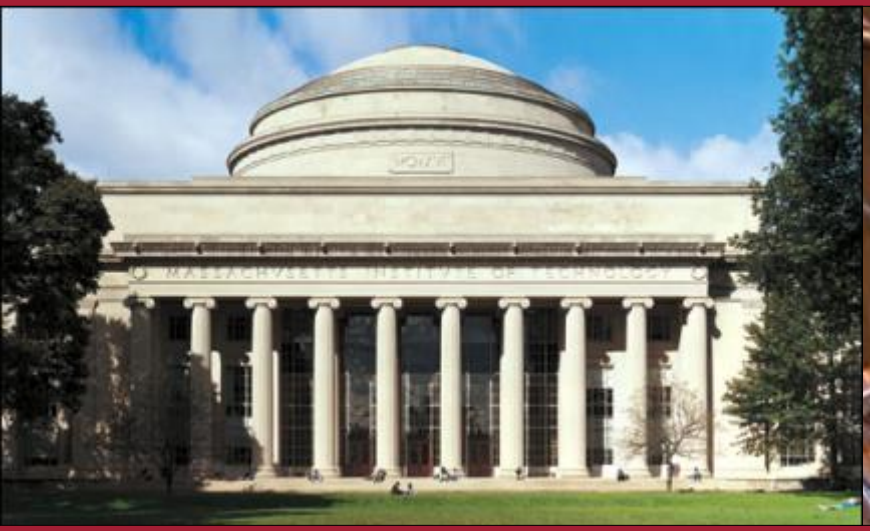
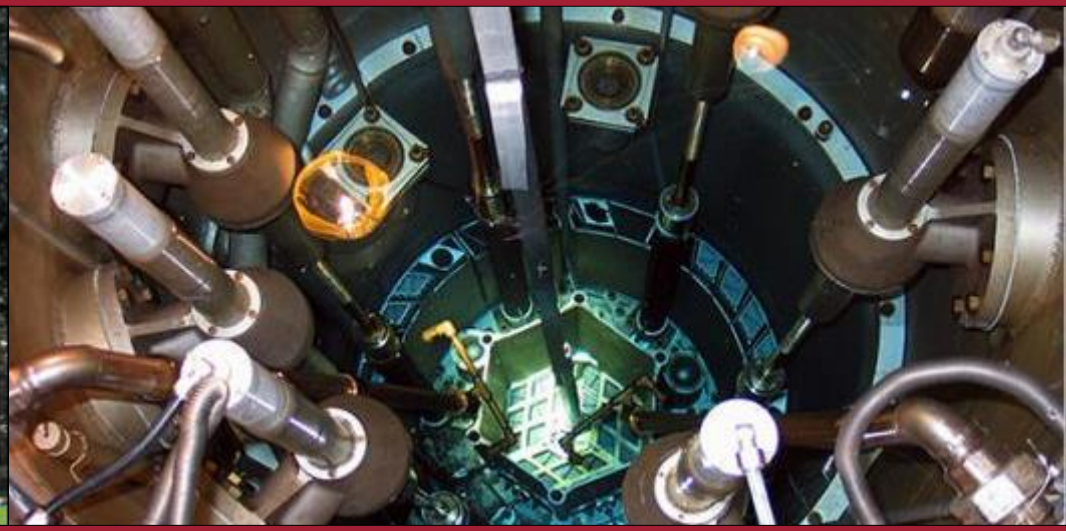
MIT NUCLEAR REACTOR LABORATORY

an MIT Interdepartmental Center





Re-starting from scratch: Waking up MITR II Nuclear Instrumentation

Dane Kouttron

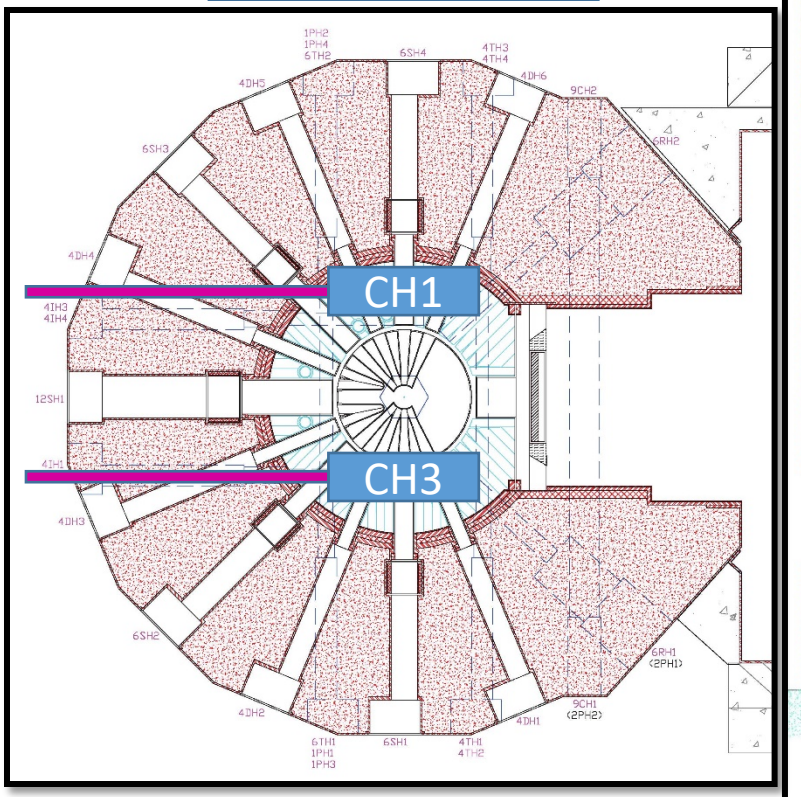
Research Engineer

MIT Research Reactor (MITR-II)

