Watts Bar Unit 2 Startup Simulations with VERA

John Ritchie

Tennessee Valley Authority

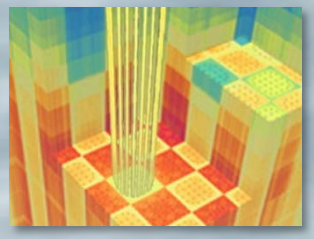
Andrew Godfrey

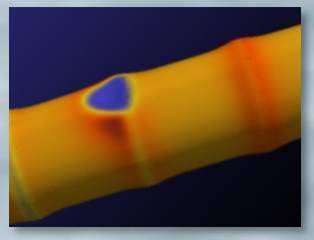
Oak Ridge National Laboratory

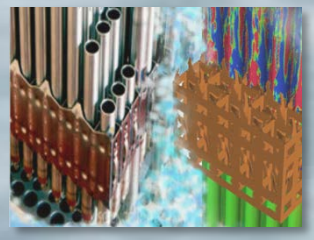
Joint IC/SC Meeting

Oak Ridge National Laboratory

October 11, 2016







The Consortium for Advanced Simulation of LWRs
A DOE Energy Innovation Hub

U.S. DEPARTMENT OF ENERGY

Watts Bar Nuclear Plant – Unit 2

- First new nuclear plant in U.S. since 1996 (WB1)
- Traditional four-loop Westinghouse PWR
- 3411 MW_{th} initial rated thermal power
- Current burnup: ~30 EFPD

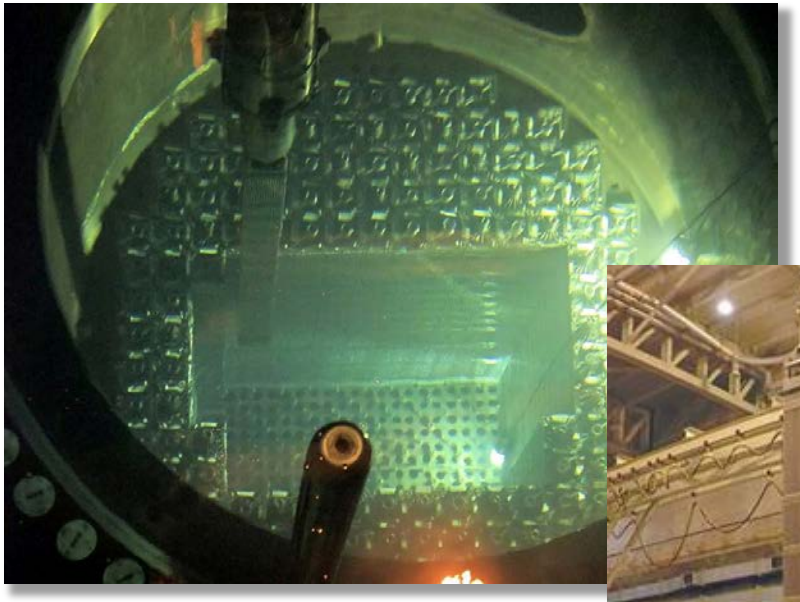
Image courtesy of TVA

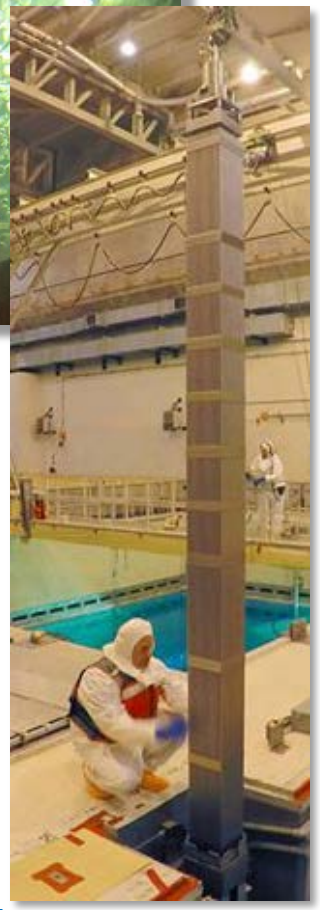
Notable Dates:

- Dec. 2015 – Fuel Load
- May 23, 2016 – Initial criticality
- June 3, 2016 – On the grid

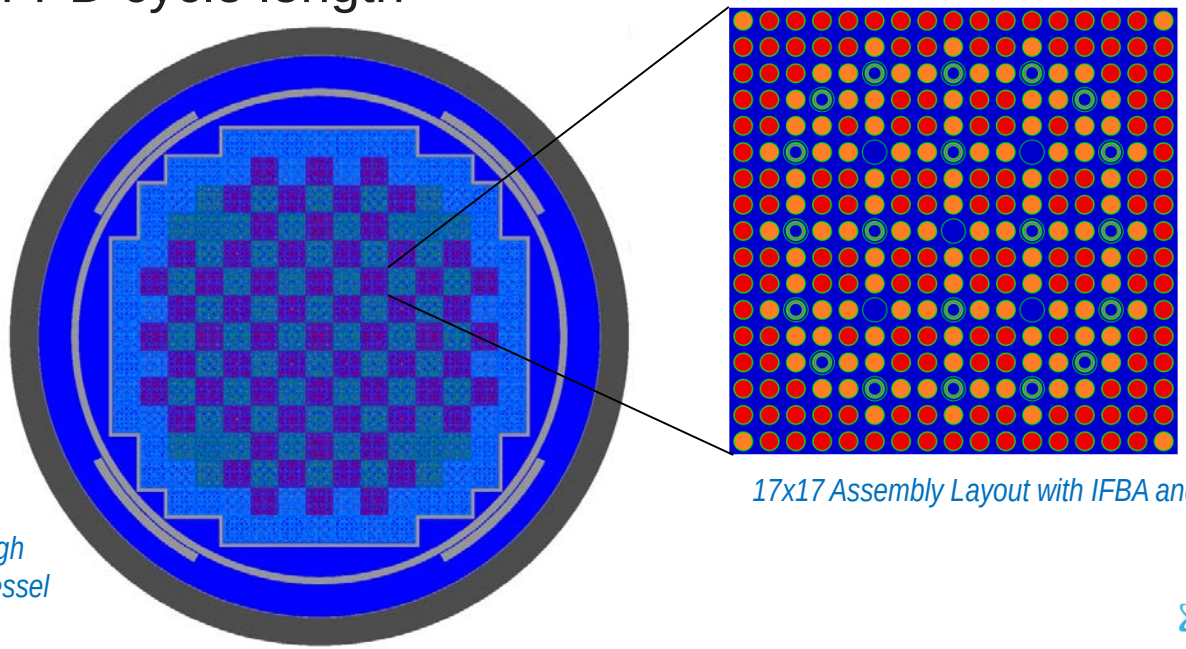
WBN2 Cycle 1 Design

- 193 Westinghouse RFA2 17x17 fuel assemblies
  - 12’ active fuel height
  - IFM spacer grids
- Three enrichment regions
  - 2.1%, 2.6%, 3.1%
- Low enriched 6” axial blankets
- IFBA/WABA burnable poisons
- ~400 EFPD cycle length





