32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

Jeren Browning – Idaho National Laboratory

Microreactor Testbed Automation through Digital Engineering and Digital Twins

www.incose.org/symp2022

Why Digital Engineering?

Design

Linkage of facility information (requirements, equipment, processes, 3D) throughout design

- Impact analysis of design changes
- Reduction of silent errors earlier in design process
- Improved communication across engineering teams

Operations

Enablement of digital twins to detect and (optionally) control an asset

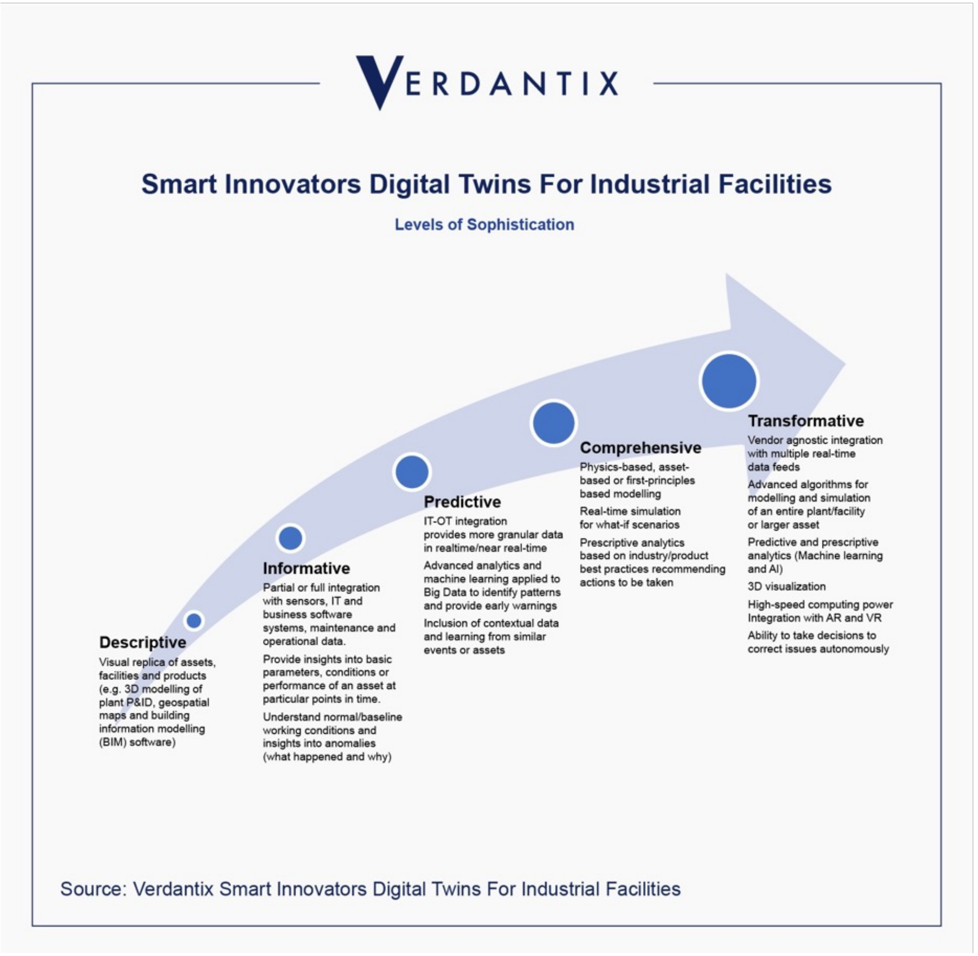
- Real-time operator feedback
- Autonomous control functionality
- Accurate predictions

What is Digital Engineering?

- Digital transformation in the way we **design (MBSE, BIM, PLM)**, and **operate (digital twins)** energy assets
- Drive research with **centralized data** across applications rather than siloed documents with heterogenous compute architectures (edge, cloud)
- Bring **new digital automation** to projects including autonomous operation, predictive maintenance, proliferation/security prediction
- Live data integrated with human interaction for **industrial optimization**

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Siloed Program	Content Management	Data Lake	Data Links	Digital Thread	Advanced Analytics	Artificial Intelligence
Data and documents disconnected	*Document storage are centralized*	*Data storage is centralized*	*Connections within each domain*	*Connections across lifecycle*	*Analytics Automation*	*Automated Design Optimization*

Digital Twin Forms and Levels



1. **Descriptive**: Visual replica
2. **Informative**: Basic insights
3. **Predictive**: Integration with operations
4. **Comprehensive**: Real-time simulation and prescriptive analytics
5. **Transformative**: Autonomous operation

What is a Digital Twin?

