Office of Nuclear Energy

Modeling and Simulation Energy Innovation Hub

First Annual Review Report

Thursday, August 18, 2011

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Executive Summary: The DOE review of the Nuclear Energy Modeling and Simulation Hub was the first formal review of the Hub since it was initiated on July 1, 2010. The focus of the review was to determine if the Hub was being managed in accordance with the plans that were originally described in the proposal made by the Consortium for Advanced Simulation of Light-water-reactors (CASL) team. This was the criteria described in the NE Hub Oversight Plan that was prepared in July 2010. The review determined that the CASL team was meeting this criterion. The review team found that there have been a few changes to the management structure (the most significant being the division of one Functional Area into two), but that those changes were appropriate and overall enhanced the management structure.

The federal review team did not have any major recommendations for changes to the current CASL structure. However the review team made a number of suggestions. These include:

- The startup phase of the Hub resulted in some problems for the CASL managers in properly tracking financial resources. These were caused by the lack of insight into sub-contractor financial status. During the startup phase of the Hub, work proceeded without full subcontracts being in place (subcontractors were issued letter subcontracts that allowed them to proceed at their own risk). This situation is resolved and full subcontracts have been completed. This has allowed corrective actions to be taken that provide better financial oversight, and the situation

seems to be back under control. The review team suggests continued vigilance to identify and correct any future issues, particularly as the Hub moves out of start-up phase to full operations.

- The review team suggests that the CASL management continue to work on the integration of the technical work being done by each Functional Area. The review showed that the Functional Areas are productively doing research, which is to be commended. Now the challenge will be to ensure their results are effectively integrated together.

- The review team suggests that CASL continue to enhance and define the "test stand" concept that will be used to deploy early versions of the virtual reactor into the hands of users. The review team sees this as an important element of the Hub and looks forward to understanding (and perhaps seeing) a "test stand" in the future.

- Finally, the review team suggests that CASL spend some time defining what will happen to the modeling and simulation products that will produced by the Hub. During the first year of the Hub, the CASL team proved that it is going to produce products of interest. Now the managers of the Hub need to determine what is going to happen to those products.

The federal review team evaluated CASL in accordance with the NE Hub Oversight Plan and found that CASL successfully met the review criteria of managing the Hub in accordance with the plans they had proposed. The team would like to commend the CASL Director and the members of his team on a very productive first year and the review team is looking forward to seeing the research results and modeling and simulation capabilities that will be produced in the future.

Background: On August 18, 2011, the Department of Energy, Office of Nuclear Energy held its annual review of the Consortium for the Advanced Simulation of Light-water-reactors (CASL) Energy Innovation Hub (aka CASL). This once a year review is part of the DOE's "light federal touch" philosophy that was established by Secretary Chu and documented in the NE Hub Oversight Plan that was published in July 2010.

The main purpose of this review was to fulfill DOE's oversight responsibilities as described in OMB Circular A123 and DOE Order 413.B. These documents provide a specific set of oversight requirements, but the overall spirit of those requirements is that DOE act as a "good steward" of the taxpayers dollars. This means that the DOE and its managers are responsible for ensuring that funds are spent in accordance with the authorization and appropriation laws, they are spent effectively and efficiently, and if problems occur (financial or performance) that those issues are identified and corrected as soon as possible. Another important point made in DOE Order 413.1B was that the government should leverage as much existing information as possible to fulfill its control responsibilities.

Shortly after the CASL team was established, the Office of Nuclear Energy analyzed the management plans that were part of the Hub proposal. That review concluded that, if executed as described, the

CASL team's management approach would meet the oversight requirements as set out in the OMB Circular and DOE Order. These include planning, cost, schedule, and technical oversight. Also, using the information developed for the Hub management for the federal oversight will satisfy the requirement to leverage existing information.

Therefore the focus of the DOE review of the CASL team was on:

- Whether or not, the CASL team is managing its activities in accordance with its proposed plans and summarized in the NE Hub Oversight Plan and
- If there have been changes, are those changes justified and do they continue to meet the requirements of the OMB Circulars and DOE Orders.

The review was conducted by a team of federal employees and independent reviewers. The federal team consisted of:

- Ray Furstenau, Deputy Manager, DOE Idaho Operations Office
- Alex Larzelere, Director, Office of Advanced Modeling and Simulation (NE-71)
- Trevor Cook, Deputy Director, Office of Advanced Modeling and Simulation (NE-71)

The independent reviewers were:

- Ed Arthur, University of New Mexico, Nuclear Engineering Department
- Bo Ewald, Former CEO Cray Research, Silicon Graphics, and Linux NetworX
- Norm Morse, President Open Scalable File Systems
- Bill Reed, Former Director NNSA ASC program and NRC administrative judge

Review Process: Preparations for this review took several months. This included the development of the NE Hub Oversight Plan that was published in July 2010, shortly after the start of the Hub. This plan established the criteria for the annual reviews that would allow for a "light federal touch" (as was specified by Secretary Chu) and still satisfy the Office of Nuclear Energy oversight obligations. To do this, the Oversight Plan sets the review criteria as whether or not the Hub is implementing the management structure that was proposed and whether or not that structure is being effective.

