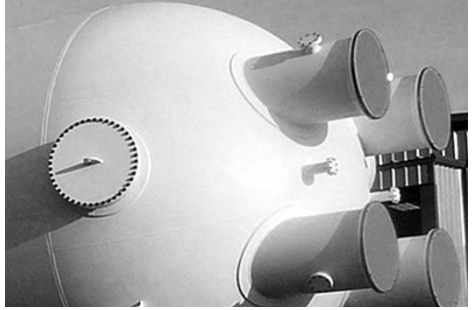
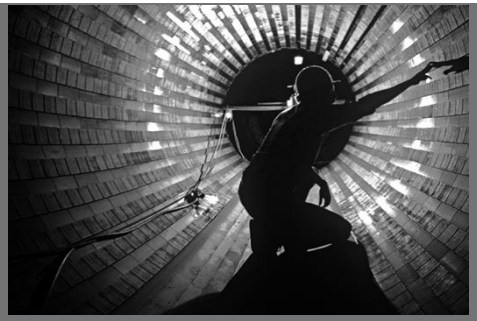
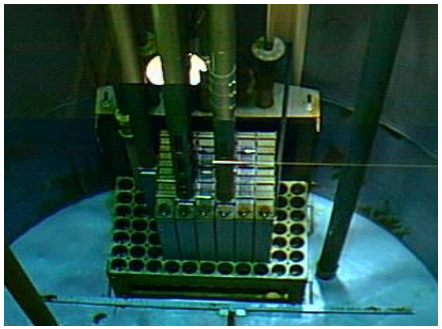




Plant Performance 2017 User Symposium

Purdue University Reactor Protection and Control System



Presenters

- **Clive Townsend (Purdue University)**
  - PUR-1 Reactor Supervisor
  - PUR-1 Upgrade Project Manager
  - clive@purdue.edu
- **Robert Ammon (Curtiss-Wright Nuclear)**
  - Director of Products and System Integration
  - PUR-1 Upgrade System Engineer
  - rammon@curtisswright.com

Purdue Nuclear Laboratories

Overview

- Very exciting time at Purdue Nuclear Engineering
- College of Engineering – Unprecedented growth
- Complete renovation of lab space to better comply with ADA Standards
- Power Uprate of PUR-1
- Reactor Protection and Control System Upgrade

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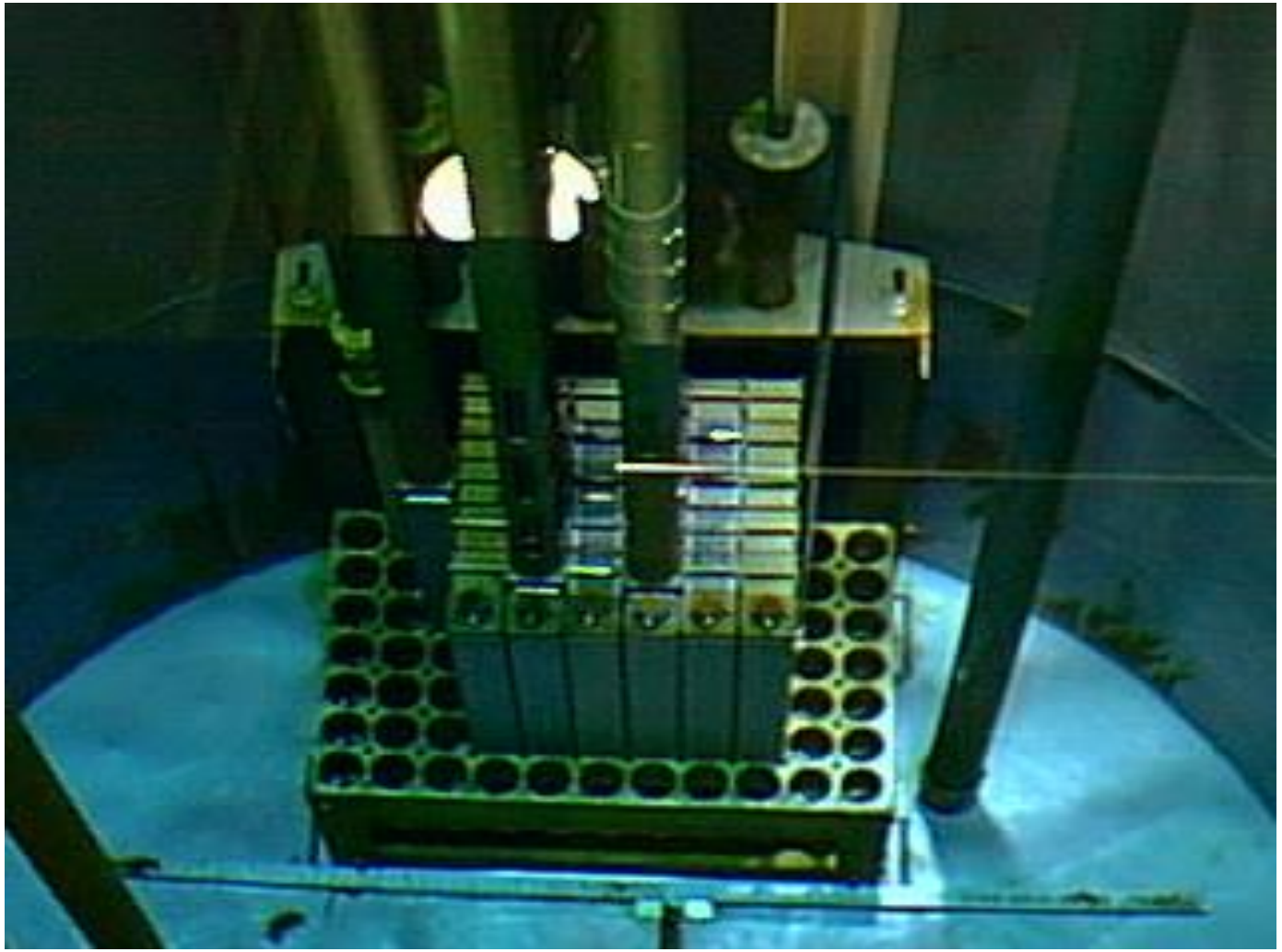
Purdue Nuclear Laboratories

PUR1 Reactor



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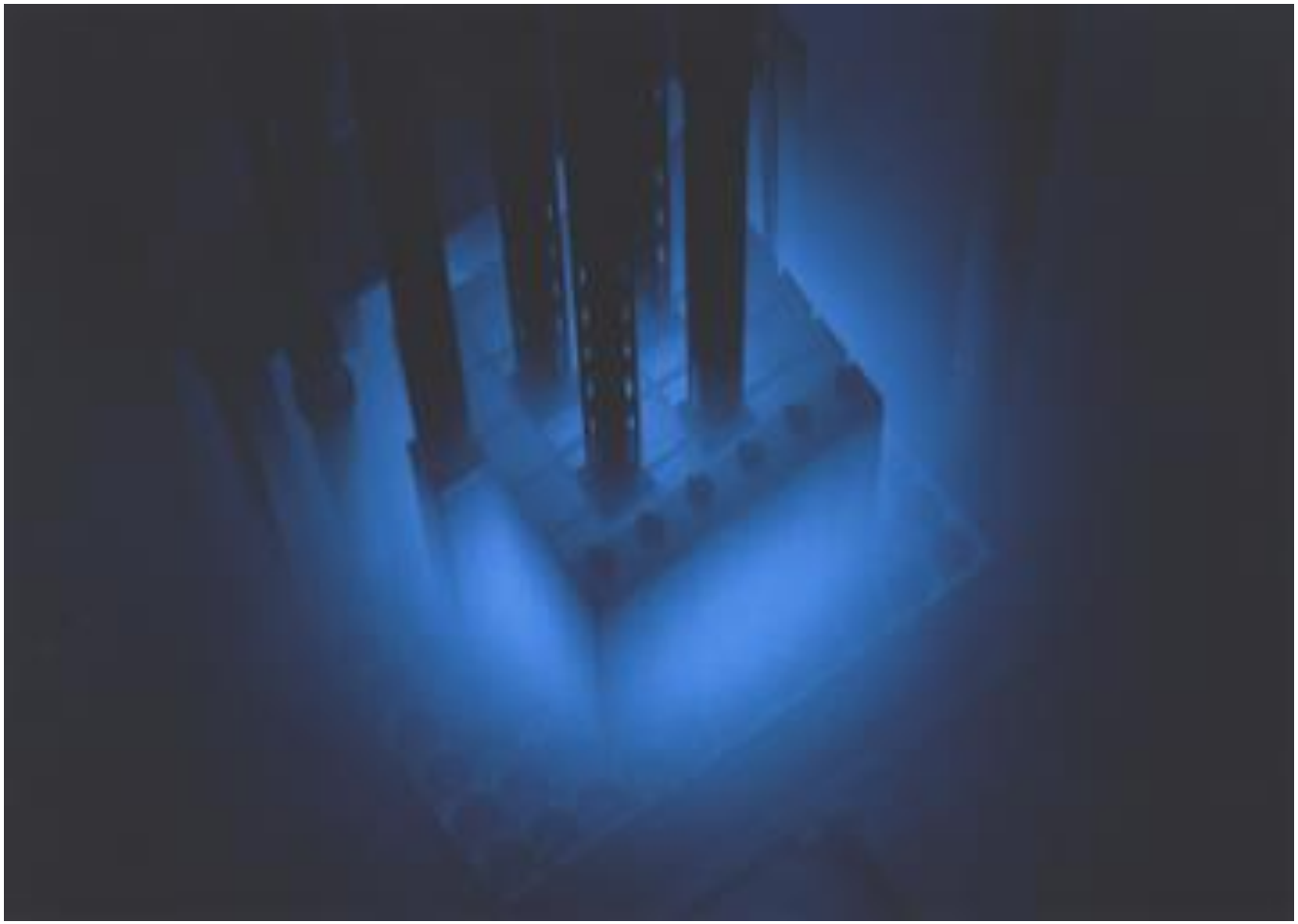
PUR1 Reactor



