Westinghouse Completes its AP1000® Test Stand

Last June, CASL launched its first Virtual Environment for Reactor Applications (VERA) Test Stand on the Westinghouse engineering computer cluster. Westinghouse selected the AP1000® pressurized water reactor (PWR) first core for the Test Stand simulation because its advanced design and operational features, and imminent deployment in units under construction, make it a particularly relevant and engaging application of CASL technology.

The Westinghouse Test Stand used VERA release 3.2 and the AP1000 PWR models were built using the VERA common input. Westinghouse engineers commented on the intuitive nature of the VERA common input, noting its simplicity is deceptive - it enabled set up of a fairly advanced core design in a relatively compact ASCII file of less than 1,000 lines. Only minor modifications to the input are required to run variations, making the VERA common input practical and effective.

Westinghouse used the VERA core simulator (VERA-CS) SP_N solver option; CASL has demonstrated the accuracy of this solver for start-up physics calculations in earlier validation simulations of Watts Bar Unit 1 [Ref. 3]. The SP_N method is a computational option to the discrete ordinates (SN) method also available in Insilico. It is known that SP_N does not converge to the true transport solution as its expansion order is increased; however, it has good computational efficiency and can achieve improved accuracy over traditional nodal diffusion core simulators.

VERA is known to be computationally demanding compared to typical industrial simulators, and in order to execute the Test Stand simulations Westinghouse purchased a dedicated computer cluster. The Westinghouse VERA cluster has 576 cores distributed on 48 nodes with a total memory of 4.6 TB (96 GB/node). Deployment to the Westinghouse cluster utilized the initial CASL VERA code build system, and provided ample opportunity to exercise the VERA code installation, build, and update process. Westinghouse did encounter several challenges associated with the first CASL Test Stand installation and resolution was attained thanks to a dedicated effort from CASL and Westinghouse personnel. The Westinghouse Test Stand deployment was instrumental in establishing a more streamlined code installation approach.

Since the initial Test Stand deployment, Westinghouse has successfully installed updates on two separate Westinghouse test stand systems. Additionally, Westinghouse worked closely with the CASL team to develop a VERA installation guide aimed at providing users with specific directions for configuring their computing cluster for VERA, installing the prerequisite utilities and third-party libraries, and obtaining later code updates. This guide has already been useful in deploying VERA to the EPRI Test Stand.

Calculations performed for the AP1000 PWR Test Stand focused on zero power physics test simulations, including predictions of 3D core hot zero power critical boron concentration, control rod worth, boron worth, Isothermal Temperature Coefficient (ITC), Moderator Temperature Coefficient (MTC), and Doppler Temperature Coefficient (DTC)). As illustrated in Figure 5, the results show excellent agreement with continuous energy Monte Carlo [Ref. 4] (CE MC) results, which are the numerical reference for the simulations performed.

Highlights from the reported results are provided in Tables 1 and 2.

¨ The Hot Zero Power (HZP) critical boron concentration predicted by VERA is within 3 ppm of

the reference.

¨ The differential from the reference in predicted boron worth is 0.2 pcm/ppm.

¨ The root mean square (RMS) difference of the control rod worth prediction is 4 pcm, with a maximum difference of 9 pcm, across the eleven AP1000 control banks.

¨ The DTC, MTC and ITC, are respectively within 0.2, 0.4 and 0.6 pcm/F of the reference, with VERA consistently predicting more negative values; Westinghouse recommended that this be investigated further by the CASL team, as the differences observed in the temperature reactivity coefficients, while small, are not insignificant.

Table 1 Hot Zero Power Reactivity Results

	CE MC	VERA	differential
Startup critical boron	**1313**	**1310**	**-3 ppm**
Boron Worth, pcm/ppm	-9.6	-9.4	+0.2
DTC, pcm/F	-1.54	-1.72	-0.18
Moderator Temperature Coefficient (MTC) pcm/F	-1.12	-1.50	-0.38
Isothermal Temperature Coefficient (ITC) pcm/F	-2.66	-3.22	-0.56

Note: CE MC temperature coefficient uncertainties estimated to be <0.1 pcm/F

The results of the simulations are also close to the Westinghouse predictions using in-house core physics tools and licensed methods, which reinforces the confidence in Westinghouse's predictions for this advanced first core start-up, scheduled to occur within 2015.

