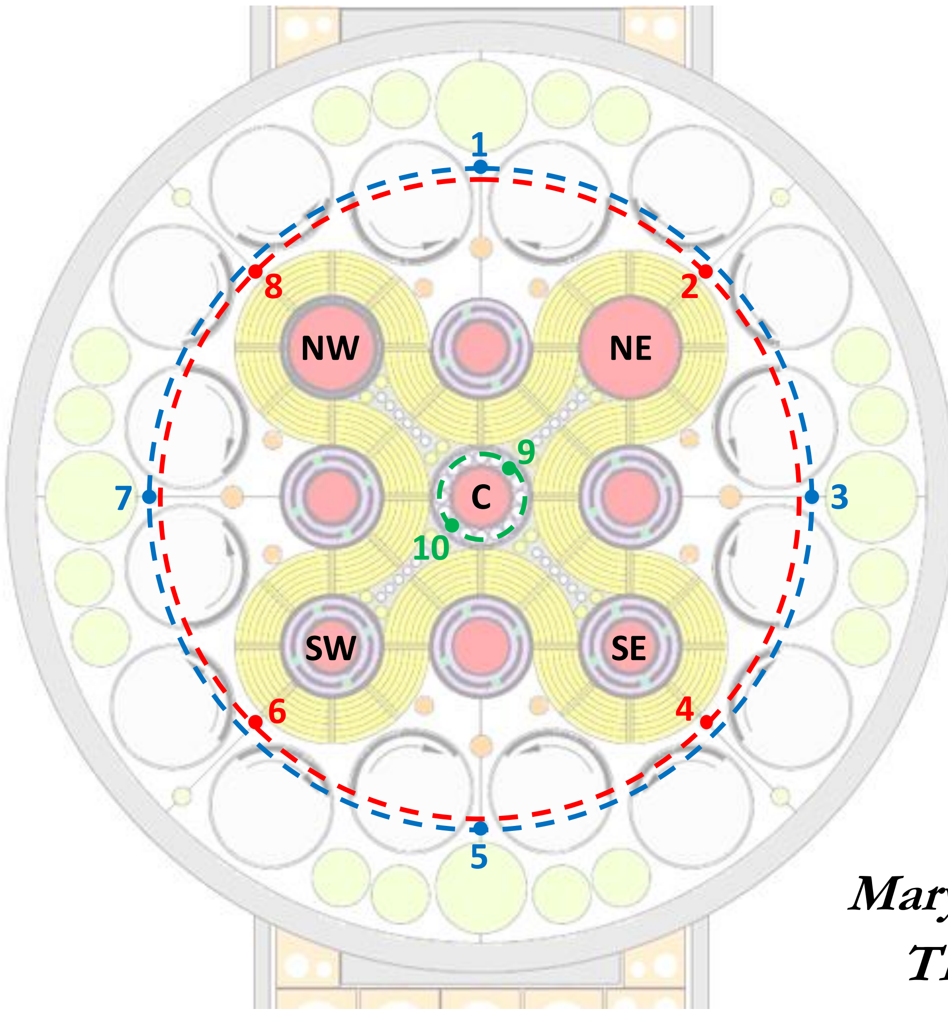
INL/CON-16-39530

Investigation and Correction of the High Thermal to N-16 Ratio in the Southwest Lobe in the ATR



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TRTR 2017

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Overview

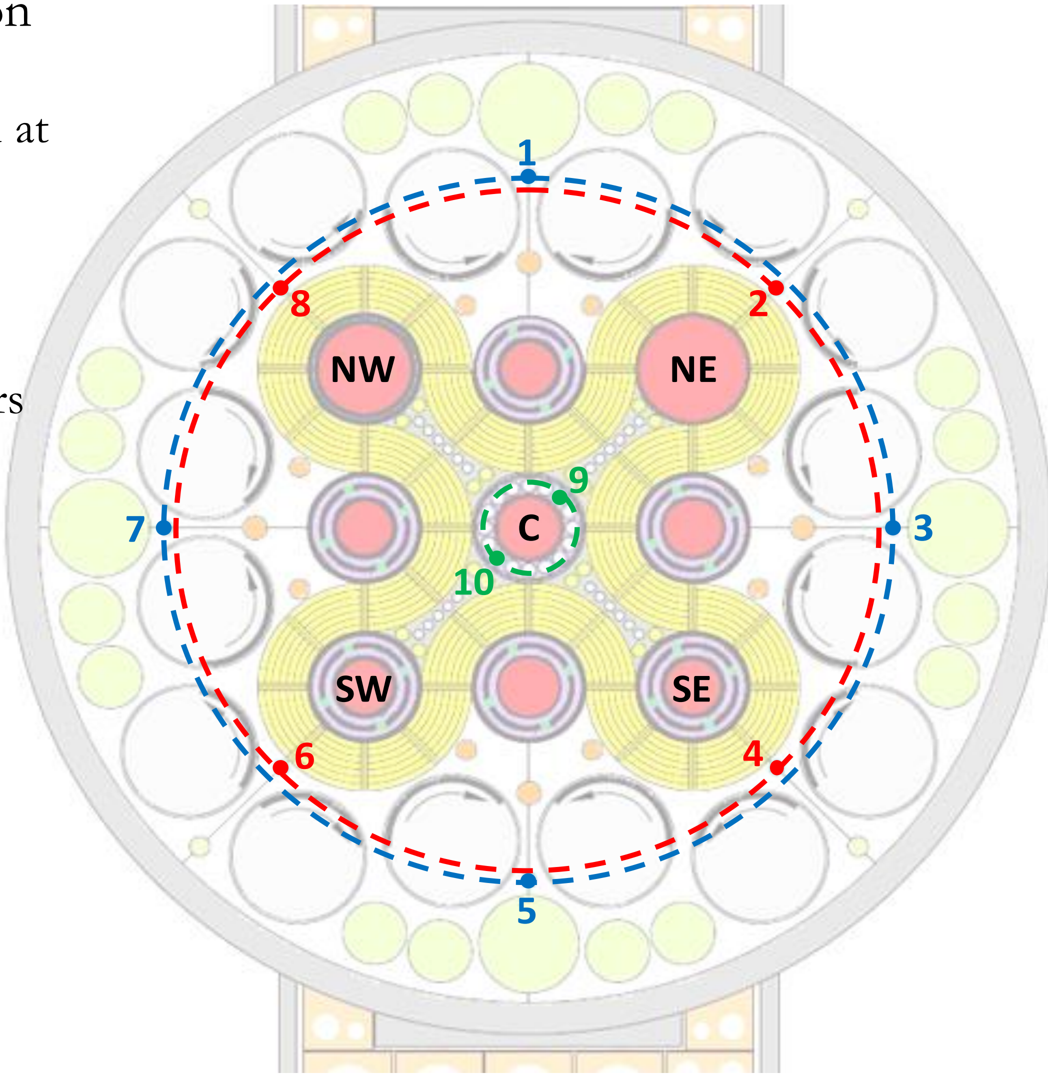
- Investigation Team
- Overview of N-16, WPC Systems
- Issues of High Thermal to N-16 Ratio
- Formal Trouble Shooting Plan
- Some Trending and Data Review
- Changes to N-16 System and Water Power Calculator
- Actions Taken for Problem Resolution

