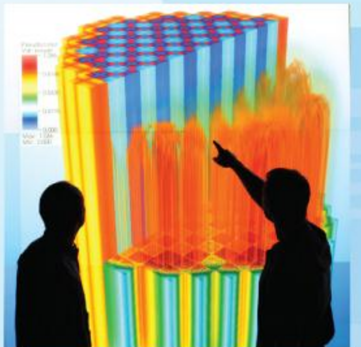
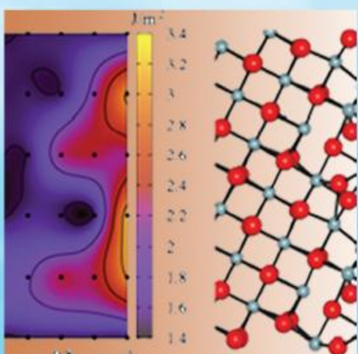
CASL-U-2012-0026-000

Power uprates
and plant life extension

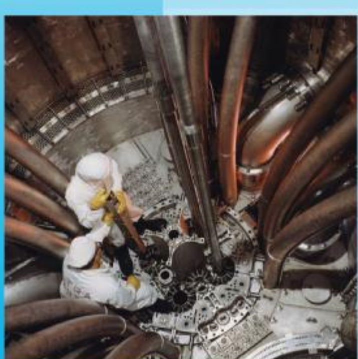


Engineering design
and analysis

Science-enabling
high performance
computing



Fundamental science



Plant operational data

CASL
Consortium for Advanced Simulation of LWRs

Evaluation of Industry Council Pilot Project Alternatives

(AMA.REQ.P4.01)

29 February 2012

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

REVISION LOG

Revision	Date	Affected Pages	Revision Description
0.0	02/29/12	All	New issue.

CONTENTS

1. PURPOSE

A critical element of the success of the Consortium for Advanced Simulation of Light Water Reactors (CASL) modeling and simulation (M&S) hub will be the ability to transfer technology (both methods and software) developed by CASL to stakeholders (including industry, regulatory and research community) and for these stakeholders to apply these methods and tools to address critical issues in the long-term efficient and safe operation of commercial nuclear power plants (NPPs). To enable the achievement of this objective, an Industry Council (IC) consisting of key external stakeholders was instituted to serve as a key advisory group. This group meets several times per year to provide the CASL leadership team with perspective on industry needs and objectives and to review work (both ongoing and planned) from the perspective of its utility to industry. From this interchange, the CASL leadership team evaluates the information provided and uses it to formulate specific projects and activities in the CASL program to address critical industry needs.

At the IC meeting conducted on 23 August 2011 at Oak Ridge National Laboratory (ORNL), the IC discussed the ways in which early releases of CASL could best be employed from their point of view. Most IC members indicated their preference for CASL not to release early versions of VERA for their direct use. Rather, they preferred that VERA be applied by CASL staff (with IC member participation) to analyze real problems of importance to industry that would demonstrate the benefits of the advanced M&S capability of VERA. As part of this IC meeting, AMA led a facilitated discussion of the IC members to identify a set of possible "early uses" which could serve to achieve these objectives. During the meeting the following potential issues were proposed and discussed by the IC members.

- Development of corresponding CASL capabilities to support analysis of pressurized water reactor (PWR) fuel from vendors other than Westinghouse
- Conduct detailed assessment of a selected CRUD related operational issue (e.g. CIPS and CILC phenomena) that have occurred at operational NPPs
- Evaluation of other PWR operational issues not currently addressed by the current CASL challenge problems.
  - Grid to baffle wear problems (including baffle bolt swelling) in Babcock and Wilcox design plants
- Evaluation of operational issues of significance to boiling water reactors (BWRs)
  - Pellet / clad interaction (PCI)
  - Channel bow
  - Fuel preconditioning / start-up ramps
  - Core stability
  - Effects of off-normal reactor coolant chemistry conditions
  - Effects of reactor coolant chemistry transients during plant startup
  - Jet pump and reactor internals vibration
- Evaluation of NPP safety issues of relevance post-Fukushima (applicable to both PWRs and BWRs)
  - Post-LOCA boron precipitation and fibrous material deposition that can lead to in-vessel coolant flow blockage
  - Effects on fuel integrity of core dryout and recovery
  - Reactor vessel and fuel behavior during severe accident conditions
  - Issues related to long-term spent fuel storage in spent fuel pool or dry cask storage
- Evaluation of postulated changes in NPP operation
  - Load following operation (PWR and BWR)

    - “Real-time” tracking of fuel / core performance
- Evaluation of issues related to the design, licensing and operation of small modular reactors (SMRs)

After this initial discussion of these candidate pilot project activities at the IC meeting, AMA agreed to work with the IC to identify an appropriate pilot project which could be conducted within an approximate one year time frame and from which significant near-term value could be obtained.

