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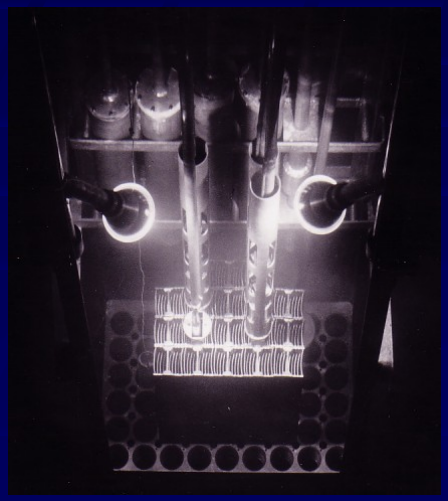
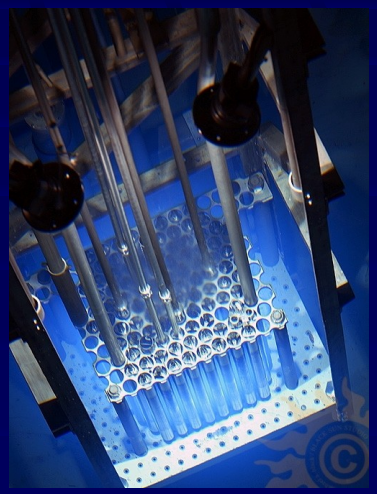
TRIGA Reactor Control and Monitoring System



Breazeale Nuclear Reactor

Radiation Science and Engineering Center

The Pennsylvania State University



Brenden J. Heidrich

PSBR TRIGA Console

- Control Console Hardware Organization
  - Reactor Safety System
  - Input / Output System
  - Control Rod Drives
  - CMS Computers
  - Human Interface
  - Auxiliary Equipment
  - Remote Monitoring Stations

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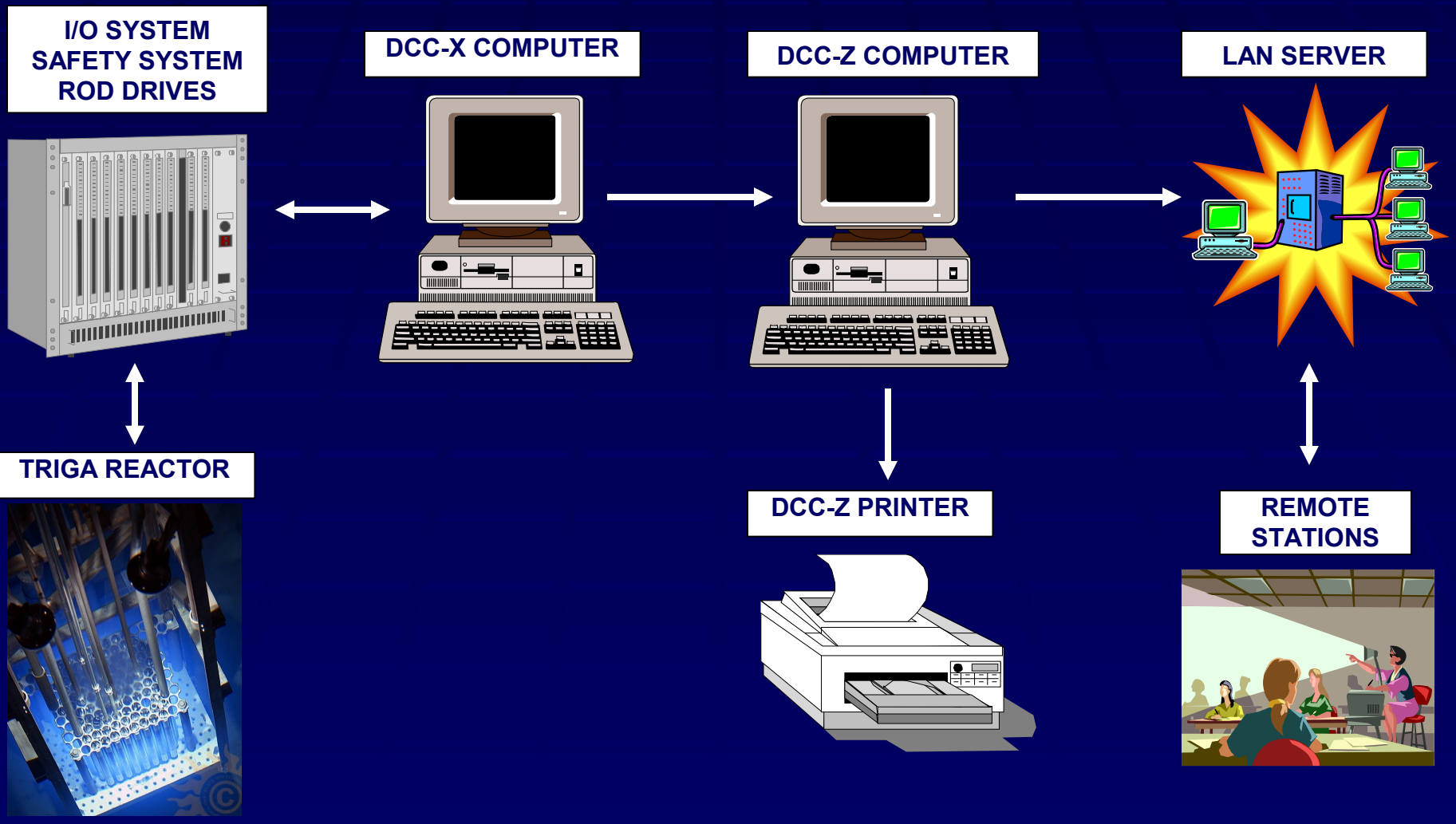
PSBR TRIGA Console



