Investigation of fuel performance during load follow operation using VERA

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Travis Mui, Dan O'Grady, and Tomasz Kozlowski *(UIUC)*
CASL Project Update
October 5, 2016

Overview

- Completed Work & Results
- Current Status & Plans
- Comments & Recommendations

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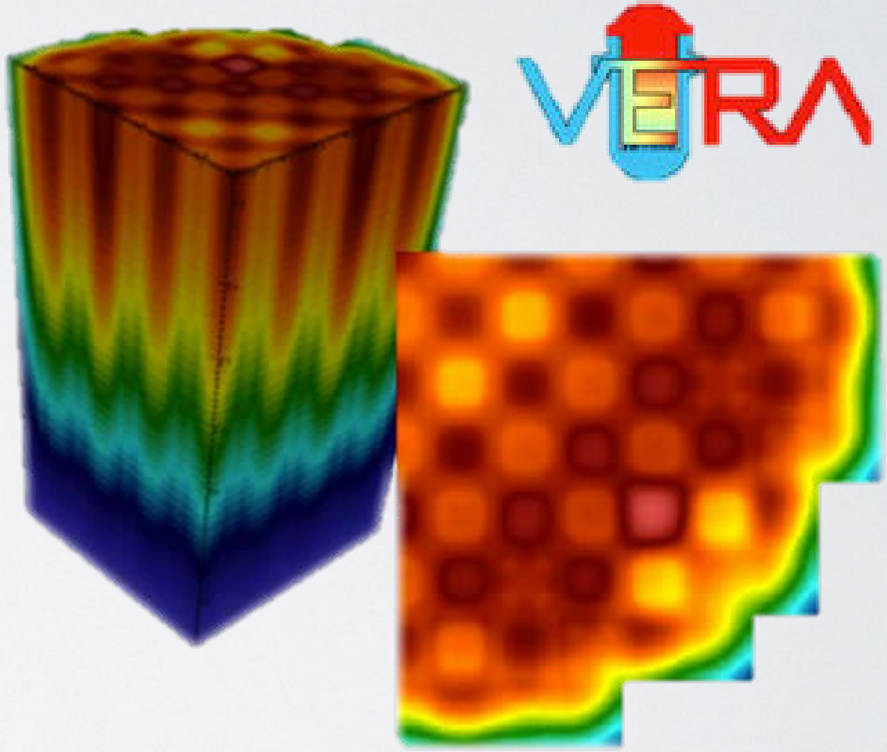
Preliminary Scope of Investigation

1. Generic model of PWR core depletion with multiple cycles and core shuffling

2. Testing load-follow power mode

3. Full-scale coupled multi-physics PWR core simulation using VERA
   - *Neutronics:* MPACT
   - *Thermal-Hydraulics:* CTF
   - *Fuel Performance:* BISON



4. Running on iForge Cluster
   - Intel "Ivy Bridge" Xeon E5 v2 2680 and Xeon E7 v2 4890

Training Sessions

- VERA Workshop, UIUC: May 16-17, 2016
  - Overview of major VERA components
  - Developing with VERAin specification
  - Working with VERAview output tools

- Training Session, U. Michigan: August 16-18, 2016
  - Worked with Brendan Kochunas and Daniel Jabaay to walk through capabilities necessary for load follow in MPACT/CTF
  - Discussion with Shane Stimpson on capabilities of BISON coupling tools and setup instructions
  - Discussed potential challenges with scaling up to a full core simulation

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Development – Multi-physics

- **MPACT + CTF: Steady-state**
  - Baseline simulation of core physics
- **MPACT + CTF: Depletion**
  - Core power history
  - Shuffling and restart capability
- **BISON: Input generation**
  - VERA-Bison tools using template file
- **BISON: Execution and Post-processing Output**
  - Managing pin-by-pin execution
  - Data aggregation using *bison_post*

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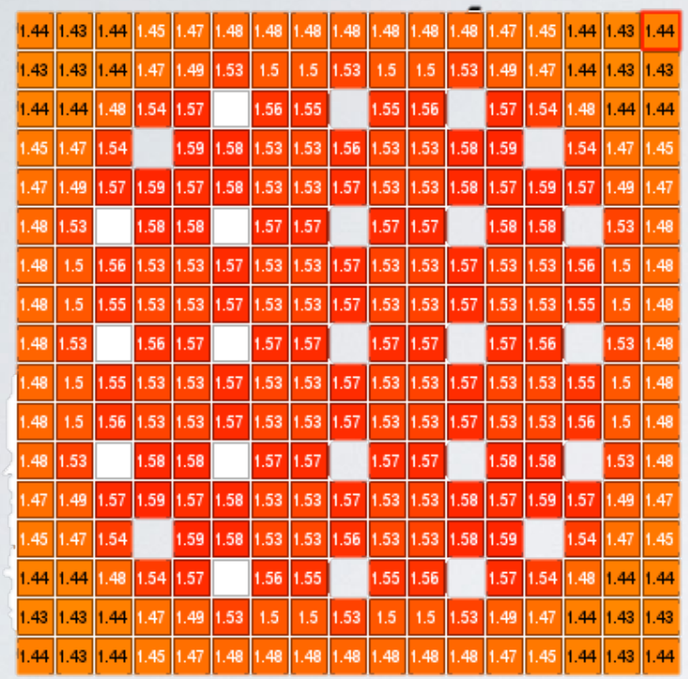
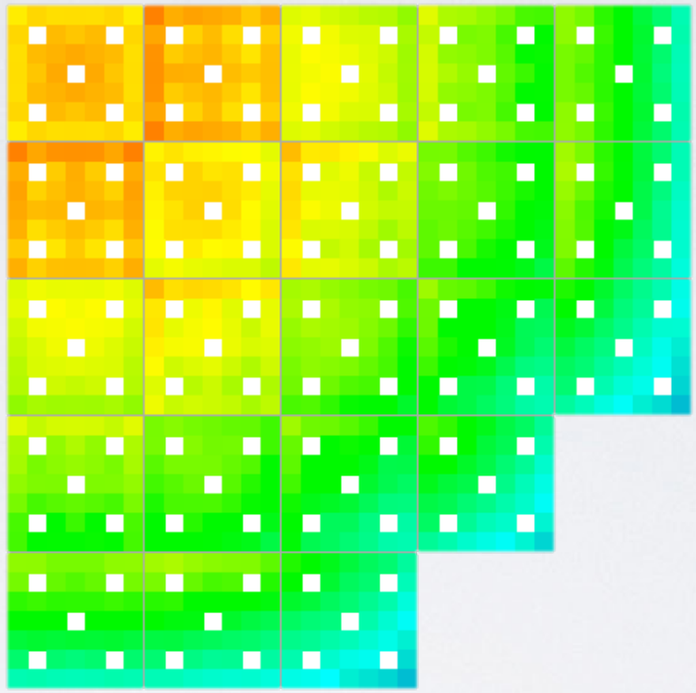
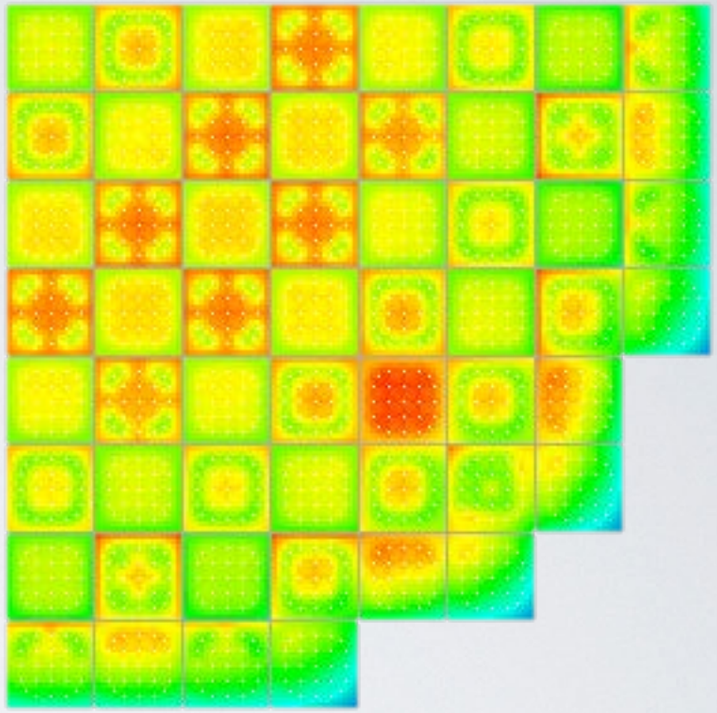
Development – Core models







