Benchmarking of Catawba Nuclear Station Cycles 19-21

Travis Lange, Jason Young, Brad Black

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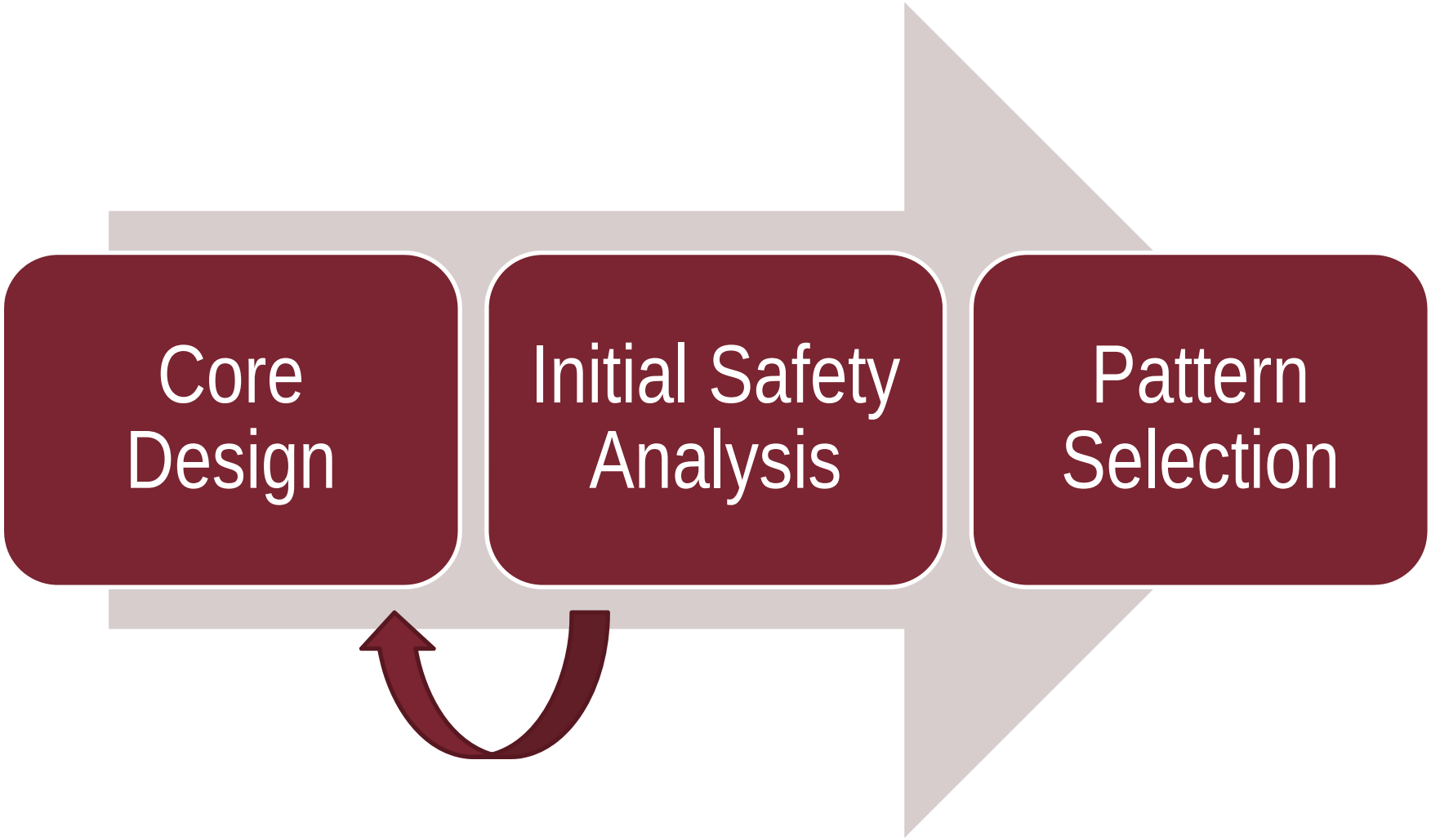
Catawba

- Catawba Nuclear Station
  - SC outside of Charlotte
- Two Unit Westinghouse 4-loop PWR
  - Unit 1 currently on cycle 23
  - Unit 2 beginning cycle 22

Duke Energy Core Design



Risk Tolerance

- BOA
  - Risk thresholds (lbm of core boron, crud thickness, steaming rate) effectively considered 'limits' when undergoing a standard core design process
  - Risk thresholds rarely breached without an outside compelling force (such as transition to 24 month cycles)
  - Normal designs have generally not been pursued with BOA risks
- CIPS
  - Magnitude of CIPS effect on axial offset is difficult to predict, especially in cores without a history of CIPS
  - Not sufficient confidence in deriving the resultant axial offset from BOA results to challenge these thresholds
  - Core designs remain CIPS-conservative

Safety Analysis

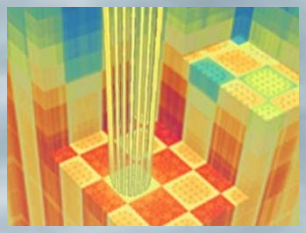
- CIPS affects many assumptions about core power distributions
  - Axial profile at steady state
  - Reactivity in core
- Continued operation with CIPS erodes excess shutdown margin
- Large power defect due to
  - Reactivity addition when boron/crud deposits disappear during a trip
  - Additional axial flux redistribution (more positive AO at HZP)
- Must assume a trip would completely remove boron in crud
  - Exposes top of core where burnup has been held abnormally low
  - Fresh boron can take its place, exacerbating axial offset

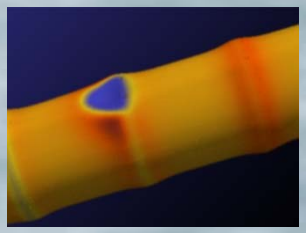
Delivering the Nuclear Promise

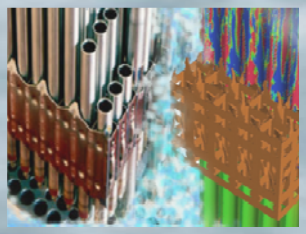
- Delivering the Nuclear Promise
  - Duke Energy is committed to providing safe, reliable, and economically competitive nuclear energy for ratepayers
  - Better quantifying CIPS risk is a potential area for improvement in designing more cost competitive core designs while maintaining safe operation
  - Knowledge of likely CIPS effects on power distributions would allow technical experts to propose designs with a potential for light CIPS, as well as examine the actual effects of CIPS on our internal safety analysis methods
- CASL
  - By first matching BOA results and eventually predicting CIPS and projecting CIPS effects, CASL can build confidence in utilities that VERA can be used to inform core designs with regards to CIPS risk
  - VERA can become a tool that would allow pursuing more economic core designs based upon an actual understanding of the true risk and likelihood of CIPS in candidate core designs

VERA Catawba 2 Cycles 19-21 Benchmarking Summary

Travis Lange







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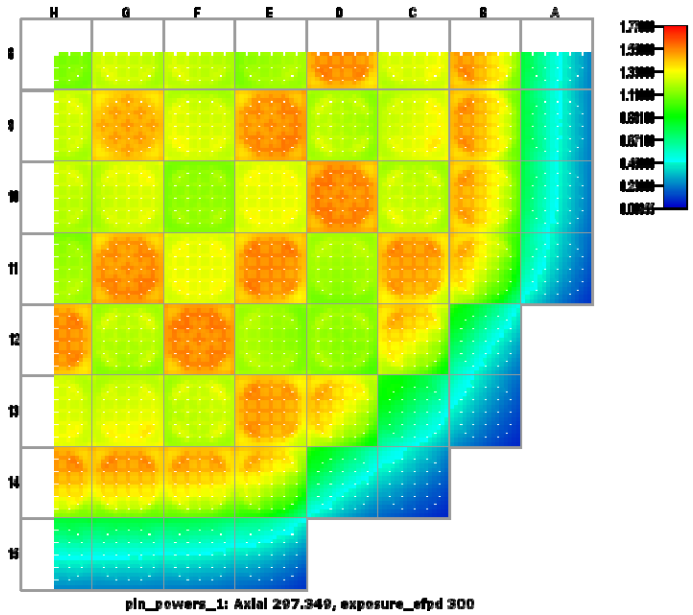
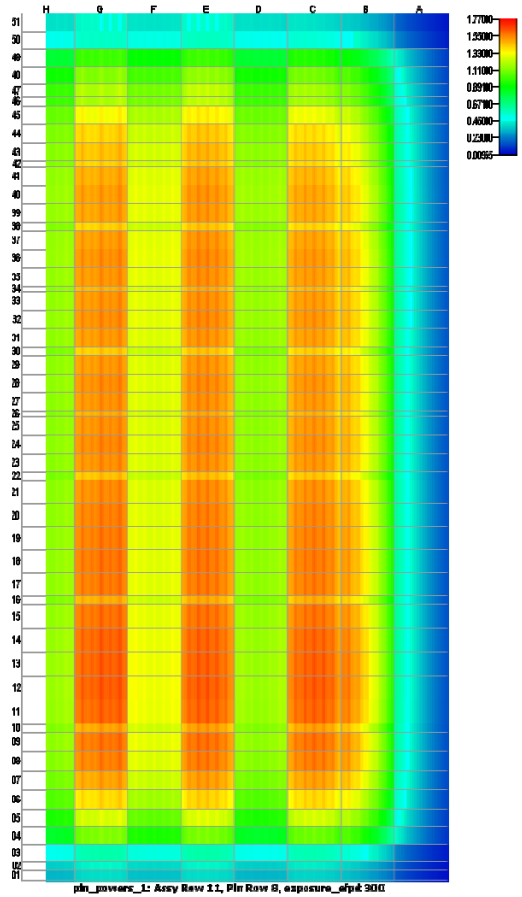
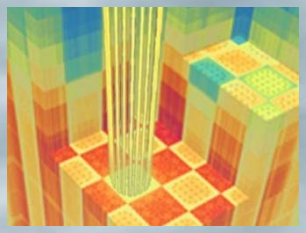
  - ZPPT
  - Full cycle comparisons
    - Critical Boron
    - AO
- Cycle 22 results
  - ZPPT
  - Preliminary CIPS results