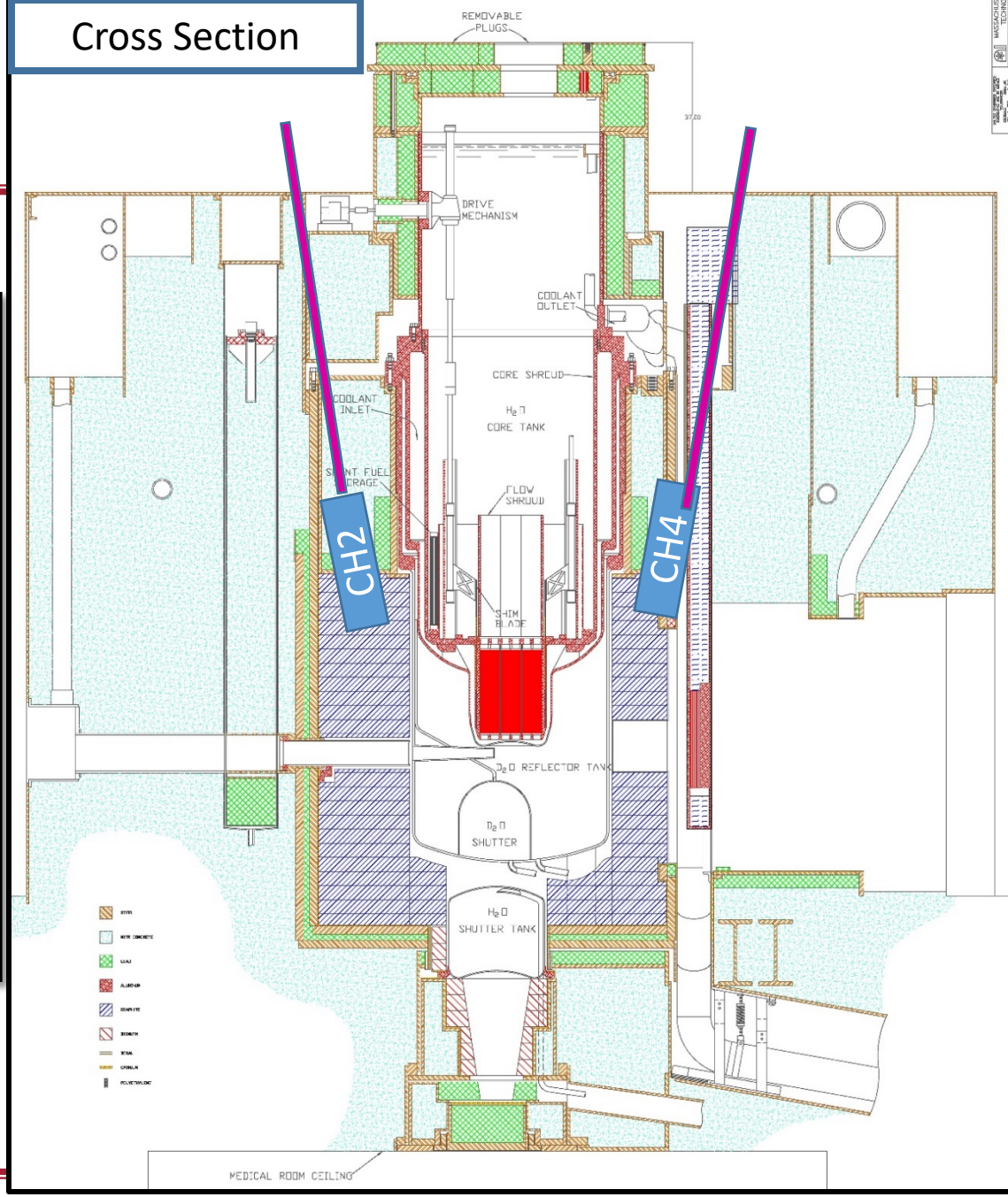
- MITR-I constructed 1956-1958
- Core and process systems redesigned for MITR-II
  - Light water cooled and moderated, heavy water reflected
  - First criticality on August 14th, 1975
- Primary/Secondary systems rebuilt in 2010 for relicensing and power uprate up to 6.0 MW
- Operates 24/7 except during scheduled outages

Profile of MITR-II

Overhead View



Cross Section



Reactor Safety Detectors

Two Vertical Fission Chambers

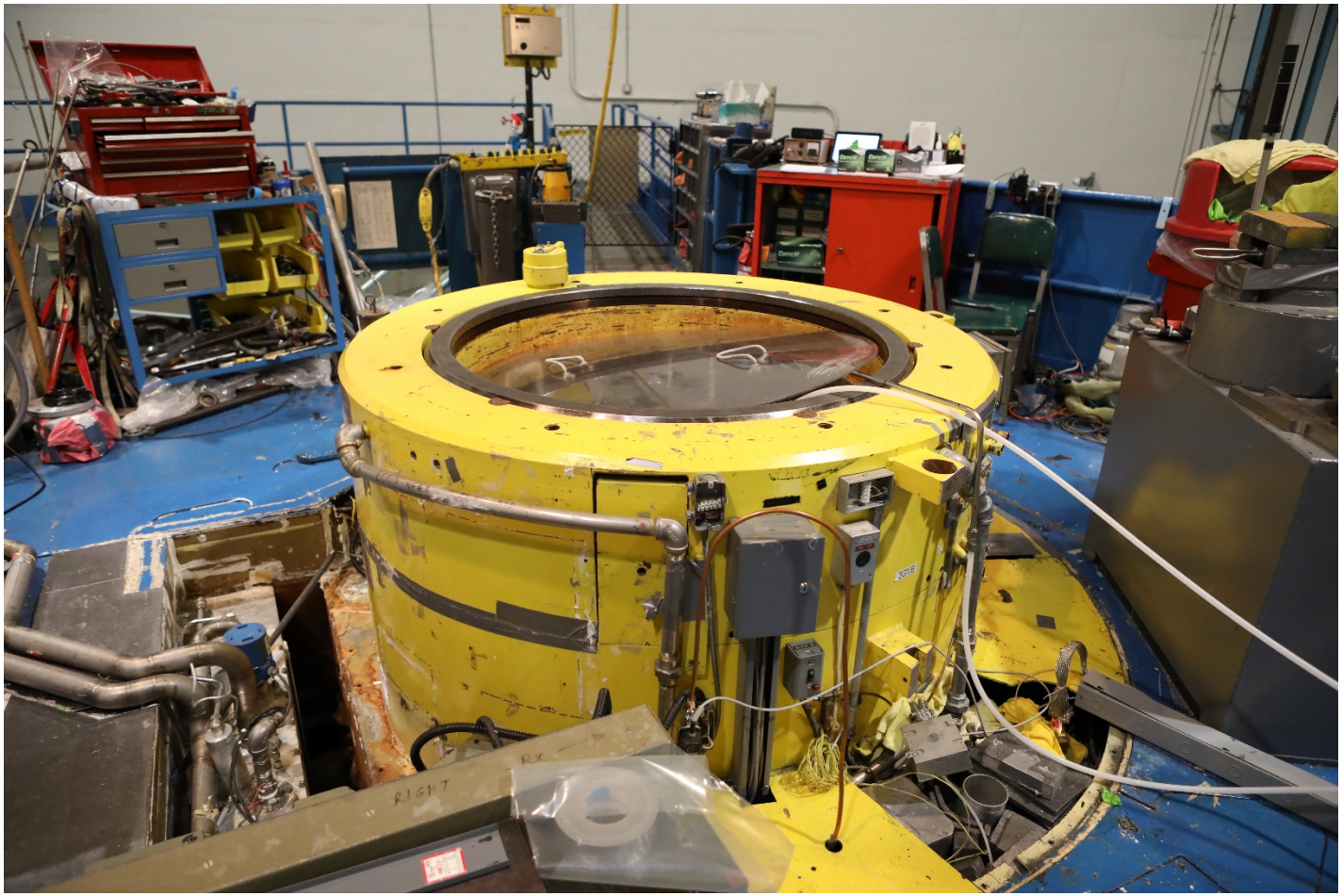
Two Horizontal Fission Chambers

Swimming Detectors

- Dec 14 2022- Vertical Port view
  - Vertical port plug removed, flooding of vertical ports confirmed
  - There's not supposed to be primary coolant there
  - Disassembly and leak discovery process begins