Step 1: Single PWR assembly

- ✓ MPACT / CTF – steady
- ✓ MPACT / CTF – depletion
- ✓ Bison – input generation
- ❑ Bison – execution + post

Step 2: Mini-core (9x9, quarter)

- ✓ MPACT / CTF – steady
- ✓ MPACT / CTF – depletion
- ✓ Bison – input generation
- ❑ Bison – execution + post

Step 3: Full PWR core (quarter)

- ✓ MPACT / CTF – steady
- ✓ MPACT / CTF – depletion
- ❑ Bison – input generation
- ❑ Bison – execution + post

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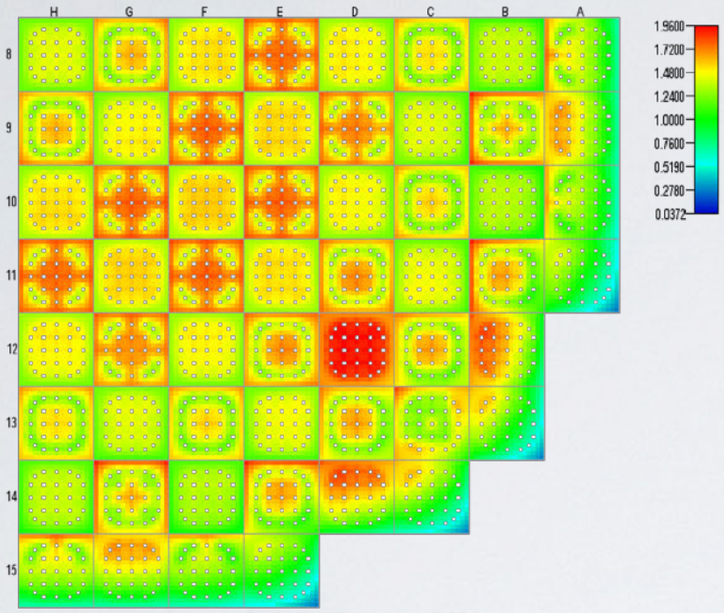
Full-core PWR depletion

Radial Power



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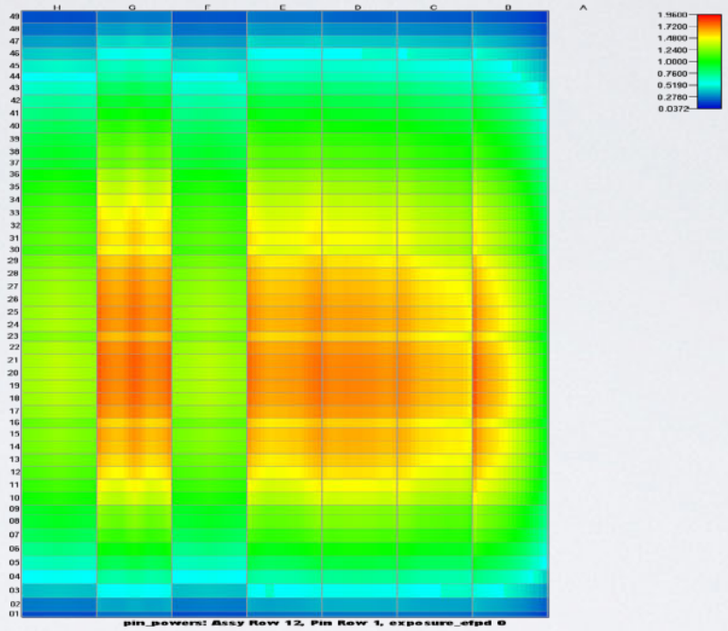
Axial Power Cross-section



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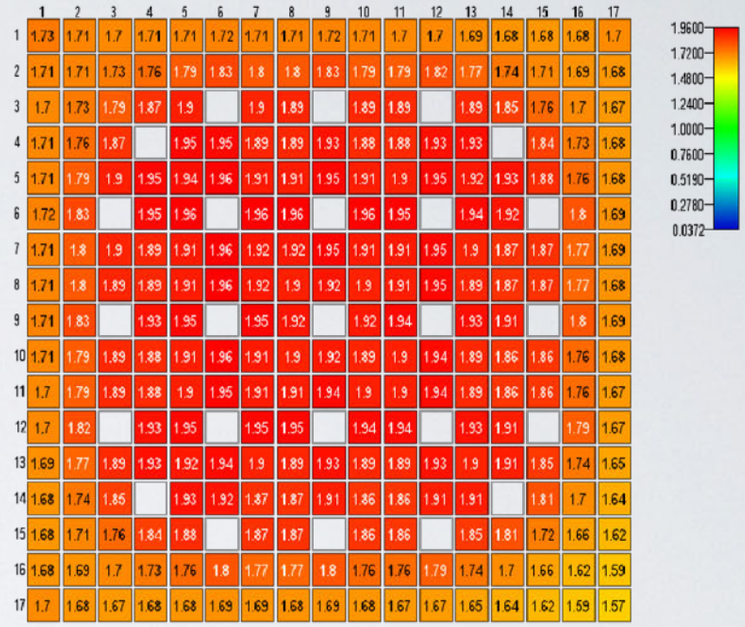
Max Assembly Pin Powers



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.73	1.71	1.7	1.71	1.71	1.72	1.71	1.71	1.72	1.71	1.7	1.7	1.69	1.68	1.68	1.68	1.7
2	1.71	1.71	1.73	1.76	1.79	1.83	1.8	1.8	1.83	1.79	1.79	1.82	1.77	1.74	1.71	1.69	1.68
3	1.7	1.73	1.79	1.87	1.9		1.9	1.89		1.89	1.89		1.89	1.85	1.76	1.7	1.67
4	1.71	1.76	1.87		1.95	1.95	1.89	1.89	1.93	1.88	1.88	1.93	1.93		1.84	1.73	1.68
5	1.71	1.79	1.9	1.95	1.94	1.96	1.91	1.91	1.95	1.91	1.9	1.95	1.92	1.93	1.88	1.76	1.68
6	1.72	1.83		1.95	1.96		1.96	1.96		1.96	1.95		1.94	1.92		1.8	1.69
7	1.71	1.8	1.9	1.89	1.91	1.96	1.92	1.92	1.95	1.91	1.91	1.95	1.9	1.87	1.87	1.77	1.69
8	1.71	1.8	1.89	1.89	1.91	1.96	1.92	1.9	1.92	1.9	1.91	1.95	1.89	1.87	1.87	1.77	1.68
9	1.71	1.83		1.93	1.95		1.95	1.92		1.92	1.94		1.93	1.91		1.8	1.69
10	1.71	1.79	1.89	1.88	1.91	1.96	1.91	1.9	1.92	1.89	1.9	1.94	1.89	1.86	1.86	1.76	1.68
11	1.7	1.79	1.89	1.88	1.9	1.95	1.91	1.91	1.94	1.9	1.9	1.94	1.89	1.86	1.86	1.76	1.67
12	1.7	1.82		1.93	1.95		1.95	1.95		1.94	1.94		1.93	1.91		1.79	1.67
13	1.69	1.77	1.89	1.93	1.92	1.94	1.9	1.89	1.93	1.89	1.89	1.93	1.9	1.91	1.85	1.74	1.65
14	1.68	1.74	1.85		1.93	1.92	1.87	1.87	1.91	1.86	1.86	1.91	1.91		1.81	1.7	1.64
15	1.68	1.71	1.76	1.84	1.88		1.87	1.87		1.86	1.86		1.85	1.81	1.72	1.66	1.62
16	1.68	1.69	1.7	1.73	1.76	1.8	1.77	1.77	1.8	1.76	1.76	1.79	1.74	1.7	1.66	1.62	1.59
17	1.7	1.68	1.67	1.68	1.68	1.69	1.69	1.68	1.69	1.68	1.67	1.67	1.65	1.64	1.62	1.59	1.57