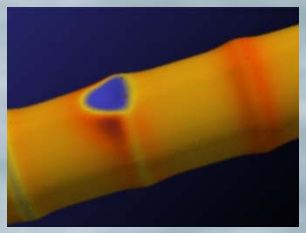
Catawba 2 Jump In Review

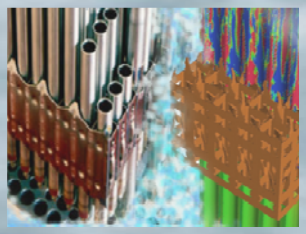
Cycles 19-21











Cycle 19 ZPPT

C2C19 BOC HZP ARO			
	Measured	Duke	VERA
Critical Boron Conc (PPM)*	1944	1955	1958
ITC (pcm/°F)	-4.53	-4.21	-5.15
MTC (pcm/°F)			
Boron Worth (pcm/ppm)		-6.12	-6.25

C2C19 Individual Bank Worths (pcm)					
	Measured	Duke	% Diff	VERA	% Diff
Control Bank A	385.2	393.8	2.2%	420	9.1%
Control Bank B	646.5	614.6	-4.9%	572	-11.6%
Control Bank C	983.5	959.3	-2.5%	959	-2.5%
Control Bank D	467.9	461.2	-1.4%	456	-2.6%
Shutdown Bank A	156.5	157.9	0.9%	143	-8.6%
Shutdown Bank B	1200.7	1145.8	-4.6%	1115	-7.1%
Shutdown Bank C	367.1	359.6	-2.0%	341	-7.2%
Shutdown Bank D	366.9	360.6	-1.7%	341	-7.1%
Shutdown Bank E	650.3	659	1.3%	674	3.6%
Total	5224.6	5111.8	-2.2%	5020	-3.9%

Cycle 20 ZPPT

C2C20 BOC HZP ARO			
	Measured	Duke	VERA
Critical Boron Conc (PPM)*	1949	1977	1950
ITC (pcm/°F)	-4.4	-4.16	-5.7
MTC (pcm/°F)			
Boron Worth (pcm/ppm)		-6.09	-6.23

C2C20 Individual Bank Worths (pcm)					
	Measured	Duke	% Diff	VERA	% Diff
Control Bank A	415.8	434.3	4.4%	425	2.2%
Control Bank B	641.6	609.9	-4.9%	616	-4.0%
Control Bank C	955.7	948.7	-0.7%	927	-3.0%
Control Bank D	523.1	516	-1.4%	517	-1.3%
Shutdown Bank A	189.9	182.1	-4.1%	188	-0.8%
Shutdown Bank B	952.4	944.6	-0.8%	934	-1.9%
Shutdown Bank C	386.4	367.9	-4.8%	376	-2.7%
Shutdown Bank D	386.7	367.9	-4.9%	375	-2.9%
Shutdown Bank E	507.4	519	2.3%	510	0.4%
Total	4959	4890.4	-1.4%	4868	-1.8%

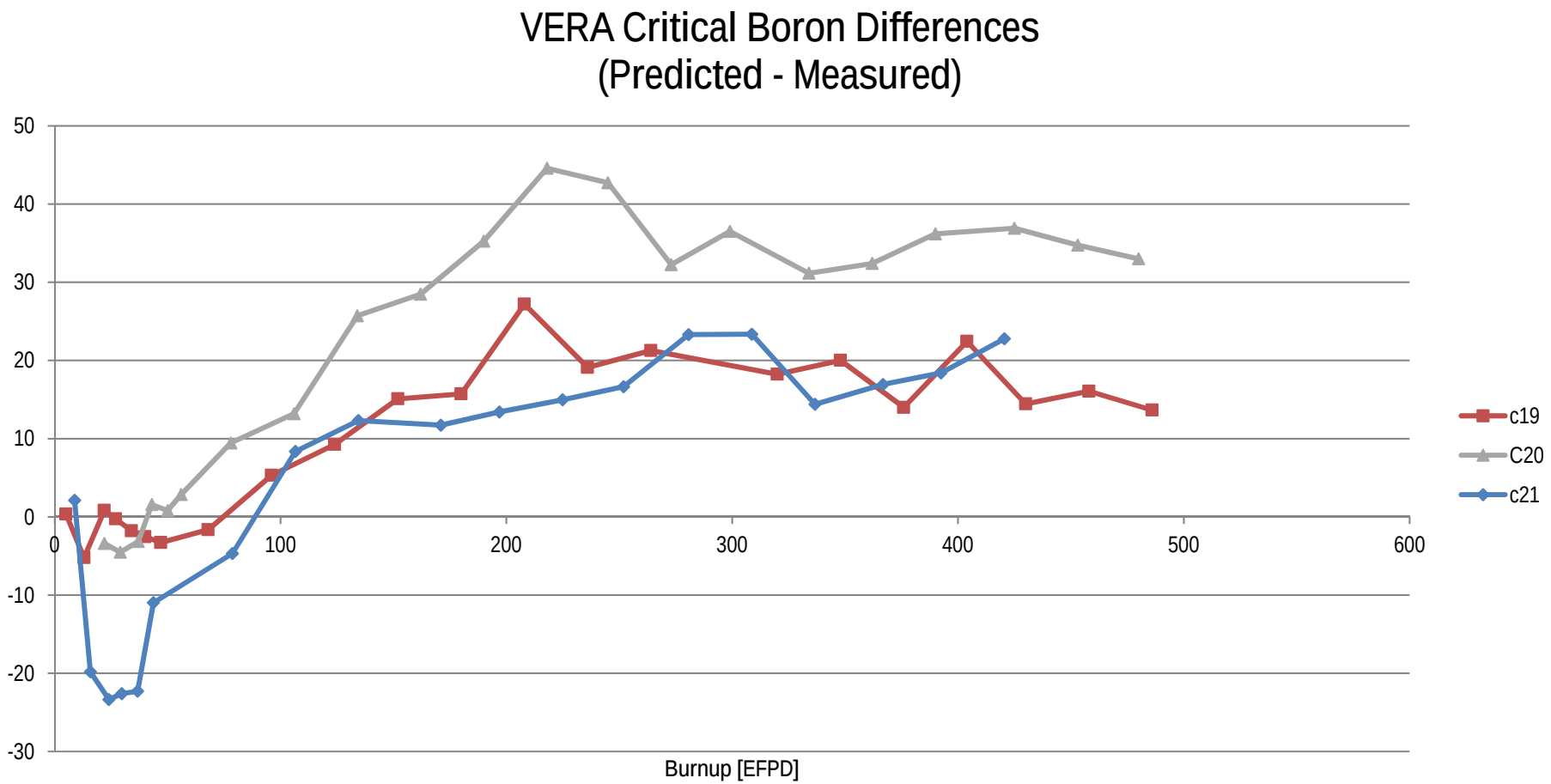
Cycle 21 ZPPT

BOC HZP ARO			
	Measured	Duke	VERA
Critical Boron Conc (PPM)*	1922	1923	1903
ITC (pcm/°F)	-4.73	-4.7	-6.1
MTC (pcm/°F)			
Boron Worth (pcm/ppm)		-6.11	-6.26

Individual Bank Worths (pcm)					
	Measured	Duke	% Diff	VERA	% Diff
Control Bank A	314.6	332.6	5.7%	338	7.5%
Control Bank B	715.8	675.6	-5.6%	683	-4.5%
Control Bank C	955.3	946.6	-0.9%	945	-1.1%
Control Bank D	545.5	538.1	-1.4%	537	-1.6%
Shutdown Bank A	160.7	167	3.9%	167	3.7%
Shutdown Bank B	1165.6	1113.8	-4.4%	1106	-5.1%
Shutdown Bank C	416.2	408.1	-1.9%	405	-2.7%
Shutdown Bank D	415.9	409.1	-1.6%	407	-2.1%
Shutdown Bank E	535.5	528	-1.4%	523	-2.4%
Total	5225.1	5118.9	-2.0%	5111	-2.2%

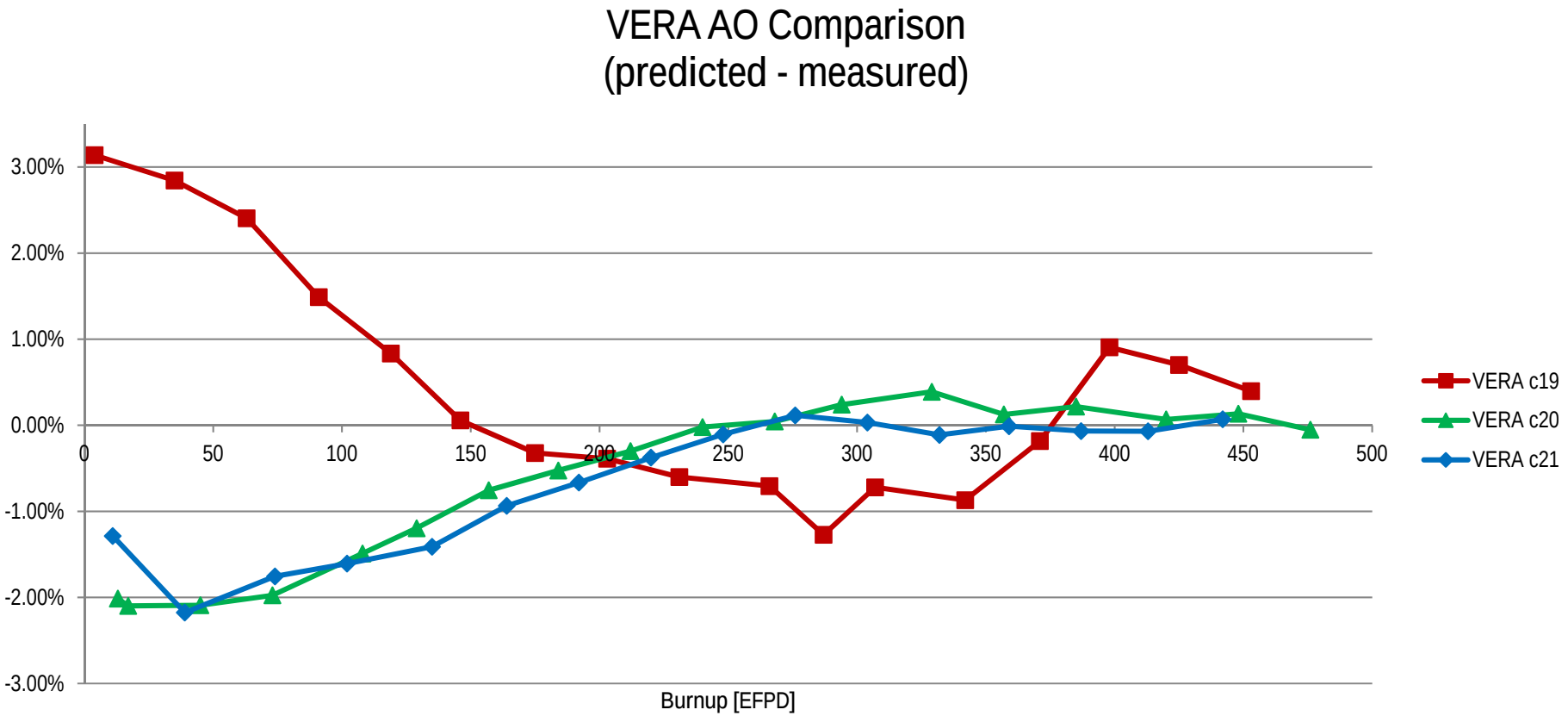
Critical Boron

	Initial Critical Boron [ppm]		
	Measured	VERA	Diff (VERA-measured)
c19	1944	1958	14
c20	1949	1950	2
c21	1922	1903	-19