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Existing Reactor Console

PURDUE UNIVERSITY

PUR1 Mission

Research

- Irradiations
- Neutron Activation Analysis
- Equipment Testing
- Benchmarking Reactor Codes

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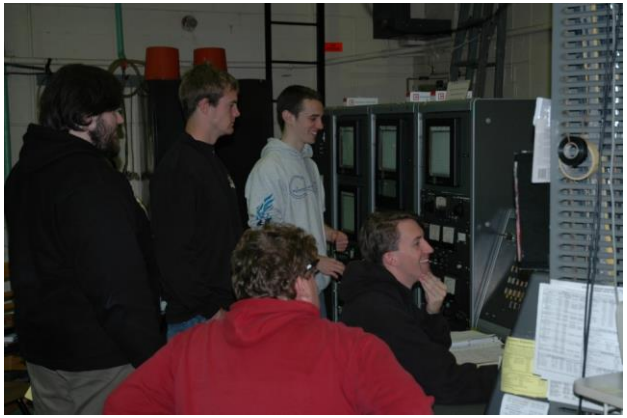
PUR1 Mission

Teaching

- Undergraduate and Graduate Lab Courses
  - Approach To Critical
  - Subcritical Multiplication
  - Rod Worth By Positive Period
  - Fermi Age



- Operations and Reactor Administration

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PUR1 Mission

Public Outreach

- Indiana's only nuclear reactor
- Over 1500 people toured PUR-1 in 2015
- Three non-nuclear courses have reactor visits as part of the syllabus
- High school visits

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PUR1 – Historical Highlights

- 1960 – Initial design work and proposal to build facility
- 1962 – First criticality of PUR-1
- 1968 – First License renewal
- 1988 – Second License renewal
- 2007 – HEU to LEU fuel conversion completed
- 2015 – Proposals Submitted for Console Upgrade
- 2016 – Third License Renewal with power uprate
- 2016 – Reactor Protection and Control System SAT
- 2017 – Expected Digital I&C Final Installation

PURDUE UNIVERSITY

PUR1 Staffing

- Laboratory Director - Robert Bean
- Reactor Supervisor – Clive Townsend
- Electronics Technician – David Storz
- Various graduate and undergraduate students



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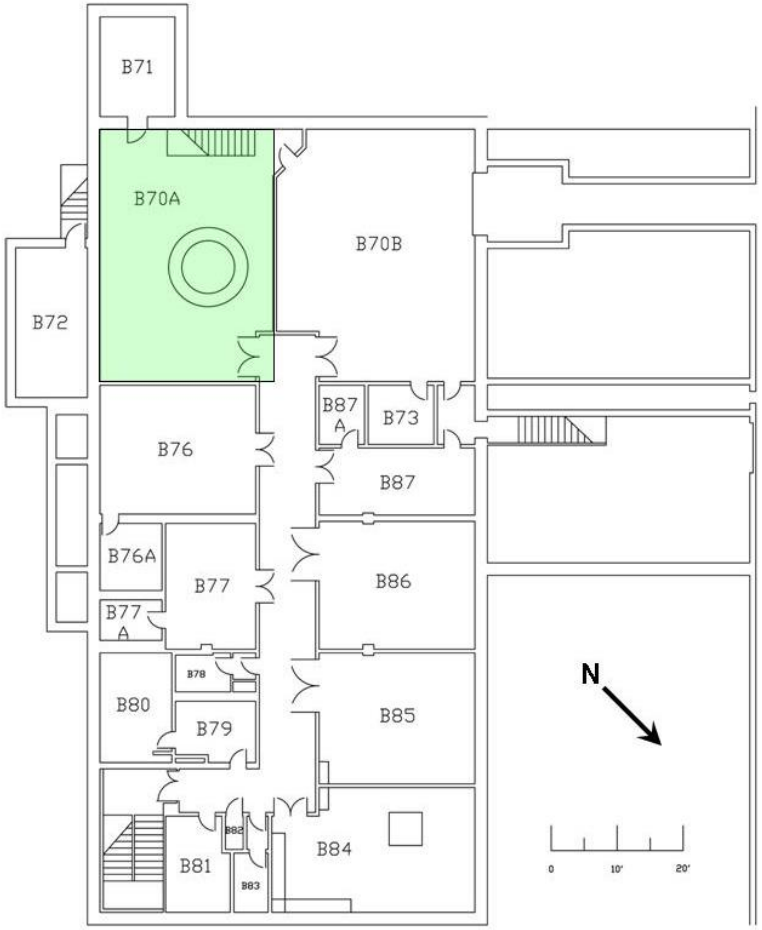
PUR1 Facility

Facility Layout



- PUR1 Reactor
- Subcritical pile
- Undergraduate Thermalhydraulic Lab
- Chem Facility Room
- Beta Voltaic Facility
- Expanding Lab Space