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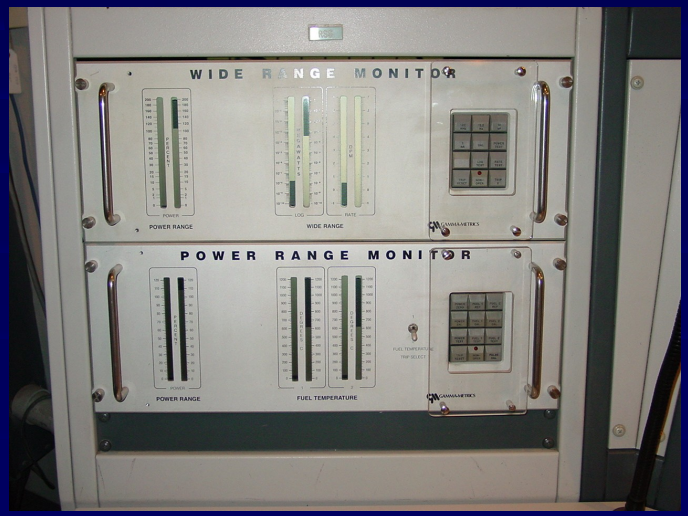
PSBR TRIGA Console

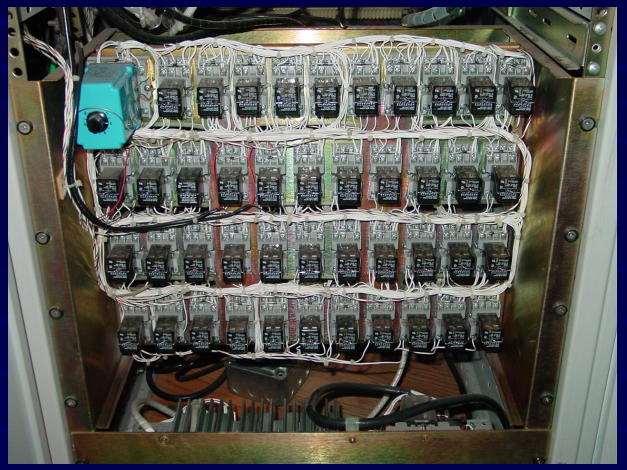
PSBR TRIGA Console - Hardware

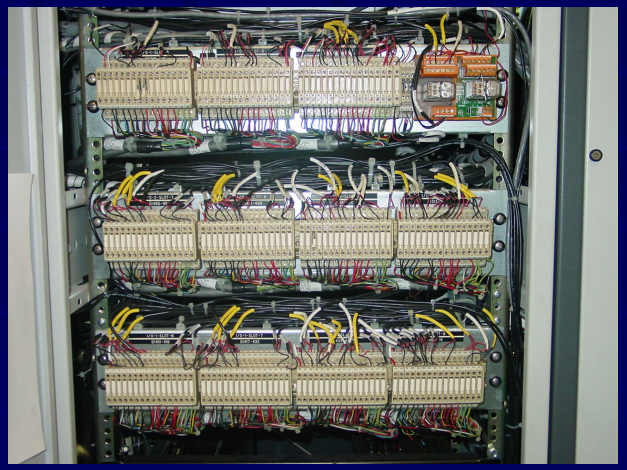
- Nuclear Detectors
  - 2 Fission Chambers (RSS / Spare)
  - 2 Gamma Chambers (RSS / Spare)
  - 1 Compensated Ion Chamber (Spare)
  - 2 Fuel Temp. Thermocouples (RSS)
- Gamma Metrics Drawers
  - Wide Range Channel
    - Fission Chamber
    - 10 Decades of Power
  - Power Range Channel
    - Gamma Ion Chamber
    - Percent Power Channel
    - Pulse Monitoring Channel



PSBR TRIGA Console - Hardware

- Reactor Safety System
  - Provides All Technical Specification Requirements
    - Reactor Shutdowns
    - Interlocks
  - Relay Logic and Hardwired Safety Components
- Input / Output System
  - Coordinates Over 200 Signals Into / Out of Control and Monitoring System
  - Interfaces with Reactor Safety System and Digital Control Computer



