INL/CON-22-69176-Revision-0

NT-1 - 5 Results in ATR: PRELIMINARY NUCLEAR TESTING RESULTS AFTER CORE INTERNALS CHANGEOUT #6 IN THE ADVANCED TEST REACTOR

Changing the World's Energy Future

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Idaho National Laboratory

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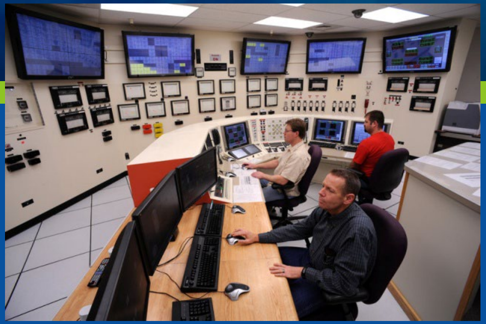
Advanced Test Reactor



PRELIMINARY NUCLEAR TESTING RESULTS AFTER CORE INTERNALS CHANGEOUT #6 IN THE ADVANCED TEST REACTOR

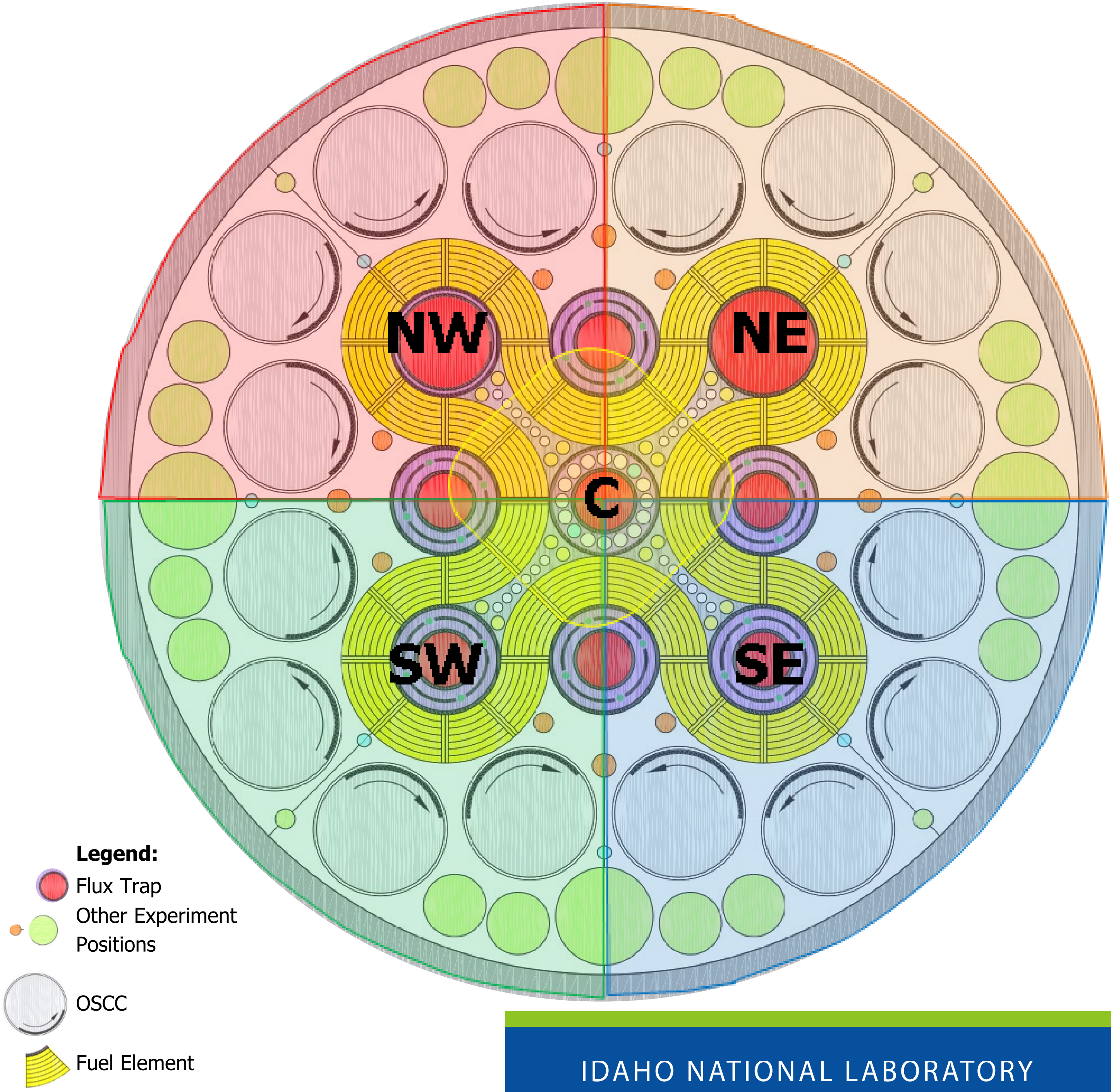
Idaho National Laboratory

Outline

- Introduction to Advanced Test Reactor (ATR)
  - Idaho National Laboratory
  - Fuel Arrangement
  - Flux Traps
- Low-power Tests
  - NT-1 – 6
  - Results of NT-1 – 5
- Power Escalation Tests
  - NT-7 – 12

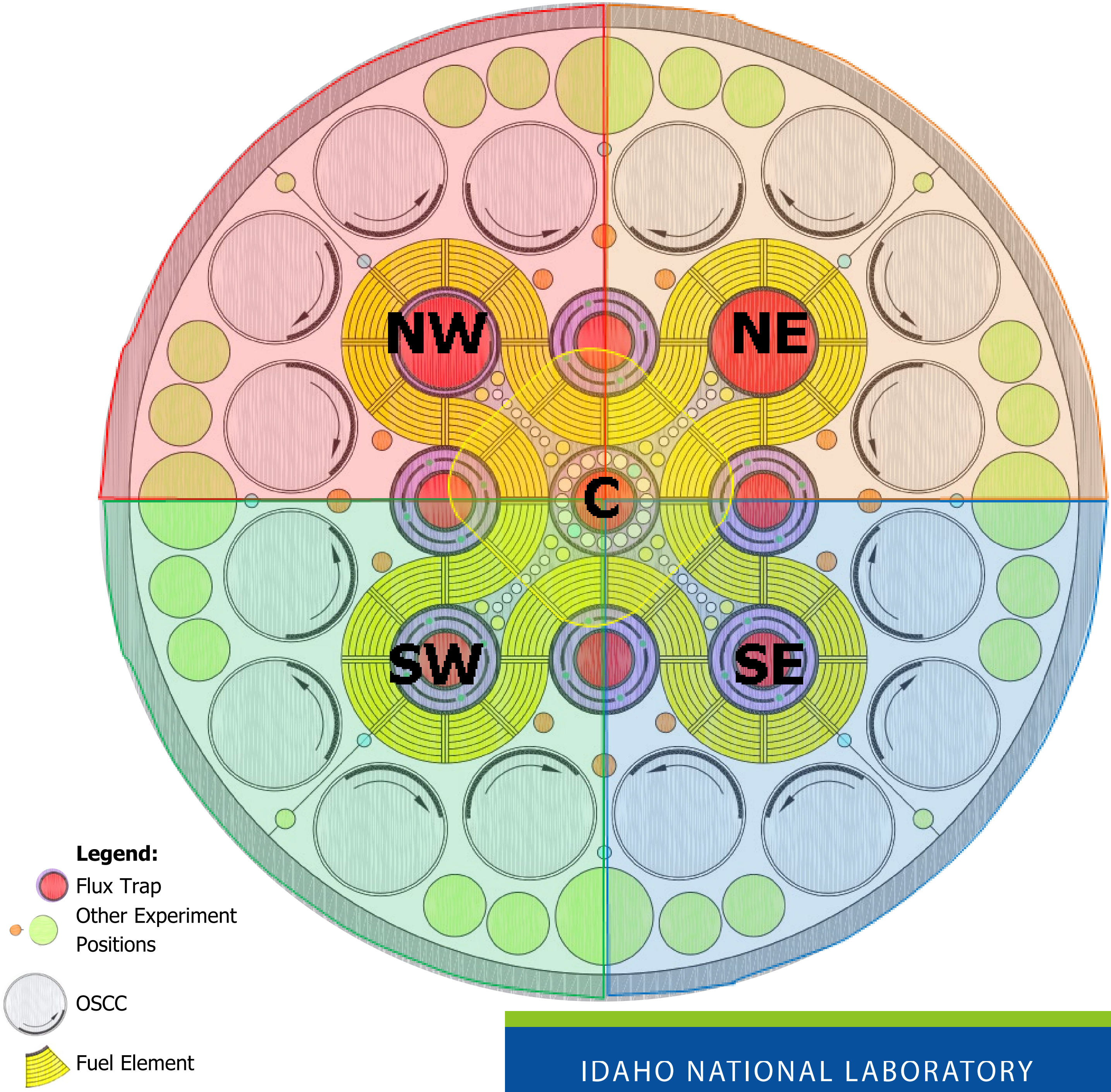
Introduction to ATR

- More than 70 test positions
  - 9 flux traps
  - 6 (of the 9) have loops
    - Independent Chemistry, temperature, and pressure
- Control Elements
  - 6 Safety Rods (annular)
  - 16 Outer Shim Control Cylinders (OSCCs)
  - 22 Neck Shims
    - +2 Regulating Rods
- 40 Fuel Elements
  - 19 plates
  - 48” (120cm) active length
  - Serpentine arrangement



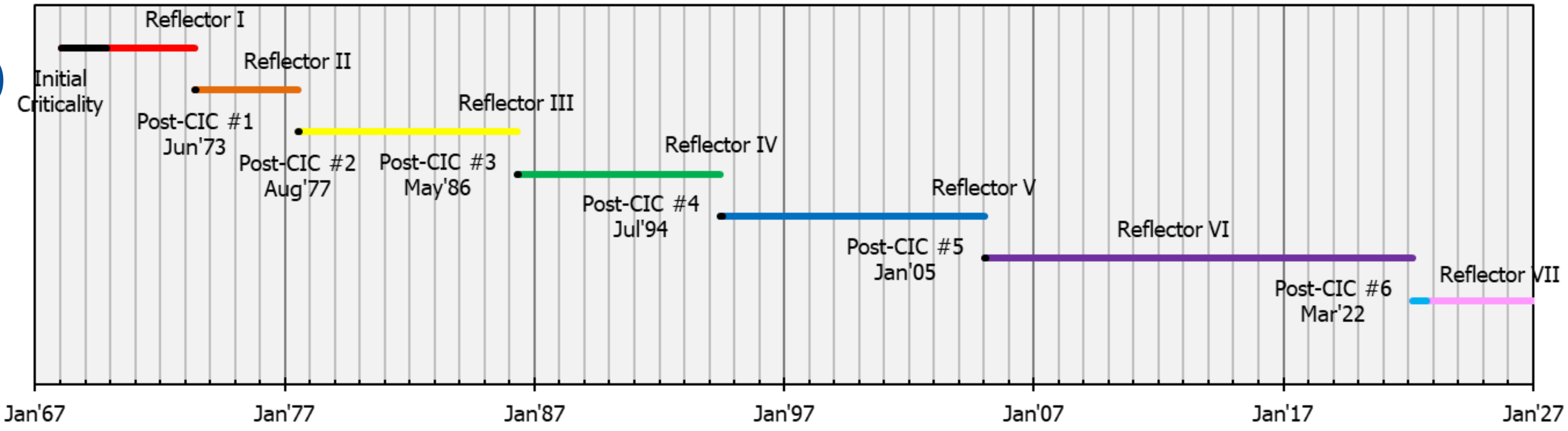
Introduction to ATR

- Design Summary
  - 250 MW_{th} (Typically 110MW_{th})
  - Max thermal neutron flux:
    - 10^{15} n/cm^2-s
  - Max fast neutron flux:
    - 5×10^{14} n/cm^2-s
- Companion ATRC
  - 5 kW_{th}