Axial Offset

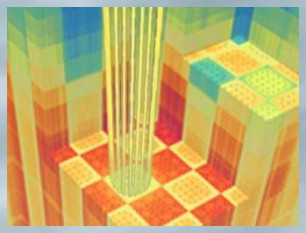
RMS Error of Axial Offset Differences (VERA - measured*)			
	c19	c20	c21
Whole cycle	1.34%	1.10%	0.99%
>150 EFPD	0.65%	0.32%	0.37%
>250 EFPD	0.73%	0.19%	0.08%

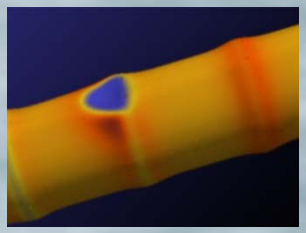


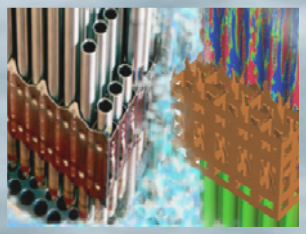
*measured data comes from COMET data from Duke
C19 still has effects from the jump in cycle at 18

Cycle 22 Results

Non-CIPS





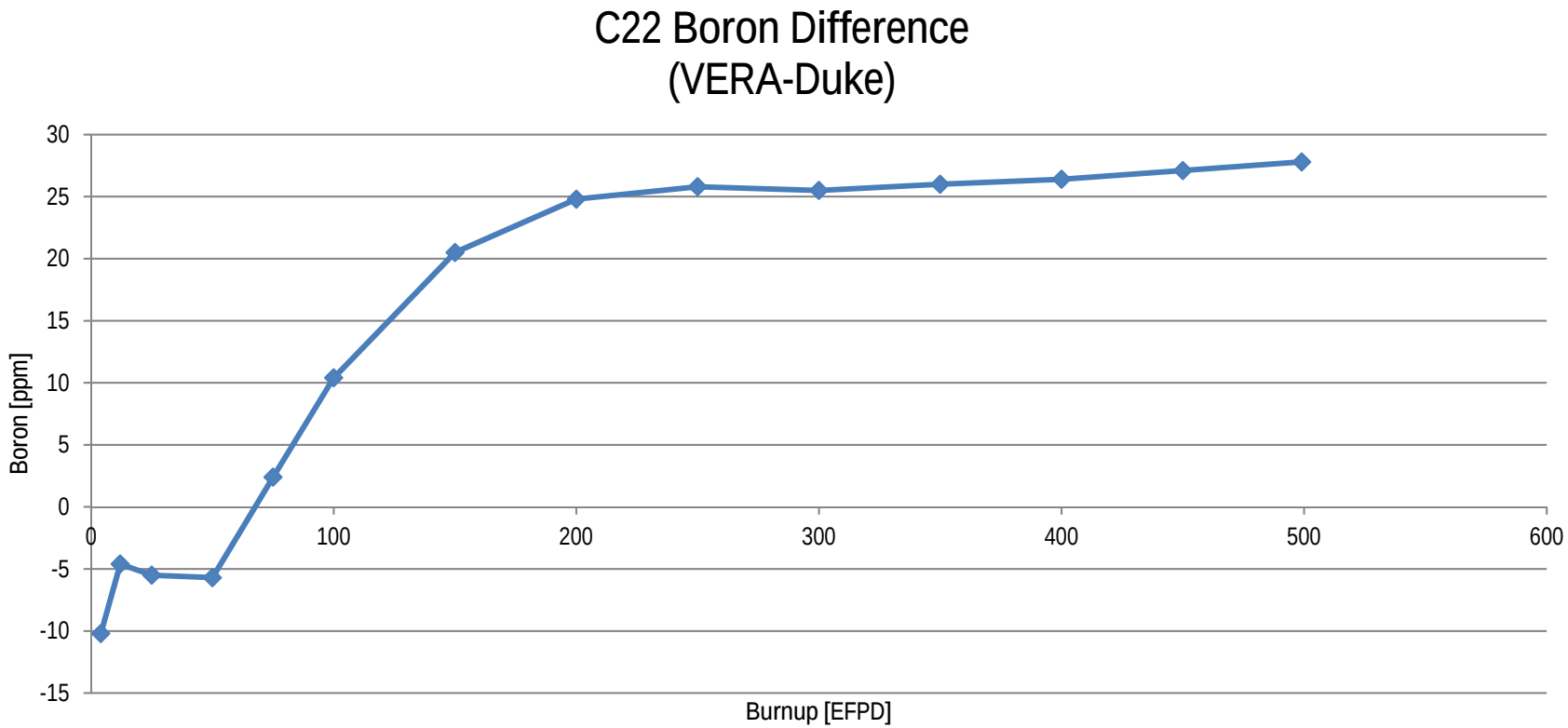


Cycle 22 ZPPT

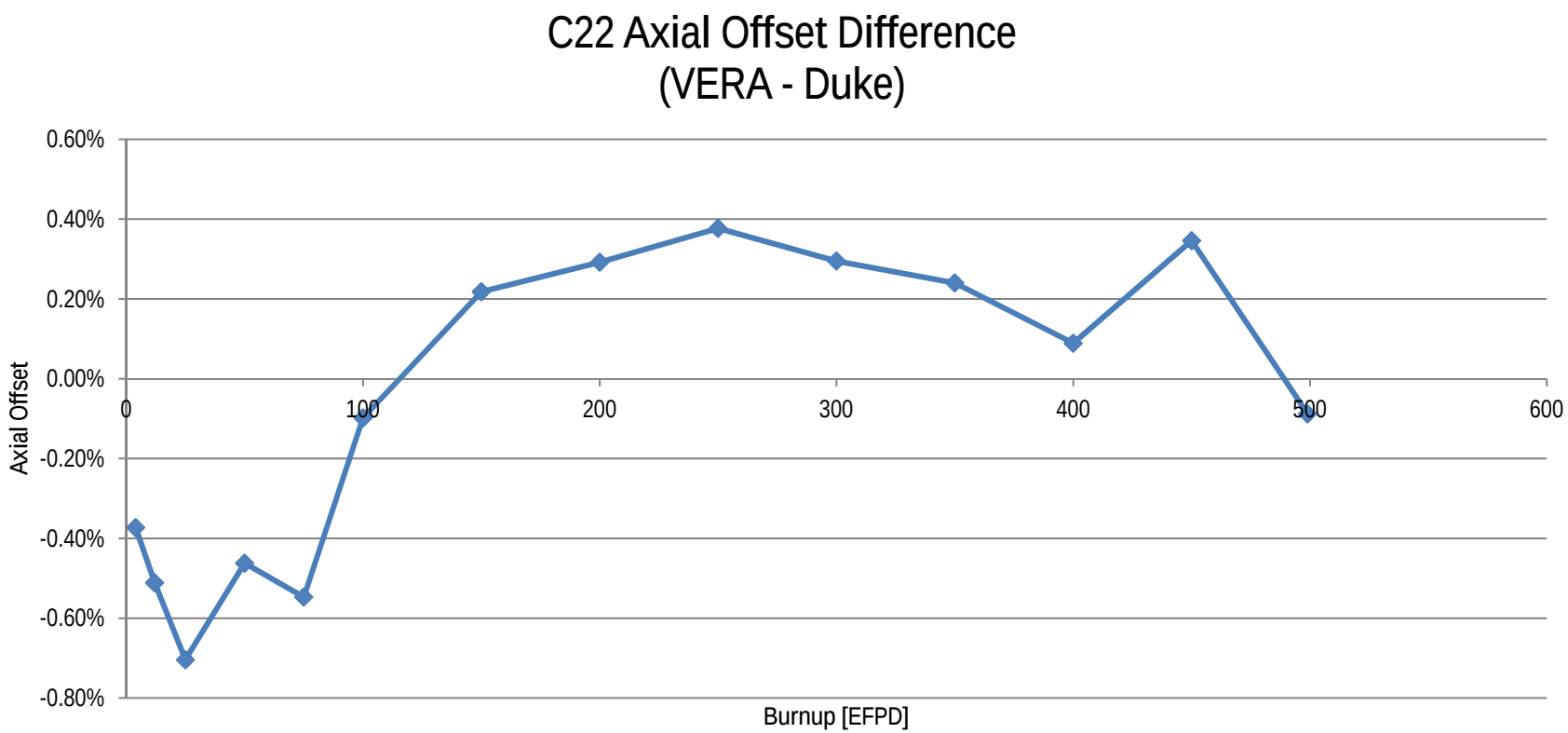
C2C22 BOC HZP ARO			
	Measured	Duke	VERA
Critical Boron Conc (PPM)*		1970	1963
ITC (pcm/°F)		-4.02	-5.13
MTC (pcm/°F)			
Boron Worth (pcm/ppm)		-6.06	-6.23

