Demonstrating Autonomous Control, Remote Operation, and Human Factors for Microreactors Under Prototypic Conditions in PUR-1

NEUP Project 22-26910

2023 Microreactor Program Review

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Goals & Objectives

Goal: Experimentally validate autonomous control and demonstrate its use by remotely operating and controlling PUR-1.

Objectives:

1. Develop a modular autonomous control platform with various levels of automation using a remote workstation with AI/ML algorithms
2. Train AI/ML using physics-based microreactor models and real-time digital operation data collected from PUR-1
3. Perform testing and evaluate performance

Team Info

- **Purdue**
  - Stylianos Chatzidakis (Assistant Professor and Associate Reactor Director, SRO)
  - True Miller (Reactor supervisor, SRO)
  - Brian Jowers (Electronics/I&C reactor staff, RO)
  - Konstantinos Vasili (Grad student – AI/ML)
- **UNM**
  - Mohamed El-Genk (Professor)
  - Timothy Schriener (Research Assistant Professor)
- **Collaborators**
  - Robert Ammon (Curtiss-Wright)
  - Rick Vilim (ANL)
- **TPOC**
  - Ben Baker (INL)

PUR-1 Fully Digital I&C

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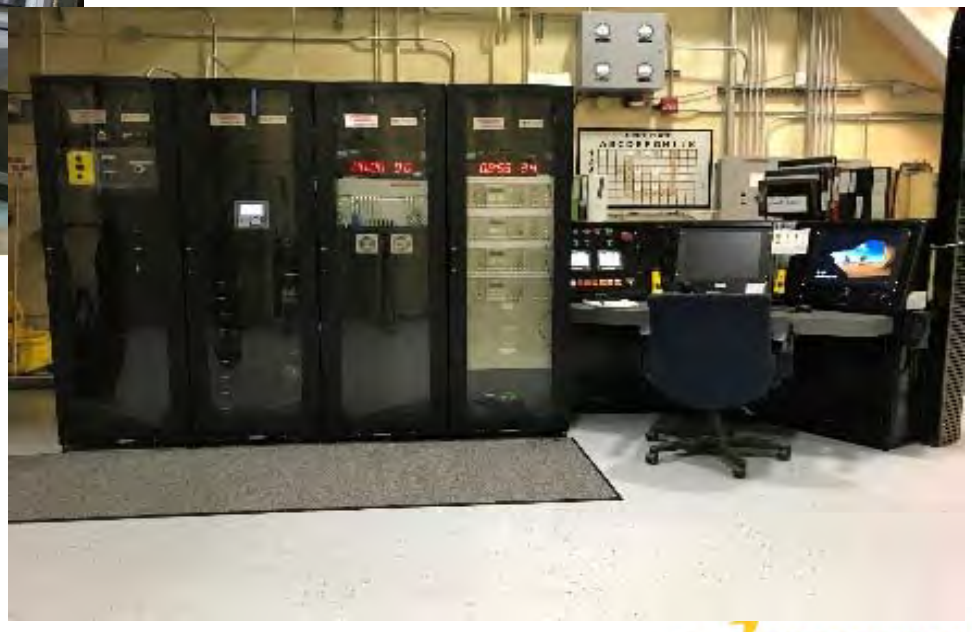
RADIATION IMAGING AND NUCLEAR SENSING LABORATORY

Before and after…

1960 - 2017

2019 - present



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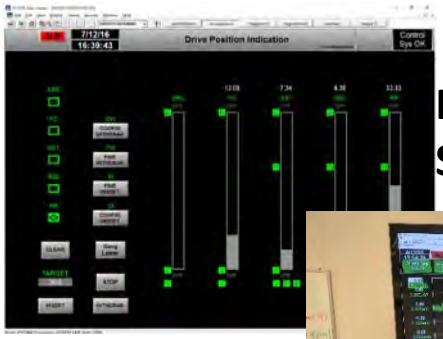
Remote Monitoring