Nuclear Testing – Historical

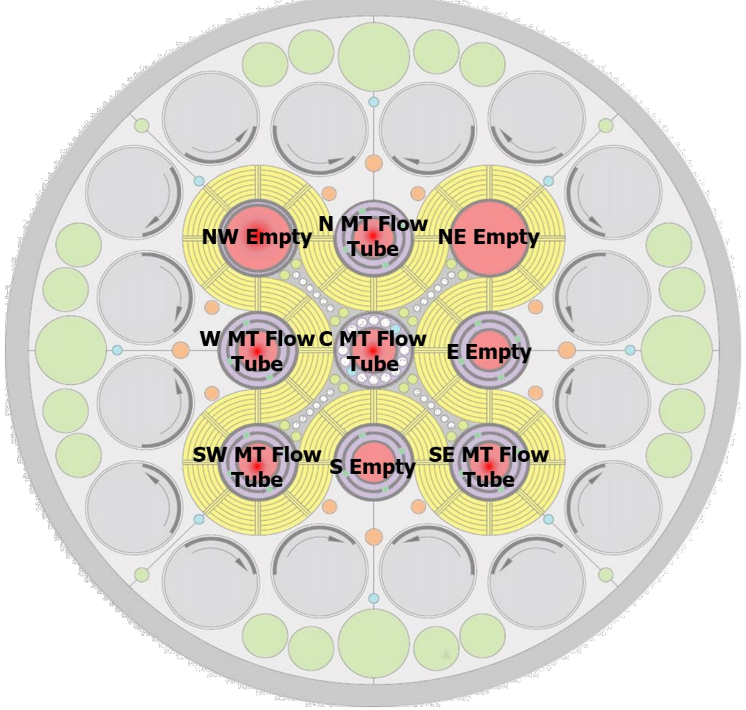
- Performed each CIC:
  - #1: 1973 (Reflector II)
  - #2: 1977 (Reflector III)
  - #3: 1986 (Reflector IV)
  - #4: 1994 (Reflector V)
  - #5: 2004 (Reflector VI)

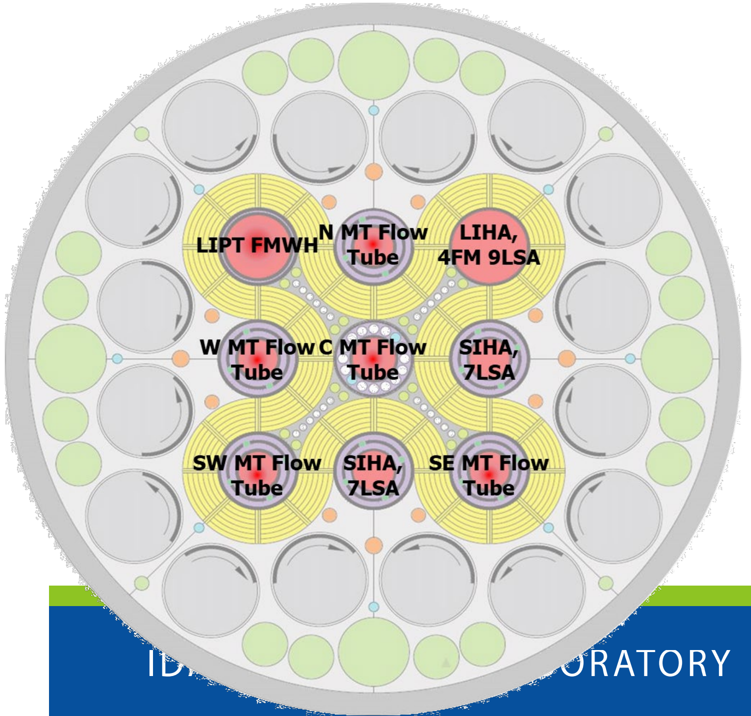


- Also for initial criticality and core reconfigurations

Nuclear Testing – Low-power Tests

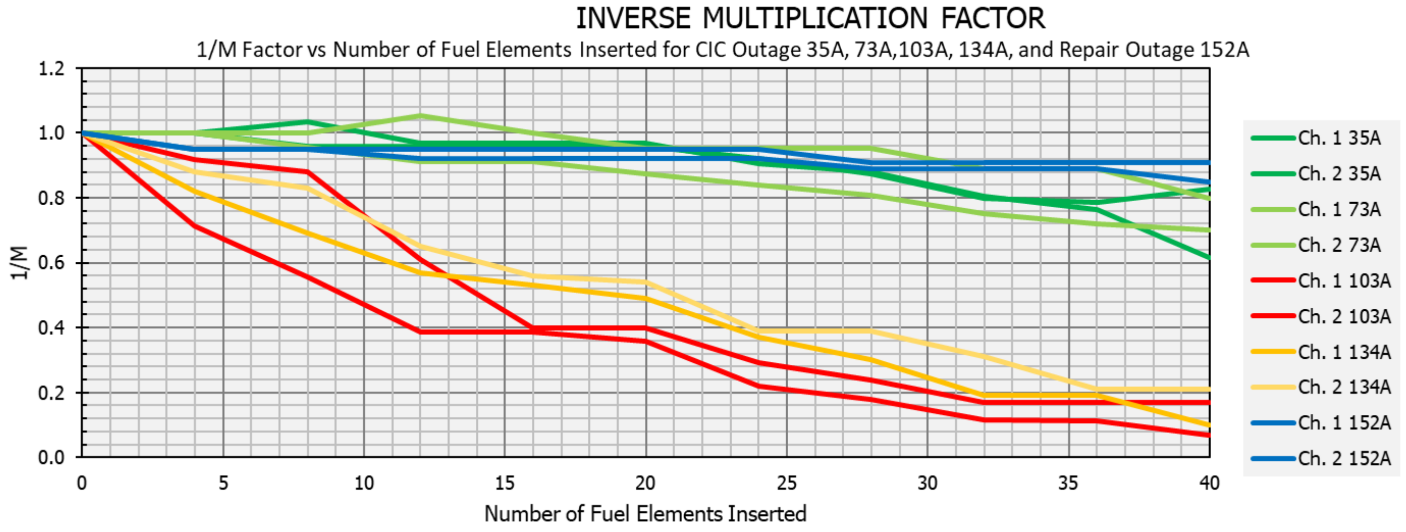
Cycle	Tests	Target Power	Experiment Loading
170CIC-1	NT-2	2 ±1 kW	Mostly Water
170CIC-2	NT-3		
170CIC-3	NT-3		Standard Hardware
170CIC-4	NT-4, NT-5	2 ± 1 MW	
170CIC-5	NT-6		
170CIC-6			
170CIC-7			

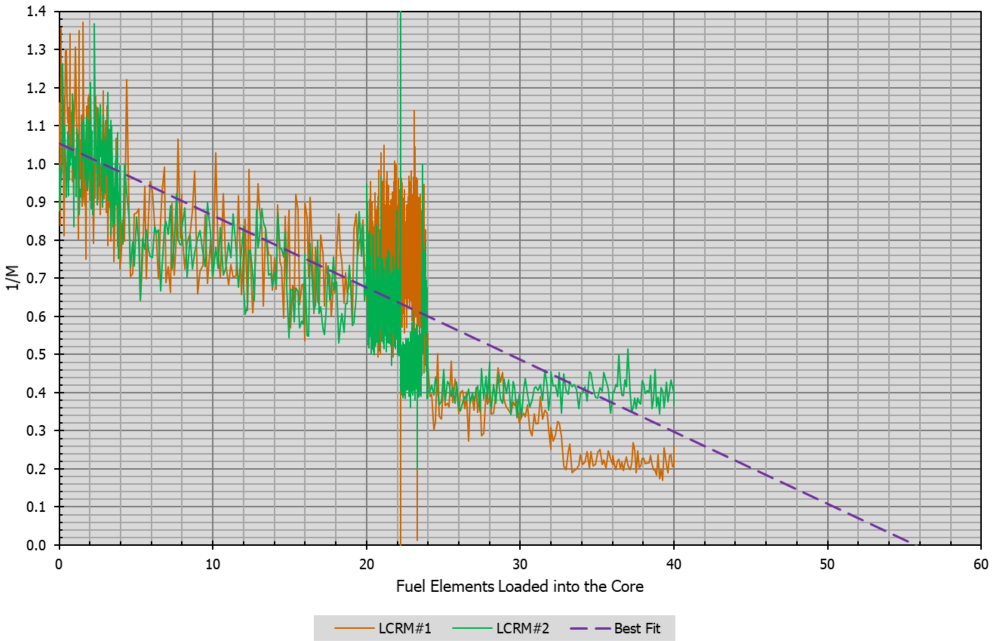




NT-1 – Fuel Loading – Cycle 170CIC-1 Outage

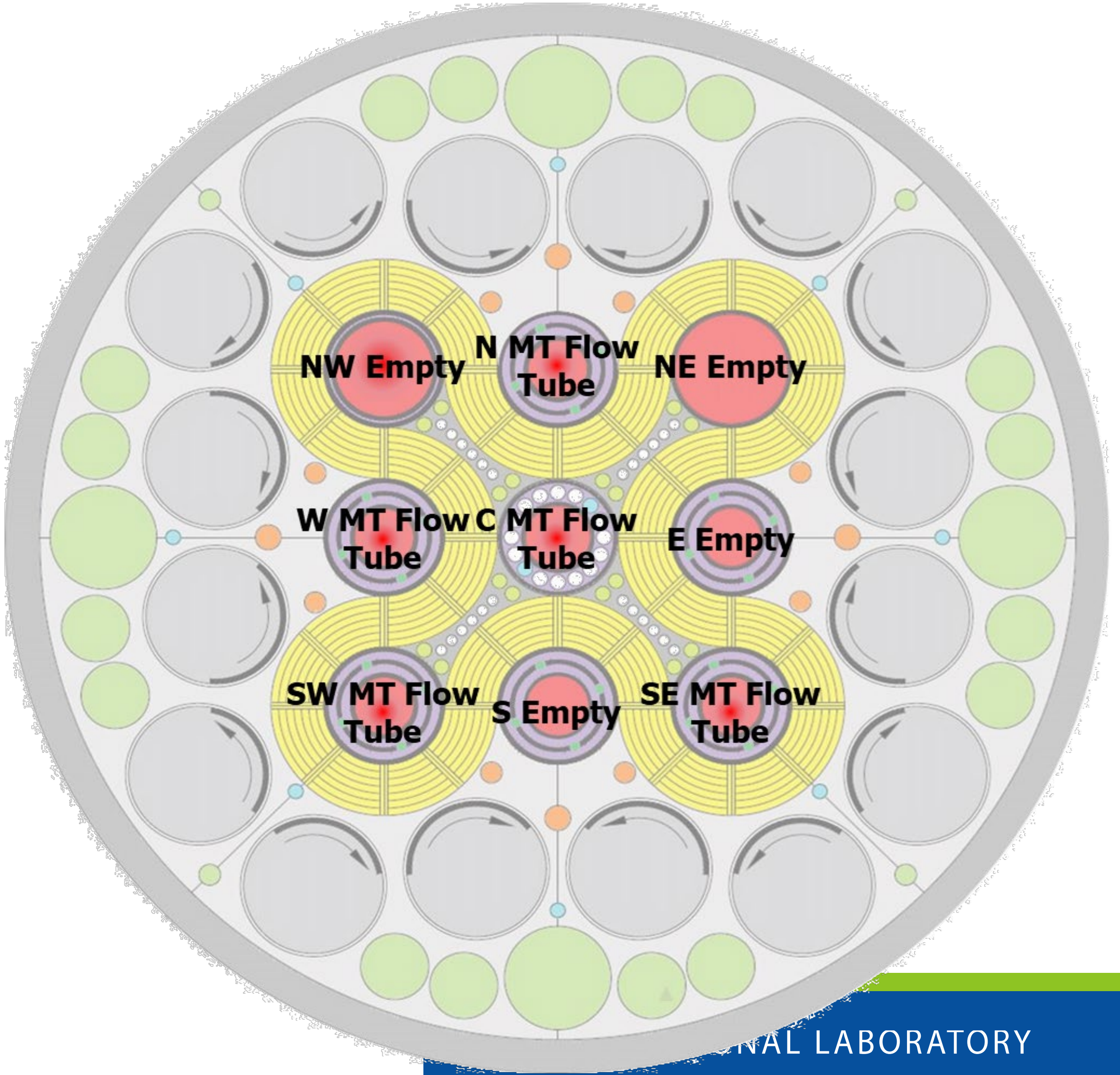
- Validate subcriticality
- Load incrementally
  - 4 FEs in each of 10 steps
  - Startup source (^{124}Sb) for (γ,n) reaction in Be
    - In past, little increase in multiplication w/o source
  - Purple dashed line is a best-fit extrapolation from LCRM data
- Fresh fuel
  - Safer to handle
  - Least uncertainty in modeling