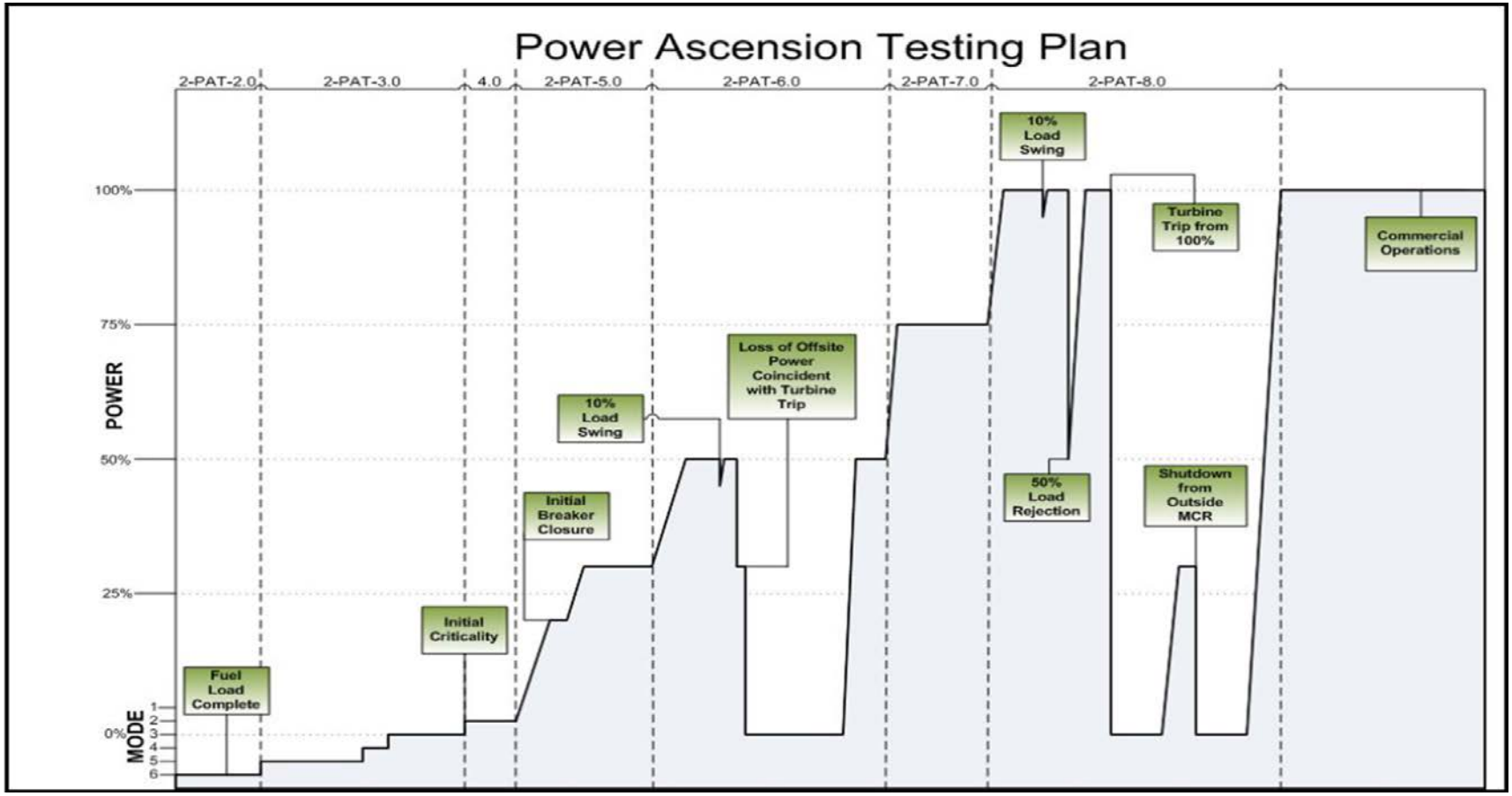
Images courtesy of TVA



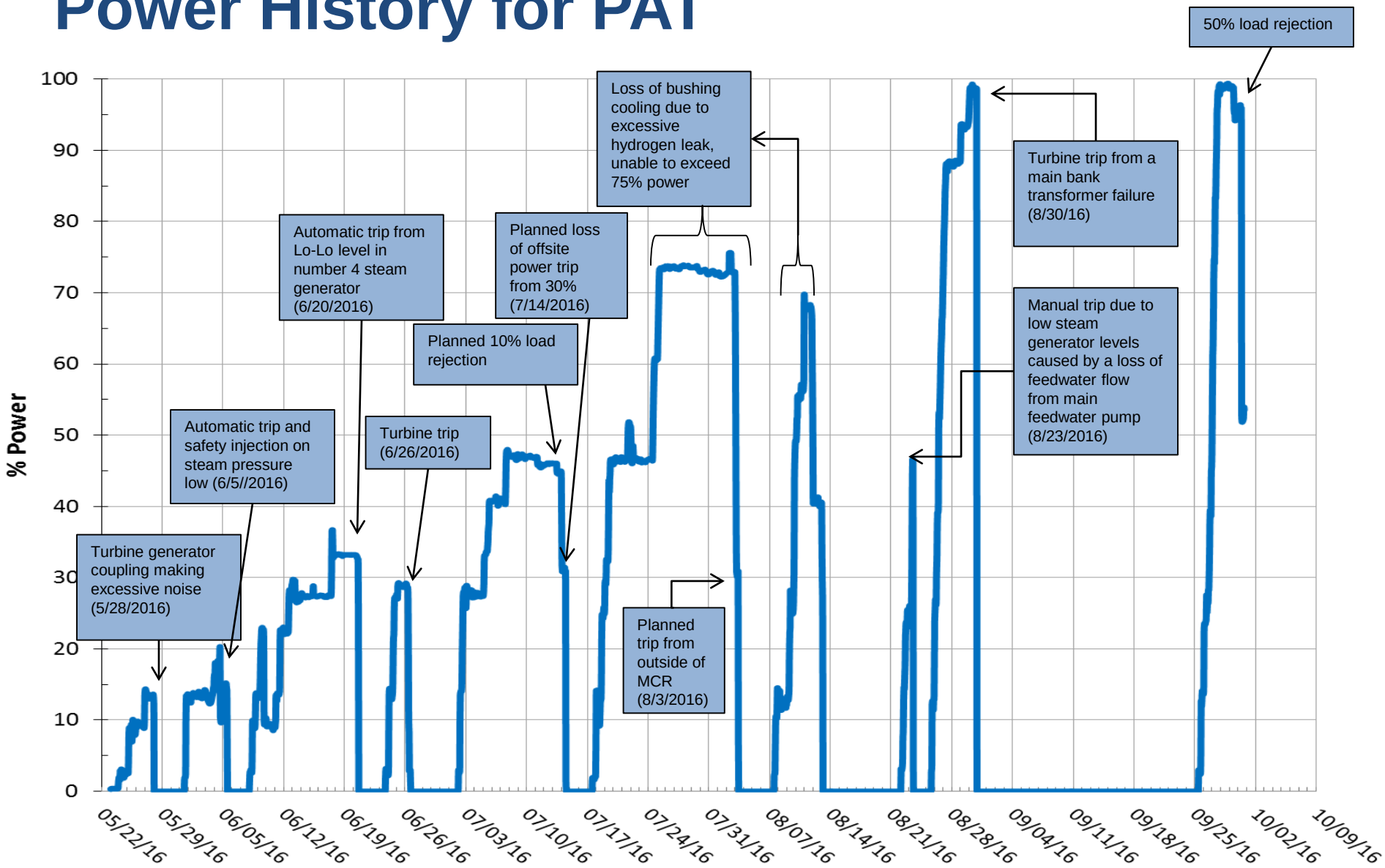
Radial Slice through WBN1 Reactor Vessel

17x17 Assembly Layout with IFBA and WABA

Power Ascension Testing



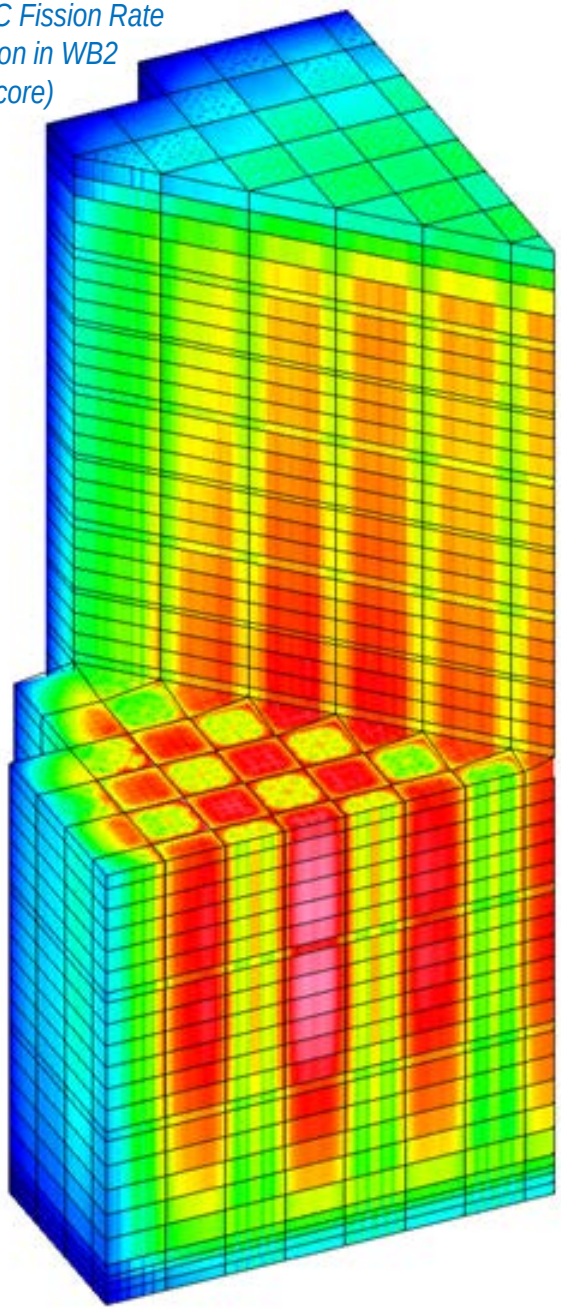
Power History for PAT



VERA Methods

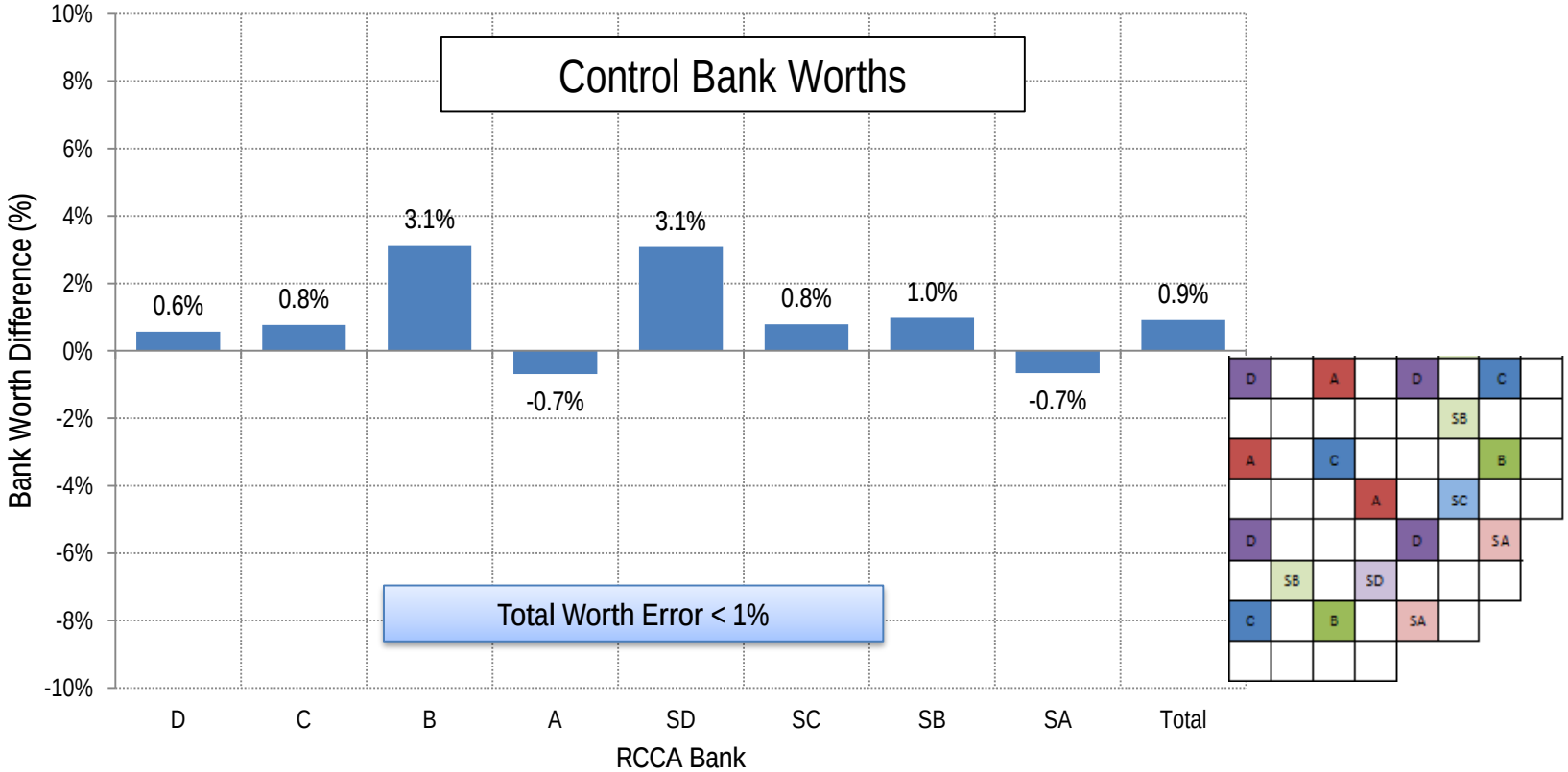
- MPACT
  - 2D/1D deterministic neutron transport based on MoC/SP_3
  - 47g ENDF/B-VII.0 subgroup library
  - 50 axial planes in the fuel/ 58 total
  - 4,234 parallel spatial domains
- COBRA-TF
  - Two phase coolant T/H
  - 14,000 channels
  - Cross flow between channels
  - 193 parallel domains (4 per assembly)
- ORIGEN
  - Explicit isotopic depletion and decay
  - 263 isotopes in 1.9 million regions
- BISON
  - Volume average full temperature tables as a functions of power and burnup
- SHIFT (BOC HZP only)
  - Continuous-energy Monte Carlo neutron transport
  - Doppler broadening and thermal scattering treatments
  - Massively parallel demonstrated up to 300,000 processors

