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Full Core Nuclear Reactor Simulation with Fuel Shuffle

MOOSE Framework: Continuous Integration for Concurrent MOOSE Framework and Application Development using GitHub

Multiscale Full Core Nuclear Reactor Simulation

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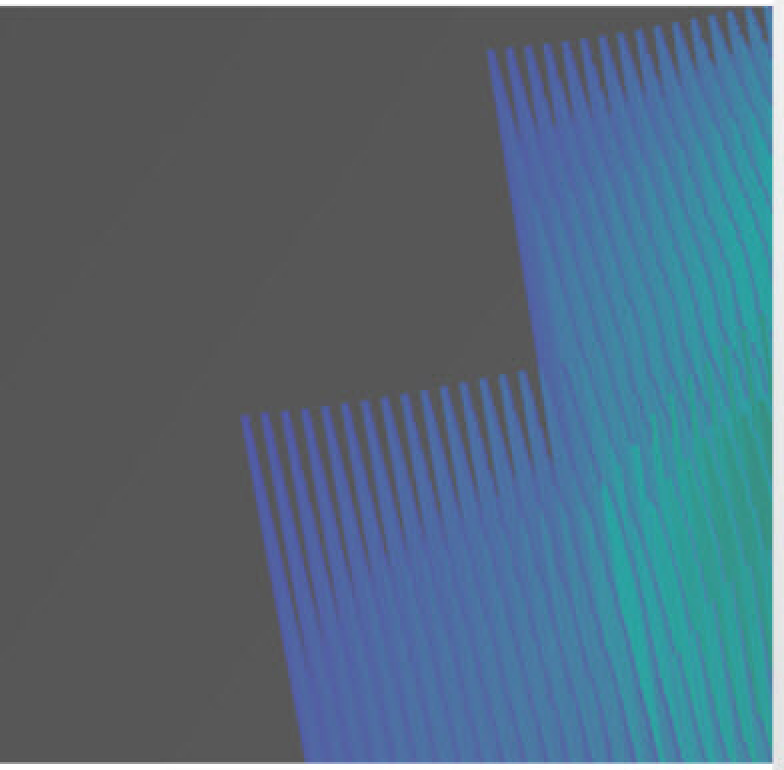
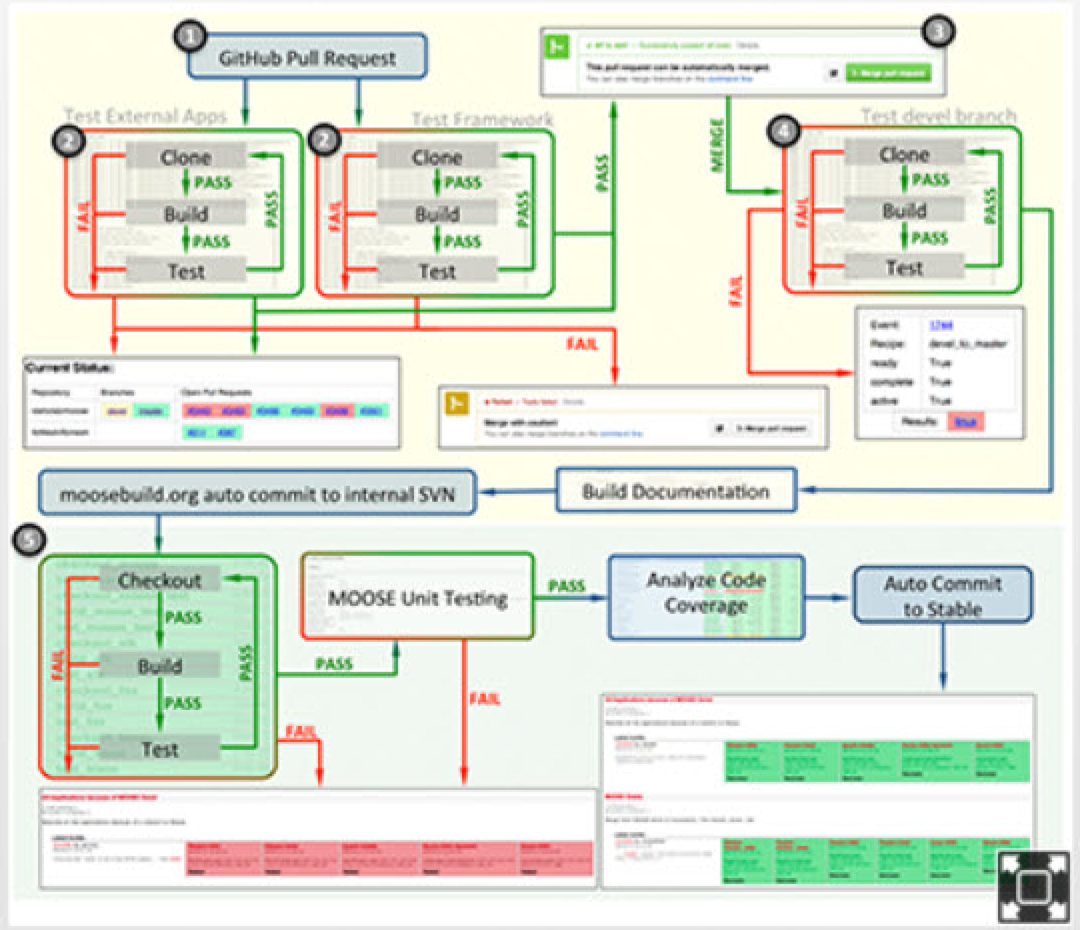


MOOSE Framework: Continuous Integration for Concurrent MOOSE Framework and Application Development using GitHub

Idaho National Laboratory's MOOSE project (www.mooseframework.org) employs modern software engineering techniques such as continuous integration (CI) and automated testing to develop open-source multiphysics simulation software in a three-tired repository structure comprised of (I) the MOOSE framework, (II) individual MOOSE-based applications (public and private), and (III) the INL-hosted SVN repository. The framework makes extensive use of GitHub-specific features such as Issue tracking, Pull Requests, and Forking.

The CI strategy requires every change to undergo a series of tests to ensure that three repository tiers continue to build and pass their test suites. Toward this end, a multi-level build and testing system called MooseBuild was developed that integrates with GitHub and facilitates the testing of MOOSE and its applications. The process is depicted graphically in the flowchart below, which begins by (1) proposing a change via "Pull Request", (2) testing the proposed changes, (3) merging the changes, (4) performing additional, more robust testing prior to merging to the "master" branch, and (5) testing internal INL-hosted applications.