Team Approach

- System Engineering
  - Bob Fulks (Lead), Jerry Mullen, and Darrin Robinson
- Reactor Instrument Technicians
  - Rick Sistrunk, Brad Packham, Russell Loveday
- Operations
  - Ken Schreck, Veryl Kirkpatric, Dave Kahn, Phil Cox, and Various Other Crew Members
- Reactor Engineering
  - Marya Morrison, Daren Norman, Rose Holtz, Ryan Little
- Instrument Shop
  - Instrument Technicians for N-16 Flow and WPC
- Maintenance
  - Fitters for N-16 Tube Change out
- S&T
  - Chris Brooks
  - Joe Nielsen
- Walsh Engineering
  - Theron Jensen

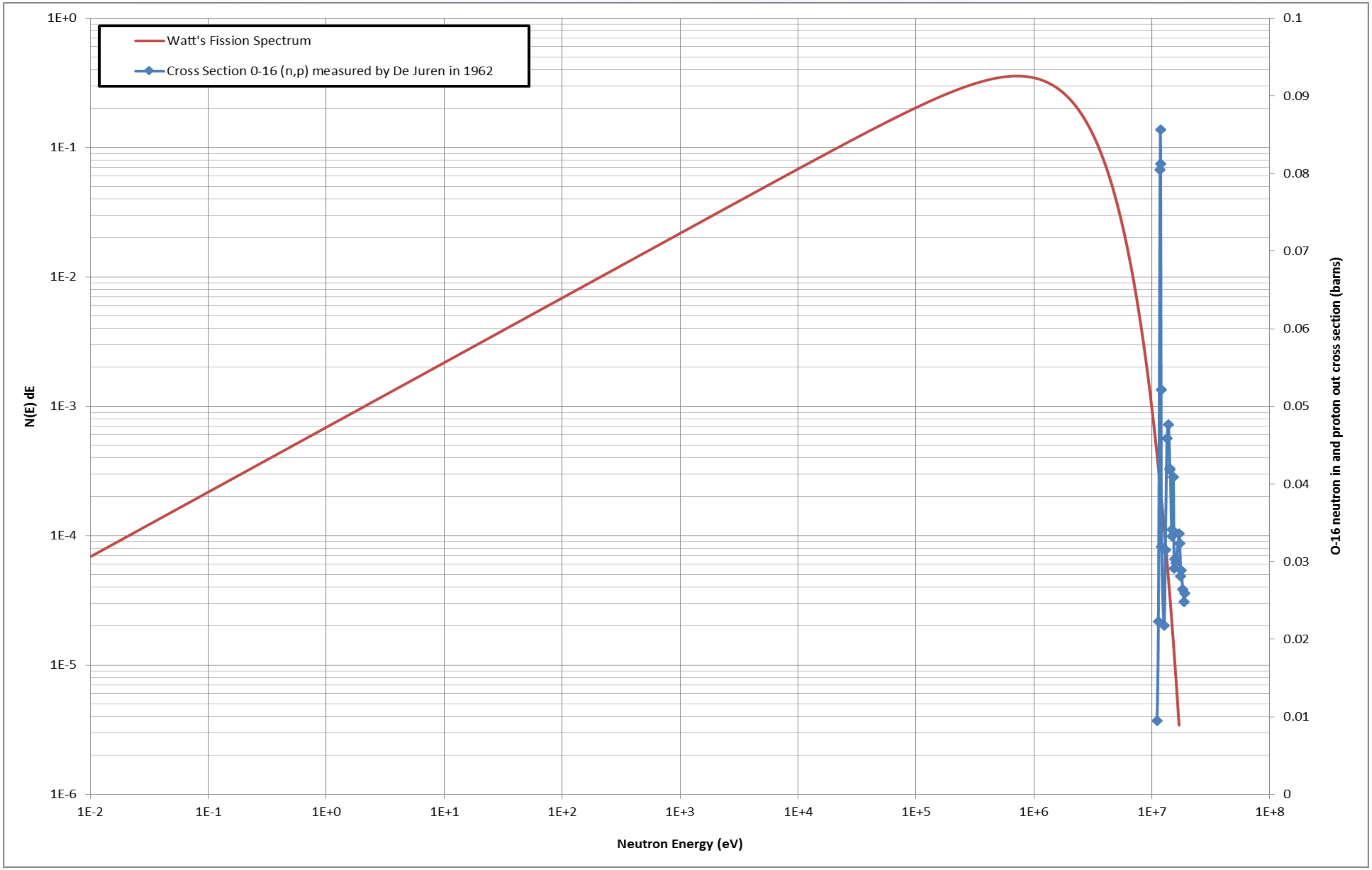
N-16 System Description

- Lobe Power Calculation and Indication System (LPCIS)
  - Uses activated N-16 that is measured at various locations within the core
    - 4 Inboard (18.74”)
    - 4 Outboard (19.00”)
    - 2 Center
  - Determines lobe and quadrant powers
