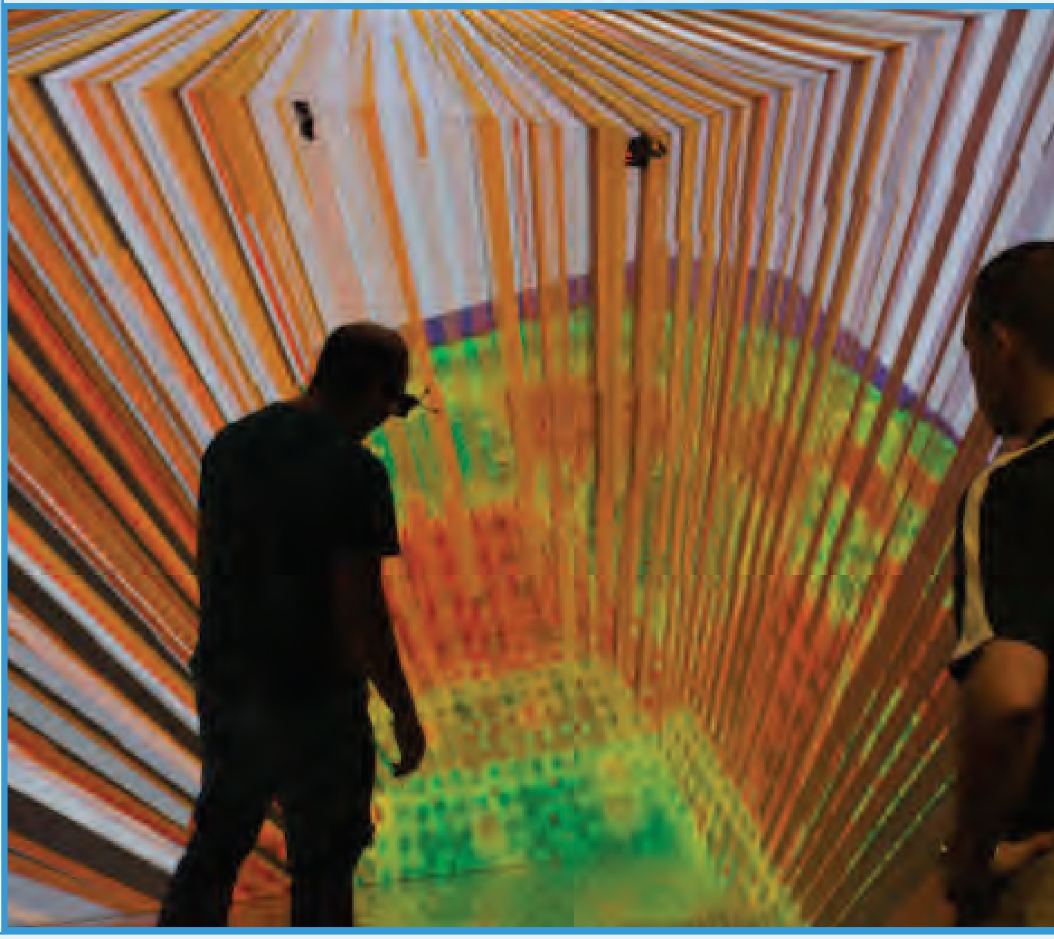
APPENDIX 1

CASL Brochure

CASL
A DOE Energy Innovation Hub

Improving reactor performance with predictive science-based simulation technology that harnesses world-class computational power



3D visualizations allow a physical walk-through of the top 20% of high-powered rods in a pressurized water reactor core. Details revealed provide insight into factors affecting core performance and aging. (Image courtesy of Tom Evans, ORNL).

Consortium for Advanced Simulation of Light Water Reactors

The Consortium for Advanced Simulation of Light Water Reactors (CASL) was established by the US Department of Energy in 2010 to advance modeling and simulation capabilities for nuclear reactors. CASL's mission is to provide computational capabilities that will make it possible to more accurately predict the behavior of phenomena that define the operational and safety performance of light water reactors (LWRs). In January 2015, the Department of Energy approved a second five-year phase for CASL, expanding its research and development activities through fiscal year 2019.