C2C22 Individual Bank Worths (pcm)			
	Duke	VERA	% Diff
Control Bank A	510	521	2.2%
Control Bank B	508	493	-3.0%
Control Bank C	894	888	-0.7%
Control Bank D	625	620	-0.8%
Shutdown Bank A	177	172	-3.0%
Shutdown Bank B	804	792	-1.4%
Shutdown Bank C	373	366	-2.0%
Shutdown Bank D	372	365	-1.9%
Shutdown Bank E	447	441	-1.3%
Total	4710	4658	-1.1%

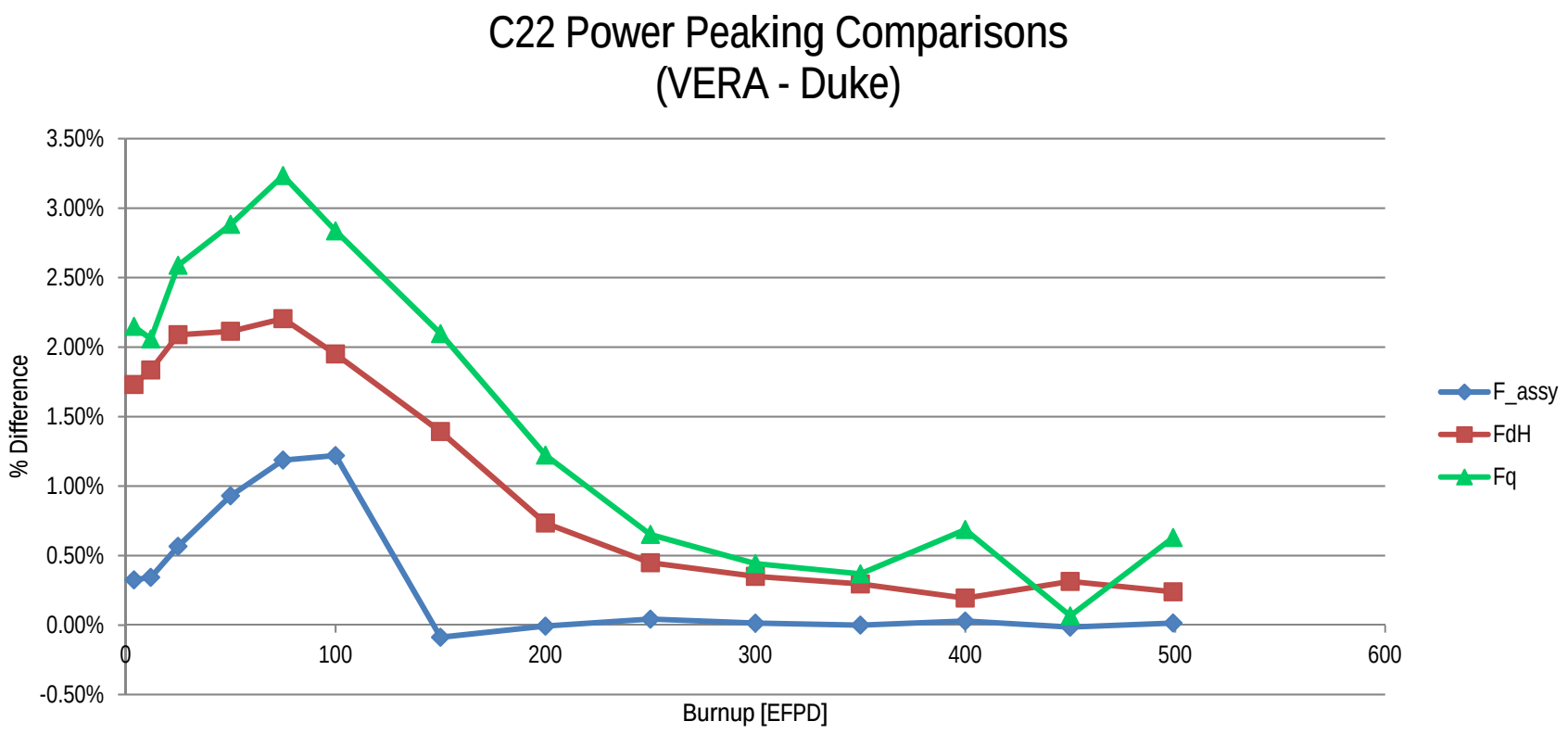
VERA Cycle 22 Boron Comparison



VERA Cycle 22 AO Comparison



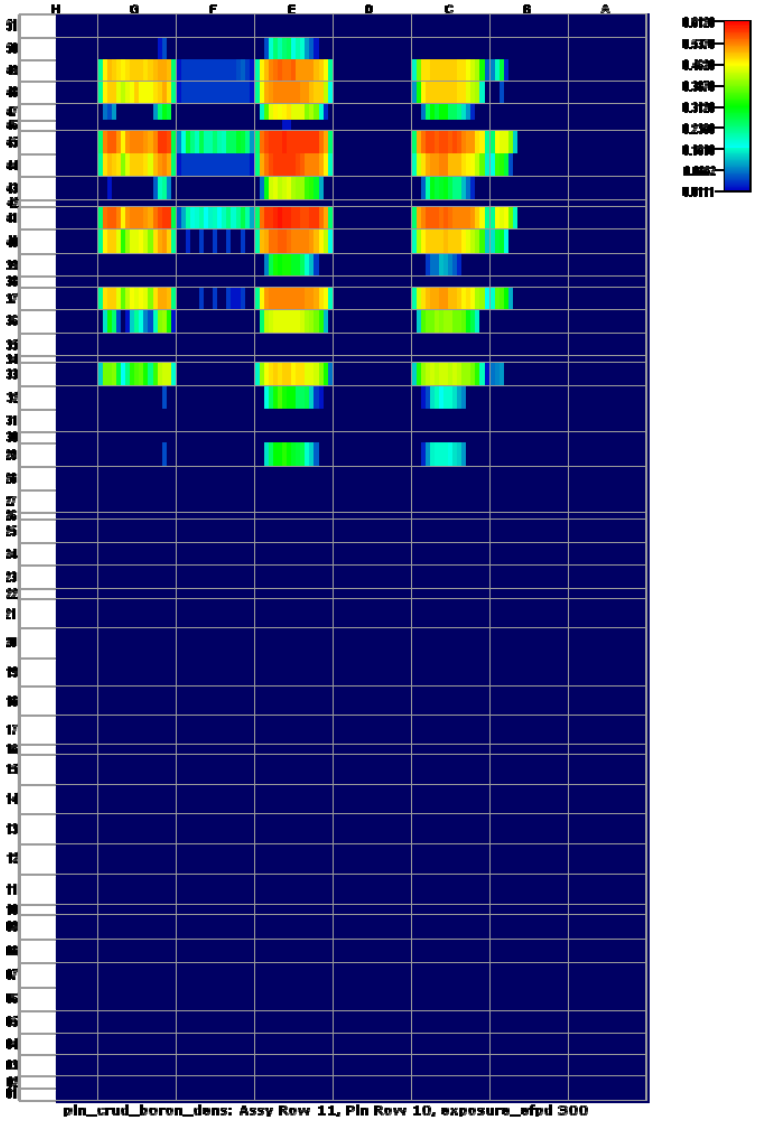
C22 Power Peaking Comparisons



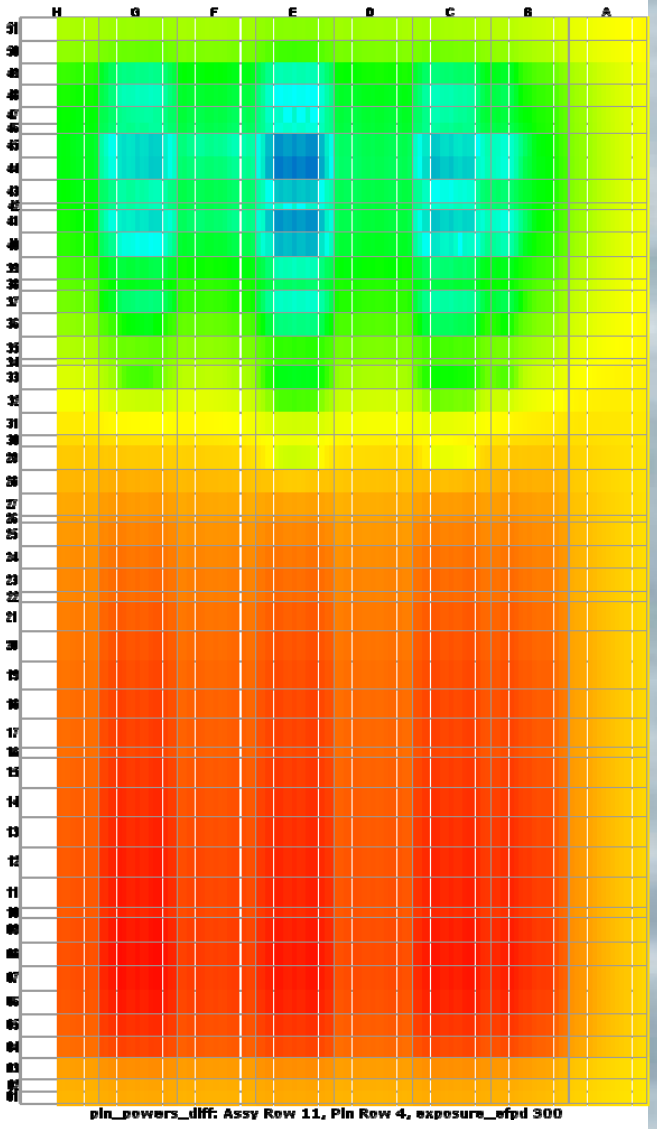
Max Power Location Comparisons

Burnup		Max Assembly Location		Max Pin Location		Max Fq Position				
EFPD		DUKE	VERA	DUKE	VERA	DUKE			VERA	
4		H-09	H-09	C-12	C-12	C-12	163		C-12	139
12		C-11	C-11	C-12	C-12	C-12	163		C-12	139
25		C-11	C-11	C-12	C-12	C-12	163		C-12	149
50		C-11	C-11	C-12	C-12	C-12	163		C-12	149
75		C-11	C-11	C-12	C-12	C-12	163		C-12	149
100		E-11	E-11	C-11	C-11	C-11	163		C-11	139
150		D-10	D-10	E-11	E-11	C-11	117		C-11	106
200		D-10	D-10	D-10	D-10	G-14	117		G-14	96
250		D-10	D-10	D-10	D-10	B-08	102		H-14	86
300		D-10	D-10	D-10	D-10	D-10	102		D-10	86
350		D-10	D-10	D-10	D-10	D-10	102		E-09	86
400		D-10	D-10	D-10	D-10	H-14	71		E-09	55
450		D-10	D-10	D-10	D-10	B-08	71		E-09	55
499		D-10	D-10	D-10	D-10	B-08	71		E-09	55