  - Constrained powers determined by solving a 5x10 matrix
- Threshold reaction
  - O-16 (n,p) N-16
  - Greater than 10 MeV neutrons
  - Cross section is about 20 millibarn
  - Unlike most N-16 system it uses the beta decay and not the gamma decay

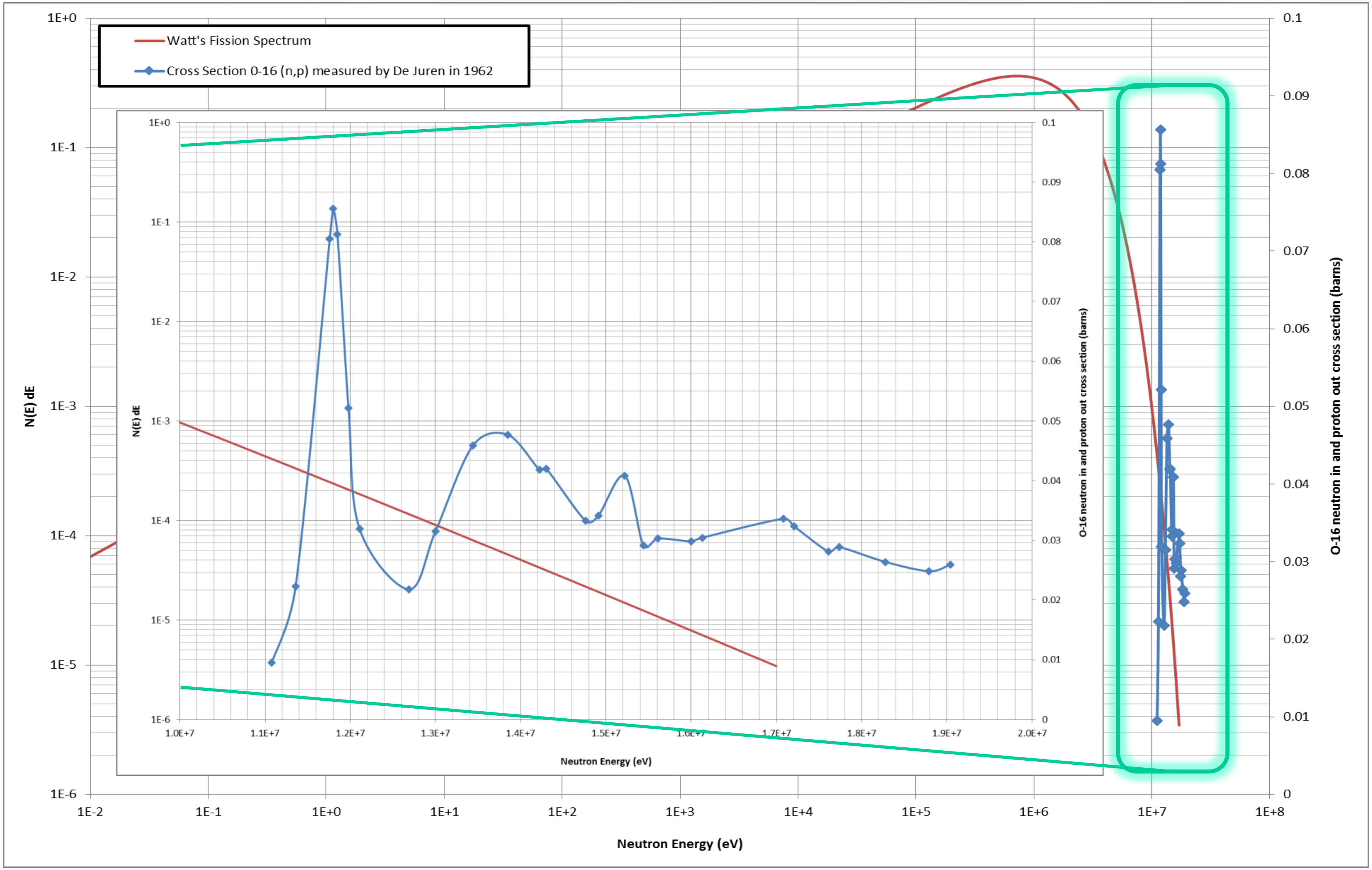


N-16 System
Detectors Located on Motor Floor

N-16 System
Spectral Considerations



N-16 System
Spectral Considerations

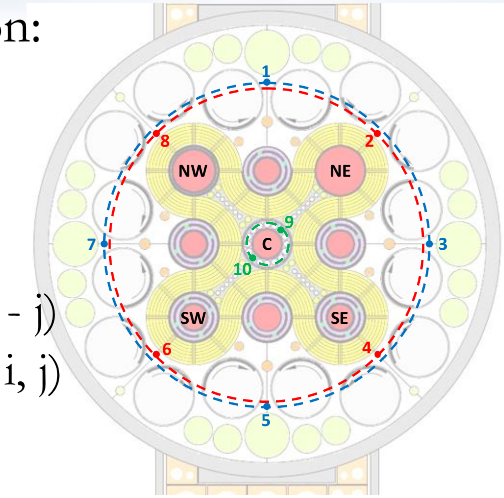


N-16 System Mathematics

- Lobe powers are calculated based on the following equation:

$$M_j N_j = \sum_{i=1}^{5} c_j^i P_i$$

  - M are the multipliers for each detector (10 values - j)
  - N are the detector signals from the ion chambers (10 values - j)
  - c are the coefficients for lobe and each detector (50 values - i, j)
  - j is the detector of concern
  - i is the lobe of concern



