

Penn State Control System Upgrade

TRTR 2017



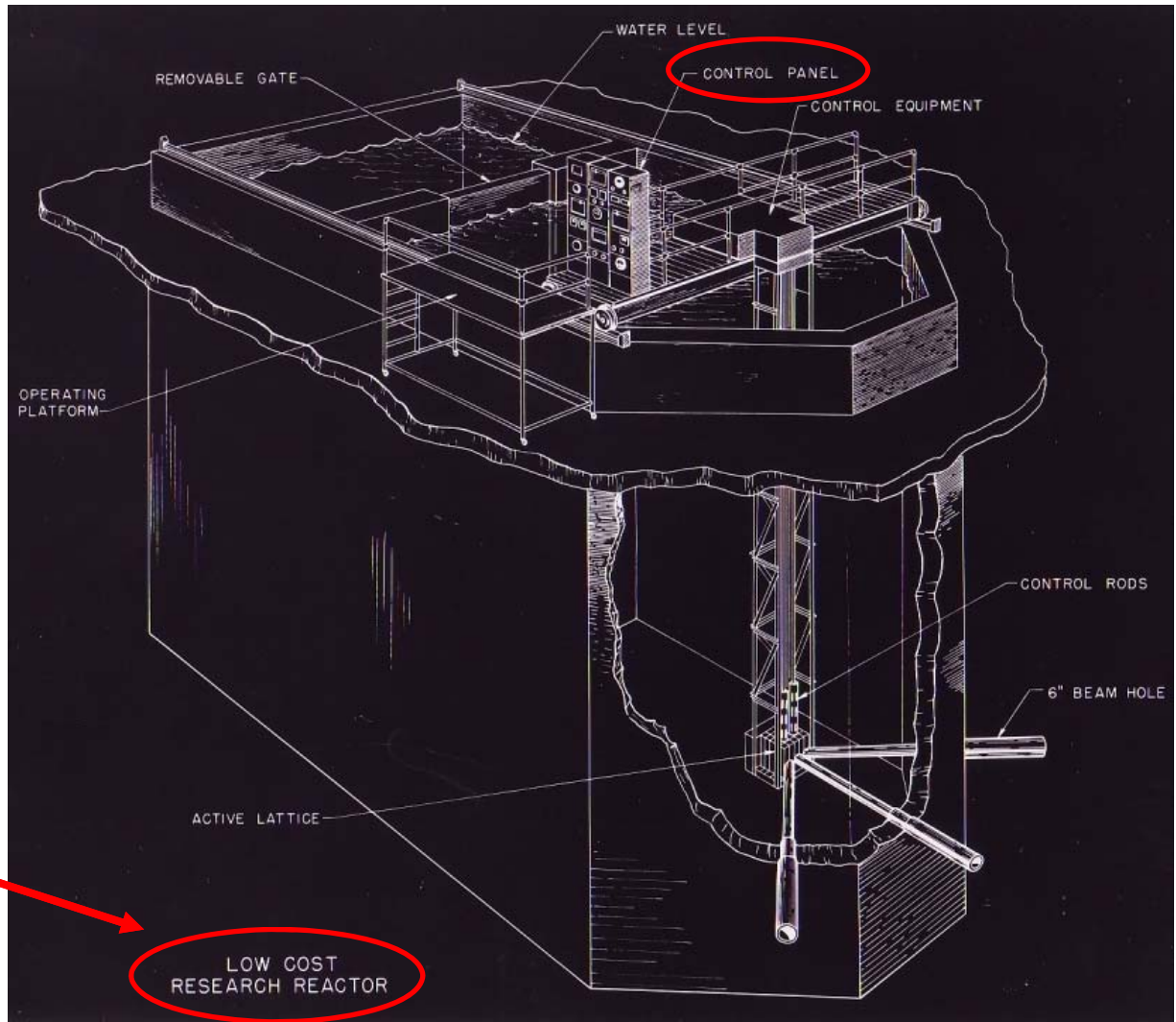
PennState

**James Turso
Assistant Director
Radiation Science and Engineering Center**

Overview

- PSBR TRIGA Description
- Existing Console
- If it ain't broke....Motivation
- New Control System
- AGARA
- Schneider Equipment Grant – Student Lab/Software Staging Area
- Preliminary Schedule

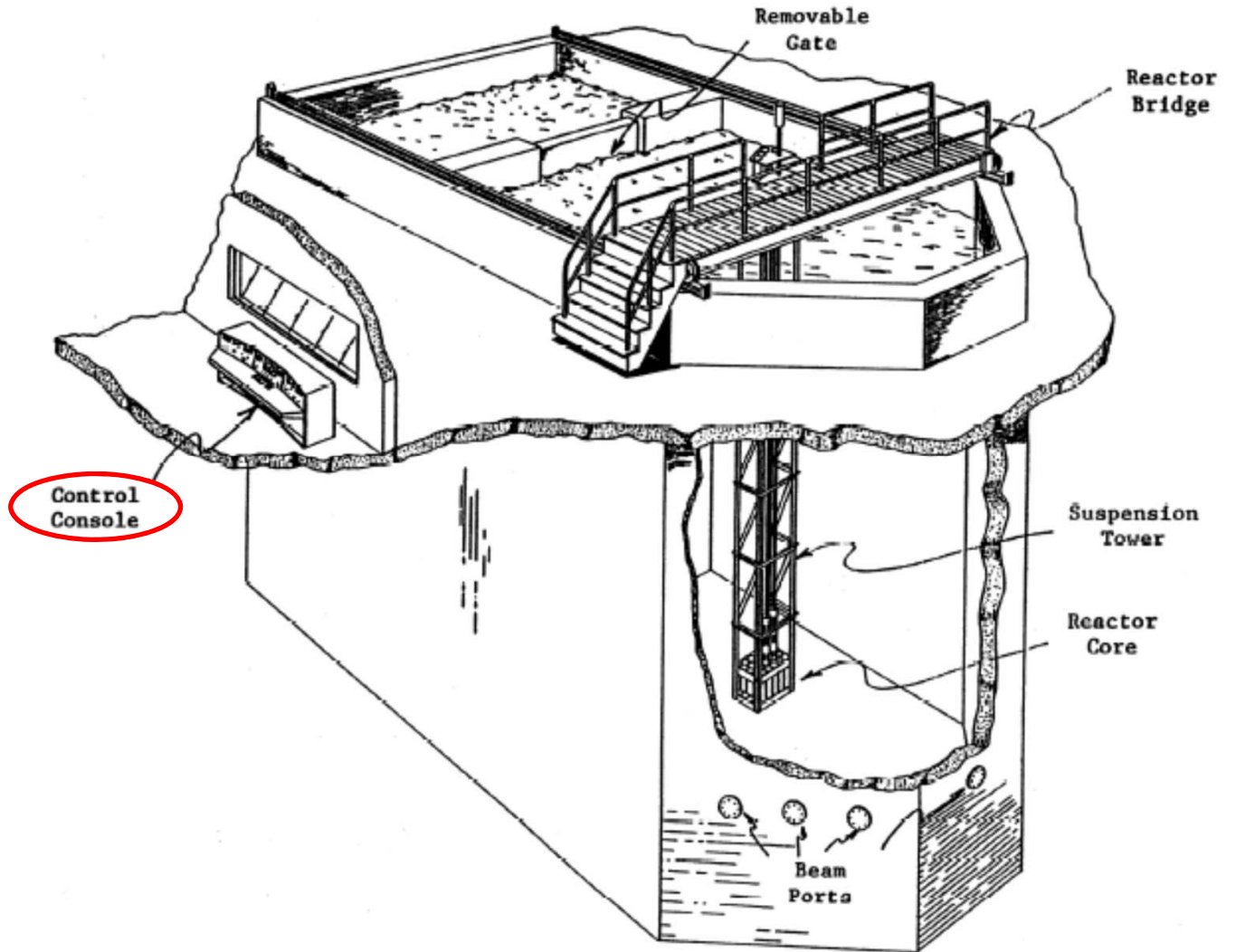
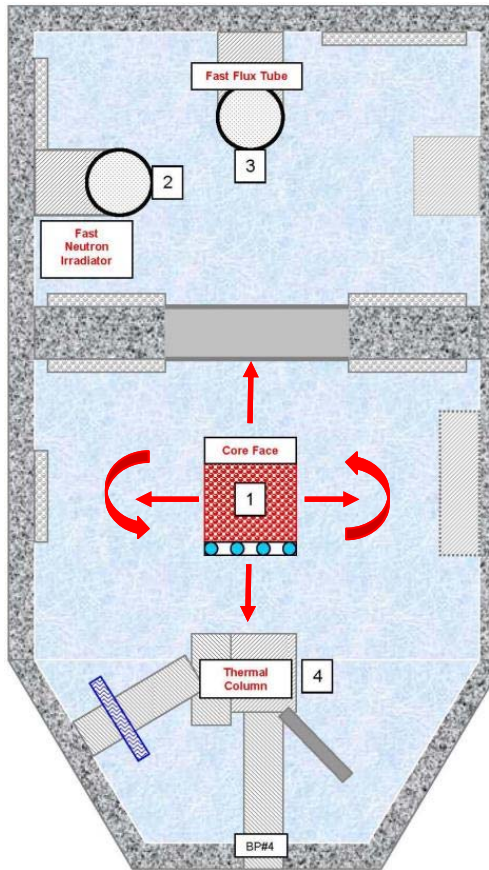
PSU TRIGA