Later, a review plan was developed that identified the reviewers and processes. Before the actual review date, the Hub provided a significant amount of read-ahead material. This included:

- The two Plans of Record that were executed by the Hub during the first year
- Sample milestone reports and documentation

- Council charters and feedback provided to the Hub
- Whitepapers developed that describe the plans for the Test Stands and the potential role of the Hub to support Small Modular Reactors
- Other background materials

The review team found that this material provided an in-depth view of the Hub activities over its first year of existence. The only complaint of the reviewers was that the background documents were not provided far enough in advance for a thorough review before the actual on-site review. However, they were used in support of the preparation of this report.

The actual on-site review took place over one day at the Hub's central collaboration site at the Oak Ridge National Laboratory. It consisted of four parts. The first was a separate caucus of the review team to discuss the review criteria and discuss any issues. The second part consisted of a large group meeting where the CASL team presented an overview of the previous year's activities. The third session broke the reviewers apart into two groups for a tour of the CASL team facilities and presentations on the technical focus areas. Finally, the review team separately met to discuss their findings. An overview of these findings was then provided to the CASL team.

The detailed agenda for the day is below:

Figure 1 - Review Agenda

Once the on-site review was completed, the review team worked over a month to prepare this report. This included several iterations of this document among the federal reviewers to develop a consensus report. In parallel, the outside reviewers developed their independent comments.

General Review Observations: The CASL team provided an excellent set of presentations that described the work they have accomplished over the first year of its existence. These presentations resulted in the following general observations made by the review team:

- **Overall Goals:** The overall goals of the Hub remain essentially the same as were described in the proposal. This includes creation of a virtual reactor (known as VERA (Virtual Environment for Reactor Analysis)). This will be used to address significant operational and safety issues as were identified by the Westinghouse, TVA , and EPRI team members that include:
    - CRUD-Induced Power Shifts
    - CRUD-Induced Localized Corrosion
    - Grid to Rod Fretting Failure
    - Departure from Nucleate Boiling
    - Cladding Integrity during Loss of Cooling Accident

  By addressing these technical operating and safety issues, the CASL team anticipates that VERA will become a tool that is used by nuclear energy technology developers to design systems that will lead to:
    - Reactor Power Uprates
    - Decrease in the volume of used fuel through higher burnups
    - Increased reactor lifetime

  Over the first year of the operation of CASL, the importance of these issues was ratified by the industry partners as well as other companies through the CASL team Industry Council.

- **Organization:** The core team members of the CASL team remain intact. There have been some modifications to the individual contributing members, but that has not decreased the effectiveness of the overall team based on the qualifications and expected contributions of the new members. The organization has split one of the Functional Areas (FAs) into two. This was the Models and Numerical Methods area which has been divided into the Radiation Transport and Thermal Hydraulics FAs. This was done in recognition of the importance of these two areas and the challenges of managing them as a single FA. There have been some changes to the Key

Personnel, but once again, without loss of effectiveness to the team. The top leadership of the Hub (Director, Deputy Director, Chief Scientist, etc.) remains the same and is very actively involved.

- **Pace of Development:** Over the last year, the CASL team has worked very hard to establish a regular pace for its developments. This includes the formulation of 6 month Plans of Record (PoR) that create a very detailed set of activities and milestones. CASL has successfully completed two PoRs and is just embarking on its third. The PoR approach provides two things: First, it is a disciplined set of activities that will occur in the short term with specifics about exactly who is going to be doing what. Second, it allows the Hub flexibility to adjust their plans and research based on prior work for the upcoming PoRs.

  The CASL team has also established a regular schedule of code development. This includes the use of a combination of the Scrum and Kanban approaches to code development. This involves the use of 30 day sprints with twice a week stand-up meetings.

- **Program Tracking:** After the award, one of the first things that CASL Director Kothe did was hire a certified Project Management Professional (PMP) to assist him with establishing a solid process for the planning, executing, tracking, and close out of Hub activities. These processes include the identification and assessment of risks and development of appropriate mitigation actions. As part of the regular Plans of Record, the CASL team establishes regular milestones and uses a variation of the Trac software development tool to track issues and progress for milestones.