Lobes

NW(1)	NE(2)	C(3)	SW(4)	SE(5)		
$C_{1,1} P_1$ +	$C_{1,2} P_2$ +	$C_{1,3} P_3$ +	0 +	0	$= M_1 \ (N_1)$	:North N-16 Monitor 1
0 +	$C_{2,2} P_2$ +	$C_{2,3} P_3$ +	0 +	0	$= M_2 \ (N_2)$	:North-East N-16 Monitor 2
0 +	$C_{3,2} P_2$ +	$C_{3,3} P_3$ +	0 +	$C_{3,5} P_5$	$= M_3 \ (N_3)$	:East N-16 Monitor 3
0 +	0 +	$C_{4,3} P_3$ +	0 +	$C_{4,5} P_5$	$= M_4 \ (N_4)$	:South-East N-16 Monitor 4
0 +	0 +	$C_{5,3} P_3$ +	$C_{5,4} P_4$ +	$C_{5,5} P_5$	$= M_5 \ (N_5)$	:South N-16 Monitor 5
0 +	0 +	$C_{6,3} P_3$ +	$C_{6,4} P_4$ +	0	$= M_6 \ (N_6)$	:South-West N-16 Monitor 6
$C_{7,1} P_1$ +	0 +	$C_{7,3} P_3$ +	$C_{7,4} P_4$ +	0	$= M_7 \ (N_7)$	:West N-16 Monitor 7
$C_{8,1} P_1$ +	0 +	$C_{8,3} P_3$ +	0 +	0	$= M_8 \ (N_8)$	:North-West N-16 Monitor 8
$C_{9,1} P_1$ +	$C_{9,2} P_2$ +	$C_{9,3} P_3$ +	$C_{9,4} P_4$ +	$C_{9,5} P_5$	$= M_9 \ (N_9)$	:Center N-16 Monitor 9
$C_{10,1} P_1$ +	$C_{10,2} P_2$ +	$C_{10,3} P_3$ +	$C_{10,4} P_4$ +	$C_{10,5} P_5$	$= M_{10} \ (N_{10})$	:Center N-16 Monitor 10

N-16 System Mathematics

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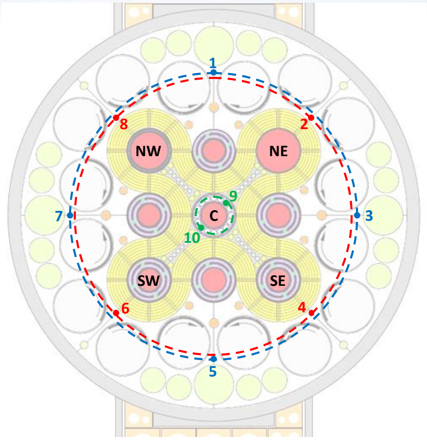


  - M are the multipliers for each detector (10 values - j)
  - N are the detector signals from the ion chambers (10 values - j)
  - c are the coefficients for lobe and each detector (50 values - i, j)
  - j is the detector of concern
  - i is the lobe of concern

- System of 5 equations used for determining lobe powers:
  - Based on Least Squares Method
  - Solved in real time during operation
  - Does not included thermally constrained correction

$$P_1\Sigma_j C_{j,1}C_{j,1} + P_2\Sigma_j C_{j,1}C_{j,2} + P_3\Sigma_j C_{j,1}C_{j,3} + P_4\Sigma_j C_{j,1}C_{j,4} + P_5\Sigma_j C_{j,1}C_{j,5} = \Sigma_j C_{j,1}M_jN_j$$

$$P_1\Sigma_j C_{j,2}C_{j,1} + P_2\Sigma_j C_{j,2}C_{j,2} + P_3\Sigma_j C_{j,2}C_{j,3} + P_4\Sigma_j C_{j,2}C_{j,4} + P_5\Sigma_j C_{j,2}C_{j,5} = \Sigma_j C_{j,2}M_jN_j$$

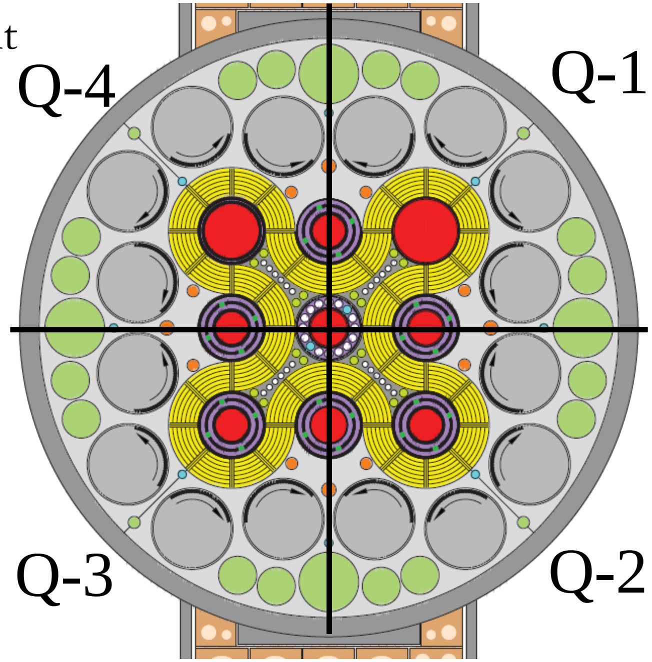
$$P_1\Sigma_j C_{j,3}C_{j,1} + P_2\Sigma_j C_{j,3}C_{j,2} + P_3\Sigma_j C_{j,3}C_{j,3} + P_4\Sigma_j C_{j,3}C_{j,4} + P_5\Sigma_j C_{j,3}C_{j,5} = \Sigma_j C_{j,3}M_jN_j$$