Good
Old Days...

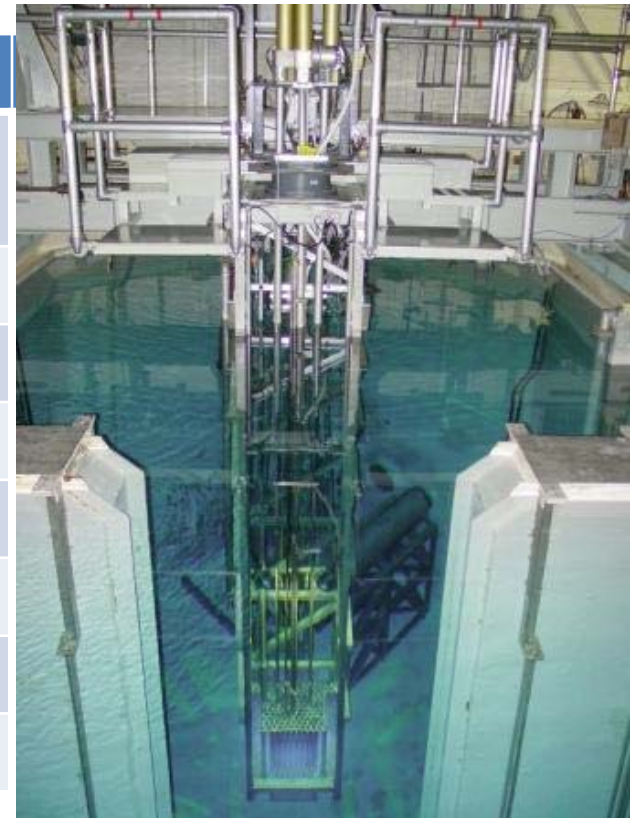


PSU TRIGA



PSU TRIGA SPECIFICATIONS

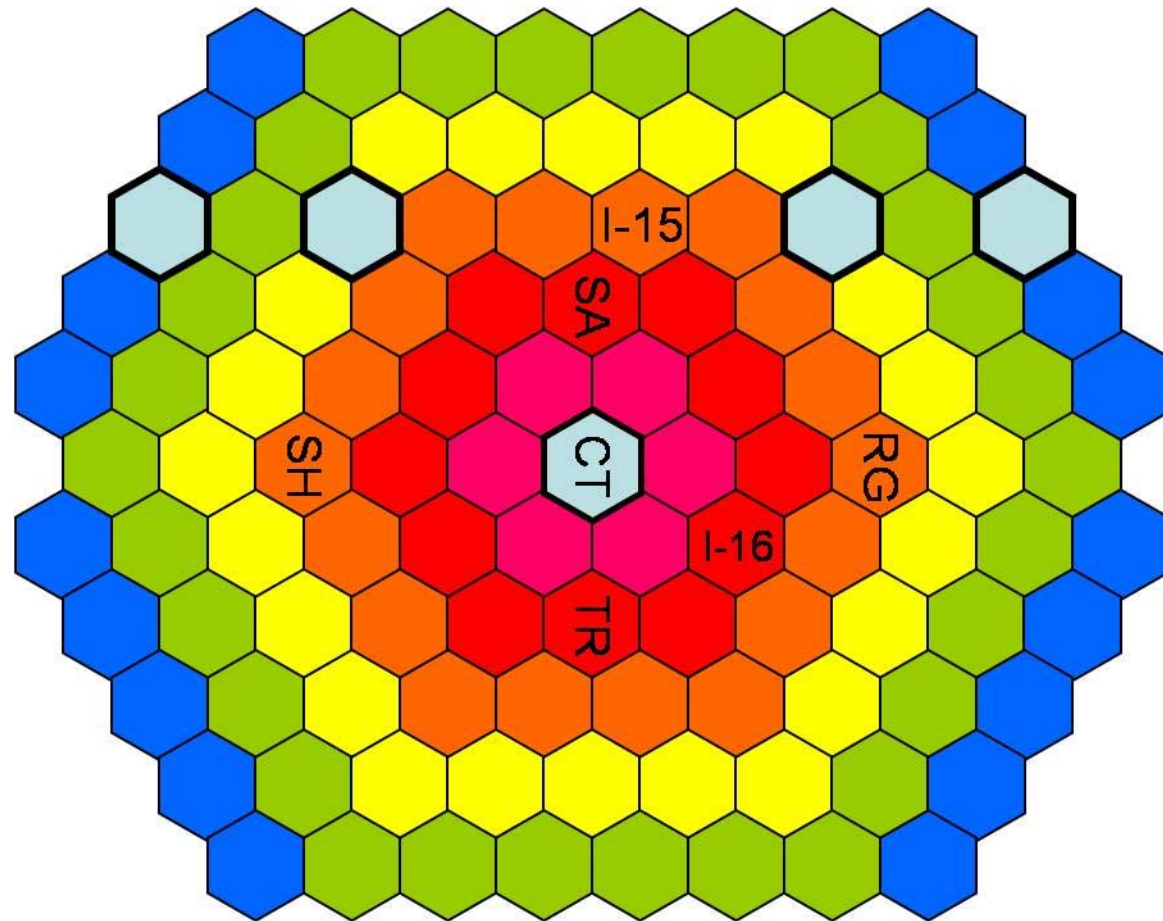
	TRIGA
Purpose	Research and Education use of radiation
Thermal Power	1 MW _{th}
Fuel Design	
Enrichment – U235	< 20%
Physical Size	~0.8 m
Fuel Matrix	Uranium metal
Primary moderator	Zr ₁ H _{1.65}
Cladding	Stainless Steel