- **Budget Performance:** CASL faced a number of challenges with budgets over its first year. On the positive side, because the prime contractor for the Hub is ORNL, the DOE was able to move the first allocation (of about $21M) quickly to the Hub using the existing M&O contract. This allowed ORNL to promptly issue “letter subcontracts” to the team members authorizing them to spend resources to be later invoiced to the Hub. This was done at the risk to the subcontractor of failing to agree to the terms of the subcontracts. The challenge with this situation was that ORNL would not see those invoices until after the subcontracts were completed. In some cases, that has taken over a year. As a result, the Hub managers did not have insight into the actual subcontractor costs until after the full subcontracts were completed. This has now been done and remedies the situation that caused the initial problems.

  Another challenge faced by the Hub was that the FY-11 appropriations for the Hub were considerably lower than what they had planned for in the proposal. The proposal assumed that $25M would be available during the second year. FY-11 consisted of a number of Continuing Resolutions (which caused their own uncertainty) that eventually resulted in the Hub receiving $16M for the year. This required that the Hub management modify their plans to accommodate receiving fewer funds than was planned for in the proposal.

For this reason, during its first year, CASL had to slip three Level 2 Milestones by three months to accommodate overspending by some team partners. To their credit, the Hub identified this problem early, informed DOE Headquarters of the slippage and took immediate corrective action. An alternative approach has been implemented that will allow the CASL team to meet the milestones without impacting the overall scope of the project.

- **Implementing Processes:** One of the challenges of starting up a new project with a new team is the creation of common processes. This is particularly challenging and important in the nuclear energy business. While not complete, the CASL team has worked diligently to establish processes for quality assurance and technology control. The progress in the first year looks promising, but there is still work to be done for full implementation across the entire team.

- **Collaboration Facility:** An important attribute of the Energy Innovation Hub concept as described by Secretary Chu is the idea of freewheeling, multi-disciplinary, and multi-institutional collaboration. As history has shown, the ideal situation for this to occur is in an environment where researchers are physically collocated in one place for extended periods of time.

  In its proposal, the CASL team chose not to relocate researchers from the partner universities, industry, and national laboratories to a single location. Rather they proposed to use a combination of physical co-location and virtual collaboration technologies. For this reason, the creation of the CASL team collaboration site and the installation of the technology were critical.

  Over the last year, the CASL team has done a magnificent job reconfiguring ORNL spaces to accommodate the collaboration center. This has included designing the new spaces, specifying the needed equipment, the demolition of the old spaces, construction of the new spaces, and installation of the equipment. As demonstrated during the review, this has largely been accomplished in little over a year. During the review this equipment was operational and used to allow the remote participation of many of the remote staff members. In addition to the technology, the facility is extensively used for the face-to-face meetings that occur at the monthly collocation weeks for the staff.

  At this point, the effectiveness of the mix of physical and virtual collocation as an alternative to the physical “one roof” collaboration that Secretary Chu proposed is not clear to the review team. However, it is clear that CASL is well on their way to installing the equipment needed to learn the results of their experiment in collaboration.

  Board of Directors: One of the important aspects of the CASL team management approach was the establishment of an active Board of Directors. This board would provide the CASL team with its own executive-level management and guidance. The membership is composed of senior laboratory, university, and industry representatives who provide high level perspectives about the Hub’s strategic direction. These board members are free to strategize over the Hub without the din of day-to-day operations that faces the Director and his staff.

During the proposal phase a number of candidates were identified for membership on the Board of Directors. Over the last year, the CASL team has managed to recruit many of those people to its board. Also, at the recommendation of the Board of Directors, three "at large" members have been added. This has enhanced the effectiveness of the board as a management tool for the CASL team.

- **Councils**: During the proposal phase, the CASL team proposed to establish five councils that would guide the CASL team in five areas. There are:
    - Science (technical performance)
    - Industry (ensuring CASL products address larger industry needs)
    - Education (training the future scientists and engineers to develop and use CASL products)
    - Commercialization (helping to ensure that CASL technology makes it to the marketplace)
    - Communications (ensuring that CASL developments are known to the broader community and relevant policy makers).

  It was evident during the review that all five councils were well established and operating. This included having clear charters and full membership. Many of the councils had met several times over the last year and were providing valuable inputs to the CASL team leadership. An example of this is the feedback provided by the Science Council through the Hub's Science Council Action Matrix (SCAM) dealing with issues like resource allocation and the architecture of the virtual reactor code.

  During the proposal stage, several of the reviewers expressed concern that the number of councils presented management challenges to the Hub. These challenges still exist, but it seems that the Hub leadership team has been able to deal with them and get good value from the councils.

- **Active Education Program:** The CASL has clearly embraced its responsibility to create a new generation of nuclear power professionals who are steeped in the development and application of advanced modeling and simulation tools. This work includes the consideration of creating a university academic certification for nuclear reactor design using the virtual reactor tools. Recently the CASL team hosted a two day student workshop at the Collaboration Center for over 35 students from universities around the country (including ones not participating directly in the Hub).