$$P_1\Sigma_j C_{j,4}C_{j,1} + P_2\Sigma_j C_{j,4}C_{j,2} + P_3\Sigma_j C_{j,4}C_{j,3} + P_4\Sigma_j C_{j,4}C_{j,4} + P_5\Sigma_j C_{j,4}C_{j,5} = \Sigma_j C_{j,4}M_jN_j$$

$$P_1\Sigma_j C_{j,5}C_{j,1} + P_2\Sigma_j C_{j,5}C_{j,2} + P_3\Sigma_j C_{j,5}C_{j,3} + P_4\Sigma_j C_{j,5}C_{j,4} + P_5\Sigma_j C_{j,5}C_{j,5} = \Sigma_j C_{j,5}M_jN_j$$

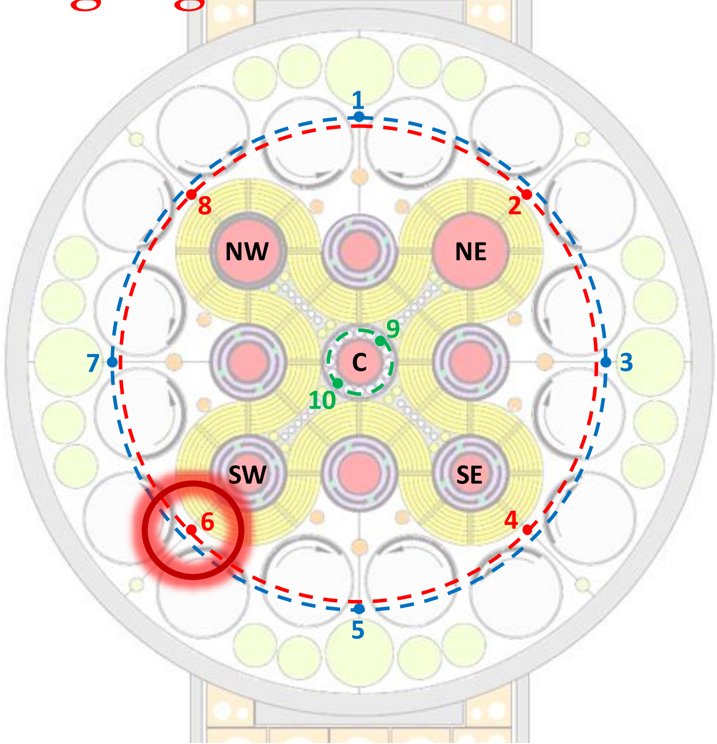
WPC System

- Water Power Calculator (WPC) uses flow rates and temperature increase to determine reactor power (simple calorimetric)
  - Flow is split into four quadrants when exiting the reactor
  - Thermal power measurement limited to quadrants
  - Total thermal power is very accurate with quantifiable uncertainties
  - There is some WPC uncertainty due to potential cross flow
- WPC power is used to correct N-16 lobe powers (Constrained)
  - An eleventh equation is inserted into the LPCIS matrix to cause the solution of N-16 lobe powers to equal total power
  - WPC and N-16 compared for system heath assessment
- SAR and TSR Safety Parameters that are implemented in the CSAP
  - Fission Density
  - Effective Plate Power (EPP)
  - Effective Point Powers
- CSAP limits are based on lobe powers
- To ensure that safety limits are not exceeded power levels are lowered if they exceed the specified limits provided in the CSAP



Problem Statement

The Southwest Quadrant (Q-3) WPC to N-16 Ratio has been operating higher than the Maximum Limit of 1.077



Formal Trouble Shooting Plan (Robert Fulks)