PSU TRIGA CORE MAP

2 Dry irradiation tubes
1 wet irradiation tube
1 source location

4 Control Rods
2 inst. Elements



Existing AECL System... Installed 1991

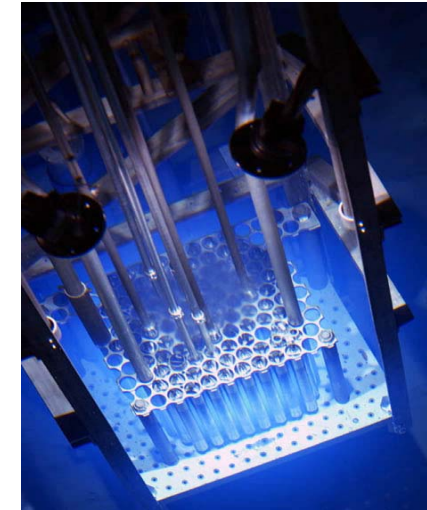
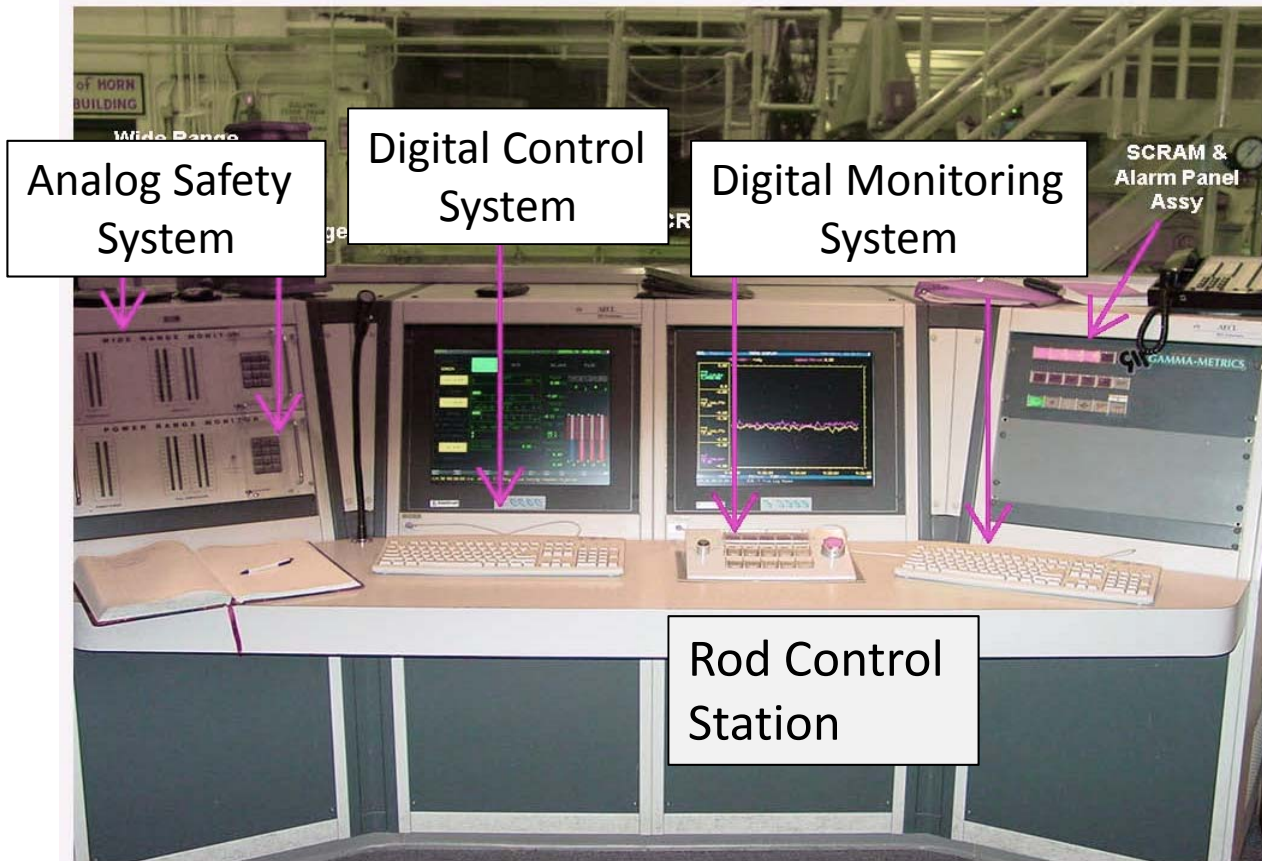
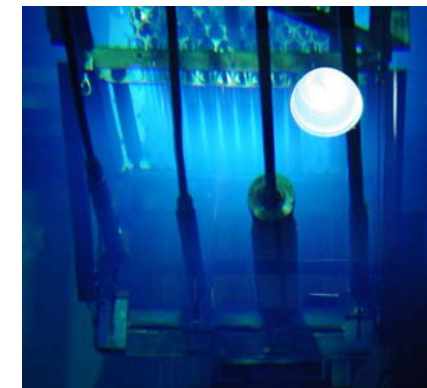
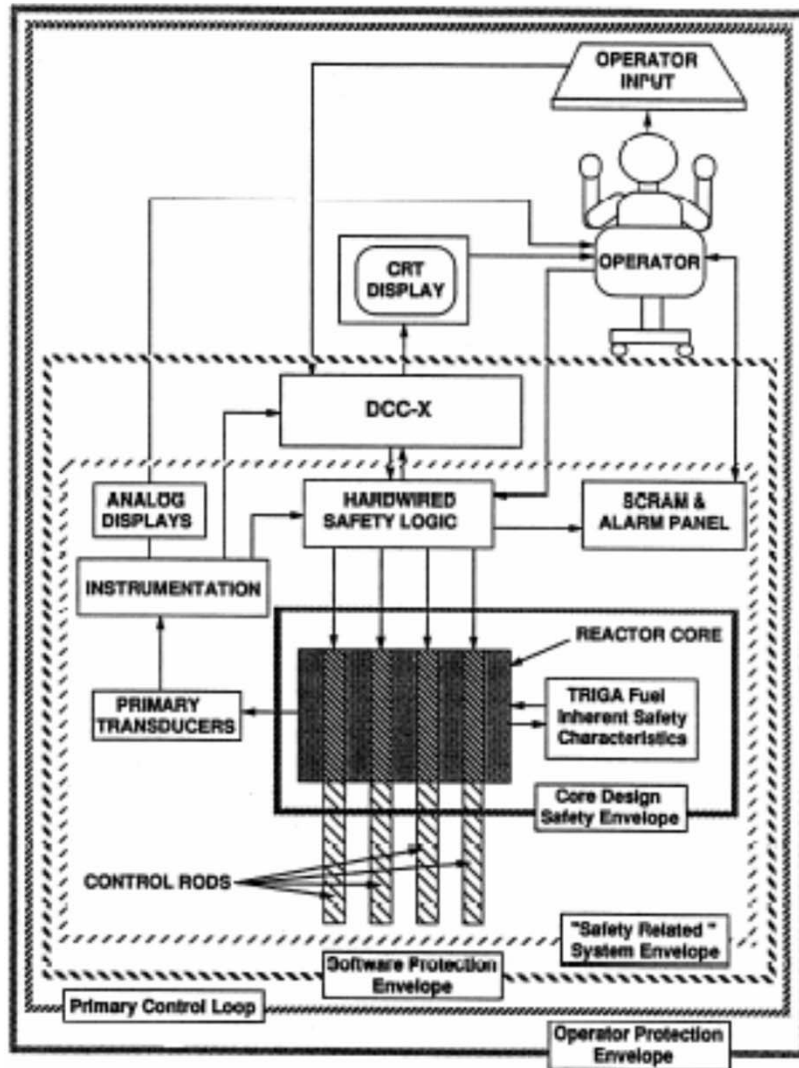


Figure 1 – The U2RR reactor Core.



