Modeling and Simulation at INL

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MOOSE Multiphysics
National Needs and INL Focus Areas

• NPP component aging and damage evolution, structural mechanics
  – Grizzly: LWRS R&D to safely operate NPPS beyond original design life

• Multi-scale fuels performance
  – BISON: Engineering-scale fuel performance application
  – Marmot: Meso-scale multiphysics simulation tool

• Radiation physics for irradiated nuclear fuel & materials
  – Rattlesnake: Multi-scale multi-level radiation transport
  – MAMMOTH: Advanced Multi-Scale reactor physics coupling Rattlesnake, BISON with depletion
  – Sabertooth: MAMMOTH with RELAP-7 and Marmot (created to address licensing issues)

• Reactor systems/safety analysis
  – RELAP-7: Reactor Excursion and Leak Analysis Program
  – REDTAIL - Risk-informed Environment for Dynamic Time-dependent Analysis)

• Seismic and Repository Analysis
  – MASTODON (Multi-hazard Analysis for STOchastic time-DOmain phenomena)
  – BADGER: Barrier Analysis Design software for Geologic Engineered Repositories

• In short, INL’s emerging M&S technologies are directed toward predicting and tracking the fuel state from beginning of life in a reactor through extended long term storage (300 years) to geologic disposal.
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National Needs and INL Focus Areas

- Do not think of this as multiple projects. It is one project composed of multiple
development efforts in closely coordinated teams
- Any of these are both INL needs and potential collaboration areas
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Potential University Collaboration Areas

- Our current funding programs include:
  - The Nuclear Energy Advanced Modeling and Simulation (NEAMS) program
  - The Light Water Reactor Sustainability (LWRS) program
  - Consortium for Advanced Simulation of LWRs (CASL)
  - INL’s Laboratory Directed Research and Development (LDRD) program

- Our funded projects support:
  - Advanced M&S for the Transient Reactor Test Facility (TREAT) - NEAMS
  - RELAP-7 development: LWRS, NEAMS
  - BISON development and validation: Accident Tolerant Fuels (ATF), NEAMS, in-kind support from Halden

- INL M&S teams are collaborating with:
  - NRC
  - NNL (Bettis/KAPL)
  - EPRI
  - ANL (PETSc)
  - UTexas (LibMesh)
  - OECD/NEA
  - LANL
  - Significant no. of universities (including all of NUC)
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Potential University Collaboration Areas

Our areas of interest outside of currently funded work:
- Advanced Test Reactor (ATR) modeling
- Validation
  - TRIGAs
  - ATR and ATR experiments
  - TREAT experiments
  - LWR measurements (startup testing, spent fuel characterization)
- Multiphysics measurements of any kind
- Flow/surface measurements for closure relationships
- HTGR and FHR concepts
- Advanced reactor concepts
- Space reactors
- 3D Kinetics
- Multiphysics based on Monte Carlo transport methods.
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Potential Funding Sources

- NEUP
- NNSA
- INL LDRD
- ART
- NEAMS
- NRC
- ARPA-E
- Office of Science
- Industry
Background information
INL Developed MOOSE-based Tools Available for NUC Collaboration

Component aging and damage evolution, structural mechanics:

**Grizzly:** LWRS R&D to safely operate NPPS beyond original design life
- Structural mechanics for reactor pressure vessel (RPV), containment vessels, fuel assemblies, etc.
- Reactor Metals (embrittlement, fatigue, corrosion, etc.), e.g. RPV, core internals, and weldments.
- Long-term concrete degradation (mechanical, chemical, and irradiation).

Multi-scale fuels performance, **BISON and Marmot:**

**BISON:** Engineering-scale Fuel Performance Application (LDRD)
- All-fuels: Models LWR, TRISO, plate, and metal fuels in 1D, 2D and 3D.
- Tightly coupled to reactor physics applications.

**Marmot:** Meso-scale Multiphysics Simulation Tool (LDRD)
- Predicts coevolution of microstructure and physical properties due to applied load, temperature, and radiation damage. Designed to correct BISON’s empirical models in a coupled manner.
- Phase field modeling coupled to finite strain mechanics and heat conduction.
Radiation Physics for Irradiated Nuclear Fuel & Materials

**Rattlesnake**: Multi-scale Multi-level Radiation Transport (LDRD):
- Multi-scale: Assembly homogenized, pin-homogenized, fuel-resolved simultaneously in one simulation
- Designed to support tightly coupled nonlinear multiphysics simulations, *primarily focused on fuel performance analysis*, both locally and core-wide for safety issues and ATF design (strong transients).
- ATR and TREAT simulation capability design goals.

**MAMMOTH**: Advanced Multi-Scale Nuclear/Reactor Physics:
- Isotopic composition to update local fuel thermal-mechanical-chemical property evolution and fission gas inventories.
- Isotope, density, and temperature feedback (to account for burnup) for cross-sections.

**Reactor Systems/Safety Analysis**

**RELAP-7**: Reactor Excursion and Leak Analysis Program
- The Next Generation Reactor System Analysis Tool
- The overall design goal of RELAP-7 development is to leverage 30 years of advancements in software design, numerical integration methods, and physical models.
- Multi-physics integration with other MOOSE-based applications (BISON, MAMMOTH, Rattlesnake)
**Reactor Systems/Safety Analysis**

**REDTAIL: Risk-informed Environment for Dynamic Time-dependent Analysis:**

- Dynamic Probabilistic Risk Analysis (D-PRA)
- Event sequence control (for D-PRA)
- Coupled multi-physics (RELAP-7, BISON, etc.)
- Risk Informed Safety Marine Characterization (RISMC)

**Seismic and Repository Analysis**

**MASTODON (Multi-hazard Analysis for Stochastic time-DoMAIN phenomena):**

- Seismic effects on NPPs (stochastic nonlinear soil-structure interaction)
- Structural dynamics provided by Grizzly
- Dynamic porous media flow, hysteretic nonlinear soil constitutive models (elasticity and plastic flow directions, and hardening softening laws)
- Hysteretic nonlinear structural constitutive models, and geometric nonlinear soil behavior (gapping and sliding)

**BADGER: Barrier Analysis Design software for Geologic Engineered Repositories (LDRD):**

- Single and multiphase porous flow
- Heat/Energy transport, Reactive Transport, Geomechanics
- Simulate across spatial and temporal scales from EBS to far field in one simulation