Technical Observations: The scope and extent of the technical work that is being done by the CASL team requires a structure that allows each individual researcher to conduct their work with some level of independence. Yet at the end of the day, the work of all these individuals must come together to produce modeling and simulation products and capabilities that will be useful to address the overall nuclear energy challenges. In other words, the whole must be greater than the sum of the parts.

The CASL team has chosen to organize itself into six Functional Areas. Each one (as shown in the diagram below) provides an important part of the technology needed to allow the Hub to reach its full potential.

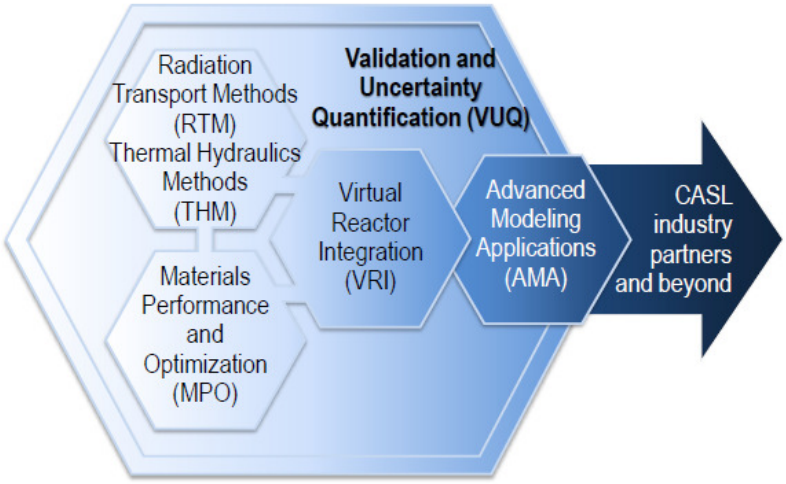

Figure 2 - CASL Technical Organization

When evaluating the technical performance of the CASL team, we must keep two things in mind. First, there is the question of the technical performance of each Functional Area. Second, there is the question of how each technical area integrates with the other Functional Areas.

The following are observations about the performance of each of the Functional Areas.

- **Advanced Modeling Applications (AMA):** The purpose of this Functional Area (FA) is to ensure that the CASL team developed modeling and simulation technologies are relevant and appropriate to the nuclear energy user community. AMA is also tasked to create an engagement with the regulatory authorities, leverage industry contributions, and to engage end users in the development and evaluation processes. Over the last year, AMS accomplishments include:
    - VERA Requirements and Plans
        - Establishment of Senor Leadership Team-approved VERA requirements

        - Developed initial validation & QA plan for CASL
    - Challenge problem specifications and simulations
        - Developed detailed challenge problem technical specifications
        - Development of scale up sequence from 3x3 pin multiphysics model to full vessel
        - Advancement of state of the art by including boron feedback in neutronics for crud challenge problem
        - Development of process to calculate turbulent rod excitation force to predict rod vibration and wear (Grid To Rod Fretting challenge problem) with Star-CCM+ (VERA "initial advanced' capability)
    - Modeling and Simulation of Physical Reactors
        - Obtained plant data for model development and validation
        - Full vessel CFD modeling (CE plant and Watts Bar Unit 1)
        - Demonstration of large-scale 3D full-core neutronics simulation on Jaguar scaling up to 260,000 cores

- **Virtual Reactor Integration (VRI):** The purpose of the VRI Functional Area is to develop and implement the architecture for the virtual reactor code known as VERA (Virtual Environment for Reactor Analysis). The VRI will deliver a suite of robust, verified and usable tools within a common multi-physics environment for the design and an alysis of nuclear reactor cores, with quantified uncertainties. Over the last year VRI accomplishments include:
    - Process
        - Rapid setup of a productive team.
        - Using Scrum-ban process (combination of Scrum and Kanban methodologies)
    - Foundation
        - VERA Release 1.0 (3/31/2011)
        - Virtual Environment for Reactor Analysis
    - Application

- Grid-to-Rod Fretting (GTRF)
- Use WEC 3x3 geometry
- Demonstration of advanced structural dynamics and CFD capabilities
- Initial coupling demonstration

- **Validation and Uncertainty Quantification (VUQ):** The objective of this FA is to develop validation and uncertainty quantification methods that will be used by the other FAs to ensure the modeling and simulation results are a reflection of the physical world. This is the reason the VUQ FA is shown in the diagram above as overlapping the others. The VUQ is dedicated to developing an overall CASL approach to verification and validation. The FA will provide the Hub with "best-estimate" predictive capabilities with reduced uncertainty and quantified predictive maturity assessments. The accomplishment of this FA include:
  - Integration of DAKOTA as library component in VERA
  - Completion of SA, Calibration/Validation, and UQ study on Crud/CIPS application
  - Development of VUQ procedures and workflows
  - Performed CFD solution verification study
  - Interfaced Percept verification library to VERA
  - Performed initial validation data review
  - Developed CASL validation data requirements plan