Swimming Detectors

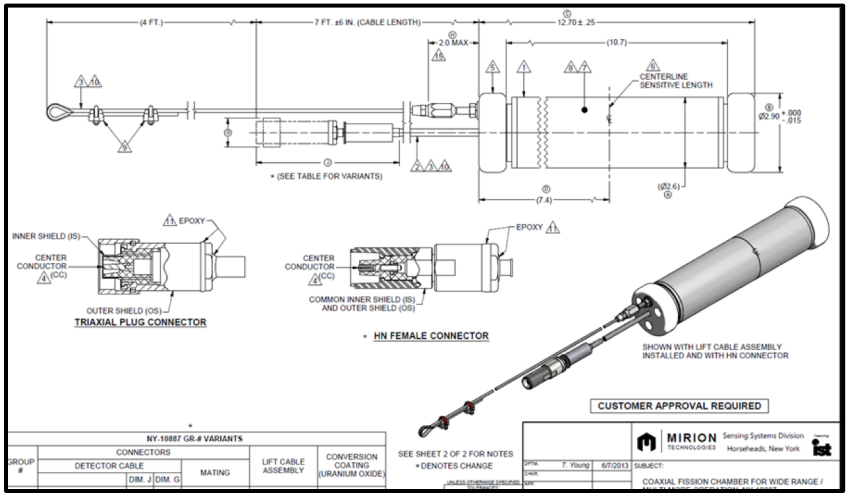
Pre-Disassembly Reactor Top

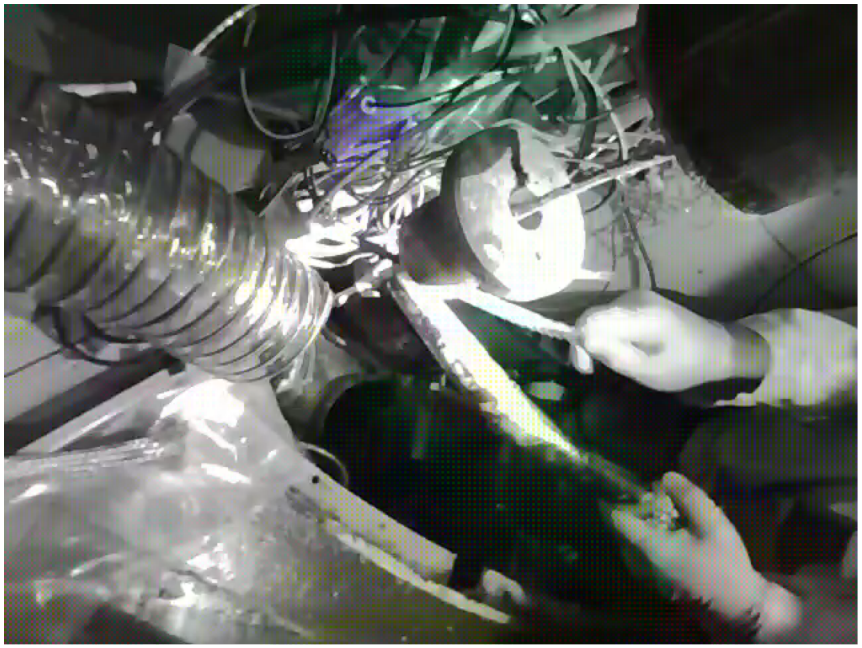


Documenting Disassembly

- Primary Coolant leak

Detectors are not submersible





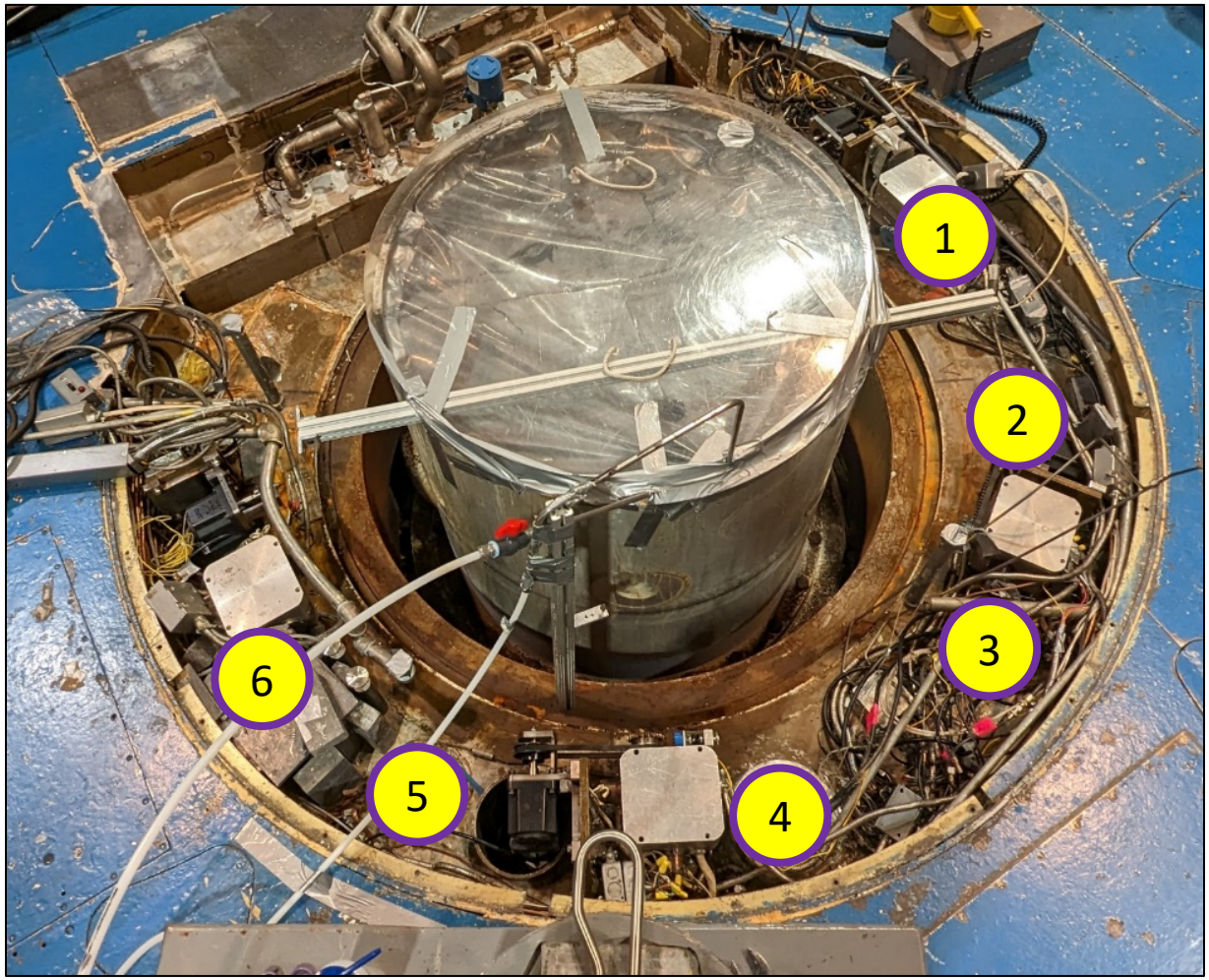
- As it turns out while our fission chambers are hermetically sealed, they are not intended to be submersible
- Vertical instrumentation port filling with water results in bonus neutron moderation, reduction in apparent flux.
- Fission chamber MI Cable damaged from extended moisture
  - One vertical Nuclear Safety system detector failed due to corrosion