HZP BOC Fission Rate Distribution in WB2 (quarter core)



Startup Results*

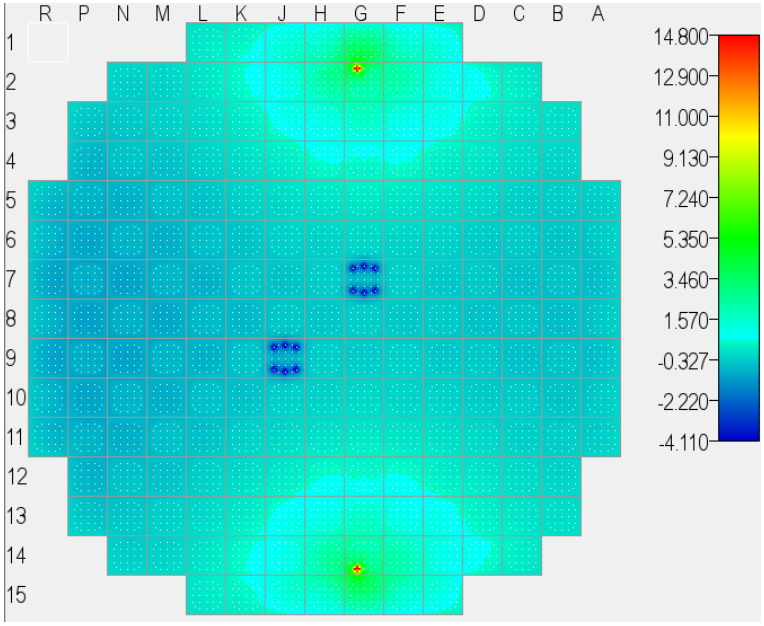
	Measured	MPACT Difference	Shift Difference
Initial Critical Boron Concentration (ppmB)	1089	-14	-2
Isothermal Temperature Coefficient (pcm/ºF)	-5.31	-0.15	--



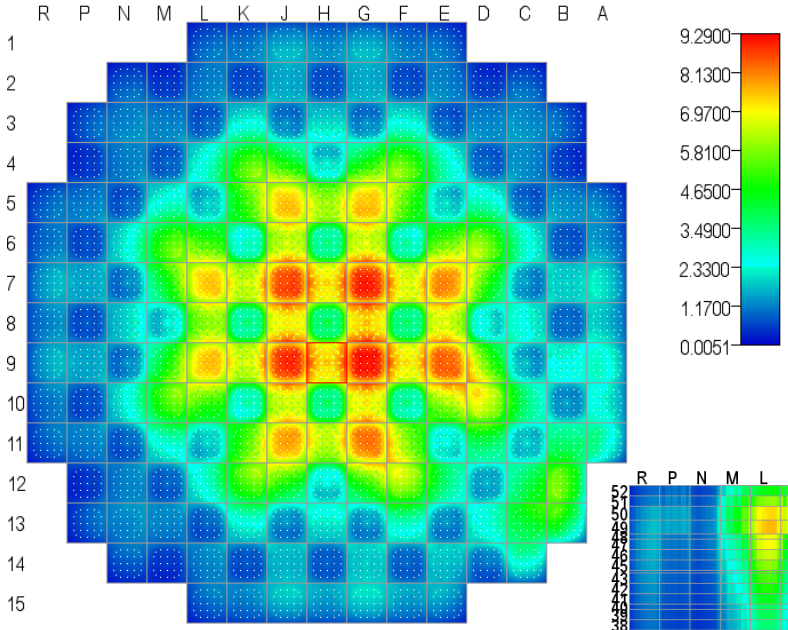
*Measurements courtesy of TVA

Miscellaneous Evaluations

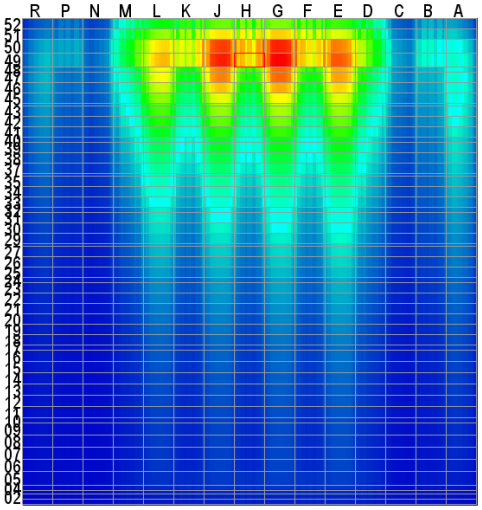
- Applications of VERA providing higher fidelity capabilities than current methods



Effects of Primary and Secondary Source Rods On Full Core Radial Power Distribution in WBN2



Fission distribution for shutdown margin calculation, All-Rods-In + Worst Stuck Rod Out