Remote Monitoring and Simulation Station

TCP/IP communications

PUR-1 Facility

Remote location

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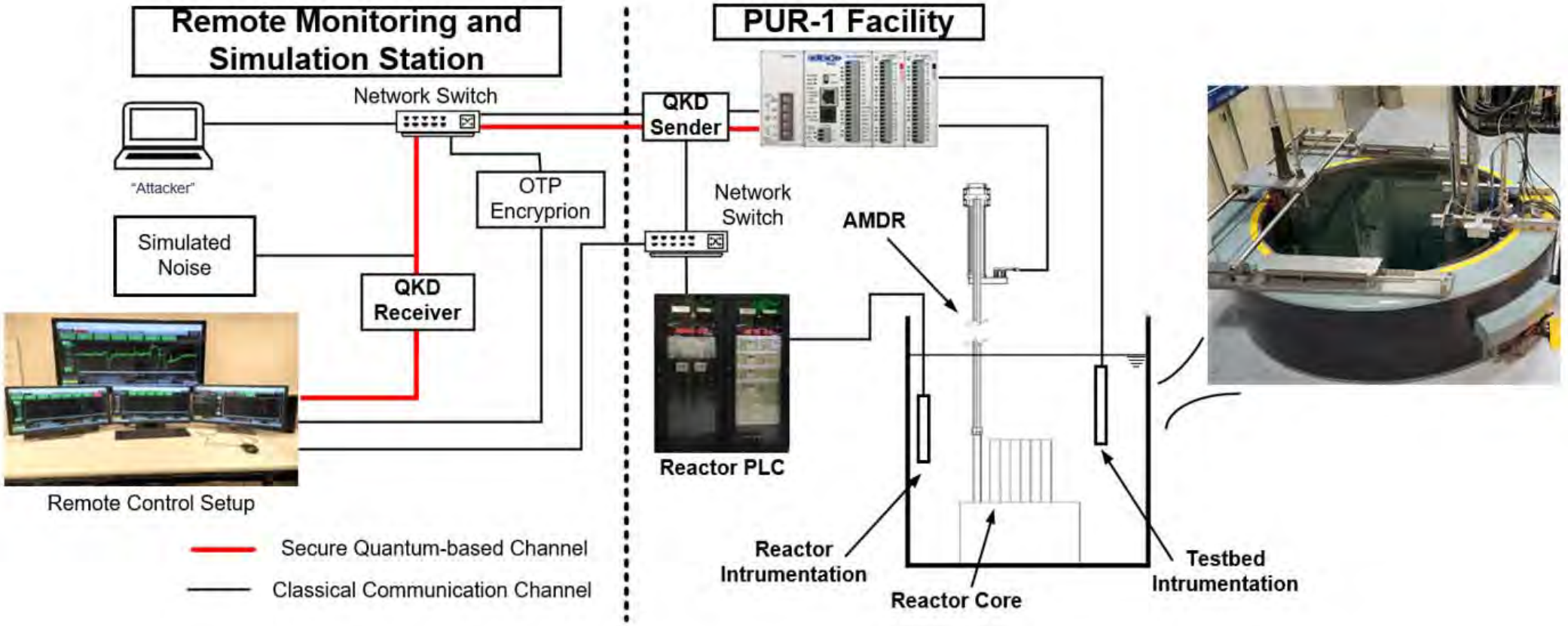
Digital Twin Testbed



Instrumentation & Control

- **Instrumentation**
  - 4 neutron detectors (FC, UIC, CIC) => cps, % power, change rate
  - 3 radiation area monitors (mR/hr)
  - 1 air monitor (Ci/m3)
  - Water chemistry (oC, µS/cm), confinement pressure (kPa)
- **Control**
  - RTP 3000, Ethernet-TCP/IP communications
  - R-Time (sampling rate up to 1 kHz)
- **Archived data (process, network, and host)**
  - All instruments, operator actions, alarms, shim and reg rod positions, source position, HVAC, magnet, pump current/voltage, etc.
  - PLC, UPS (battery status, freq, V, A), and system diagnostics
  - Network traffic (bandwidth, packet analysis, etc.)
  - Engineering workstation host system processes

