CASL: Consortium for the Advanced Simulation of Light Water Reactors: Program Update

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

Program Update

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EPRI Fuel Reliability Program
Action Plan Committee Meeting
January 28th, 2015
Outline

• Overview of CASL
• Industry Challenge Problems
• Industry Applications for VERA
• Examples of Current VERA Results
• Path for Industry Implementation
### Overview of CASL

**Vision**

*Predict, with confidence, the performance and assured safety of nuclear reactors, through comprehensive, science-based M&S technology deployed and applied broadly by the U.S. nuclear energy industry*

### Goals

- Develop and effectively apply modern virtual reactor technology
- Provide more understanding of safety margins while addressing operational and design challenges
- Engage the nuclear energy community through M&S
- Deploy new partnership and collaboration paradigms

**CASL Mission: provide leading-edge M&S capabilities to improve the performance of operating LWRs**
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Industry Challenge Problems
VERA products and use cases

PCI
Predict Core Wide PCI Margin with **BISON-CASL 2D**
Zoom in and Predict MPS PCI leaker with **BISON-CASL 3D**

CRUD
**CIPS**: Predict Boron Uptake with **MAMBA** subgrid model in **COBRA-TF**
**CILC**: Predict Crud thk & corrosion with **MAMBA** subgrid model in **HYDRA-TH**

Cladding Integrity (RIA)
Predict PCMI Margin using **MPACT** and **BISON-CASL2D**

Cladding Integrity (LOCA)
Predict PCT – Oxidation Margin using **BISON-CASL2D** & System Code **RELAP5** or **W COBRA-TRAC**

DNB
Predict DNB Margin for RIA with **MPACT** and **COBRA-TF**
Predict Mixing & DNB with CFD using **STAR** or **HYDRA-TH**

GTRF
Predict Minimum GTRF Margin in Core using **BISON-CASL2D** – grid to rod gap, **STAR** or **HYDRA-TH** excitation force

For each Challenge Problem apply uncertainty quantification where scope permits
Important Modeling Attribute
Multi-Physics Coupling

Thermal Hydraulics
- Clad heat flux
- Clad Surface Temperature
- Gamma Heating
- Fluid Temperature
- Fluid Density
- MPACT

Fuel Performance
- Power
- Fuel Temperature
- BISON-CASL

Neutronics

With rigorous representation of physics feedback, simulations yield higher confidence predictions of core performance
Important Modeling Attribute

Uncertainty in Predictions

• Best Estimate + Uncertainty is the current norm

• Moving toward predictions of fuel integrity - versus using a conservative surrogate such as experiencing DNB - will require probability density function predictions
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Potential Benefits of Advanced Simulation

- Greater freedom in loading pattern determination
  - Reduction of feed region size
- Improved core product designs
  - Enhanced mixing vane design
  - Crud resistant fuel designs
- Increased operating flexibility
  - Improved load follow capability
  - Power uprates
- Addressing NRC safety concerns
  - Recent LOCA and RIA issues
Example: Flexible Operations

• Load follow is routine at international plants; some domestic utilities are considering the use of load following

• EPRI TI project to estimate fuel performance margins in load following conditions
  – Load follow requires PCI margin and risk quantification (INPO 07-004, Attr. 3)
  – Experiments are expensive; M&S needed for assistance
  – VERA core simulator can assess high-risk rods core-wide (2D r-z fuel rod model)
    • Further assess limiting rods (high risk rods using 3D fuel rod model)
    • VERA will inform licensed codes that calculate the specific risk

• Interactions with EPRI Falcon team mutually beneficial

Goal: VERA provides a methodology for core-wide PCI failure risk assessment
Example: Optimizing Fuel Design

• Fuel assembly design needs from M&S
  – Assembly design candidates require expensive tests (e.g. critical heat flux)
  – VERA capabilities could assist with design candidate down selection
  – Does not require NRC methods approval for use in this context

• VERA simulation requirements
  – Must be able to predict relative changes among designs
  – Minimal tuning is desired
  – Adequate benchmarking against relevant phenomena
  – Needs to allow proprietary models
  – Reasonable simulation times acceptable

CASL tools help optimize designs, minimize costly testing and introduce new products to market faster.
Example: CRUD Risk Assessment

• CIPS
  – VERA tools provide direct method for CIPS evaluation
    • Improved crud/chemistry model
    • Advanced chemical thermodynamics
    • Address current methods lack of ability to accurately treat assemblies with power gradients or Gad BAs
    • Fully coupled so all feedbacks treated consistently

• CILC
  – Targets enhanced PWR Level IV crud risk assessment tools

• VERA tools and insights are being used to inform potential crud reducing strategies

• Interactions with EPRI BOA team mutually beneficial

VERA will enhance crud risk assessment capability (Level III → Level IV)
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Results: Core Analysis

Full core pin-resolved neutron transport and Monte Carlo benchmark

• Simplicity
  – Single deck to run all neutronics and TH
  – Quick to setup (<2hr for a new core) and easy to verify

• Accuracy
  – Direct full-core transport calculation
  – Many group cross-sections
  – Coupled physics
  – Pin-resolved results

• Robustness
  – Assumptions eliminated
    ➢ Two-step (i.e. lattice physics + nodal diffusion) approach
    ➢ Pin-power reconstruction
    ➢ Diffusion theory

Consolidates workflow tasks while achieving more reliable core behavior prediction capabilities
All AP1000 startup tests simulated with VERA; comparison to in-house predictions confirmed satisfactory agreement.