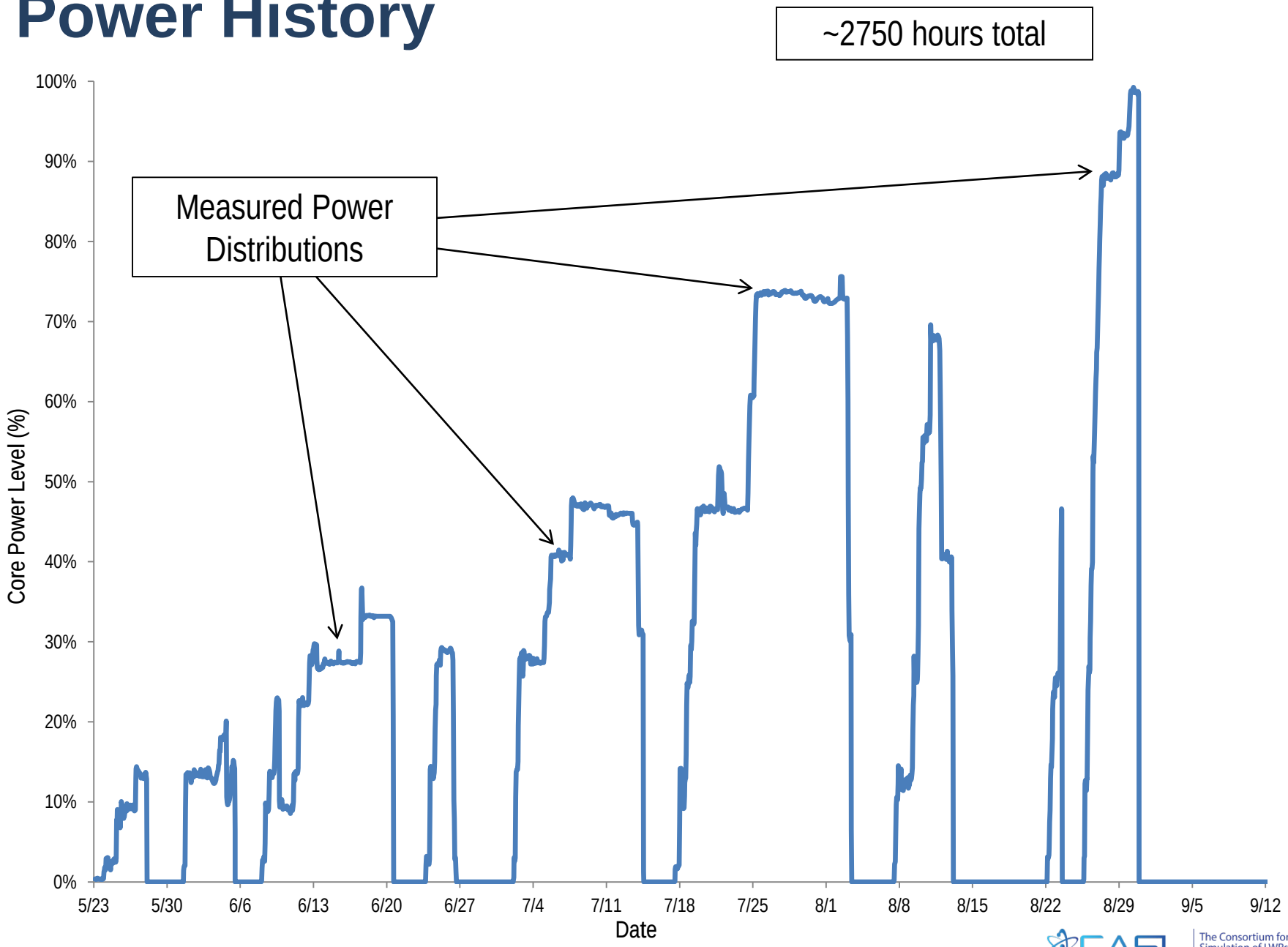


Power Ascension Testing

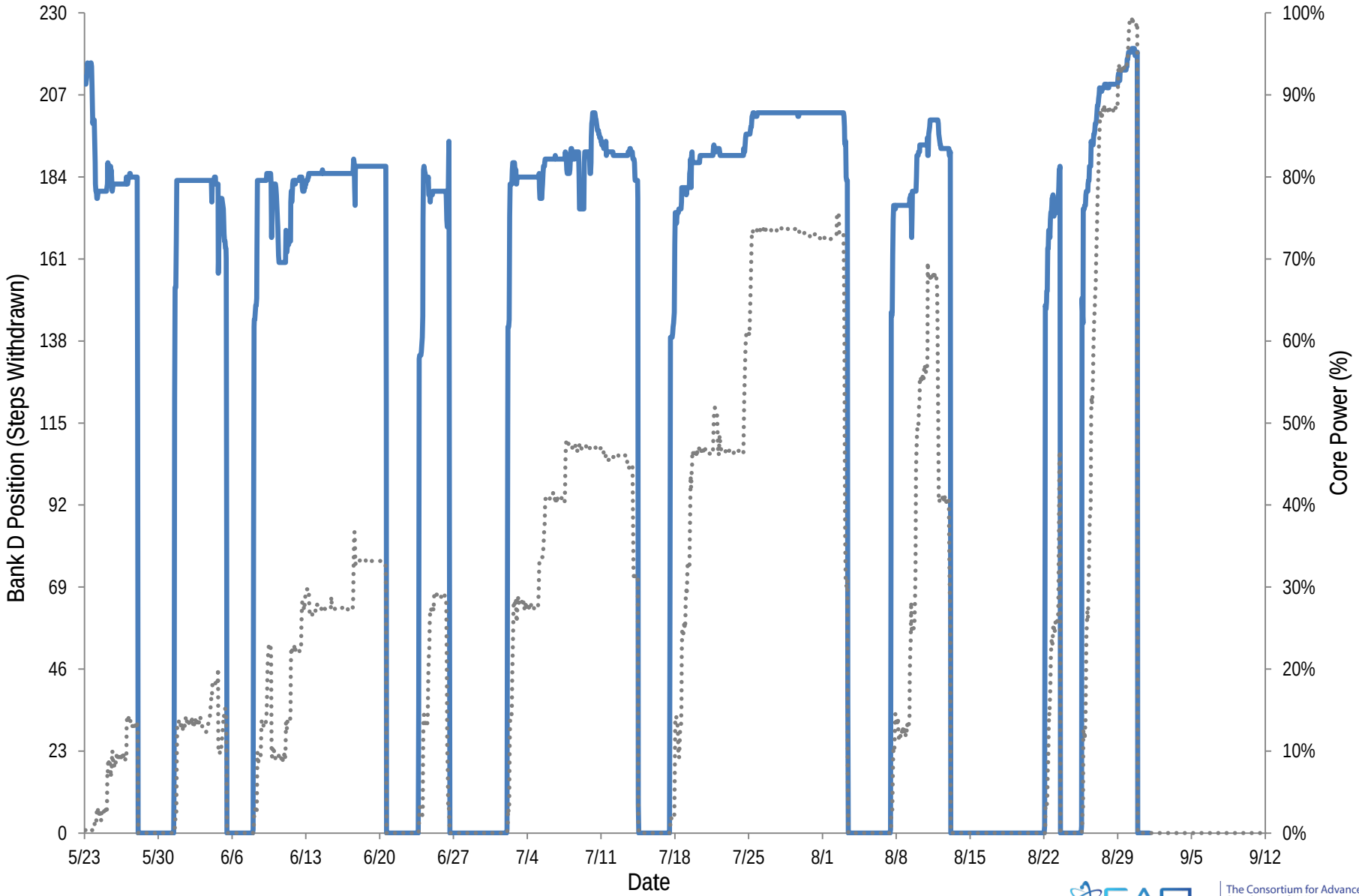
- Power escalation began May 23, 2016
- Plan requires ~90 days from criticality to commercial operations
- TVA has provided power history data and measurements
- VERA has been used to follow the startup procedure with hourly statepoints
- Oak Ridge Leadership Computing Facility has supported all calculations over the last 3½ months with priority on Eos supercomputer
- Comparisons to measured data have included:
  - Critical boron concentrations at operating conditions
  - Subsequent critical conditions after shutdowns
  - Measured neutron flux distributions at certain checkpoints

The Largest Simulation Ever Performed by CASL!