Through CASL, experts from national laboratories, universities, and industry are developing and deploying the Virtual Environment for Reactor Applications (VERA), a "virtual reactor" that can accurately simulate the physical processes taking place in a reactor at previously unattainable levels of detail. These processes include neutron transport, thermal hydraulics, nuclear fuel performance, corrosion, and surface chemistry. VERA incorporates science-based models, state-of-the-art numerical methods, modern computational science and engineering practices, uncertainty quantification and sensitivity analysis, and validation against data from operating reactors, experiments, and other sources to replicate these physical processes and to model their interactions.

Oak Ridge National Laboratory (ORNL) supercomputer, Titan, rated in 2014 as the leading HPC facility in the western world, supports CASL computational needs. (Image courtesy of ORNL)

CASL Achievements to Date

CASL is meeting milestones established by a well-defined yet flexible plan and delivering technologies that address industry issues. VERA has been deployed through "test stands" (prototype installations in actual engineering and design environments) and used to match actual startup and operations data for a Generation 2 reactor on the grid (the Tennessee Valley Authority's Watts Bar Unit 1) and to predict startup data for a Generation 3+ reactor design, the Westinghouse AP1000®, that is the basis for eight reactors now under construction. The CASL team is working to ensure that a subset of VERA, the VERA Core Simulator, can follow operational reactors through depletion, power maneuvering, and fueling cycles.

The models, methods, data, and understanding developed by CASL are being applied to create "useful and usable" tools to help the nuclear industry address three critical areas of performance for nuclear power plants (NPPs): (1) reducing capital and operating costs per unit of energy by enabling power uprates for existing NPPs and by increasing the rated powers and lifetimes of next-generation NPPs; (2) reducing nuclear waste volume generated by enabling higher fuel burnup, and (3) enhancing nuclear safety by enabling high-fidelity predictive capability for component performance through the onset of failure.

Innovations, Deployed Technologies, and an Effective Public-Private Partnership

- Integrated, goal-oriented, productive team spanning a geographically dispersed, heterogeneous set of organizations (national labs, universities, industry)
- Demonstrated, industry-reviewed predictions of reactor core behavior at previously unattainable levels of physical and geometric fidelity
- Multi-physics modeling and simulation of nuclear materials, corrosion chemistry, and fluids revealing insights that support enhanced operational maneuvering
- New fluid dynamics, chemistry, and materials modeling technologies that can resolve 3D reactor/fuel geometries via High Performance Computer oriented, advanced solution methodologies, for realistic nuclear fuel performance assessments
- Designer and researcher access to VERA's broad multi-physics simulation capabilities through a common "industry-friendly" interface for analyzing reactor operations

CASL Mission

Provide coupled, high-fidelity, usable capabilities needed to predict behaviors of light water reactor operational and safety performance-defining phenomena