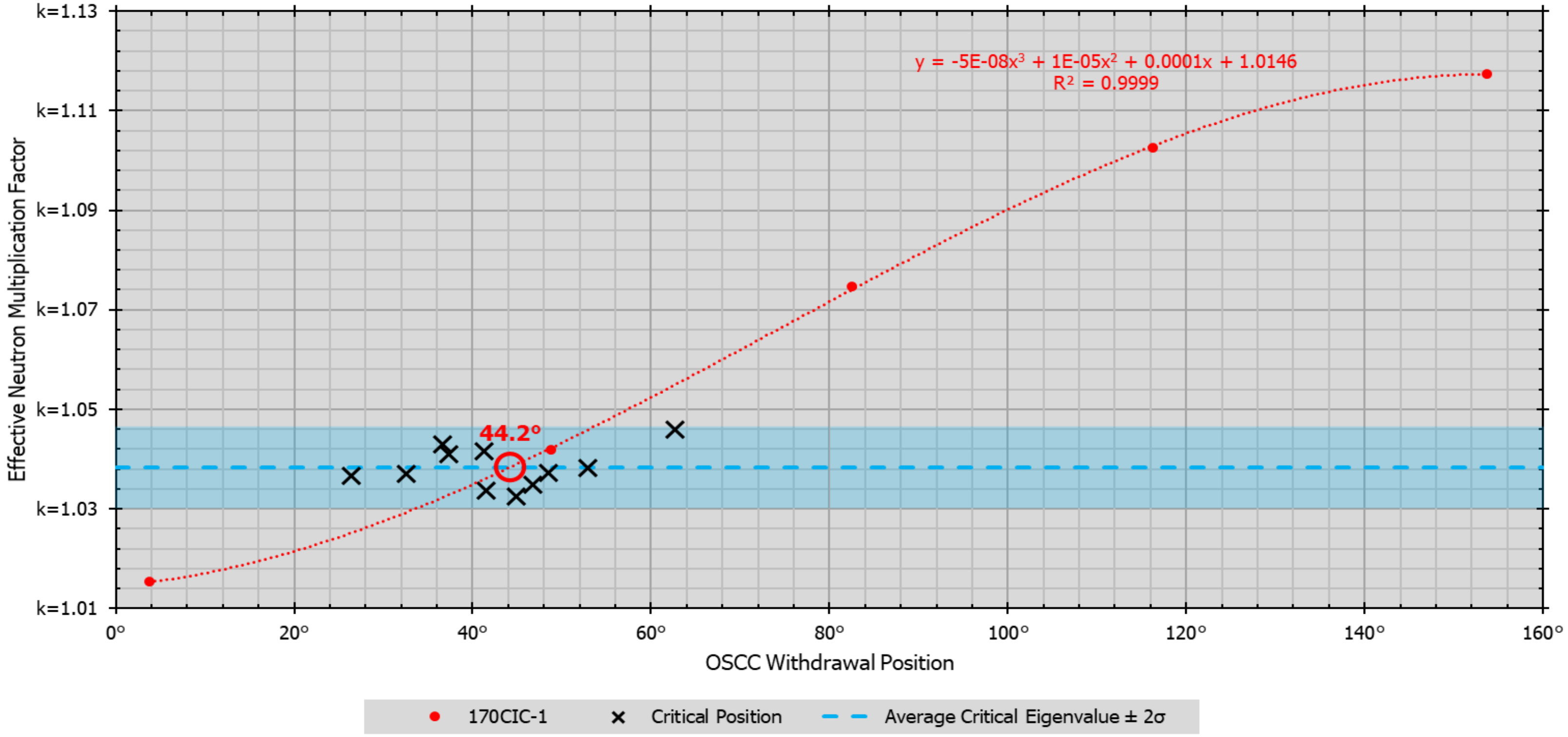
NT-2 – Initial Criticality – Cycle 170CIC-1

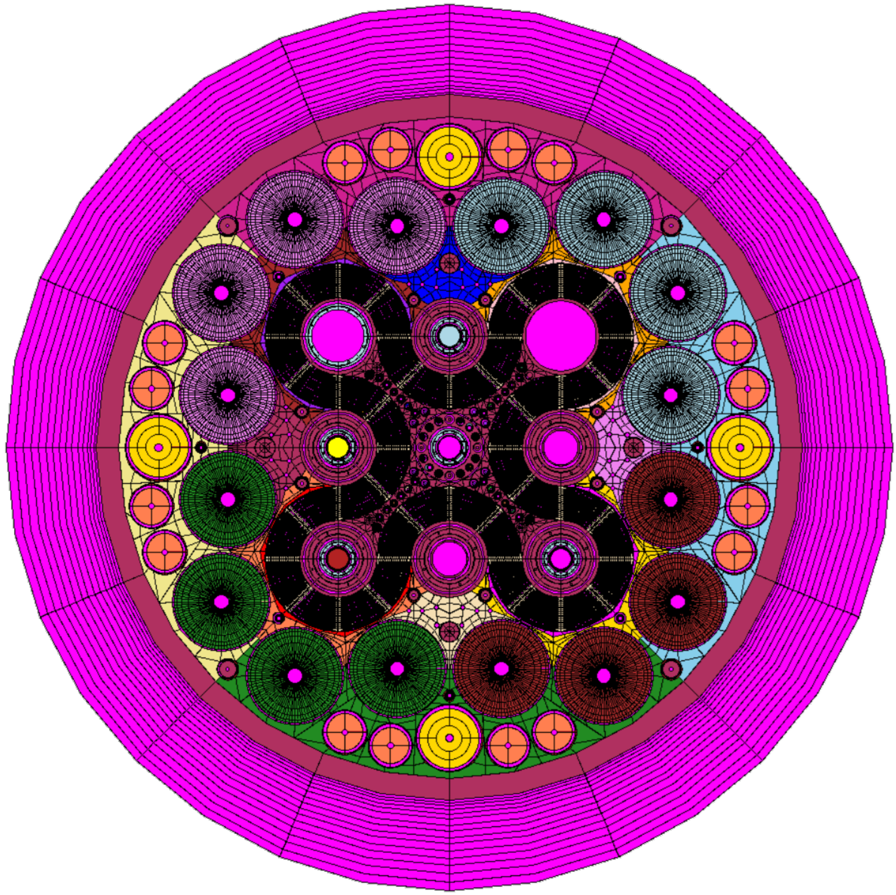
- Validate model's representation of core assembly
  - Quantifies holddown reactivity margin
- Calibrate nuclear instruments, to target desired power in NT-3
- Differing experiment loading in the past (all with fresh fuel):
  - 1986: 57.5°
  - 1994: 52.4°
  - 2004: 29.3°
  - 2012: 28.8°
  - 2022: 52.2°



NT-2 – Initial Criticality for Cycle 170CIC-1

- Model: ≈44.6°
  - Reach Critical Eigenvalue
- ATRC: ≈53.2°
- Actual: 52.2°

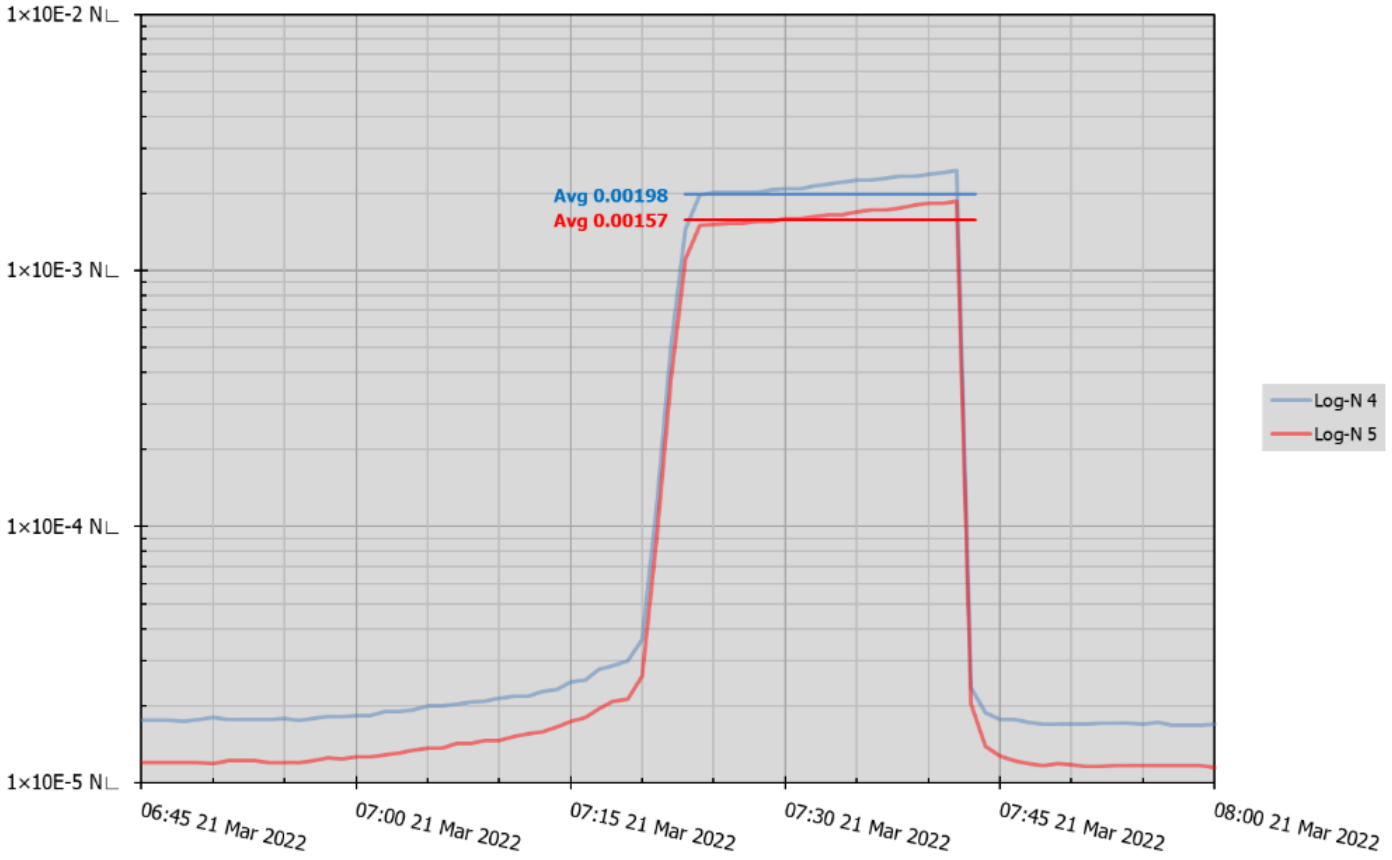




NT-2 – Initial Criticality for Cycle 170CIC-1

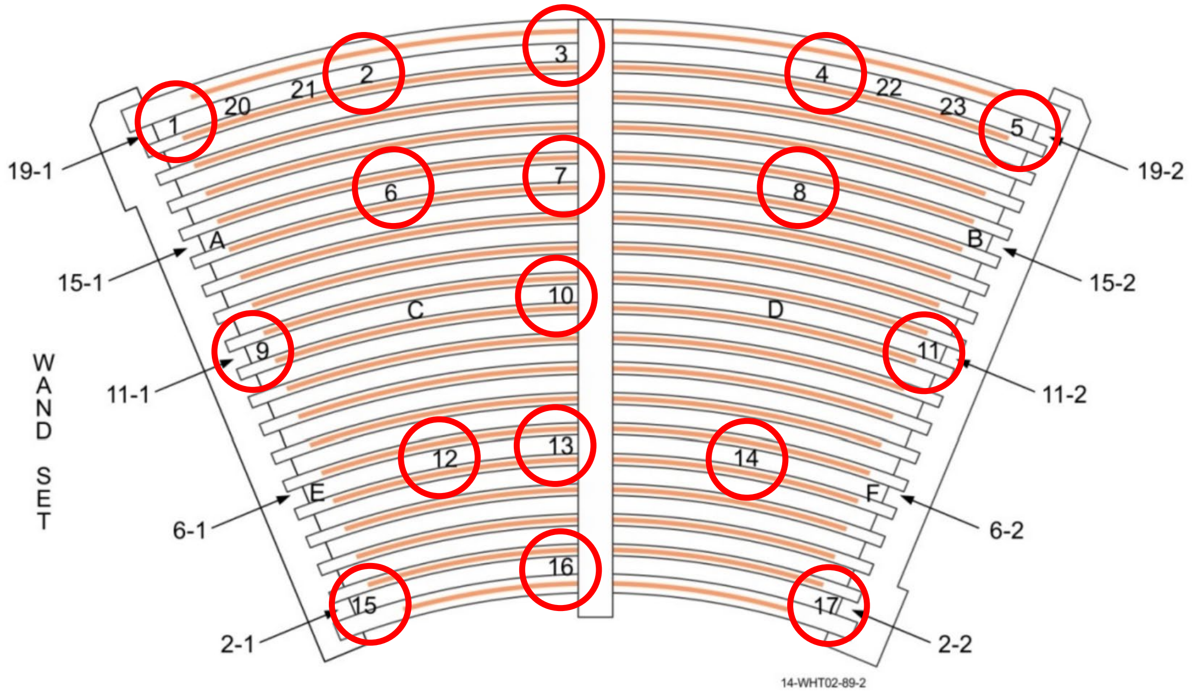
- Log-N instruments calibrated with Co dosimetry
  - ATRC Measured Power: 0.696kW
  - ATR Power from Co Ratio: 1.6kW
    - Validates Log-N: ≈1.8kW