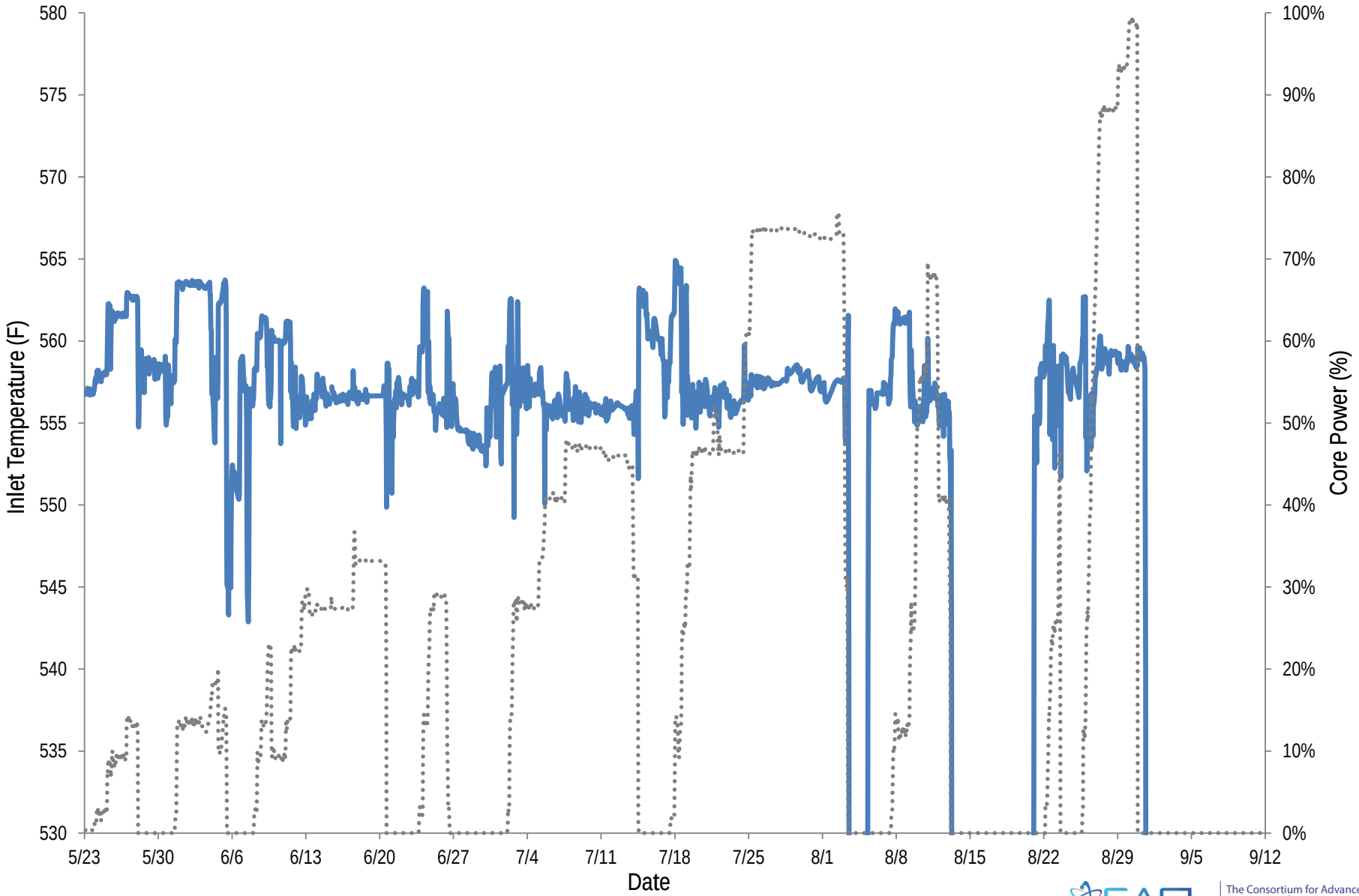
Power History



Bank D History

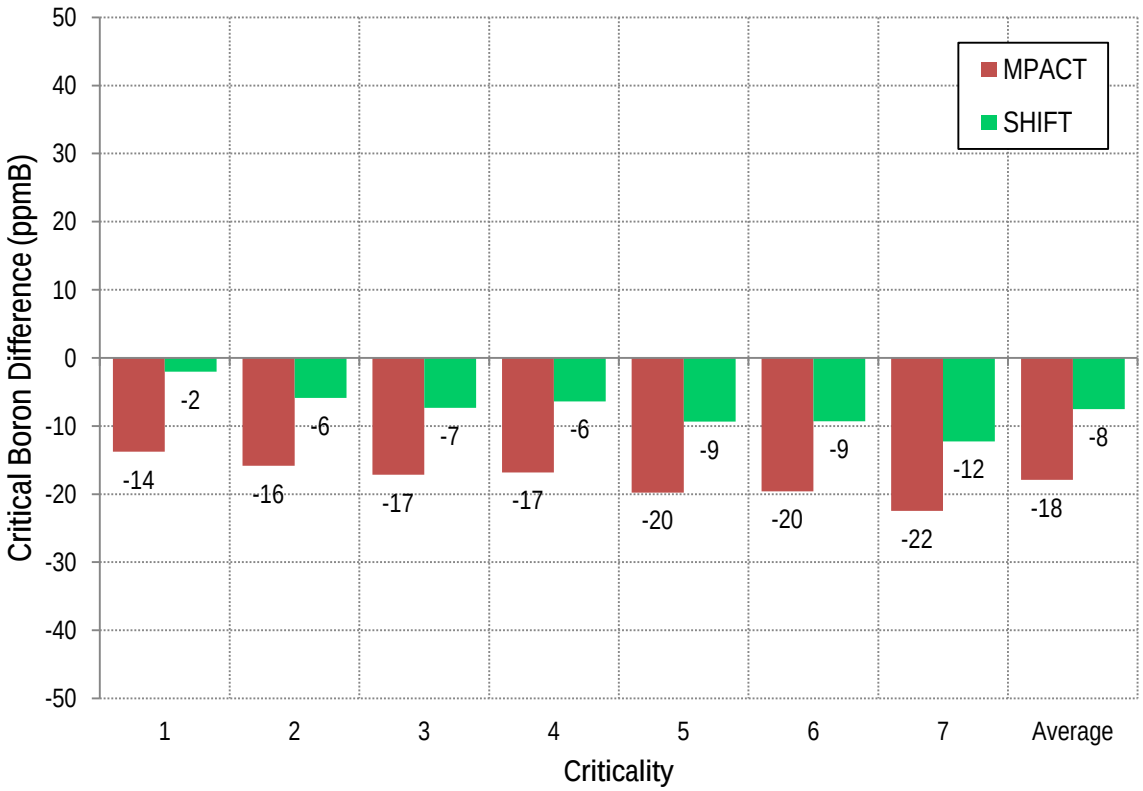


Inlet Temperature History

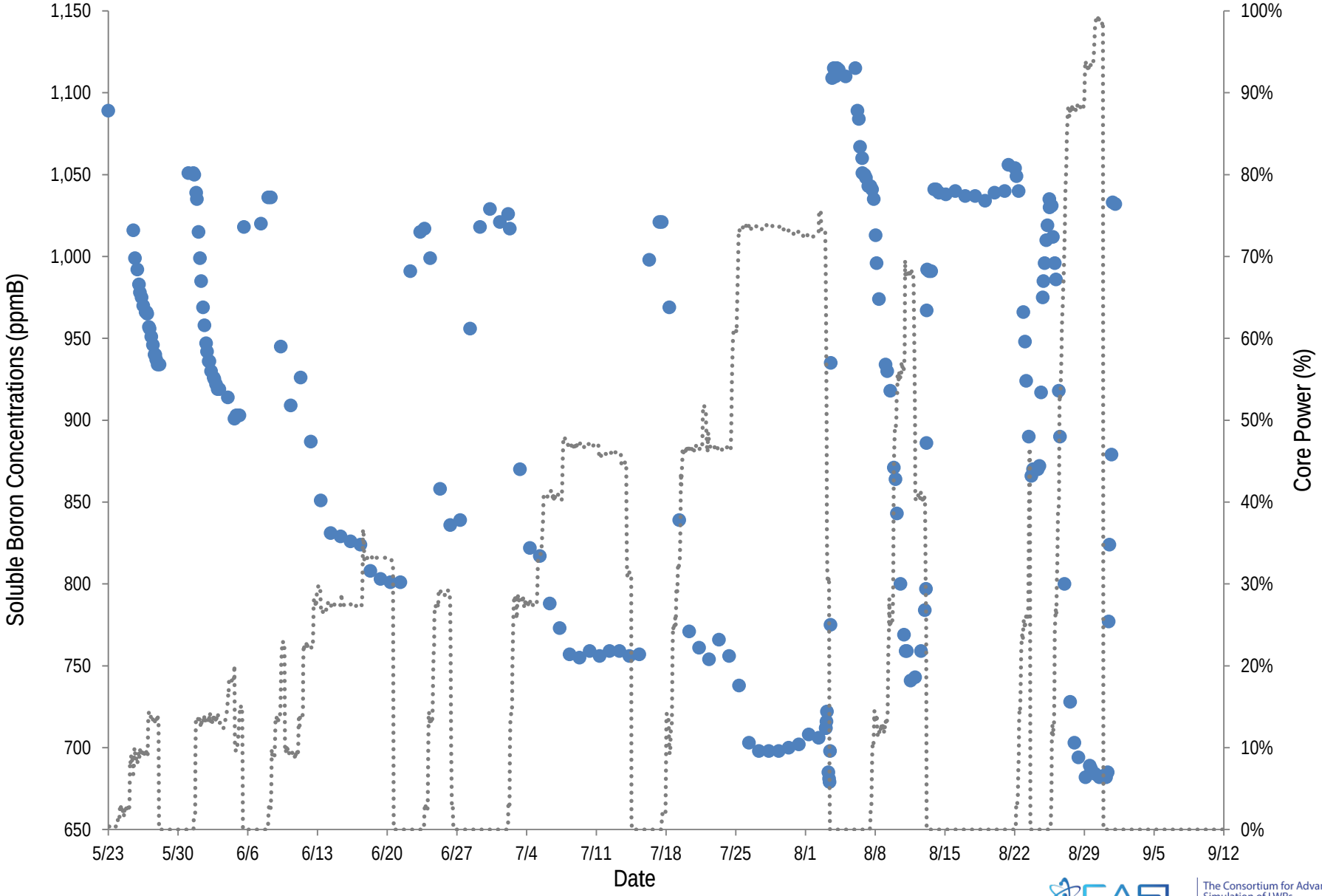


Zero Power Criticality Measurements

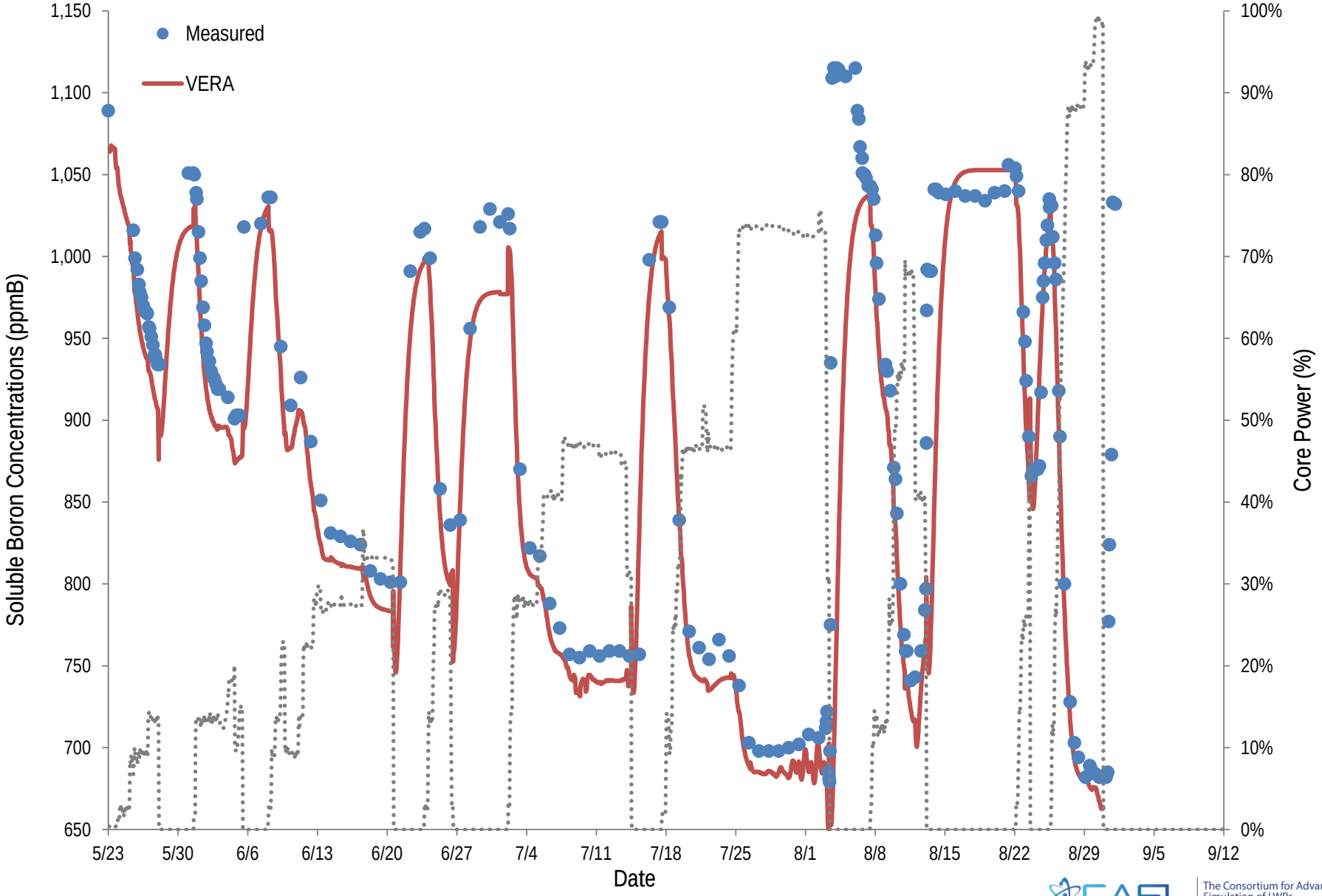
- Criticality Measurements taken at HZP conditions following shutdowns
- Include various Bank D positions and transient Xenon-135 conditions