Normal and Abnormal States

- **Normal operation/state**
  - Startup procedure
  - Any power level up to 100% (up to 2% change rate per supervisor guidance)
  - Irradiations
  - Shutdown by gang lower or SCRAM
  - Multiple operators
- **Simulated abnormal states (tentative)**
  - Power excursion (ramp up > 2%, alarm @6%), modify critical rod positions, etc.
  - Oscillations (e.g., equipment degradation), unusual power levels
  - Equipment on/off (pump, HVAC, temperature increase)
  - Cyber
    - Eavesdropping (e.g., process and operation data)
    - Data exfiltration (e.g., Monju type attack, steal host system data)
    - DoS (e.g., Davis-Besse, Browns-Ferry)
    - False data injection (e.g., Stuxnet type replay attack, data tampering)
  - Multiple scenarios (e.g., DoS for distraction+replay attack+oscillations)

Project Schedule & Tasks

	Task	Year											
		1st				2nd				3rd			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Architecture Development and Training of ML/DL Algorithms												
1.1	Architecture Development												
1.2	Training of ML/DL Algorithms												
2	Testing and Demonstration on PUR-1												
2.1	Testing and Demonstration on PUR-1												
3	Performance Evaluation and Licensing Gap Analysis												
3.1	Performance Evaluation and Vulnerability Assessment												
3.2	Microreactor Regulatory Licensing Gap Analysis												