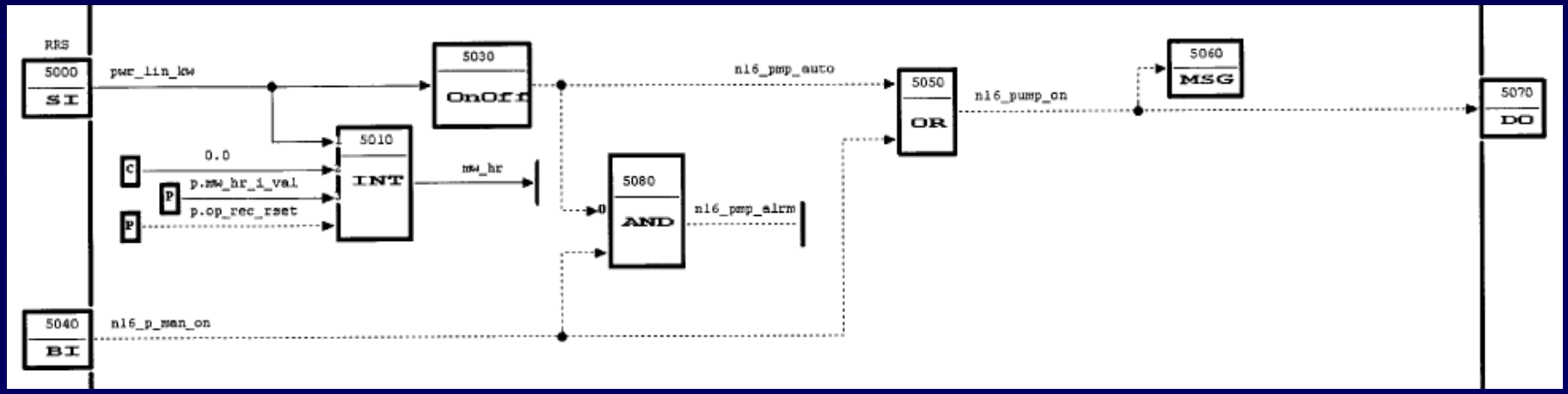


PSBR TRIGA Console - Hardware

- Digital Control Computers
  - Utilizes digital technology to:
    - Analyze Inputs From Various Systems
    - Provide Appropriate Indications
    - Initiate Control Functions
  - Separate Computers for:
    - Control Functions (X)
    - Data Display (Z)
    - Data Storage (Z)

PSBR TRIGA Console - Software

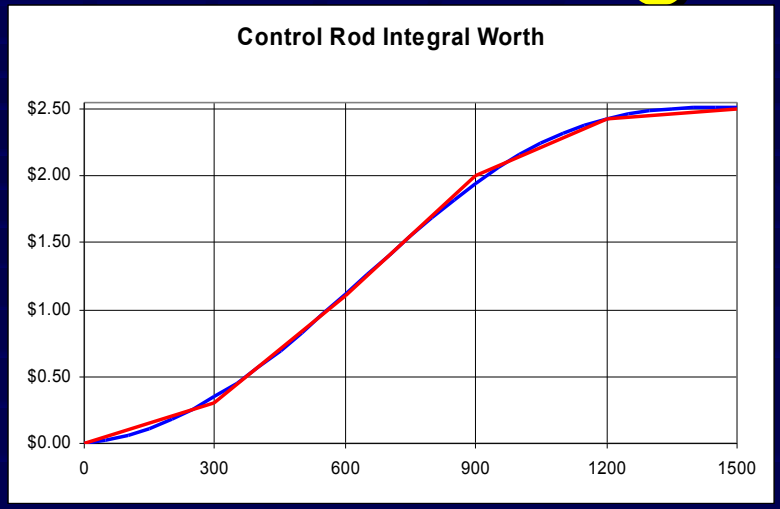
- **PROTROL™** Language (AECL)
  - Logic Blocks Written in Pascal Programming Language
  - Blocks Connected to Form Logic Pathways
  - Used in Commercial Nuclear Power Applications
  - Easily Configurable (By Vendor) for New Applications



PSBR TRIGA Console - Design

DCC Software Tuning

- Certain Blocks Allow User to Change Values to:
  - Update Facility Configurations
  - Set Alarm and Action Points
- Rod Height vs. Control Rod Reactivity Conversion
- Input Signal Calibrations
- Tuning Performed by Specific Authorization Following Safety Analysis



PSBR TRIGA Console - Control

DCC-X (Control)

- Modes of Operation
  - Manual
  - Automatic
  - Square-Wave
  - Pulse
- SCRAM and Interlocks
  - Back-up for Reactor Safety System
  - Additional Interlocks
  - Non-Tech. Spec. Functions

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PSBR TRIGA Console - Control