- **Materials Performance and Optimization (MPO):** This FA provides the physics-based material models for fuel/clad/internal property evolution to enable predictive modeling of CRUD, Grid to Rod Fretting and Pellet Clad Interface with the virtual reactor. First year accomplishments in this area include:
  - Delivery of a structural mechanics frame work for the Grid to Rod Fretting challenge problem.
  - Assessment of the available experimental data for the development of models for Pellet Clad Interface and CRUD deposition.

- Progress on developing a 3D nodal representation of fuel and cladding in a structural mechanics/chemistry code suite that implements industry/EPRI material databases and empirical models.

- **Radiation Transport Methods:** The objective of this FA is to deliver next generation, non-proprietary, scalable radiation transport simulation tools to the virtual reactor code. Accomplish that were reported in this area include:
  - Coupling of CFD to full core neutronics – the production CFD code Star-CCM+ was coupled to the 3D transport/diffusion code DeCART and successfully applied to a full-core reactor configuration.
  - The 3D transport code Denovo was applied to a huge configuration with 1.7 trillion space-energy-angle unknowns using > 100,000 processors on Jaguar.

- **Thermal Hydraulics Methods:** Last but not least, this FA will deliver next-generation thermal hydraulics simulation tools to VERA, interfaced with the latest VUQ technologies, and accommodating tight coupling with other physics. First year accomplishments include:
  - Identification of 2 non-proprietary HPC codes for further development, each with unique capabilities
  - Definition of Interface Tracking Method (ITM) test cases and performed initial simulations of turbulent flows with wall-attached bubbles
  - Publication of sensitivity study of CFD to multiphase / boiling parameters
  - CASL special session at NURETH-14, the premier T-H conference, with 9 papers on advanced thermal hydraulics

Answers to Review Questions: Prior to the review, a set of questions was prepared by DOE to help focus the scope of the review. The intent of these questions was to allow the review team to assess whether or not the Hub meets the criteria as is described in the NE Hub Oversight Plan. These questions are listed below with the responses from the DOE review team.

- **Question #1:** Is CASL managing the Energy Innovation Hub in accordance with the plans provided in the proposal and summarized in the NE Hub Oversight Plan?

- **Response #1:** The CASL team is being managed in accordance with the plans that were presented in their proposal and that were summarized in the Hub Oversight Plan. For this reason, the DOE team is confident that the Hub is meeting its oversight responsibilities while maintaining the "light federal touch" philosophy that was established at the start of the Energy Innovation Hubs.

- **Question #2:** Have the management plans changed and if so, are the justifications for those changes sufficient?

- **Response #2:** There have been some changes to the CASL team management structure, but nothing significant. These changes include:

    - The separation of the Models and Numerical Methods Functional Area into the Radiation Transport and Thermal Hydraulics Functional Area.

    - The reduction in scope of the Communications, Policy, and Economics Development Council to focus only on Communications.

    - Some changes in assigned key personnel

  Each of these changes was discussed during the review and the CASL team provided good justification for them. The review team feels that none of these changes are significant enough to impact the overall management approach of the Hub.

- **Question #3:** Is CASL receiving feedback and direction from its Board of Directors and Councils? What actions are being taken in response to that feedback?

- **Response #3**: Most of the chairs of the Councils attended the review and reported that they have an excellent interface with the CASL team and its leadership team. They reported that they are actively involved with the Hub and feel strongly that it is being responsive to the Councils recommendation. Also, the CASL team showed some of the mechanisms that are being used to trace recommendations and their resolution from the Board of Directors and the various Councils. The review team believes it is clear that the CASL team is making excellent use of these advisory panels.

- **Question #4**: Are the CASL team financials being adequately managed and appropriately adjusted given the available funds?

- **Response #4:** As discussed in an earlier section, the financial management of CASL may be as challenging as the technology development they have undertaken. Possibly adding to the financial management challenge is the fact that the CASL team leadership team is made up of outstanding scientific leaders (as per the DOE guidelines established for the Hubs). These challenges include the number of sub-contractors and the changes in the financial resources made available to the Hub. Given those challenges, it was clear to the review team that improvements were needed in this area. This was demonstrated by the need to change milestone accomplishment dates because of lack of resources. The review team believes that the CASL team leadership understands what happened to cause these problems and have taken good actions to correct the situation. These actions include the completion of subcontracts that provide greater insight into the subcontractor's financial status and the establishment of regular financial reviews with the subcontractors.