	ATRC	ATR
B-1	0.0670µCi/g	0.169µCi/g
B-2	0.0650µCi/g	0.231µCi/g
B-3	0.1170µCi/g	0.249µCi/g
B-4	0.1020µCi/g	0.273µCi/g
B-5	0.1100µCi/g	0.246µCi/g
B-6		0.142µCi/g
B-7	0.0771µCi/g	0.142µCi/g
B-8	0.0578µCi/g	0.134µCi/g
Average	0.0851µCi/g	0.1983µCi/g
Core Power	0.69602kW	1.6209kW



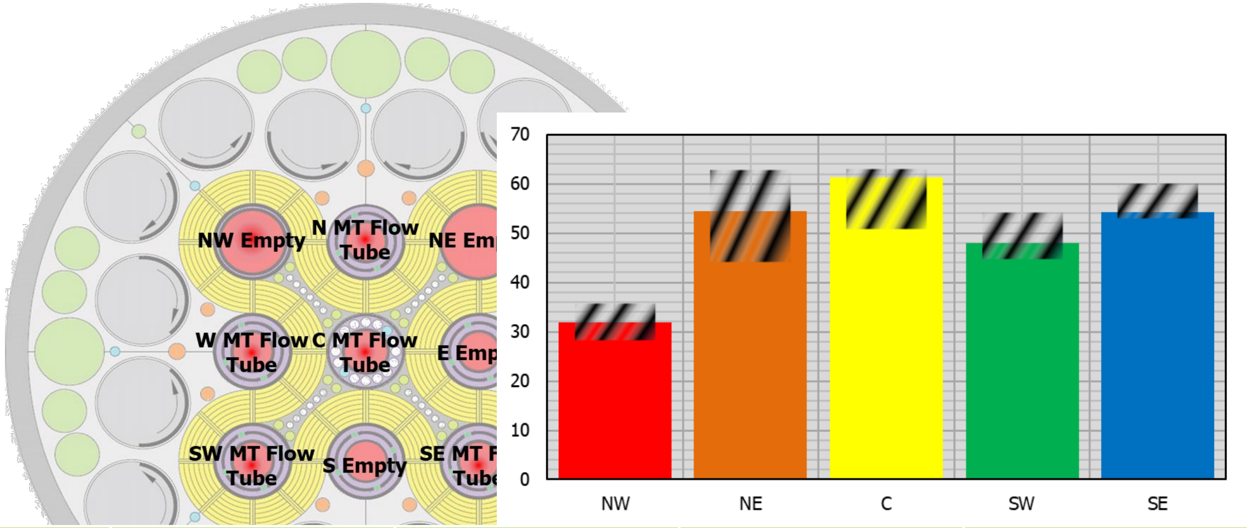
NT-3 – Power Division Measurement – Cycles 170CIC-2/3 Flux Run Basics

- Load flux wands + fission wires
  - Measure midplane power directly, by activations in U-Al wires
  - 10 wands
  - 17 total wires
    - (20-23 and A-D not used in ATR)
- Exactly 20min irradiation
  - Avoids saturating
  - Start $^{1}/_{e}$ times 2kW
- Frequently performed in ATRC
  - Only real way to know ATRC power

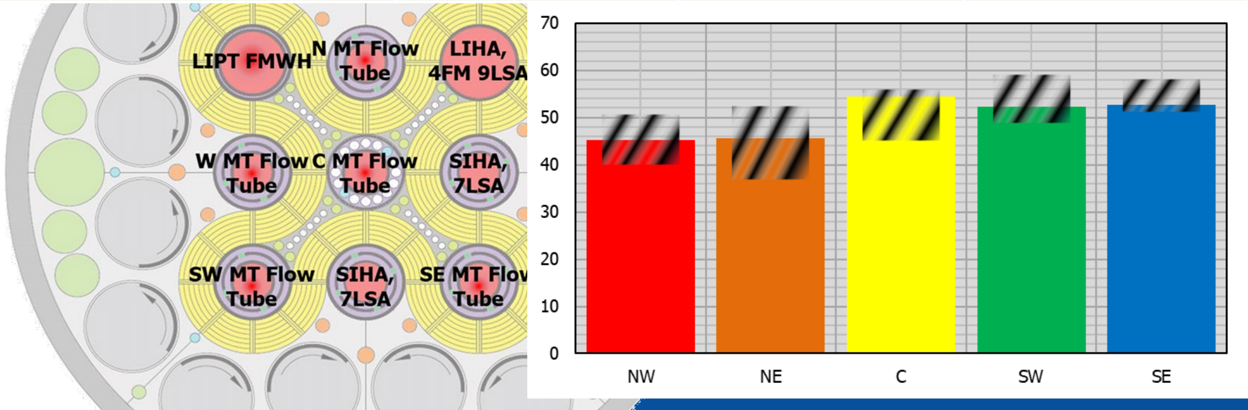


NT-3 – Power Division – Cycles 170CIC-2/3

- Need ___W/Bq/mg for NT-6
  - NT-3 power (kW) is appropriate for fission wires
  - NT-6 power (MW) is needed for installed power indication
  - Calibrate Nb dosimetry in NT-3 for NT-6
    - Previous NT used Ag dosimetry and was often unsuccessful due to competing thermal and fast activations

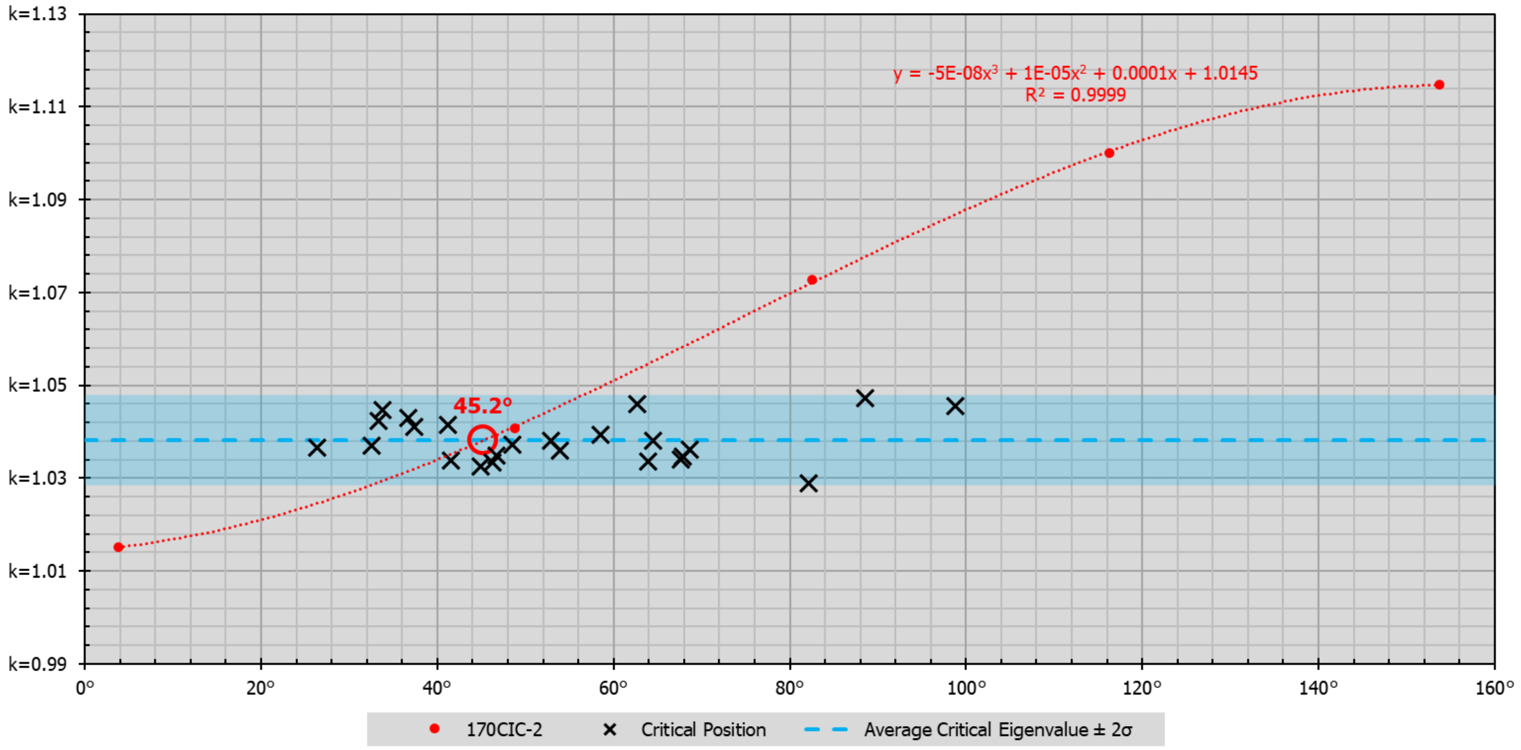


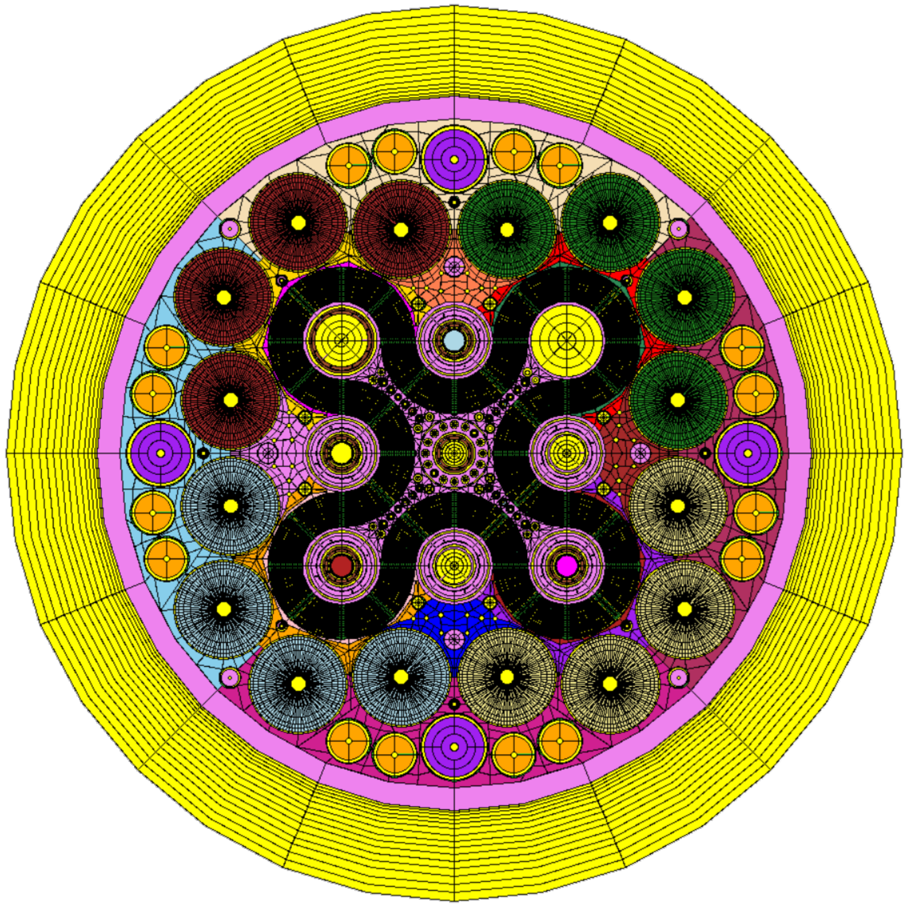
	NW	NE	C	SW	SE
170CIC-2	31.94	54.52	61.28	47.89	54.33
170CIC-3	45.16	45.55	54.47	52.20	52.61