Detectors are not submersible

- Fission chamber directly exposed to water showed signs of cable failure
- Linear Flux chamber with top mounted connectors comically corroded

Disassembly Begins

Instrumentation Vertical Ports



Disassembly Begins

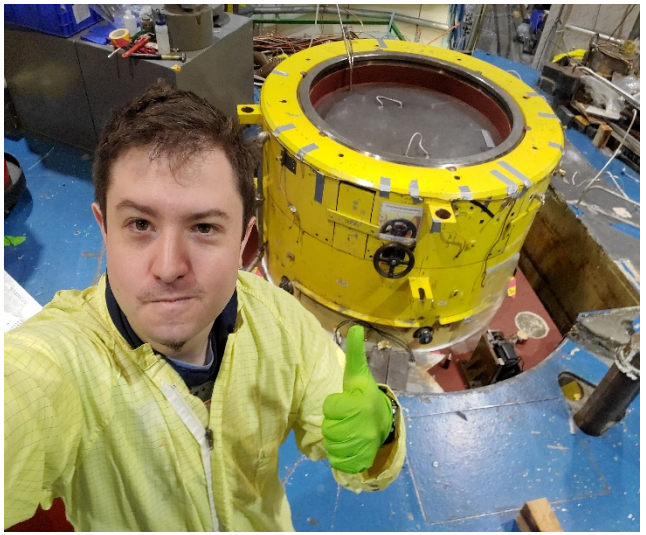
Cabling & detectors removed

Disassembly

- Early 2023
  - Core De-Fueled
  - Vertical Detectors, experiments, leak detection tapes removed
  - Meters of cables removed
  - Existing systems disturbed with ‘accelerated disassembly’
  - 3D View of core tank with hardware removed [See 2023 TRT talk for more]

Re-Assembly

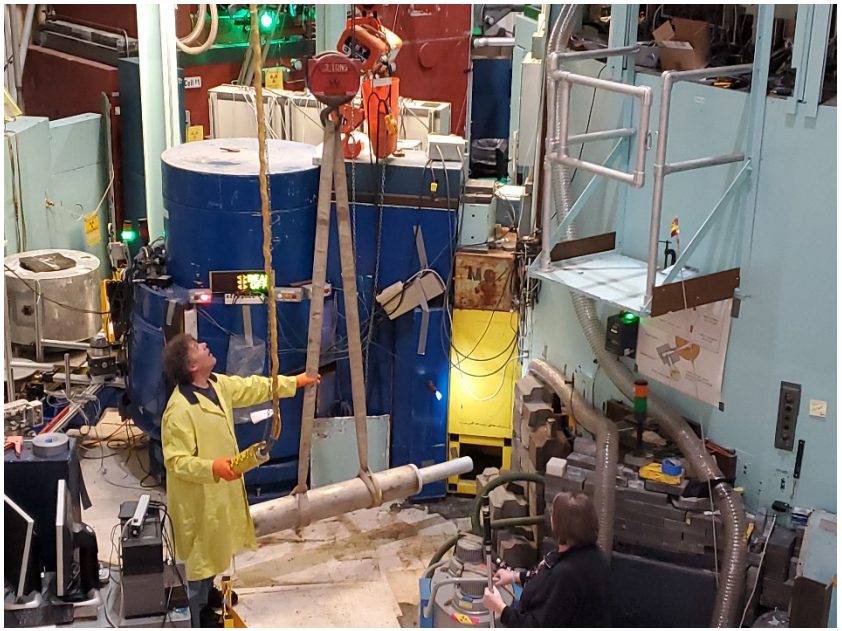
- Late 2023
  - Mechanical disassembly, leak identification and repair took months
  - Meters of cables removed to aide in leak identification
  - Existing systems disturbed with ‘accelerated disassembly’
  - Re-cabling & Re-Terminating required for all of nuclear safety system
- New cables, new detector positions, what could possibly hinder restart?



Re-Assembly

- Late 2023
  - Fuel daughter-product Neutrons nearly exhausted
  - Nuclear instrumentation issues begin!
  - Initial detector locations intended for neutron flux proportional to 6MW, required significant re-location
  - One detector failure due to MI Cable damage from re-location.

