CASL SCIENCE & TECHNOLOGY
Consortium for Advanced Simulation of Light Water Reactors

Watts Bar Operating Cycles Simulated to Present

Among the most important accomplishments during CASL Phase 1 is the development and deployment of CASL's Virtual Environment for Reactor Applications (VERA), a high-fidelity, multi-physics engineering tool that utilizes modest high-performance computing (HPC) systems and engineering-scale clusters to simultaneously simulate the local fuel rod neutronics and coolant channel thermal-hydraulics over the life of the reactor. VERA has the potential to predict core performance with higher fidelity than is currently afforded by existing industrial codes, and can perform analyses relating to common evolutions of operating commercial pressurized water reactors (PWRs), including startup testing, power escalation, fuel cycle depletion, and fuel assembly discharge, reinsert, and shuffling. To demonstrate VERA's capability, CASL has, in the past, simulated Watts Bar unit 1 (WBN-1). In his most recent installment of these important benchmark problems, CASL researcher Andrew Godfrey utilized the VERA core simulator's new shuffle capability to bring its WBN-1 predictions up to the current cycle. These predictions lay the groundwork for follow-up demonstrations of Challenge Problem capabilities; for example, initial CRUD prediction capability was demonstrated using WBN-1 cycle 7's CRUD event as a validation opportunity.

The WBN-1 VERA models are based on the reactor and fuel specifications provided by TVA and Westinghouse. 193 Westinghouse 17x17 nuclear fuel assemblies are operated on 18-month cycles in the 4-loop Westinghouse reactor core. Burnable absorbers are used to control the power distribution in the fresh fuel. Additionally, WBN-1 has participated in the U.S. Department of Energy's Tritium Production Program, with many Tritium-Producing Burnable Absorber Rods (TPBAR) included in most cycles.

Many of the WBN-1 fuel cycles had distinguishing characteristics, including:

- Cycle 1 used Pyrex burnable absorber rods; also cycle 1's power history 1 was more complicated than others due to frequent periods of low power operation or shutdowns.
- Cycle 2 began the use of IFBA/WABA poison types and included TPBAR LTAs.
- Cycle 3 began the use of annular blanket pellets for the fuel rods containing IFBA.
- Cycle 4 implemented a 1.4% mid-cycle power uprate.
- Cycle 6 transitioned to a slightly different fuel design with IFM grids and began the batch inclusion of TPBARs.
- Cycle 7 experienced CIPS.
- Cycle 11 significantly increased the number of TPBARs and had no WABAs.
- Cycle 12 changed the control rod design and also had no WABAs.

A 53 axial level model was chosen in the fuel for the edits and thermal-hydraulic coupling to resolve each spacer grid (approximately three inch mesh in between grids). For parallelization, complete spatial decomposition was performed by axial plane and by fuel assembly, resulting in 59 axial planes (3 for the top reflector and 3 for the bottom) and 73 radial nodes, requiring a total of 4307 processors for the calculation. The number of processors could be reduced to as few as 472, requiring less than 4 GB/core of memory; however, this would increase the runtime by approximately a factor of ten.

WBN-1 utilizes both in-core and ex-core instruments to monitor the neutron flux in the reactor. The in-core detectors are moveable fission chambers that are used to perform core surveillance activities and ex-core calibration at prescribed intervals ranging from one to three months. The signals returned from these detectors are aligned and processed into "flux maps" that are compared to predicted power distributions. The flux maps are also an excellent source of validation data for reactor physics applications.

Each cycle depletion was run using quarter-core rotational symmetry, even though a few of the cycles were not symmetric. For these cases it is assumed that the effect on the core power distribution is small and the asymmetric assemblies, being low power and on the core periphery, are not significant for core reactivity or flux mapping. Every power maneuver and shutdown performed in each cycle was not simulated; depletion is performed by burnup at representative conditions. Comparison points (boron and flux maps) are made at HFP conditions at sufficient intervals (~1 week) following maneuvers that that the plant is considered to be close to equilibrium isotopics and depletion is performed using equilibrium xenon.