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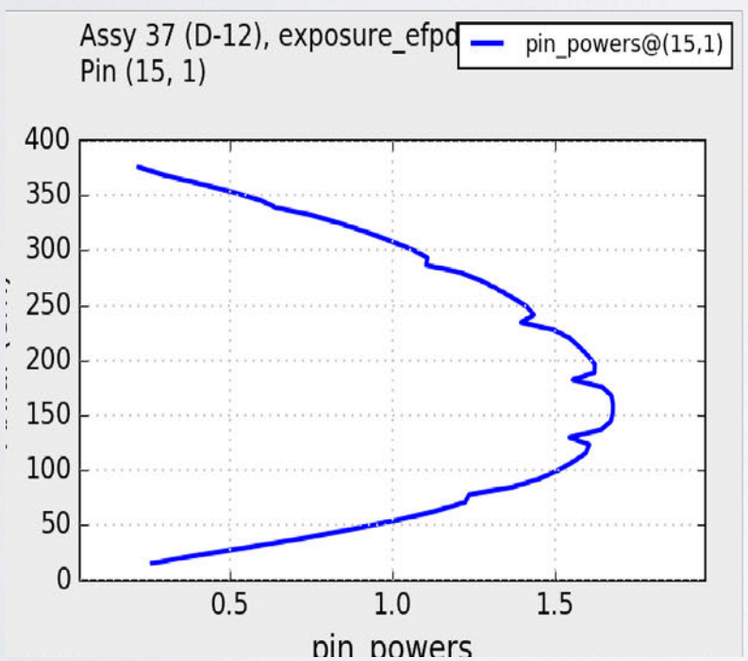
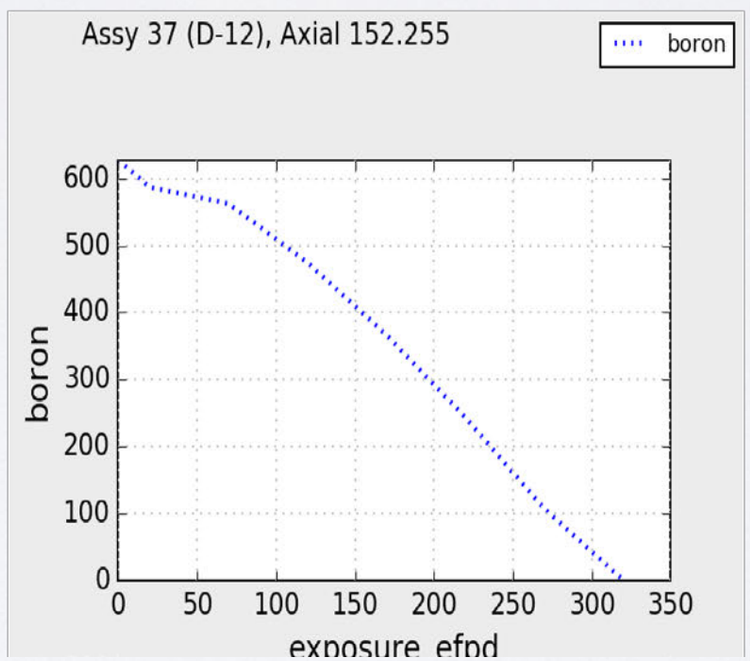
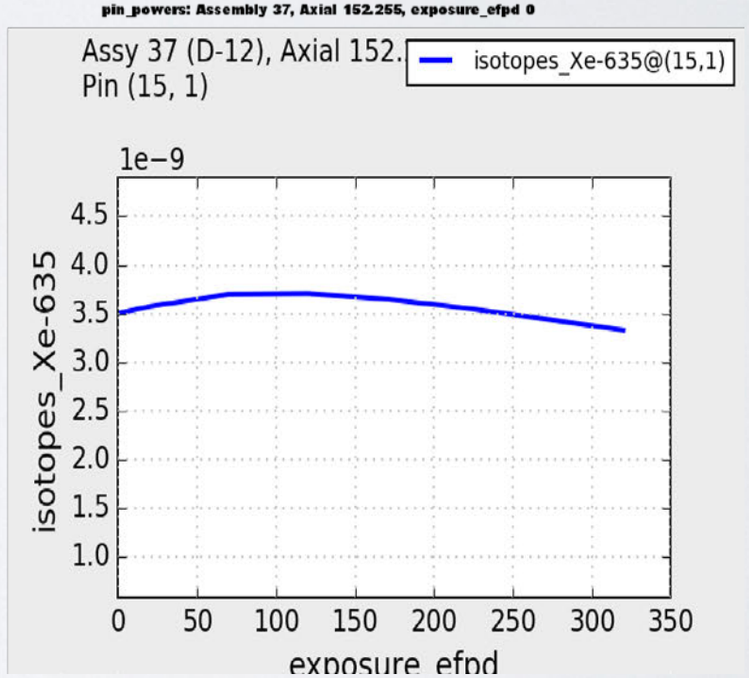