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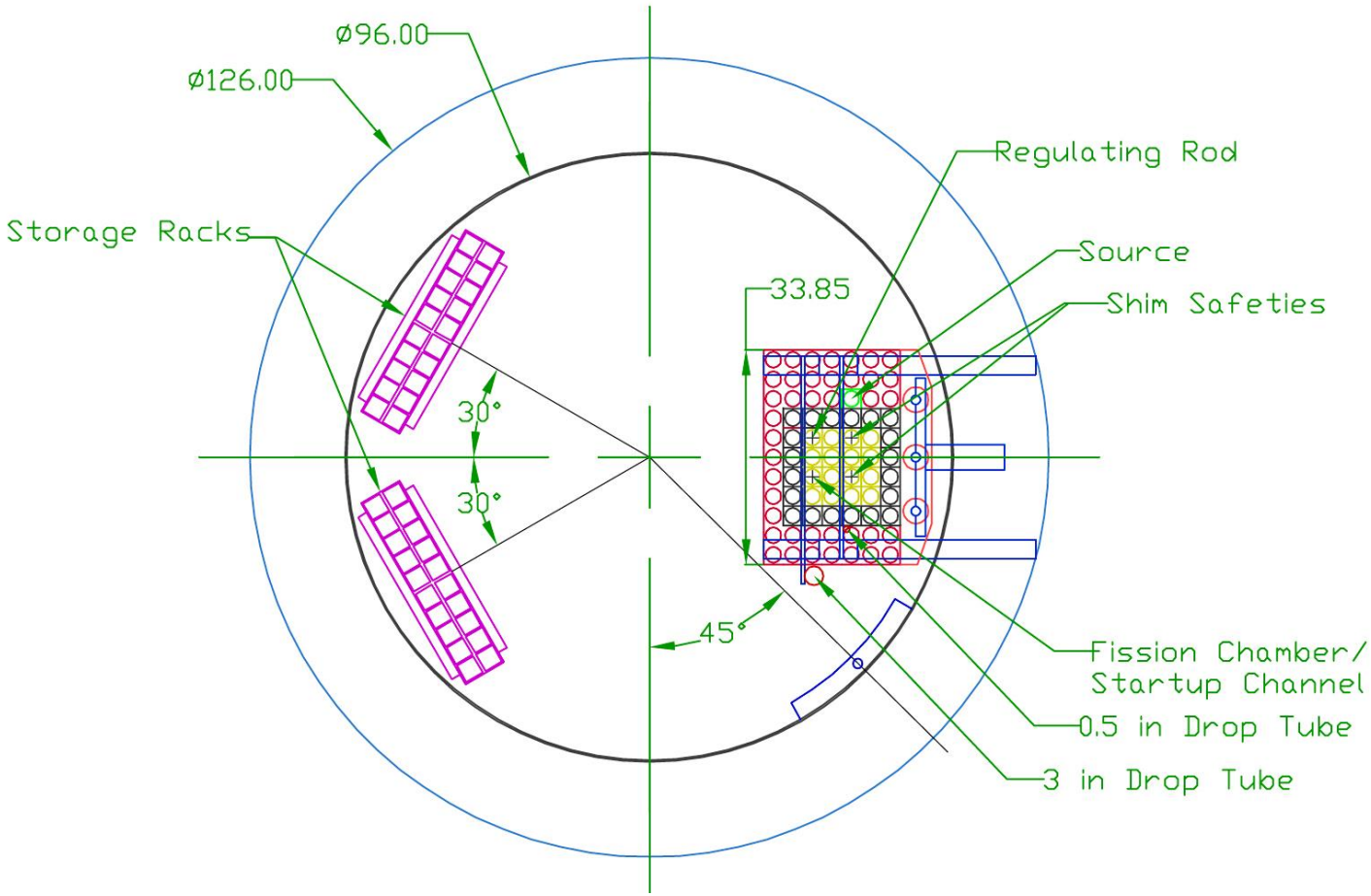
PUR1 Facility

Pool Layout



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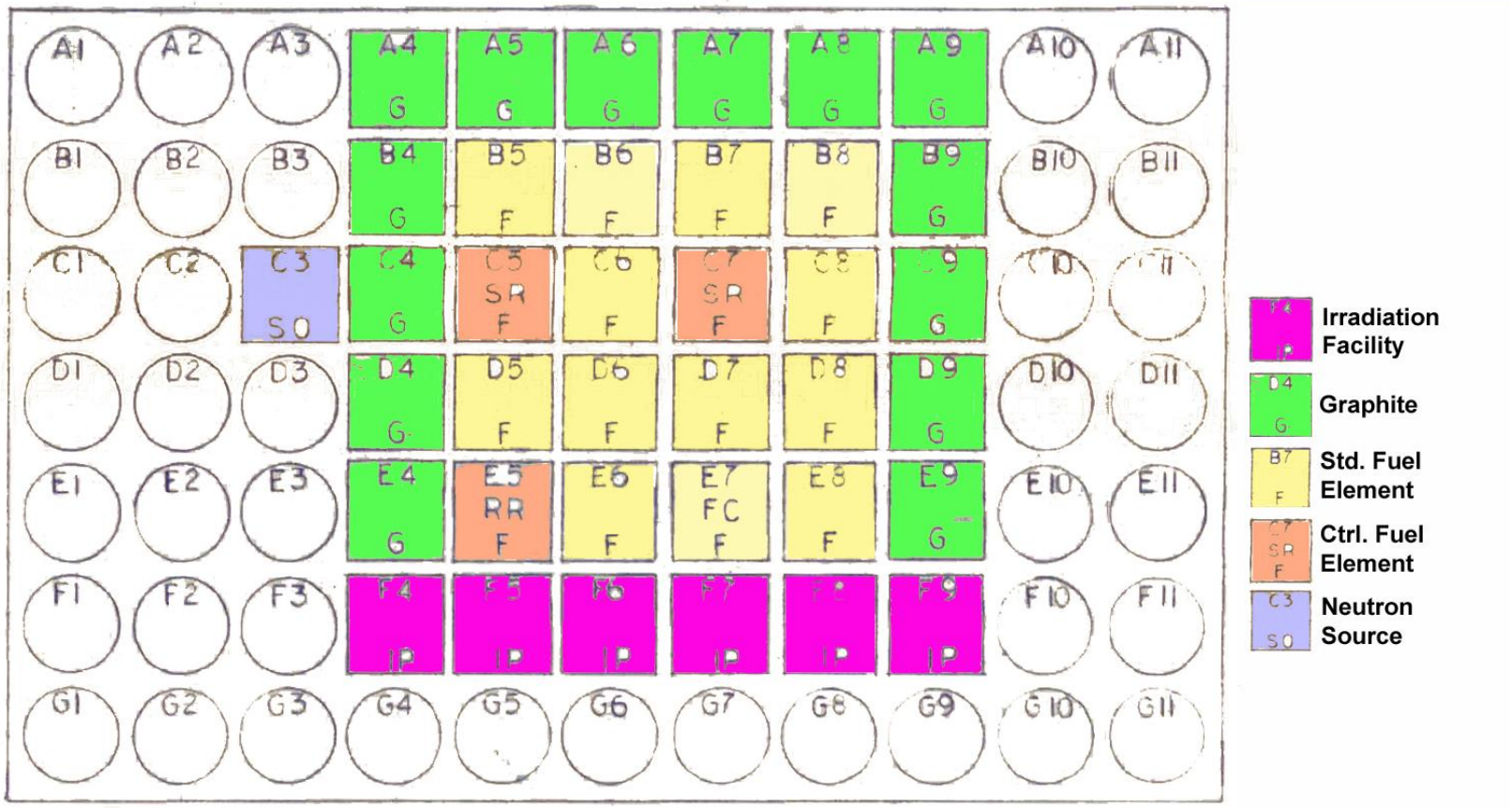
PUR1 Facility

Core Layout



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PUR1 Design

- Materials Test Reactor (MTR) – Pool Type
- Built by Lockheed Nuclear Products
- 10 kW design level (Possible in future to expand)
- Licensed at 1 kW in 1962
- Entered timely renewal of license in 2008
- Power uprate to design level (10kW) approved by the US NRC in 2016

PUR1 Design

Fuel Summary

- Flat Plate Type Fuel by BWXT Technologies
- Fuel Material
  - Low Enriched Uranium $(19.75\%\ ^{235}U)$
  - $U_3Si_2 - Al$
- Plates are $7cm \times 64\ cm$
- Standard Element has up to14 fuel elements per assembly
- 16 Total Assemblies

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PUR1 Design

Control Rods

- Two Shim Safety Rods
  - Boron-Stainless Steel
  - Total calculated worth $-5.8\%\ \Delta k/k$
  - Operating Speed – $4.4\ inches/min$
- One Regulating Rod
  - 304 Stainless Steel
  - Total Worth $-0.47\ \%\ \Delta k/k$
  - Operating Speed – $17.7\ inches/min$

PUR1 Design

Current Nuclear Instrumentation

- Startup Channel
  - Fission Chamber
  - Range: $1\ cps$ to $10^4\ cps$
- Log-N Channel
  - Compensated Ionization Chamber
  - Range: 10^4 to $10^{10} n/cm^2 sec$
- Linear Channel
  - BF_3 Ion Chamber
  - Range: 10^4 to $10^{10} n/cm^2 sec$
- Safety Channel
  - Compensated Ionization Chamber
  - Range: 10^{-3} to $150\ \%\ Power$