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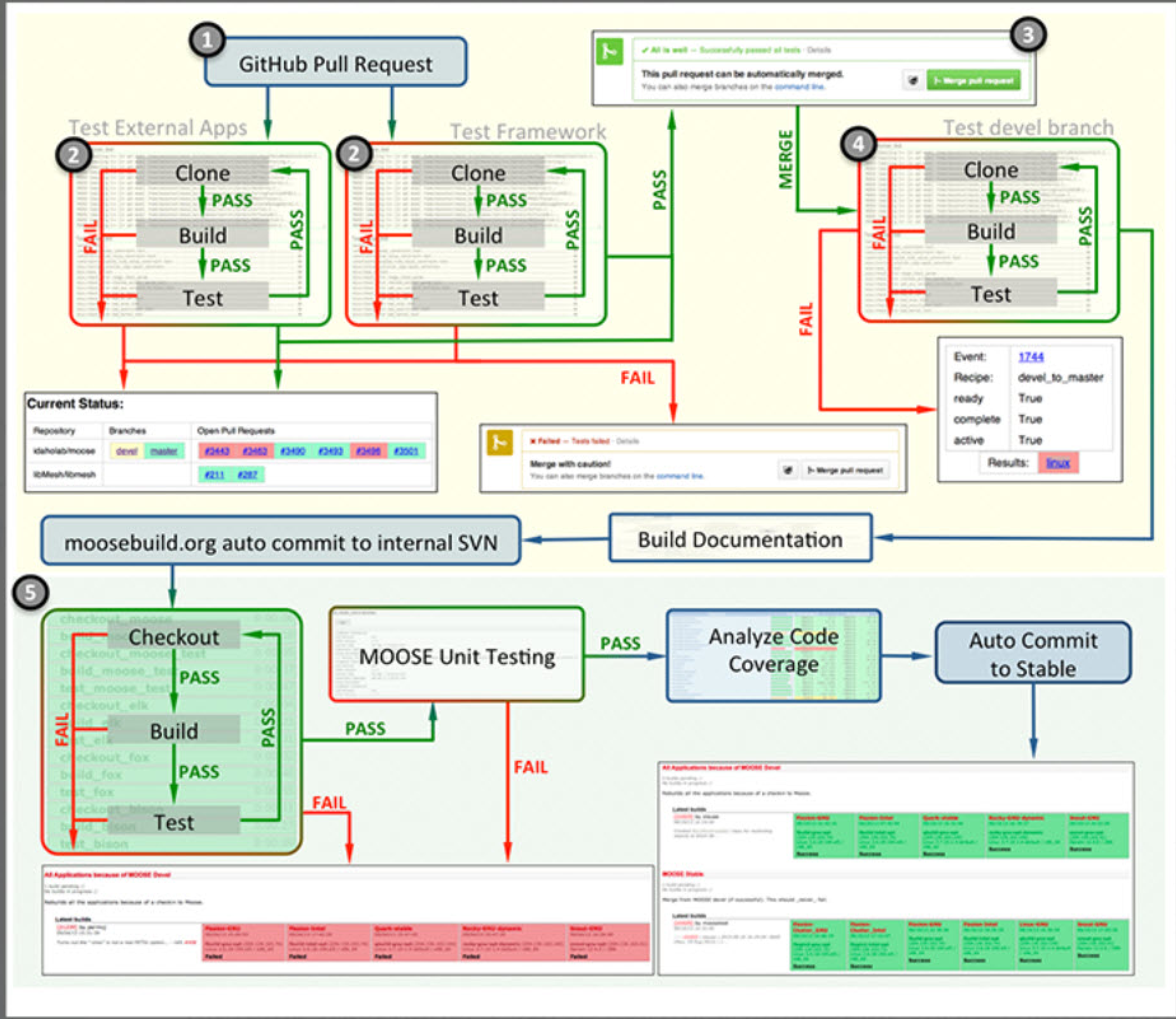

Flowchart depicting the MooseBuild system. Developers propose changes to MOOSE using GitHub pull requests, which are automatically tested. If all tests pass and the code is approved, the change is merged, which triggers the second (merging devel to master) and the third (merging master into the INL-hosted repository) levels of testing.

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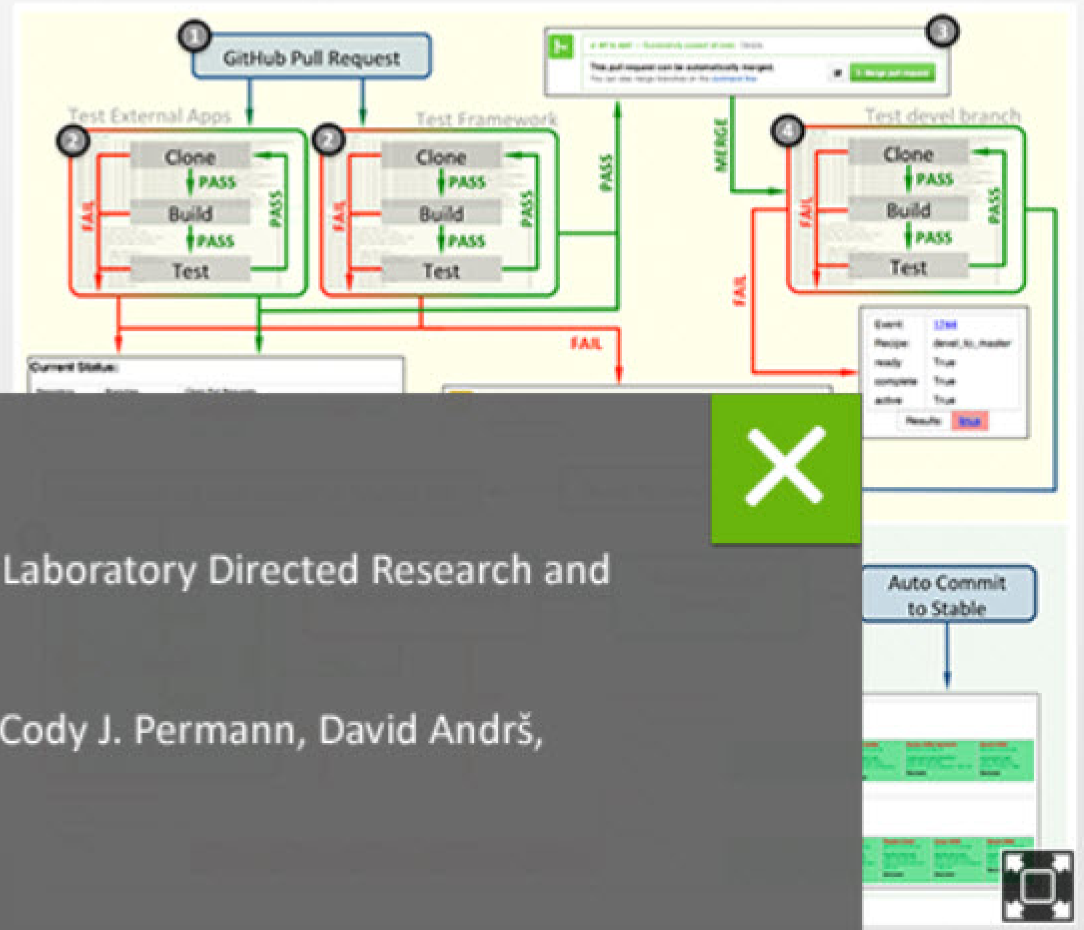

FUNDING AGENCY: Idaho National Laboratory: Laboratory Directed Research and Development

AUTHORS: Derek R. Gaston, John W. Peterson, Cody J. Permann, David Andrš, Jason M. Miler, and Andrew E. Slaughter