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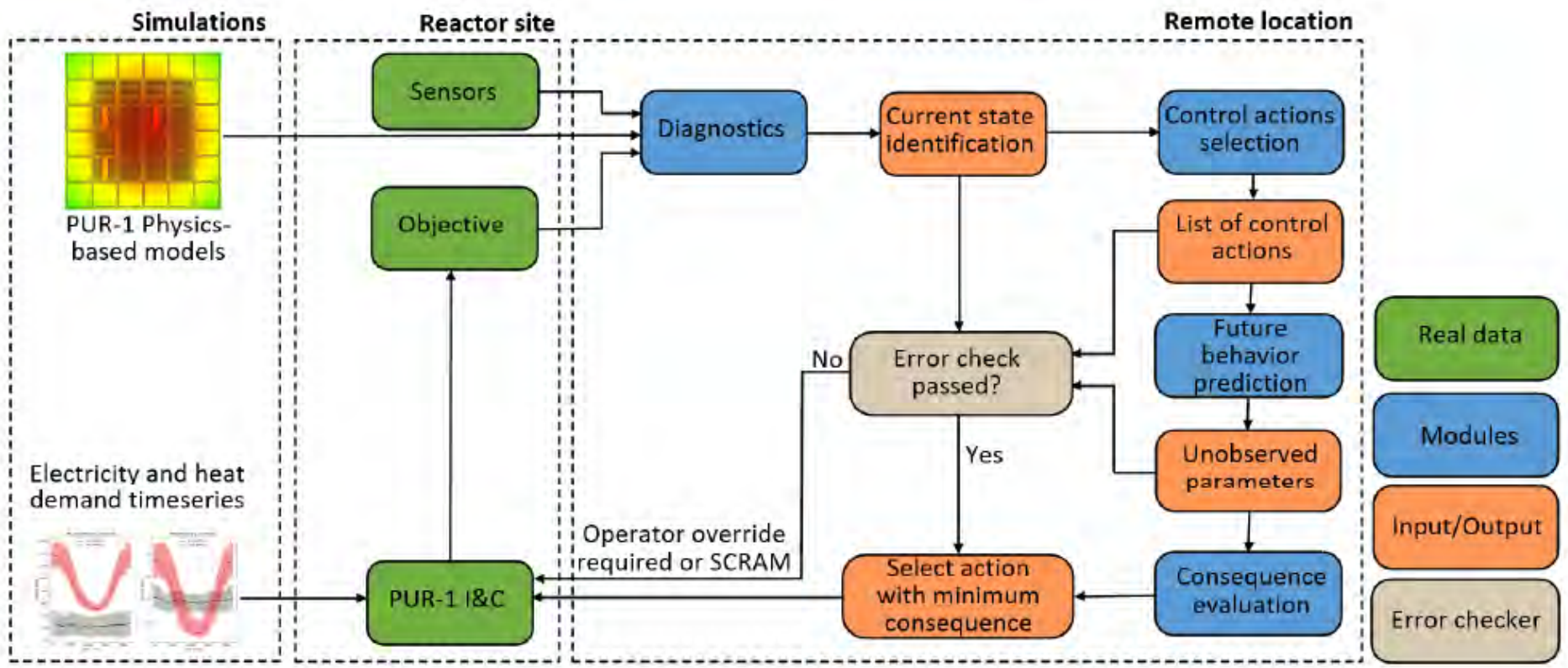
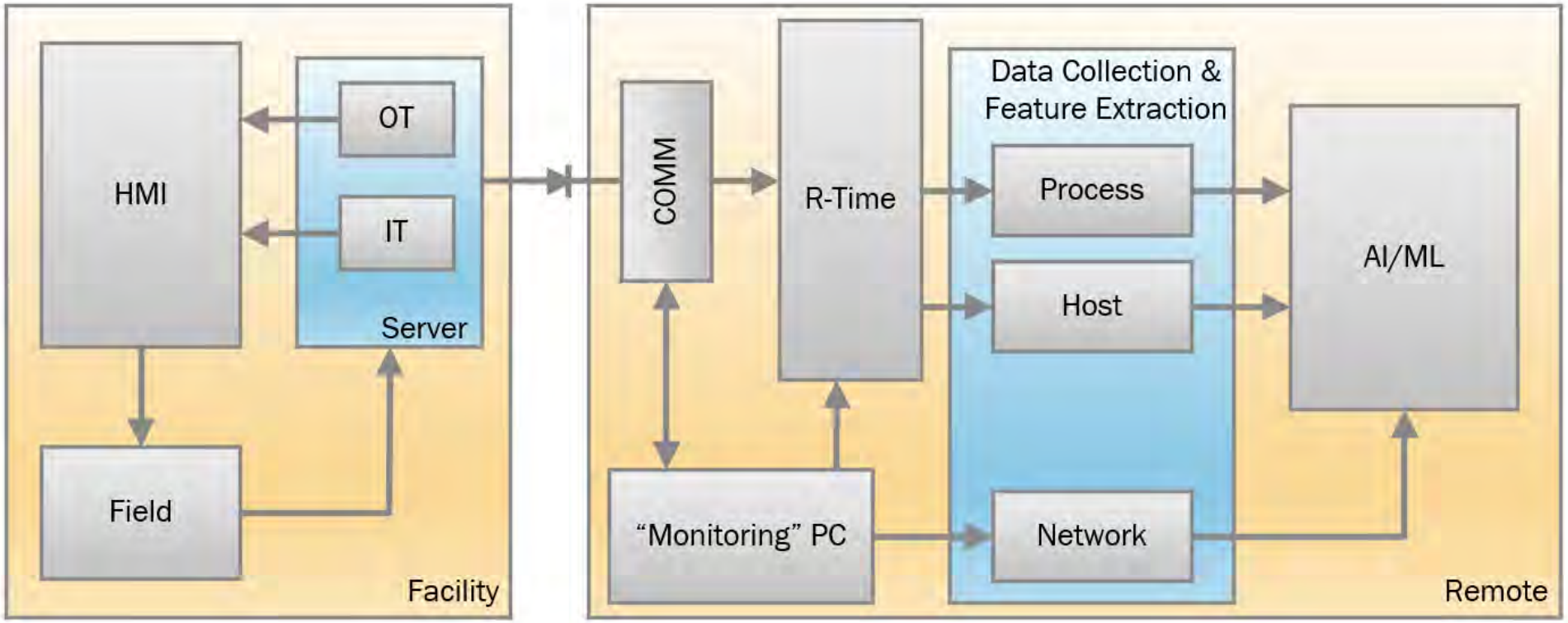