NT-3 – Cycle 170CIC-2

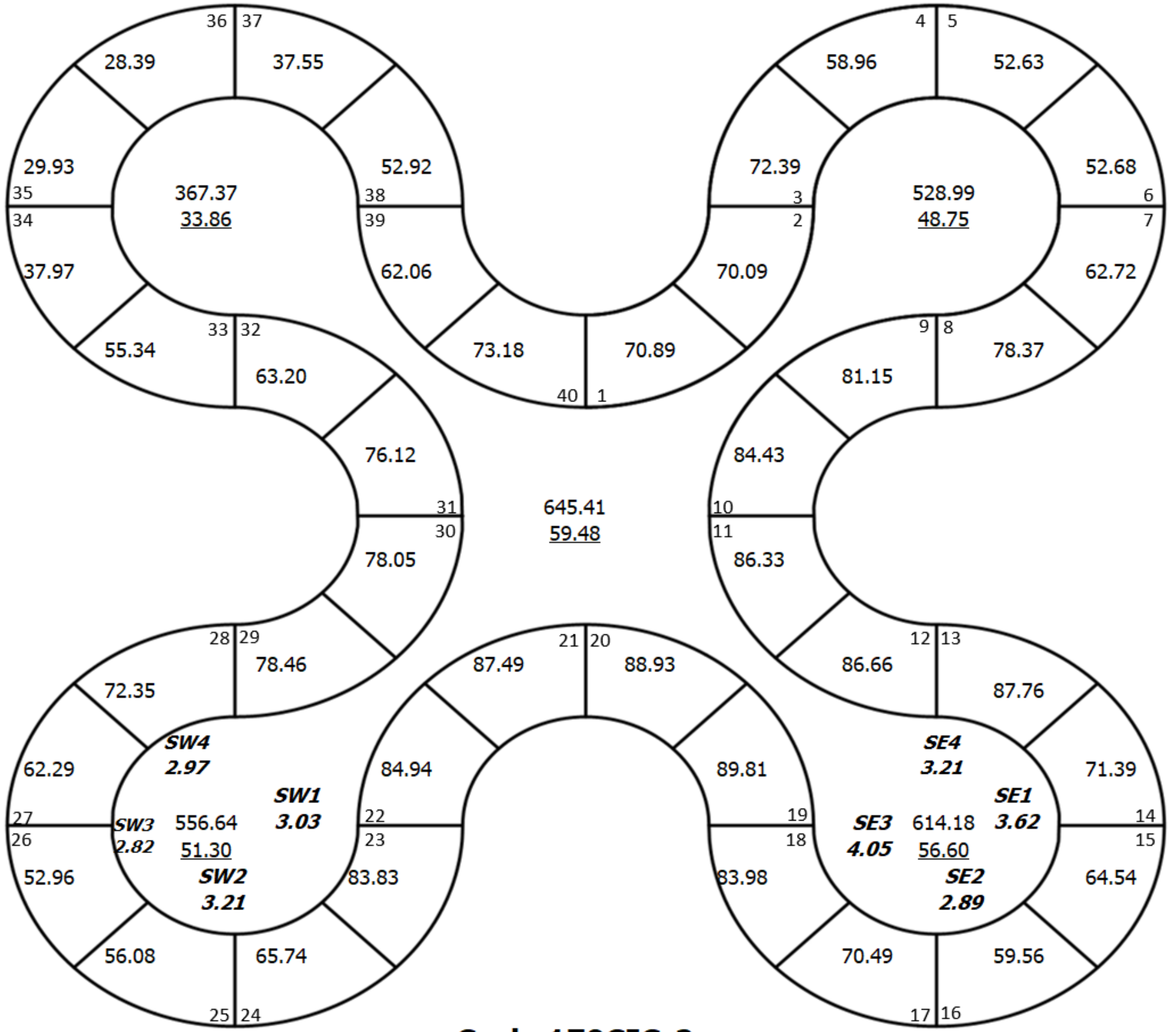
- Model: ≈45.2°
- ATRC: ≈57.2°
- Actual: 57.3°





NT-3 – Power Division Measurement – Cycle 170CIC-2

- 170CIC-2 dosimetry only in SW/SE
  - Dosimetry positions in Safety Rods
- Other lobes' dosimetry requires hardware to be loaded, which interferes with intended water-filled benchmark

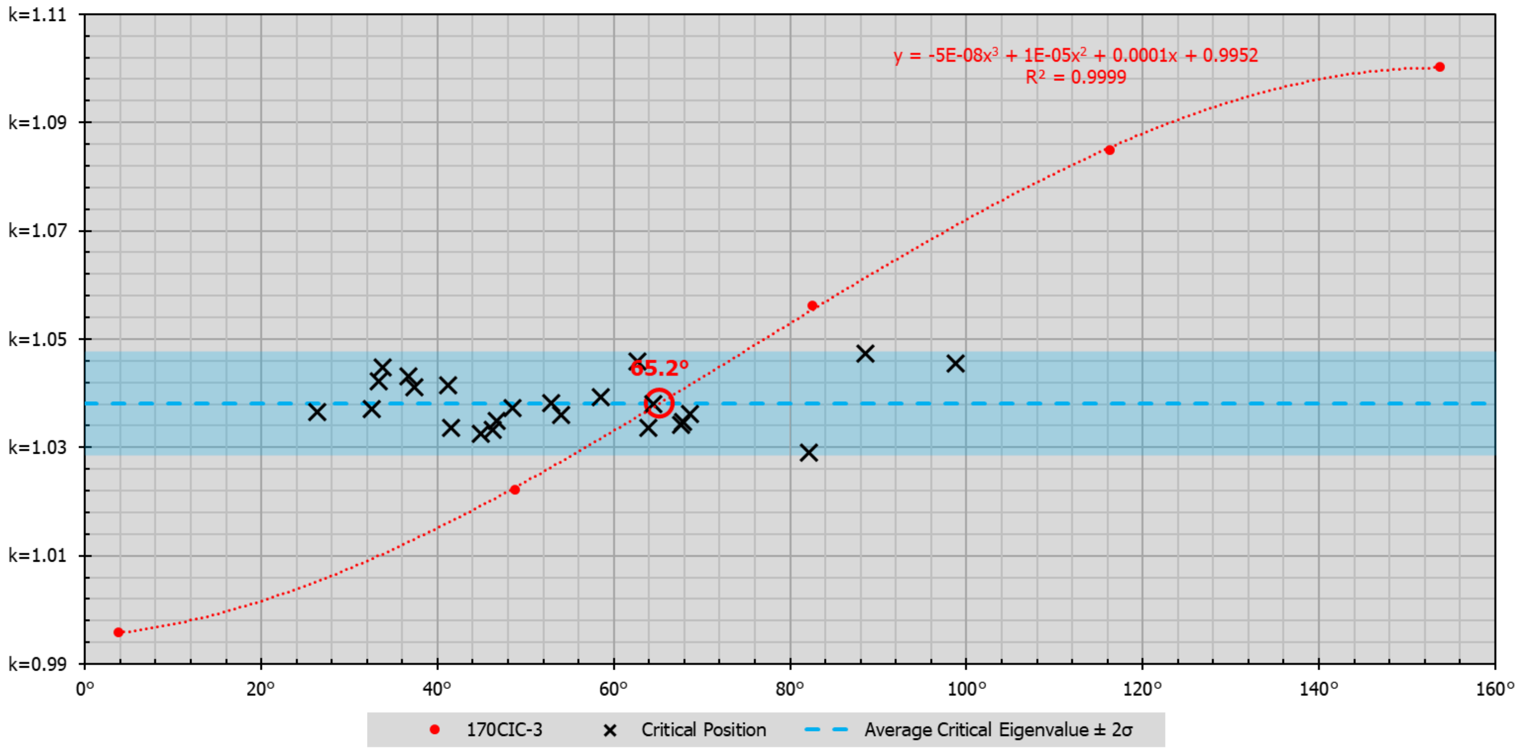


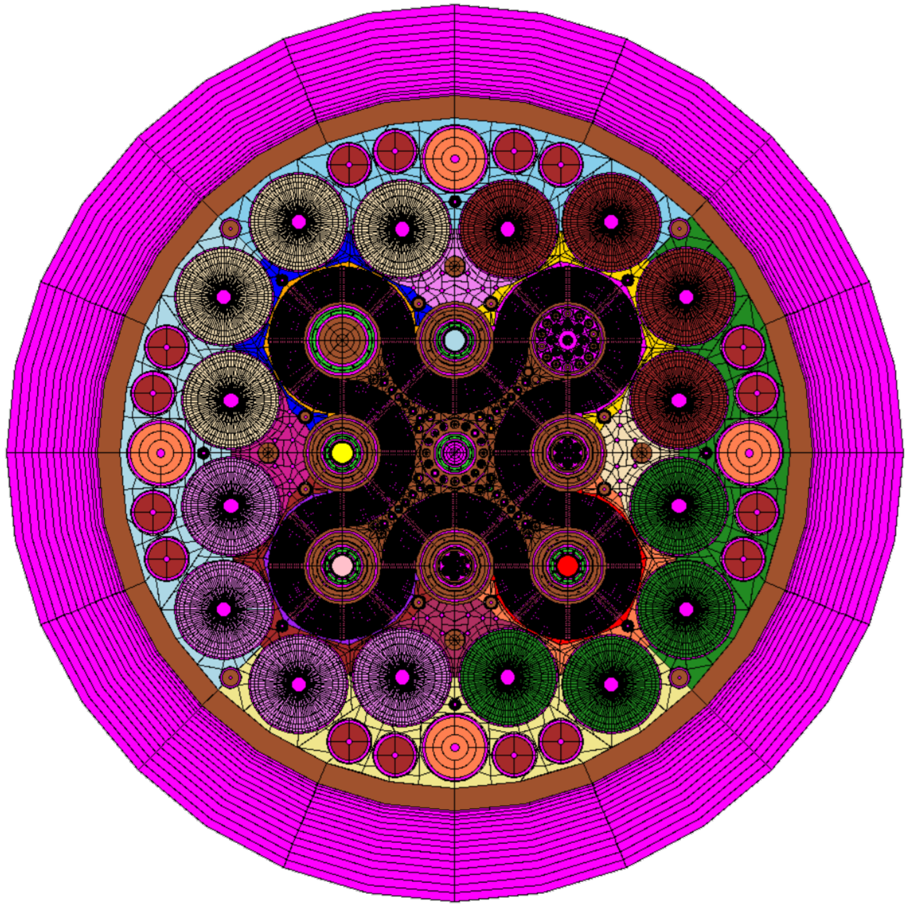
Cycle 170CIC-2

Fuel Element Powers are shown in watts. Lobe Powers are shown within the respective lobes. Underlined lobe powers are normalized to 250 watts.
Total Core Power = 2,712.60 watts

NT-3 – Initial Criticality for Cycles 170CIC-3 through -7

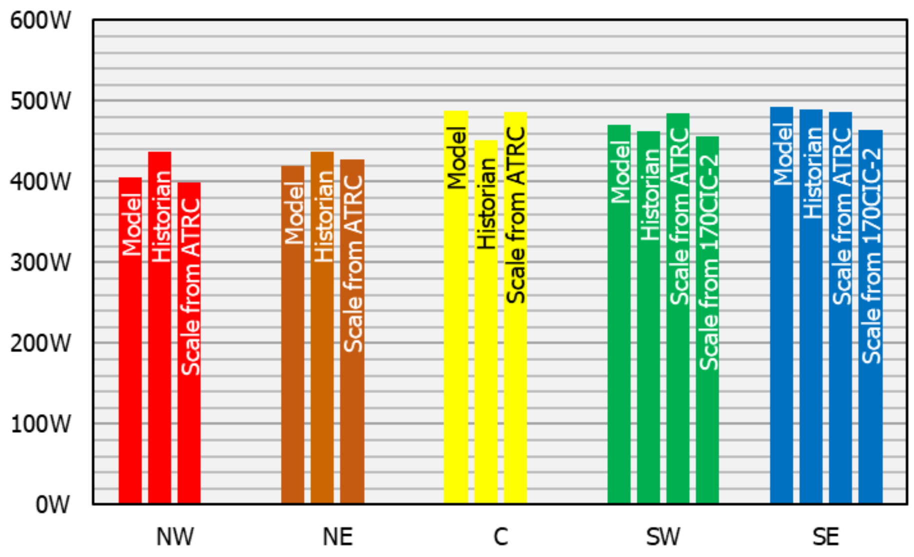
- Model: ≈65.2°
- ATRC: ≈63.5°
- Actual: 65.5°