- **Question #5:** Given the available funds, is CASL achieving its planned technical milestones? Are those milestones being reviewed and accepted as being met by adequate technical experts?

- **Response #5:** As was noted in a previous section, the technical work of CASL needs to be considered in two ways. First there are the technical accomplishments of each of the six Functional Areas, and second, how well those functional areas are integrated into a single set of modeling and simulation capabilities?

  On the first question, the review team believes the Hub is making excellent progress in the various technical areas. It is clear that each FA has spent the last year assembling an excellent team and has established a good collaborative effort. The FAs have also done a good job defining their requirements and the approaches to addressing them. On the second question of integration, the review team believes the CASL team has made good progress but there is still room for improvement.

  It seems that the Advanced Modeling Applications, Virtual Reactor Integration, and Validation and Uncertainty Quantification teams have made very good progress integrating the products of their work. It is not clear how well the work of the Materials Performance and Optimization, Radiation Transport Methods or Thermal Hydraulics Methods is being integrated. That being said, that is not necessarily surprising given the longer-term nature of this work.

  As noted in a previous section, CASL was required to slip some Level 2 milestones due to financial issues. While this did not impact the content of those milestones it did affect the planned schedule. The CASL team seemed to recognize the issues that caused that slippage and have taken action to correct them (see the description of the actions in the response to question four).

- **Question #6:** What metrics are being used to guide the management of CASL and are they sufficient to assess the performance of the Hub?

- **Response #6:** The CASL team presented their approach to performance metrics during the review. They have developed three performance themes that include:

    - Technical Performance
    - Management Performance
    - Innovation and Agility

    They have also provided definitions for each of the themes. The team also showed how these high level areas of metrics are being incorporated into specific metrics for each of their Plans of Record (starting with the 2nd one).

    The review team recognizes the challenges of quantitatively measuring the progress of a fundamentally research and development program. The review team believes that the CASL team is making very good progress in implementing a system of performance metrics. The review team does not believe the job is complete and encourages the CASL team to continue to refine their approach with an eye towards making the metrics more quantifiable.

Summary: Overall, the review team believes that the CASL team has satisfactorily addressed all of the review questions and is doing excellent work. For this reason the review team does not have any major recommendations about changes to the technical or operational direction of the Hub.

The review team commends the CASL team Director Doug Kothe, Deputy Director Ronaldo Szilard, and Chief Scientist Paul Turinsky for their excellent work in establishing an effective multi-disciplinary, multi-institutional research enterprise in just one year. Given the limited timeline for the Hub, the review team recognizes that getting through a fast start-up is critical to making the Hub successful.

The review team would also like to commend the leads for the six Functional Area and the five Councils. During the review the complicated nature of the Functional Areas and Councils was viewed as a possible risk. It was clear during the review that this risk had not been realized through the hard work of those leads.

Another Functional Area that deserves recognition is the Virtual Office Community and Computing (VOCC) effort. Over the last year that team has done a fabulous job of creating the “One Roof” (both physically and virtually). The original Funding Opportunity Announcement requirement for the Hubs was to ideally be located under roof. Teams were allowed to propose alternatives to being continuously physically collocated. CASL proposed a hybrid approach that involved regular monthly physical collation and the use of modern information technology. The VOCC team has created an environment that

makes good use of collaborators time when they are collocated and working remotely. Their work will be vital in implementing the Hub's original vision of tight multi-disciplinary, multi-institution collaboration. CASL now has a home.

Finally, the review team would like to commend the non-technical staff (project management,` lawyers, technology transfer expert, contracting, and administration) associated with the Hub. The review team recognizes the very hard work that the Hub has created for these people (often in addition to their current duties). The speed in which the Hub was provided access to proprietary source code was critical to making the first release of the virtual reactor a success. Their work is recognized as being very important to establish the foundation for the success of the CASL team.

While the review team does not have any major recommendations, there are a few suggestions they would like to make to the CASL team. These suggestions include:

- Provide good follow up to the corrective actions taken to deal with the financial tracking issues. These actions were taken in response to issues generated by the start-up phase and other unexpected issues may be expected as the Hub proceeds. Be ready to identify those issues early and take appropriate actions.

- Continue to work on the integration of all six Functional Areas. The review team found that very good work was being done in each area, but the integration of those Functional Areas could use additional work. Part of this is a technical challenge and part a management challenge. On one hand the technical products of a Functional Area must be appropriately integrated into the technical products of the other Functional Areas. On the other hand, there are real management challenges of pulling together the people (particularly from the different institutions) together to make that happen. Successfully doing both will be vital to achieving the vision of the Energy Innovation Hubs. One suggestion by a reviewer is for the different Functional Areas to spend more time being physically collocated.