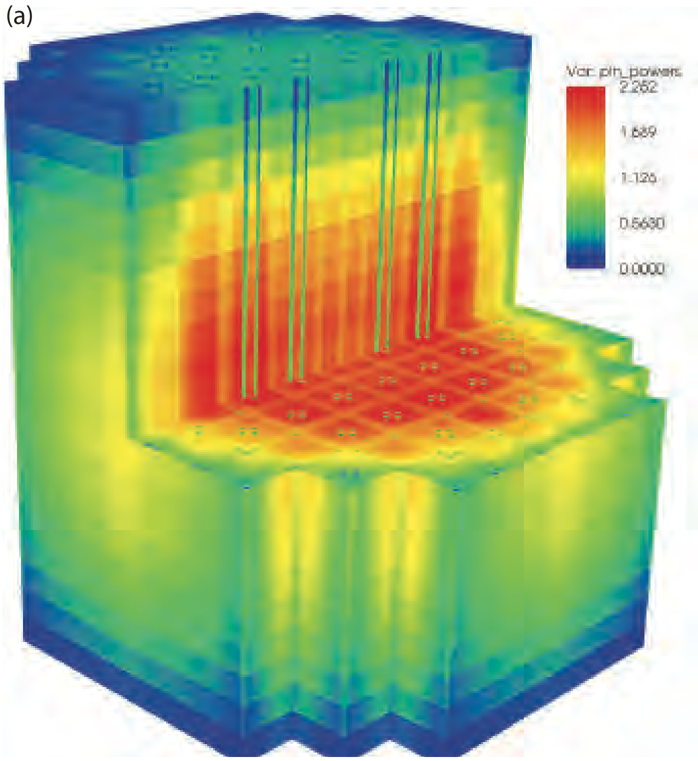
Strategic Goals

1. Develop and effectively apply modern virtual reactor technology (CASL's Virtual Environment for Reactor Applications: VERA)
2. Address design, operational and safety challenges for light water reactors (CASL Challenge Problems)
3. Engage the nuclear energy community through modeling and simulation
4. Deploy new partnership and collaboration paradigms

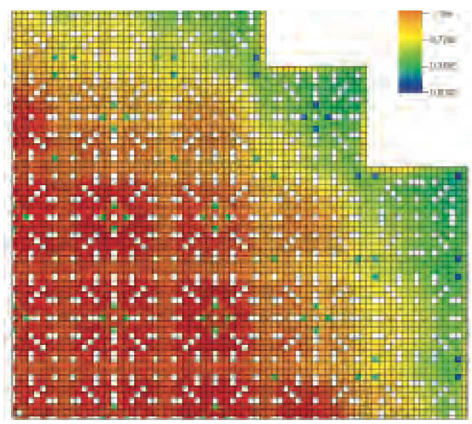
Illustration of VERA-CS Application to Integral Pressurized Water Reactor (iPWR) Small Modular Reactor (SMR)

The CASL VERA-CS is being used to model a four-year iPWR SMR cycle. The work has progressed to the 3D quarter-core calculations illustrated below: a) the 3D relative pin power distribution with a cutout section revealing the interior; b) the relative pin power distribution at the mid-axial plane; c) the core loading plan developed in the study associated with the power distributions.

(a)



(b)

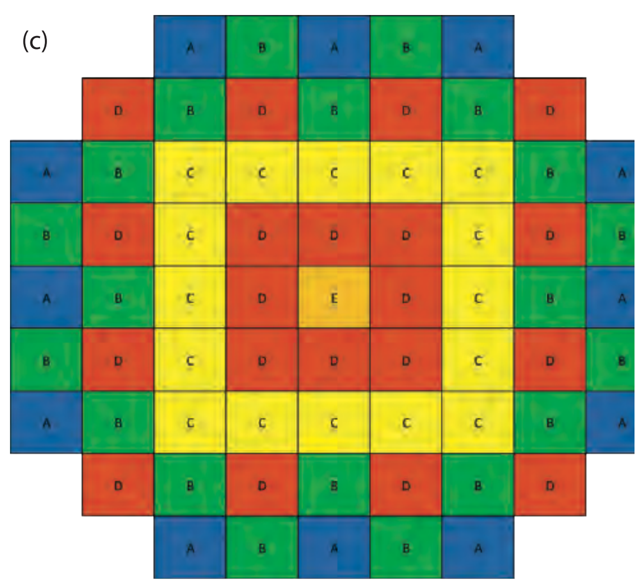


The white spaces in the image correspond to the pins that do not produce power (control rods and BPR pins).

Assembly Type	# Standard Fuel Pins	Standard Fuel Pin Enrichment	# Gd Fuel Pins	Wt% Gd
A	248	4.95	4	3
B	244	4.95	4	3
C	240	4.95	4	3
D	236	4.95	4	3
E	236	4.95	0	3

(Images courtesy of Kelly Kenner, Ivan Maldonado, University of Tennessee at Knoxville, Rose Montgomery, TVA, and Dudley Raine, B&W)

(c)



Achievements to Date
(FY 2010–FY 2014)

Year 1 . . .