Safety System: TRIGA Fuel



3. DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

3.1 Design Criteria

The major design feature criterion to protect the safety of the public is the physical mechanisms and characteristics of the stainless steel clad TRIGA fuel elements (see section 4.5). The facility confinement (see section 6.2.1) and facility emergency exhaust system (see section 13.1.1, Engineered Safety Features) are adequate to help mitigate any airborne environmental release and limit any significant hazard to the public.

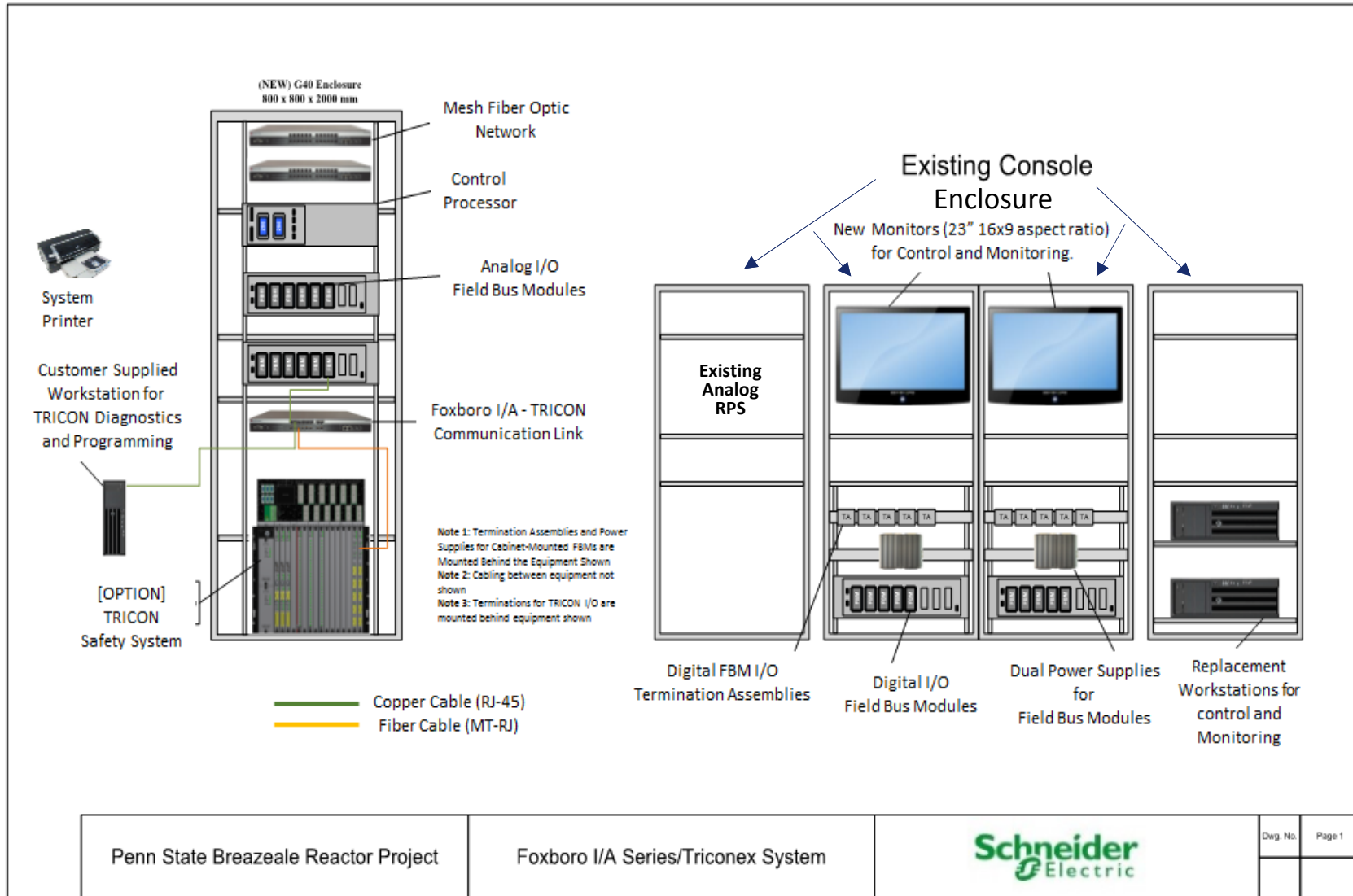
3.5 Systems and Components

Reliance on the safety of the TRIGA fuel precludes the need for reliance upon other systems, structures, and components to ensure the safety of the general public. The emergency exhaust system would mitigate the consequences of the MHA (section 13.1.1) but is not required to be operable when the reactor is secured (see section 7.5).

PSU Control System Replacement

- AECL Console: Outstanding Performance for 26 years
- Still Operating: OEM No Longer Supports/Software Upgrades Costly
- PSU Pursuing Obsolescence Upgrade (Replacement of Digital Components) - \$1M DOE Grant
- Keep Analog Safety System (Initially)
- Replace Digital Control System (50.59)
- Phase-In 1E Digital Safety System (License Amendment)

New Control Console



PSU Control System Replacement – Other Goals:

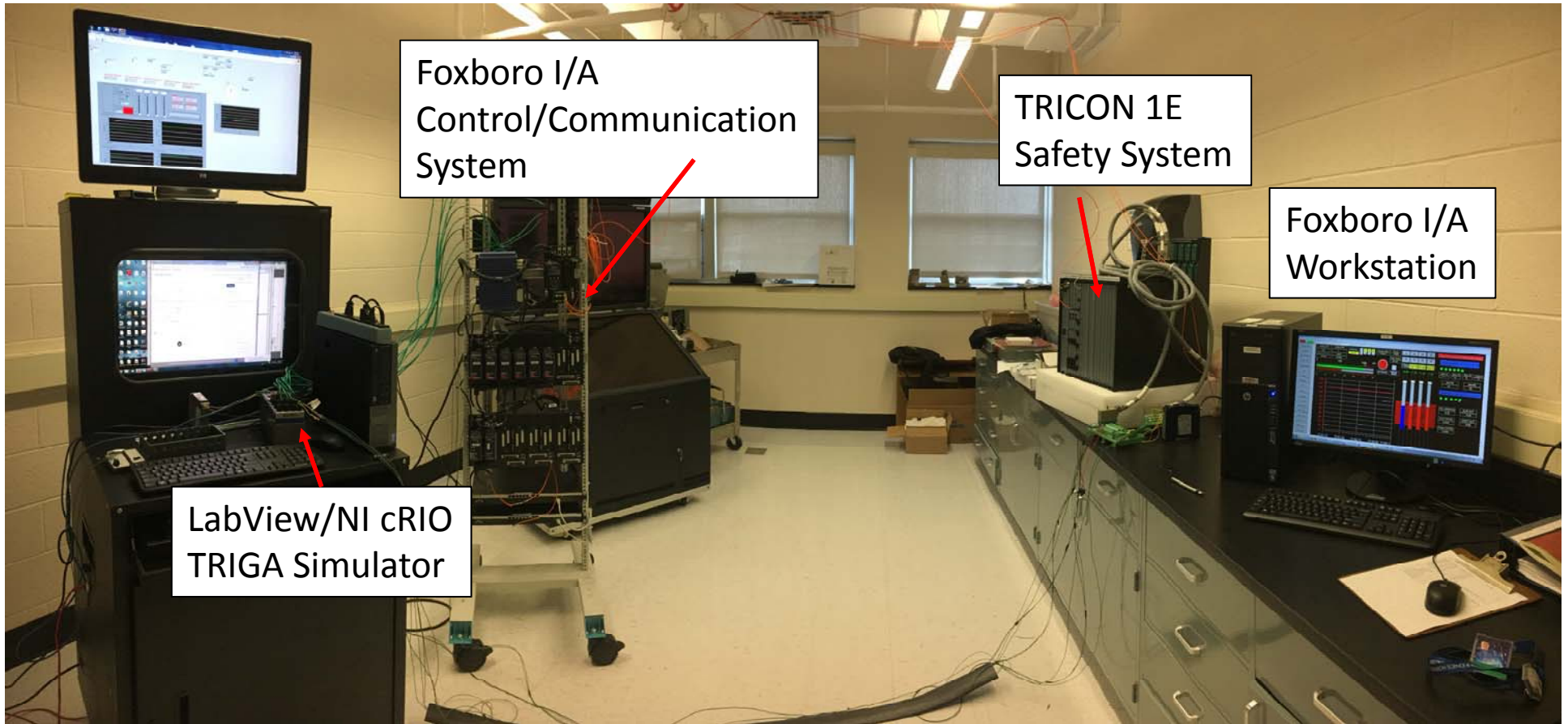
AGARA

(As Generic As Reasonably Achievable)