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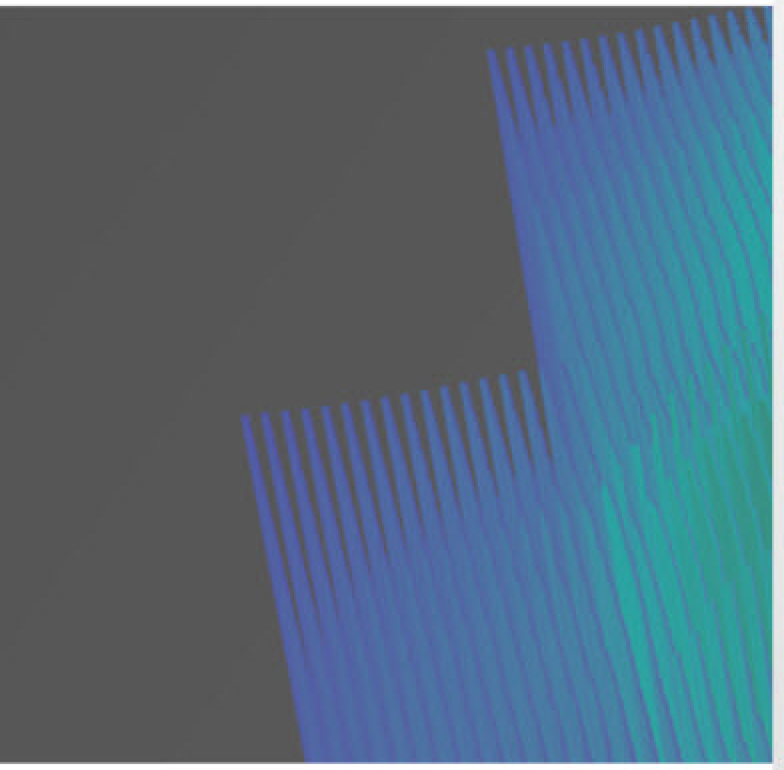

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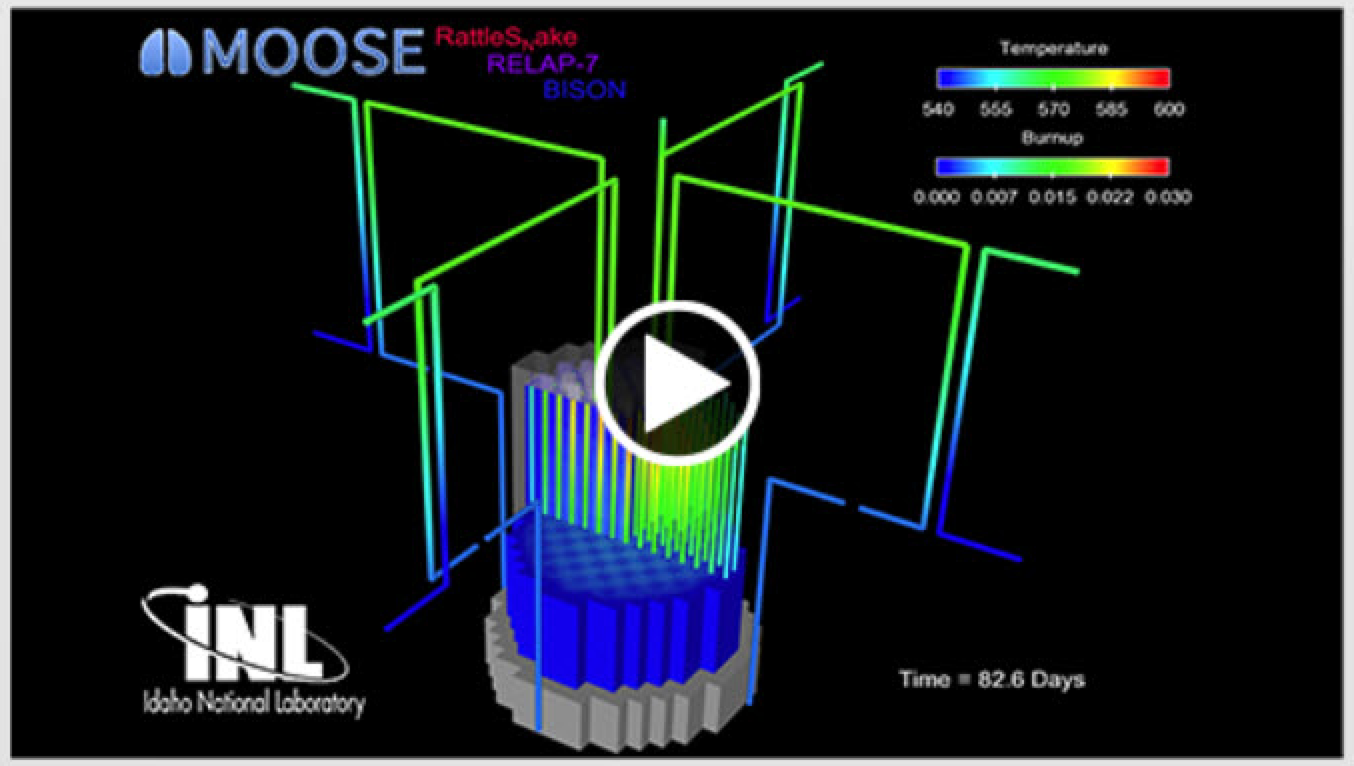
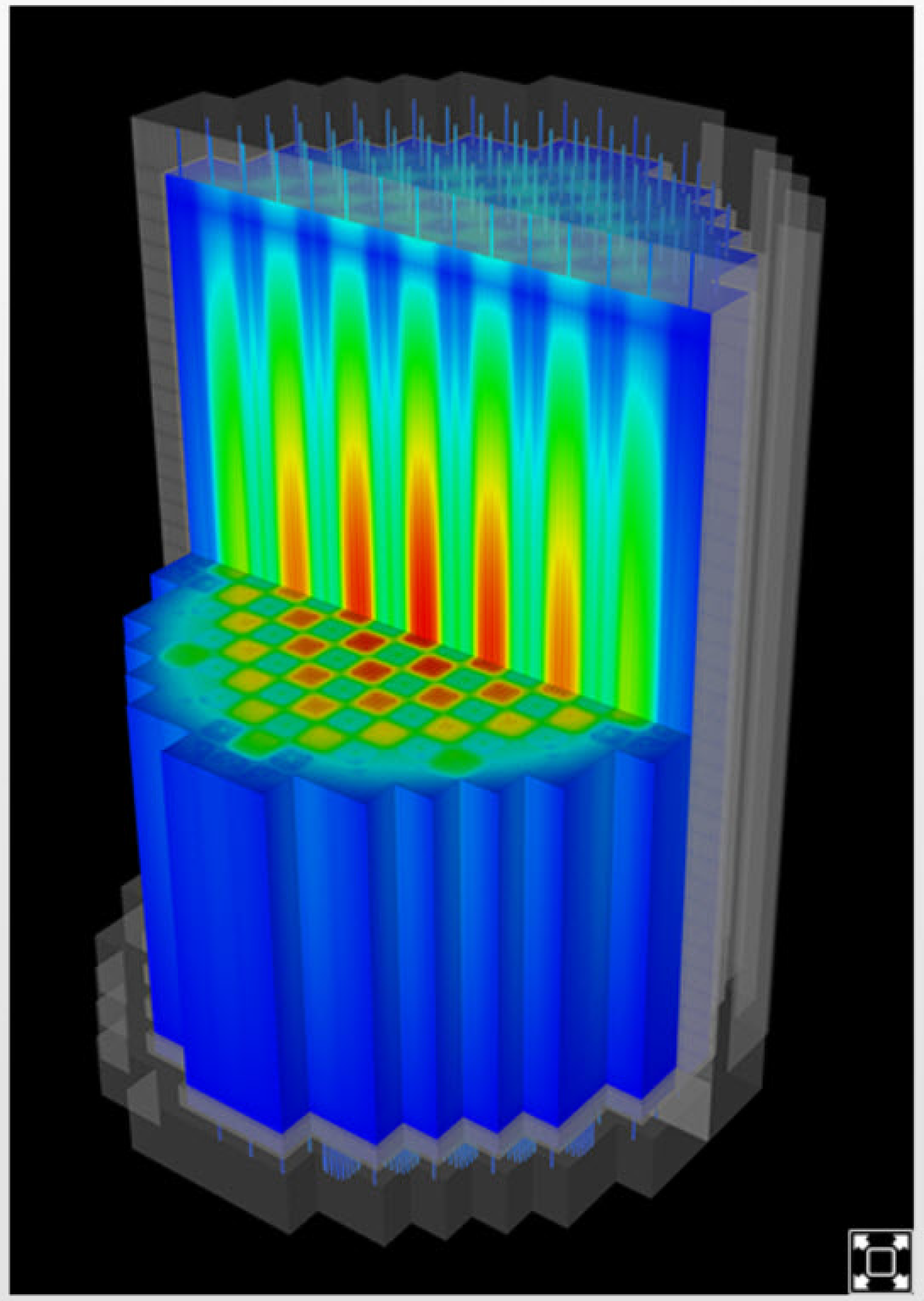
Full Core Nuclear Reactor Simulation with Fuel Shuffle