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PUR1 Design

Neutron Flux – 1 kW

- Average thermal flux in fuel region:

$$1.2 \times 10^{10} \frac{n}{cm^2 sec} \ (10^{11}\ Expected)$$

- Maximum thermal flux in fuel region:

$$2.1 \times 10^{10} \frac{n}{cm^2 sec}$$

- Drop Tubes

$$0.5\ in\text{: } 1.55 \times 10^{10} \frac{n}{cm^2 sec}$$

$$3.0\ in\text{: } 4.88 \times 10^{7} \frac{n}{cm^2 sec}$$

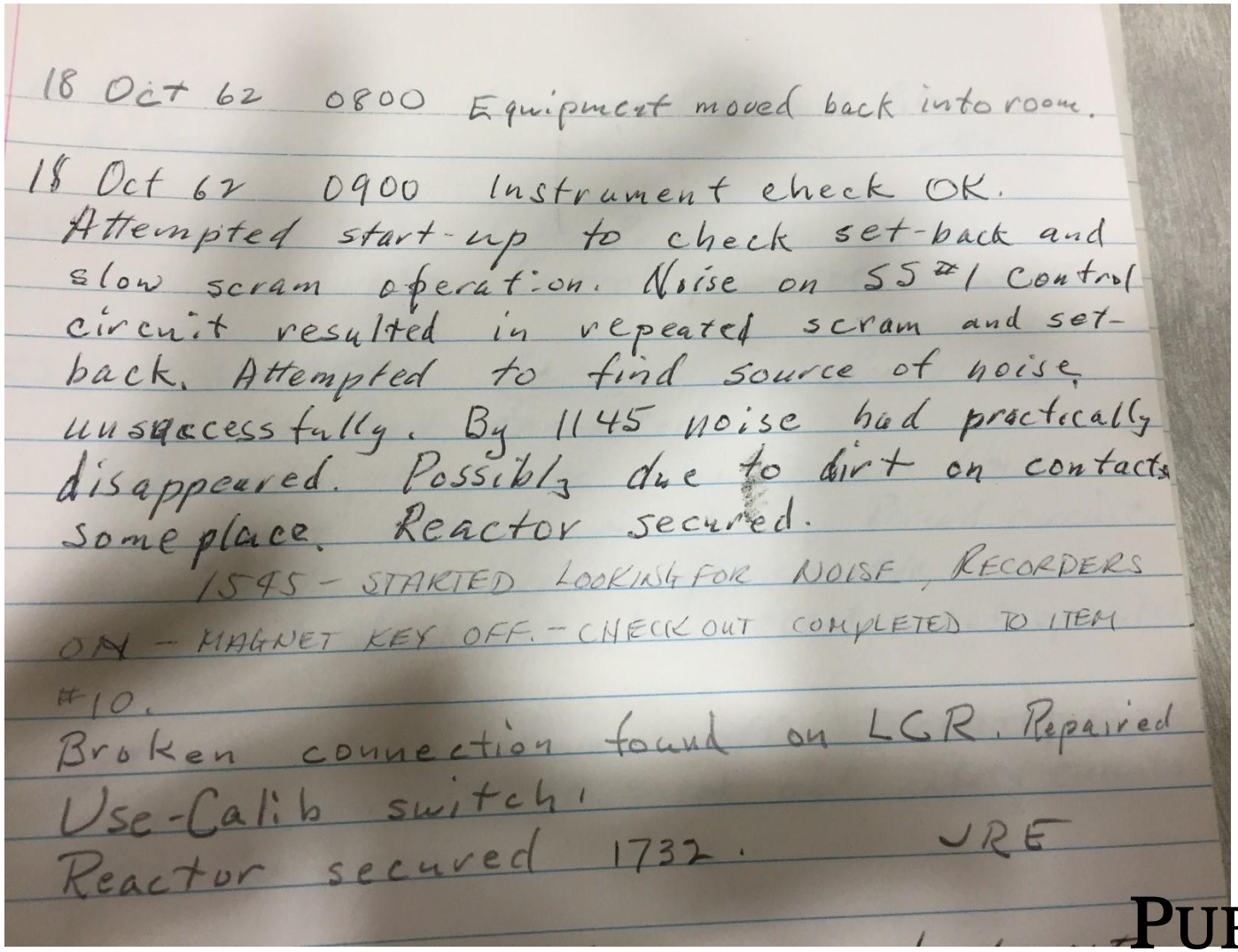
PUR1 Design

Safety Limits per Technical Specification Amendment #13

- Limiting Safety System Setting of 12 kW
- Safety Limit of Fuel and Clad Temperature - $530\ °C$
- No Explosives
- Very low reactivity worth
  - Movable or unsecured experiments - $0.003\ \Delta k/k$
  - Secured experiments - $0.004\ \Delta k/k$
- Sealed samples easiest to approve
- Limited to $1\ R/hr$ upon removal

Upgrade Motivation

PUR-1 Reactor Upgrade



18 Oct 62 0800 Equipment moved back into room.

18 Oct 62 0900 Instrument check OK. Attempted start-up to check set-back and slow scram operation. Noise on 55#1 control circuit resulted in repeated scram and set-back. Attempted to find source of noise, unsuccessfully. By 1145 noise had practically disappeared. Possibly due to dirt on contacts some place. Reactor secured.

1545 - STARTED LOOKING FOR NOISE, RECORDERS ON - MAGNET KEY OFF. - CHECK OUT COMPLETED TO ITEM #10.

Broken connection found on LCR. Repaired Use-Calib switch.

Reactor secured 1732. JRE

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Upgrade Timeline

- Summer 2015 – Solicitation of bids
- Fall 2015 – Bid awarded to Mirion Technologies
- Spring 2016 – Functional Requirements Specifications Document Complete
- Summer 2016 – Software and Hardware Design Locked
- August 29 – Factory Acceptance Testing (Idaho Falls, ID)
- September 16 – Delivery to Purdue
- September 30 – Final System Staging
- December 21 – Site Acceptance Testing
- 2017 – Final Reactor Integration

Upgrade Strategy

PUR-1 Reactor Upgrade

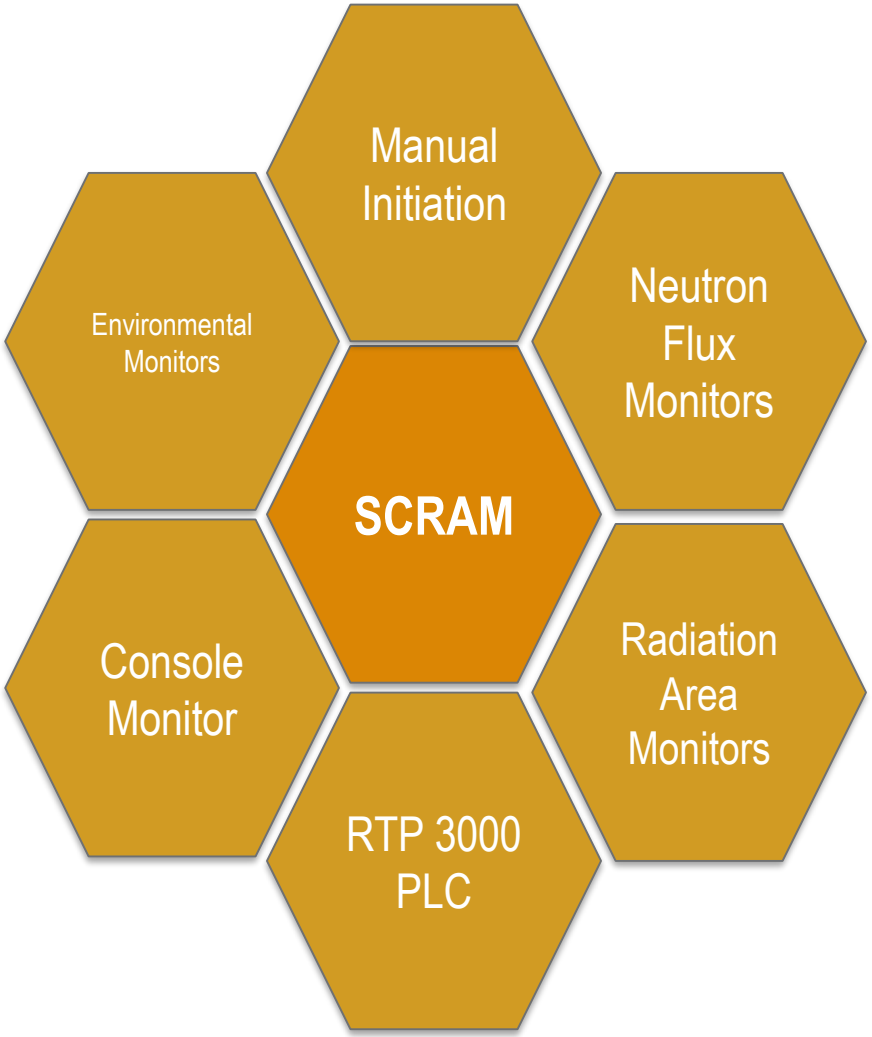
- Like-for-like performance
  - 4 Channels Remain
  - Exact replication of interlocks and other functionality
  - Replacement of detectors by same type
  - No voting of channels to increase licensability
  - Isolated workstations to mitigate cyber risk
  - Complete replacement of controls and instrumentation to ensure compatibility
  - SCRAM capability in all major subsystems