- Digital Twins represent the merging of integrated and connected data, sensors and instrumentation, artificial intelligence, and online monitoring into a single cohesive unit.

- It is a **living virtual model** that mirrors a physical asset to predict future behavior.

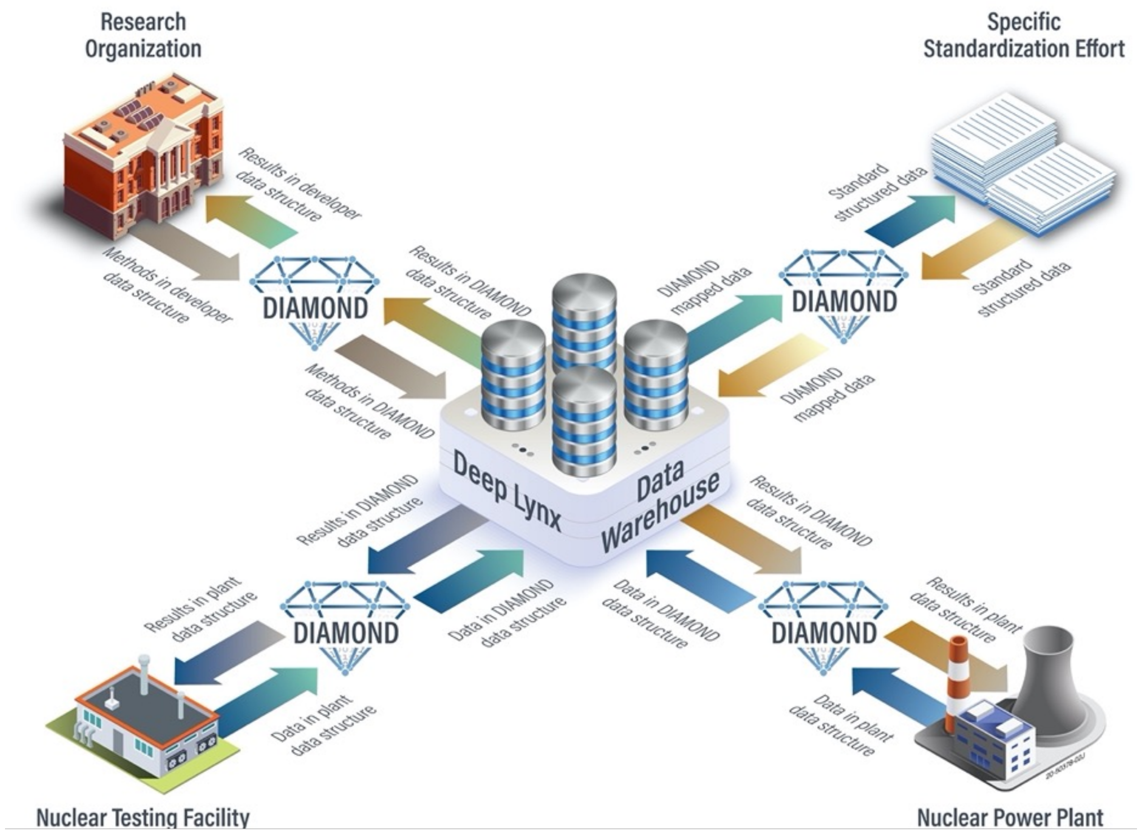
- Digital Twins use **real-time bi-directional communication** to track and trend both simulated and measured asset information.

What is different than a traditional simulation?

- Integration of real-time data
- Dynamic model update (AI/ML integration)
- Real-time operator feedback (visualization)
- Accurate predictions with fused (integrated) data
- Ability to enable autonomous control
- Distributed across computing platforms