All figures of merit compared within acceptable limits.

Reduced uncertainty of rod worths enabled more flexibility in setting loading patterns.

Gives utilities and vendors much better confidence that startup and operation will go as planned.
Results: Accident Analysis
Simulation of Steamline Break

- Simulation of DNB limiting time step for PWR DNB event steam line break without offsite power
- High resolution modeling with coupled neutronics to recover margin in safety assessments
- CFD to be applied for inlet boundary conditions
- Rigorous test of model and algorithms
VERA Core Simulator Validation

Four-component plan

- Measured data from operating nuclear power plants
- Measured data from experiments with small critical nuclear reactors
- Measured isotopics in fuel after being irradiated in a nuclear power plant
- Calculated quantities on fine scales from continuous energy Monte Carlo methods
Operating Constraints: Recent CIPS/CILC Simulation of Seabrook 1 Cycle 5 CRUD

- Seabrook Cycle 5 experienced both CIPS & CILC
- Validation exercise performed using MAMBA for simulated crud deposition event using 5x5 rod bundle
- Based on coupled computational fluid dynamics (CFD) with CRUD

Planned for FY15 is crud predictions for an operating PWR based upon coupled neutronics + Thermal-hydraulics (subchannel) + CRUD model
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• Expand capabilities for PWR Challenge Problems
• Extend and apply capabilities to SMRs (iPWRs)
  – Natural circulation
  – DNB in low-flow conditions
  – CRUD for long-cycle operations
• Extend capabilities to BWR challenge problems
  – Thermal-hydraulic flow regimes
  – Core simulation (sub regions and potentially full core)
  – Fuel performance – PCI, cladding integrity
  – Convective and solute flows and mixing
• Continued releases and deployment to potential end users
Future Plans: Some Key Challenges

1. VERA compute requirements amenable to platforms accessible to industry

2. Verification & Validation of VERA to a stage that industry is willing to adopt and complete the necessary validation

3. Advancing CFD capabilities to the level that meaningful two-phase flow calculations can be completed

Engagement with industry is essential to understand Items 1 and 2
Value Guided by Industry Council

Strong engagement from the Industry Council

- Industry Council evolving toward model similar to EPRI Advisory Committee
- Scott Thomas from Duke Energy has agreed to be the Industry Council Chair

CASL's new Technology Deployment and Outreach (TDO) group created to facilitate more aggressive industry engagement and deployment

- Led by industry partners and formed to facilitate deployment to industry
- Business assessment of CASL extension beyond 10 years being initiated

CASL welcomes enhanced interactions with EPRI FRP (and industry advisors) via IC and APC as requested
Technology Deployment: Test Stands

3 Test Stands deployed; another 1-2 anticipated annually moving forward

• CASL Test Stand
  - Westinghouse (Mar 2013): Test VERA core simulator’s ability to analyze AP1000 first core startup
  - EPRI (Nov 2013): Benchmark VERA fuel performance on PCI applications
  - TVA (Mar 2014): Test VERA CFD capability on lower plenum flow anomaly

• CASL Test Stands have exposed technology gaps, deployment needs, and driven continuous improvement

• More Test Stands on the horizon
  - Discussions ongoing with BMPC, Duke, GSE, AREVA, UIUC, UCB, …
Evolving the VERA User Community

- **Industry**
  - Test Stands will be deployed to not only CASL Partners, but also others
  - Training material is being developed (first training March 2015 at ANFM-V ANS topical meeting)

- **University/Academia**
  - Several universities gearing up to use VERA as their simulation environment
  - VERA can become the new education training tool for new engineers

- **NRC**
  - Regularly scheduled meetings held with RES and Commissioners

- **Naval Reactors**
  - Completing CASL defined core simulator benchmarks
  - Desire to further collaborate in a meaningful fashion

- **Other Federal Agencies**

  Flexibility: Software environment constructed to incorporate other modeling tools
VERA is envisioned to be distributed as several codes
- Central repository resides at Oak Ridge National Laboratory
- Source code and binaries will be available for licensed users

User interaction and support
- User documentation packages will include user manuals, examples, theory manuals, training modules
- A Working Group and training classes will be established in FY16

Required computing resources vary based on simulation needs
- Many simulations can be solved using 500-1,000 core machines
- Private cloud options are being researched
- HPC allocations at universities and national labs may be available

Technology delivery to industry is a key CASL Phase 2 goal
Path Envisioned for Advanced Simulation Tools

**Today**
Early Deployment
- Integrate existing toolkit
- Selected applications and users
- Most of the applications on current LCF

**Next 5 Years**
Expansion
- Broaden applications and user basis as experience and computer power increase
- Most applications on Industry HPC
- Exascale computing facility for most demanding applications

**Next 10 Years**
Integration
- Full integration of advanced tools in industry workflow
- Licensing with Nuclear Regulator

**Next 20 Years**
Replacement
- Advanced simulation tools become a stand-alone design tool
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