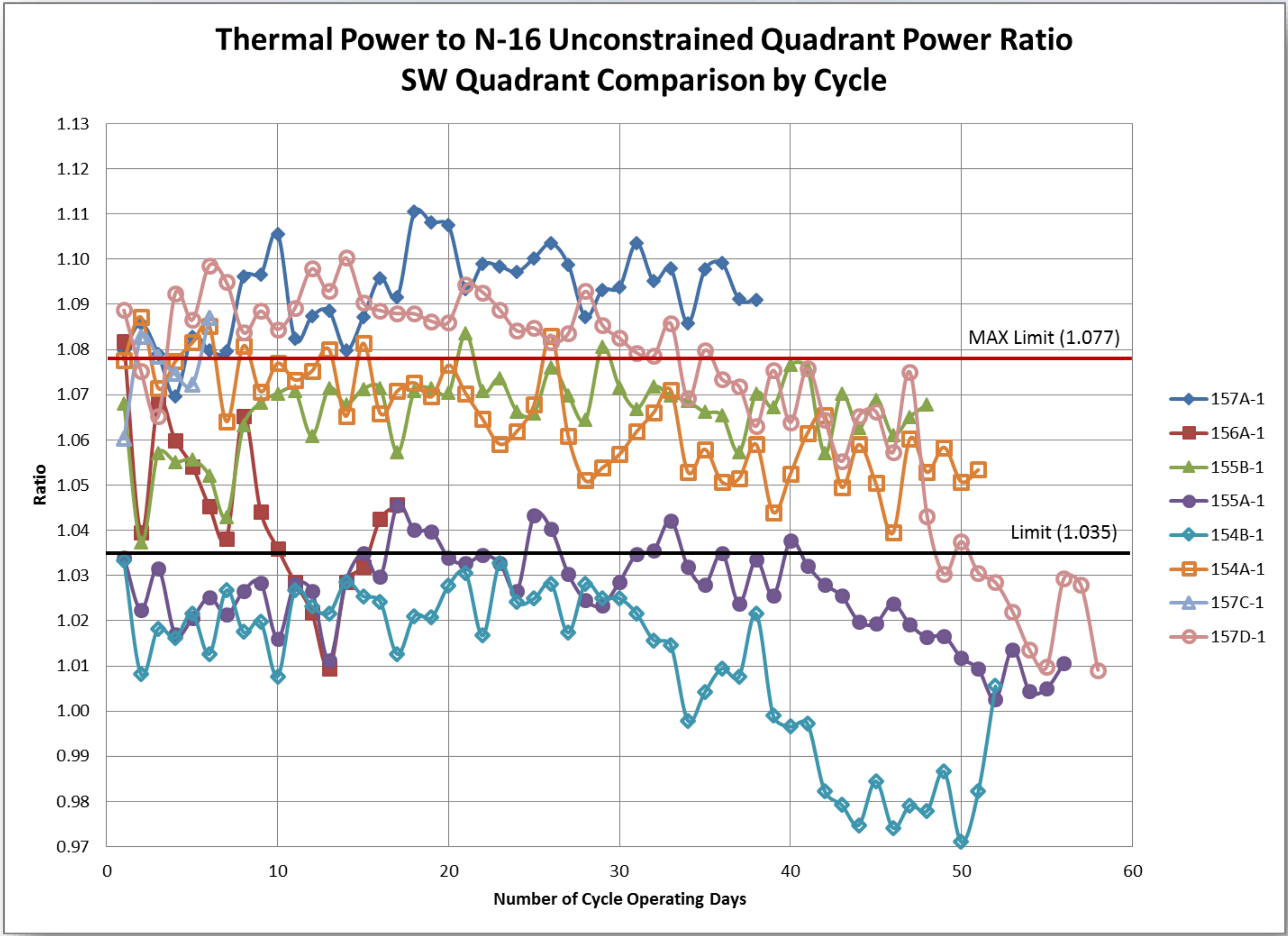
- Troubleshooting plan per MCP-6045

- The thermal to N-16 power ratio in the Southwest Quadrant was exceeding the maximum limit of 1.077 (no EPP limit)
  - Cycle 157D-1 exceeding limit at the beginning of cycle (~ 36 days)
  - Cycle 157A-1 exceeded limit at the end of cycle (~ 20 days)

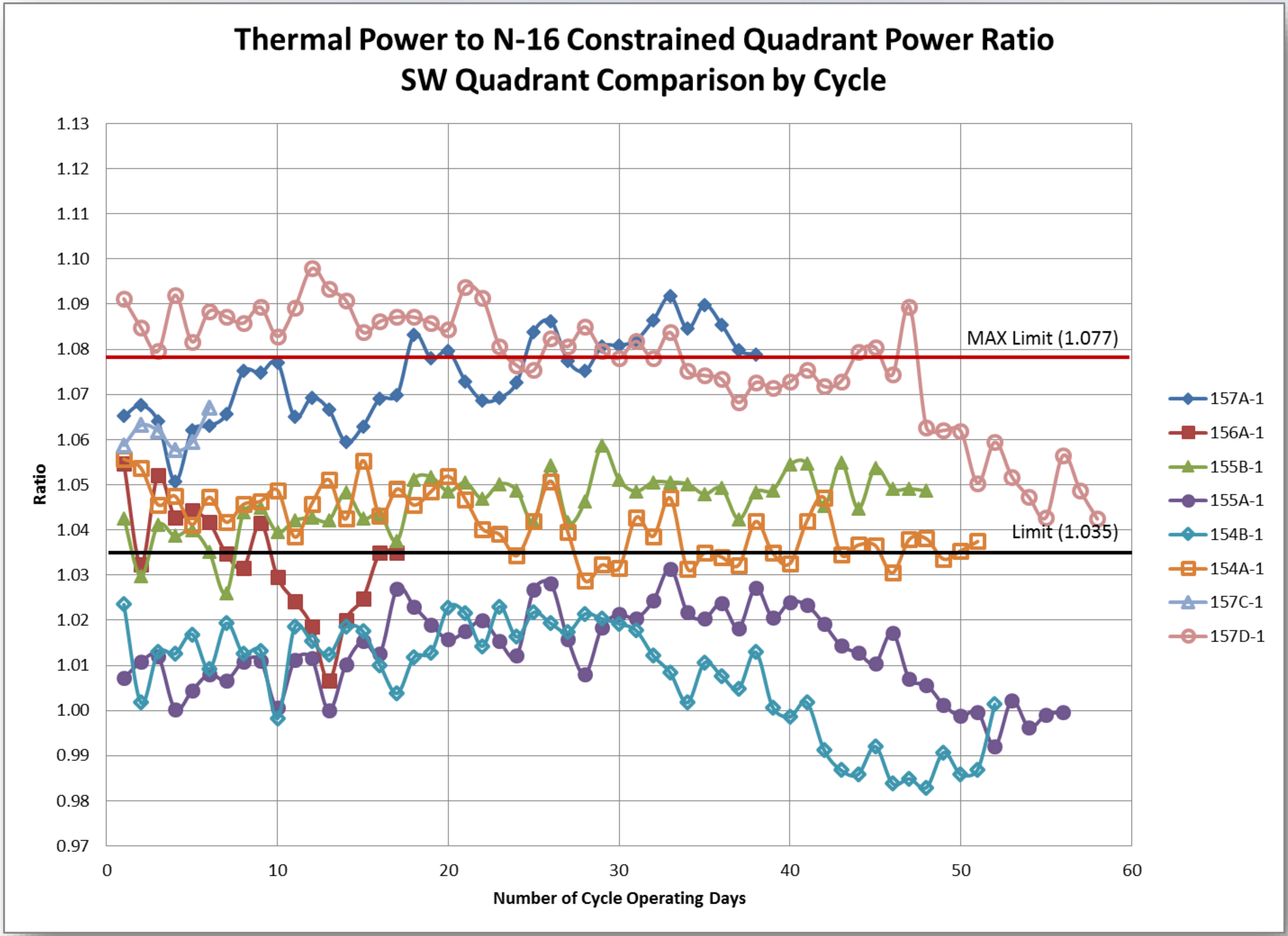
- The thermal to N-16 power ratio in the Southwest Quadrant had exceeded the nominal limit of 1.035 (no EPP limit)
  - Cycle 157D-1 exceeding limit at beginning of cycle (59 days)
  - Cycle 157C-1 exceeded limit for the entire cycle (5 days)
  - Cycle 157A-1 exceeded limit for the entire cycle (37 days)