DCC-X (Control) Main Operator Screen

- Nine Alarm Windows
- Four Mode Windows

- Control Rod Mimic
- Control Rod Height
- Control Rod Reactivity

- Power Digital Displays
- Power Bar Graphs

- Reactor Period Display
- Period Bar Graph

- Temperature Display
- Temperature Bar Graph

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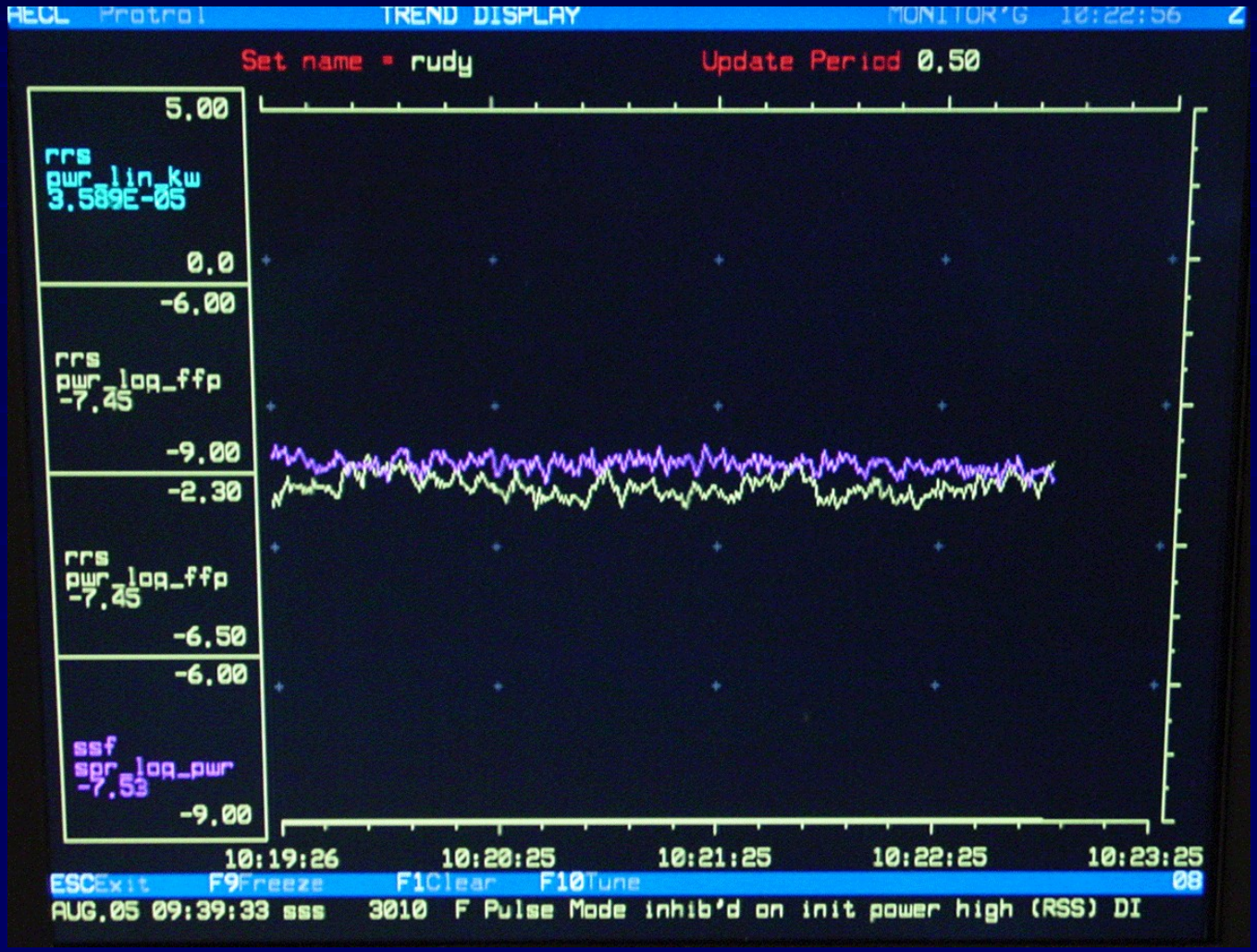
PSBR TRIGA Console - Monitoring

DCC-Z: Real-Time Trending – Up To Four Signals



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PSBR TRIGA Console - Monitoring

Real-Time Bar Charts – Up To Eight Signals

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PSBR TRIGA Console - Monitoring