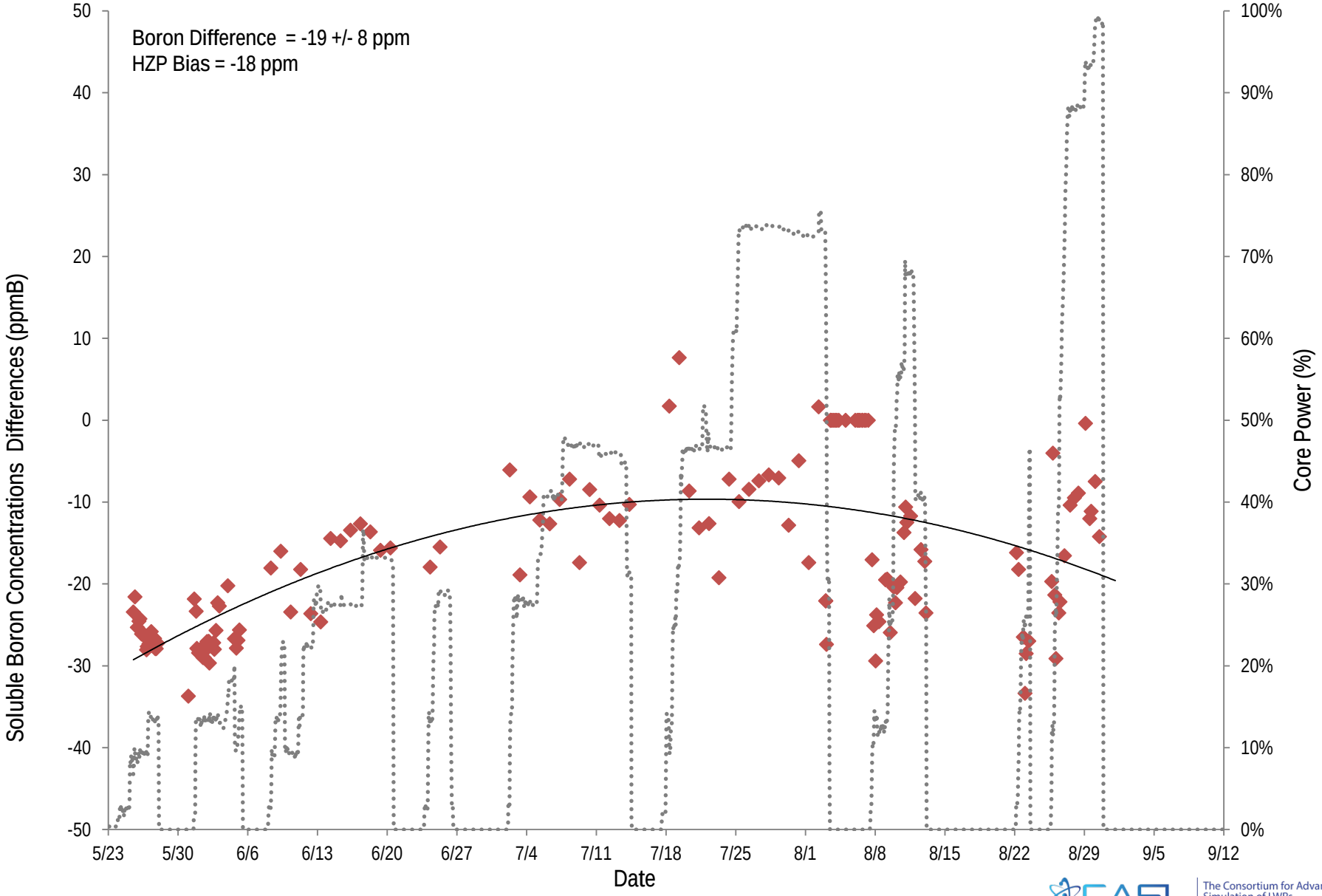
Boron Concentrations



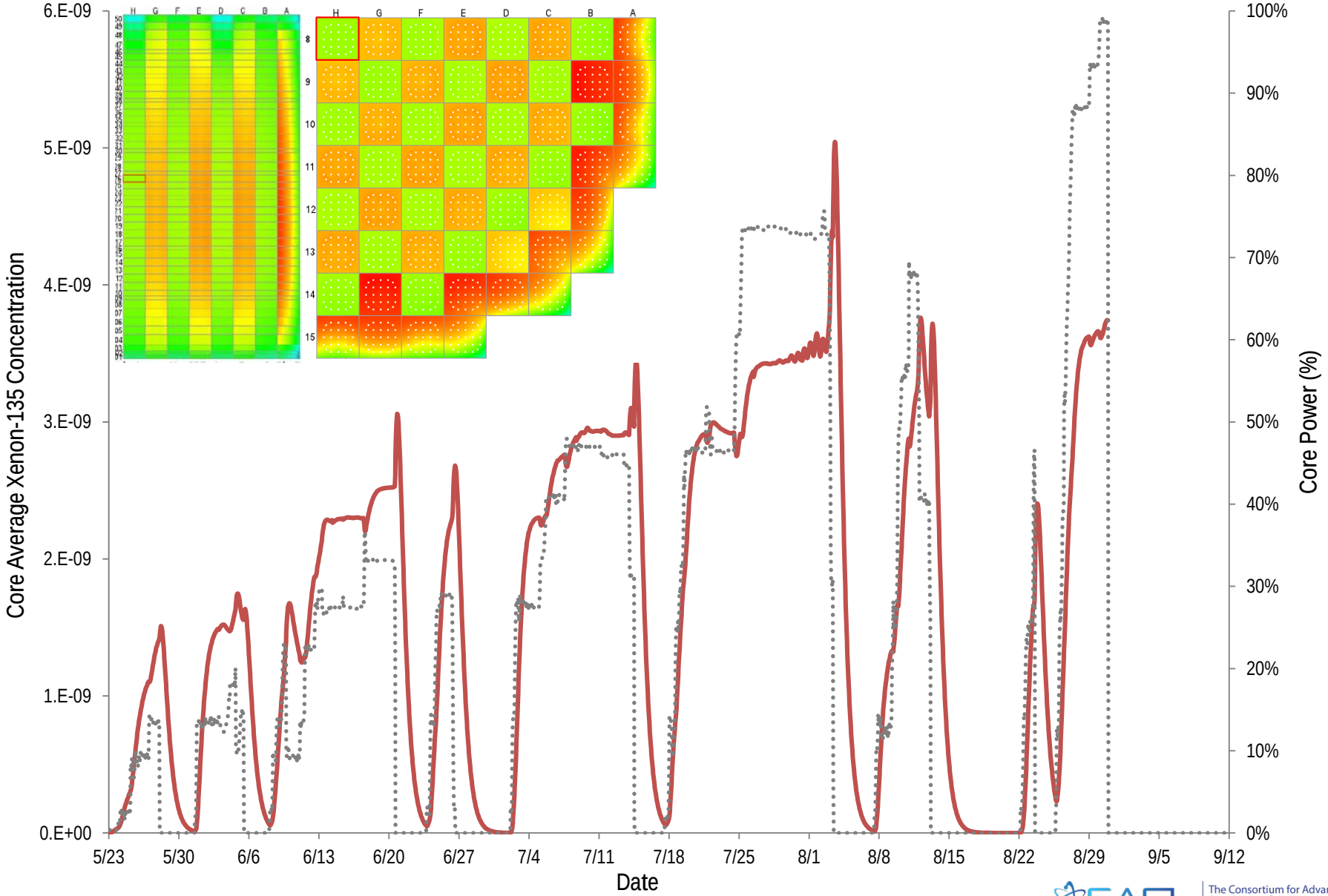
Boron Concentrations



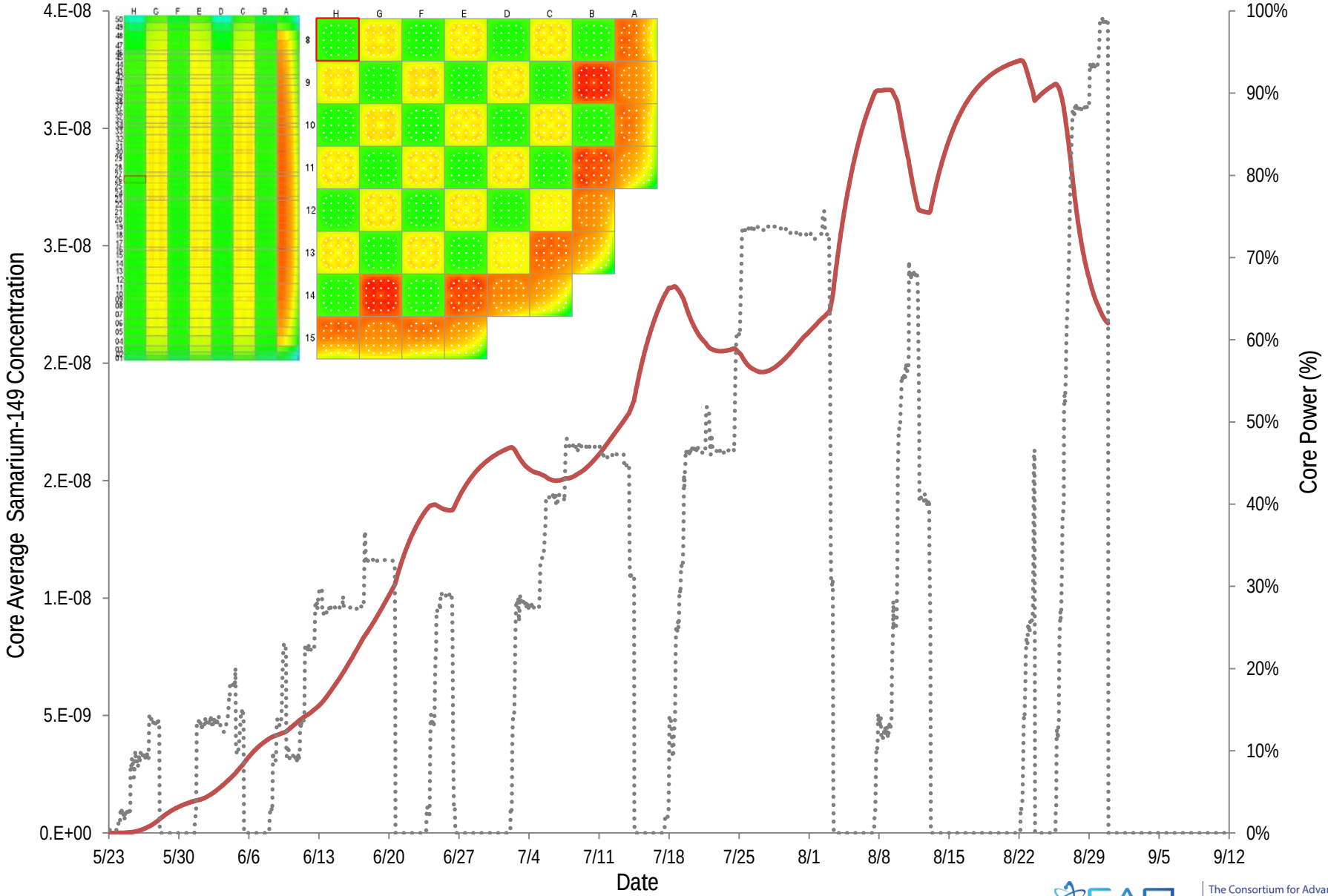
Boron Concentration Differences



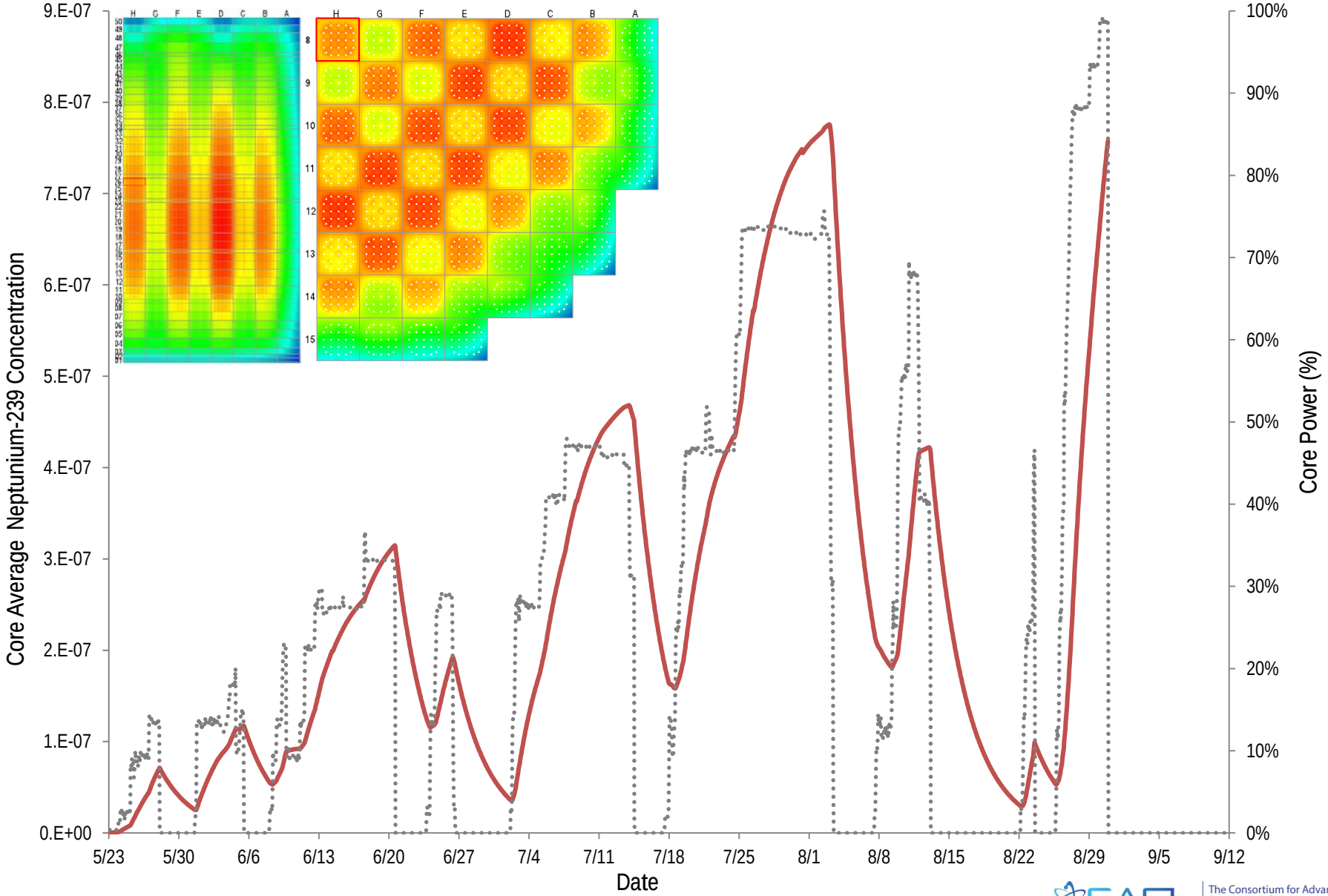
