Panel Discussion:

Discussion on Trends in Multi-Physics Simulation

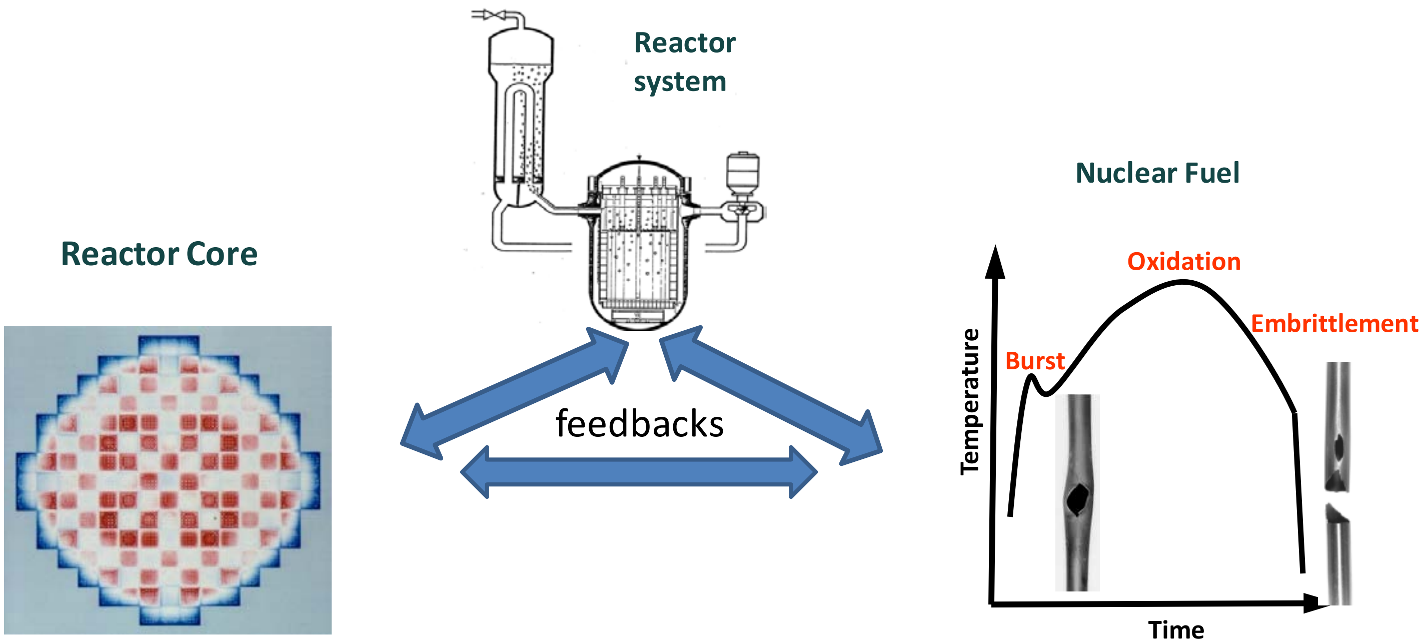
First Workshop on Multiphysics Model Validation