Relocating Detectors



- Port Plugs removed
  - Existing port plugs purposely restrict detector location

- Detector re-cabling
  - To re position detectors closer to fuel, cable extensions fabricated
  - Horizontal detector port tubes sleeved with PVC to limit resistance when re positioning detectors

Re-Assembly

- Relocating Detectors
  - Full Power Fission chamber Detectors re-located to closest to core position
  - Temporary high sensitivity Helium-3 detectors installed to provide better indication of core status for re-fueling
  - Apparent disconnect between reactor safety system count-changes and Helium-3 counts during reflector level changes & shutdown blade height changes

Where are my neutrons

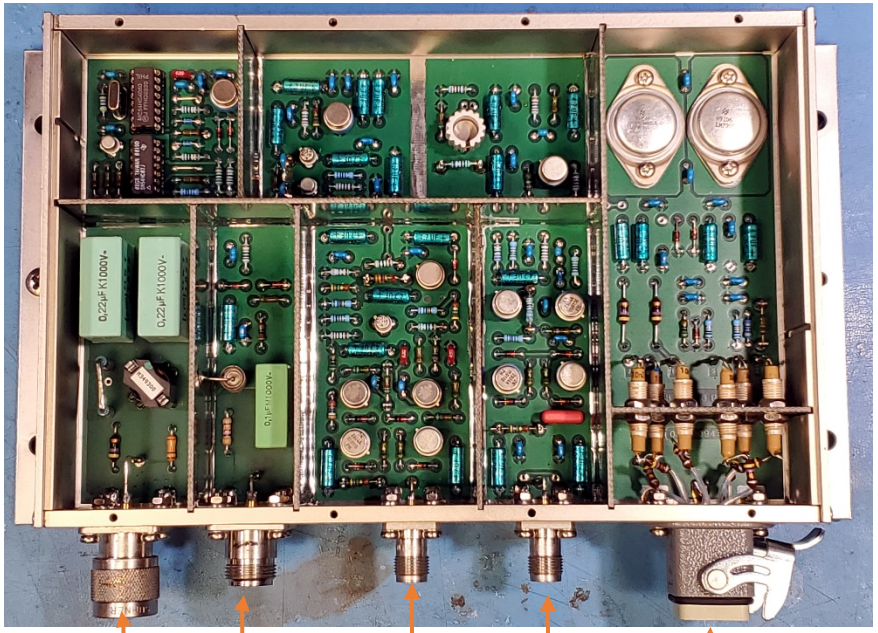