Max Assembly Axial Power



Boron Concentration



Xenon Concentration

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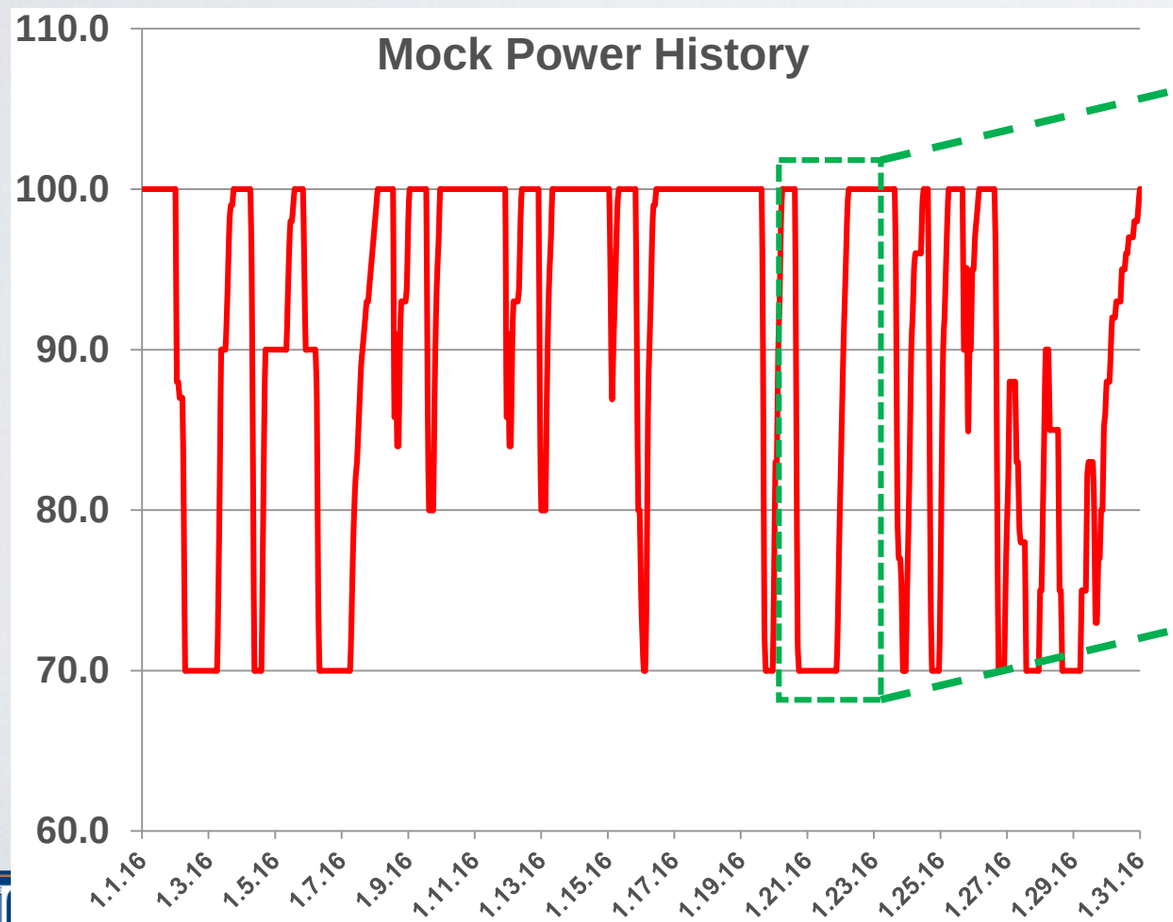
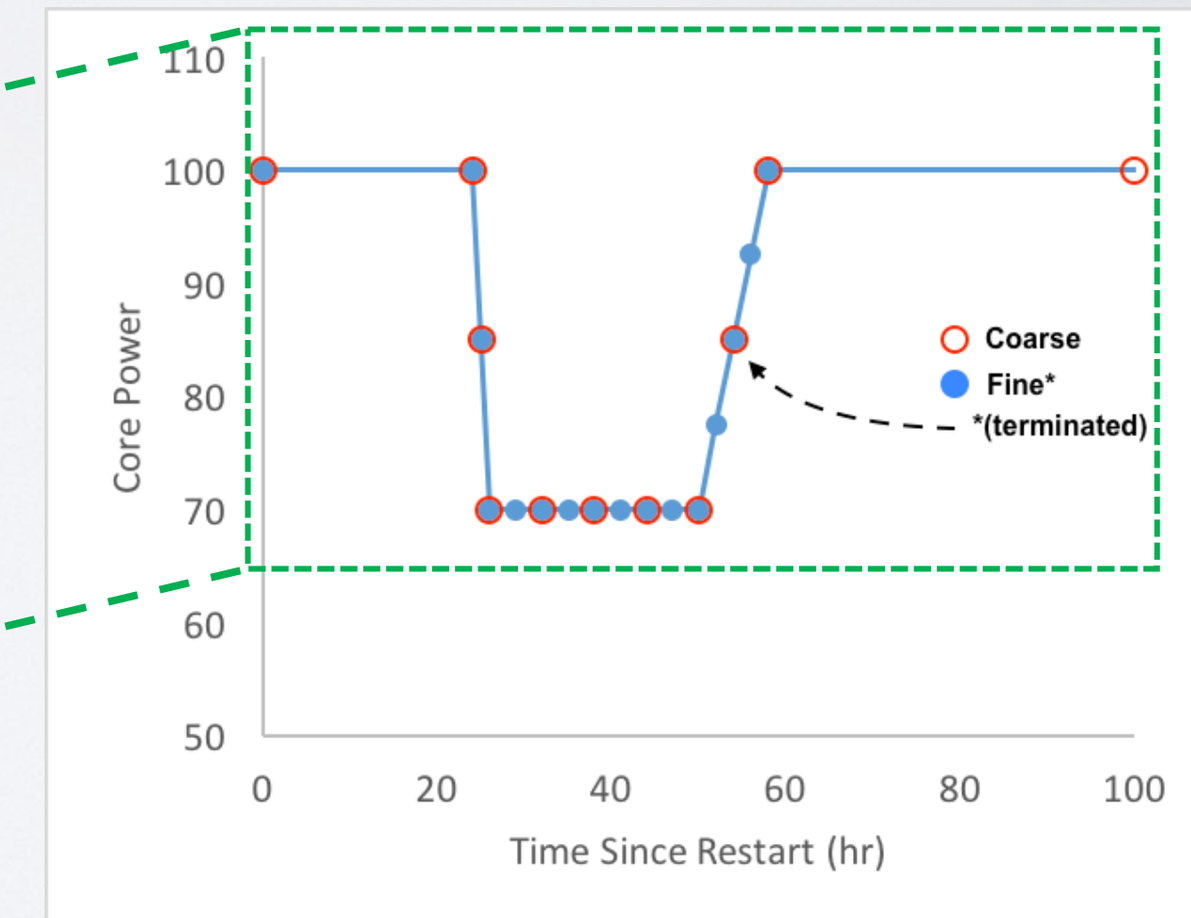
Depletion and Load-follow

- **Case 1:** full-power depletion
- **Case 2:** 100-hour “synthetic” load-following transient
  - **“Coarse”:** 11 state points
  - **“Fine”**: 17 state points, aborts / fails at state 14