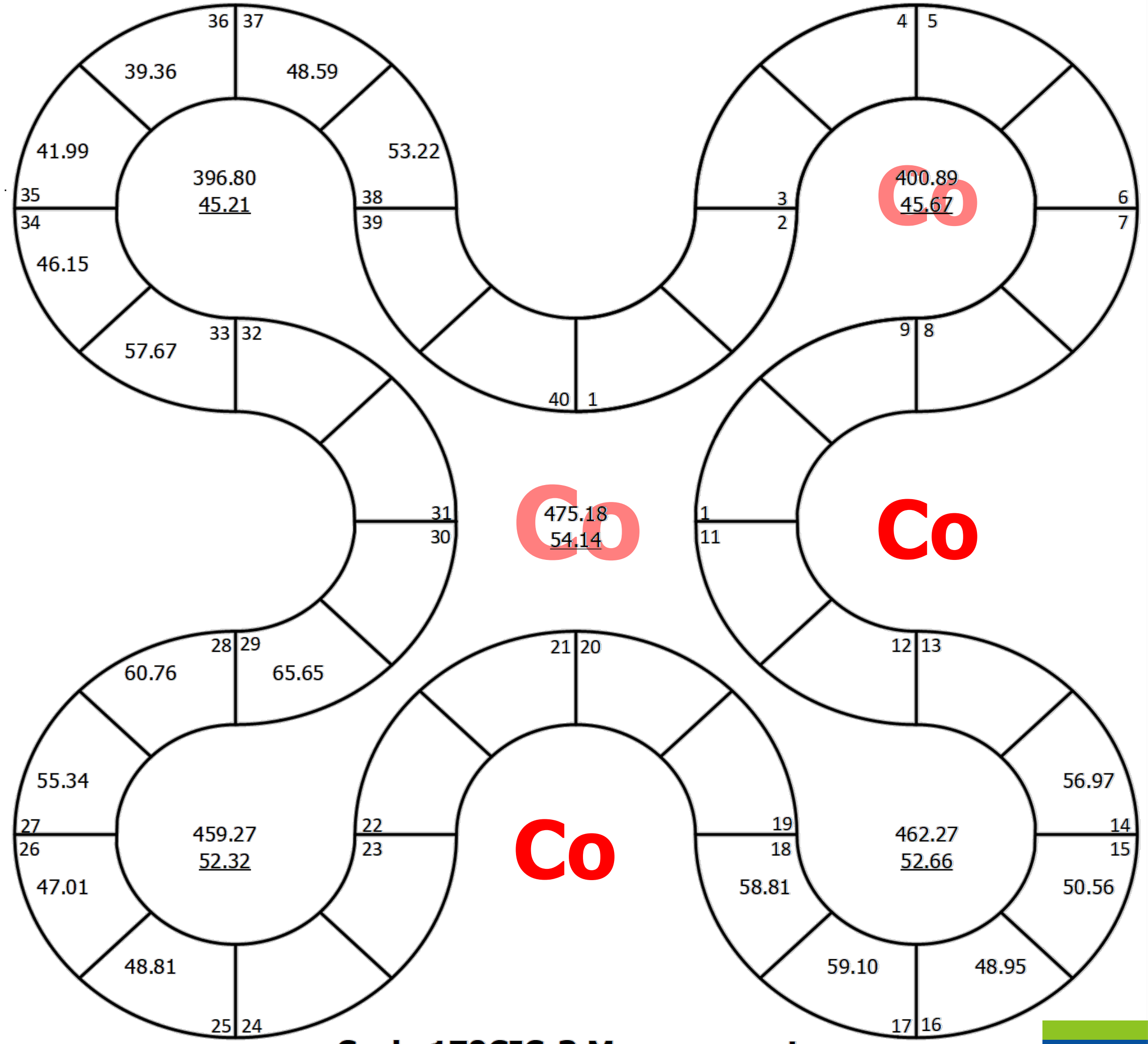




NT-3 – Power Division Measurement – Cycle 170CIC-3

- 170CIC-3 Results:
  - Most fuel element measurements failed
  - Several remaining ways of computing lobe powers

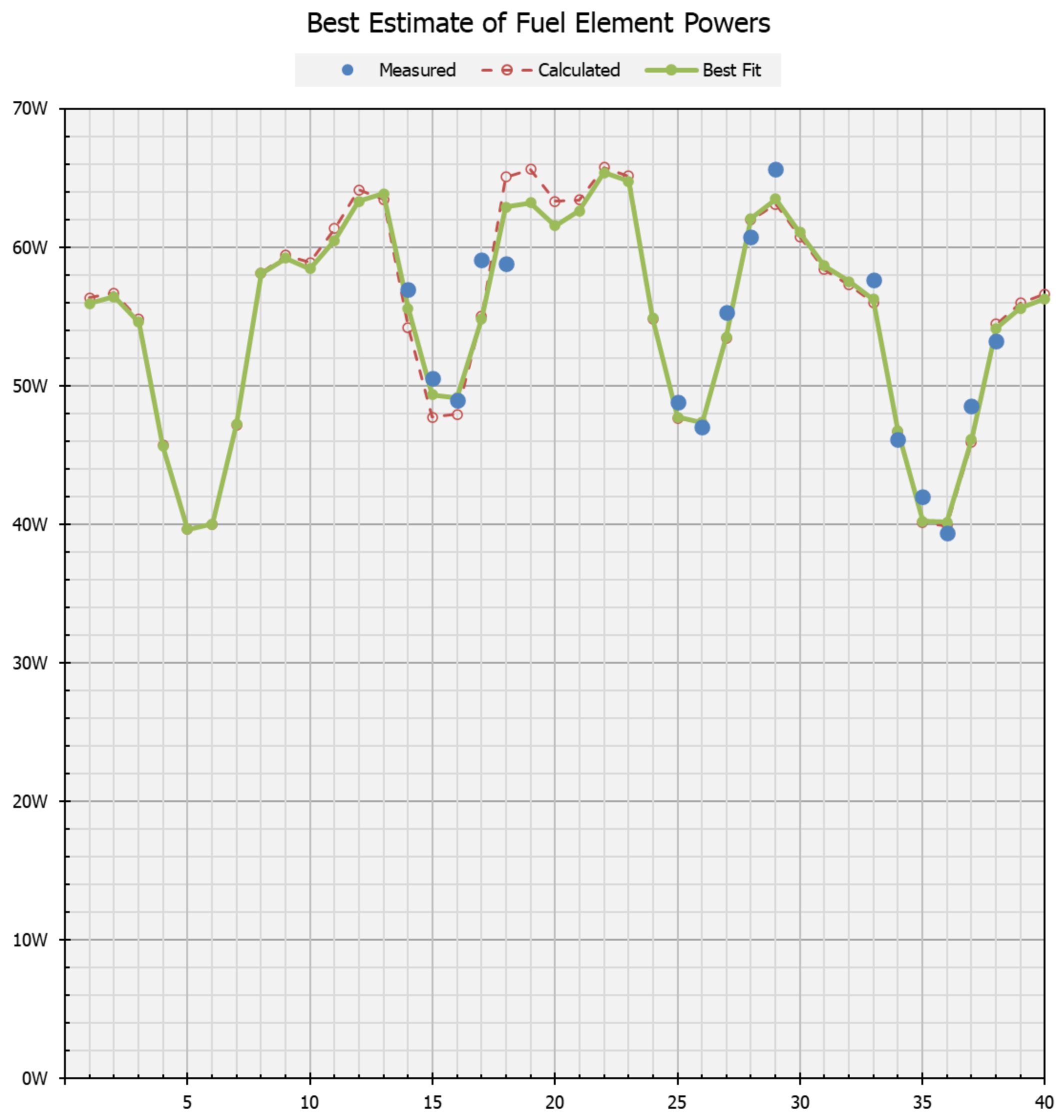




Cycle 170CIC-3 Measurements

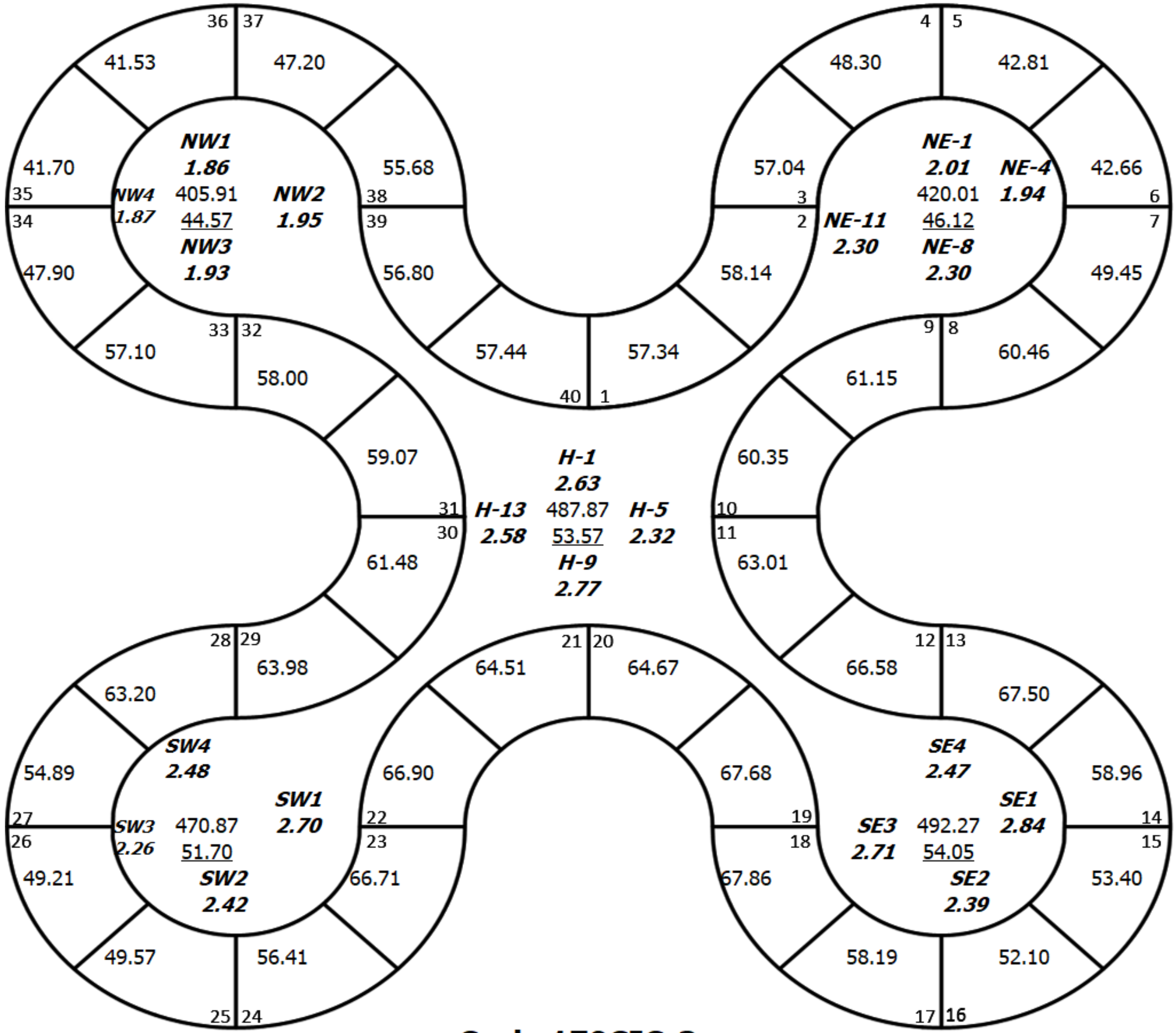
NT-3 – Power Division Measurement – Cycle 170CIC-3

- Modeled FE powers can be adjusted to best-estimate powers
  - Leverages available measurements
  - See J. W. NIELSEN, D. W. NIGG, and A.W. LaPORTA, "A Fission Matrix Based Validation Protocol for Computed Power Distributions in the Advanced Test Reactor," *Nucl. Eng. Des.*, **295**, 615 (2015).
  - This method gives additional credibility to modeled powers



