Griffin: A Reactor Physics Tool for Multiphysics Modeling Simulation of Advanced Nuclear Reactors

Product/category

- IT/Electrical

Primary submitting organization:
Idaho National Laboratory

Name(s) of co-developing organization(s) if applicable:
Argonne National Laboratory

Product/services brand name:
Griffin

Price of product/service in U.S. dollars:
Free

When product was introduced to the market:
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Abstract:
The Griffin reactor physics tool for multiphysics modeling and simulation makes advanced nuclear reactor design cheaper and safer by predicting how different reactor designs, fuels and materials will perform in real life. Used by nuclear energy researchers, regulators and industry, Griffin is a cornerstone of the nation's advanced-reactor development.

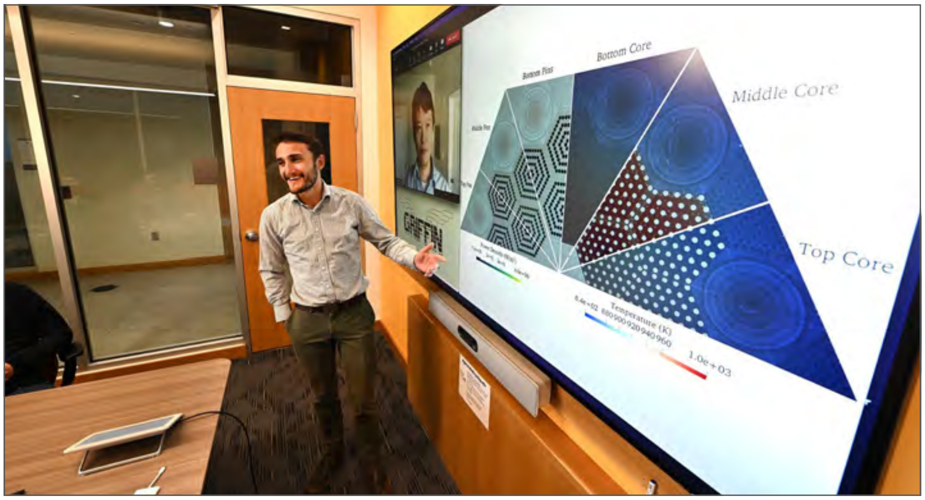

Figure 1: Griffin helps predict how different reactor designs will perform.

Executive summary:
As the U.S. craves new energy sources to increase the standard of living, power new technologies and increase the nation's energy security, advanced nuclear energy has emerged as an important option for 24-7 reliable electricity and heat.

Researchers and industry have developed dozens of reactor designs that will soon power remote communities, mining operations, military bases and data centers. Other advanced reactors will provide high-temperature heat and electricity for communities and industry.

But before these advanced reactors become a reality, researchers, industry and regulators need a way to test their safety and performance without building expensive prototypes.

Griffin is a reactor physics tool for multiphysics modeling and simulation that makes advanced nuclear reactor design cheaper and safer by predicting how different reactor designs, fuels and materials will perform in real life.

Where some modeling tools can simulate the basic functions of a reactor, Griffin provides the underlying physics that govern countless real-life interactions in the extreme environment of a reactor core.

Griffin has been used to analyze the designs of pebble-bed reactors, prismatic reactors, molten-salt reactors, fast reactors, microreactors and several experimental facilities.

Further, Griffin is an important tool for the Nuclear Regulatory Commission(NRC), NASA and fusion safety. In the end, Griffin is a cornerstone of the nation's advanced reactor development.

Video:
https://youtu.be/WUW2rrqeRhQ?si=Taap9XW1g55BuLSh

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What does this product or technology do?

Griffin is a reactor physics tool for multiphysics modeling and simulation for advanced nuclear reactors. Whereas some modeling tools can simulate the basic functions of a reactor, Griffin provides the underlying physics that govern countless real-life interactions in the extreme environment of a reactor core.

These extreme environments—which may include high temperatures, pressures and highly corrosive chemicals—can cause density changes, dimensional changes and changes in the chemical composition of materials and fuels.

Griffin is vital for designing the next generation of nuclear reactors because it helps researchers, industry and regulators understand these complex interactions without building expensive real-world prototypes. In other words, testing ideas by running a computer simulation in Griffin is infinitely cheaper and safer than building an actual prototype reactor.