- Technical roadmaps established for addressing high-priority Challenge Problems
- First high-resolution reactor core model for TVA Watts Bar plant
- First-of-a-kind three-dimensional (3D) assessment of fuel pellet-to-cladding interaction
- **VERA** founded with infrastructure and basic industry Core Simulator

Year 2 . . .

- Established methods for placing computer-based tools in industrial environments for real-life testing
- **VERA** produced neutronics simulation (prediction of changing neutron distribution in reactor core)

Year 3 . . .

- Expanded the neutronics capability to obtain unprecedented details on the movement of neutrons in a reactor core (demonstrated how to model the individual performance of thousands of fuel pins in an entire reactor)
- **VERA** internal release: Core neutronics + thermal hydraulics + fuel performance

Year 4 . . .

- Demonstrated application VERA tools to improve understanding of fuel-to-cladding interactions and the corrosion-induced power losses that result (reduding corrosion prevents power losses)
- **VERA** limited external release: Refinements to prior capabilities + corrosion and surface chemistry
- Completion and validation of VERA Core Simulator

Year 5 . . .

- **VERA** broad external release: Validate VERA with data from Watts Bar Unit 1 operating cycles and demonstrate CRUD challenge problem capababilites

CASL-U-2014-0089-001

Key Goals for 5 Year Extension
(FY 2015–FY 2019)

1. In it's second five-year phase, CASL will deepen its research and development for simulation of PWRs and broaden its applications to SMRs and BWRs through:
   - Fuel performance under accident conditions →further enhance safety of plants
   - Chemical and corrosion interactions between materials and coolants →reduce corrosion for longer-life plants
   - Two-phase thermal hydraulics for operational and transient reactor scenarios →more efficient plant performance
   - Expand to other types of reactors and reactors of the future →achieve industry-wide performance improvements
2. Develop the VERA core simulator kinetics capabilities and improve computational performance and accuracy → maximize value
3. Establish a self-sustaining organization, drawing from the CASL Industry Council, that is dedicated to the advancement and industry-wide deployment of VERA technologies → establish sustainable support for VERA

All narrative and images contained in this publication were provided for uses relating to the Consortium for Advanced Simulation of Light Water Reactors (CASL), which is managed at Oak Ridge National Laboratory by UT-Battelle for the U.S. Dept. of Energy.

ORNL 15-G00729/asg

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APPENDIX 2

CASL Virtual Environment for Reactor Applications Fact Sheet

CASL
A DOE Energy Innovation Hub

U.S. DEPARTMENT OF ENERGY

Virtual Environment for Reactor Applications (VERA)

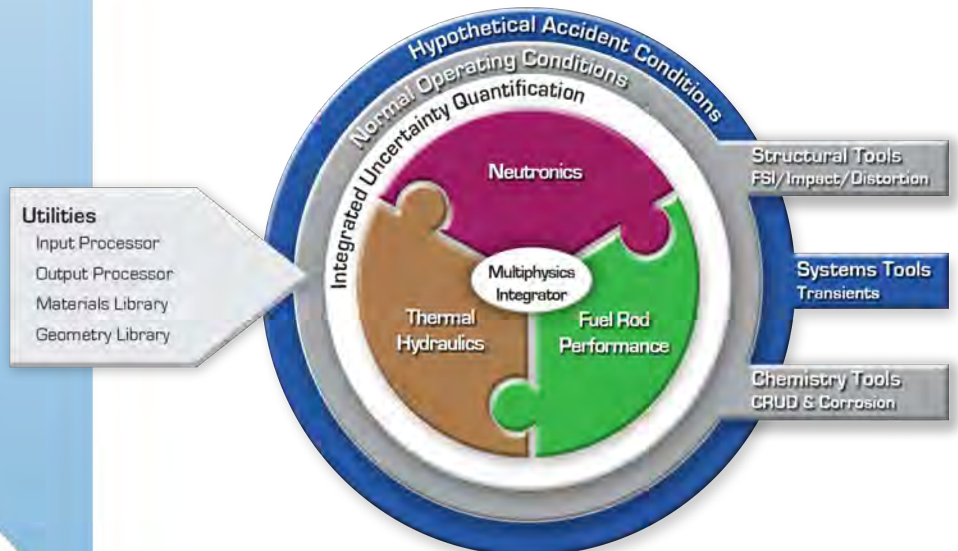
Modern high performance computing (HPC) platforms bring an opportunity for modeling and simulation (modsim) at levels of detail previously unimaginable. Many of the complex phenomena occurring in light water reactors (LWRs) can be explored and better understood through the use of modsim able to exploit HPC.