MIT NRL Digital Safety System Overview

Fission Chamber

Preamplifier

DWK-250

Mirion Preamplifier Overview



HV Supply

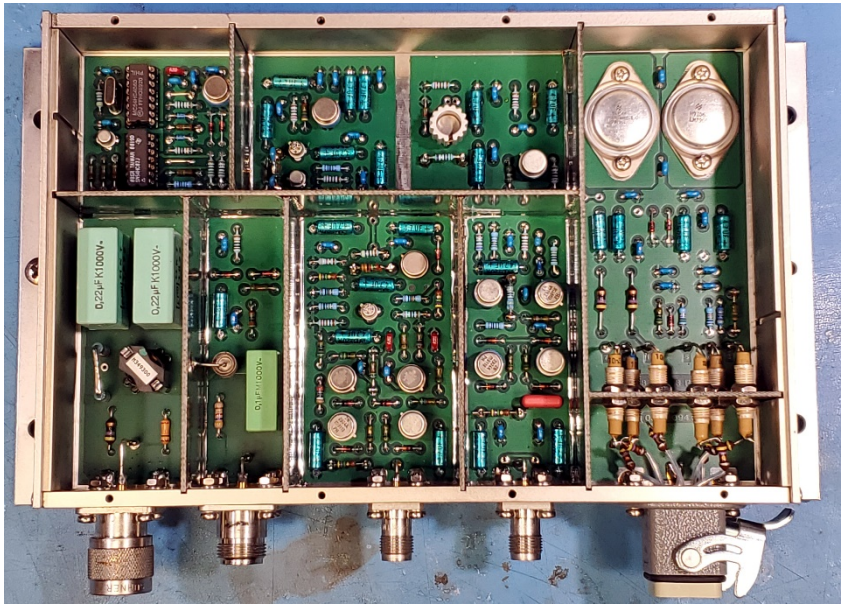
Detector

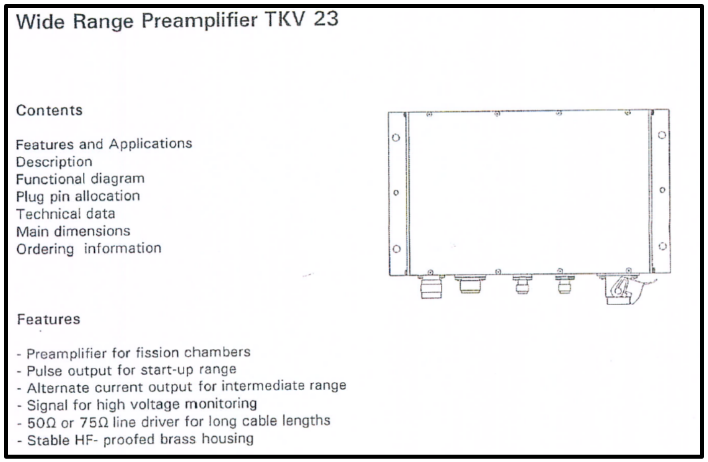
Logic Power & Test Functions

Pulse Mode Output

Current Mode Output

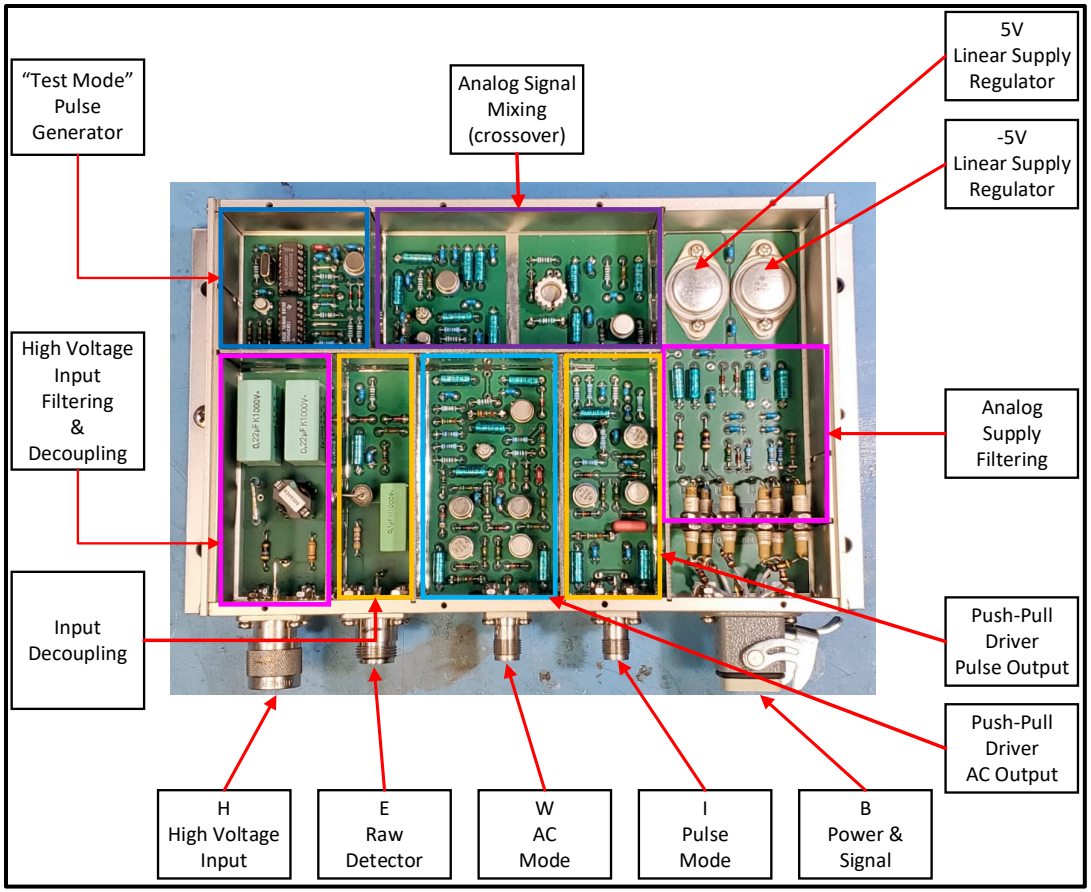
Mirion Preamplifier Issues





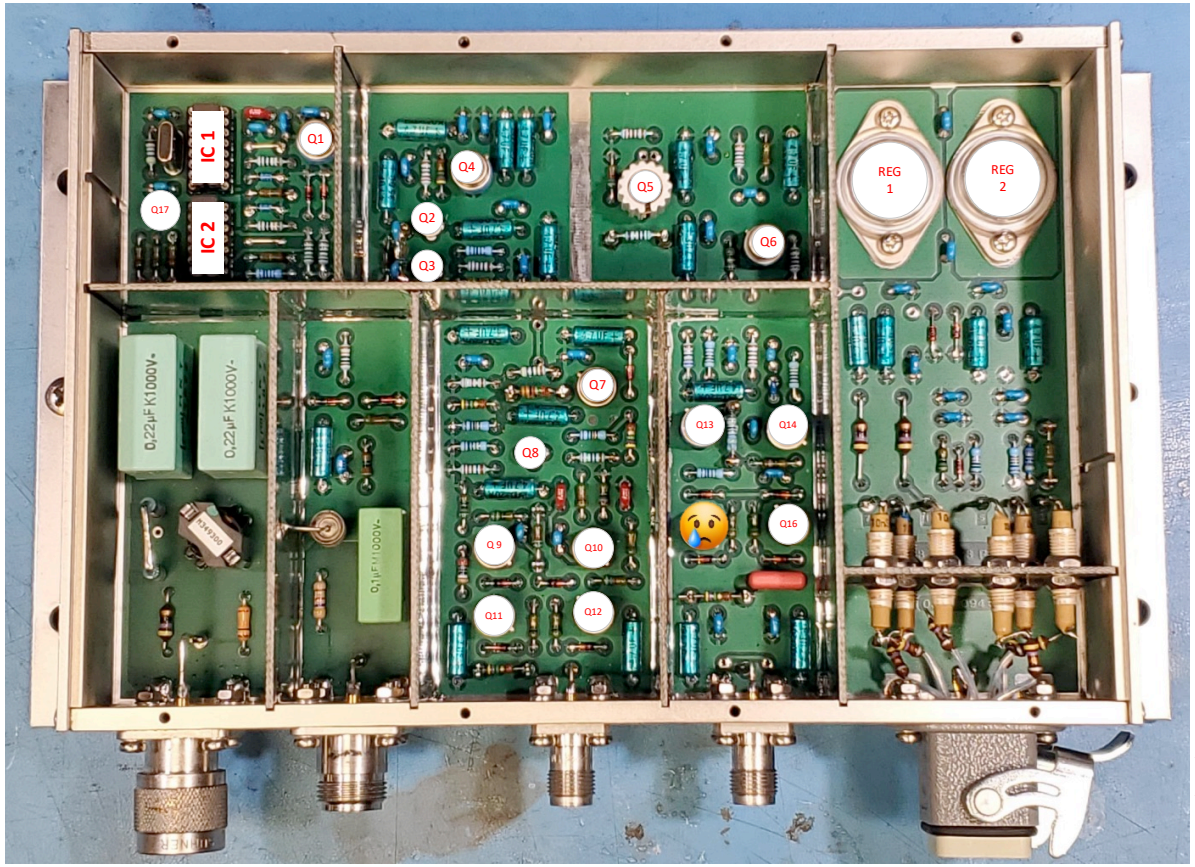
- Facility disassembly prioritized leak location identification
- Order of operations resulted in hardware issues
  - Significant damage to channel pre-amplifiers caused by disconnecting at detector in powered down state
  - In powered-down state, cable disconnection order appears to overstress internal component
  - 4+ Month lead time on replacement units

