Predictive Power—CASL aids startup of TVA's Watts Bar Unit 2

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The startup of the Tennessee Valley Authority's Watts Bar Unit 2 nuclear power plant gave researchers at Oak Ridge National Laboratory's Consortium for Advanced Simulation of Light Water Reactors a chance to showcase the predictive power of the group's advanced simulation code. Credit: TVA

Few jobs are more massive than that of building a nuclear power plant, a project that takes years and billions of dollars to complete. But once a new plant is finished, how do engineers know it will operate as designed?

In October 2016, the Tennessee Valley Authority (TVA) began full commercial operation of its Watts Bar Unit 2 (WB2) nuclear power plant, the United States' first new nuclear reactor in 20 years. WB2 produces about 1,150 megawatts of electricity—enough to power 650,000 homes in East Tennessee. Furthermore, the power is generated without creating any carbon emissions, greenhouse gases, or other pollutants that affect air quality and contribute to climate change.

After 6 months of testing, TVA authorized commercial operation of the plant. As part of the plant startup, TVA leveraged advanced computer simulation capability provided by the Consortium for Advanced Simulation of Light Water Reactors (CASL), a US Department of Energy (DOE) Innovation Hub based at DOE's Oak Ridge National Laboratory (ORNL). Established in 2010 with partner institutions from government, academia, and industry, CASL develops and deploys advanced modeling and simulation of nuclear reactors to better understand plant behavior at unprecedented scales.

Using data supplied by CASL members—TVA and the Westinghouse Electric Company—and high-performance computing (HPC) resources managed by the Oak Ridge Leadership Computing Facility (OLCF), a DOE Office of Science User Facility at ORNL, CASL carried out the largest time-dependent simulation of a nuclear power plant to date. The simulations confirmed engineers' predictions related to the safe and reliable operation of WB2—including when the reactor would sustain a fission reaction—and provided a detailed picture of the reactor's hour-by-hour behavior during power escalation.

The project marked the first time CASL had the opportunity to showcase its high-fidelity code suite, the Virtual Environment for Reactor Application (VERA), as a predictive tool.

"Even though VERA is essentially a research code, the results of our Watts Bar Unit 2 simulations demonstrate that this is a state-of-the-art tool that industry can use to make real decisions," said Andrew Godfrey, senior R&D staff member at ORNL. "In this case, CASL's high-fidelity predictions helped cement TVA's and Westinghouse's confidence that the plant would operate as expected. That confidence was later confirmed when measurements made during Unit 2's initial cycle closely matched VERA's simulated results."

Within light water reactors, electricity generation starts with controlled nuclear fission sustained by rods of uranium fuel. Knowing when and under what conditions the fuel will sustain a fission reaction is a critical piece of information for plant operators.

Using VERA, the CASL team built a model of the WB2 reactor core before the plant's startup. Simulations of the core's initial cycle, conducted on the OLCF analysis cluster Eos, calculated reactor startup conditions and the underlying physics up to the point of self-sustaining fission. Specifically, the CASL team used VERA to predict boron levels, which control reactivity, and control rod reactivity worths, which quantify how much control rods affect the rate of reactivity. Both simulated figures were found to be well within acceptable levels, information that proved valuable to TVA at startup.

"Our participation in CASL allowed us to obtain accurate design predictions for the startup of Watts Bar Unit 2," said David Brown, TVA Nuclear general manager of reactor engineering and fuels. "In the past, some reactor analysis methods have had trouble simulating the first cycle of a reactor.

"To overcome the challenges, the supercomputing capability at Oak Ridge was used to complete several large calculations that were validated against actual plant measurements as Watts Bar Unit 2 reached criticality," he continued. "Validation of the data against real-world results will help CASL continue to improve modeling and simulation technology for the nuclear industry."

During WB2's power escalation period between June and October, CASL continued to simulate plant power history through the startup phase, which spanned nine shutdown periods. Using Eos and Titan, the OLCF's 27-petaflop Cray XK7 supercomputer, the team produced hour-by-hour snapshots, or state points, that captured significant reactor properties in fine detail, including changes in short-lived fission product isotopes, power distribution, and core reactivity. In total, the CASL team calculated 4,128 state points, a task that required more than 2 million core-hours of compute time.

The comprehensive WB2 simulations provided CASL with excellent validation of VERA, which includes new parallelization methods and application features. Additional work by the CASL team has adapted VERA to run on smaller-scale HPC systems (about 1,000 processing units) so that industry researchers can use the technology on in-house systems in the near future.

Encouraged by CASL results and in anticipation of future expectations, Westinghouse is planning to upgrade its internal HPC capabilities soon, according to Zach McDaniel, manager of pressurized water reactor core methods at Westinghouse.

"Initial applications of CASL tools to industry challenges, including test deployments of VERA on Westinghouse systems, have clearly demonstrated the benefits of HPC for the nuclear industry," McDaniel said.

Through partnerships with a dozen active nuclear power plants, CASL is continuing to develop VERA to better serve industry by investigating challenges such as how to mitigate boron deposits on the outside of fuel rods and how to predict fuel rod failures. Addressing these issues could extend the life of power plants and lower the cost of operation. The CASL team is also simulating new reactor designs, such as NuScale's integral pressurized water reactor, a small modular reactor, and Westinghouse's AP1000, which is set to come online in China in 2017 and the US in 2019.

"We're starting to build a case for industry to take the next step in HPC," Godfrey said. "With our modeling and simulation tools, we are hoping to show industry partners they can solve problems that no one has been able to solve before and make nuclear power a more competitive source of commercial energy."

More information: Andrew Godfrey, et al., "Analysis of the Startup of Watts Bar Nuclear Unit 2 Using VERA." *International Conference on Mathematics & Computational Methods to Nuclear Science & Engineering*, Jeju, Korea, April 16–20, 2017. www.casl.gov/docs/CASL-U-2017-1306-000.pdf

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