Consortium for Advanced Simulation of LWRs

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Challenge Problems . . .
A Strategy that Demonstrates Progress

The nuclear industry employs a variety of science and engineering analysis techniques to understand and predict the performance of materials, components and subsystems involved in the diverse aspects of electric power generation. These analysis techniques, originating as far back as the 1960s and 1970s, have evolved over the past several decades as analytical methods have advanced and are validated based on experimental data from test reactors, commercial power reactors and unirradiated test loops.

Traditional industry simulation techniques are often based on the simplifying assumption that multiple and simultaneously interacting physical processes occurring can be conservatively bounded through simulation as uncoupled (independent), or loosely coupled (mildly dependent) processes. This approach has served the industry well and continues to support the safe operation of reactors and reliable performance of nuclear fuel. However, in order to achieve the key CASL challenges of enabling power uprates, increasing fuel burn-up and cycle length, and lifetime extension for U.S. nuclear plants, there is a need for higher fidelity tools and closely coupled tools. CASL's approach is to develop and apply modeling and simulation techniques that incorporate key science-based physical models, state-of-the-art numerical methods, and modern computational science into a useful and usable problem-solving simulation environment for nuclear scientists and engineers.

CASL's development plan is built around several issues relevant to operating commercial power reactors called "Challenge Problems" to drive development and demonstrate progress with results that can be applied to today's commercial power generation industry. CASL scientists are able to more precisely represent the normal operating conditions in a reactor. The integrated, coupled solutions are expected to reduce the uncertainties intrinsic in sequential analyses and provide a more realistic representation of the reactor behavior.

What is a Challenge Problem?

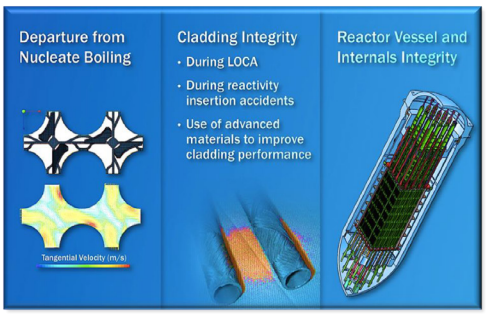
CASL is focused on a set of specific *Challenge Problems* that encompass phenomena currently limiting the performance of some pressurized water reactors. The Challenge Problems drive the development of the higher-fidelity coupled physics tools and demonstrate the application of the tools on existing issues, bringing immediate insights to the commercial nuclear power industry.

CASL defines a *Challenge Problem*s as one whose solution is:

1. important to the nuclear industry and
2. amenable to, or enabled by, modern modeling and simulation techniques.

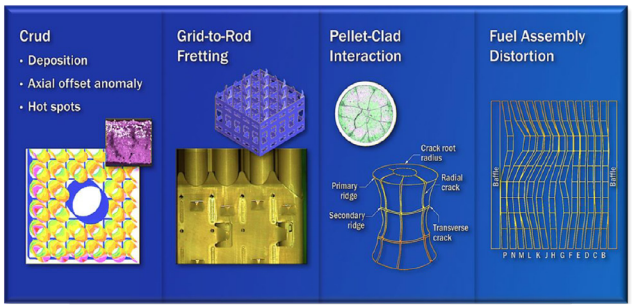
CASL Focuses on Selected Challenge Problems

Key safety-relevant reactor phenomena that limit performance



CASL is committed to delivering simulation capabilities for

- Advancing the understanding of key reactor phenomena
- Improving performance in today's commercial power reactors
- Evaluating new fuel designs to further enhance safety margin



Clear milestone-driven technical strategy for solving real-world reactor problems

Chalk River Unidentified Deposits (CRUD) and CRUD-induced Localized Corrosion (CILC)