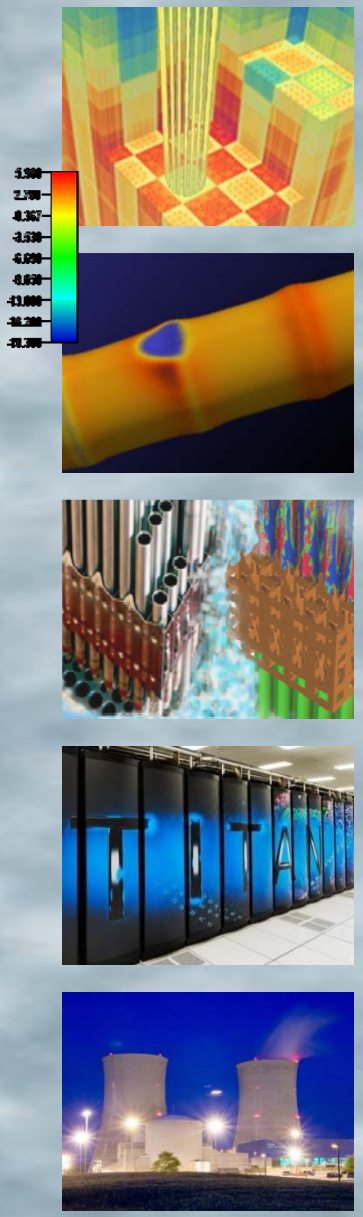
Preliminary C22 CIPS Results



Boron Mass Density



Pin Power Differences



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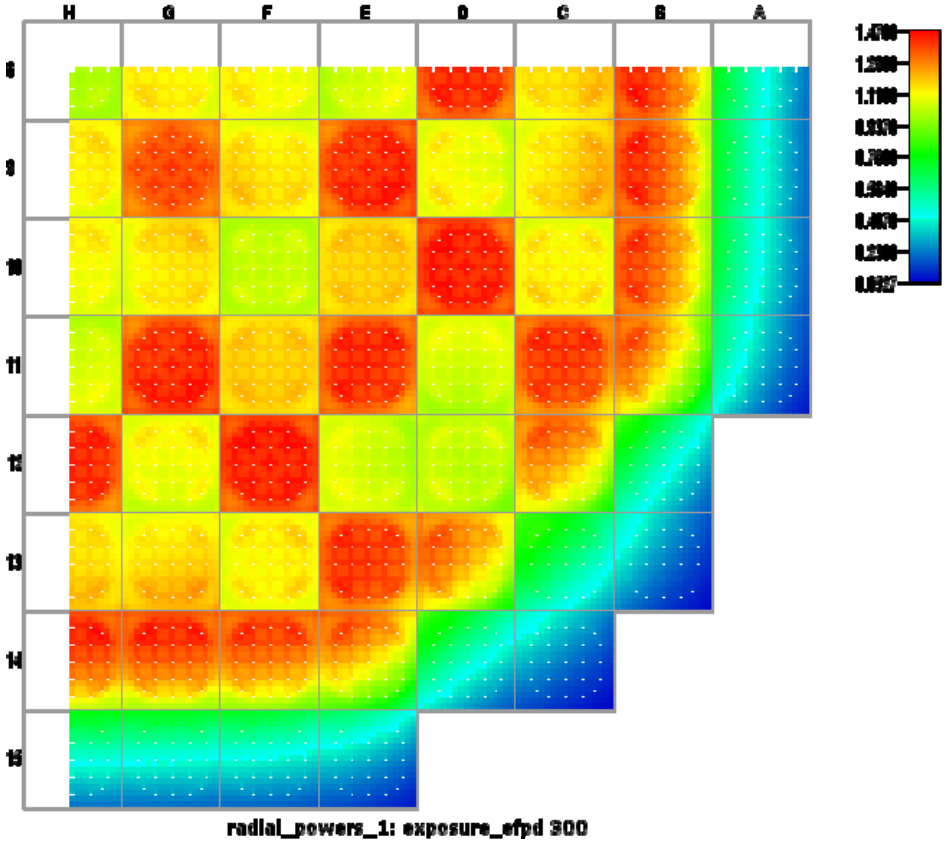
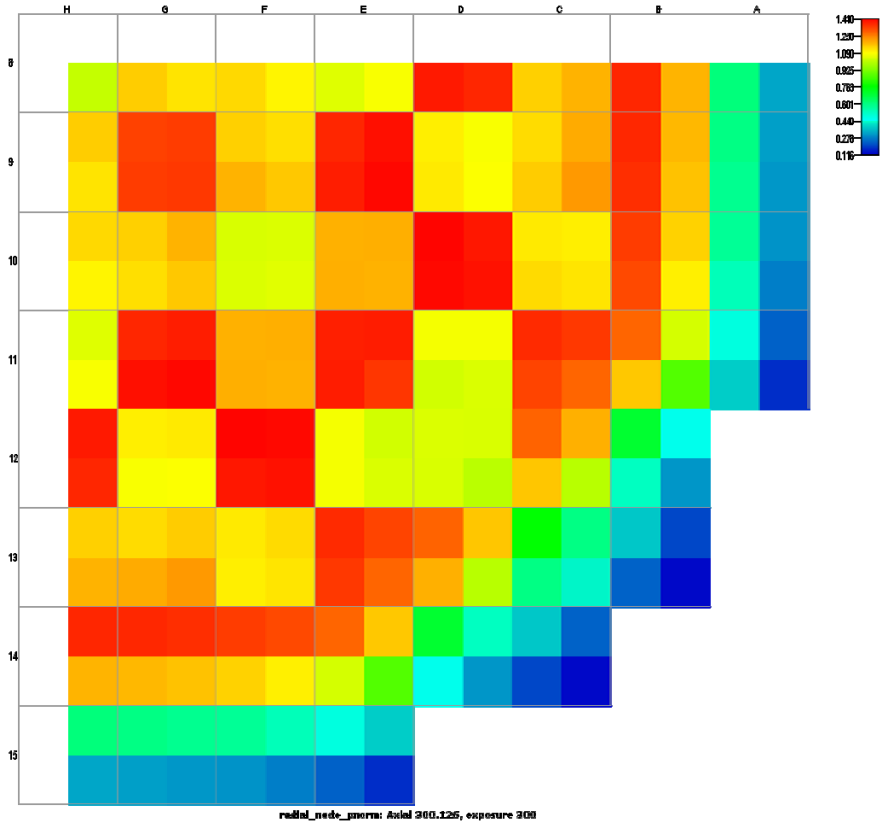
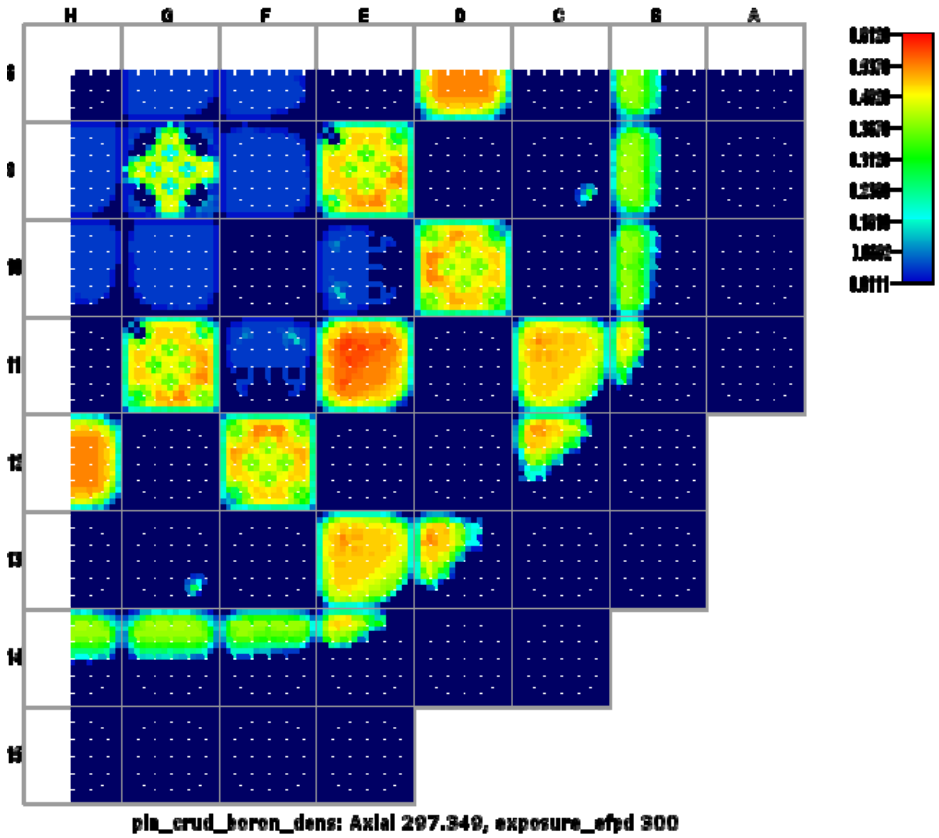
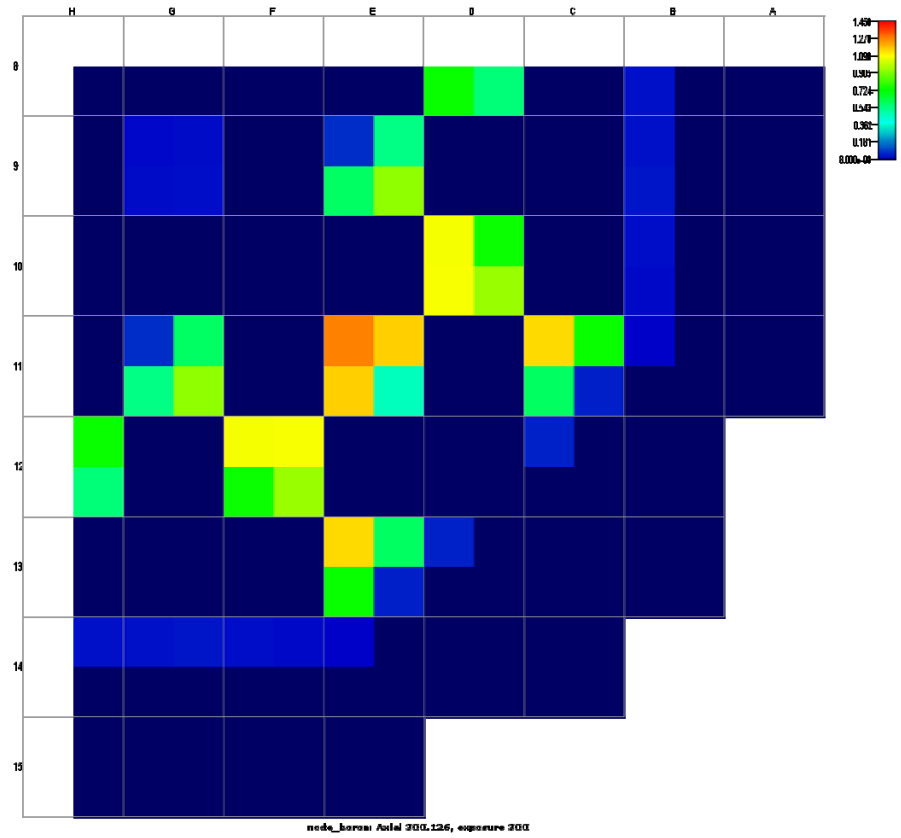
VERA vs BOA Pin Powers
300 EFPD at 300 cm