VERA bridges the gap between research and engineering by bringing together a suite of coupled software applications that simulate the behavior of a commercial LWR core under a variety of normal operating conditions. VERA integrates specialized knowledge of the multiple physics involved in nuclear power production by leveraging the contributions from leading scientists and engineers in government, industry and academia. As a result of this research, systems and processes can be engineered to higher levels of performance with longer and more productive lifetimes.

VERA incorporates science-based models, state-of-the-art numerical methods, modern computational science and engineering practices, and uncertainty quantification and validation using data from operating pressurized water reactors (PWRs), separate-effects experiments, and integral tests. The resulting Virtual Environment for Reactor Applications (VERA) will be among the most comprehensive and capable modsim toolset worldwide in the field of LWR science and technology.

CASL is focused on improving the performance of light water reactors with predictive, science-based simulation technology that harnesses the world-class computational power of ORNL's Titan high performance computer. VERA is being organized to rapidly advance the CASL mission through:

- Incorporating higher-fidelity modsim tools provided by DOE National Labs, academia, and industry into an integrated set of software tools for broad user access
- Coupling of the applications simulating the physics that drive reactor core performance
- Focusing on uncertainty quantification, validation, and verification of the applications
- Directly engaging stakeholders in the requirements driven research & development process
- Assuring that CASL products are effective and practical for ultimate use by designers and operators of LWRs in the future

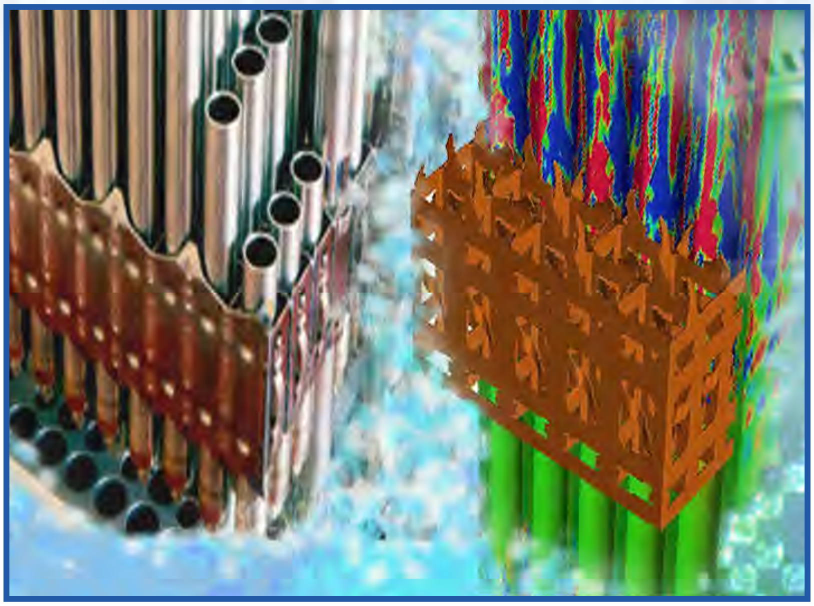


VERA simulates a nuclear reactor core by using an integrated suite of computational tools that predict nuclear core performance based on the governing physics.