Simulation of nuclear reactors is a key technology in the quest for advances in efficiency, safety, and reliability of existing and future reactor designs. Historically, simulation of a reactor was accomplished by linking existing codes that each simulated a portion of the reactor. Recent advances in the MOOSE (Multiphysics Object Oriented Simulation Environment) framework have enabled a new approach, dubbed "multicoupling," in which multiple domain-specific applications, all built utilizing the same software framework, are efficiently linked to create a cohesive application. A first-of-a-kind multiphysics simulation of a full Westinghouse AP-1000 nuclear reactor was accomplished using this flexible capability.

Based on public design documents, a neutronics mesh was developed, cross-sections were computed using DRAGON-4, a RELAP-7 piping network was created, and a BISON fuel rod model was generated for the AP-1000. The simulation used RattleSNake for modeling neutronics, and was comprised of 41,448 fuel rods, each modeled with BISON. In total, 157 assemblies, with one flow channel per assembly, were used. The simulation includes a fuel shuffle at a simulation time of 351 days that relocates high-burnup fuel and adds new fuel to the center assembly.





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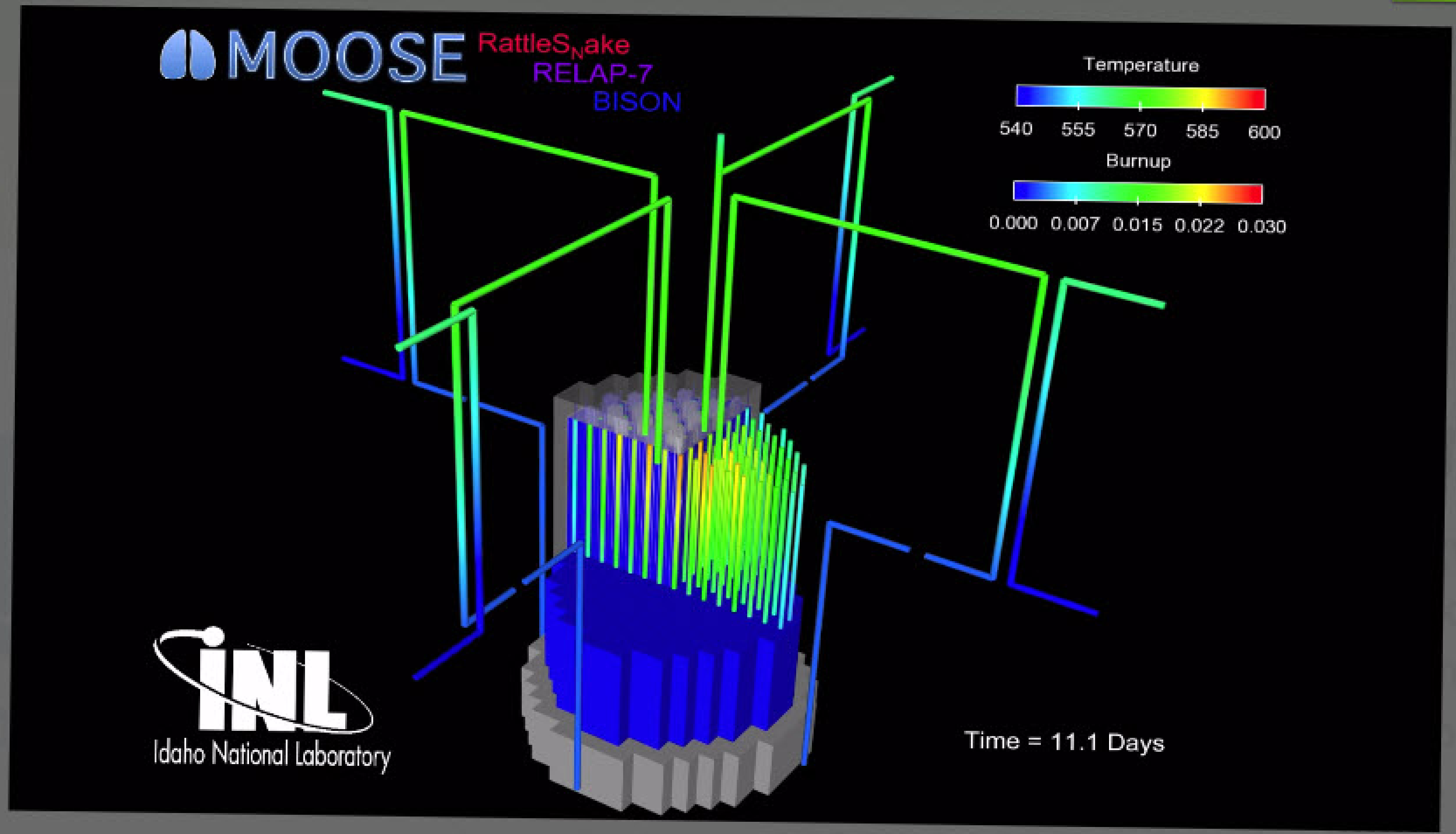

Results of the full core Westinghouse AP-1000 simulation. The first movie shows burnup computed by the neutronics code RattleSNake and the second shows the displacement and temperature of the fuel as computed by the 41,448 BISON simulations.