- The review team suggests that the CASL team continues to work on defining exactly what a "test stand" is and how it will be used to deploy CASL developed products to end users. During the proposal this concept was very intriguing and helped to show how CASL was going to do more than just develop codes for their own use. The review team notes the whitepaper on test stands and hopes that the CASL team continues to work on moving that vision into reality.

- Finally, the review team suggests that the CASL team start to work on defining the "end game" for the Hub. This should address questions about what will happened to Hub products once they are ready for production use. This includes finding answers to questions of whether these products will turn into "shrink wrapped" software, service companies, embedded in nuclear fuel vendor's products, or open source university codes? There will like be many answers to these questions and the review team encourages the CASL team to start to explore them. Happily in its first year the CASL team has proven they are going to produce something very valuable to improve U.S. energy security. Now we need to start figuring out what is going to happen to it.

Additional Comments by Independent Reviewers

Ed Arthur:

General Observations

1) CASL's leadership and technical team are first rate, combining expertise and commitment together to make the Hub a success. The original CASL proposal was the best-developed and thought out one of the original Hub proposal set. CASL ongoing activities, planning, and results-to-date since the award support the decision to award the Hub project to them.

2) CASL's ability to hit the ground running in terms of both assembling and linking a suite of heritage codes while making significant progress in methods and physics development areas is also impressive.

3) CASL has been able to put in place a diverse (and geographically dispersed) team that appears to work together in an efficient and productive manner, aided significantly through use of state-of-the art distance interaction technology systems.

4) The ability to implement necessary IP and NDA agreements was noted as a major challenge in most, if not all, of the Focus Areas (FA) presentations. It was unclear to me how such difficulties may impact technical progress in FY12.

5) CASL has shown some impressive computational capabilities and results -- examples being in the fretting problem area and in the full 3-D neutronic transport simulation of the whole reactor core that involved solution of a trillion or so transport equations.

6) The need to really define the concept of the virtual reactor simulator remains a challenging one -- although one that is rightly receiving more attention as CASL activities have gotten off the ground. Defining so called "test stands", and more importantly understanding their importance to future reactor design and operational analysis should be a number one priority for the CASL team effort. The white paper on this subject provided to the Review Team indicates that there is a long way to go in fully addressing this issue.

7) The future acceptance and use by the reactor industry and by the Nuclear Regulatory Commission of the code system and capabilities developed by CASL is unclear at this early date, and stands as the major measure of the Virtual Reactor HUB concept. Thinking about this challenge and ways to address/overcome should be a major task, not only of the CASL team leadership, but also its Board of Directors and Advisory Committees such as Science and Industry. Also planning should start now to ensure that long-term commitment to support and

maintenance of the CASL team product is key, otherwise there could be a danger that CASL's products will become "orphaned" and fall into disuse.

Input on Charge to the Review group

1) Is CASL managing the Energy Innovation Hub in accordance with the plans provided in the proposal and summarized in the NE Hub Oversight Plan?

CASL's leadership is managing the Hub in accordance with their proposal, subject to challenges faced during the startup period of the Hub -- principally associated with funding delays (government CR) and implementing contractual agreements among CASL member organizations.

2) *Have the management plans changed and if so are the justifications for those changes sufficient?*

For the most part CASL management plans have only changed when some focus activity (FA) area required addition of management/leadership staff or changes in FA leadership.

3) Is CASL receiving feedback and direction from its Board of Directors and Councils? What actions are being taken in response to that feedback.

CASL is receiving feedback and direction from its BOD and Councils. In particular the Science Council and Industry Council appear to provide important guidance and feedback in key areas associated with technology development and application activities. In the materials provided to us comments, critiques, and suggestions were given along with CASL responses to them.

4) Are the CASL team financials being adequately managed and appropriately adjusted given the available funds?

Program management materials provided in our briefing but not presented due to time constraints showed a robust program management approach. For areas related to providing effective real-time interaction among dispersed participants (VOCC and HUDDLES are examples), projects came in under cost and ahead of schedule.

5) Given the available funds, is CASL achieving its planned technical milestones? Are those milestones being reviewed and accepted as being met by adequate technical experts?

CASL met the majority of its technical milestones (level 1 and level 2) even though funding was less than original projections. However such milestones, in some cases, appear to have been descoped although their definitions, being rather general, could make it difficult for outside entities to understand the importance of adequate funding levels to the success and impact of the Hub.

6) What metrics are being used to guide the management of CASL and are they sufficient to assess the performance of the Hub?

Metrics need further definition and specificity to really address this charge. Qualitative metrics do exist, and appear to be met within the (general) constraints of their definition.