Xe-135 Concentration



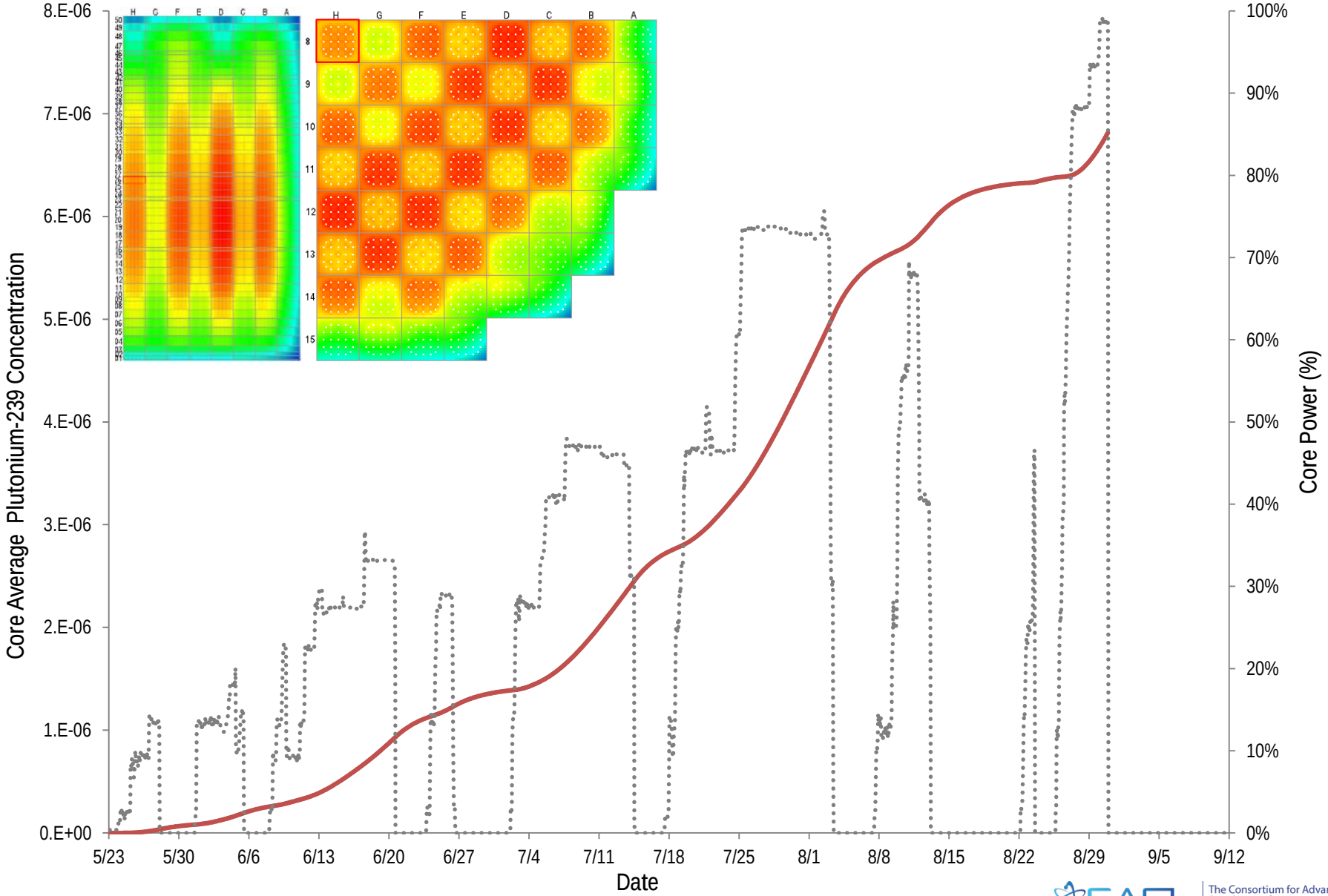
Sm-149 Concentration



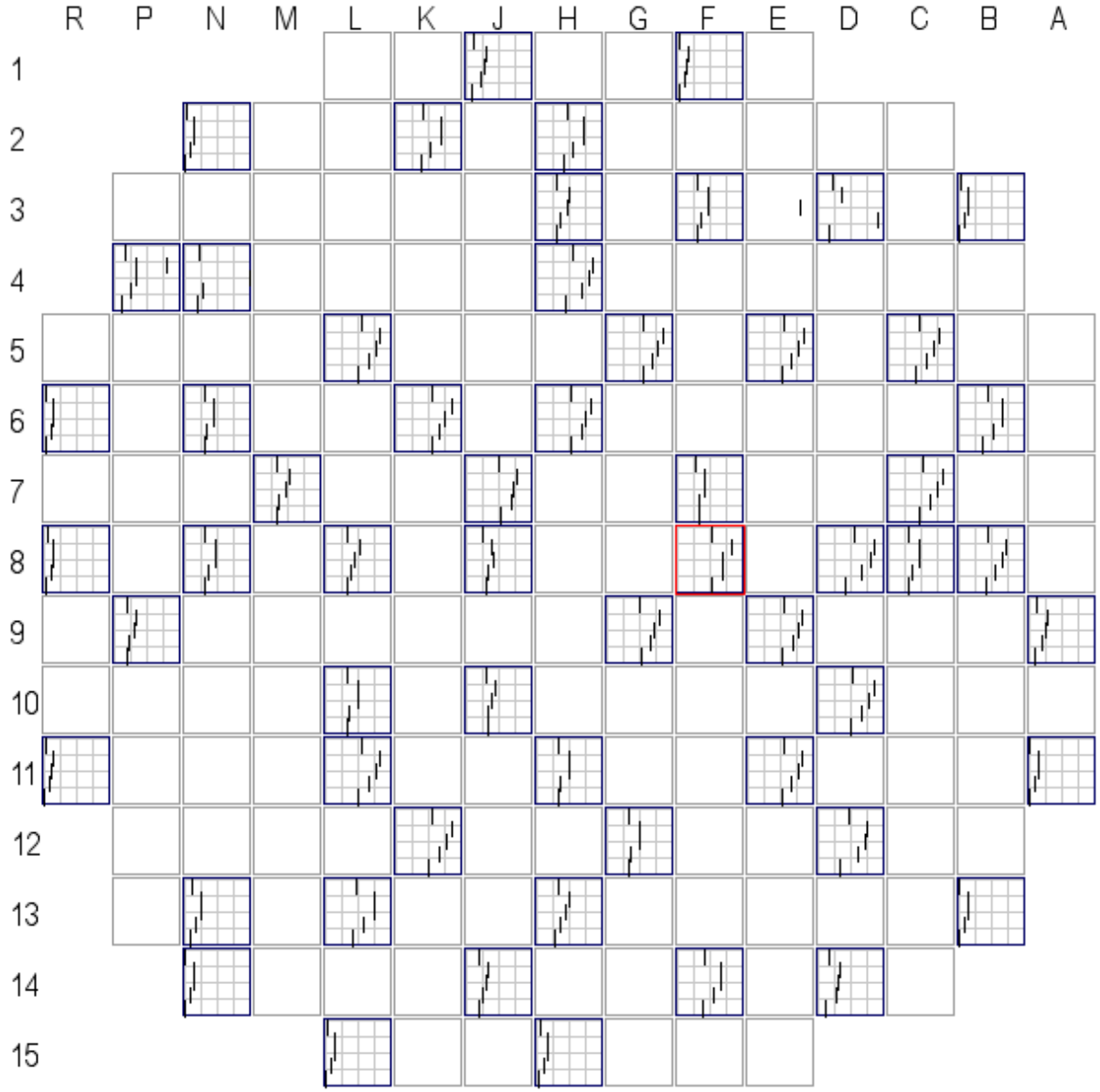
Np-239 Concentration



Pu-239 Concentration



Measured Power Distributions
(in progress)