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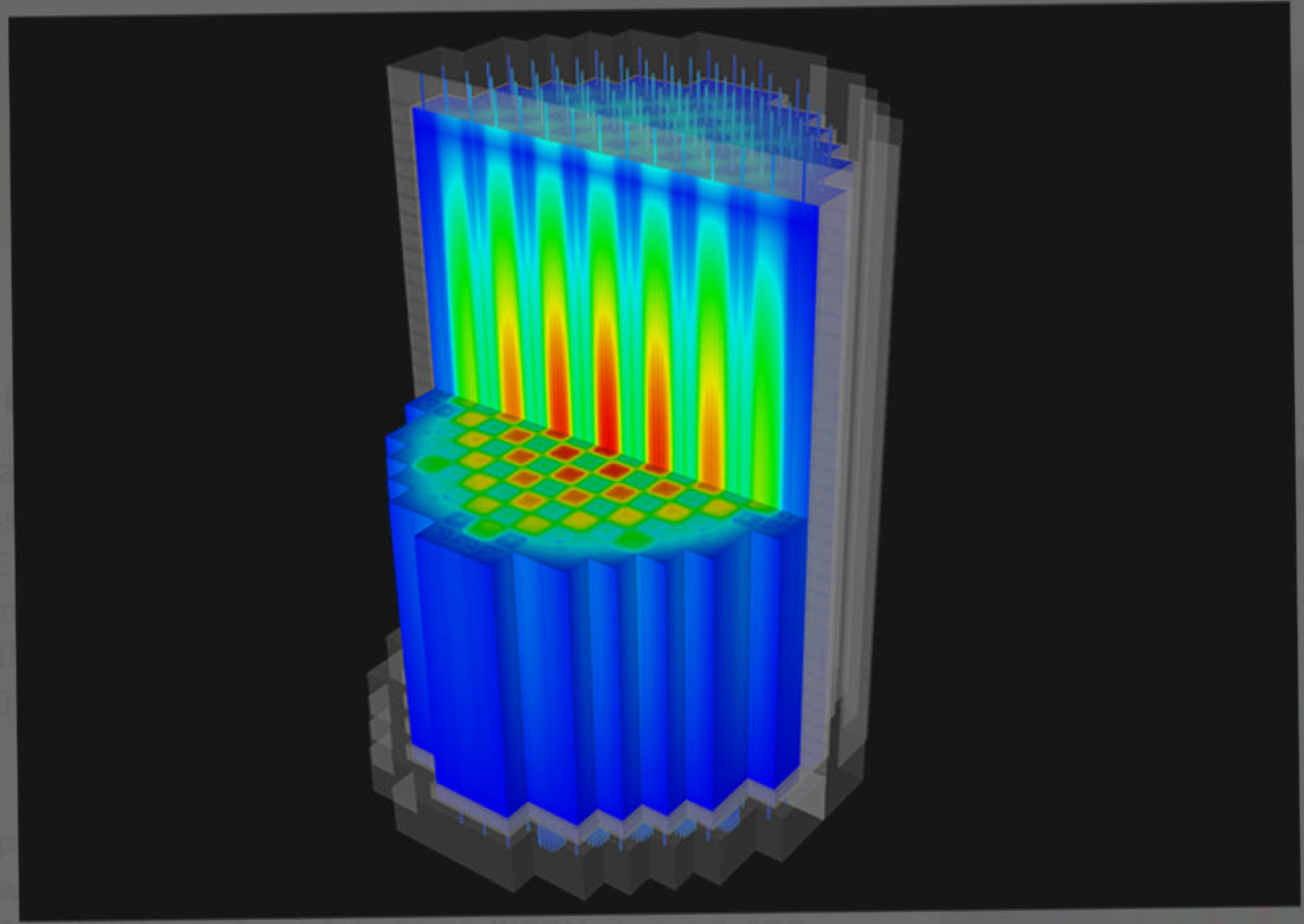
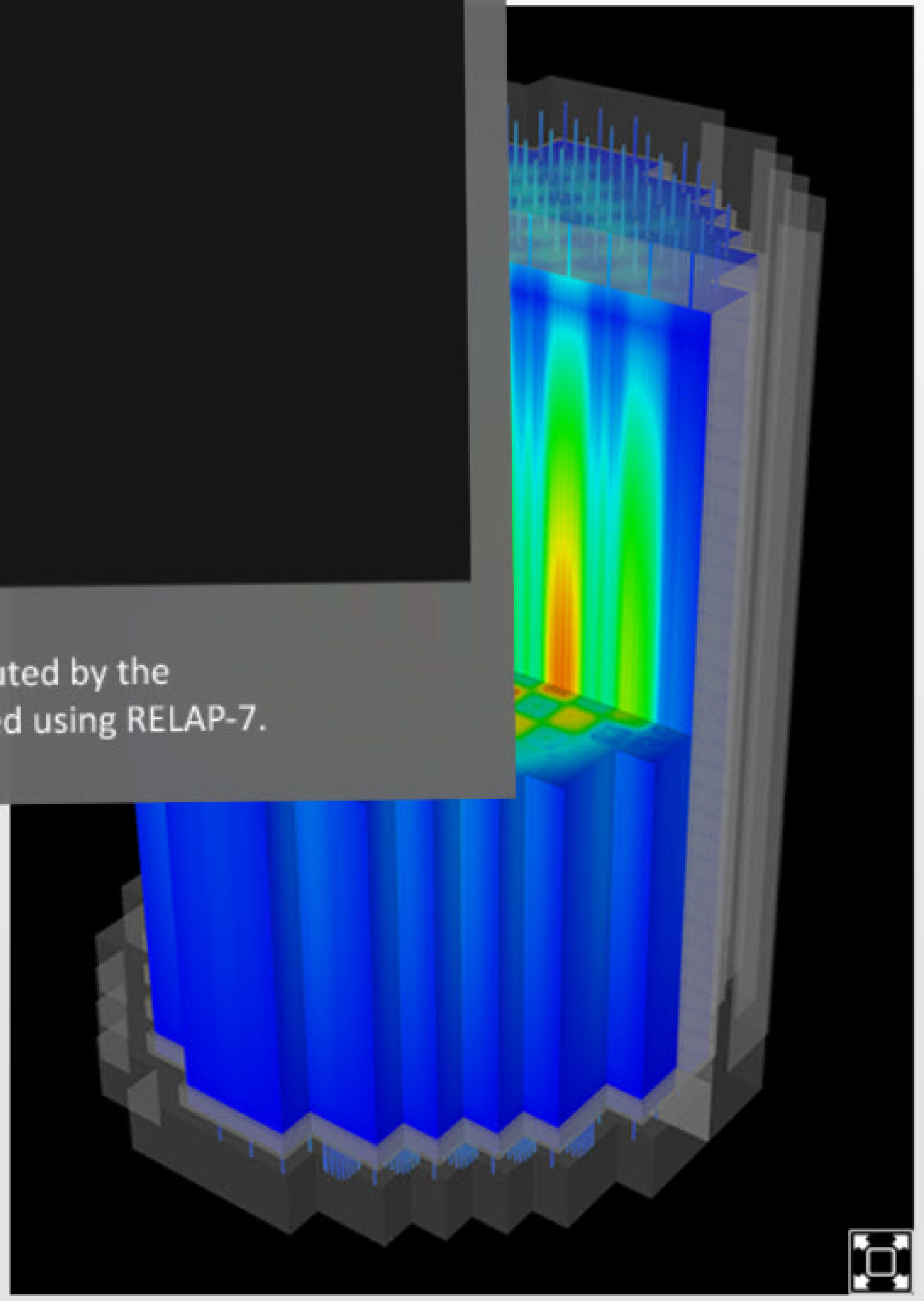
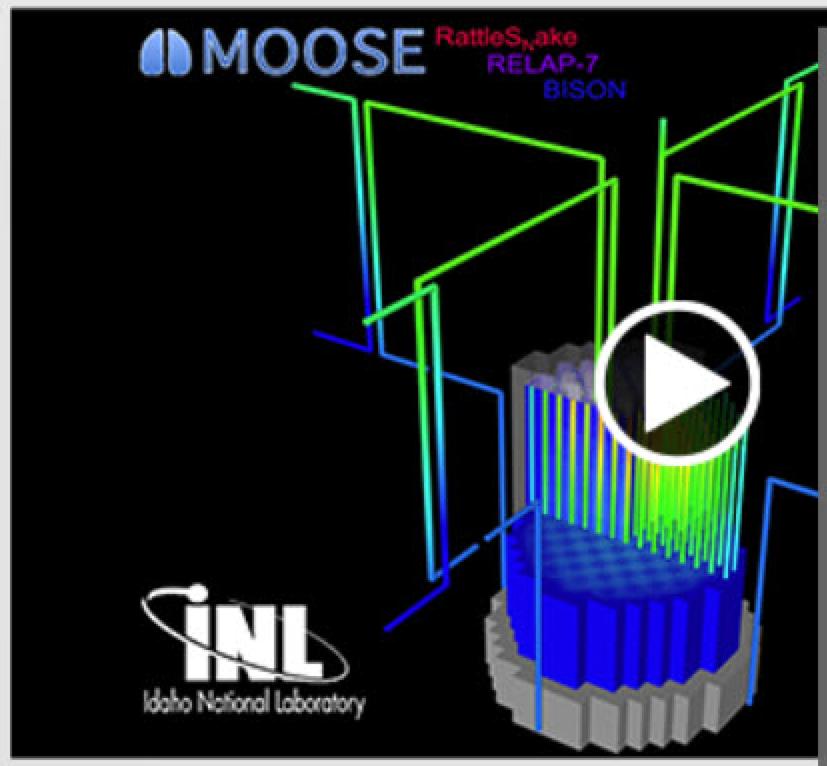


Westinghouse AP-1000 reactor core showing burnup (as computed by the neutronics code RattleSNake) and the coolant channels modeled using RELAP-7.