NCSU, Raleigh

June 27-29, 2017

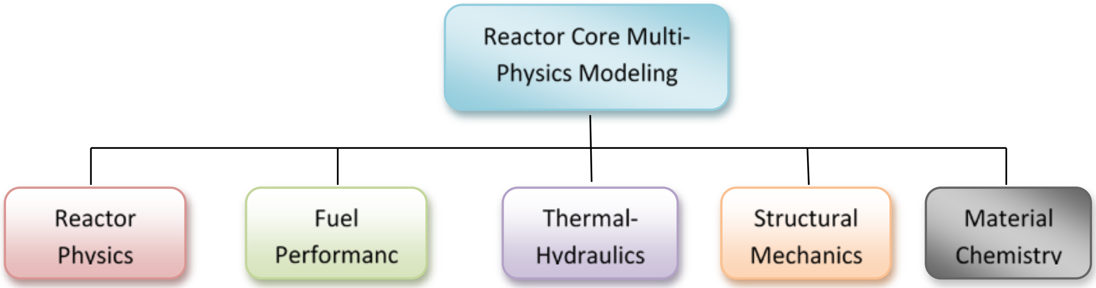
Multi-physics Modeling

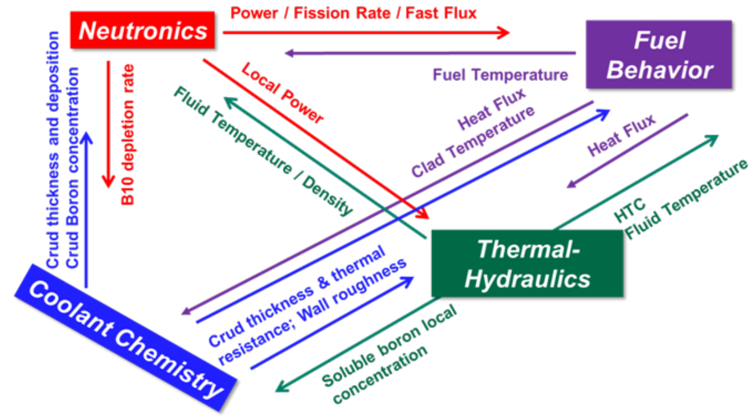
- The NPP predictive modelling capabilities have evolved from the so-called best-estimate calculations to first-principle high-fidelity multi-physics simulations
- The multi-physics interactions in a NPP are manifested in both global-length-scale behavior and lower-length-scale behavior
- Especially important are the multi-physics interactions in reactor cores including neutronics (reactor physics), fuel thermo-mechanical performance, thermal-hydraulics, material chemistry, and structural material behaviors.
- Usually the focus is on interactions between reactor physics (neutronics) and thermal-hydraulics in a reactor core (where the fuel thermo-mechanical performance is integrated in the thermal-hydraulics codes via simplified fuel rod models)

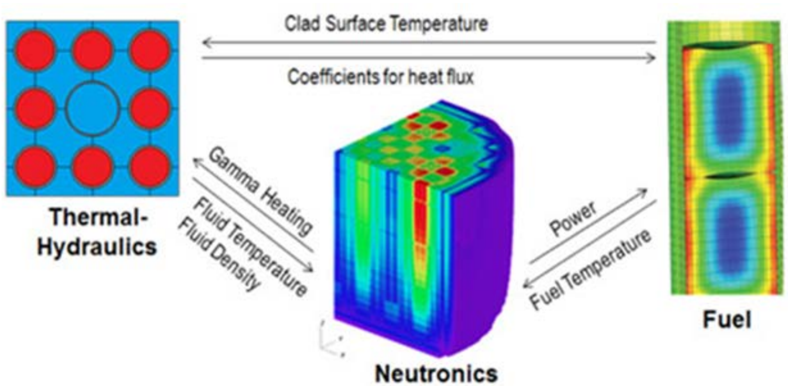


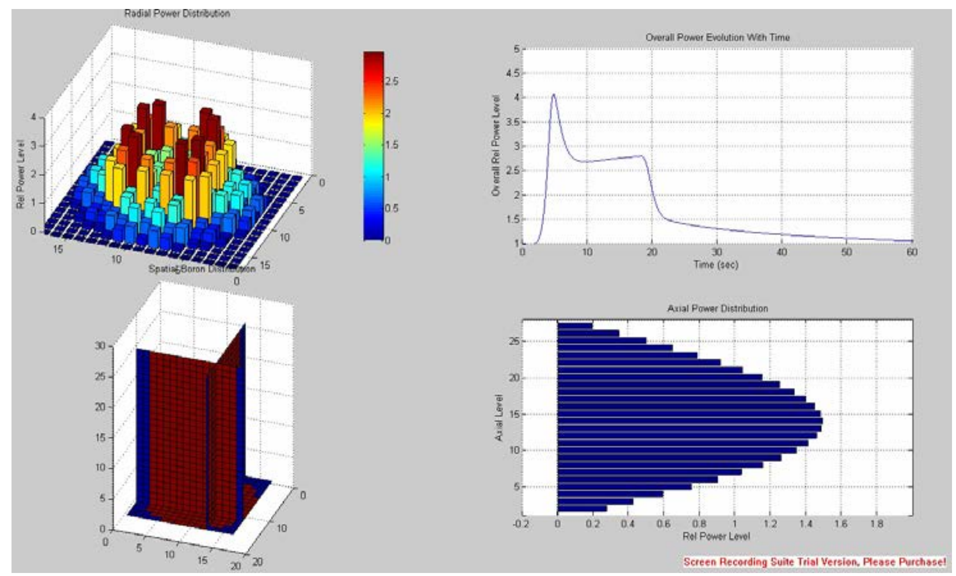
Multi-physics multi-scale interactions in a NPP