NT-3 – Power Division Measurement – Cycle 170CIC-2

- 170CIC-3 dosimetry in all 5 lobes
- This graphic shows modeled powers, as only a few measurements were successful



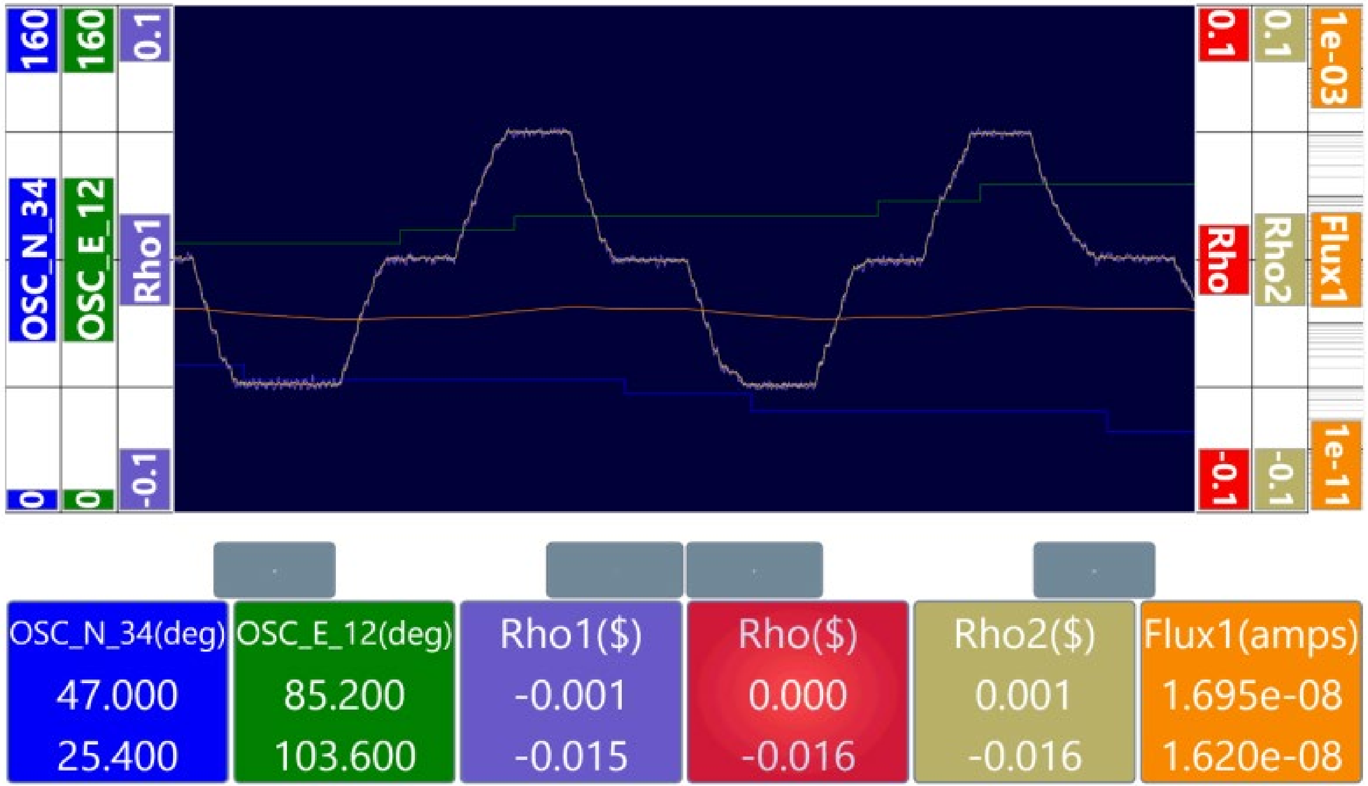
Cycle 170CIC-3

Fuel Element Powers are shown in watts. Lobe Powers are shown within the respective lobes. Underlined lobe powers are normalized to 250 watts.

Total Core Power = 2,276.93 watts

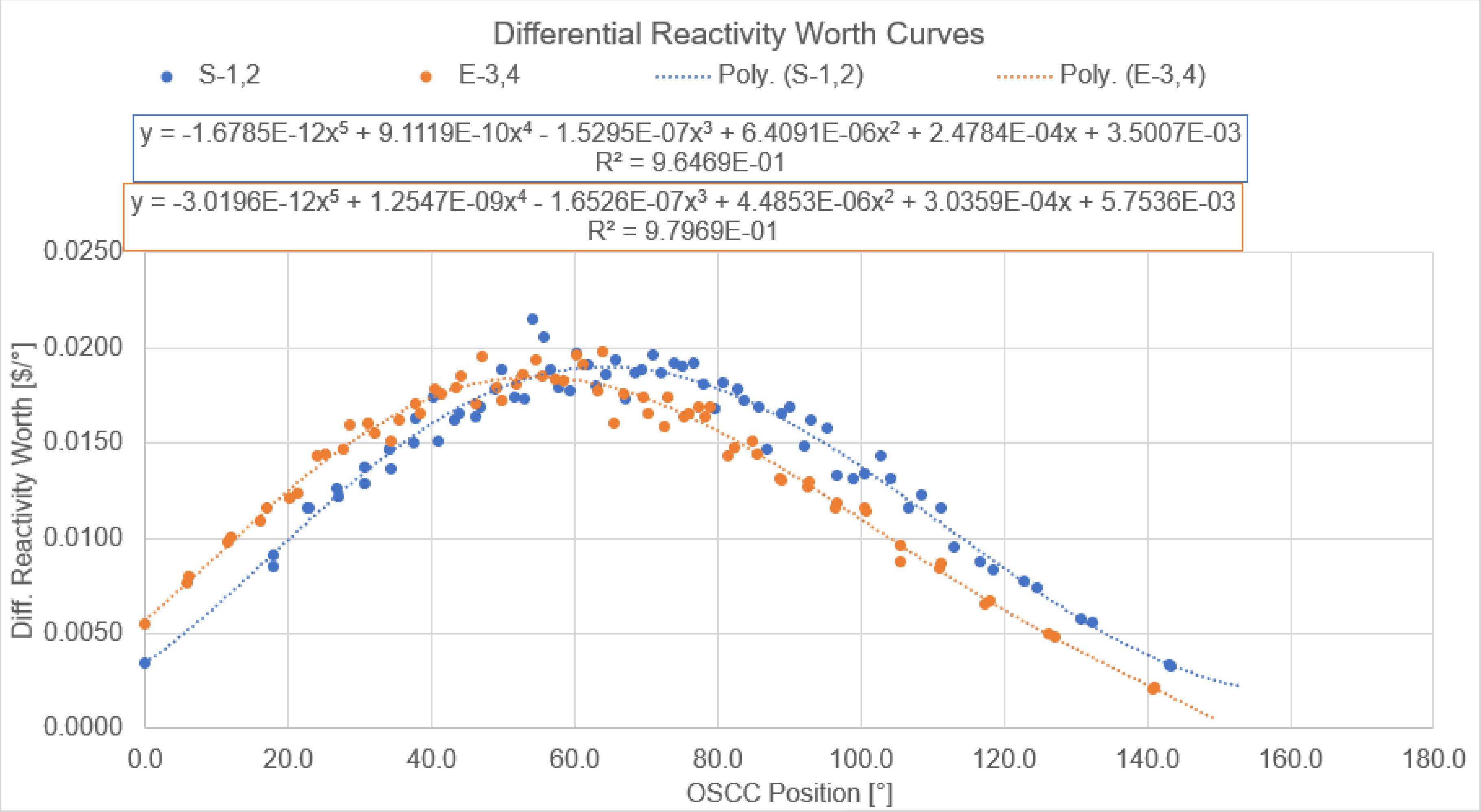
NT-4 – Shim and Coolant Worth Calibrations – Cycle 170CIC-4

- Reactivity Measurement Acquisition System (RMAS) computers
  - Directly indicate core reactivity
- Shim incrementally and track core reactivity
  - Safety Rods
  - OSCCs
  - Neck Shims
  - Regulating Rods
- Primary isothermal temperature coefficient of reactivity
- Loop temperature coefficient of reactivity



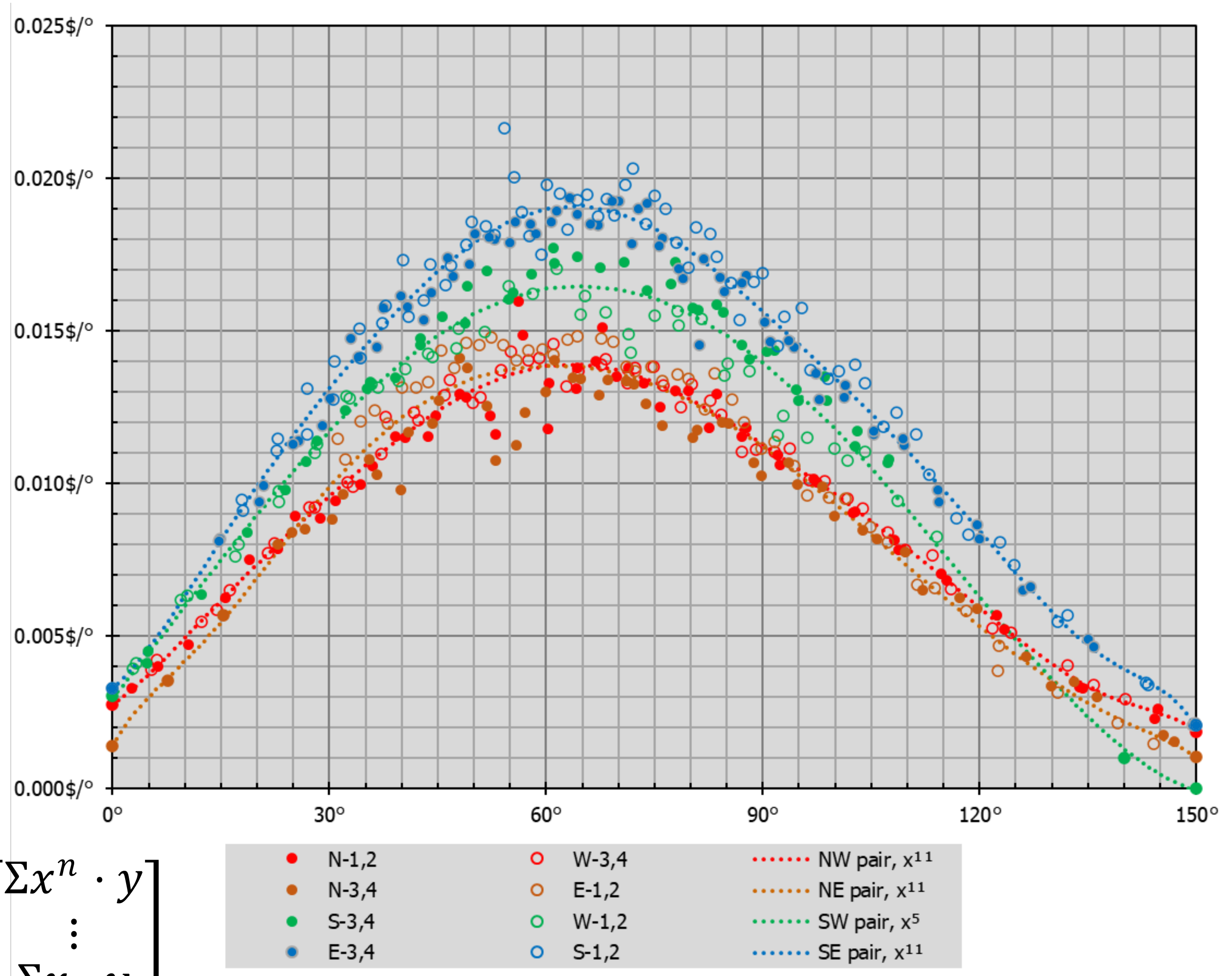
NT-4 – Shim and Coolant Worth Calibrations – Cycle 170CIC-4

- OSCCs pairs misaligned
  - NE by 6.5°
  - SE by 8.8°
- These curves should lie exactly on top of each other