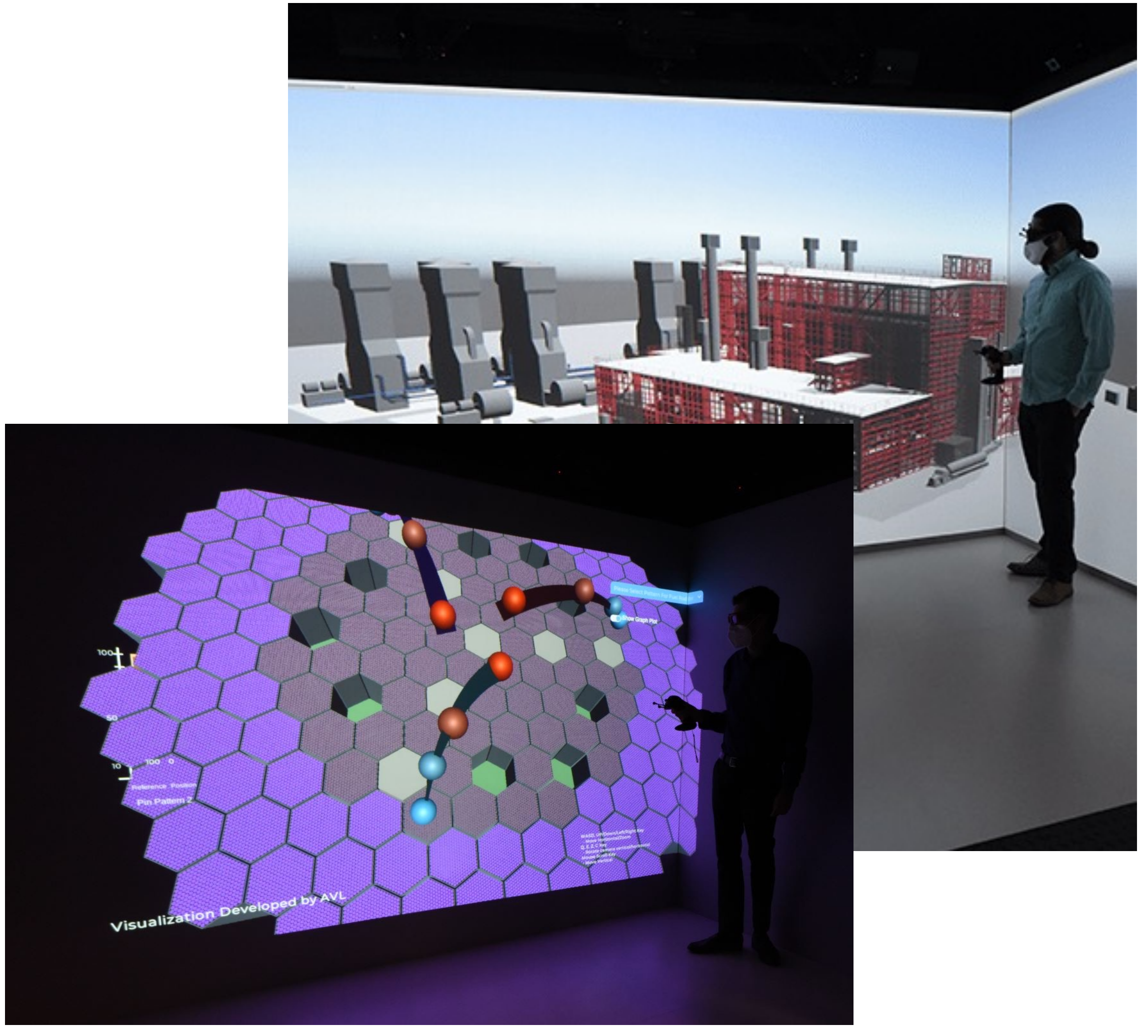
Integration: Holistic Data Hub

- Reusable and repeatable **framework**
- Using and expanding existing open-source resources (**DeepLynx**, **DIAMOND**, **MOOSE**)
- Proving and improving on the concept through **test facilities** (MAGNET)



Digital Twin Maturity Model

1. Define architecture and ontology
   Model-Based Systems Engineering
2. Integrate data into a digital thread
   Deep Lynx and Associated Adapters
3. Integrate first-principles models and/or historical data
   MOOSE Multi-Physics
4. Provide explainable prediction of asset performance, reliability, and economics
   Explainable AI *(Connected with Deep Lynx)*
5. Autonomous asset prediction, protection, and/or operation for physical assets
   Control Adapters *(Connected with Deep Lynx)*