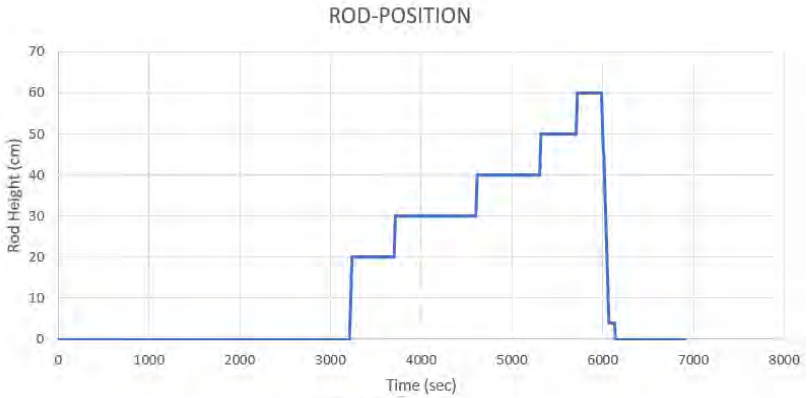
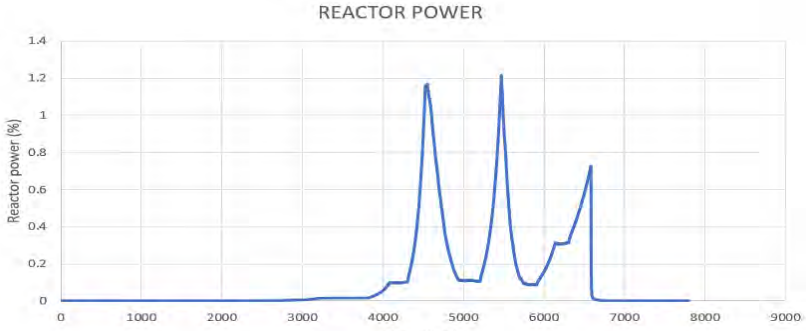
Early efforts…