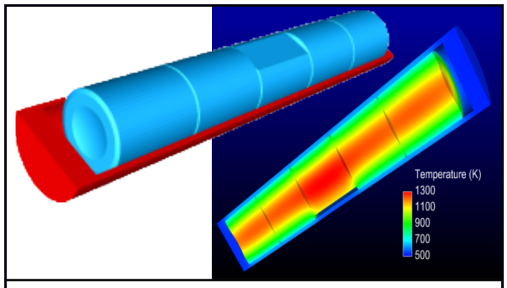
Decades ago, the unidentified deposits on Chalk River fuel elements were corrosion products from the reactor and steam generator piping; today it is known that the thickness of CRUD on the fuel is directly related to local rod power density. Thick CRUD deposits can lead to CILC and leaking fuel rods, and commercial power operations can be limited to reduce the risk of CILC failures. *Improved understanding could allow reactors to move to higher power densities.*

Grid-to-Rod-Fretting (GTRF)

Flow fields around the reactor fuel can cause the rods to vibrate against the supporting structures, eventually wearing a small hole through the fuel rod cladding. Some fuel designs are more vulnerable to vibration than others, and higher power operation and higher burn-ups can exacerbate the vulnerability. *Higher fidelity coupled physics simulations can provide a more comprehensive understanding of the design sensitivities leading to GTRF and allow for optimization of fuel designs to completely eliminate this failure mode.*

Pellet–Cladding Interaction (PCI)

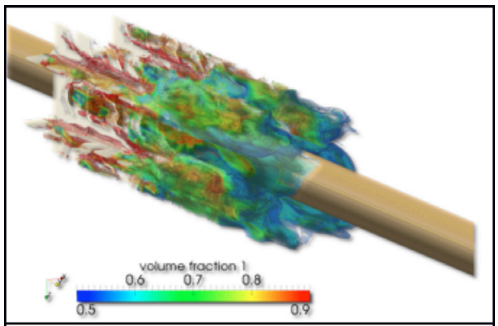
Commercial nuclear fuel utilizes pelleted uranium dioxide powder inside a zirconium-based alloy tube called "cladding." As-manufactured fuel rods include a small gap between the pellet and the cladding, and as the fuel rod is operated in the reactor, the cladding creeps down to rest on the pellet diametrical surfaces, resulting in pellet-cladding interaction. As power is varied, the pellet can swell or shrink, and the cladding tries to keep up. Very fast power changes can result in small tears in the cladding. Power uprates and increased burn-up reduce the ability for the cladding to keep up with power-induced pellet swelling, increasing the likelihood for cladding tears (fuel rod leaks). *Higher fidelity models could provide a high-resolution local simulation of the pellet and cladding behavior, providing a local best estimate (rather than bounding) performance margin for power maneuvers, insights into better pellet designs, and simulations of rod performance during postulated accident conditions.*



CASL PCI Simulation illustrating the local effects of a fuel pellet chip

Departure from Nucleate Boiling (DNB)

Nuclear reactors create electricity efficiently through the heating of the reactor coolant in a process called nucleate boiling. Departing from the nucleate boiling regime to a film boiling regime leads to local dryout of the cladding surface , causing a dramatic reduction in heat transfer capability during certain accident transients (e.g., overpower and low coolant flow). Predicting the critical heat flux (CHF) that causes the departure from nucleate boiling is currently accomplished through extensive, expensive testing and is highly design dependent. These empirical correlations do not allow for any extrapolation, and new fuel designs cannot be developed without a DNB test. *A science-based high fidelity simulation tool can allow for more efficient fuel designs and potentially allow or deriving more power from existing reactors.*



CASL Multi-field flow mixing proof of analytical concept

Cladding integrity during Loss of Coolant Accident (LOCA) or Reactivity Insertion Accident (RIA))

During an accident event, it is desirable to keep the fuel pellets contained within the fuel rod cladding. Maintaining the cladding integrity allows for containment of any fission products and provides a coolable fuel geometry. Predictions for cladding integrity during challenging accident scenarios are currently based upon a limited number of irradiated fuels tests. *A science-based high fidelity simulation tool can allow for better understanding of fuel performance, allowing for optimization of current designs and perhaps facilitating the development of future accident tolerant designs.*

CASL's Challenge Problem approach provides a flexible framework to drive development while providing near term insights for industry implementation. CASL's industry partnership allows for seamless industry integration and offers quick course corrections when needed.

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