Licensing Strategy

PUR-1 Reactor Upgrade

- 10 CFR 50.59 Review not practical or likely to result in positive outcome
- Communicate early and often with the NRC
- Understand regulatory stance when making design decisions
- Deviate as little as possible from current design
- Comprehensive License Amendment Request
- …while avoiding operability traps

SCRAM



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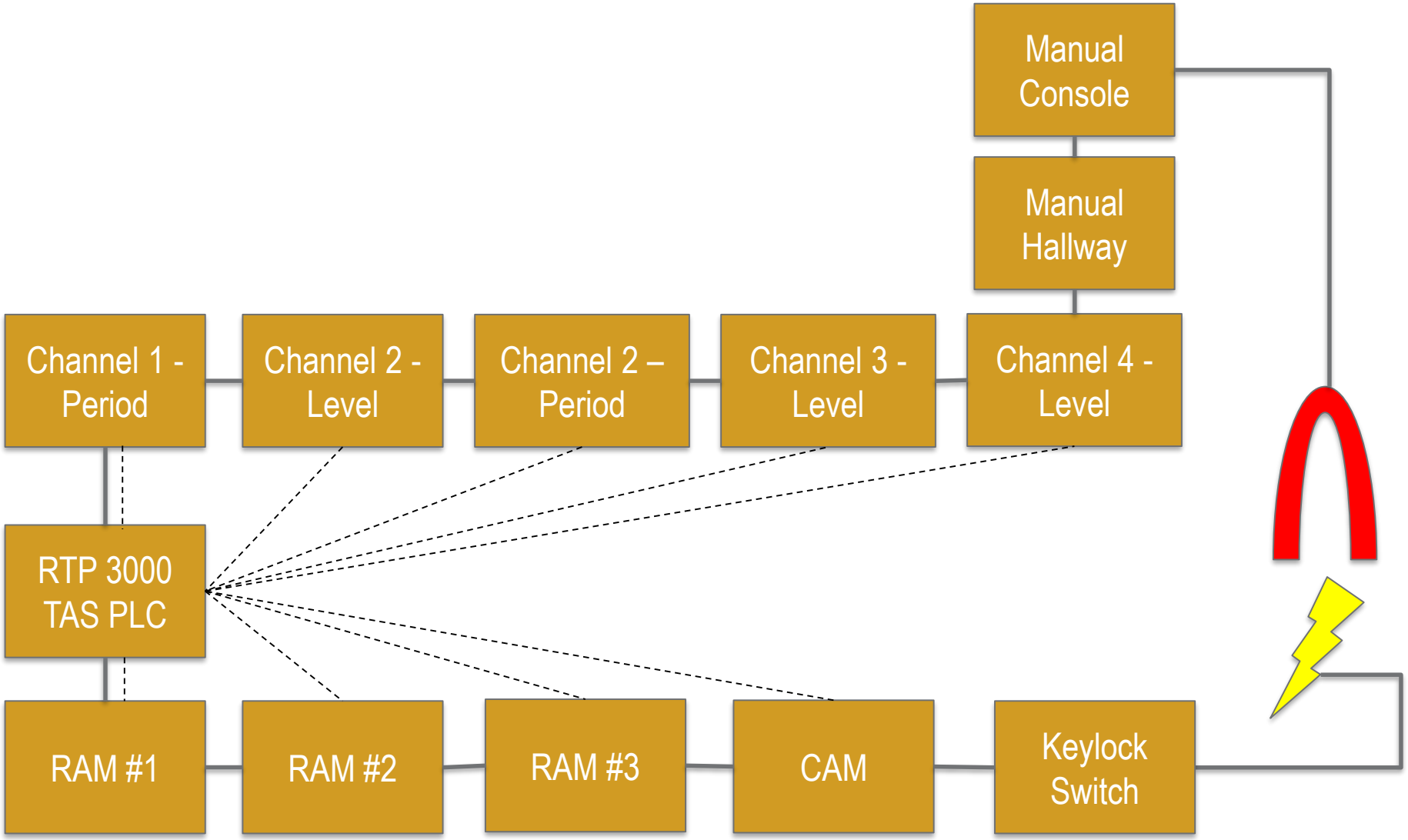
SCRAM Flow



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Protection vs. Control

PUR-1 Reactor Upgrade

Protection	Control
Mirion Channels (DGK, DWK, DAK)	RTP 3000 TAS PLC
Manual Scram	Dell Computer Workstation
Radiation Area Monitors	
Continuous Air Monitor	

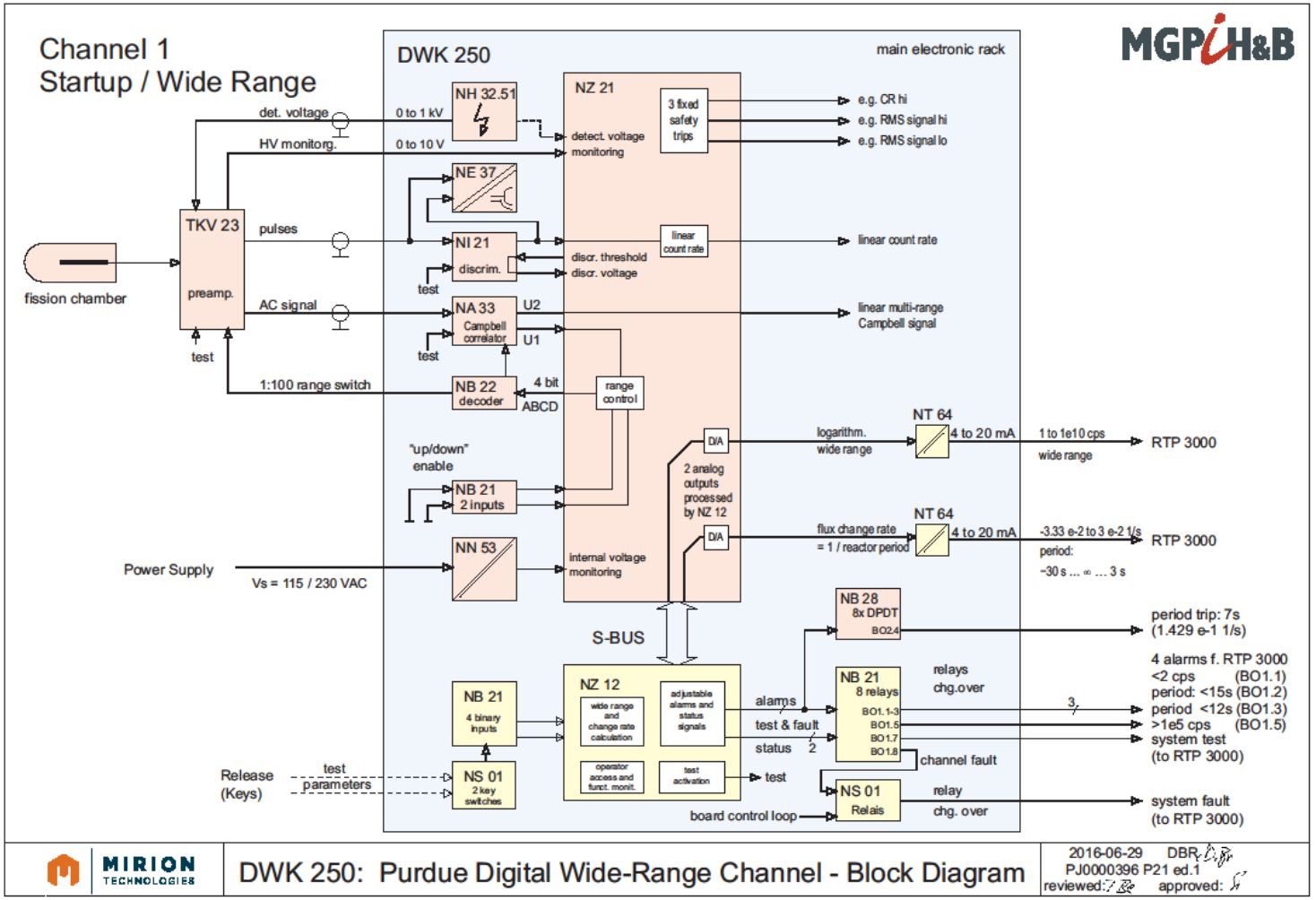
Neutron Flux Monitoring Equipment

- **Channel #1 (Startup Range)**
  - Mirion Fission Chamber Detector
  - Mirion TKV 23 Pre Amplifier
  - Mirion DWK 250 Wide Range Channel
- **Channel #2 (Intermediate Range)**
  - Mirion Compensated Ion Chamber Detector
  - Mirion NV 102 Pre Amplifier
  - Mirion DAK 250-g Log N and Period Channel