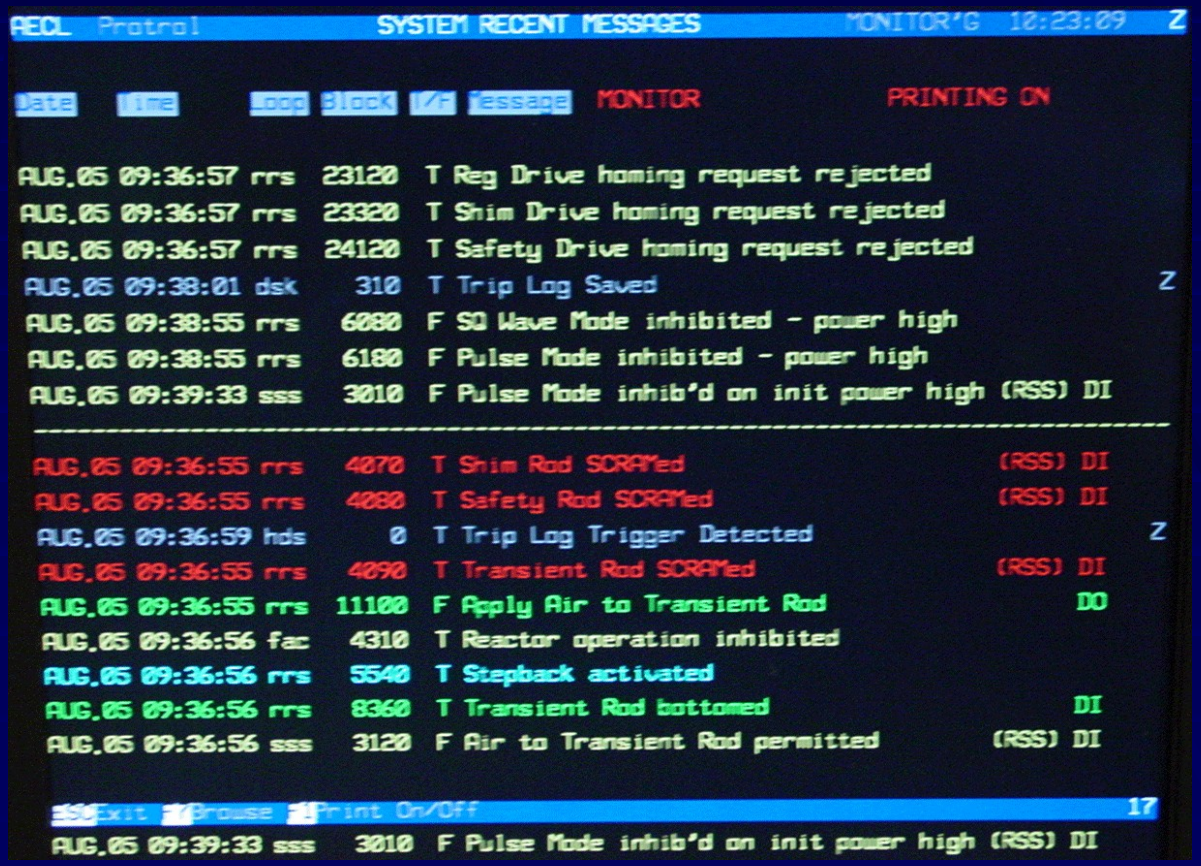
Real-Time Messages – 100 Message Queue

DCC Software Runs in "Loops"

Loop	Time
SSF	0.12 sec
RRS	0.25 sec
OPR	0.25 sec
DSP	0.50 sec
SSS	1.00 sec
FAC	1.00 sec

Tasks Within Loop Run in Numerical Order

FAC 5030 Runs Before FAC 5050



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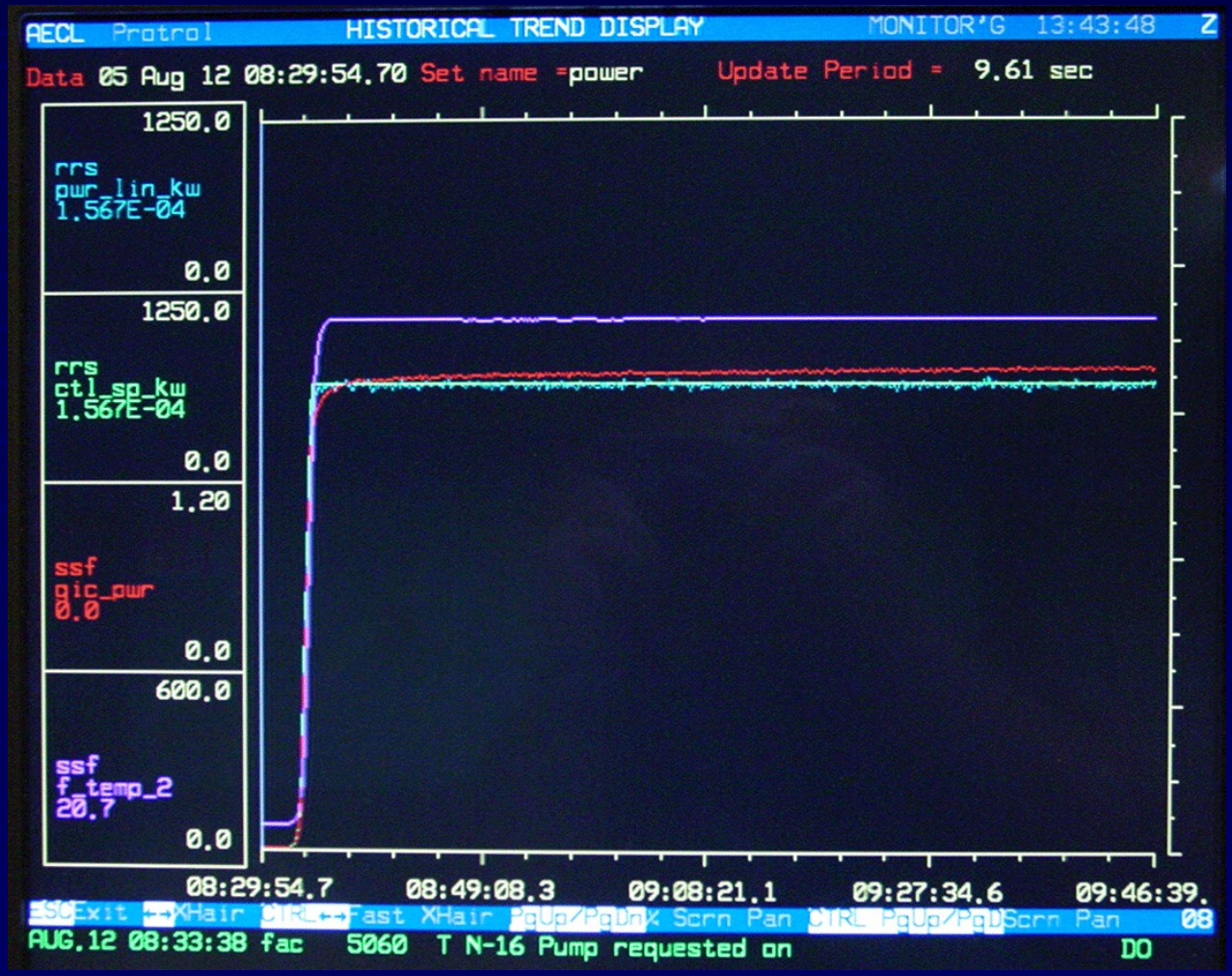
PSBR TRIGA Console - Monitoring

DCC-Z Historical Trending – Up To 4 Days In The Past.



