Demonstrating Autonomous Architectures for Microreactors Under Prototypic Conditions in PUR-1

2025 Microreactor Program Review

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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)
  - V. Theos, Z. Dahm, K. Vasili, K. Gkouliaras, W. Richards (Grad students)
- **UNM**
  - Mohamed El-Genk (Professor)
  - Timothy Schriener (Research Assistant Professor)
- **Collaborators**
  - Robert Ammon (Curtiss-Wright)
  - Rick Vilim (ANL)
- **TPOC:** Ben Baker (INL)

Goals & Objectives

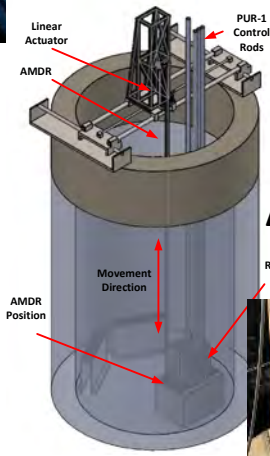
Goal: Experimentally validate semi-autonomous control and demonstrate its use in PUR-1 and VSLIMM.

Objectives:

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

Towards a Real-Time Cyber-Physical Digital Twin

PUR-1



AMDR

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OT/IT Comms

OT & IT System Sensor Data

HMI

Testbed

PLC

PUR-1

PUR-1 I&C System

Reactor Instrumentation

Neutron Detector

Reactor Facility

Digital-Twin

Data & Information Analysis

Simulation Software

Recommended Actions

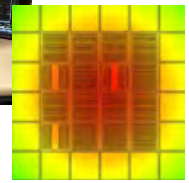
Diagnostics/Consequences Analysis

Actions

PUR-1 Facility

Remote location

RMSS



Control rack

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Digital/Cyber Remote Station