Share Project Artifacts With TRTR Community:

- Regulatory Documents (50.59 Screening/Evaluations)
- Design Documents/Schematics/BOM
- Software
- License Amendment Documents / SAR Upgrades

Foxboro Control and Monitoring System Potential Replacement for PSU System \$300K Equipment Donation



Familiarization Through Senior Design Projects



Design and Implementation of PSBR Control Console Replacement

Ryan Arblaster, Gokhan Corak, Justin Montio, Austin Nosal
 Advisors: Dr. Jim Turso (Faculty), Ryan Marcum (TRICON), Timothy Frost (Foxboro)
 Facilitated By: Penn State Radiation Science and Engineering Center



Introduction

- The current digital control system at the PSBR was installed in 1991 by AECL (Fig. 1)
- Due to its age, this product is no longer supported by the manufacturer and is becoming obsolete



Motivation

- A new and robust control system is needed to replace the aging technology currently installed
- This project is a proof of concept that the Foxboro Digital Control System is a viable replacement candidate
- The RSEC believes that the technology that we are testing will be used in the future for the inevitable control system replacement

Project Summary

- The design team was able to complete four main goals (shown to right) throughout the project duration
- This project has shown that the Foxboro Software is a good replacement candidate for the current PSBR control system
- Added control rod pushbutton functionality for manual operator control is still required
- More time is also required for controller gain adjustments to reduce overshoot and decrease settling time



Main Design Goals

PSBR Model Validation

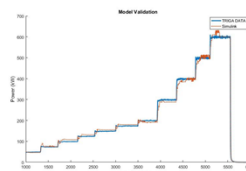


Figure 2: Simulink Model vs. PSBR data

- Reactor physics model was created in Simulink and validated against PSBR operational data (Fig. 2)
- The validated model was translated to LabVIEW I/O system which was used for reactor simulation (Fig. 3)

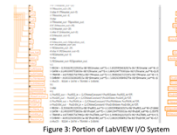


Figure 3: Portion of LabVIEW I/O System

Power and SUR Control

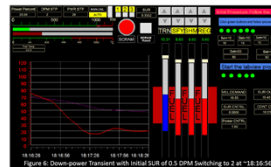


Figure 6: Down power Transient with Initial SUR of 0.5 DPM Switching to 2 at 18:15:56

- Two separate PI controllers allow the user to select both the power set point and the rate of power change. Figures 6 and 7 show a down and up power transient respectively

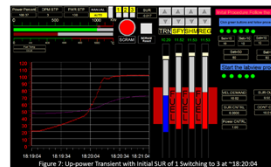
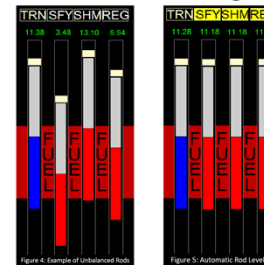


Figure 7: Up power Transient with Initial SUR of 1 Switching to 3 at 18:20:04

Control Rod Leveling



- Previous Foxboro system would track to power set point but control rod height was not forced to level (Fig. 4)
- This caused the rods to hold total worth but move in opposite directions. This behavior would result in flux tilting within the core, decreasing reactor safety
- A feature was added that would level out the control rods which were under automatic control (Fig. 5)

TRICON Safety System



Figure 8: TRICON Chassis



Figure 9: TRICON Input Dock

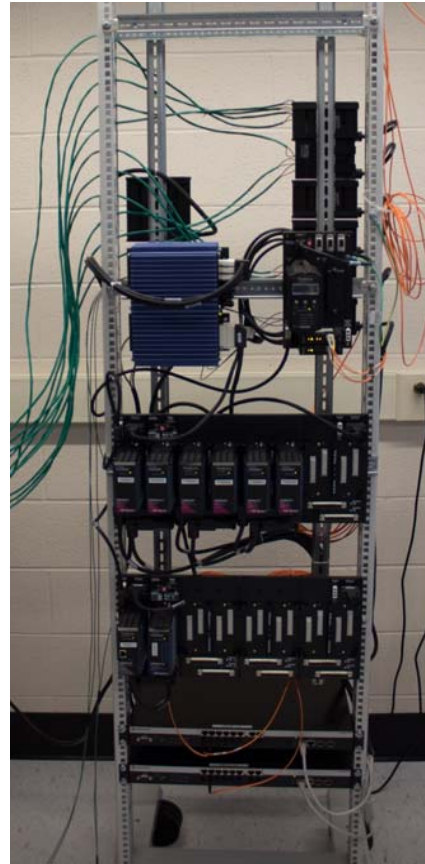
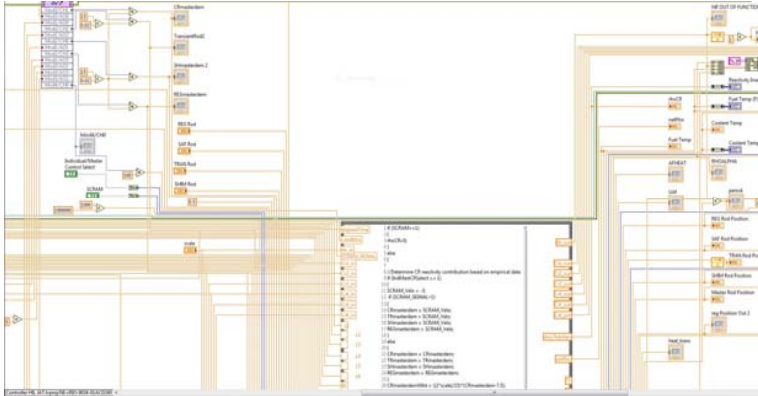


Figure 10: Foxboro Signal Processing Tower

- The TRICON safety system (Fig. 8) was used to implement a reactor SCRAM if unsafe conditions were met (i.e. over-power)
- Signals from the Foxboro and LabVIEW digital systems were converted to an analog signal and sent to the TRICON Input Dock (Fig. 9)
- Signal conversion is done in the Foxboro Signal Processing Tower so that the Analog and Digital components can communicate (Fig. 10)

Foxboro Control and Monitoring System Potential Replacement for PSU System

LabVIEW Reactor Simulator



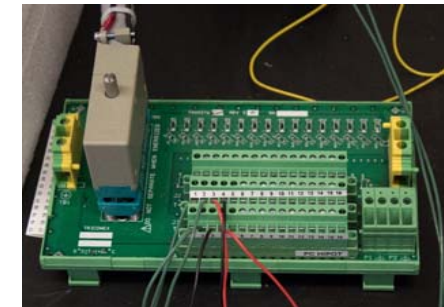
Foxboro System



TRICON System Chassis



Foxboro Control
Workstation



TRICON I/O Connector
Block

LabView HIL cRIO-Based Simulator

**PKE – Based
Neutron Dynamics**

$$\frac{dn(t)}{dt} = \frac{(\rho - \beta) * n(t)}{\Lambda} + \frac{\sum_{i=1}^{i=6} \beta_i C_i(t)}{\Lambda}$$