Sampling Time	Retention Time
0.2 sec.	1 hour
1 sec.	4 hours
10 sec.	72 hours

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PSBR TRIGA Console - Upgrade

Reasons For Upgrade

- Spare Parts Difficult To Procure for Obsolete Equipment
  - Smart Serial Data Transmission Card (8 Port)
  - Special Video Display Card (Multiple Pages)
  - CPU Card For Computers (Industrial i386)
  - Fixed Disk Drive For Computers (rll Format Drive)
- Operating System Software No Longer Supported by OEM
- Console Was Providing Excellent Service In Terms Of Reliability and Utility

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PSBR TRIGA Console - Upgrade

- **Upgrade Priorities**
  - Maintain Reliability of System
    - Very Few System Errors Over Last 12 Years
  - Maintain “Look and Feel” of System
    - Years Of Experience Showed That Interface was Very Successful Design
    - No Need or Desire to Change
    - Shallow Learning Curve for Reactor Staff / Experimenters
  - Extend Lifetime of Upgraded Console 10-20 yrs
    - Periodic Smaller Upgrades for Hardware and Software
    - Plan For Obsolescence of Components
    - Buy Spare Components or Upgrade

PSBR TRIGA Console - Upgrade

- **Upgrade Process**
  - Work Began in 2001 With Series of Meetings Between Penn State and Vendor
  - Design Specifications and Contract Negotiations Took Most of a Year
  - Most of Actual Work Performed Between January 2002 and April 2003 (16 months)
  - System Testing Conducted from May 2003 to August 2004 (16 months)
  - Installation Completed August 2004

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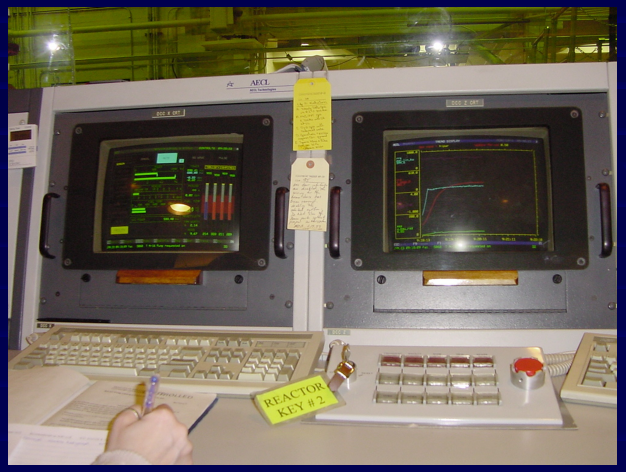
PSBR TRIGA Console - Upgrade

- **Upgraded Items**
  - Hardware Changes
    - Replaced Obsolete Equipment
    - Upgraded Computer Systems
    - Added I/O Channels
  - Software Changes
    - Generic Software Fixes to PROTROL™
    - Specific Penn State Changes
  - Extensive Testing
    - Testing During Upgrade Work
    - Testing Following Nominal Completion Of Work
    - Testing Prior to Return to Operations

PSBR TRIGA Console - Hardware

- **Hardware Changes**
  - Monitors
    - 14” CRT to 18” LCD
  - Computers
    - 386 to Pentium I
  - Program Storage
    - HDD to Flash Drive (X)
    - Larger HDD (Z)
    - Floppy to Zip™ Drives
  - Additional I/O Capabilities



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PSBR TRIGA Console - Software

- **Generic Software Changes – SCRs**
  - SCRs are Requests from Customers to Make Generic Changes to Software
  - Y2K Issue
    - Tested Mid -1999: Mostly Compliant
    - Historical Data Storage Update Required
  - Double “Print Screen” Lockup
  - “Real-Time” Trend Lockup (t>892 Seconds)
  - Keyboard Watch-Dog SCRAM

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PSBR TRIGA Console - Software

- **Application Layer Changes**
  - Changes To Facility Configuration
    - New NBL Shielding Arrangement - Interlocks
    - Change in Maximum Fuel Temperature
    - Make Message Text Agree with Alarm Text
    - Delete Unused Logic Blocks – Legacy Equipment
    - Reorganize Pulse Mode Keystrokes
    - Add Extra Radiation Monitor Input
    - Add Name Tags for New I/O Channels

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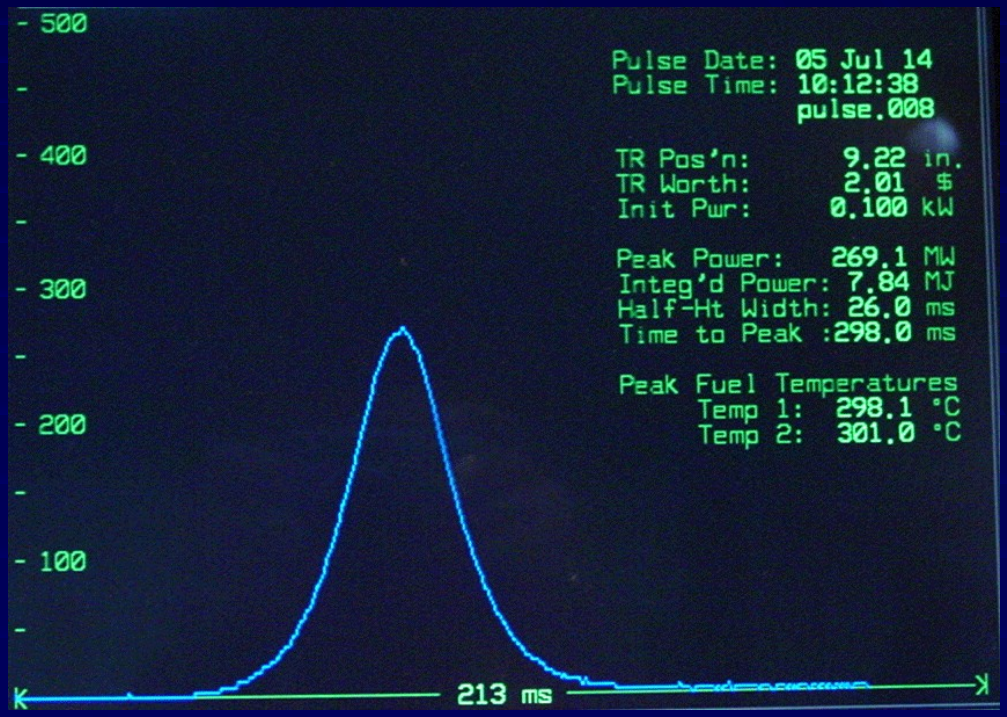
PSBR TRIGA Console - Software