The NRC has faced challenges developing regulations for advanced reactors, which have designs, fuels and coolants different from the current light-water reactor fleet. Thanks to its ability to produce highly accurate results, Griffin is becoming the go-to modeling and simulation tool for the NRC when evaluating advanced-reactor designs. The software has become a third-party arbiter and independent verifier for analyzing different versions of these designs. Griffin's software team has built reference models of the various advanced reactors that contain all the ingredients of the technology. The NRC contracts with the team to refine those reference models to reflect a reactor under review.

Griffin has been used to analyze pebble-bed reactors, prismatic reactors, molten-salt reactors, fast reactors, microreactors and several experimental facilities.

Further, Griffin has become important for space exploration. Its developers are now using the tool to help design nuclear systems for NASA. These systems include nuclear engines for rockets, microreactors for permenant settlements on moons and planets, and devices that provide heat and electricity for remote applications and spacecraft.

For example, Griffin is being used to model nuclear thermal propulsion for NASA's Demonstration Rocket for Agile Cislunar Operations, (DRACO) program, which is a demonstration of a nuclear thermal rocket engine in space with the ultimate goal of sending a crewed mission to Mars. Nuclear rockets produce more thrust than chemical rockets and can be fueled for years of space travel without the huge payload or refueling required for rockets that use chemical propellents. For NASA, that means that spacecraft could haul more equipment and personnel faster and farther, without exposing the crew to as much cosmic radiation.

In the future, Griffin will support safety design in fusion reactors. The code is useful for modeling neutron interactions in the breeding blanket—the part of the fusion reactor where neutrons interact with lithium to create the tritium fuel. Griffin will be important for ensuring the efficiency and safety of these fusion technologies.

How does the product operate?

When the U.S. Department of Energy envisioned a master modeling and simulation tool for advanced reactors, it picked Idaho National Laboratory and Argonne National Laboratory to serve as the development hubs.

Griffin evolved from the Rattlesnake and MAMMOTH modeling and simulation tools that were developed at Idaho National Laboratory as part of the award-winning Multiphysics Object Oriented Simulation Environment (MOOSE) modeling and simulation platform. In addition, Griffin incorporated technologies from the PROTEUS and MCC-3 codes developed at Argonne National Laboratory.

Griffin can operate within MOOSE or independently. Within MOOSE, Griffin provides the basic physics from which all other MOOSE tools are derived. Thanks to Griffin, MOOSE tools can simulate everything from nuclear-fuel performance and structural material degradation to fluid flow, heat transfer and chemical reactions within a reactor, and more.

To get a realistic idea of the behavior of a nuclear reactor, a modeling and simulation tool must be capable of simulating all aspects of the reactor physics, including the fuel rods, the fuel pellets, the pressure vessel, the pumps and the coolant.

In the simplest terms, Griffin models all of these real-world materials, structures and processes in a scientific way using a complex array of equations.

Griffin provides a mixed-fidelity picture of the power distribution within a reactor, one that ranges from simple to complex, depending on the need.

Figure 2: Griffin provides essential physics data that allows MOOSE tools to function.

The tool contains multiple neutronics solvers—algorithms that can calculate the interactions of gamma and neutron particles with different materials—each with different fidelities and uses. The heart of the Griffin neutronics code is the solver to the Boltzmann transport equation, a well-known and understood equation that models much of the fundamental physics within our universe.

Using these codes, Griffin can calculate point kinetics, diffusion, spherical harmonics and discrete ordinates, all of which can be used to describe physical phenomenon within a reactor system.

The second key technology in the Griffin reactor-physics code is its depletion algorithms. During nuclear reactions, fissile elements such as uranium-235 split into smaller atoms, forming new isotopes and emitting neutrons. Those neutrons, in turn, interact with still more atoms forming new isotopes. In other words, the isotopes in a reactor are constantly changing. The depletion codes keep track of which isotopes exist within the reactor along with the material-depletion capability of fuels, neutron poisons, etc. In a reactor, the governing equations for the isotope concentrations describe the increases and decreases of each isotope, which is critical to simulating long-term reactor operation.

Another indispensable component that makes Griffin so useful is the availability of nuclear data. The DOE Office of Science charges the Brookhaven National Laboratory with publishing all nuclear data necessary to compute neutron distributions in the reactor as well as the time evolution of isotopes. Without this nuclear data, Griffin would be of limited value.