2. ASSESSMENT OF CANDIDATE PROJECTS

2.1 Assessment Process

To identify a useful pilot project that could be sponsored by the CASL IC, several items were considered. First, from the vantage point of the IC, the primary purpose of the pilot project is to apply CASL developed methods and tools to an issue of current relevance to the industry such that the value of both the VERA tool and advanced modeling and simulation capabilities can be demonstrated early in the CASL research and development program. This objective is intended to obtain increased industry engagement and support for the CASL program and also to demonstrate the application of modeling and simulation capability to address issues important to commercial NPP operation, safety and sustainability. Thus, the perceived value to the CASL industry stakeholders represents a critical input into the prioritization of the candidate projects identified in Section 1 of this report.

In the evaluation of the candidate IC sponsored pilot projects identified in Section 1, three elements were identified as important. The first and most significant of these elements is that the project selected would provide a high level of near-term value to the industry stakeholders. The second element in the selection is the degree to which the current capabilities of the VERA software can support the required technical analyses. Finally, the third element is the capability of the project to demonstrate the value of advanced modeling and simulation capabilities.

2.2 Evaluation of Candidate Projects

To assess the characteristics of the candidate projects identified in Section 1, the characteristics of each project with respect to the first two fundamental decision criteria (value to stakeholders and current VERA capabilities) were identified. The results of this characterization are provided in Table 1. We note that each of the candidate projects considered have unique attributes that could benefit from application of advanced modeling and simulation capabilities. Thus, the specific aspects of this element for each candidate project are not discussed in Table 1.

Because of the relatively simple nature of the decision and the results of the characterization of the projects against the criteria, it was not considered necessary to develop a formal weighting system to perform the ranking. This was further reinforced by several additional characteristics associated with the pilot project.

- Due to budget limitations, only one pilot project would be conducted over the course of Fiscal Year 2012. As a result of this limitation only the highest ranked project would serve as an initial IC pilot on which work would be conducted. (Note that as work on this initial pilot project progresses, as part of the ongoing interaction between the CASL staff and the IC, additional pilot projects could be initiated as industry needs change and additional resources become available.)
- The rankings developed are intended to serve as an initial prioritization which will be presented to the IC members for discussion at the next IC meeting on 7 – 8 March 2012. As a result of these discussions it is intended that the IC will select an appropriate pilot project (based on the characteristics previously discussed).

In Section 3 we summarize the significant insights from the characterization of the candidate pilot projects and provide initial recommendations that will be presented to the IC during the March meeting.

Project	Near-Term Value to Industry Stakeholders	Current VERA Capability to Execute	Description	Comments/Concerns	Estimated Effort Required (5 = High / 1 = Low)	Rank
Evaluate potential core flow impact of post-LOCA fibrous material	High	Yes	Using the existing quarter-core Watts Bar CFD model, evaluate coolant flow paths for post-LOCA conditions with fibrous material buildup and considering anticipated operator actions. The fibrous material will not be tracked in the simulation; rather, the blockage will be simulated as an increased pressure drop across the bottom nozzle/lower end grid portion of the fuel assemblies. All spacer grids will be simulated as porous media to reduce computation requirements.	Initial conversations with NEI and the PWROG indicate strong level of interest in supporting and contributing to this effort. A full-core model may be needed to simulate asymmetric flow conditions such as those imposed when a single RCP restart is completed. All evaluations would be single-phase flow, steady state conditions, forced and natural convection enabled using current baseline tool (STAR-CCM+).	2	1
GTRF	Med	Partial	Using the existing quarter-core Watts Bar CFD model, locate and rank high risk GTRF locations within the reactor core. Consider studying the effects of penetrations in the baffle walls (such as B&W unit LOCA holes) with the same model.	Pilot scope represents currently envisioned CASL milestone activities. Current model may not have a fine enough mesh. Vessel details may need to be added. These changes represent a significant effort.	2	2
CIPS	Med	Partial	Use Advanced VERA to simulate several cycles of a unit having large CRUD deposition and CIPS (suggest Duke units) and compare/contrast with measured results and baseline predictions.	Pilot scope represents currently envisioned CASL milestone activities. This project would demonstrate coupled multi-physics capability of VERA. However, recent assessment of current Advanced VERA capabilities provides some level of doubt that this could be successfully completed using CASL advanced codes within desired timeframe (end of 2012).	3	3
Post-LOCA boron mixing	Med	Partial	Use VERA to simulate post-LOCA boron distribution and precipitation of boron in the core.	Rigorous analysis will require use of systems code (e.g. RELAP-5). Using some boundary condition assumptions, it is possible to do some simulations without RELAP. It is likely that MAMBA will contain the basic science necessary; however, it will need to be modified to handle post-LOCA conditions. Since this capability is not available, this effort cannot be completed within desired timeframe (end of 2012).	5 (with RELAP-5) 3 (after MAMBA integration into VERA)	4