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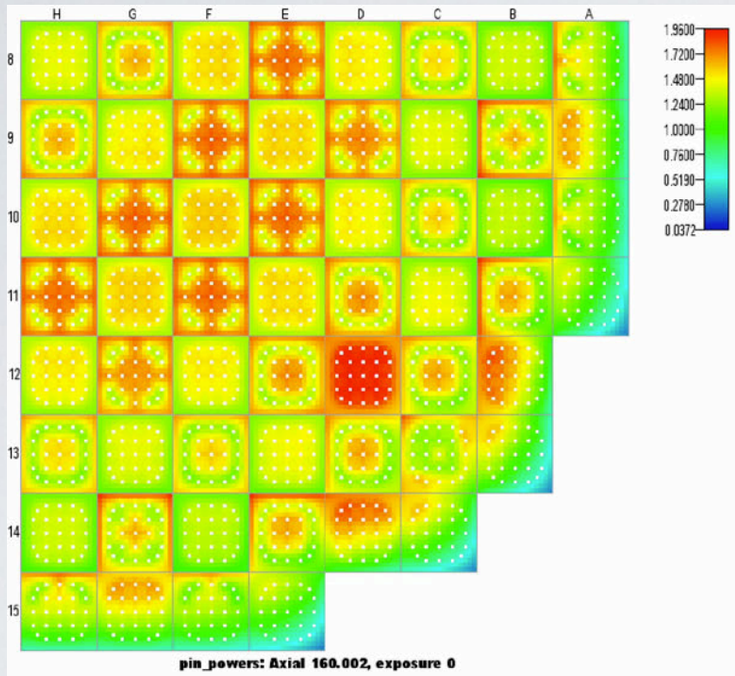
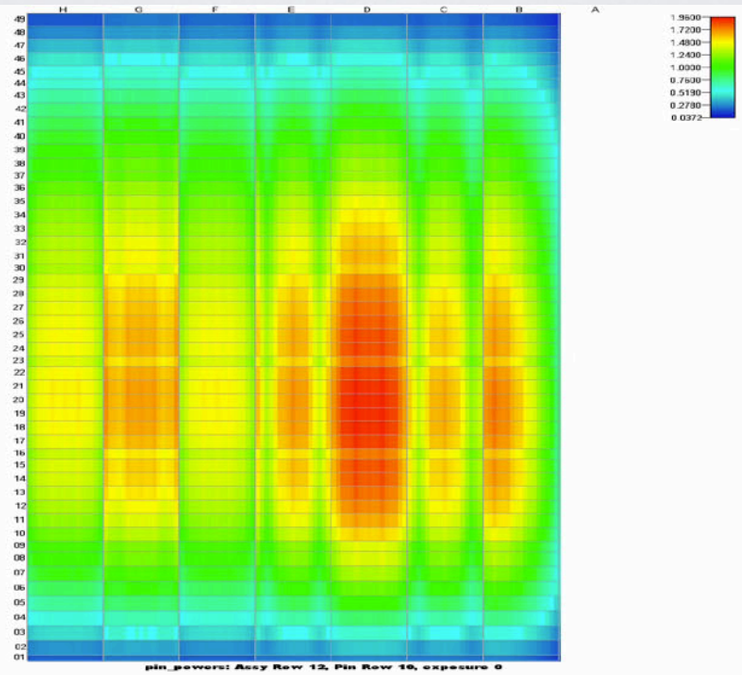
Case 1: Depletion at Full Power