- Pertinent Information
  - The power ratio has been increasing over the past several cycles
  - The Southwest power ratio is by design more heavily weighted with Center N-16 power signal than the other quadrants

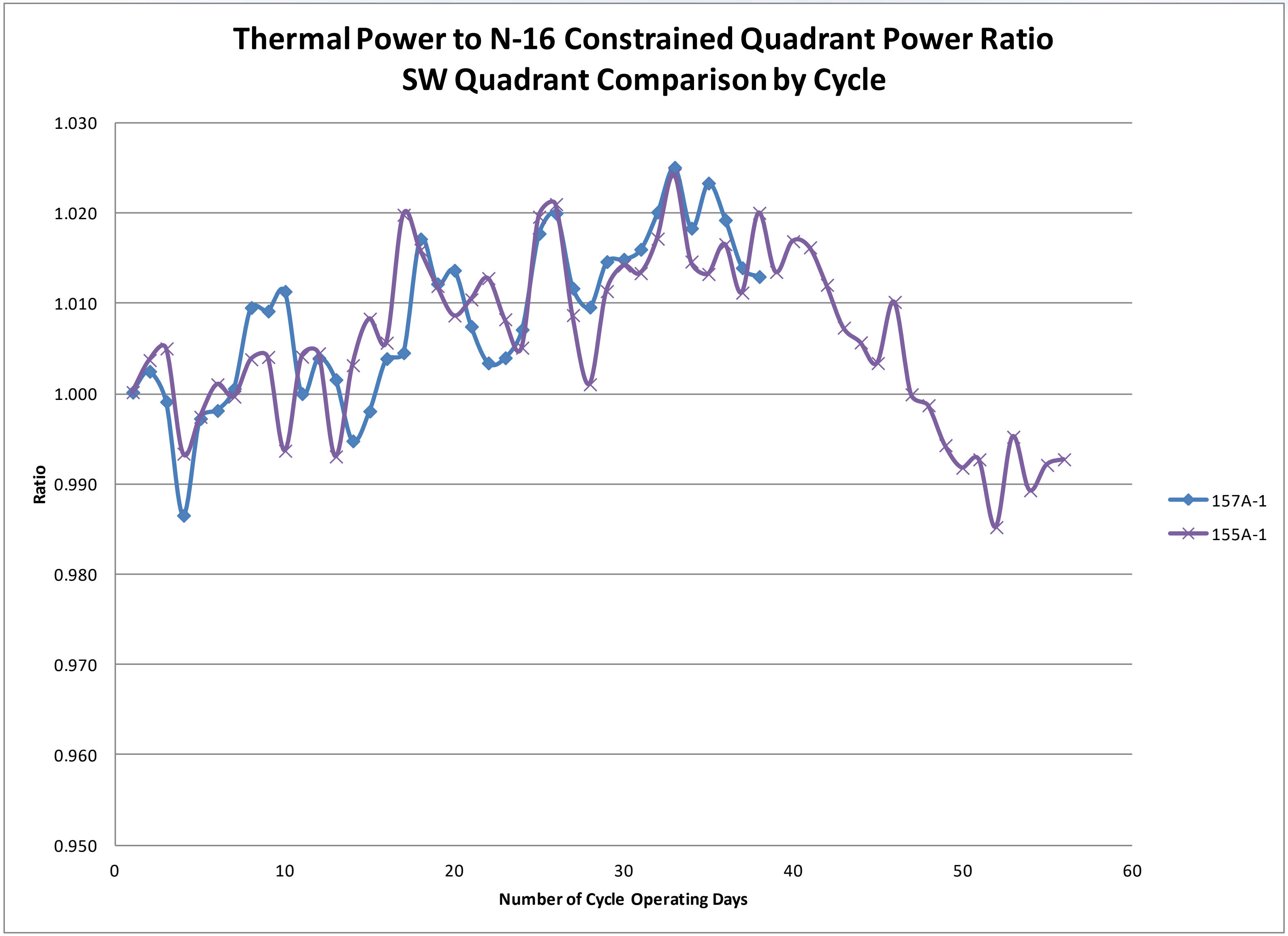
Ratios for some Recent Cycles



Ratios for some Recent Cycles



Normalized Ratios for Two Cycles

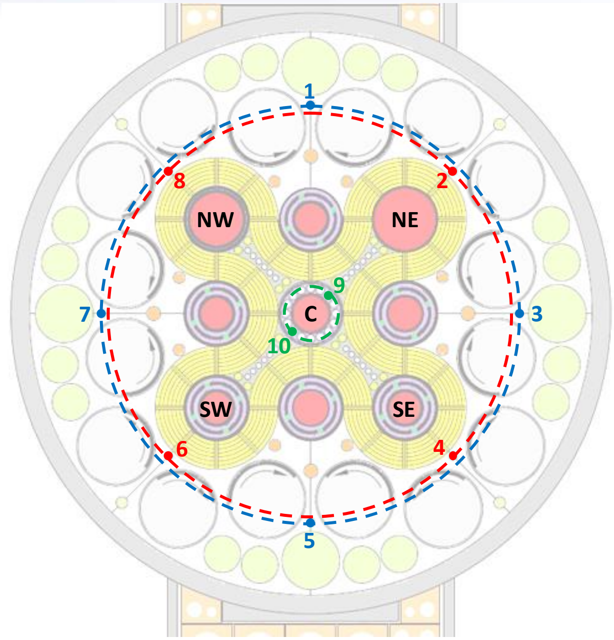


Formal Trouble Shooting Plan (Robert Fulks)

- Actions performed
  - ✓ Verified N-16 multipliers were correct for the flow source
  - ✓ Verified N-16 flow rates (inlet and outlet) at 1.15 GPM
  - ✓ Verified N-16 flow orifices cleaned and flushed (ref. WO-205278)
  - ✓ Switched to LDW to verity BPD was not the cause of the problem
  - ✓ Verified High/Low Gain Switch was in Low position
  - ✓ Switched from SW to spare beta chamber
  - ✓ Performed DOP-7.7.19 N-16 flow calibration check
  - ✓ Performed preliminary N-16 to Water Power Calculator data point checks
  - ✓ Performed comparison between current data and historical data
  - ✓ When in TEST mode, the Center N-16 instrument historically indicates Out-of-Spec low. (Calibrates in spec when in Operate mode.)
  - ✓ All mechanical and electrical components (pipe, orifice, D/P detector, wires interconnections, power supplies, amplifiers, and N-16 detector) have been verified satisfactory