Project	Near-Term Value to Industry Stakeholders	Current VERA Capability to Execute	Description	Comments/Concerns	Estimated Effort Required (5 = High / 1 = Low)	Rank
Grid and Baffle wear for B&W plants	Med	Partial	Simulate the motion of fuel assemblies and the reactor vessel under normal steady state flow conditions to identify contact conditions with the core baffle plates. Calculate wear of fuel assembly spacer grids based on predicted contact and using available wear coefficient data. Calculate wear of fuel rods based on predicted contact and using available wear coefficient data. Compare predictions of spacer grid damage and rod leak predictions against end of cycle visuals and date in cycle when leaker was reported.	The simulation is partially supported by the GTRF wear challenge problem solutions. Additional VERA development would need to be completed to address the required structural and vibration capabilities; however, this development effort yields much-needed VERA capabilities (supports seismic evaluations). Limited broad applicability to industry (large wear is limited to B&W plants). Likely better suited as a CASL Test Stand application.	4	5
Study of tradeoffs between EPUs and 24 month cycles	Low	No	With coupled VERA capabilities, run parametric studies varying cycle length (to 24 months), fuel enrichment (with greater than 5wt% acceptable), core loading pattern and unit power to determine the optimum cycle conditions, considering performance parameters such as pin peaking, pin centerline temperature, and DNB margin. Financial considerations such as current cost of enrichment will not be considered.	Current Advanced VERA capabilities do not support this assessment at this time.	5	6
Other CFD applications	Low	No	Use VERA to simulate hot leg streaming, lower plenum anomaly, and other flow-based issues.	Although current VERA advanced capabilities do not support this assessment at this time; existing tools being used with VERA can perform these types of analyses for single phase flow. The detailing of the existing CFD models is not targeted towards the relevant core locations; thus, it is likely a new model would need to be constructed.	5	6
Post-LOCA cladding integrity analysis	Low	No	Use VERA coupled advanced tools to predict cladding condition, including temperature, stress, strain, internal pressure, corrosion, hydriding, clad ballooning, and failure. Map core damage based on predictions.	Rigorous analysis will require use of systems code (e.g. RELAP-5). Using some boundary condition assumptions, it is possible to do some simulations without RELAP. Current VERA advanced capabilities do not support this assessment at this time.	5	6

Table 1: Evaluation of Candidate Industry Council Pilot Projects

3. CONCLUSIONS AND RECOMMENDATIONS

Based on the current and near-term planned additional capabilities of VERA, a significant number of the candidate pilot projects identified at the last IC meeting could not be addressed with a high degree of confidence at this time. Thus, the actual potential projects that are viable candidates for selection include the following:

- Evaluation of potential core flow impact due to fibrous material generated during post-LOCA conditions.
- Identification and ranking of high risk GTRF locations within the reactor core.
- Simulation of several operating cycles of a unit having large CRUD deposition and CIPS and comparison / contrast with observed measurements.
- Simulation of post-LOCA boron distribution and precipitation in the core.
- Evaluation of grid and baffle wear (with primary application to B&W plant designs).

As summarized in Table 1 in the previous section, the characteristics of the candidate issues combined with the current level of VERA capabilities lead to the conclusion that the project to evaluate the potential core flow impact of fibrous material would be the project that provides the greatest potential for near term value and a high likelihood of success within the proposed project timeframe. Although the issue has the largest impact on PWR plants, it is generically applicable to all LWR designs. This is reflected in the fact that this is an outstanding regulatory issue in the United States. It also is an issue where modeling and simulation could potentially provide significant insights and understanding that could contribute to resolving differences in experimental results that have been obtained to date. Finally, performance of this project is completely within the current capabilities of VERA. From the standpoint of the desired outcomes of such a pilot project, the project's only negative feature is that it does not demonstrate any of VERA's capability to employ coupled physics (i.e. it is predominantly an outcome of large scale CFD modeling).

The next two highest ranked projects (i.e. the identification and ranking of high risk GTRF locations within the reactor core and the simulation of several operating cycles of a unit that has experienced large CRUD deposition and the CIPS phenomenon) are very similar in scope. However, as these issues are the focus of significant CASL Challenge Problem research, use of these issues as an IC pilot project would likely only add marginal generic value above that which would reasonably expected to be obtained as a result of the existing identified workscope. As a result, these projects would likely be better suited to be conducted by interested plants as a CASL Test Stand activity. Additionally, because the physics capabilities necessary to conduct these analyses are only partially integrated into VERA at the present time, there also is an increased level of uncertainty in the time that will be required to complete the associated analyses and provide useful information to the IC stakeholders.

For the next ranked project (simulation of post-LOCA boron distribution and precipitation within the core) requires the use of systems level modeling (using RELAP-5). Since RELAP-5 has only recently been integrated into VERA, it currently is not coupled to any other physics capabilities. This results in a project that would require significant resources and effort to accomplish in the anticipated project execution timeframe (i.e. completion by year end 2012).

Finally for the lowest ranked viable candidate IC project (evaluation of grid and baffle wear), although this issue has been observed to some degree at all PWR designs deployed in the United States, it has only been a significant issue for B&W plants. In addition, enhanced VERA development would need to be completed to address the required structural and vibration capabilities to analyze this issue. As a result, there is a significant amount of uncertainty in the likelihood of successfully completing this project within a timeframe that would provide significant benefit to the IC stakeholders (e.g. support Watts Bar Unit 2 completion and startup).