RTP 3000 TAS N+
Nuclear grade PLC
16 CH AI/AO
32 CH DI/DO

Field Programmable Gate Array

Power distribution unit

Actuator control

IT Monitoring

R-TIME GUI

Real-time diagnostics

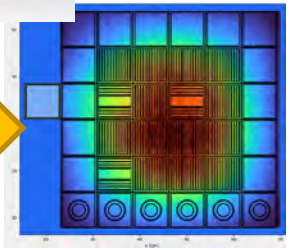
Siemens S7 PLC

UPS APC/1500

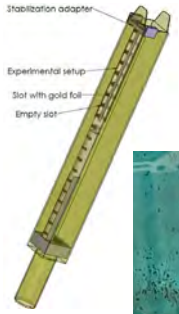
Stats:
2000 parameters
1kHz sampling

OpenMC
COMSOL
OpenFOAM

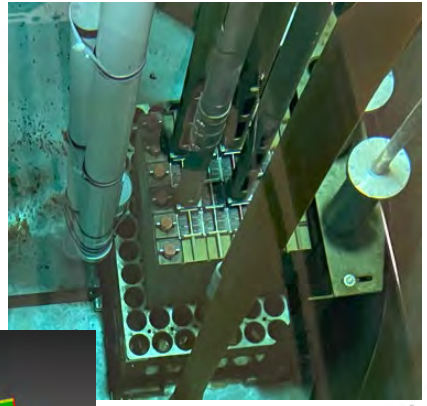
To GPU



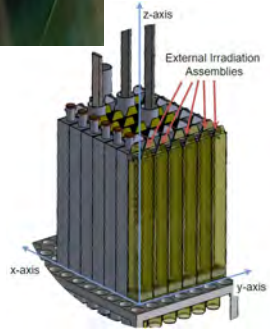
Modeling and Simulation

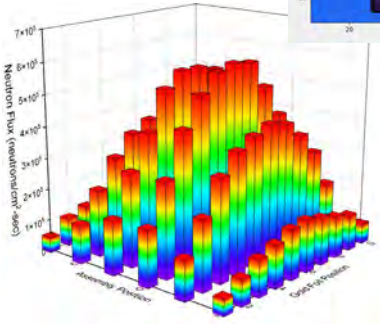


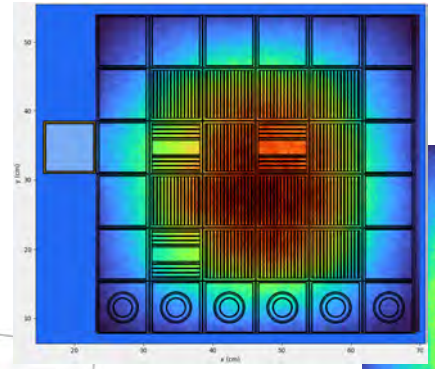
PUR-1



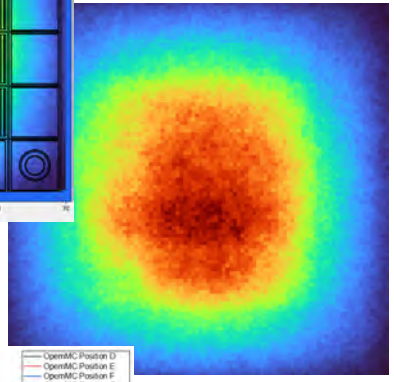
CAD Model