Neutron Flux Monitoring Equipment

- **Channel #3 (Power)**
  - Mirion Uncompensated Ion Chamber Detector
  - Mirion NV 102 Pre Amplifier
  - Mirion DAK 250-g Linear Power Channel
- **Channel #4 (Safety)**
  - Mirion Uncompensated Ion Chamber Detector
  - Mirion DGK 250 Linear Power Channel

Neutron Flux Monitoring Equipment



Reactor Control System Equipment

- **RTP 3000 TAS I/O Equipment**
  - 4-20 mA Current Inputs
  - 0-10 VDC Voltage Inputs
  - 0-10 VDC Voltage Outputs
  - 24 VDC DI inputs
  - 24 VDC DO outputs
- **Reactor Operator Console Display Workstation**
  - Dell Precision Tower 5810 workstation
  - Dual 19 inch display monitors
  - R*TIME Server V 14.1
  - R*TIME Viewer V 4.10

Reactor Control System Equipment

- **Control Rod Magnet Power Supply**
  - Acopian Constant Current Supply
  - 30 mA nominal
- **Miscellaneous**
  - Interposing Relays
  - 24 VDC Power Supply
  - Wiring Terminations

Plant Server System Equipment

- **Canary Data Diode**
- **Plant Server System**
  - Dell Precision Tower 5810
  - Cisco Network Switch
  - HP Printer

External System Equipment

- **UPS**
  - One for Reactor Protection System
  - One for Reactor Control System
- **Makeup Water Instrumentation**
  - Makeup Water Temperature (Pool and Process Equipment)
  - Conductivity (Pool and Process Equipment)
- **HVAC Controls**

External System Equipment (cont.)

- **Radiation Area Monitors (3)**
  - Reactor Pool
  - Makeup Process Equipment
  - Operator Console
- **Continuous Air Monitor**
- **Environmental Monitor**
  - Negative Air Pressure Monitor

Control Algorithm

PUR-1 Reactor Upgrade

- Response time to facility parameter changes less than 50 milliseconds
- Any bad signal will be set automatically to the most conservative value
- Any off-normal equipment causes Reactor SCRAM
- Power (Linear Channel Reading) and Period always visible to operator

Security

PUR-1 Reactor Upgrade

- Workstation Logins protected at same level as console keyswitch
- External media restricted to facility personnel
- Plant Server System for secondary display use
- No external network access to Reactor Control System (data diode between RCS and PSS)

Additional Features

PUR-1 Reactor Upgrade

- Capability to directly enter final rod height
- Automatic rod drop timing calculations
- Ability to plant up to 12 facility parameters on up to 4 simultaneous screens
- Custom live data analysis by experimenters
- Ability to present large variability of values depending on tour level
- Display data on facility screens for exterior viewing

Console Comparison

PUR-1 Reactor Upgrade

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Console Comparison

PUR-1 Reactor Upgrade

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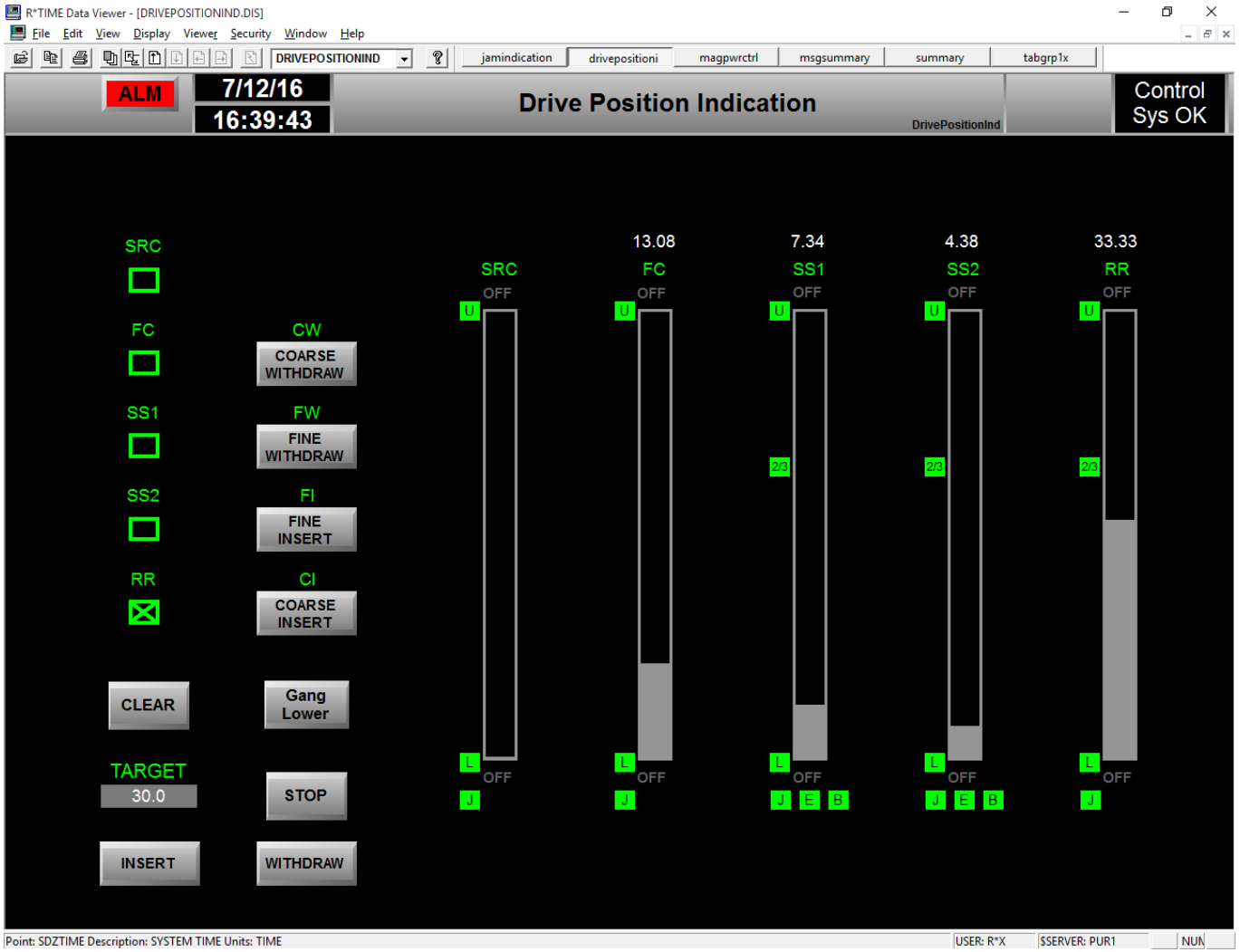
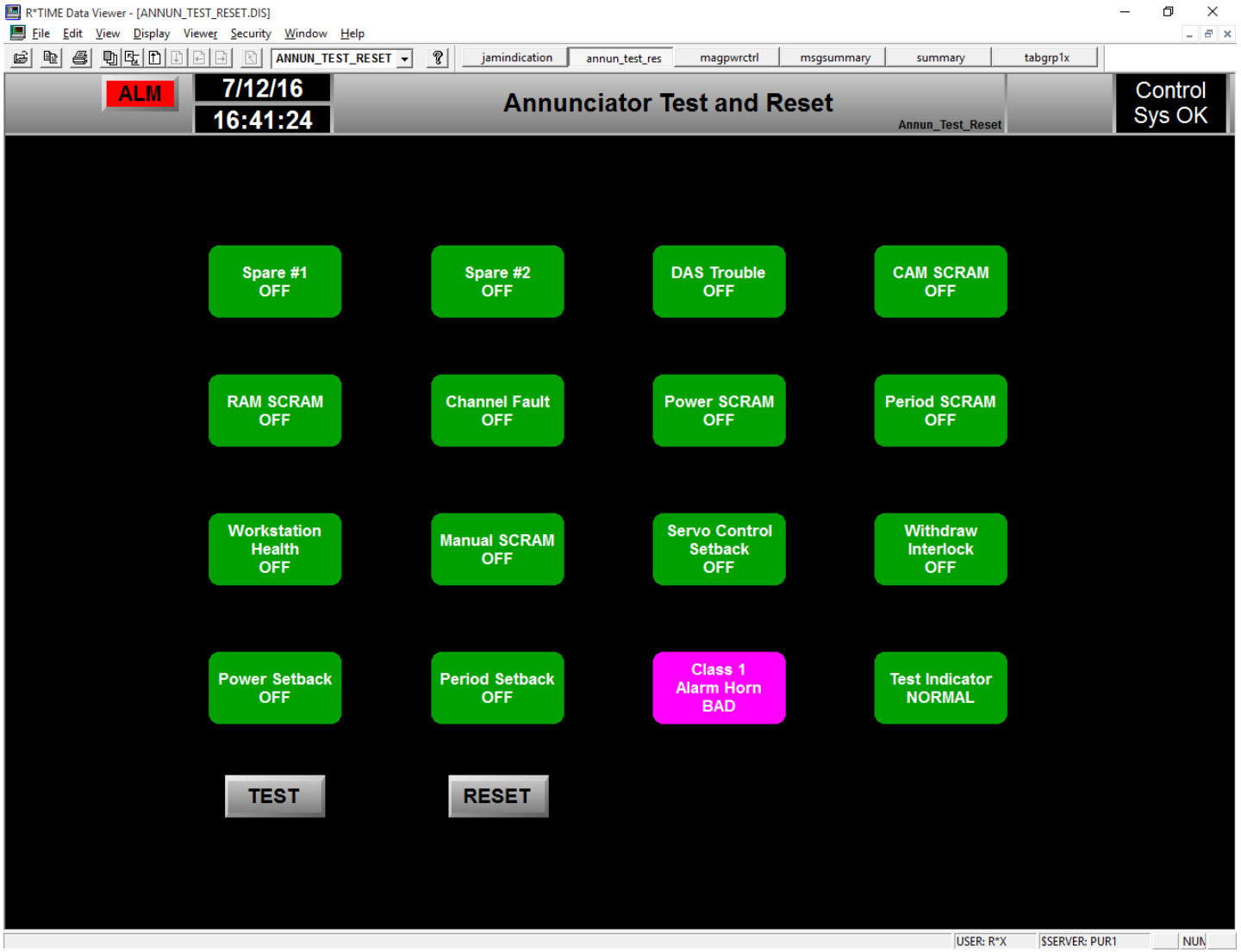
Console Comparison