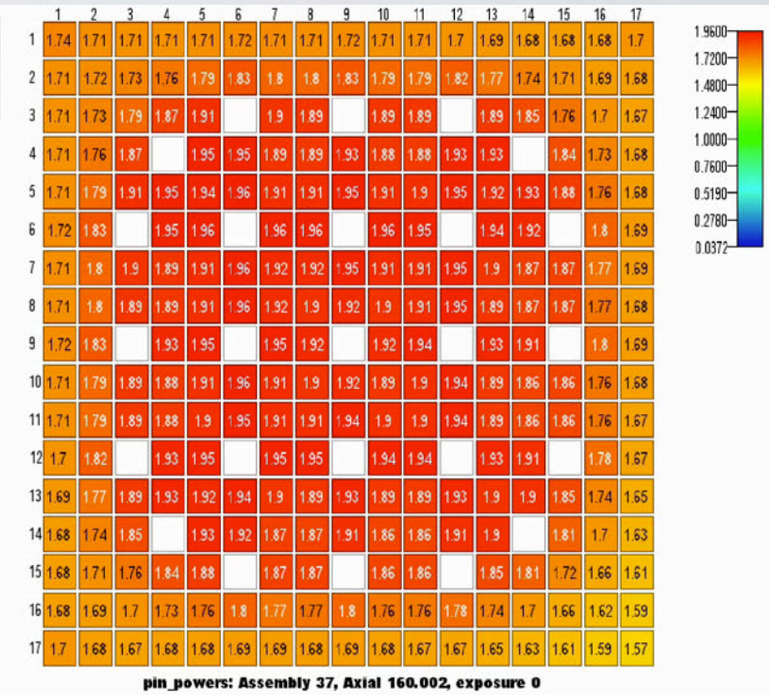
Radial Power

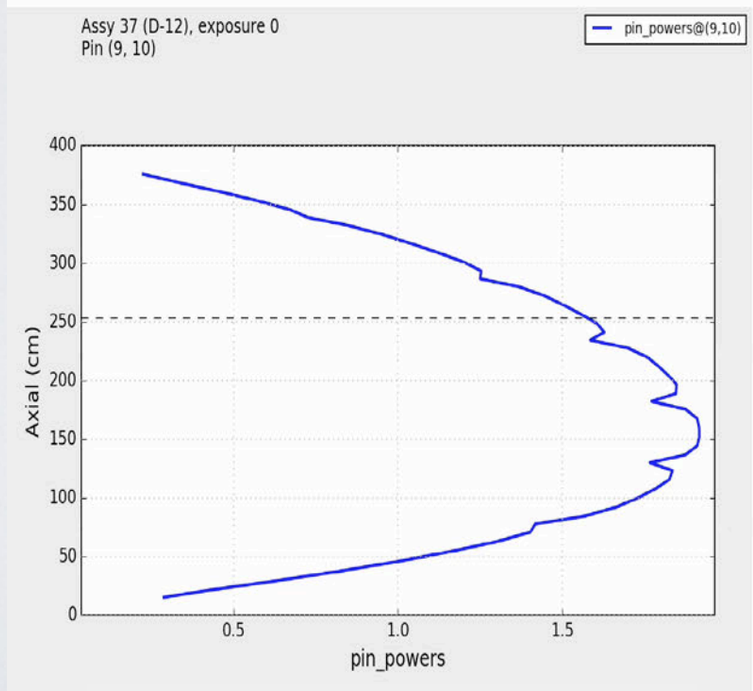


Axial Power Cross-section



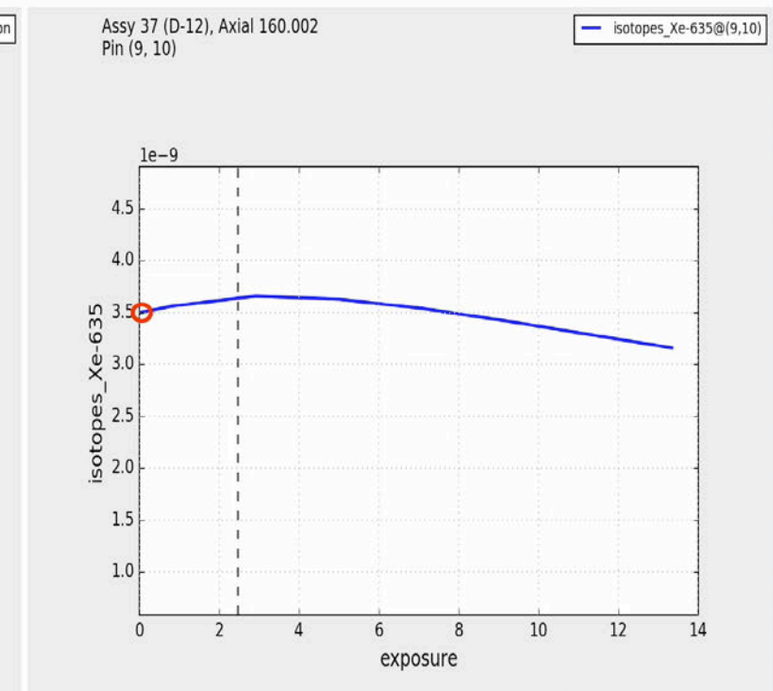
Max Assembly Pin Powers





Max Assembly Axial Power

Boron Concentration



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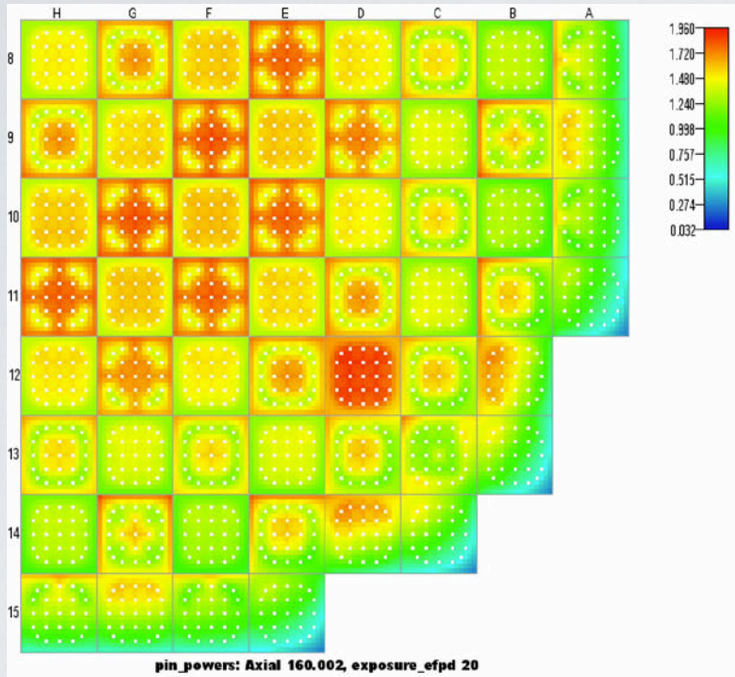
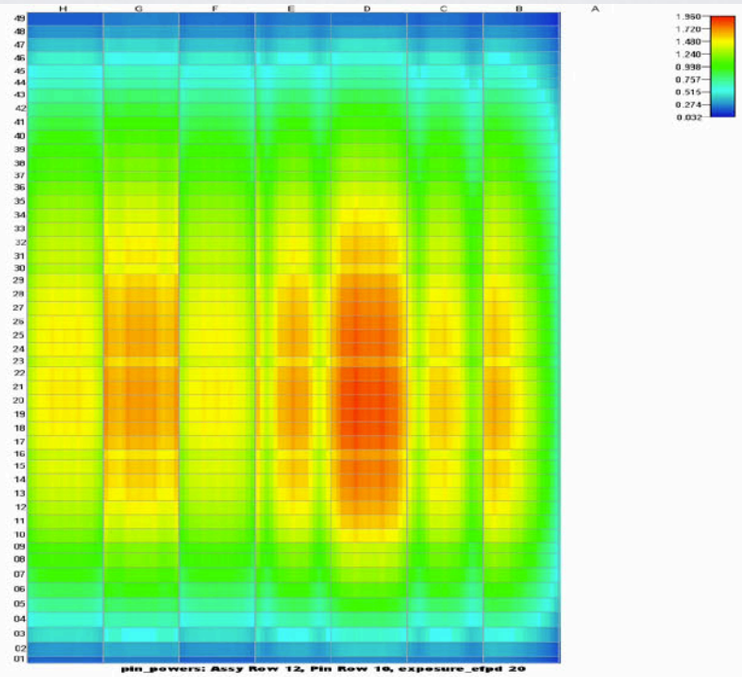
Case 2: Load-follow (coarse time step)