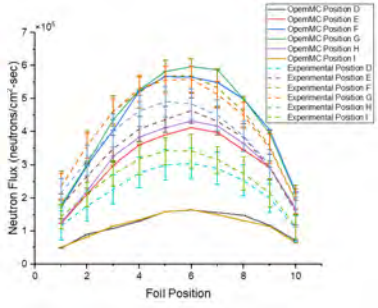






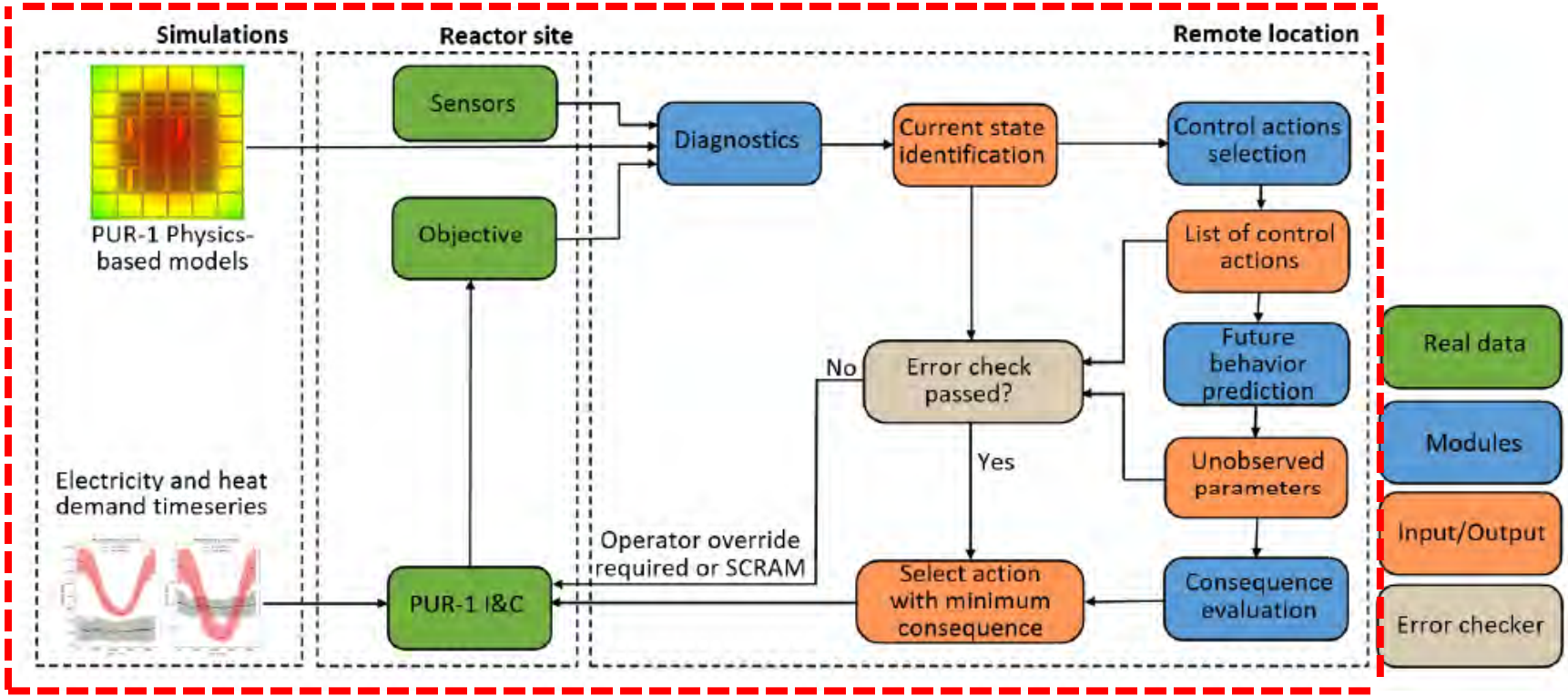
OpenMC Model



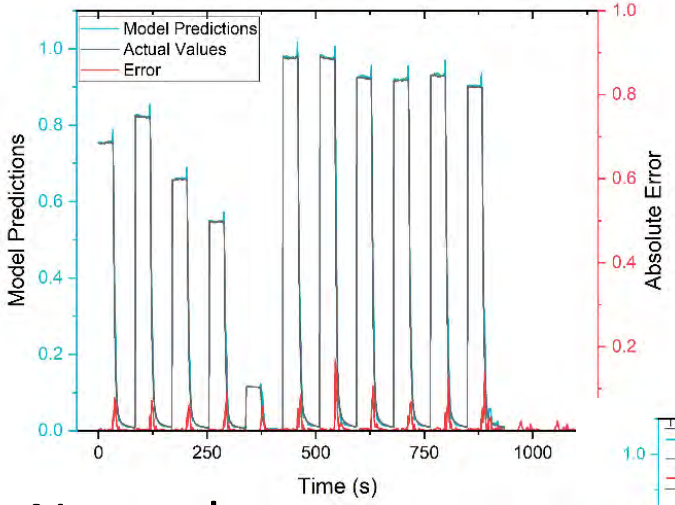


Semi-autonomous Architecture

Completed

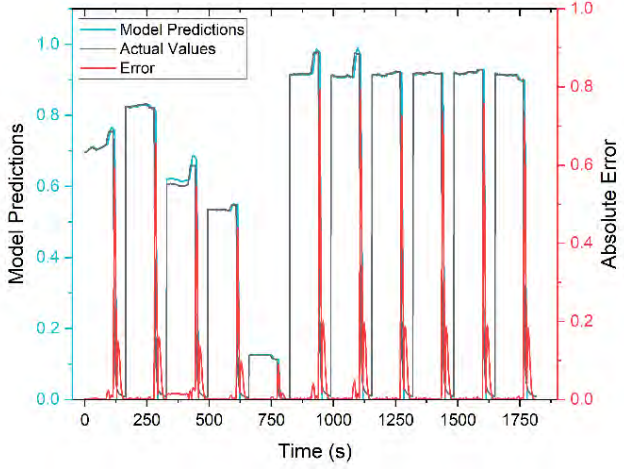


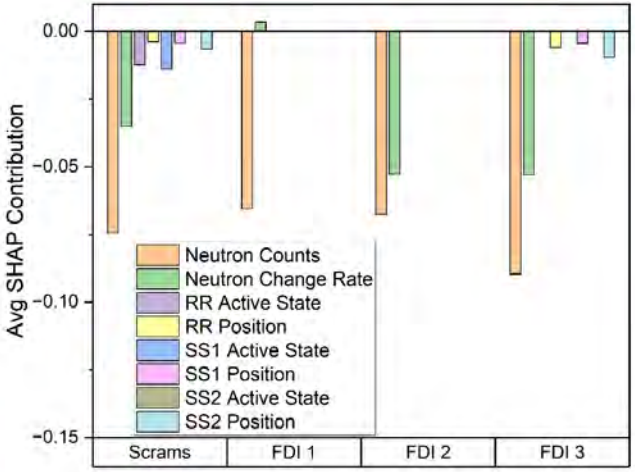
Initial Results – Anomaly Detection



Normal operation

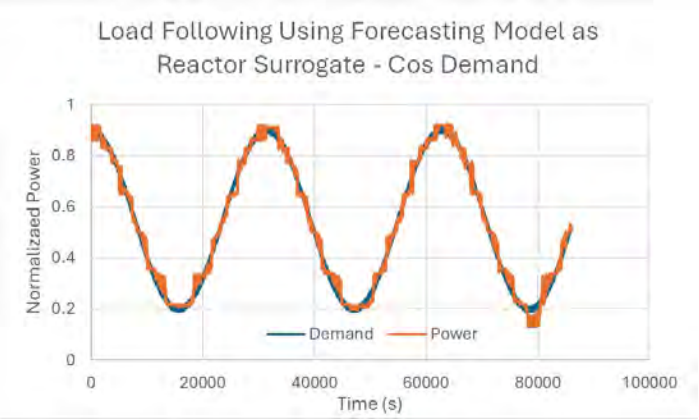
Cyber event detection

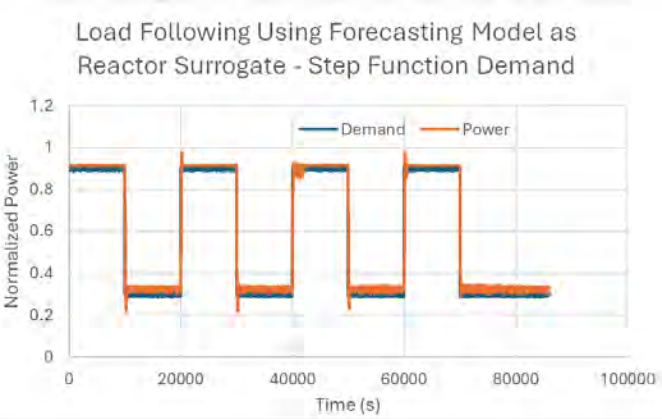


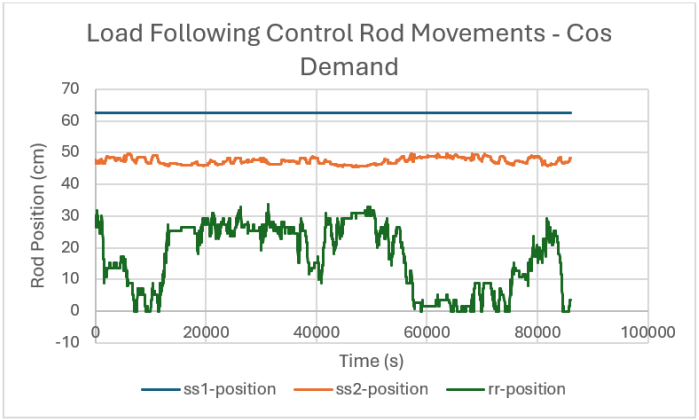


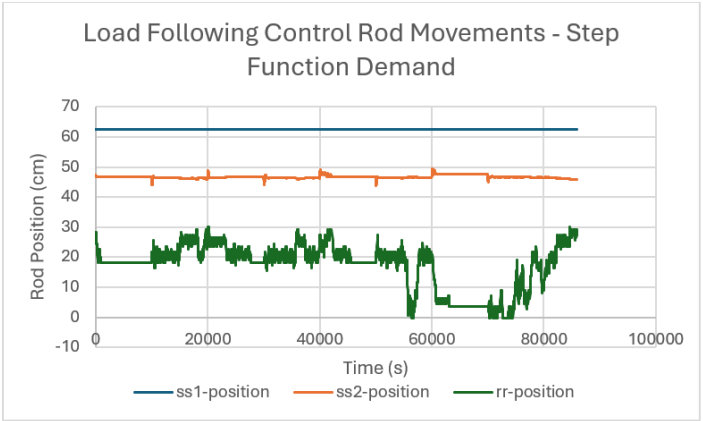
Interpretation of results identifying source of FDI

Initial Results – Load Following









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Future Work

- Use of OpenMC model to train surrogate forecasting model.
- Validation of control loop, completed by using control loop with DL model to operate physics-based model as reactor surrogate, and vice-versa.
- Implementation of control loop with other forecasting models (point kinetics, DL models trained using OpenMC data, other ML architectures)
  - Emphasis on runtime, loop should run at 1hz minimum
- Combination of lightweight forecasting models into ensembles

Acknowledgements

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Questions?