Table 2 Control Bank Worth Results

		CE MC	VERA-CS	
Bank	**Material**	**Worth (pcm)**	**ΔWorth (pcm)**	**ΔWorth (%)**
MA	Tungsten	258	-1	-0.5
MB	Tungsten	217	-5	-2.1
MC	Tungsten	188	-2	-1.1
MD	Tungsten	234	0	0.0
M1	Ag-In-Cd	651	-4	-0.6
M2	Ag-In-Cd	887	3	0.4
AO	Ag-In-Cd	1635	-4	-0.3
S1	Ag-In-Cd	1079	0	0.0
S2	Ag-In-Cd	1096	-9	-0.8
S3	Ag-In-Cd	1124	0	0.0
S4	Ag-In-Cd	580	-3	-0.4
		RMS **Max**	**4** **9**	**0.8** **2.1**

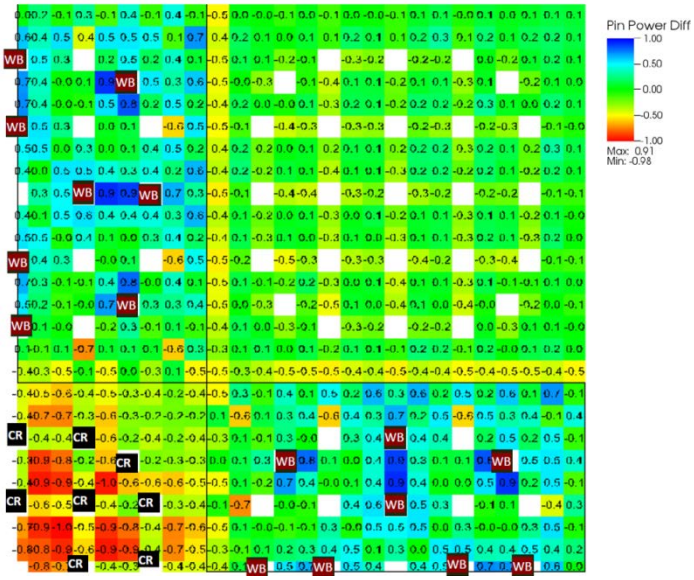
Detailed power distribution analyses have also been completed using the CASL Test Stand. Several configurations were simulated, including an entire radial slice of the core with reflector and 3D multiple assemblies with partial control rod insertion, demonstrating the functionality of the AP1000 Axial Offset bank used for axial power distribution control. Comparison with CE MC simulations indicate a good agreement for VERA also from the power prediction standpoint, with a root mean square of the difference in pin power below 1.0% for all cases.

CASL is also working to incorporate its own CE MC capability, Shift, to VERA. The Westinghouse Test Stand applied Shift to the simulation of an entire AP1000 PWR 3D core model with multiple control banks inserted, as shown in Figure 6.

A primary objective of the CASL Test Stand was to obtain objective feedback on the

applicability of the VERA tools to industrial applications. Westinghouse Fellow Engineer Fausto Franceschini led the Test Stand activities and performed the VERA simulations. Per Fausto, “VERA has demonstrated a potential to go one step beyond the current industry tools. While more extensive comparisons need to be performed, the results so far are very promising. VERA-CS could allow reliable high-fidelity predictions for a range of commercial reactors and operating conditions that could be used to anticipate and mitigate operational issues, resolve discrepancies with plant measurements, benchmark new methods, and corroborate the design of advanced cores.” However, Fausto cautioned that the current simulations have already stretched the resources of Westinghouse’s new industry-class engineering computing cluster. As the CASL team further implements depletion, thermal-hydraulic feedback, and fuel shuffling within VERA-CS, the computational needs are expected to multiply, and will likely exceed the capacity of the Westinghouse cluster. Westinghouse notes, “One of the challenges when developing a core simulator is to meet the computational resources available with an implementation of the underlying physics that leads to the appropriate accuracy for the foreseen range of applications and user base.

The computational resources available now are much higher than when first-generation industry core simulators were conceived, but there are limits. It is acceptable to utilize leadership-class HPC such as ORNL’s Titan for some applications, but it is also important to ensure that the VERA development path leads to capabilities that are usable by a broader engineering community.”



The Westinghouse VERA Test Stand also identified other development items to address - thermal expansion capabilities to account for dimensional changes as the reactor heats up; provisions for advanced reflector and fuel designs; and the development of better documentation for VERA, though these are not cited as urgent development priorities.

All in all, the CASL-Westinghouse Test Stand was a resounding success. The code deployment methods were exercised, the codes were tested, and important experience feedback was obtained. Westinghouse PWR Core Methods Manager Bob Oelrich noted, “The benefits of the Test Stand go well beyond those of the technical analyses performed. The direct engagement of our engineering team with the CASL team and VERA-CS has raised much interest within Westinghouse. The enthusiasm and dedication offered to this project by the many people involved, inside and outside Westinghouse, are a testimony of their engagement and key contributions to the success of the Westinghouse VERA Test Stand”.

Westinghouse will continue to obtain VERA code updates as they become available, and plans to extend the AP1000 reactor simulations to cycle depletion with coupled thermal-hydraulics. For more information, see the Westinghouse VERA Test Stand report posted on the CASL website at

http://www.casl.gov/docs/CASL-U-2014-0012-001.pdf.

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