PUR-1 Reactor Upgrade



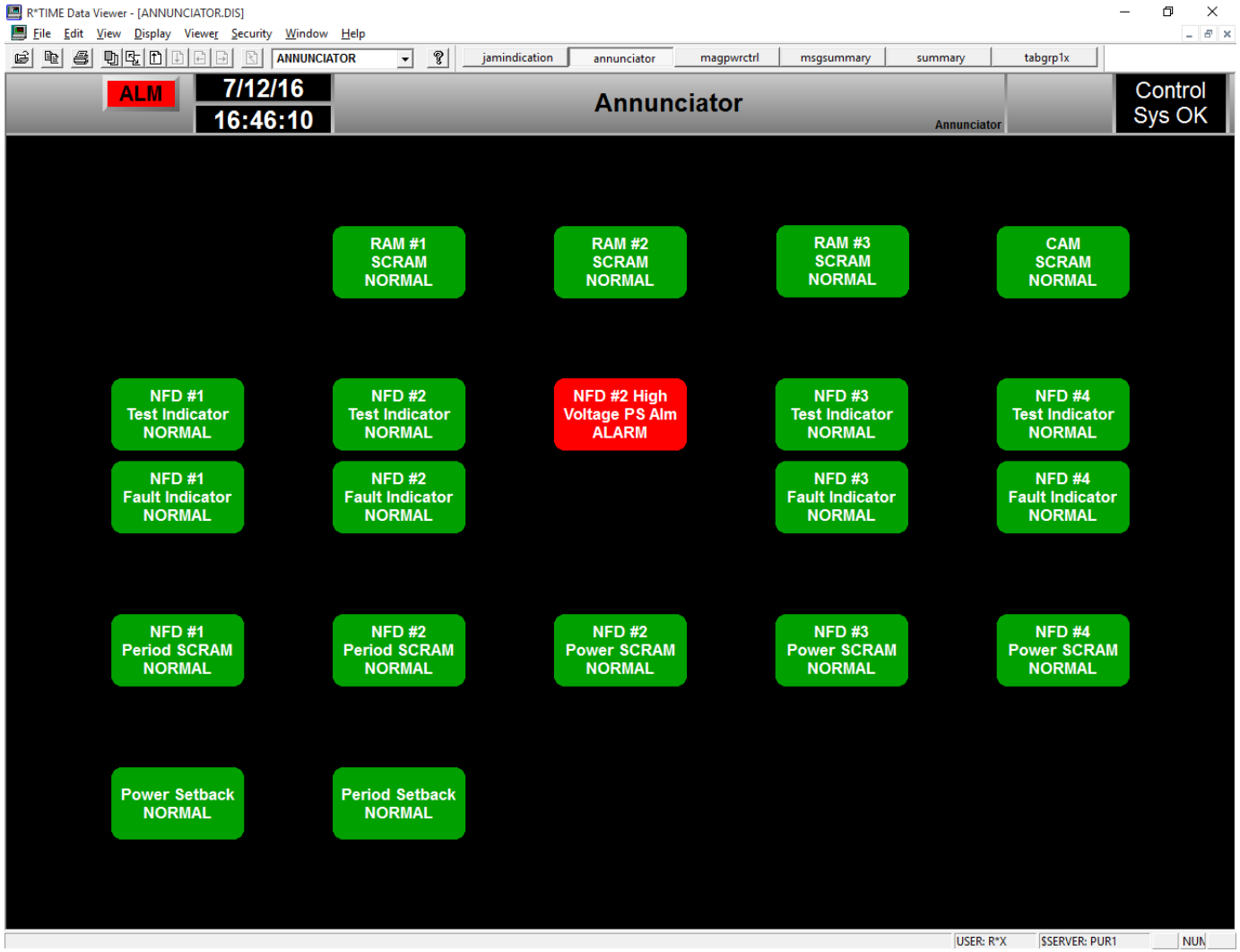
Console Comparison

PUR-1 Reactor Upgrade



Console Comparison

PUR-1 Reactor Upgrade



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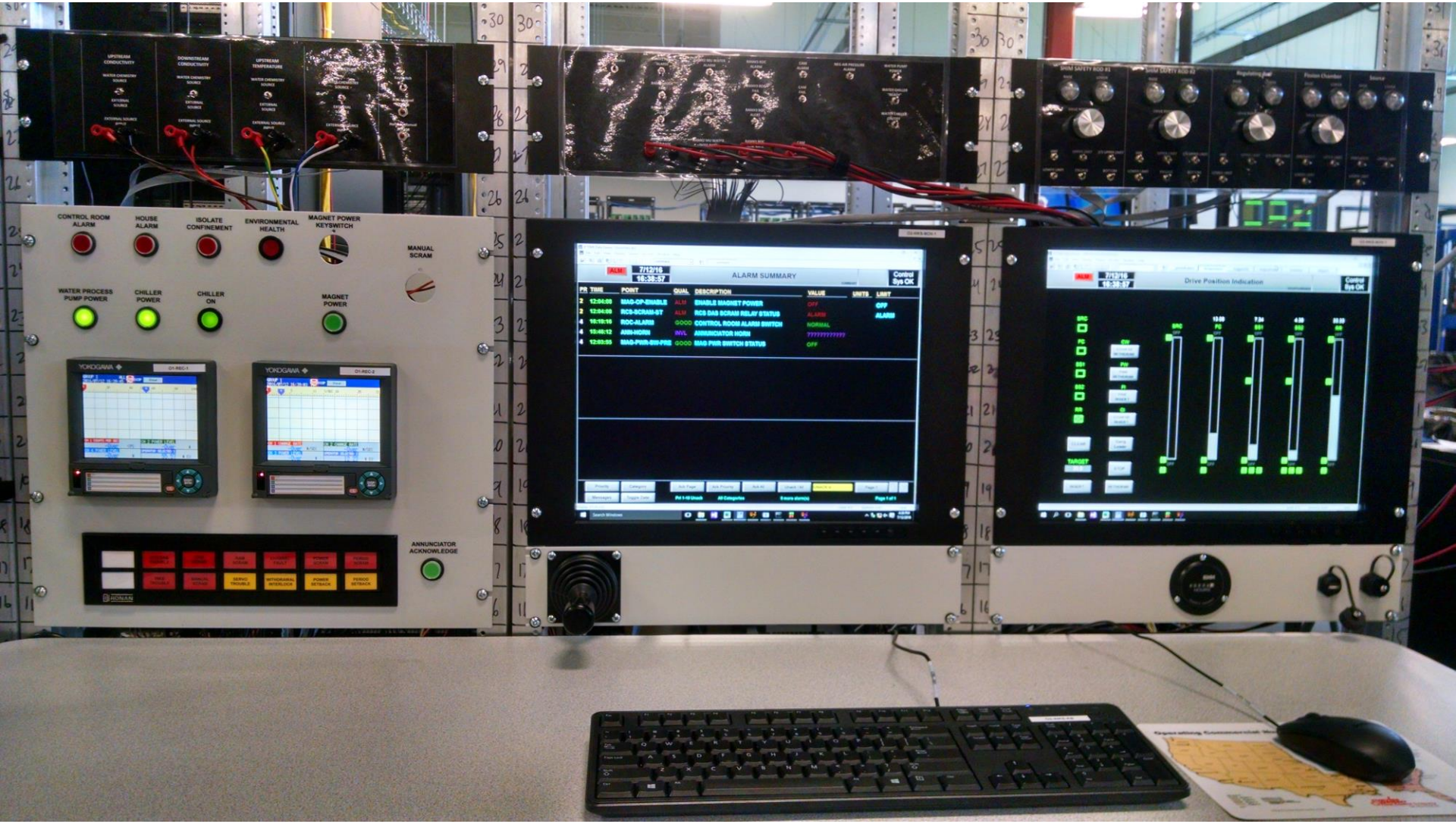
Console Comparison

PUR-1 Reactor Upgrade



Site Acceptance Testing

- **Parallel Installation with Existing System**
  - Mirion detectors in the Reactor Pool in new canisters
  - Mirion electronics connected to Reactor Control System (RCS) and Mirion detectors
  - Control Rod Magnet Power controlled from existing system only
  - RCS connected to external systems
    - New RAMs
    - New CAM
    - New Makeup Water Sensors
    - New Environmental Sensors
    - Existing Rod Drive Controls
      - New cables switched with existing system
    - Existing Rod Drive Position Sensors
      - New cables switched with existing system

Site Acceptance Testing

- **Final Installation**
  - After NRC approval of License Amendment Request (LAR)
  - Removal of existing system control console equipment cabinets
  - Gut and retain existing operator console frame
  - Installation of new equipment cabinets