FUNDING AGENCY: Idaho National Laboratory: Laboratory Directed Research and Development

RESOURCE: Fission, Idaho National Laboratory High Performance Computing

ALLOCATION: 2160 AMD Opteron processors; 51,840 core hours; 16.875 TB of memory; 2.2 TB of results

AUTHORS: Derek R. Gaston, Cody J. Permann, John W. Peterson, Andrew E. Slaughter, David Andrš, Jason M. Miller, Yaqi Wang, Michael P. Short, Danielle M. Perez, Michael R. Tonks, Richard C. Martineau

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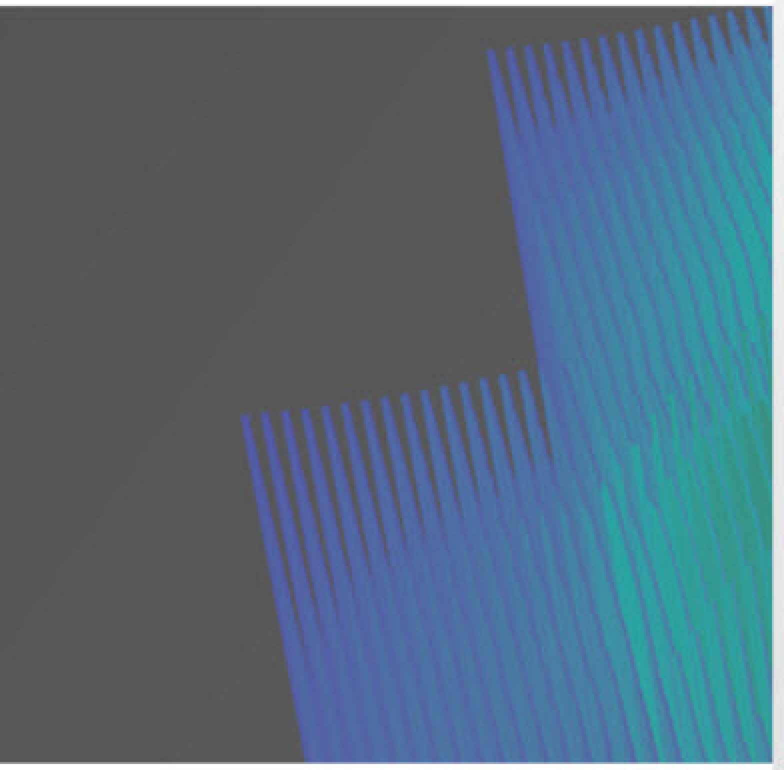

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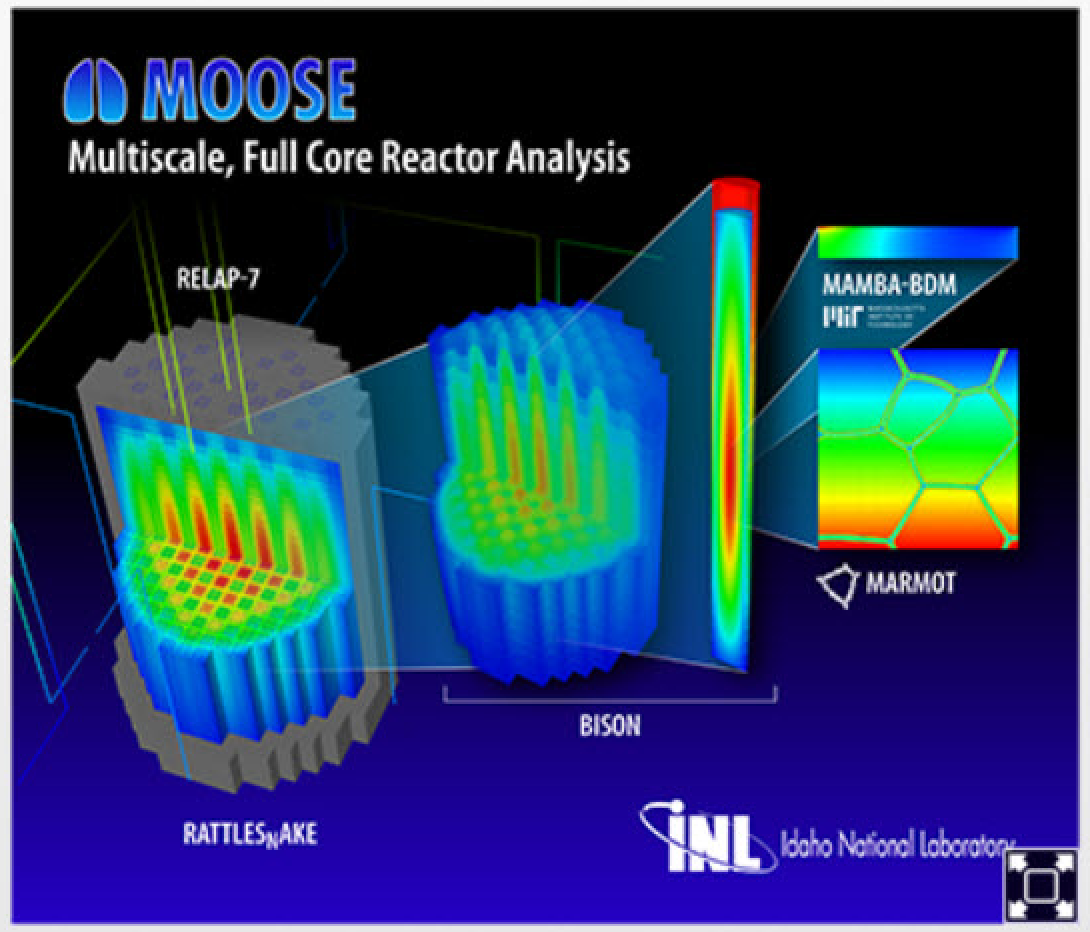
Multiscale Full Core Nuclear Reactor Simulation