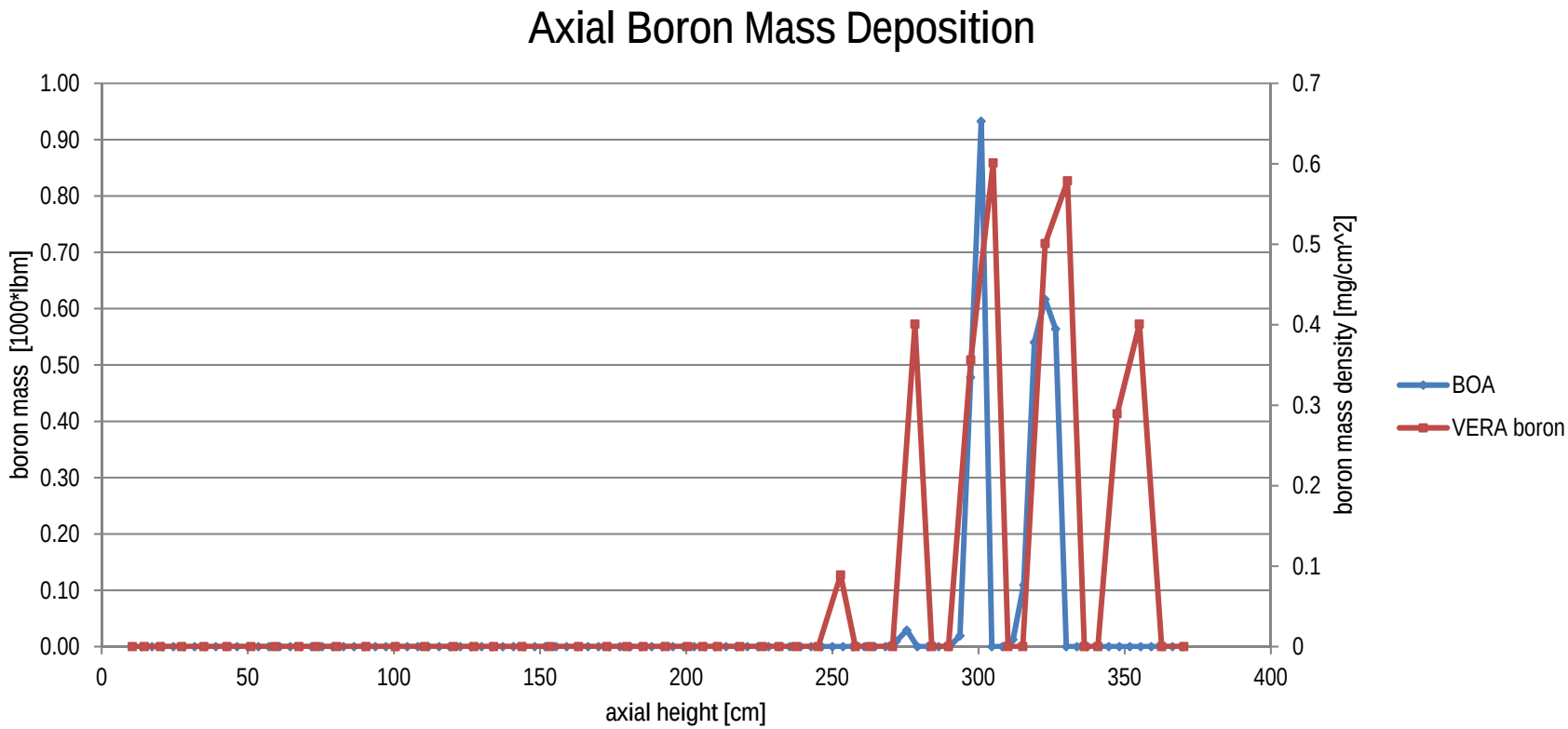


Radial Boron Mass Buildup
300 EFPD at 300 cm

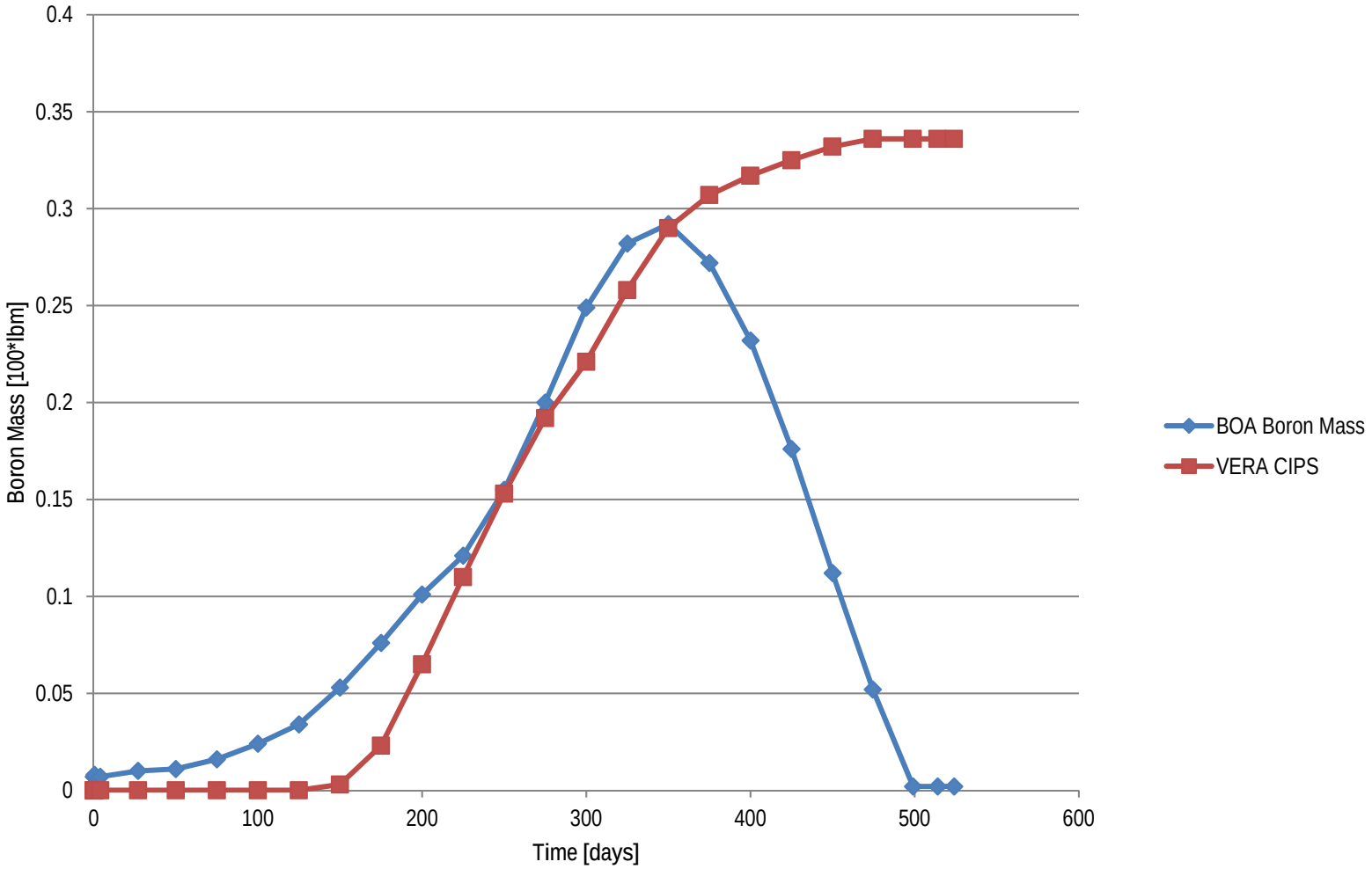




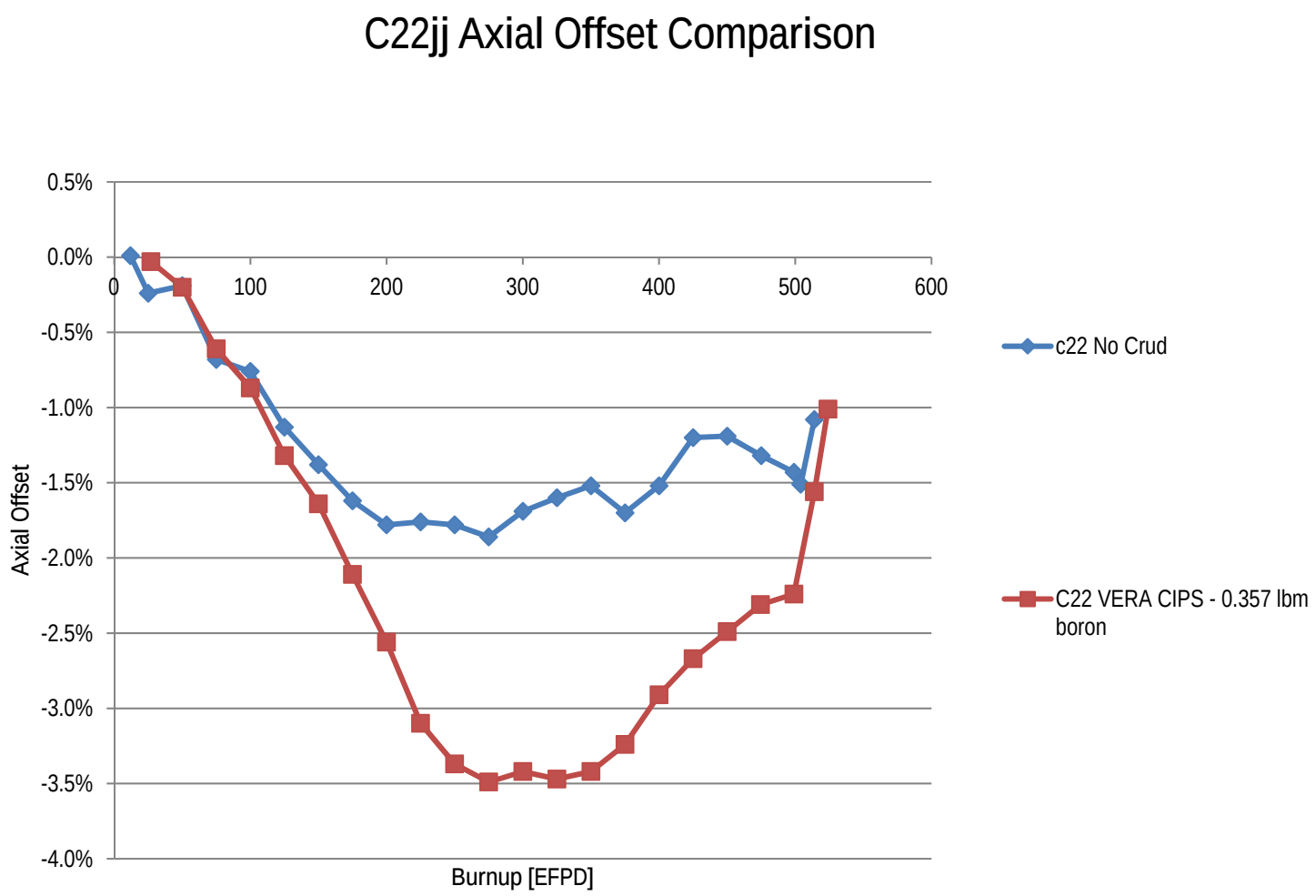
Axial Boron Deposition Channel 81
Top left of assembly E11