  - Transfer of RPCS from temporary racks to new equipment cabinets and operator console frame
  - Transfer in pool detectors to final location
  - Final installation SAT tests
    - Mirion neutron equipment calibration
    - RCS Control Rod Movement
    - RCS Control Rod SCRAM Timing

Temporary Installation

Complete renovation of lab space …

- **Major Building Modifications occurring at the same time as Parallel System Installation and SAT**
  - Heating and Cooling system complete replacement
  - Fire protection system complete replacement
  - Electrical power distribution complete replacement
  - Building reorganization (removal of lots of walls and addition of lots of walls)
  - Significant exterior window additions

Purdue Nuclear Laboratories

Before

Purdue Nuclear Laboratories

During

Purdue Nuclear Laboratories

Before

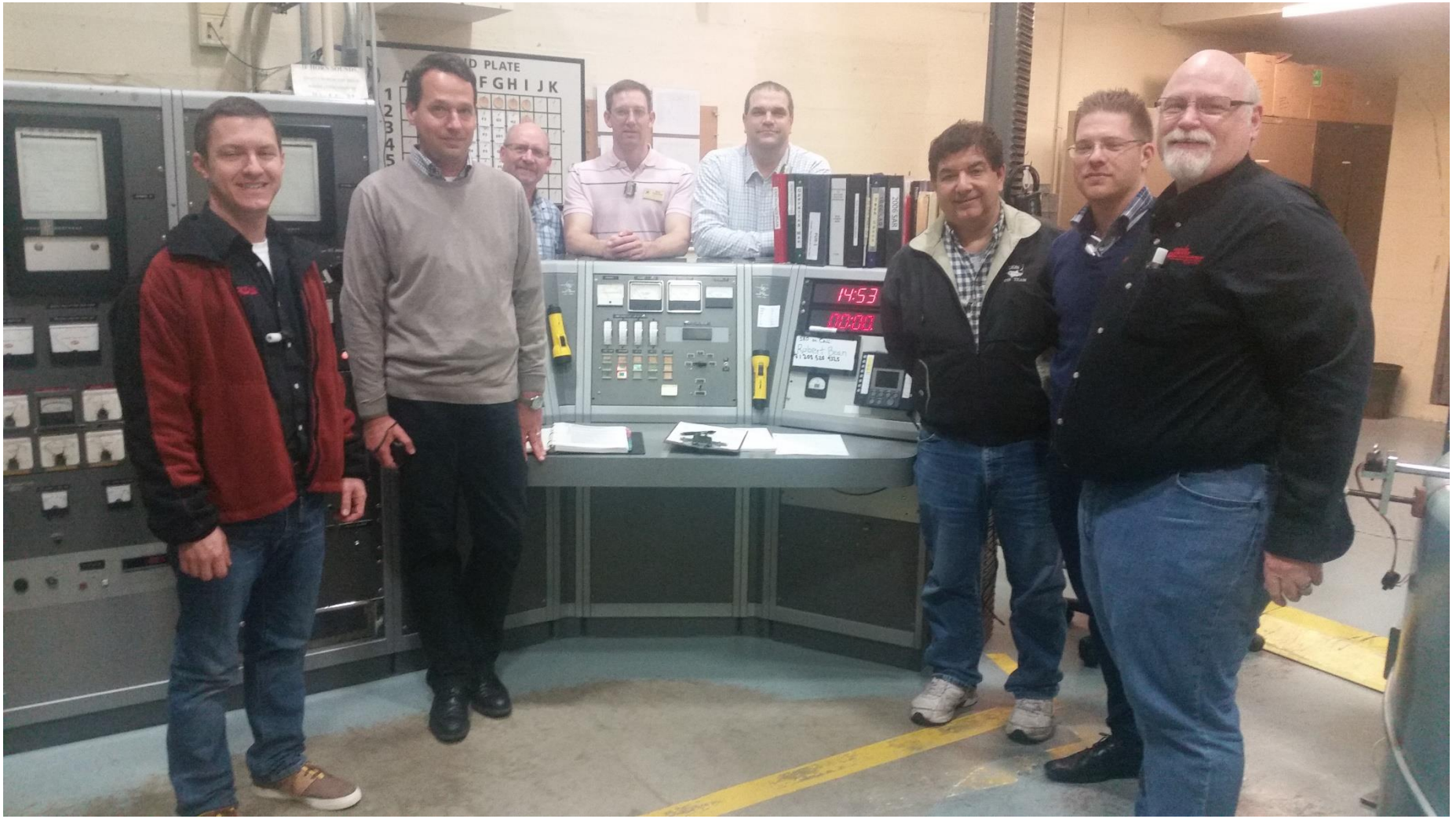
Purdue Nuclear Laboratories

During

Purdue Nuclear Laboratories

During

The Team …



Questions?

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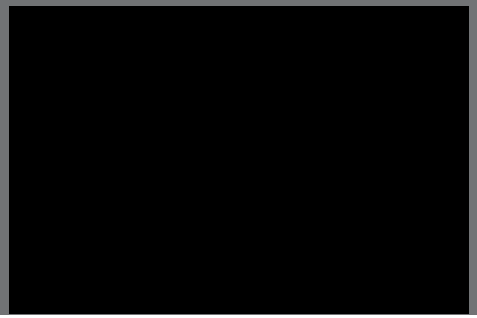
Robert Ammon
rammon@curtisswright.com



https://engineering.purdue.edu/NE/research/facilities/reactor/index_html