  - ✓ Completed DOP-7.7.12, N-16 Chamber Sensitivity Checks, twice, once in Cycle 157C-1 and once in 157D-1, both with satisfactory results.
  - ✓ Replaced Southeast N-16 reentrant tube.
  - ✓ Added south N-16 channel by running it through the spare detector

Changes of Interest to the N-16 and WPC

- Reentrant Tubes Replacement Dates:
  - Southwest - August 2012
  - West - August 2012
  - South - May 2013
  - East - July 2013
  - Northeast - October 2013
  - North - October 2013
  - Southeast - May 2015

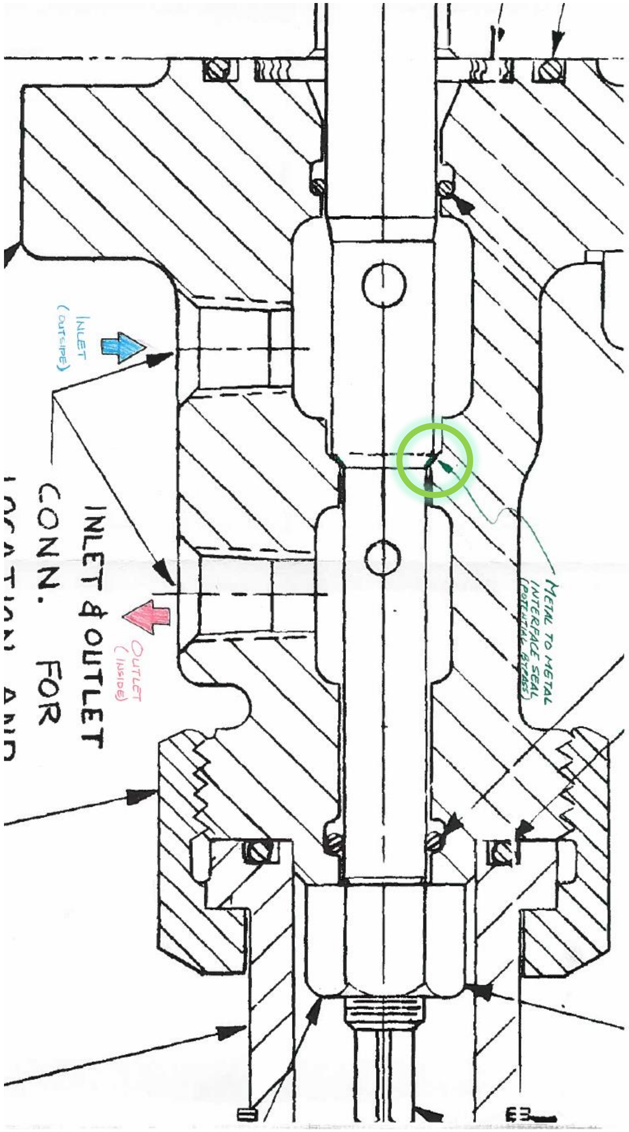


- Center Flux Trap Baffle and N-16 aluminum reentrant tubes replaced with stainless steel – August 2012

- Water Power Calculator Update and new RTD calibration curves – August 2012

Actions Taken for Problem Resolution

- Replaced of the Southwest reentrant tube because a potential bypass flow
- Gathered RDAS data and assessed the WPC and N-16 detector signals
- System engineering evaluated new multipliers. The LPCIS was be taken out-of-service and multipliers were tested
  - (M_{10} expected to increase by ~ 23%)
- Flux wire data was assessed to identify potential shifts in the thermal to fast ratios
- Numerical Modeling indicated changes to Multipliers needed for Cycle 158A-1 due to experiment demands
- Evaluated using Northeast flow channel for N-16 Chamber Sensitivity Tests



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