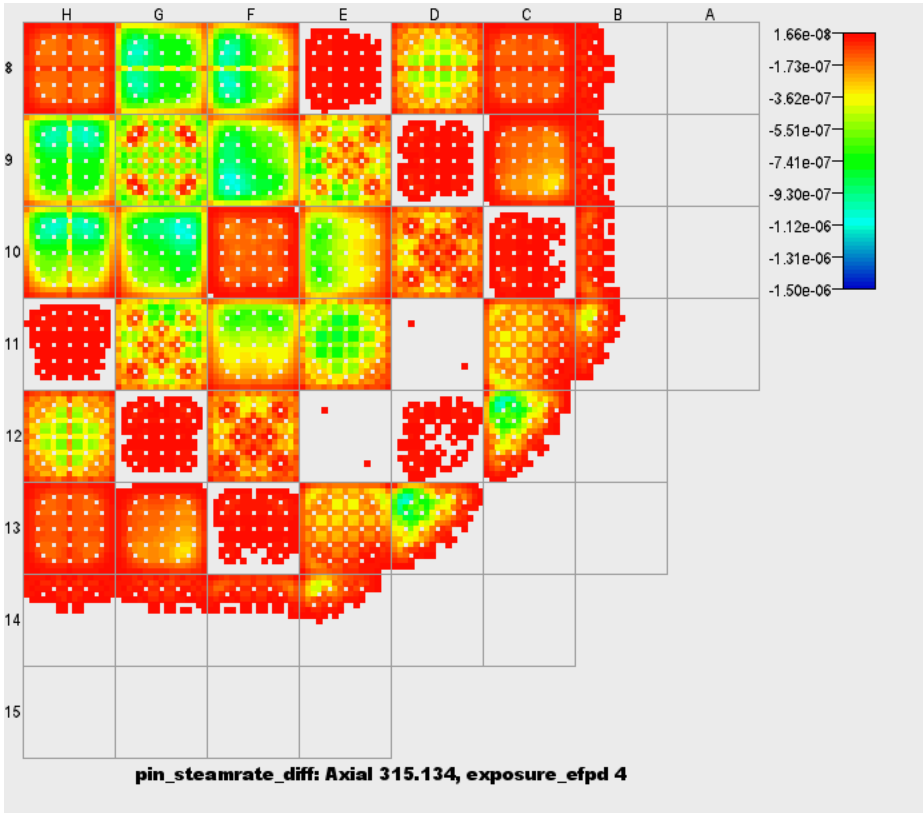
C22 Core Boron Buildup

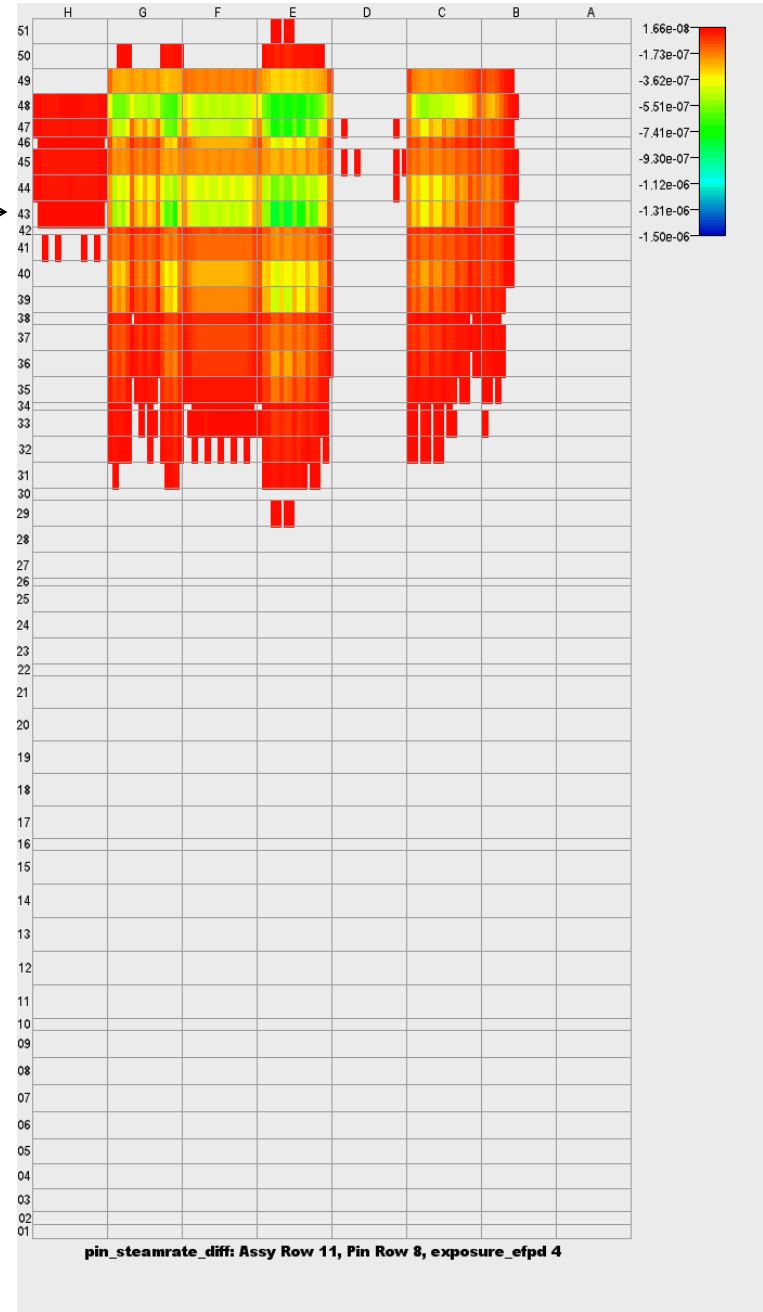


C22 CIPS Axial Offset

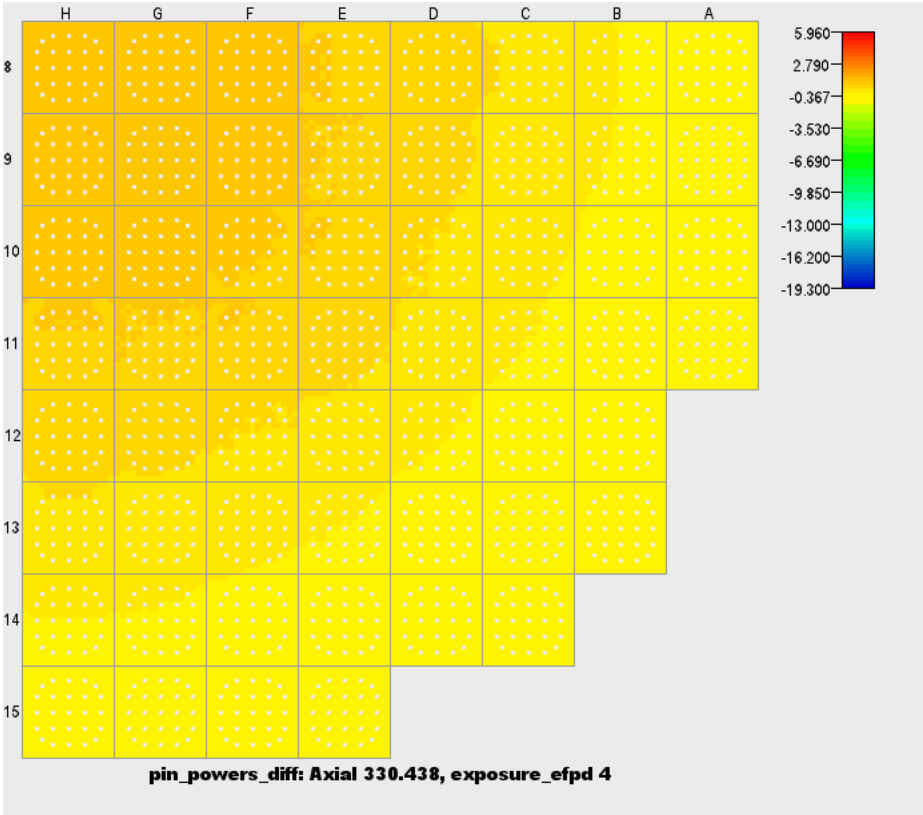


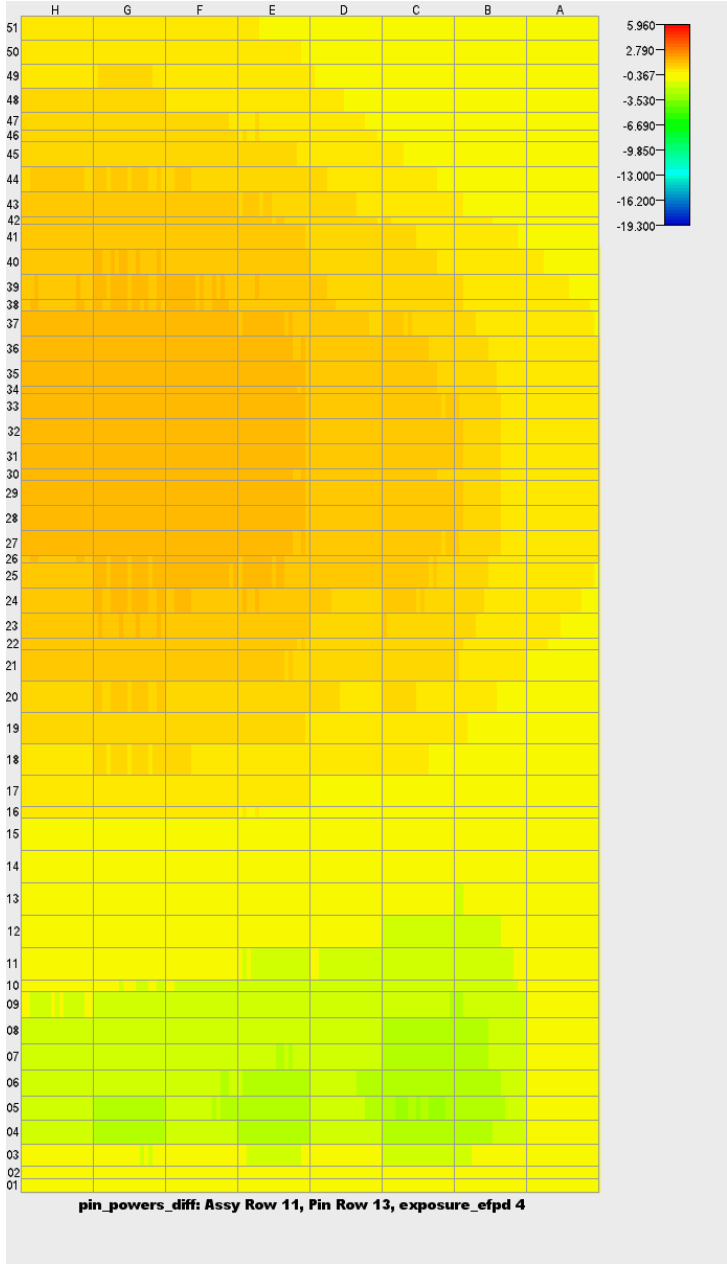
VERA Pin Steaming Rate Difference



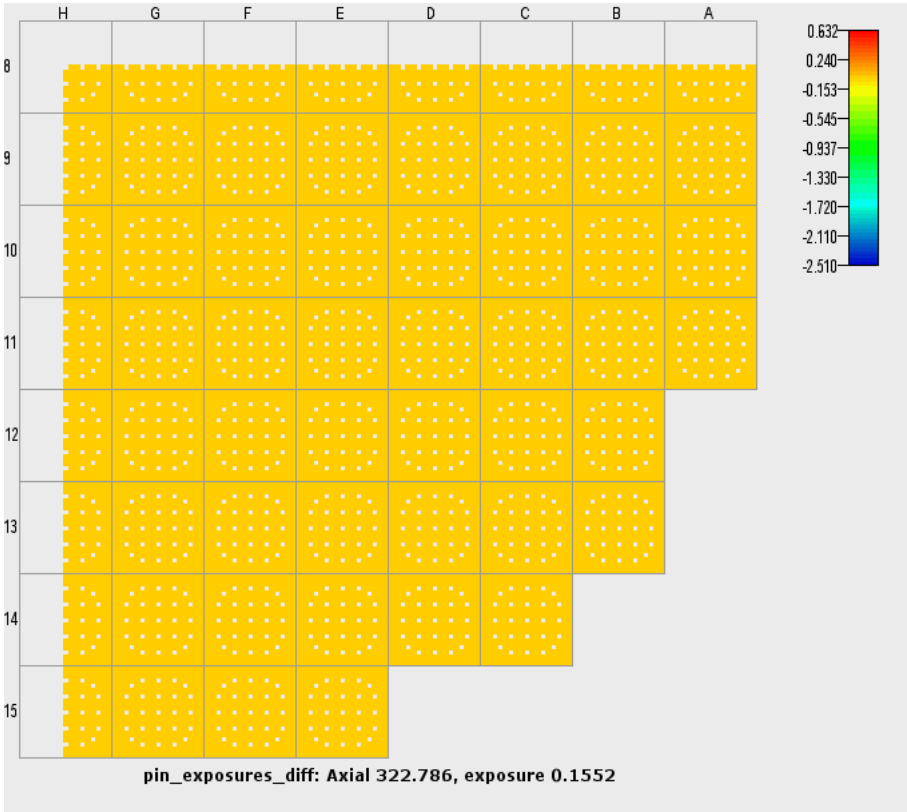


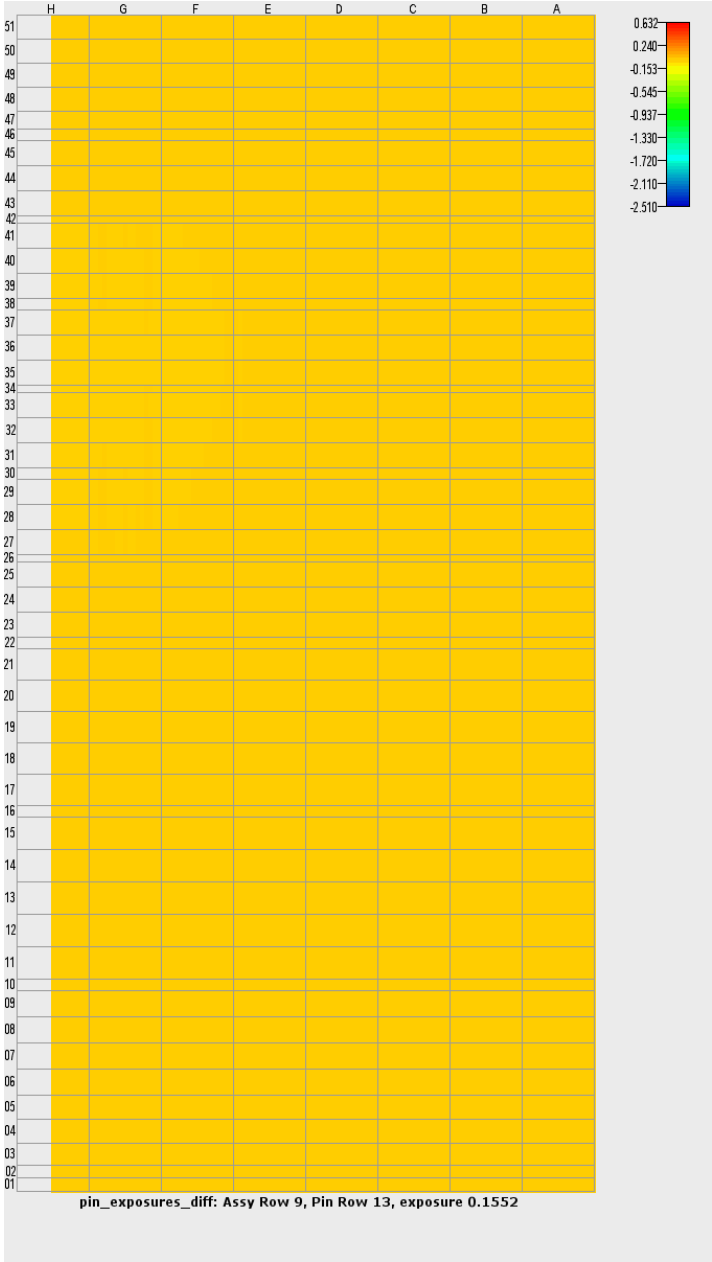
VERA Pin Power Difference





Pin Exposures Diff





Summary and Next Steps

- Successful Jump In
  - First model of an active core with history effects
- CIPS models show excellent feedback
  - Consider adding models (boron re-solution, etc.)
  - Need to define criteria for acceptable design

- A Big Thanks
  - Jason Young, Brad Black, Nick Stehle, Stanley Hayes, Jonathan Hackelton, and Matt Cameron for their expertise and continued support.
  - Those that made it possible for me to visit Duke:
  - Scott Thomas, Mike Blom

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