NT-4 – Shim and Coolant Worth Calibrations – Cycle 170CIC-4

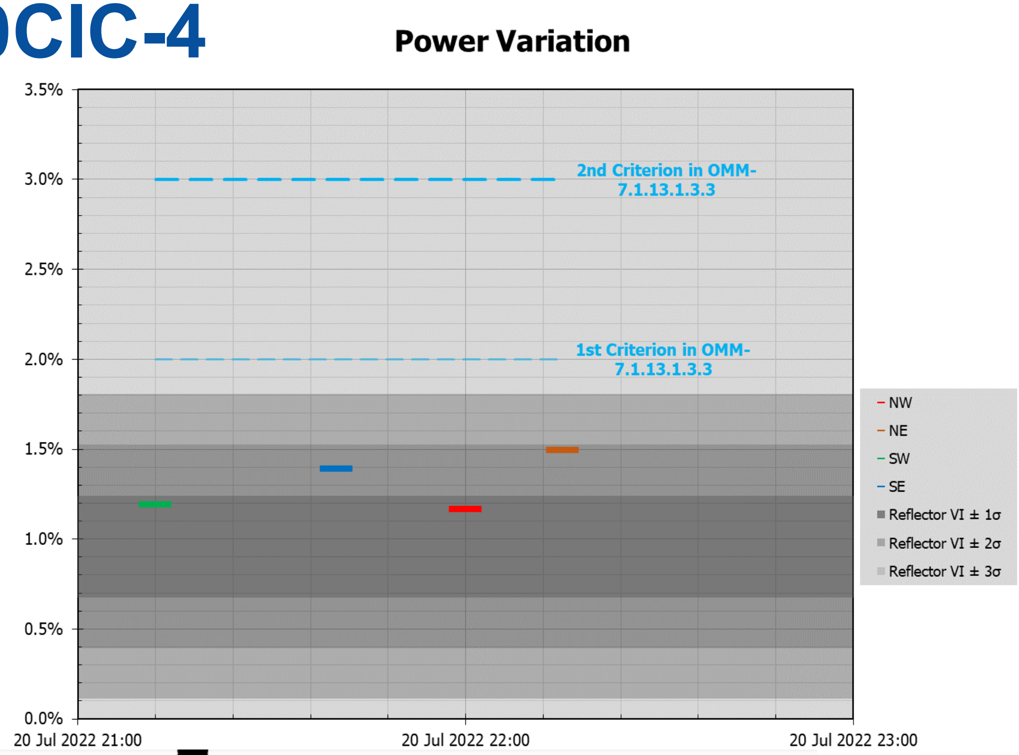
- OSCCs have most data
- Assume the true integral worth curve is strictly monotonic
  - Found highest-order polynomial with
    - 0$ at 0°
    - >0$ on (0° - 150°)
    - 1st derivative >0$/° on (0° - 150°)

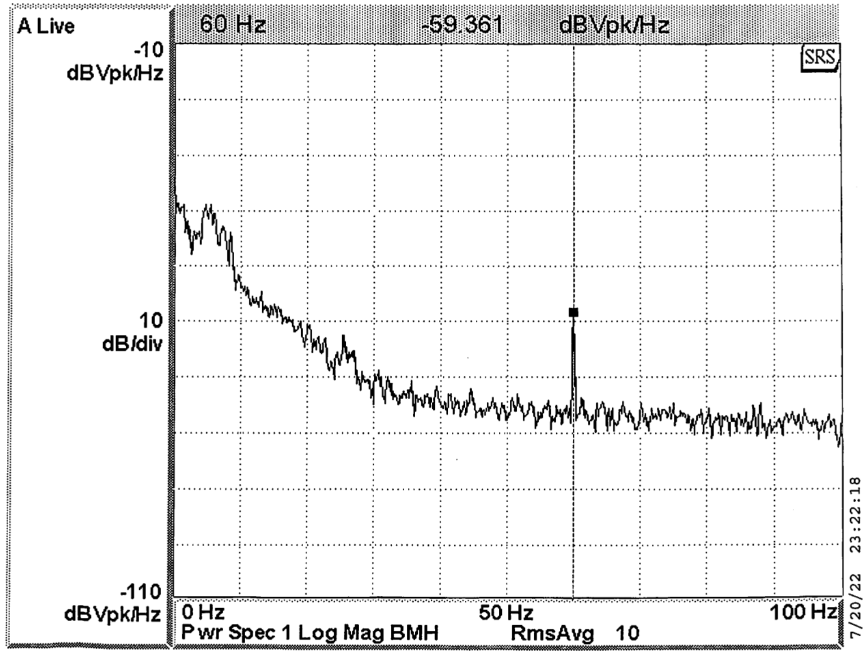


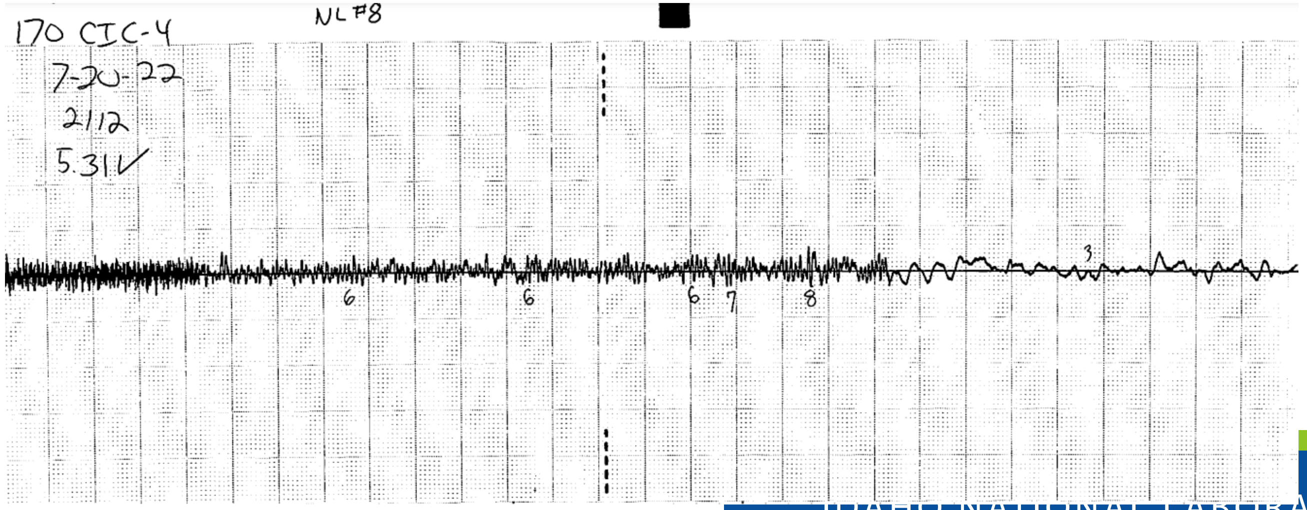
$$\begin{bmatrix} \Sigma x^{2\cdot n} & \Sigma x^{2\cdot n-1} & \cdots & \Sigma x^{n+1} & \Sigma x^{n} \\ \Sigma x^{2\cdot n-1} & \Sigma x^{2\cdot n-2} & & \Sigma x^{n} & \Sigma x^{n-1} \\ \vdots & & \ddots & & \vdots \\ \Sigma x^{n+1} & \Sigma x^{n} & & \Sigma x^{2} & \Sigma x \\ \Sigma x^{n} & \Sigma x^{n-1} & \cdots & \Sigma x & \Sigma x^{0} \end{bmatrix} \times \begin{bmatrix} a_n \\ \vdots \\ a_1 \end{bmatrix} = \begin{bmatrix} \Sigma x^{n} \cdot y \\ \vdots \\ \Sigma x \cdot y \\ \Sigma y \end{bmatrix}$$

NT-5 – Power Variation – Cycle 170CIC-4

- Power Variation measurement for each quadrant's neutron level instrument
  - All ±2σ from expectation
- Power spectral density for SW
  - Expected peaks for known hardware



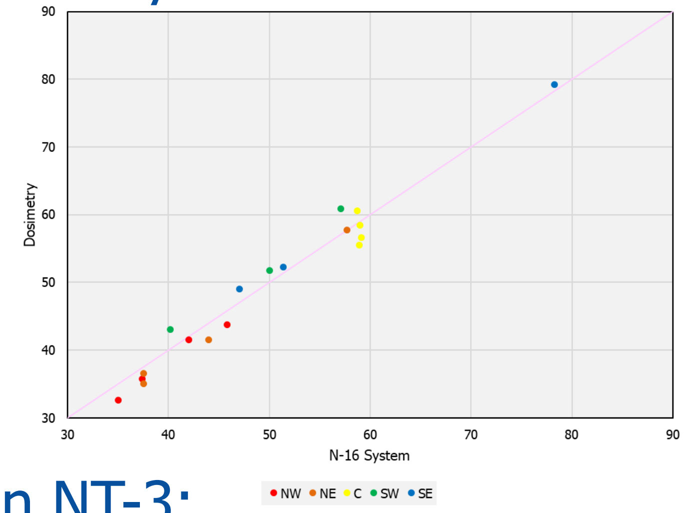




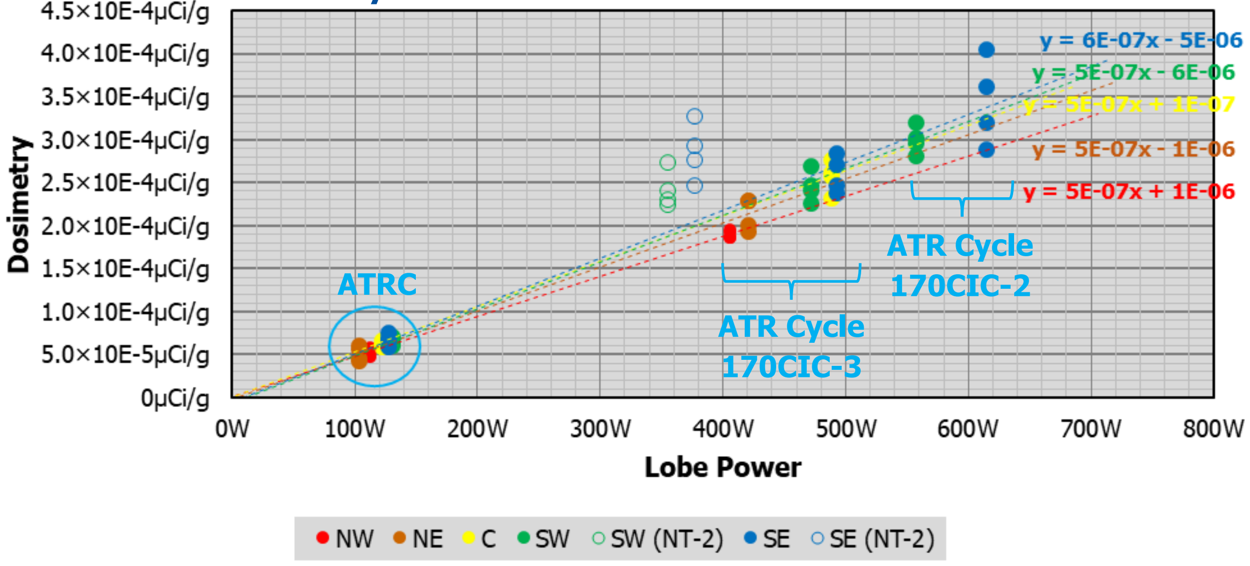
NT-6 – N-16 Calibration – Cycles 170CIC-5+

- Need ___W/Bq/mg from 170CIC-3
- Flux Trap dosimetry needed in NT-6
- Whereas 170CIC-3 is balanced OSCCs
  - Cycle 170CIC-5: balanced
    - Failed due to incorrect dosimetry
  - Cycle 170CIC-6: push toward S
  - Cycle 170CIC-7: repeat failed 170CIC-5

Hope to see linearity in NT-6:



Saw linearity in NT-3:



Power Escalation Tests NT-7 – NT-12 – Cycle 171A-1

- Cycle 171A-1 is a normal cycle
  - Sponsored experiments
  - Designed Fuel loading
- 3 tests are normal parts of reactor startup
  - NT-7: critical shim prediction
  - NT-8: comparison of power division to prediction
  - NT-10: power variation data
- 1 test takes dedicated time
  - NT-9 OSCC calibrations
    - Validate misalignment corrections from NT-4
- 2 test are done in parallel with experiment irradiation
  - NT-11 At-power loop temperature coefficient of reactivity measurement
  - NT-12 N-16 multiplier characterizations

Cycle	Power Escalation Test	Corresponding Low-power Test
171A-1	NT-7	NT-2
	NT-8	NT-3
	NT-9	NT-4
	NT-10	NT-5
	NT-11	None
	NT-12	