- 88% Power Map
- 5 level vanadium detectors
- 2 segments flagged as inoperable

Preliminary Radial Power Comparison

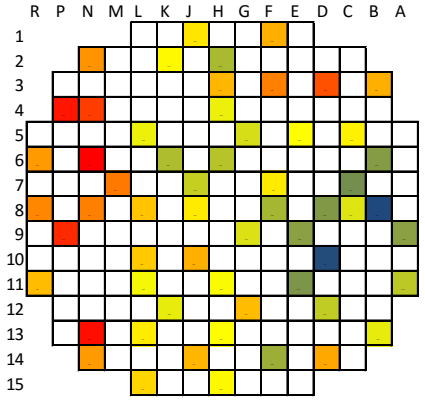
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							3.1%			2.4%					
2			1.8%			-1.1%		-3.3%							
3								1.5%		1.8%		2.3%		1.6%	
4		3.4%	2.2%					-1.3%							
5					-3.1%				-3.0%		-2.0%		-1.6%		
6	2.7%		4.2%			-4.4%		-3.9%						-3.7%	
7				2.1%			-3.1%			0.7%			-4.4%		
8	4.4%		2.6%		1.0%		0.6%			-3.6%		-3.4%	0.2%	-5.6%	
9		5.2%							-1.4%		-3.7%				0.1%
10					0.8%		2.2%					-7.0%			
11	2.7%				-2.1%			0.7%			-4.0%				0.2%
12						-1.7%			2.8%			-1.8%			
13			3.5%		-1.0%			1.4%						0.3%	
14			2.3%				3.2%			-1.6%		2.2%			
15					2.6%			3.0%							

Radial RMS = 2.9%

1st Flux Map
26.7% power

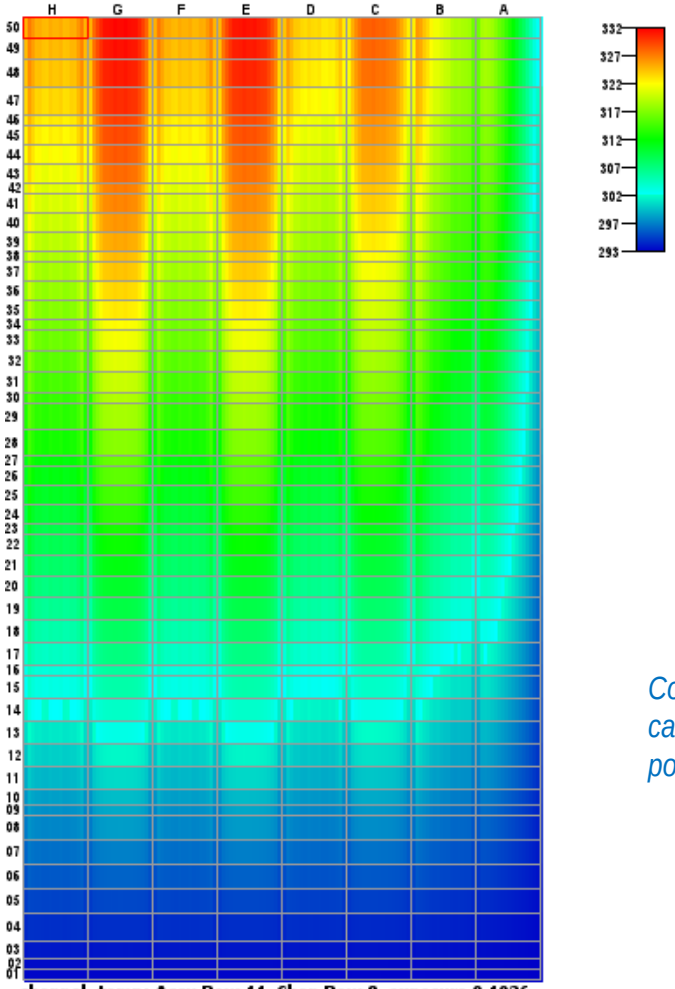
In progress

BEACON – Measured Radial Shape

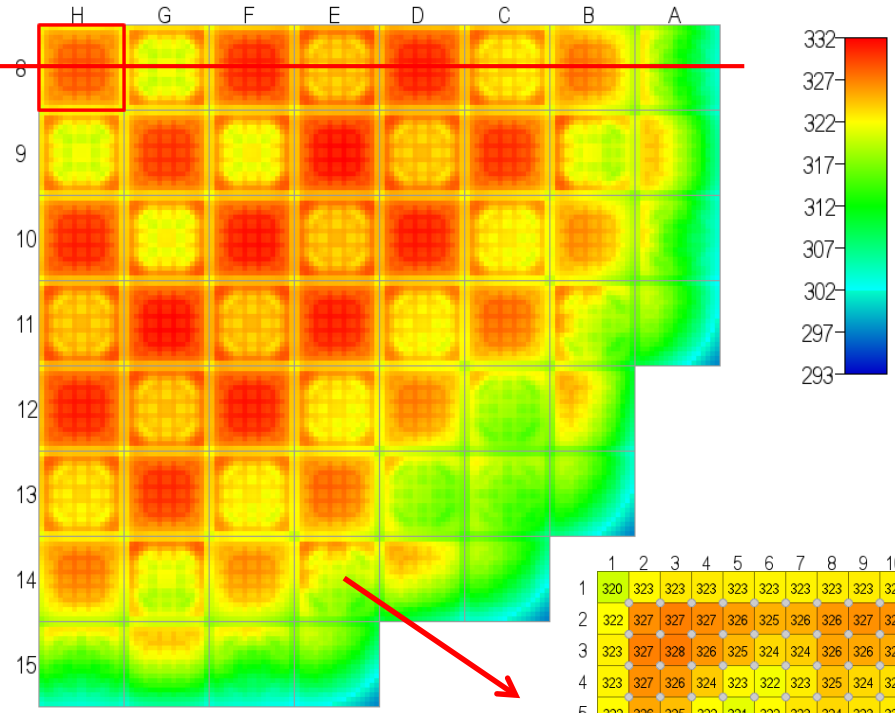


MPACT – Measured
Axial Integrated Instrument Responses

COBRA-TF Solution @ 88% Power



channel_temp: Assy Row 11, Chan Row 8, exposure 0.1036



channel_temp: Axial 371.26

Coolant Temperatures (shown at core exit) calculated by COBRA-TF for the 88% power map

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	320	323	323	323	323	323	323	323	323	323	323	322	322	322	321	321	320	319
2	322	327	327	327	326	325	326	326	327	327	326	325	324	325	325	325	324	322
3	323	327	328	326	325	324	324	326	326	326	326	324	323	323	324	325	324	322
4	323	327	326	324	323	322	323	325	324	324	324	322	321	321	322	323	324	322
5	322	326	325	322	321	322	323	324	323	323	323	322	321	320	320	322	322	321
6	322	325	323	322	322	322	322	323	322	321	322	321	321	320	319	320	321	320
7	322	325	324	322	323	322	321	322	321	320	321	320	320	321	320	320	321	320
8	322	325	325	324	323	322	322	322	321	321	321	321	320	321	321	321	321	320
9	322	326	325	323	323	321	320	321	321	320	321	319	319	320	320	321	321	320
10	322	325	324	322	322	321	320	321	320	320	320	318	318	320	319	320	321	319
11	321	324	324	323	322	321	320	320	320	320	320	319	319	319	319	320	320	318
12	320	323	322	321	321	320	319	320	318	318	319	318	318	318	317	317	318	317
13	320	322	321	319	320	319	319	319	318	318	318	317	317	317	315	316	317	316
14	319	322	321	319	318	319	319	319	319	318	318	318	316	315	315	316	316	315
15	319	322	321	319	318	317	318	319	318	318	318	316	315	314	315	316	316	314
16	318	322	322	320	319	317	318	319	318	318	318	316	315	315	315	316	315	313
17	318	321	321	320	319	318	318	319	319	318	317	316	315	315	315	315	314	312
18	316	318	319	318	318	317	317	317	317	316	316	315	314	314	313	312	311	310

channel_temp: Assembly 50, Axial 371.265

VERA Runtime Performance

- Each quarter-core calculation has used 4234 cores on OLCF's Eos supercomputer

- Currently completed:
  - 27 jobs
  - 2,429 hourly statepoints
  - 14,163 complete MPACT/CTF converged iterations
  - 11.6 days walltime
  - 1.2 million core-hours (33 years on my laptop!)
  - ~7 mins per statepoint

OLCF's TITAN Supercomputer at Oak Ridge National Laboratory

Acknowledgements

- ORNL
  - Ben Collins
  - Cole Gentry
  - Ron Lee
  - Shane Stimpson
  - OLCF (Eos)
- TVA
  - Kathleen Cunningham
  - John Ritchie
- Westinghouse
  - Fausto Franceschini
  - David Salazar
  - Vefa Kucukboyaci
- INL
  - High Performance Computing (Falcon)

Leveraging CASL partnerships for this unique opportunity

CASL

A DOE Energy Innovation Hub

godfreyat@ornl.gov