CASL Founding Partners

Bridging the Gap between Research and Engineering

New technologies are "game-changers" in research if they can rapidly advance scientific understanding and lead to better-engineered systems and processes that are optimized for performance. However, the translation from basic scientific findings to applied engineering solutions requires tools that are practical if they are to be broadly employed in practice. CASL is working to achieve a technology "step change" by creating a scalable set of applications delivered through a powerful integration infrastructure.



The foundation of CASL's coupled capabilities lies within the physics methods and numerical solutions encompassed within the VERA components. CASL's commitment to higher fidelity understanding of reactor phenomenona incorporates a rigorous 3D approach to the underlying scientific methodologies using explicit 3D techniques and utilizing leadership-class computing capabilities. Additionally, recognizing the need for higher-fidelity simulations on an industry-sized computing platform, CASL has elected to provide a scaled capability using alternative, less computationally intensive methods to allow for faster running on smaller computing clusters. Both higher-fidelity foundational capabilities represent a transformational advance in commercial LWR modsim through the physics coupling.

CASL Consortium partner Westinghouse Electric Company LLC has provided specifications for a commercial pressurized water fuel assembly (left) for explicit modeling using VERA (right).

A Virtual Nuclear Core

Many of the applications selected for CASL's VERA are general purpose codes; CASL has added a necessary layer of capabilities to the higher fidelity applications to track fuel through multiple commercial reactor cycles and to provide inventory information such as fuel depletion. CASL has also coupled several key feedback parameters such as fuel density and temperature and has demonstrated the strong effects of the feedback parameters on the simulation. Simulation of commercial LWR operational issues such as CRUD deposition using the higher fidelity coupled physics allows for better understanding and opens the door for better solutions. This coupled, higher fidelity capability sets a new standard of performance for LWR modsim and is unmatched anywhere in the nuclear science and engineering community. This capability has been tested on user computing platforms and through the deployment of VERA on CASL Test Stands.

Comparison of VERA with Typical Industry Core Simulator Methods

Physics Area	Typical Industry Core Simulator Method	VERA running on an Industry Class Platform	VERA running on a Leadership Class Platform
Neutron Transport	3-D diffusion (core) 2 energy groups (core) 2-D transport on single assemblies	2D/1D transport 23+ energy groups	3D transport 23+ energy groups
Thermal-Hydraulics	nodal average (1-D)	subchannel (w/crossflow)	subchannel (w/crossflow) or CFD
Fuel Performance	Bounding empirically-based	pin-by-pin (r,z) empirically-based	pin-by-pin empirically-based with some science based model
Fuel & clad Temperatures	nodal average & peak	pin-by-pin (r,z)	pin-by-pin
Power Distribution	nodal average with pin-power reconstruction	explicit pin-by-pin	explicit pin-by-pin
Depletion	infinite-medium cross sections, quadratic burnup correction history corrections, spectral corrections, reconstructed pin exposures	pin-by-pin with actual core conditions	pin-by-pin with actual core conditions
Reflector Models	1-D cross section models	actual 3D geometry	actual 3D geometry
Target Platforms[1]	workstation (six-core)	1,000 cores and up	10,000 cores and up

The Virtual Environment for Reactor Applications (VERA) provides a suite of simulation tools for analysis of physical phenomena in operating commericial nuclear fission reactors. It includes a spectrum of capabilities, with emphasis on advanced, high-fidelity approaches that provide unique and valuable insight into the behavior of reactors and effects of operational changes.

To find out more about VERA and to follows its research and development activity related to modeling and simulation of nuclear reactor cores, please visit www.casl.gov • casl-info@casl.gov

CASL

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ORNL 15-G00769/mhr

Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
Oak Ridge National Laboratory

Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives

Hearing on Department of Energy (DOE) Innovation Hubs

June 17, 2015

APPENDIX 3

CASL Challenge Problems Fact Sheet

CASL
A DOE Energy Innovation Hub

U.S. DEPARTMENT OF ENERGY

Virtual Environment for Reactor Applications (VERA)

Modern high performance computing (HPC) platforms bring an opportunity for modeling and simulation (modsim) at levels of detail previously unimaginable. Many of the complex phenomena occurring in light water reactors (LWRs) can be explored and better understood through the use of modsim able to exploit HPC.