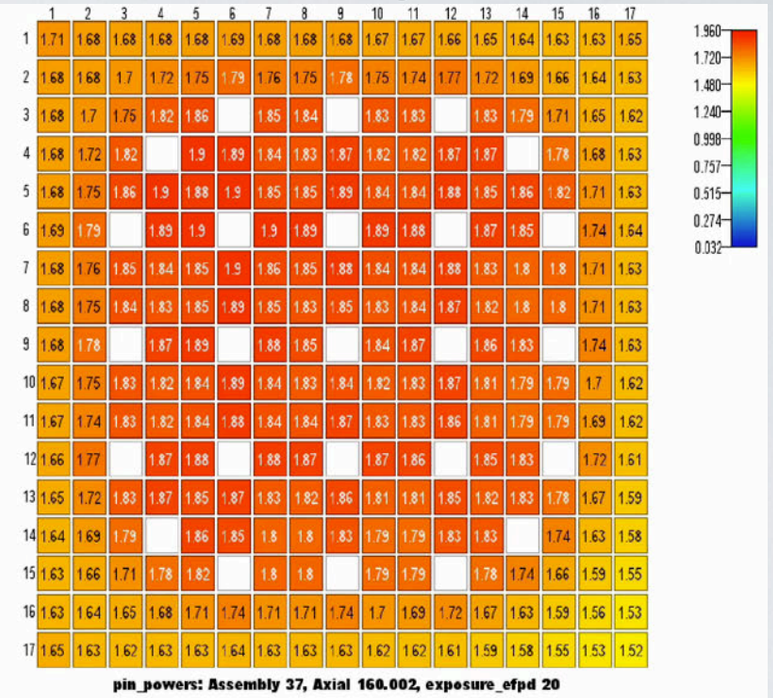
Radial Power

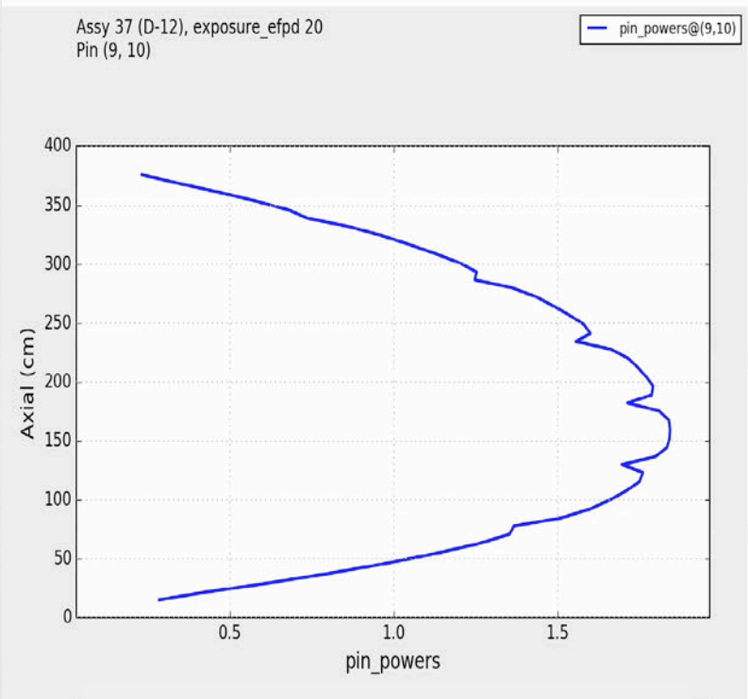


Axial Power Cross-section

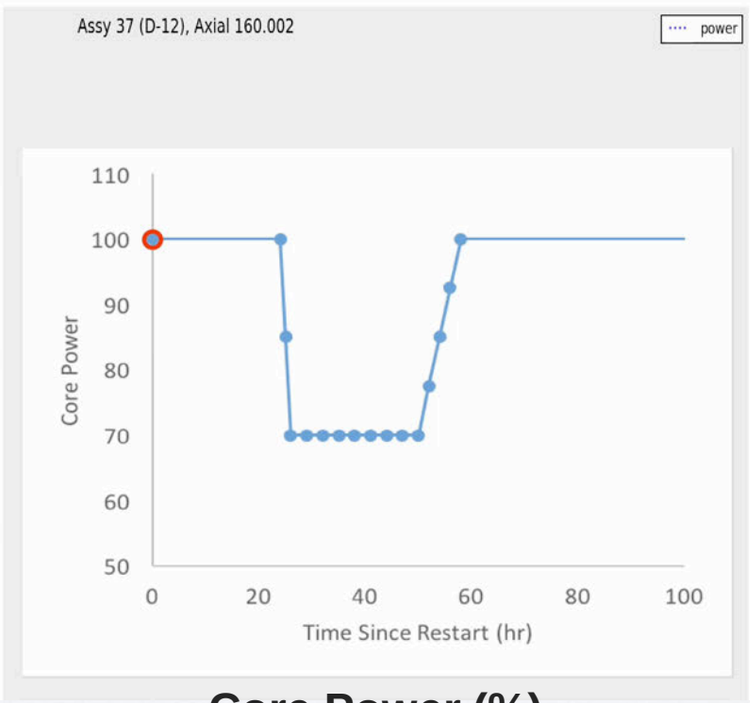


Max Assembly Pin Powers

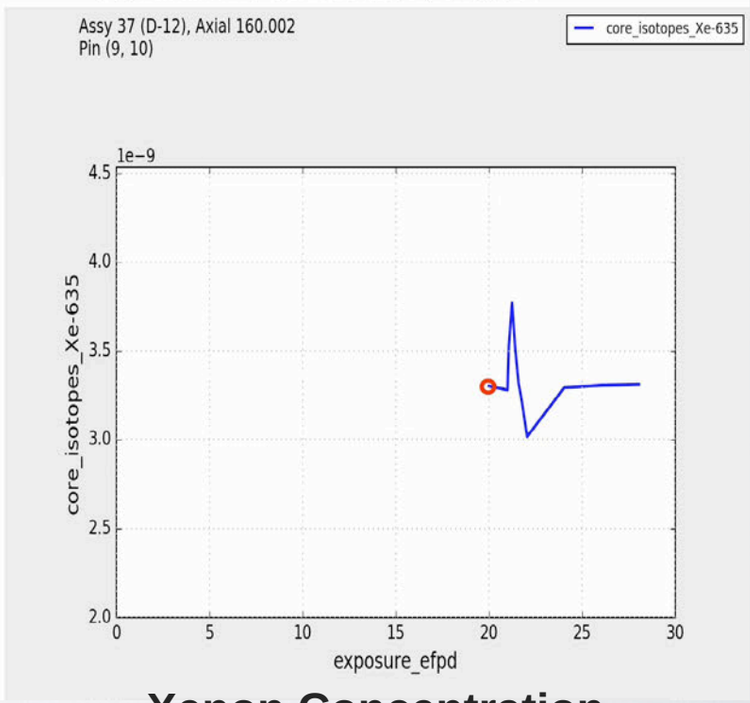




Max Assembly Axial Power



Core Power (%)



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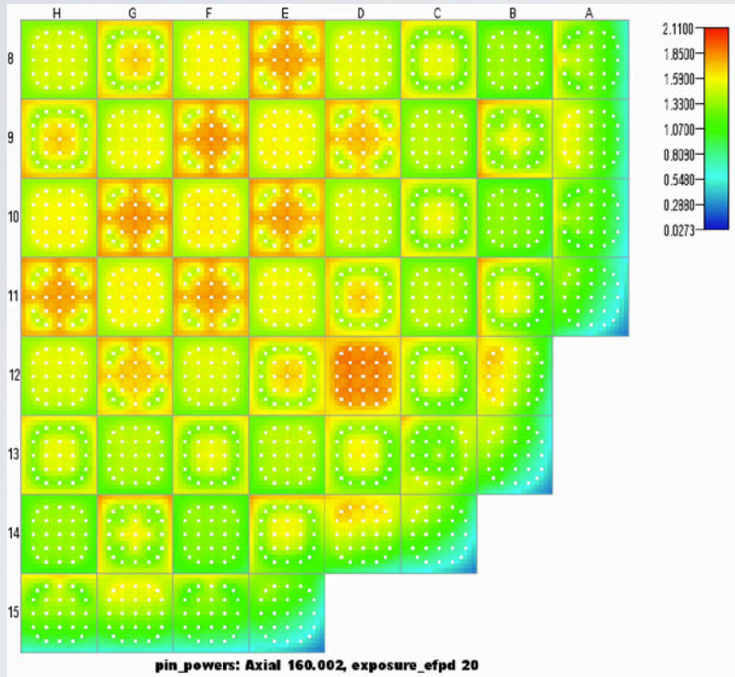
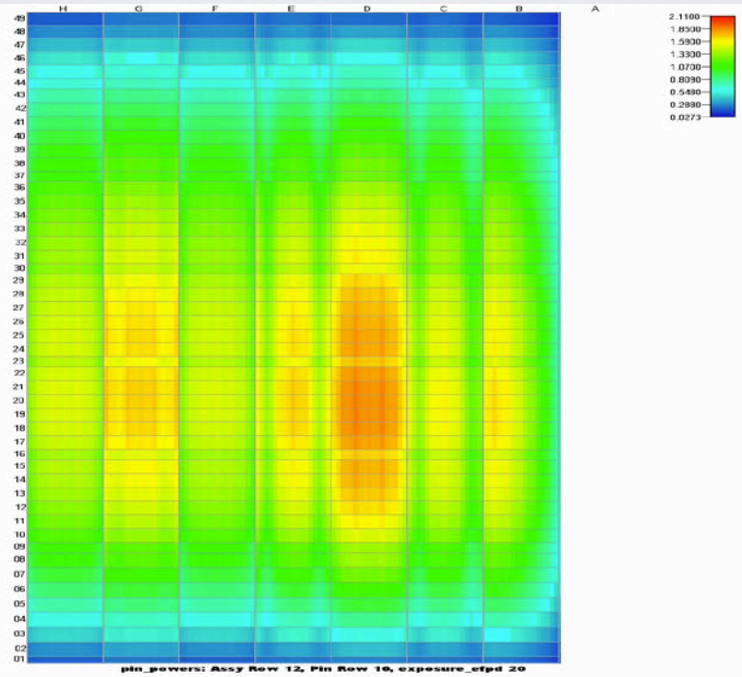
Case 2: Load-follow (fine time step)