- Changes to improve usability
  - Improvement of Historical Data Storage System
  - Radiation Monitor Readout in mR/hr and cpm
  - Improvement of Curve-Fit Accuracy
    - Control Rod Height to Worth Conversions
    - Pulse Power and Temperature References
  - Alarm Windows Flashing on Change of State
  - Alarm Windows “Black” for Normal Conditions
  - Add New Inputs to SSF Loop
  - Add New DCC-Z and LAN Signals

PSBR TRIGA Console - Pulsing

- 7500 Pulses Over 40 yrs
- Pulse Characteristics:
  - dk_{pulse} = \$1.00 to \$3.50.
  - FWHM = 100mS to 10mS
  - Time to Peak = 100-400mS
- Original System Could Not Capture All Values of Pulses, No Pulses < \$1.50 Were Routinely Performed
- Adjustable Parameters Added to Allow Full Range of Pulsing



PSBR TRIGA Console - Testing

- Extensive Testing Performed to Ensure That Upgrade Performed in Accordance With All Requirements
  - Testing During Work
    - AECL Software Version Control (V&V)
    - AECL Test Facility (Hardware and Software)
  - Factory Acceptance Test
    - Performed at AECL by Penn State
  - Local Testing – Test Bed
    - Testing on a Complete Mock-up of Console System During Work and Prior to Installation
  - Site Acceptance Test
    - Performed at Penn State Following Installation

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PSBR TRIGA Console - Testing

AECL Testing

- Testing During Work
  - Software: AECL vDiff Process (V&V)
    - Each Software Change Performed, Documented, Tested Prior to Next Change
    - vDiff is Software Verification And Validation Program that Documents Changes to Program Line-by-Line
  - Hardware: AECL Test Bed And Hardware Lab
    - Test Bed Comprised Actual DCC-X, Z Computers, and Some Associated I/O
- Factory Acceptance Test
  - Performed At AECL In 2003
  - Utilized AECL Test Bed
    - Covered All Changes and,
    - Some Original (1992) Testing

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PSBR TRIGA Console - Testing

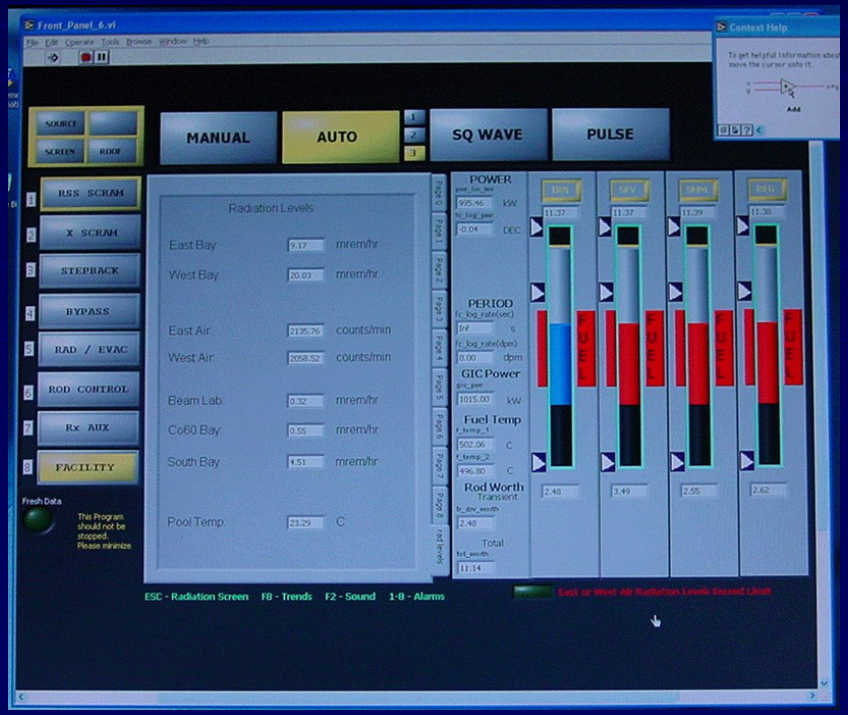
- **Local (PSU) Testing**
  - Local Testing – Test Bed
    - Tested Both DCC-X and DCC-Z
    - I/O Racks and Real or Simulated Inputs
    - Each Software Version Tested as if on Actual Console
  - Site Acceptance Test
    - Performed Initially on Test Bed
    - Performed on Console Following Installation
    - Consisted of 1992 FAT & 2003 FAT
    - Also Performed PSBR Console Surveillance and Maintenance Procedures Including Extensive Verification Of Tuning Parameters
  - Safety Analysis
    - Performed Upgrade as a “Change” Under 10CFR50.59