**Delayed Neutron
Precursor Dynamics**

$$\frac{dC_i(t)}{dt} = \lambda_i(n(t) - C_i(t))$$

**Thermal Power
Produced in Fuel**

$$\dot{Q}_{fuel} = P_{average\ fuel\ element} \times n(t)$$

**Fuel Temperature
Dynamics**

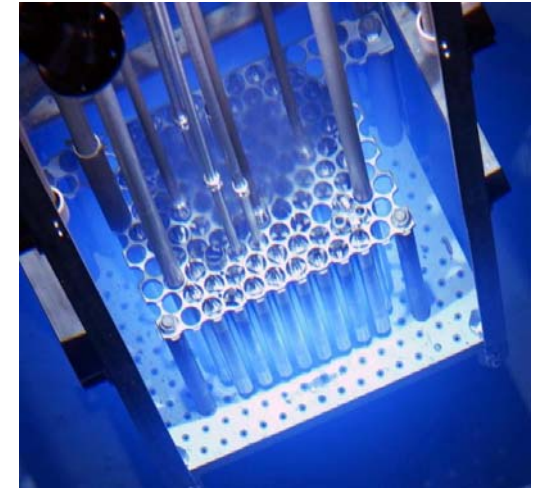
$$M_f C_f \frac{dT_f(t)}{dt} = \dot{Q}_{fuel} - U_f A_f (T_f - T_c)$$

**Coolant
Temperature
Dynamics**

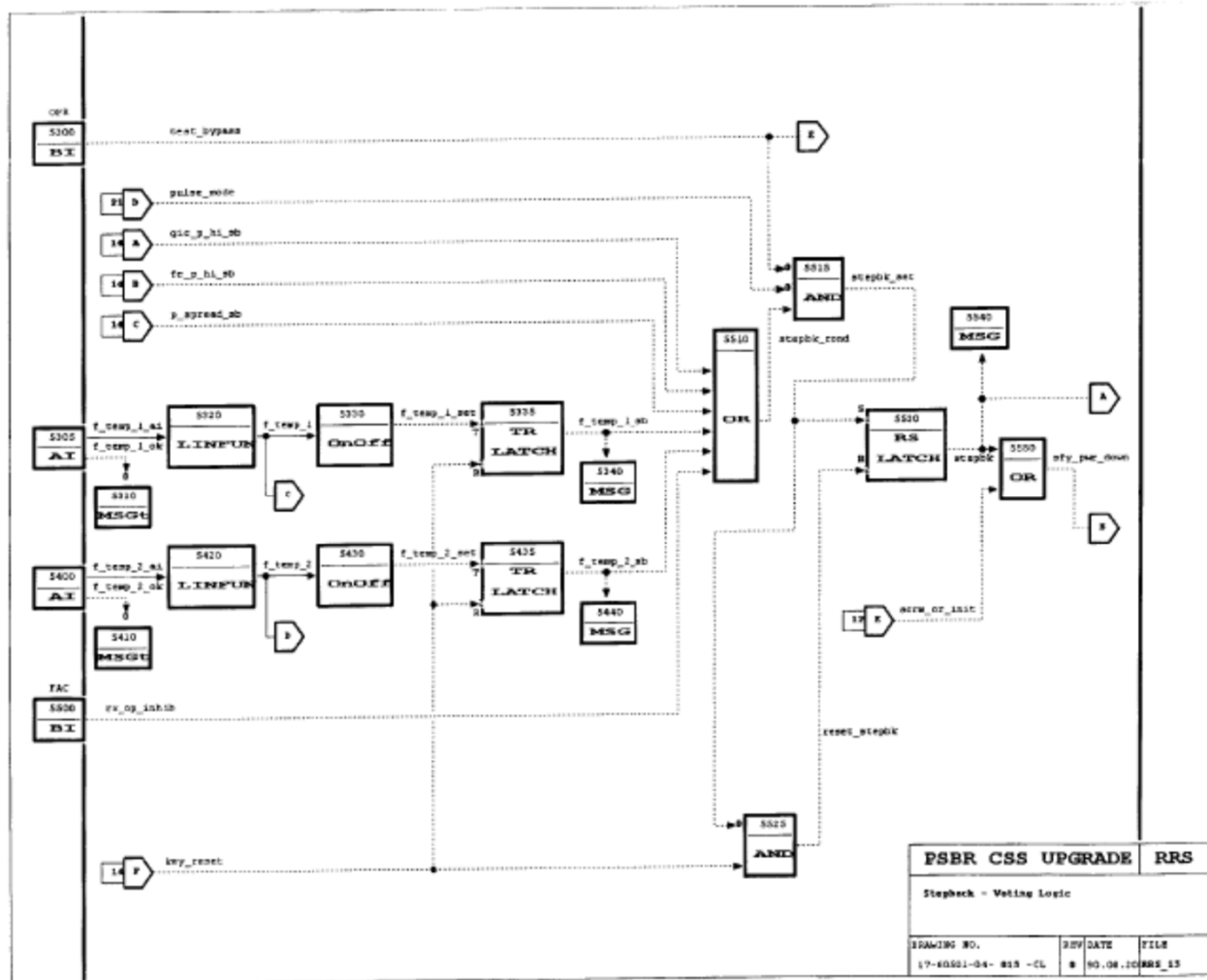
$$M_c C_c \frac{dT_c(t)}{dt} = U_f A_f (T_f - T_c) - 2\dot{m}_c C_{cp} (T_c - T_{into\ core})$$

Reactivity Feedback

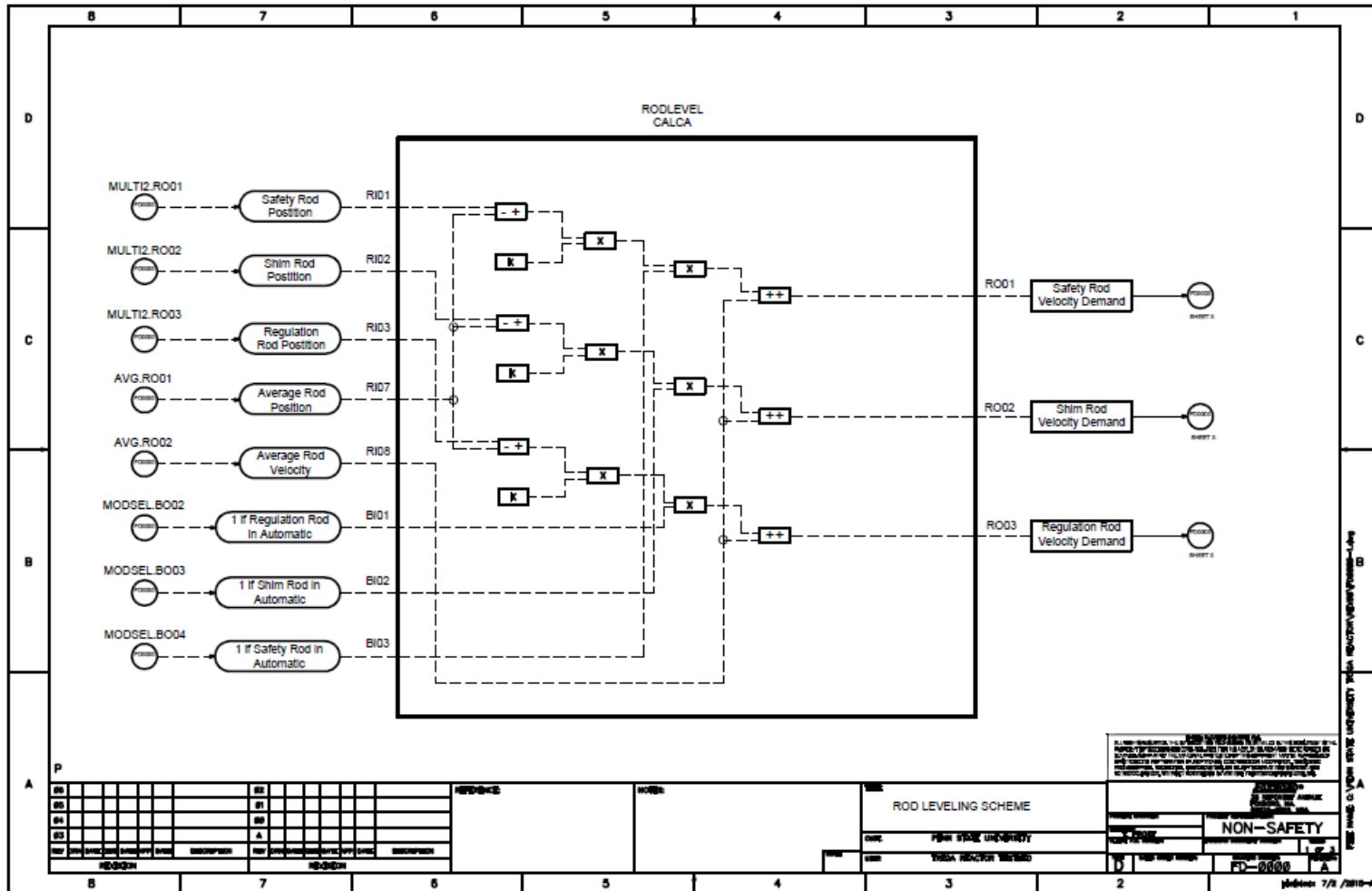
$$\rho_{net} = \rho_{rods} + \alpha_f (T_f - T_o) + \rho_{fission\ products} + \rho_{shutdown}$$