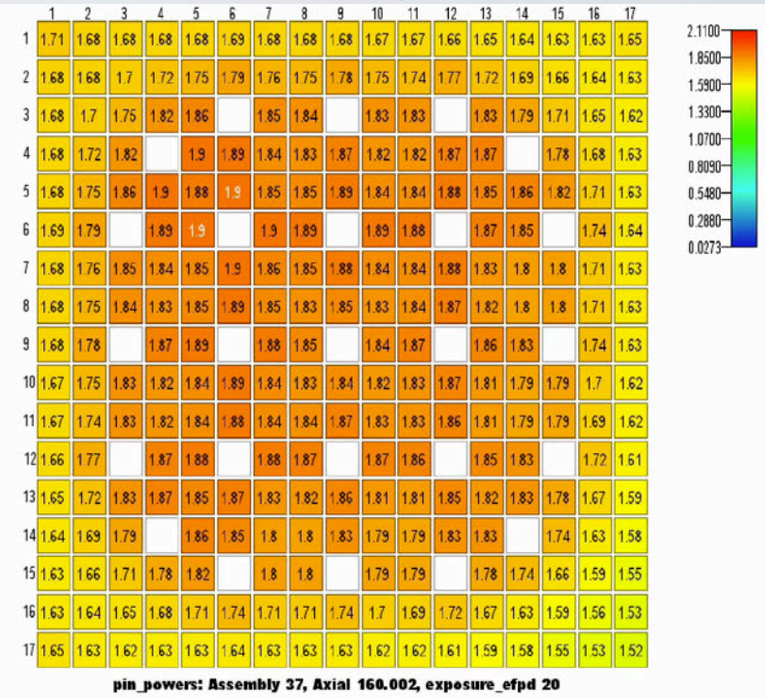
Radial Power

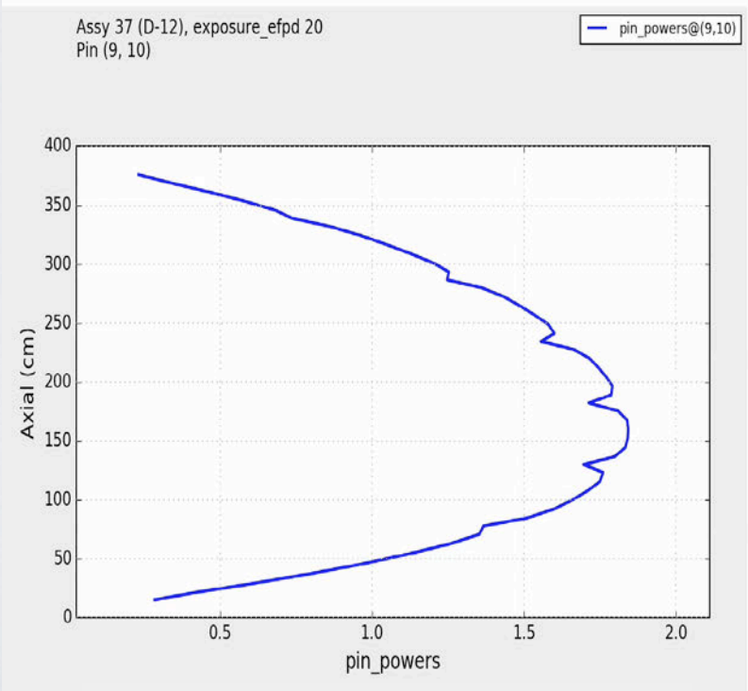


Axial Power Cross-section

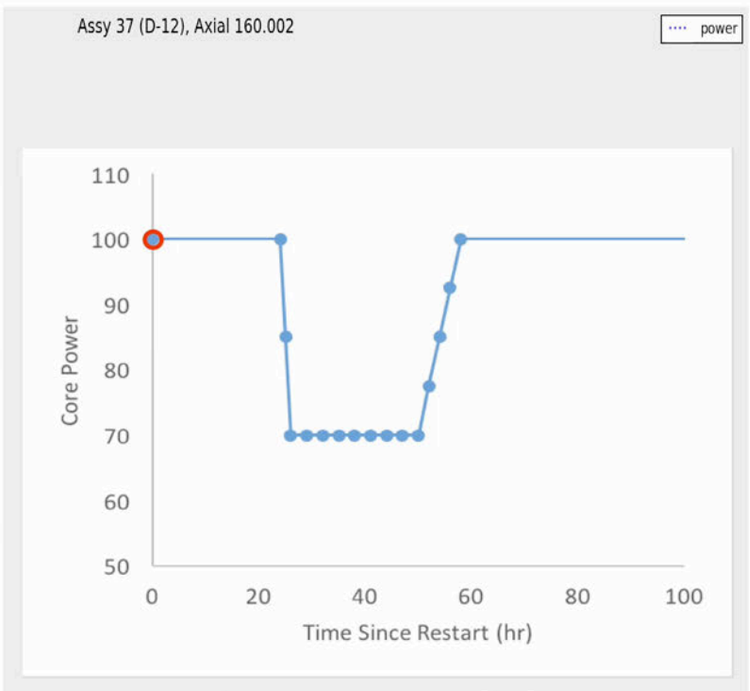


Max Assembly Pin Powers

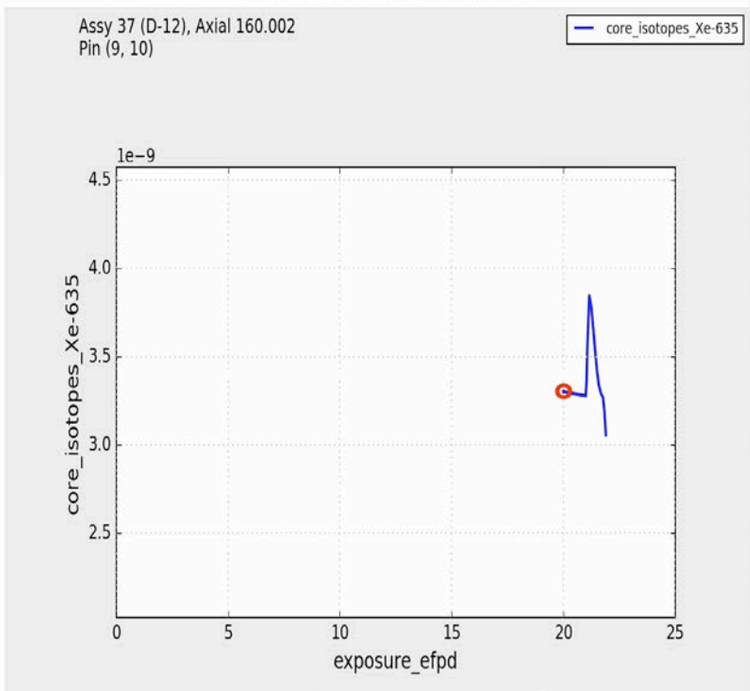




Max Assembly Axial Power



Core Power (%)



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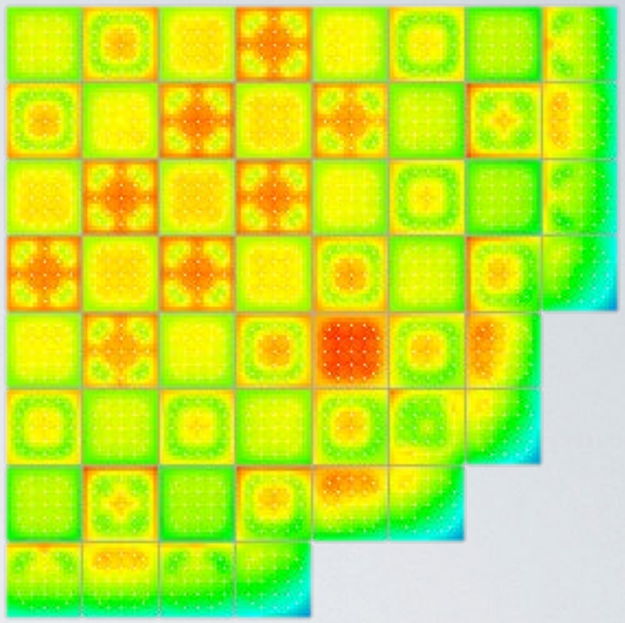
Present Roadmap



1. ✓ Quarter PWR core MPACT + CTF model
   - Source: 4-loop Westinghouse design
2. ✓ Set up burn-up, restart, and shuffling capability
3. ✓ Baseline case– full cycle depletion
   - Resources: 3-5 days on ~250 cores, VERA 3.4
4. ✓ Implement synthetic load-follow power profile (from Exelon)
   - Resources: similar requirement to cycle depletion case due to shorter state points (hours vs. weeks between power changes)
5. ☐ Simulate load-follow at different points of interest in the cycle
   - Beginning, middle and end of cycle
   - Ongoing: Some cases complete, others fail to converge
6. ☐ One-way coupling to BISON for every modeled fuel pin
   - Resources: We are anticipating ~10K core hours per case (~14K pins)
   - Status: Awaiting updated release of VERA with BISON coupling capability

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Comments & Recommendations

- Obstacles encountered
  1. VERA 3.4 does not include BISON coupling capability
  2. Extensive resource management necessary for full-core BISON simulation (14K pins, 10K core-hours)

- Recommendations to CASL
  1. Resource-saving tools greatly desired (skip-solve for input checking, memory allocation estimation, etc.)
  2. Flexibility in *bison_post* processing tool (Specifying alternative output parameters)

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