Mirion Preamplifier Issues



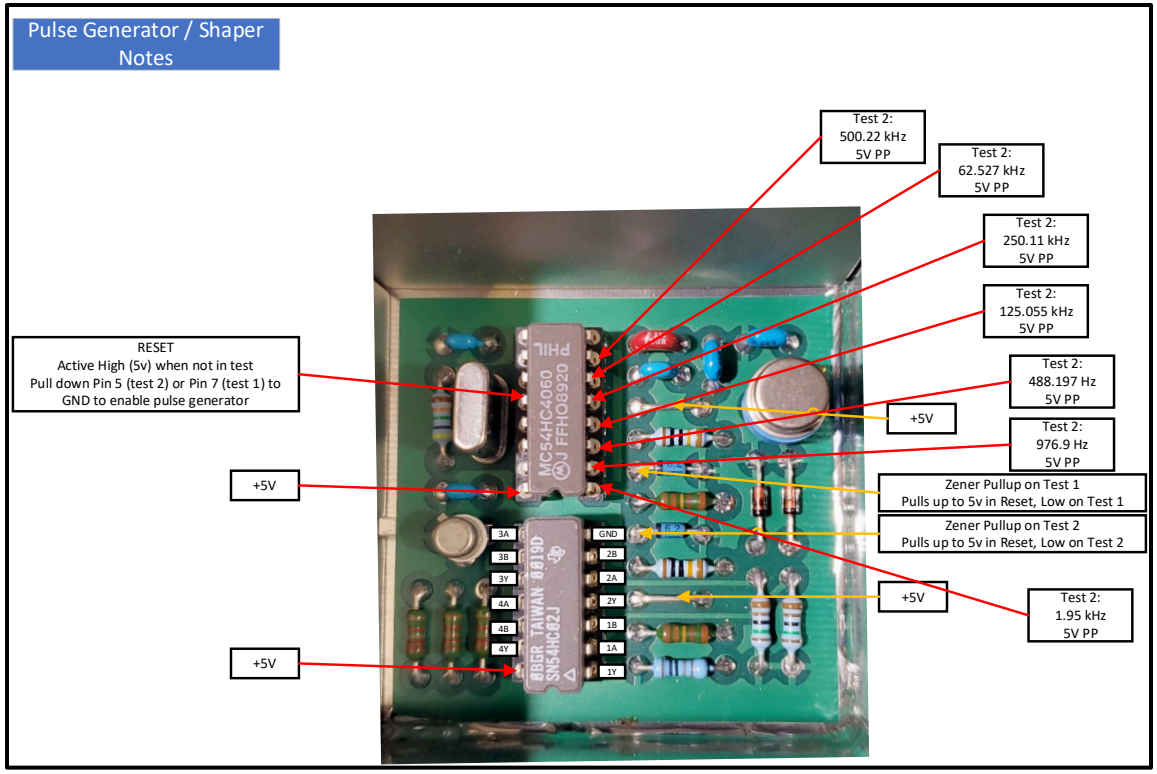
- Black box reverse engineering
  - Pre-amplifier uses no component reference designators
  - A number of components are no longer manufactured
  - Schematic & signal level repair unavailable
  - Design is 2 layer allowing for easier reverse engineering
  - Through hole components appear hand assembled

Mirion Preamplifier Issues

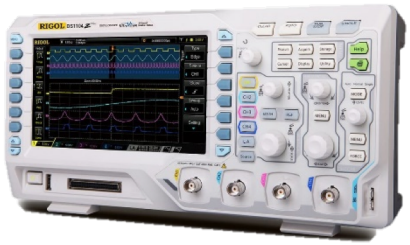


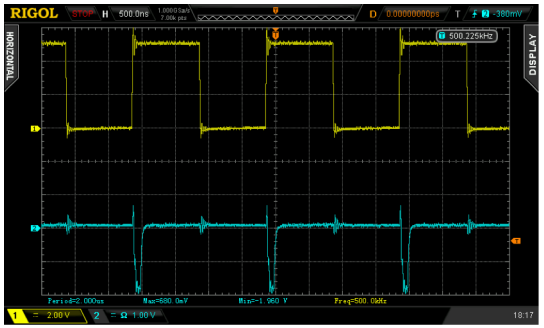
- Labeling and Beginning Diagnostics
  - Pre-amplifier uses no component reference designators [R1, Q1, etc]
  - A number of components are no longer manufactured
  - Schematic & signal level repair unavailable
- Vendor repair timeline significant
  - Three pre-amps initially damaged during RX disassembly

Mirion Preamplifier Issues



- Using one working unit to Identify component failures
  - Pre-amplifier uses no component reference designators [R1, Q1, etc]
  - A number of components are no longer manufactured **: /**
  - Schematic & signal level repair unavailable

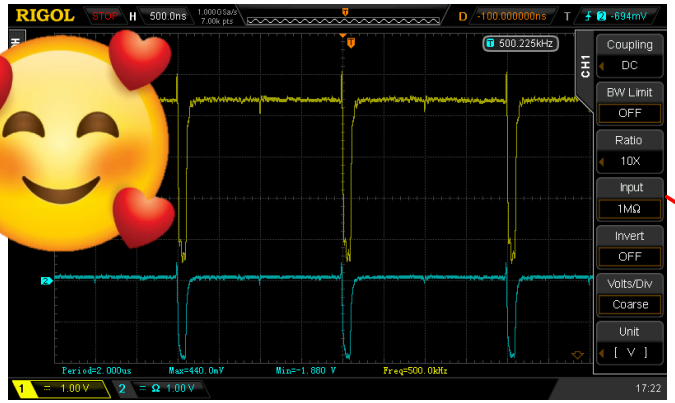


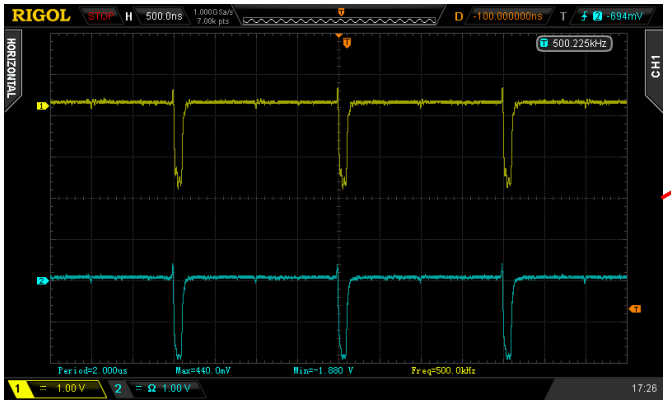


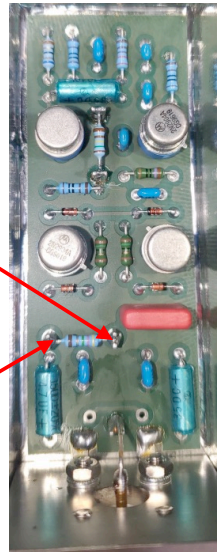
Mirion Preamplifier Issues

- Hardware issues tied to output stage issue
  - Multiple units appeared to have similar failure mode, count-rate level pulse train generation
  - Identical component fortunately replicable and available for purchase
  - Failed push-pull output resulted in malformed pulse-mode signal

Mirion Preamplifier Issues

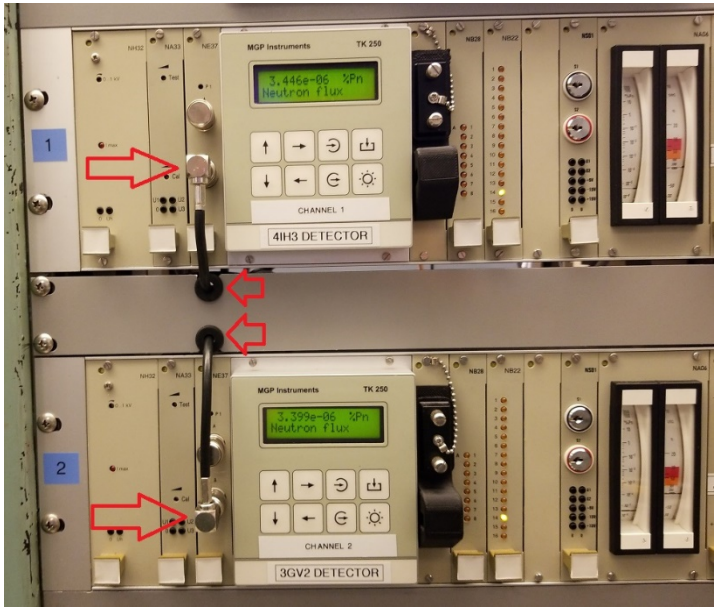






- Component replaced with identical qualified part with appropriate QA
  - They still make metal-can individual transistors?
  - Surprisingly yes