Existing AECL Console Programmed With PROTROL Configuration Software



Foxboro System Programming Integrated Control Configurator



Foxboro System Programming Integrated Control Configurator

```

FOXBORO: Integrated Control Configurator
HELP  SHOW  FBM  PRINT  NEW  CHECKPOINT  MAINT  BUFFER  EXIT
Integrated Control Configurator  Active  STA = FCP001 @PSU001
JUSTIN  Block Definition:
END ECB***  Name:  CONT
REGIN      Type:  PIDA
REGOUT     RSP   JUSTIN:MULTI.R002
SWCHREG    LR    0
AVG        INITLR 2
RODLEVEL   LOCSP 0
RODSEL     LOCSW 0
MODESEL    REMSW 0
VFINAL     MODOPT 4
SIGNAL     INCOPT 0
PISW       PBAND 250
SHIMIN     INT    0.125
SCRAMRESET DERIV 0
SCRAM      KD     10.0
SHIMOUT    SPLLAG 1.0
JATOUT     DTIME 0.0
RODPOSIN   FILTER 0.0
SURPIDA    NONLOP 0
CONT       HZONE 100
SWCHSHIM   LZONE 100.0
SWCH       KZONE 1.0
Done  Cancel
  
```

```

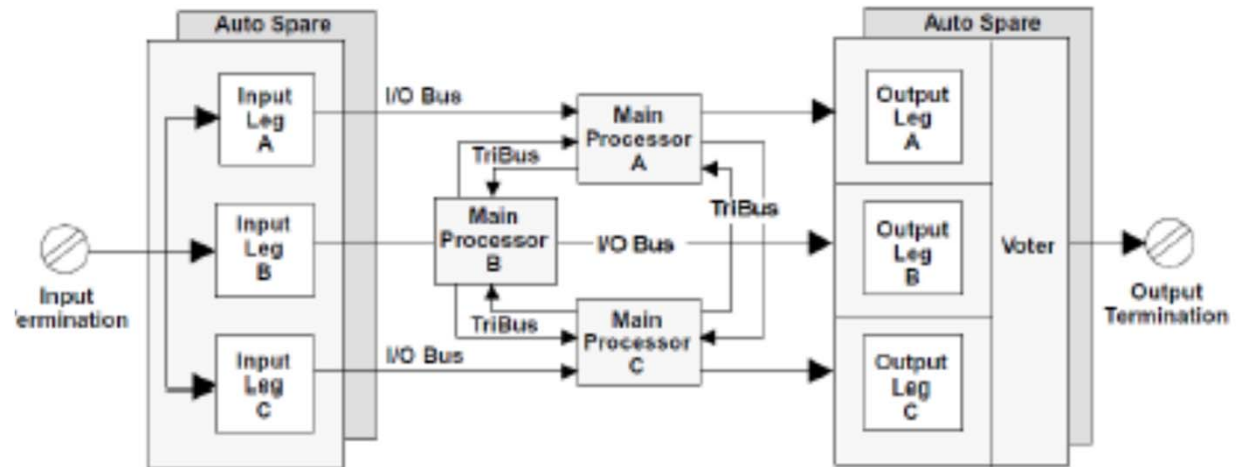
FOXBORO: Integrated Control Configurator
HELP  SHOW  FBM  PRINT  NEW  CHECKPOINT  MAINT  BUFFER  EXIT
Integrated Control Configurator  Active  STA = FCP001 @PSU001
JUSTIN  Block Definition:
END ECB***  Name:  SWCH
REGIN      Type:  SWCH
REGOUT     DESCRP
SWCHREG    PERIOD 9
AVG        PHASE 0
RODLEVEL   LOOPID
RODSEL     PROPT 0
MODESEL    EROPT 1
VFINAL     INP1 100
SIGNAL     HSCI1 100.0
PISW       LSCI1 0.0
SHIMIN     DELTI1 1.0
SCRAMRESET EI1    %
SCRAM      INP2 0.0
SHIMOUT    HSCI2 100.0
JATOUT     LSCI2 0.0
RODPOSIN   DELTI2 1.0
SURPIDA    EI2    %
CONT       TOGGLE JUSTIN:CALCA.B001
SWCHSHIM   HSC01 10.5
SWCH       LSC01 9.5
Done  Cancel
  