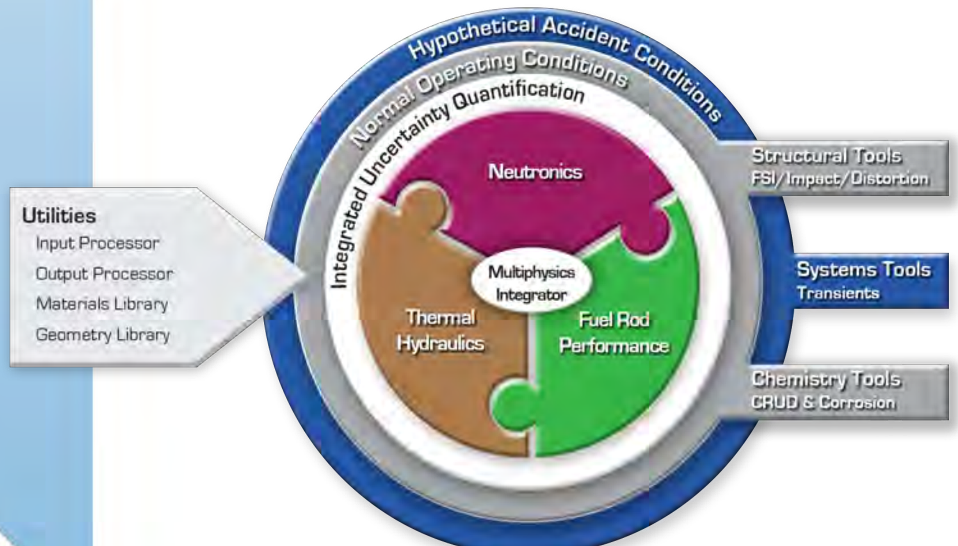
VERA bridges the gap between research and engineering by bringing together a suite of coupled software applications that simulate the behavior of a commercial LWR core under a variety of normal operating conditions. VERA integrates specialized knowledge of the multiple physics involved in nuclear power production by leveraging the contributions from leading scientists and engineers in government, industry and academia. As a result of this research, systems and processes can be engineered to higher levels of performance with longer and more productive lifetimes.

VERA incorporates science-based models, state-of-the-art numerical methods, modern computational science and engineering practices, and uncertainty quantification and validation using data from operating pressurized water reactors (PWRs), separate-effects experiments, and integral tests. The resulting Virtual Environment for Reactor Applications (VERA) will be among the most comprehensive and capable modsim toolset worldwide in the field of LWR science and technology.

CASL Founding Partners

CASL is focused on improving the performance of light water reactors with predictive, science-based simulation technology that harnesses the world-class computational power of ORNL's Titan high performance computer. VERA is being organized to rapidly advance the CASL mission through:

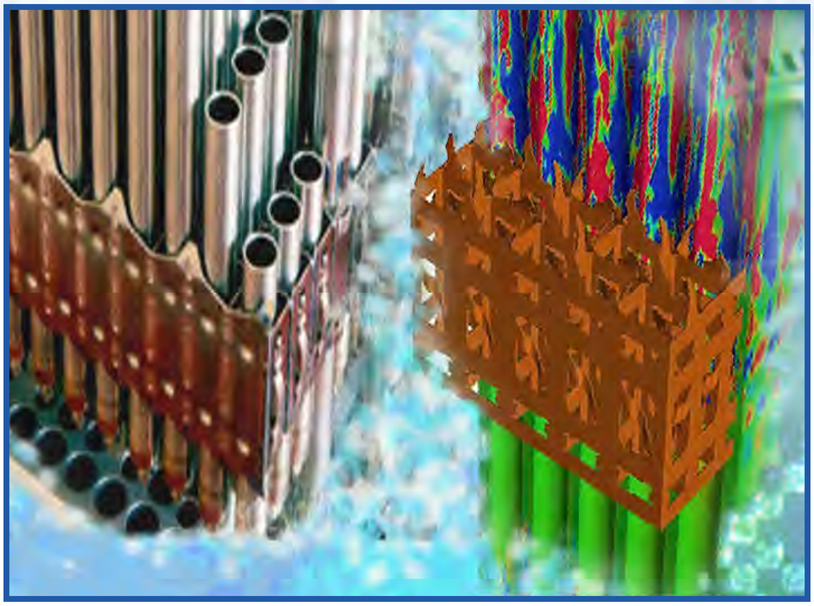
- Incorporating higher-fidelity modsim tools provided by DOE National Labs, academia, and industry into an integrated set of software tools for broad user access
- Coupling of the applications simulating the physics that drive reactor core performance
- Focusing on uncertainty quantification, validation, and verification of the applications
- Directly engaging stakeholders in the requirements driven research & development process
- Assuring that CASL products are effective and practical for ultimate use by designers and operators of LWRs in the future



VERA simulates a nuclear reactor core by using an integrated suite of computational tools that predict nuclear core performance based on the governing physics.

Bridging the Gap between Research and Engineering

New technologies are "game-changers" in research if they can rapidly advance scientific understanding and lead to better-engineered systems and processes that are optimized for performance. However, the translation from basic scientific findings to applied engineering solutions requires tools that are practical if they are to be broadly employed in practice. CASL is working to achieve a technology "step change" by creating a scalable set of applications delivered through a powerful integration infrastructure.



The foundation of CASL's coupled capabilities lies within the physics methods and numerical solutions encompassed within the VERA components. CASL's commitment to higher fidelity understanding of reactor phenomenona incorporates a rigorous 3D approach to the underlying scientific methodologies using explicit 3D techniques and utilizing leadership-class computing capabilities. Additionally, recognizing the need for higher-fidelity simulations on an industry-sized computing platform, CASL has elected to provide a scaled capability using alternative, less computationally intensive methods to allow for faster running on smaller computing clusters. Both higher-fidelity foundational capabilities represent a transformational advance in commercial LWR modsim through the physics coupling.

CASL Consortium partner Westinghouse Electric Company LLC has provided specifications for a commercial pressurized water fuel assembly (left) for explicit modeling using VERA (right).

A Virtual Nuclear Core

Many of the applications selected for CASL's VERA are general purpose codes; CASL has added a necessary layer of capabilities to the higher fidelity applications to track fuel through multiple commercial reactor cycles and to provide inventory information such as fuel depletion. CASL has also coupled several key feedback parameters such as fuel density and temperature and has demonstrated the strong effects of the feedback parameters on the simulation. Simulation of commercial LWR operational issues such as CRUD deposition using the higher fidelity coupled physics allows for better understanding and opens the door for better solutions. This coupled, higher fidelity capability sets a new standard of performance for LWR modsim and is unmatched anywhere in the nuclear science and engineering community. This capability has been tested on user computing platforms and through the deployment of VERA on CASL Test Stands.

Comparison of VERA with Typical Industry Core Simulator Methods

Physics Area	Typical Industry Core Simulator Method	VERA running on an Industry Class Platform	VERA running on a Leadership Class Platform
Neutron Transport	3-D diffusion (core) 2 energy groups (core) 2-D transport on single assemblies	2D/1D transport 23+ energy groups	3D transport 23+ energy groups
Thermal-Hydraulics	nodal average (1-D)	subchannel (w/crossflow)	subchannel (w/crossflow) or CFD
Fuel Performance	Bounding empirically-based	pin-by-pin (r,z) empirically-based	pin-by-pin empirically-based with some science based model
Fuel & clad Temperatures	nodal average & peak	pin-by-pin (r,z)	pin-by-pin
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