Multi-Physics Modeling





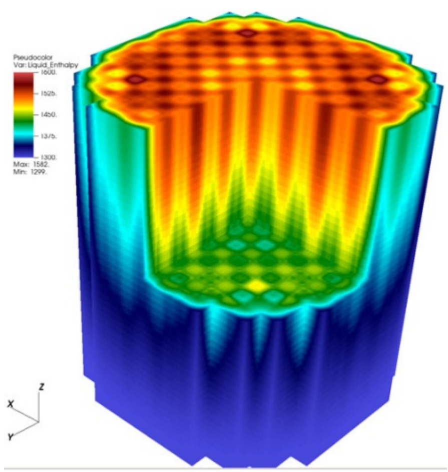




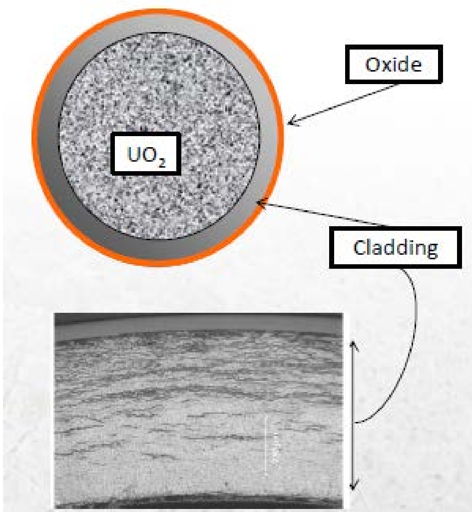
Multi-physics modeling of reactor core

Classification

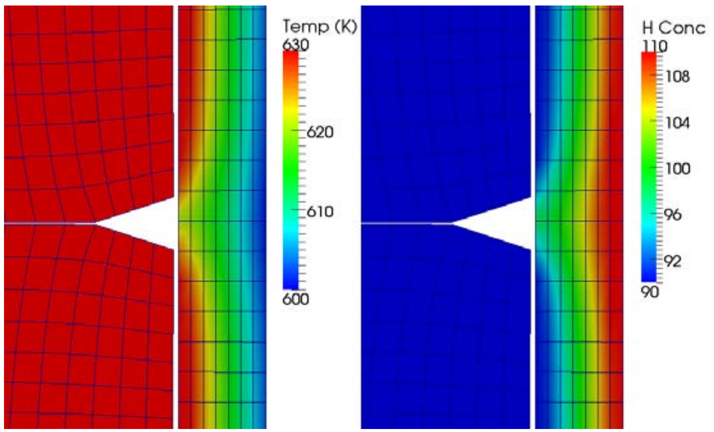
- The definitions of multi-physics simulation tools in the two groups (categories) are:
  - ✓ “Ttraditional” (T) tools, which include mostly neutronics/thermal-hydraulics coupling into reactor core on assembly/channel basis. The coupling of reactor core to the system and coupling of the system to containment also belongs to traditional (T) multi-physics simulations;
  - ✓ “Novel” (N) or state-of-the-art tools, which include high-fidelity coupling on pin/sub-pin (pin-resolved)/sub-channel level of several physics phenomena in reactor core such as neutronics (reactor physics), thermal-hydraulics, fuel performance, structural mechanics, chemistry, etc.



Pin / Subchannel Resolution (Liquid Enthalpy)



Hydride distribution and oxide layers on Zircaloy-4 irradiated for 6 cycles in a PWR



Prediction of the temperature and dissolved hydrogen distributions near the triple point in a LWR fuel rod

High-Fidelity Multi-Physics

- A significant opportunity exists to apply advanced modeling and simulation and high-performance computing to improve designs of reactors, reduce uncertainty of predictions, and improve safety

- An integrated high-fidelity system of software tools should describe the overall nuclear plant behavior taking into account coupling among the different systems and physical phenomena during reactor operations or safety related transients

- This coupling should link neutronics, fuel behavior, fluids and heat transfer, chemistry and structural mechanics. The system must also be coupled with the balance-of-plant software tool

- Such system should perform sensitivity and uncertainty analyses to assess margins, qualify, validate, and optimize designs

- The recent advances and developments in reactor design and safety analysis are towards more physics-based high-fidelity simulations, which allow for insights and understanding needed to resolve industry challenge/high impact problems previously impossible with traditional tools

Approaches to High-to-Low Fidelity Model Information

- ✓ Currently there is a trend in nuclear reactor research and industry to use high-fidelity models and codes to inform low-fidelity models and codes.
- ✓ Due to their complexity, the high-fidelity codes are computationally expensive, and may take on the order of hours to days to complete a simulation run.
- ✓ This motivates the use of low-fidelity models, which are less comprehensive but provide numerical efficiency required for practical applications in design and safety evaluations.
- ✓ These low-fidelity codes have parameters or inputs which must be informed or calibrated using experimental data or simulations from validated high-fidelity codes.
- ✓ High-fidelity models can be used to predict physical behavior in regimes or on scales where physical data is not available.
- ✓ A number of methods have been proposed to address the integration of high-fidelity and low-fidelity codes to predict quantities of interests in an efficient manner.
    - o The first approach is based on ***non-linear multi-scale frameworks***, which have been applied in reactor physics (neutronics) and heat-transfer simulations.
    - o This second type utilizes information theory in ***a Bayesian framework*** to use high-fidelity codes to calibrate low-fidelity codes.
    - o In the third approach, the overall physical phenomena and corresponding effects are dissected in corresponding building basic processes, and corresponding models are informed using high-fidelity codes. This method is called a ***Physics-based Approach*** for High-to-Low Model Information.