```

TRICON 1E Safety System

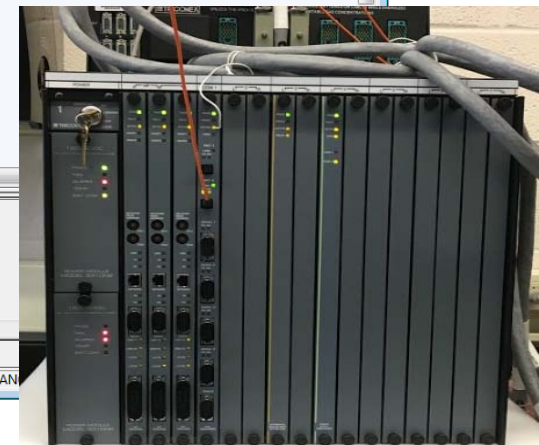
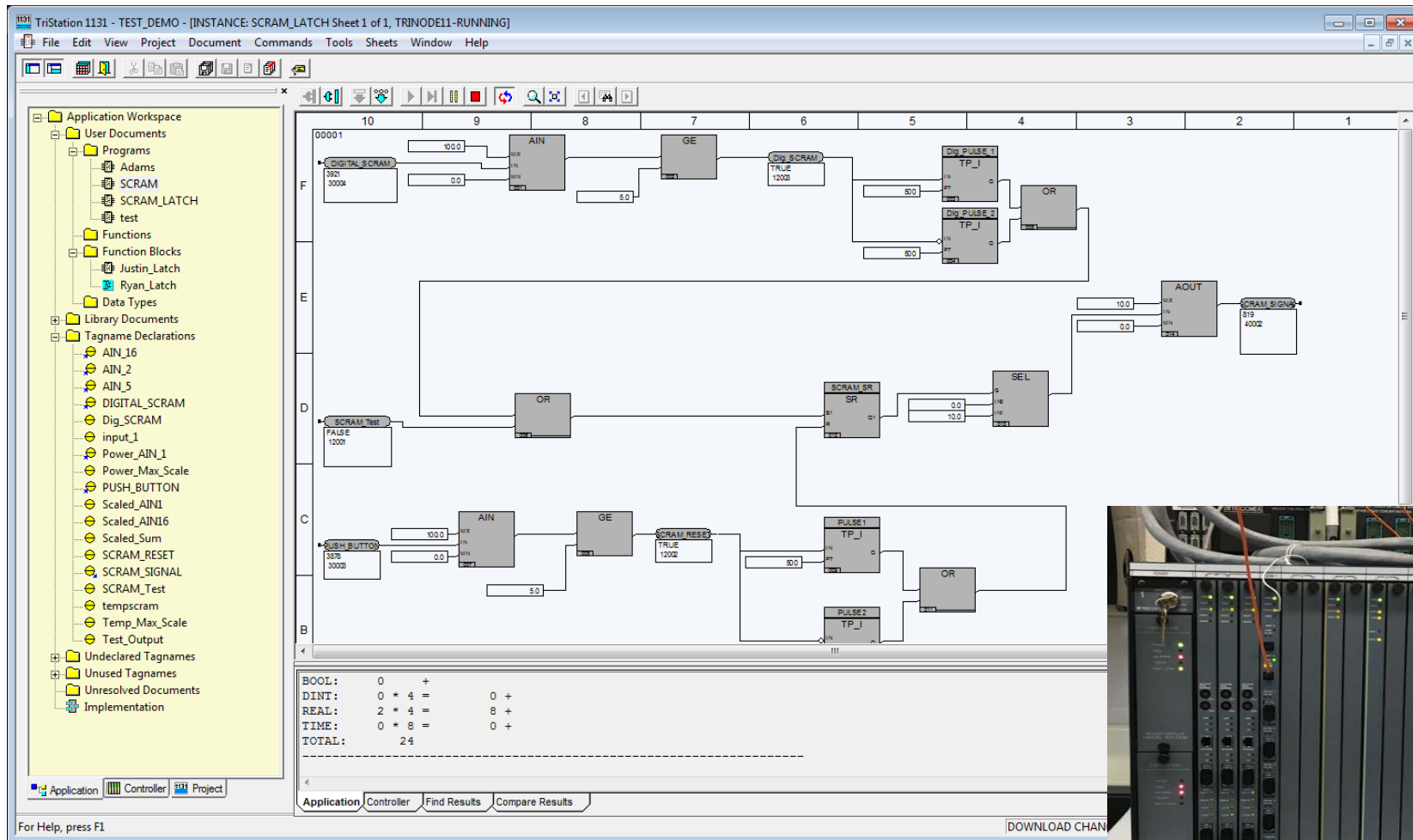


TRICON Enclosure

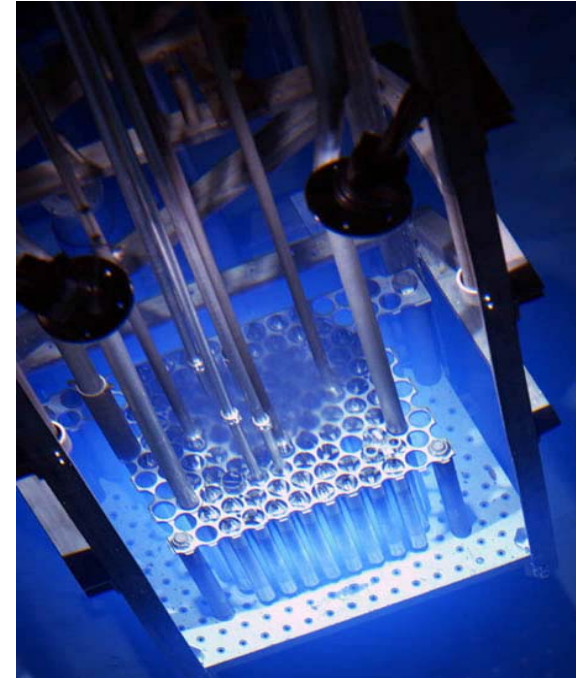
TRICON: Triple Redundant Architecture



TRICON 1E Safety System Programming



Work With GSE Systems to Develop 3D RELAP-Based Hardware-In-The-Loop Test Bed for New Console



[Figure 1](#) – The U2RR reactor Core.

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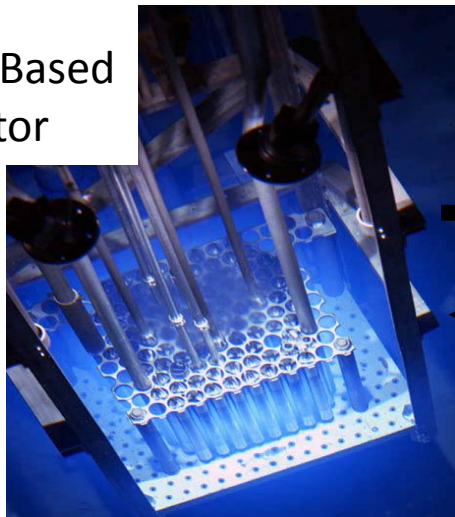
Operator Station



Digital Control System



3D RELAP-Based Simulator



Power,
Temperature
signals from
Reactor



Velocity DMD
To CRDM



[Figure 1](#) – The U2RR reactor Core.

PSU Console Replacement Timeline

October 2015: Received Equipment Grant from Schneider Electric (Foxboro I/A and TRICON systems)

Spring 2016/2017: 2 Student Senior Design Groups Implemented Existing Console's Algorithms in Foxboro/TRICON Equipment

September 2017: Received DOE Grant for PSU Control System Modernization

December 2017: Develop Project Requirements/SOW

June 2018: Contract Award / Project Kick-Off

September 2019: Factory Acceptance Tests, Foxboro MA

January 2020: Delivery of System to PSU/Beginning of Site Acceptance Tests

May 2020: Disassembly of Old Console / New Console Installation


July 2020: Testing/Commisioning of New Console

Triconex
by Schneider Electric

Foxboro
by Schneider Electric

Design and Implementation of PSBR Control Console Replacement

Ryan Arblaster, Gokhan Corak, Justin Montio, Austin Nosal
Advisors: Dr. Jim Turso (Faculty), Ryan Marcum (TRICON), Timothy Frost (Foxboro)
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RADIATION SCIENCE & ENGINEERING CENTER

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Figure 1: Existing Graphical User Interface

Main Design Goals

PSBR Model Validation

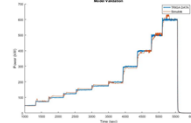


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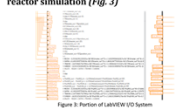


Figure 3: Portion of LabVIEW I/O System

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Control Rod Leveling

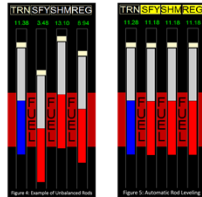


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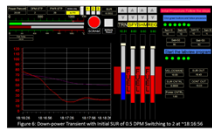


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TRICON Safety System

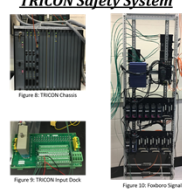


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TRICON Input Deck






Figure 9: TRICON Input Deck



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College of Engineering



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