PSBR TRIGA Console - LAN

- **Local Area Network**
  - Provides Remote Monitoring of Reactor Parameters for Normal & Emergency Situations
  - Accessible in **Classroom** as Instruction Tool
  - Accessible in Various Other Locations in & Around Reactor Facility
  - Programmed in LabView™ By Penn State
    - Upgrades Performed On-site

PSBR TRIGA Console - LAN

- Main Screen of LAN Computer Interface Very Similar to DCC-X Computer in Appearance and Navigation
- Facility Radiation Levels Foremost on LAN to Aid in Assessing Facility Conditions from Remote Locations



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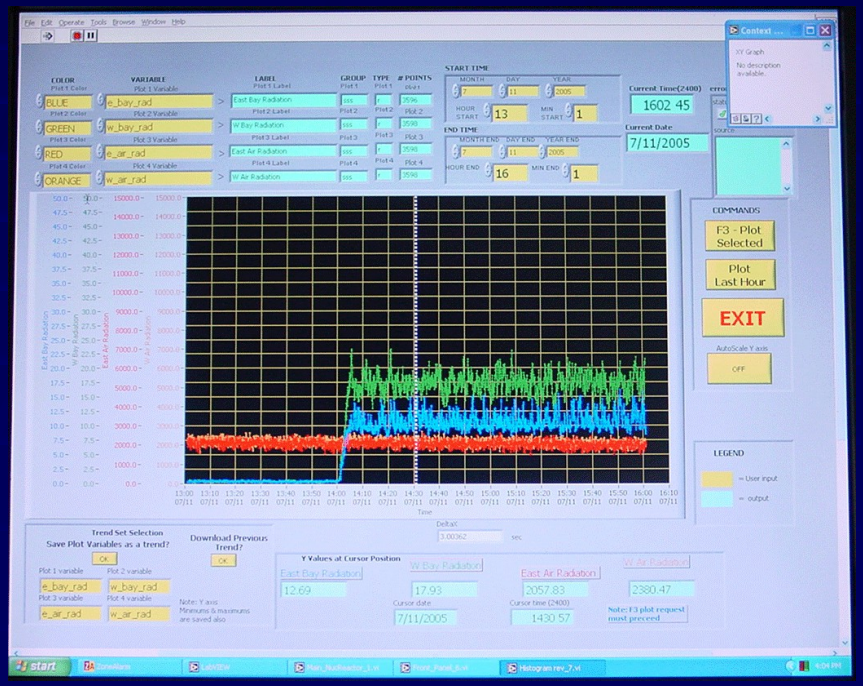
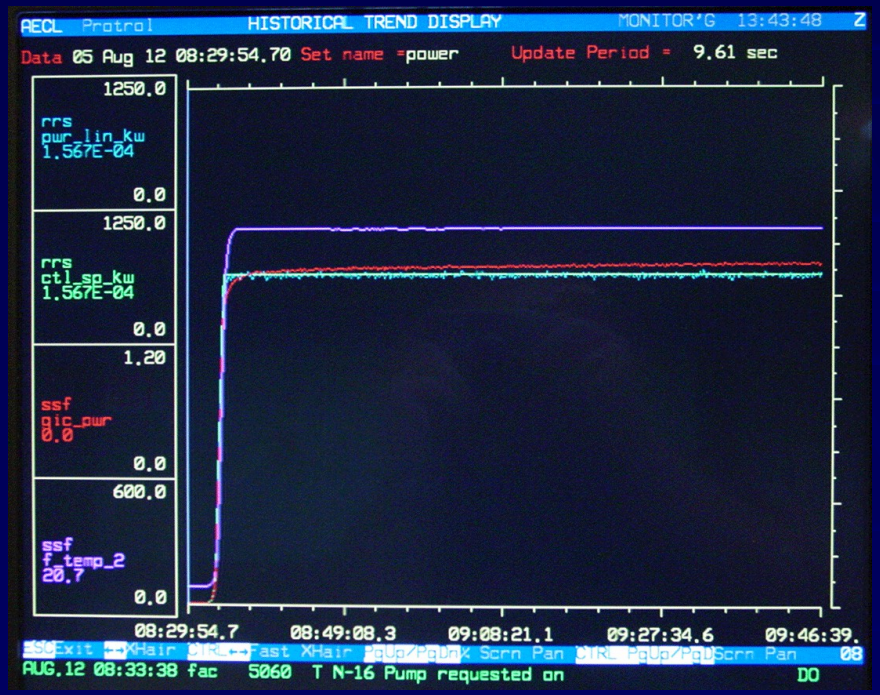
PSBR TRIGA Console - LAN

- The Historical Data screen of LAN Computer Similar To DCC-Z
- LAN is Tool for Monitoring Reactor Conditions for
  - Operator Training
  - Student education
  - Other Staff Functions





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PSBR TRIGA Console Upgrade

- Conclusion
  - Vendor Relationship with AECL Resulted in Product with High Reliability and Usefulness
  - Penn State has Experienced 13 Months of Successful Operation Following Installation
  - Four Requirements for Successful Project:
    1. Extensive Planning Prior to Project
    2. Constant Interaction with Vendor During Work
    3. Thorough Installation Plan and Safety Analysis
    4. Exhaustive Testing During and after Work