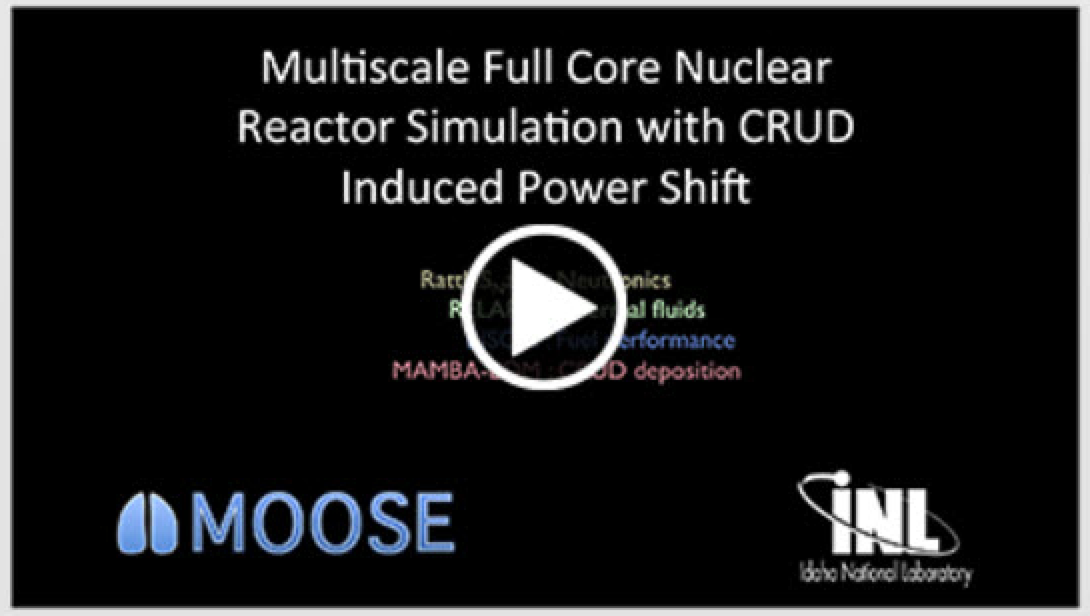
The MOOSE (Multiphysics Object Oriented Simulation Environment) framework is capable of modeling a complete light water reactor (LWR), enabling exploration of issues relevant to the nuclear power industry. Nuclear reactors are inherently multiscale systems. Several reactor operational issues are the direct result of microstructural effects, including: CRUD (Chalk River Unidentified Deposits) Induced Power Shift (CIPS), clad hydride formation and embrittlement, and fuel thermal conductivity degradation.

Due to the hierarchical nature of MOOSE's "MultiApp" system, these effects can be easily integrated into a multiscale LWR simulation composed of various independently developed MOOSE-based codes. This integration is possible without direct modification to the source code of any of the individual applications.

A complete reactor simulation coupling five independent applications was performed. The simulation utilized RattleSNake for modeling neutronics, BISON for the 3,432 fuel rods, RELAP-7 for the coolant channels, MARMOT for microstrucutral evolution of the fuel, and MAMBA-BDM for modeling CRUD. Each of the 3,432 BISON rods included three MARMOT simulations (10,296 in total) and six MAMBA-BDM simulations (20,592 in total). The CRUD microstructure simulation incorporated models for porous flow and Boron deposition

Of particular interest is the Boron deposition within the pores of the CRUD, which is the source of the axial power shift in LWRs. These CRUD deposits form at sites of sub-cooled nucleate boiling, typically on the upper spans of the fuel rods where the coolant is the warmest. The disproportionate amount of Boron in the upper part of the reactor absorbs neutrons, damping fission rates in that area.





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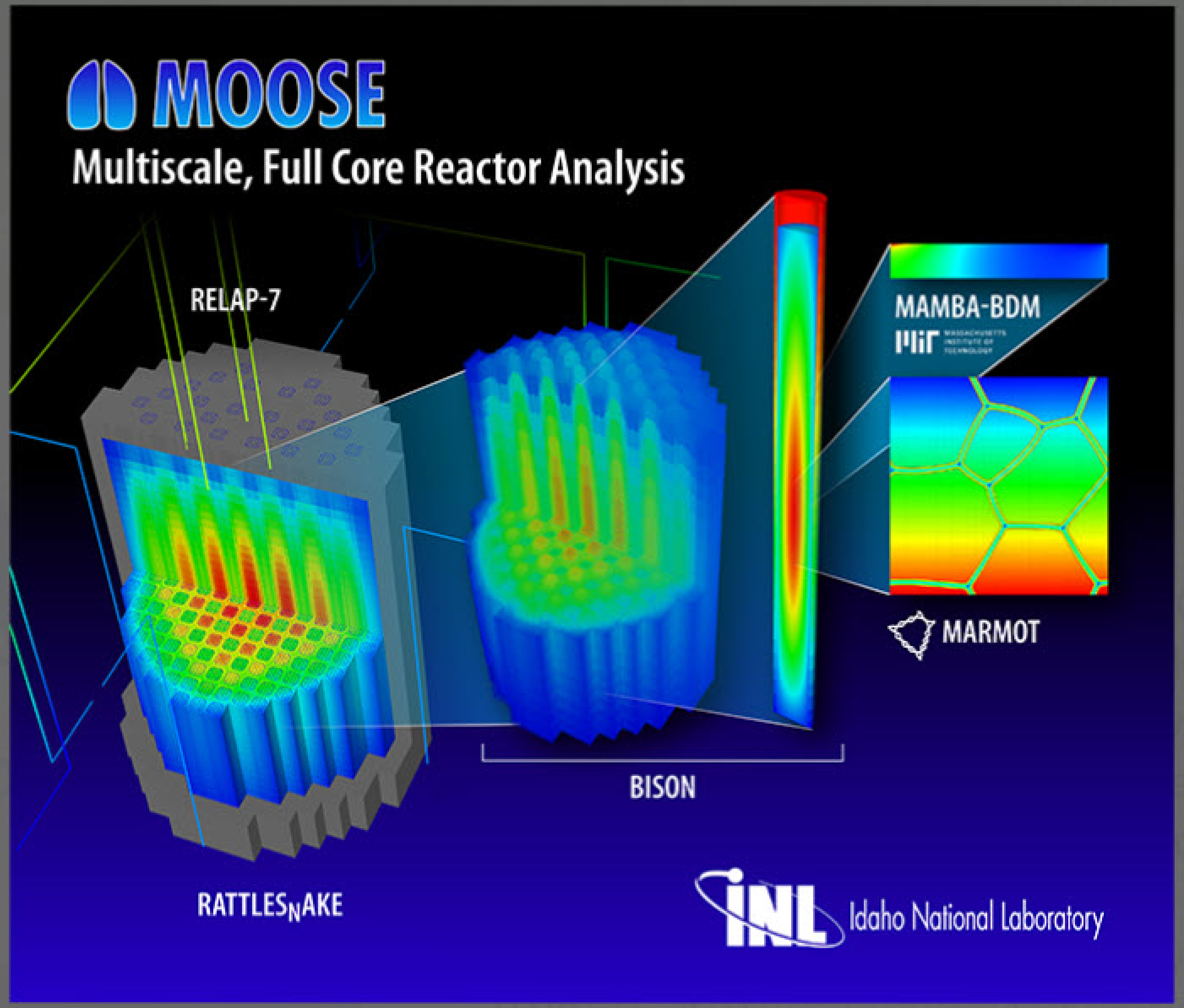

Depiction of full-core, multiscale light water reactor simulation including microstructure evolution of the fuel (MARMOT) and CRUD (MAMBA-BDM).

Results of the full core, multiscale simulations of the 3D KAIST-3A benchmark. The first movie shows a power shift due to CRUD as modeled with MAMBA-BDM, and the second movie shows the complete multiscale simulation using both microstructure models: MARMOT and MAMBA-BDM.