How does the product / service improve upon competitive products or technologies?

Griffin improves on other nuclear modeling and simulation tools in several important ways, starting with its ability to leverage the power of supercomputers throughout the national-laboratory complex. This computing power provides researchers with the luxury of developing models and running simulations with greater accuracy and detail, increasing the degree to which Griffin replicates real life (fidelity). The end result is that Griffin can produce more-accurate results much faster than other options.

Griffin's variable fidelity—its ability to create very simple or very complex models, depending on the question—is a big strength that allows researchers to focus computing power where it's needed most. It allows industry to try new ideas quickly and easily without the time, energy and expense of a more-complex model that might be necessary for, say, qualifying a nuclear reactor with the NRC before it is built in real life.

Provide a matrix demonstrating how key features compare to other products:

Technological Capability (Physics/Model)	OpenMC	Version5 (DRAGON/ DONJON)	ntkFoam	OpenSN	MPACT	CASMO5 SIMULATE5	SCALE	Griffin
Neutron transport (with high order PN scattering)	✓	✓	✓	✓	✓	✓	✓	✓
Gamma transport	✓	✓	✗	✓	✓	✓	✓	✓
Fast reactor cross section preparation	✗	✗	✗	✗	✗	✗	✗	✓
Thermal reactor cross section preparation	✓	✓	✗	✗	✓	✓	✓	✓
Multi-group	✓	✓	✓	✓	✓	✓	✓	✓
Cross sections for Pebble Bed Reactors	✓	✓	✗	✗	✗	✗	✓	✓
Continuous energy	✓	✗	✗	✗	✗	✗	✓	✗
Isotope depletion and transmutation	✓	✓	✗	✗	✓	✓	✓	✓
Fuel cycle analysis	✓	✓	✗	✗	✓	✓	✓	✓
Pebble Bed Reactor running-in/equilibrium	✗	✗	✗	✗	✗	✗	✗	✓
Irregular geometry	✓	✗	✓	✓	✗	✗	✓	✓
Decay heat calculation	✓	✓	✗	✗	✓	✓	✓	✓
Kinetics Solver (time-dependent)	✗	✗	✗	✗	✓	✓	✗	✓
Pseudo isotope generation	✗	✓	✗	✗	✗	✗	✗	✓
Explicit pebble representation	✓	✗	✗	✗	✗	✗	✓	✓
Coupling to thermal fluids	✓	✓	✓	✗	✓	✓	✗	✓
Coupling with fuel performance code (BISON, etc.)	✓	✗	✗	✗	✗	✗	✗	✓
Leverages massively parallel machines	✓	✗	✓	✓	✓	✗	✗	✓
Time-dependent control rod movement with cusping treatment	✗	✓	✗	✗	✓	✓	✗	✓
Time-dependent control drum rotation with cusping treatment	✗	✓	✗	✓	✗	✗	✗	✓
Kinetic parameter calculation	✓	✓	✗	✗	✓	✓	✓	✓
Adjoint solution	✗	✓	✗	✓	✓	✓	✓	✓
Thermal expansion feedback	✗	✗	✗	✗	✗	✗	✗	✓
Machine Learning (Neural Network Support for Data Input)	✗	✗	✗	✗	✗	✗	✗	✓
Liquid fuel advection	✗	✗	✓	✗	✗	✗	✗	✓
Native uncertainty and sensitivity analysis	✗	✗	✗	✗	✗	✗	✓	✓

What are the limitations of the product/service?

Griffin's capabilities are limited by the size of the supercomputer. In the future, Griffin will be able to create higher-fidelity models using more-powerful supercomputers. These higher-fidelity models will create a more-detailed and accurate description of what's happening within a reactor, making nuclear energy even safer and more economical.

Griffin cannot support continuous particle energy (as opposed to quantized particle energy), which means the tool will have a lower level of resolution than other types of codes (Monte Carlo simulations, for example).

Also, the Griffin team would like to perform more code validation against real-world measurements, though it is currently working to add validation cases to the Griffin repository.

Griffin also uses more memory because it relies on a multiphysics framework. While the Griffin team has taken action to minimize the impact of increased memory usage on customers, it will always be a limitation.