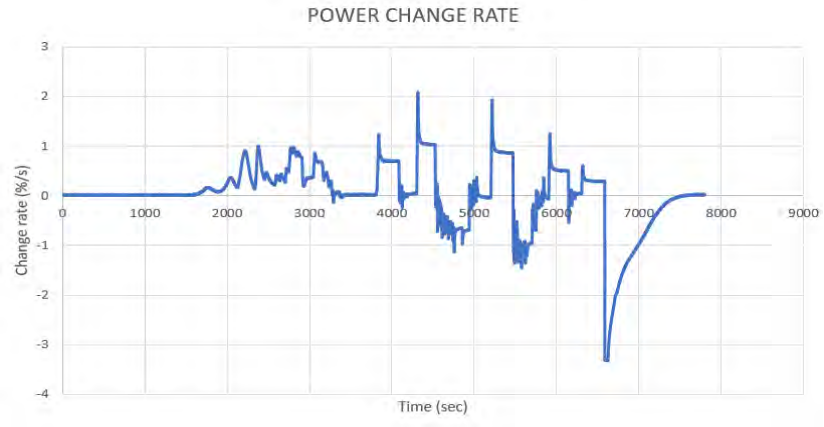


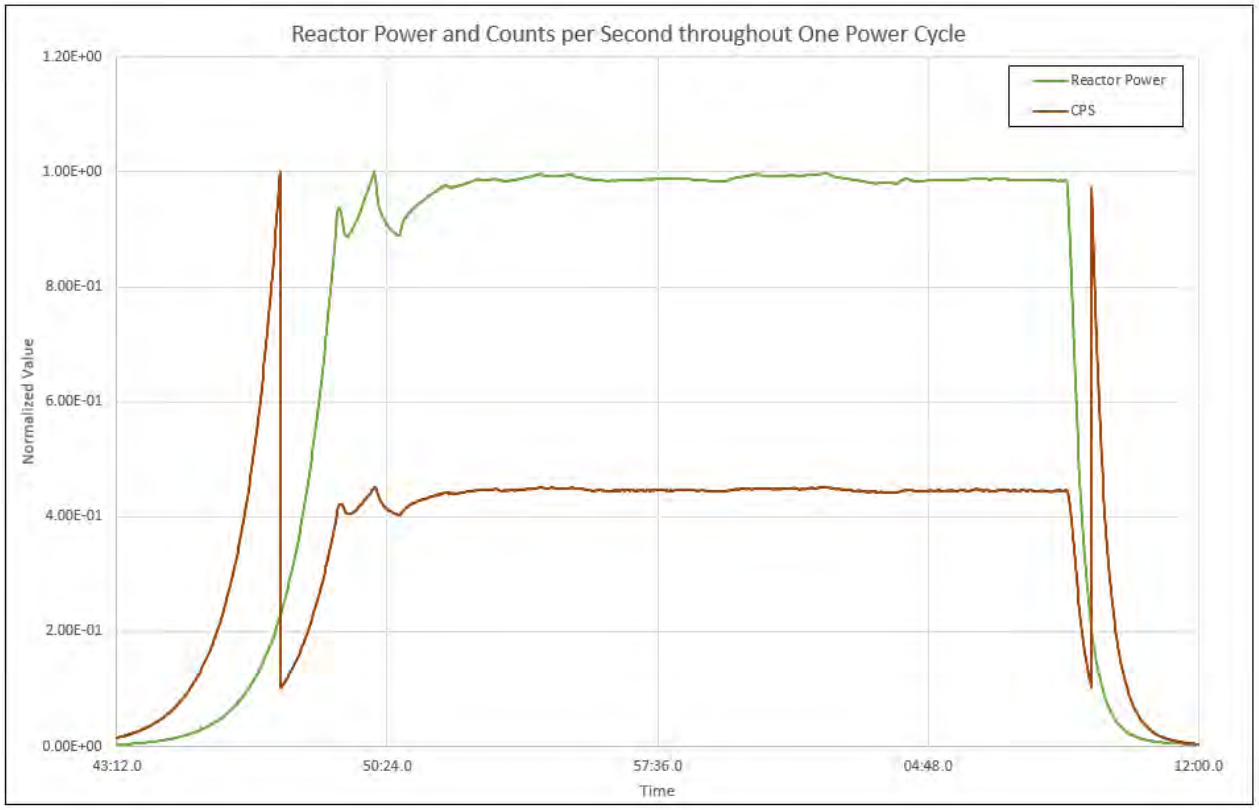
Early efforts…











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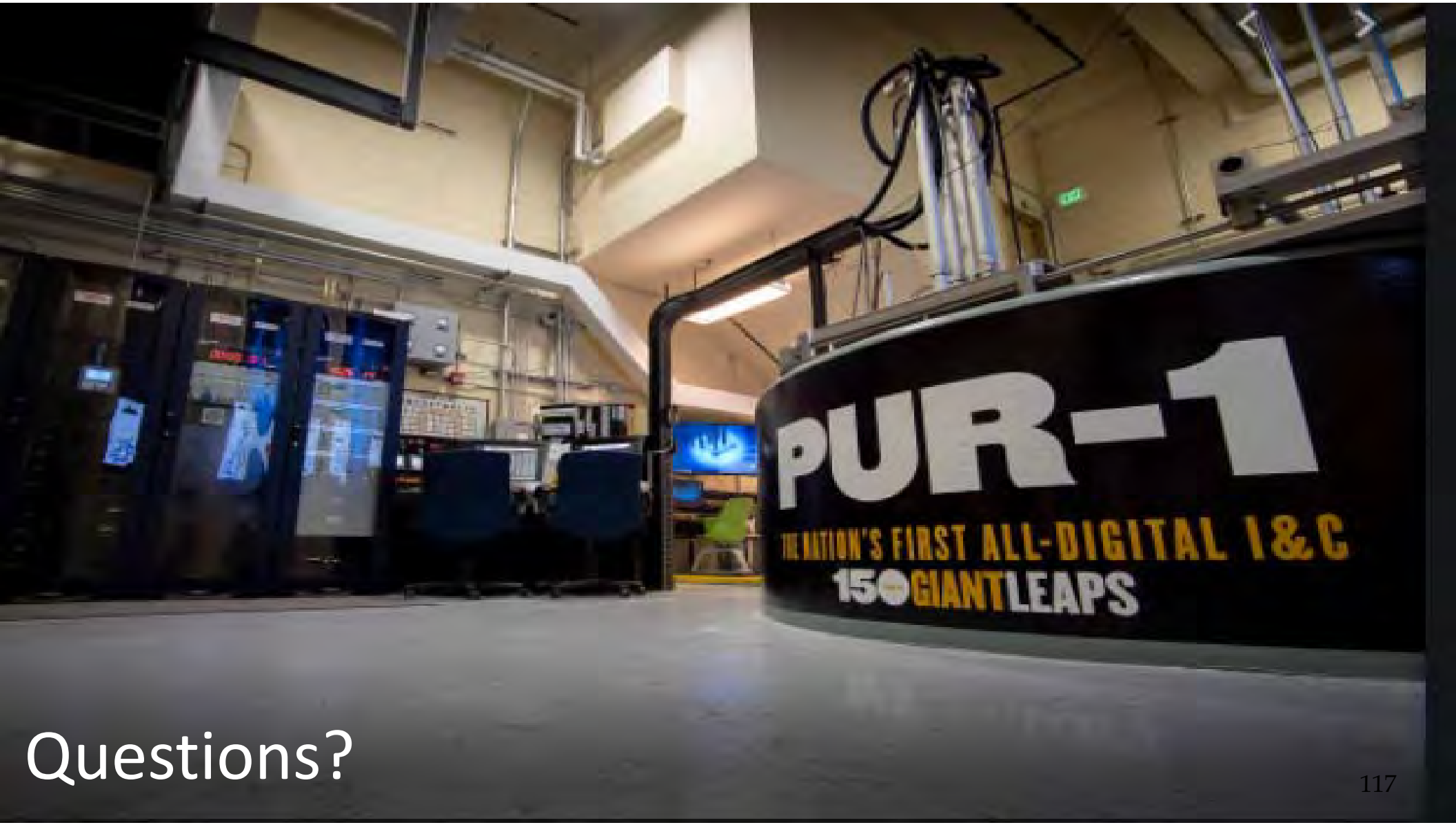
Next steps

- **Continue development of architecture**
- **Implement representative use case**
  - Start-up
  - Power changes
- **Develop microreactor model (VSLIMM)**
- **Generate data and train algorithms**
- **Test and optimize in PUR-1**



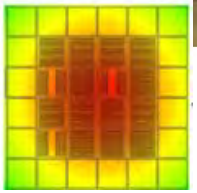
Questions?

Digital Twin Testbed Capabilities

Autonomous control using AI/ML

Ethernet communications

Digital twin: OpenPLC, OpenMC, MCNP, COMSOL, RELAP5



Operation: steady state and transient operation

Cybersecurity: Delay transmission, Denial-of-Service (DOS), False real data transmission, Eavesdropping