Restarting with a handful of neutrons

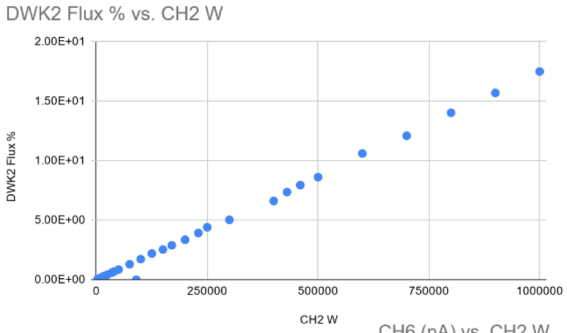


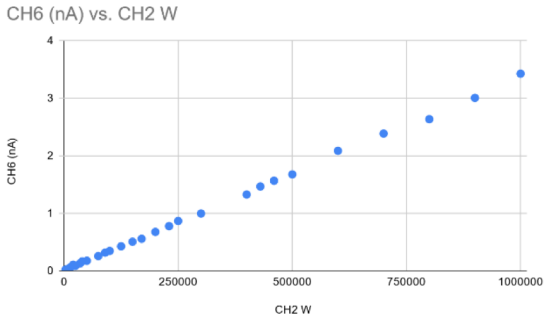
- 1/M Shuffle
  - Full Power detectors as close to the core as possible
  - Low initial counts were repeatable and counts followed reactivity removal actions (reflector level, subcritical blade motion)
  - Long integration length counts now repeatable
  - Initial 1/M startup achieved 70 watts at full power indication
  - Reactor shutdown for subsequent restarts

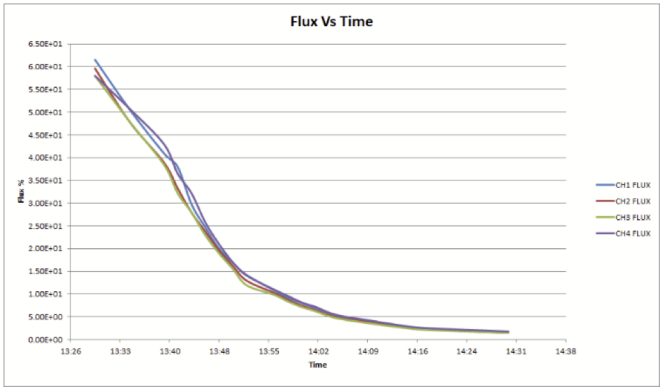
Restarting with a handful of neutrons

- 1/M Shuffle
  - Full Power detectors as close to the core as possible
  - Low initial counts were repeatable and counts followed reactivity removal actions (reflector level, subcritical blade motion)
  - Long integration length counts now repeatable
  - Initial 1/M startup achieved 700 watts at full power indication
  - Reactor shutdown for subsequent restarts
- Detector Position Relocation cumbersome process

Restarting with a handful of neutrons







- Eight 1/M Detector Shuffles
  - Performing stepwise reactor 1/M restarts, verifying data, adjusting position and restarting required
  - Stepwise detector relocations required not only position changes, but detector disconnection, re-cabling through port plugs, and subsequent restarting
  - Initial detector positioning significantly below threshold for thermal power indication
- Getting up to megawatts had it's own hurdles
  - Significant building argon levels delayed intermediary restart steps as air gaps were identified and sealed
  - Data logging was somewhat manual for 1/M datasets

Recommendations

- Research Reactor staffing
  - Significant unplanned extended outages require extra hands
  - Staffing levels generally intended to cover normal operation, not reconstruction, which results in a time consuming bottleneck
  - Adopt personnel from other academic laboratories to load-share
  - Communicate and plan operations scheduling
- Hardware Vendors
  - Provide actual diagnostic manuals with signal acceptance criteria

Acknowledgements

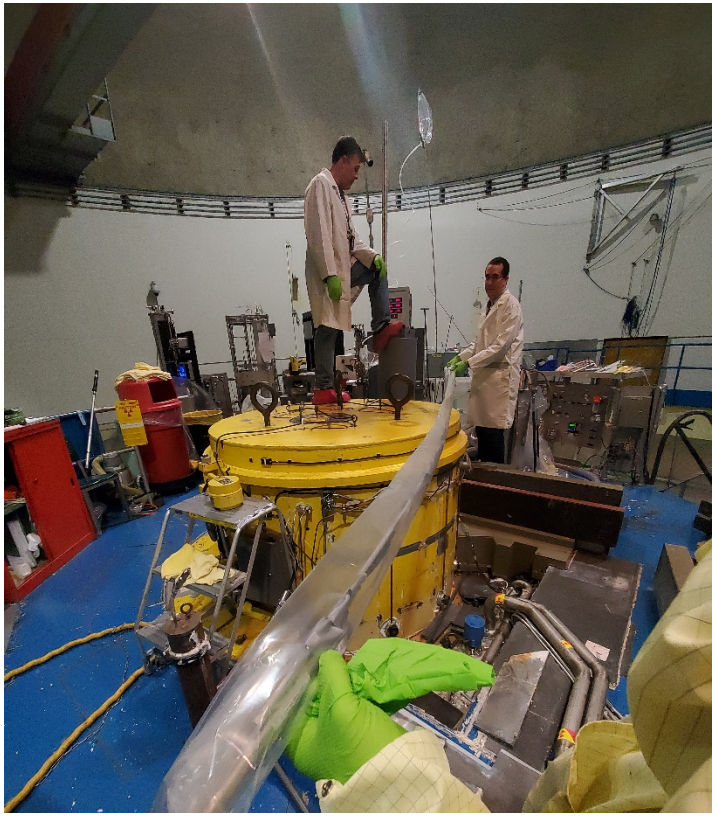
NRL Operations and Maintenance Staff

Paul Menadier

David Carpenter

Adam Grein

Taylor Tracy



Questions?