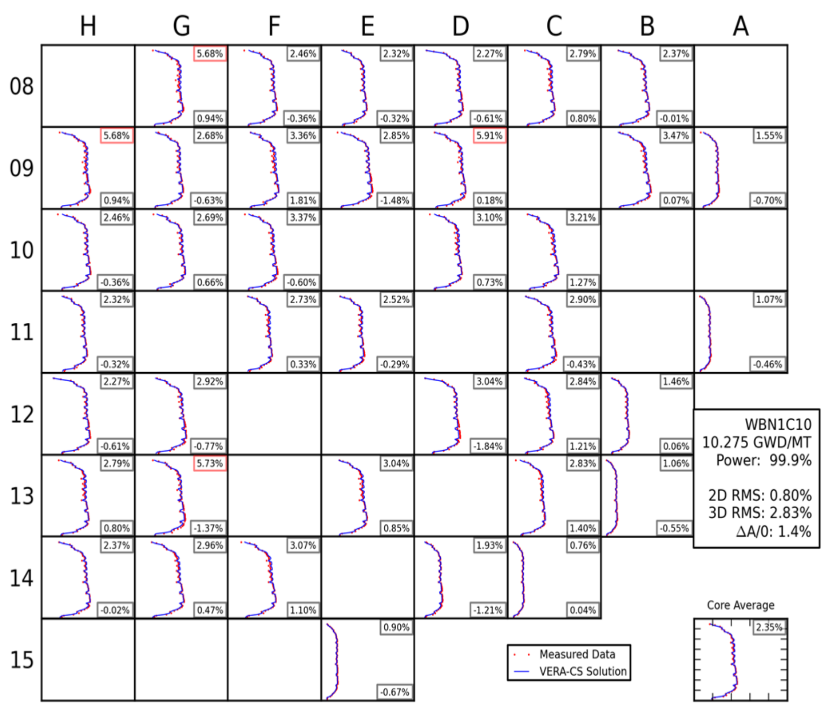

Figure 1 Hot Full Power Flux Map Comparisons of VERA predictions to WBN-1 Measurements, cycle 10.

Coming in our next issue of :

The following parameters were calculated with VERA and compared with TVA-provided measured WBN-1 data:

- Beginning-of-cycle (BOC) criticality of the reactor;
- BOC hot-zero-power (HZP) control bank reactivity worth (CBW);
- BOC HZP isothermal temperature coefficient (ITC);
- Hot-full-power (HFP) critical boron letdown over the entire fuel cycle; and
- HFP in-core instrument response distributions (flux maps).

Table 1 provides a comparison summary of the measured versus VERA-predicted results, and include over 400 critical boron measurement and 183 HFP measured flux map comparisons (an example flux map comparison is shown in Figure 1). The majority of the results look very good, especially given that this is the first application of VERA on a multi-cycle scale. A few outliers exist and may require further investigation to rule out possible issues with the methods. The VERA calculations were performed on the INL Falcon HPC resource, and the average fuel cycle depletion required approximately 21 hours on 4307 cores, or 88,000 cpu-hours. The total cpu resource utilization over all cycles was 1.06 million cpu-hours. For the 440 statepoints calculated (~37 per cycle), the average runtime of a single statepoint was 35.9 minutes, and the average number of iterations between MPACT and CTF was 11.1. In total, 4899 fully coupled iterations were successfully performed and fully converged. For more information, see CASL-U-2015-0206-000.

Table 1 Comparison of VERA Results with WBN-1 Measurements

Measurement	Sample Size	Mean ± 1 sigma	Runtime per Cycle
BOC HZP Critical Boron	12	-9 ± 24 ppm	1.75 hours
BOC HZP Bank Worth	76	1.2 ± 4.3%	3.33 hours
BOC HZP ITC	11	-0.8 ± 0.7 pcm/°F	0.75 hours
HFP Boron Letdown	384	-24 ± 19 ppm	21.9 hours
HFP Flux Maps **–Radial** **– Total**	165	1.9 ± 0.3% RMS 3.7 ± 0.4% RMS	--