Robert Ewald

- Overall, I believe that CASL has made very good progress in the past year
    - The overall plan seems sound
    - The management is in place and generally seemed strong and engaged (I was particularly impressed with the breadth of Doug's knowledge about the various parts of the project)
    - The detailed planning for the project is much improved
    - They have made good technical progress v. their plan
    - The people in general seem committed, bright and diverse.
    - The work that they did on mission, vision and acceptance was well done and will help focus their efforts
- Areas which need attention are:
    - Completing contracts (probably sub-contracts)
    - They are underspending (which is ok in this environment perhaps), but will that impact their progress?
- Areas of potential future concern include:
    - Will their work be applicable to the real world – will it be useful to industry? (industry uses much smaller computers than CASL, so they will need to be alert to that fact and ensure that their codes can run on industry's systems.)
    - Between all of the review/advisory/oversight committees, I'm surprised that they've had enough time to get as much done as they have. It may not be as time consuming as I perceive, but there are lots of oversight groups, with lots of people, meeting frequently.

William H. Reed

General: I was favorably impressed with the very informative and professional series of presentations delivered by the Hub management, staff, and council chairs. It is clear that this program has made significant progress since its inception. Indeed, it was surprising to me that so much progress has been made in such a small period of time, especially since the program is still in its start-up phase. It appears to me that essentially all components of this project are on track to meet their milestones.

Management: Project management deserves much credit for establishing a clear set of milestones and objectives, for recruiting an extremely capable staff, and for creating an organization that seems to be working in a cooperative fashion. These milestones and objectives are clearly set forth in program planning documents, and management has also set in place an effective review mechanism for tracking progress toward completion of established milestones. Although the Hub personnel are drawn from an exceedingly large number of diverse institutions, effective communication channels have been established that appear to be functioning as intended.

Budget: Allocation of available resources seems to be reasonable. Creation of the VOCC (Virtual Office, Community, and Computing) has consumed a large share of the first-year budget, but this was to be expected and will not likely have to be repeated in future years.

Board of Directors and Councils: With the inclusion of the present Annual Hub Review, this project seems burdened with oversight and review by an excessively large number of boards and councils. I am not able to determine whether this has actually impeded technical progress or whether the advice offered by the councils has been constructive. It is my impression, however, that at least the Science Council has performed a valuable review function and has contributed useful and perceptive criticism to the project.

Computational Methods: It seems to me to be a sound policy to start with existing methods and codes for computational fluid dynamics and neutron transport. I'm particularly impressed with the demonstrated capability to run a 1.7 trillion unknown transport problem with the Denovo code using 100,000 processors on the Jaguar machine. This problem was run using a Cartesian mesh. The project has set an ambitious goal of running large transport problems on unstructured grids, and it will be interesting to see whether this can be accomplished for a full-core reactor configuration, as envisioned. I'm also impressed with the capability to model two-phase flow by tracking interfaces of individual bubbles. This will probably be a key to solving the challenge problems of crud development and grid-to-rod fretting.

Structural Analysis: Impressive results have already been obtained for structural analysis of a single pin and the surrounding grid spacer. This analysis was preceded by a CFD simulation of the unsteady flow in the channels surrounding a single fuel rod, which yielded the time-dependent pressure field that serves as the forcing function for the structural analysis. The subsequent structural analysis has yielded a number of quantities of interest, including displacements and contact forces on the grid.

Validation and Uncertainty Quantification: This is an area that is usually underfunded in the early stages of code development projects. I'm pleased to see the emphasis that is being placed on VUQ by the Hub, and I believe that this will pay significant dividends over the life of the project. I have some concern about over-reliance on data from operating reactors. While extremely valuable, this data is quite sparse and will provide little detail about flows and power distributions within the reactor core. It will need to be supplemented extensively by data from more detailed experiments. Fortunately, this data should be forthcoming from Hub partners.

Materials Performance: The proposed phased approach seems a logical way to approach this area. However, it is not clear to me what the deliverables are from this sub-project. Much of the proposed work appears to repeat or overlap what is proposed to be done in other parts of the Hub.

Advanced Modeling Applications: This is an extremely ambitious program area. The initial approach in this area is the development of an advanced model for a 3 by 3 array of fuel pins. This will eventually be followed by expansion of the model to a full reactor core with coupled fluid dynamics and neutronics models. The project recognizes the importance of developing a closer relationship with the Nuclear Regulatory Commission, which is essential if it is to achieve its goals of supporting power uprates, life extensions, and higher burnup.

Virtual Reactor Integration: It seems to me that the development of the Virtual Environment for Reactor Applications (VERA) is the loftiest goal of the entire Hub project. It is clear from the presentations on this topic that the staff is aware of the difficulties that they face. Their approach of starting by coupling existing neutronics and thermal-hydraulics methods is the most reasonable way to get started on this daunting task. The proposed evolution towards higher-fidelity methods coupled to RELAP for full-systems analysis should eventually get them to their ultimate goal.