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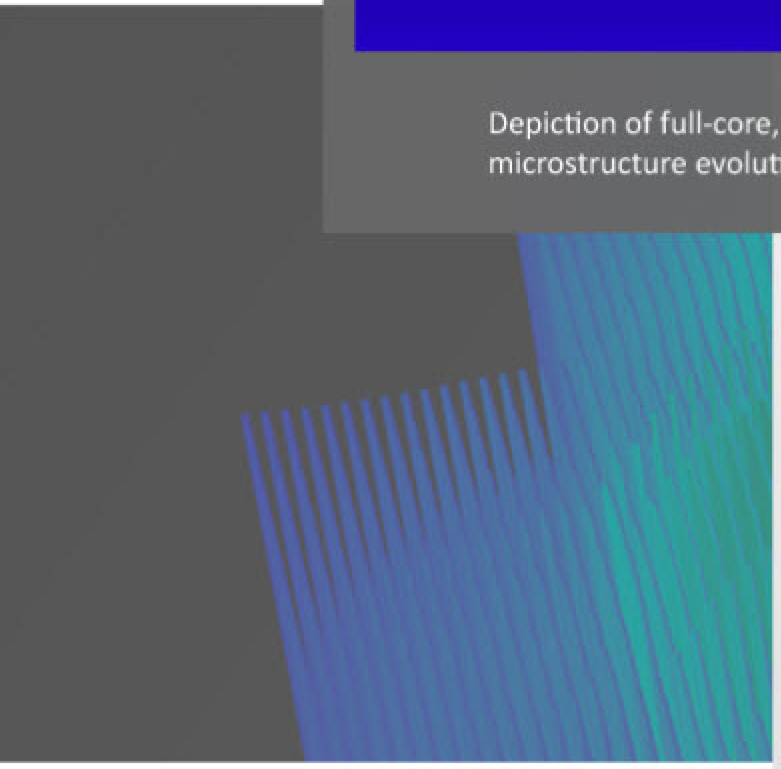
FUNDING AGENCY: Idaho National Laboratory: Laboratory Directed Research and Development

RESOURCE: Fission, Idaho National Laboratory High Performance Computing

ALLOCATION: 3,432 AMD Opteron processors; 467,899,997 total degrees-of-freedom

AUTHORS: Derek R. Gaston, Cody J. Permann, John W. Peterson, Andrew E. Slaughter, David Andrš, Jason M. Miller, Yaqi Wang, Michael P. Short, Danielle M. Perez, Michael R. Tonks, Richard C. Martineau



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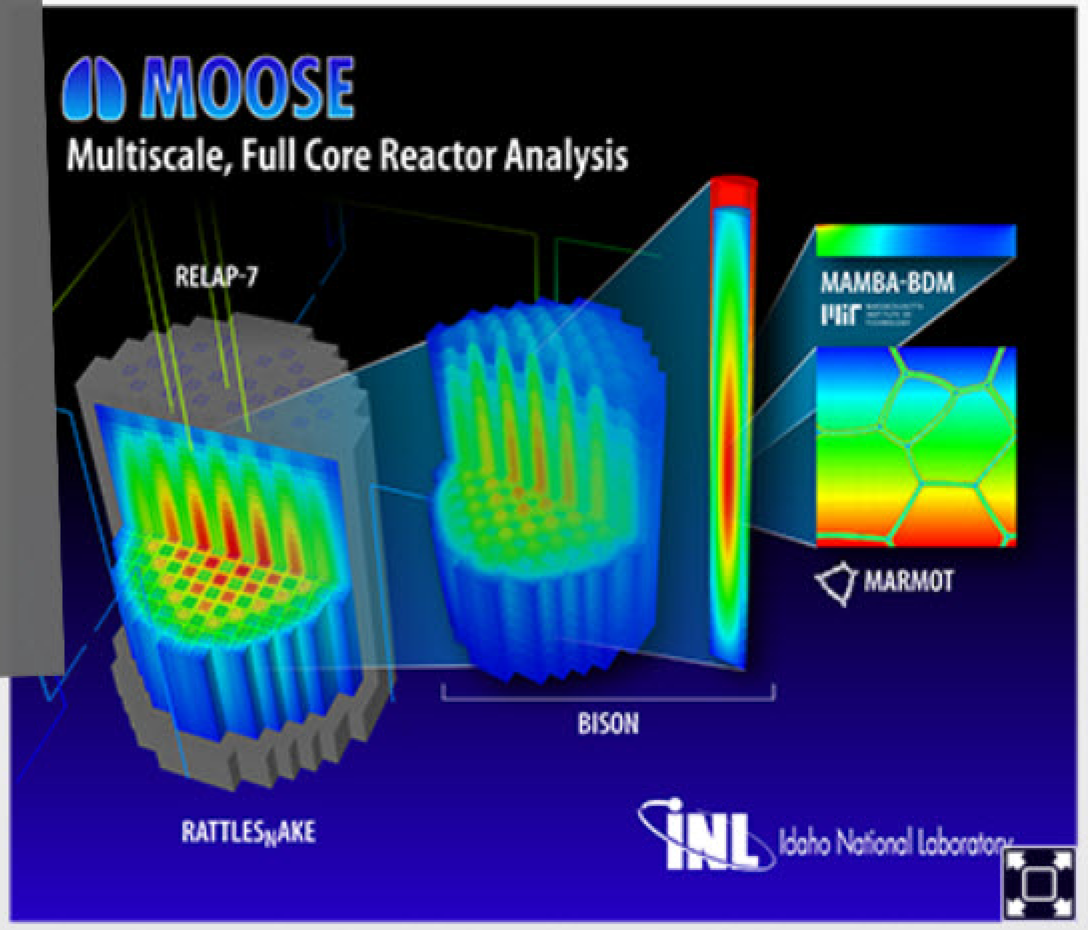

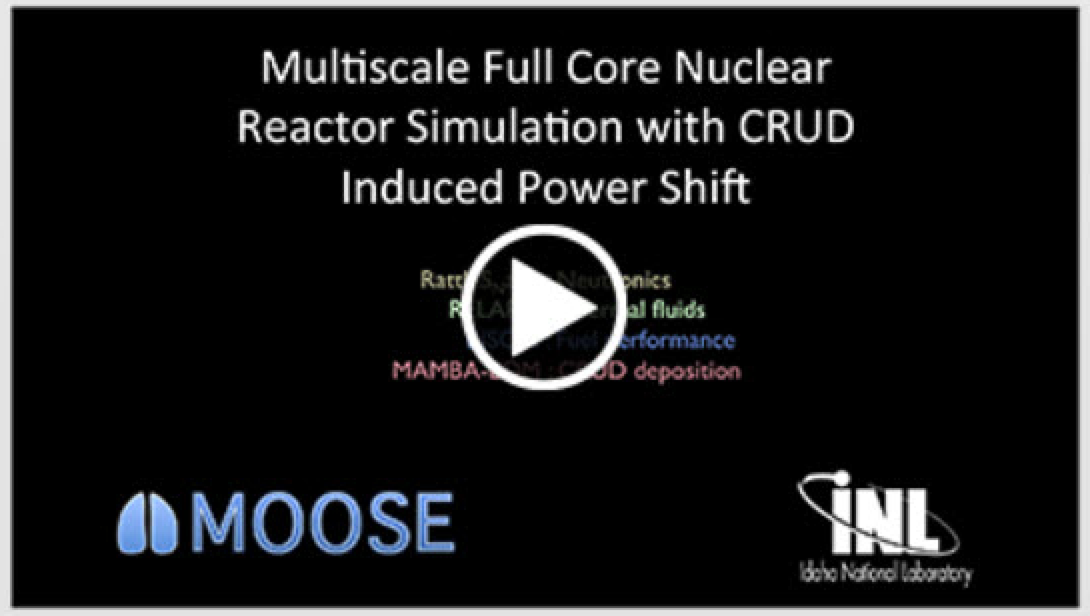

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