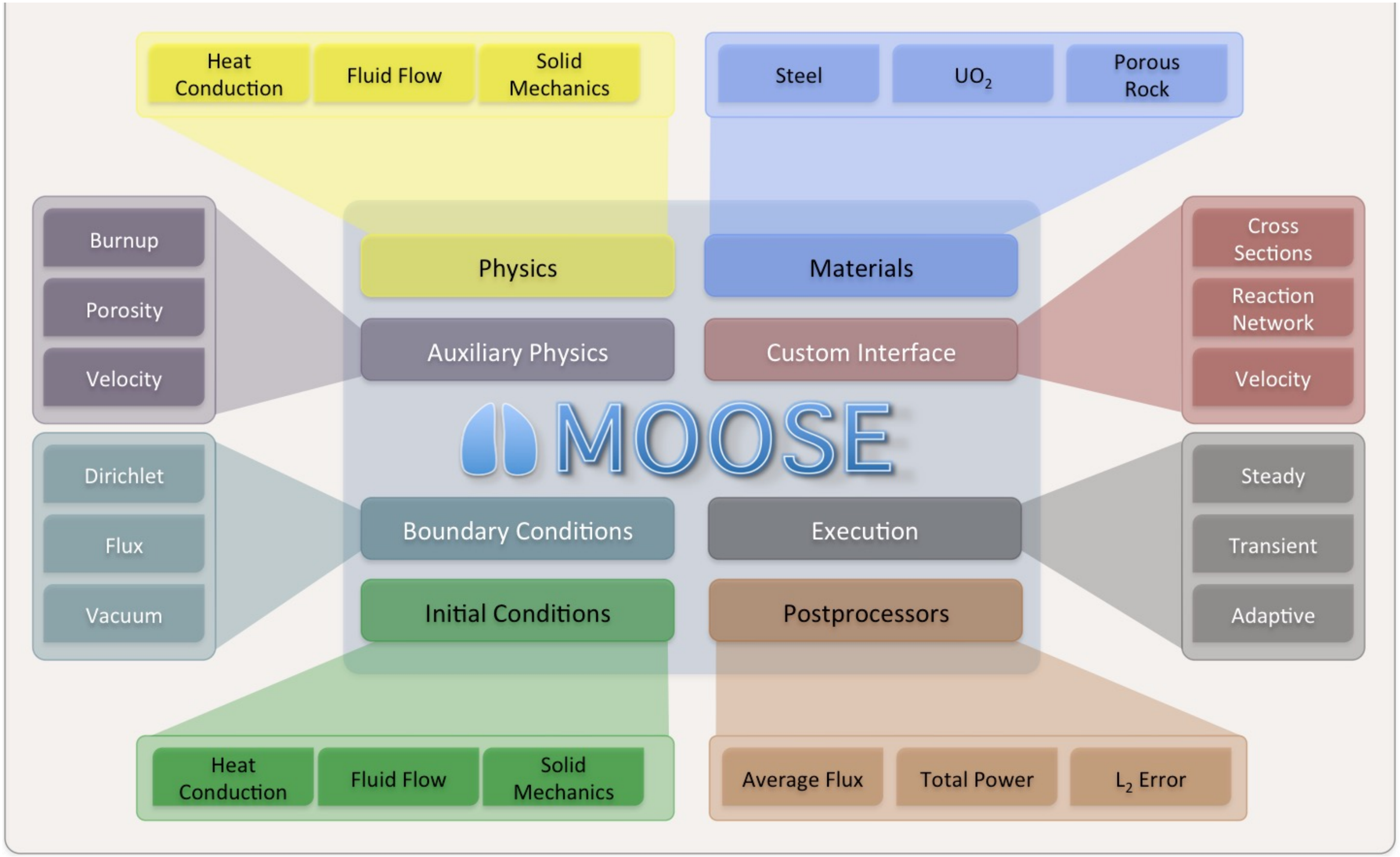
Deep Lynx

- Centralized digital twin data warehouse and live event system
- **Ontological and time series storage** of digital twin data streams
- **Event system** to push and pull data in real-time around a digital twin
- Offline historian capability across operating power plant fleet
- Proven in operation of MAGNET digital twin

Integrations with the following data sources:

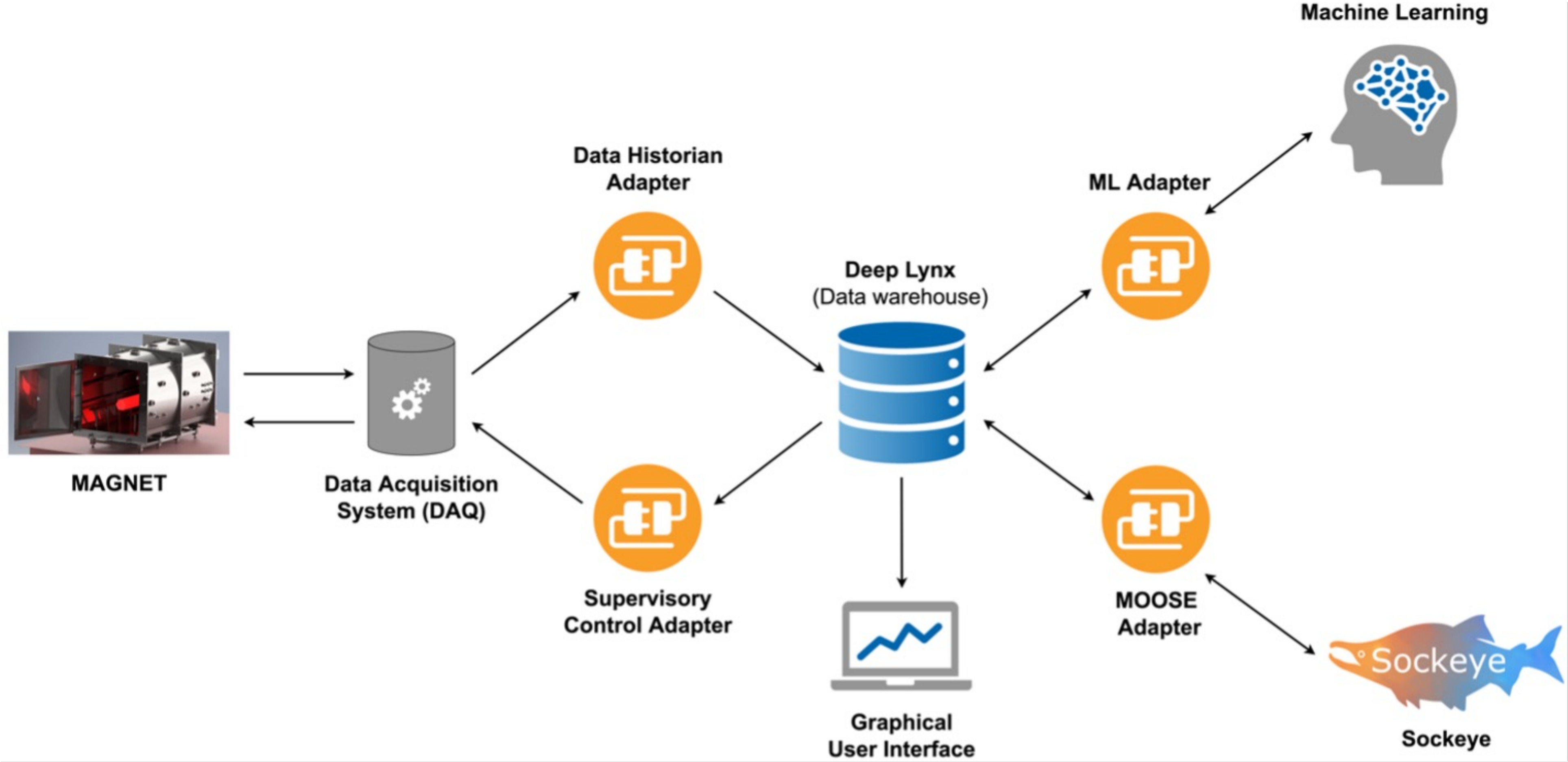
- AutoDesk Vault (CAD)
- AVEVA (BIM)
- Hololens (MR)
- UNC (HPC)
- Lab View (DAQ)
- IBM Jazz ELM (RM)
- Innoslate (MBSE)
- Mathematics (DiffEq)
- MOOSE (Multi Physics)
- ML Adapter (AI/ML)
- Primavera P6 (Schedule)
- SERPENT (Neutronics)
- RAVEN (In Development)

MOOSE Multi-Physics



MOOSE (**Multiphysics Object Oriented Simulation Environment**) enables simulation tools to be developed in a fraction of the time previously required. The tool has revolutionized predictive modeling, especially in the field of nuclear engineering — allowing nuclear fuels and materials scientists to develop numerous applications that predict the behavior of fuels and materials under operating and accident conditions.

Digital Twin Architecture



Microreactor AGile Non-Nuclear Experimental Test Bed (MAGNET)

- General-purpose, non-nuclear microreactor test bed
- Thermal-hydraulic and materials performance data for design performance verification and analytical model validation (V&V)
- Expandable design with capability to demonstrate an integrated power conversion unit (PCU)
- Advanced sensors identification, development, and testing for potential autonomous operation

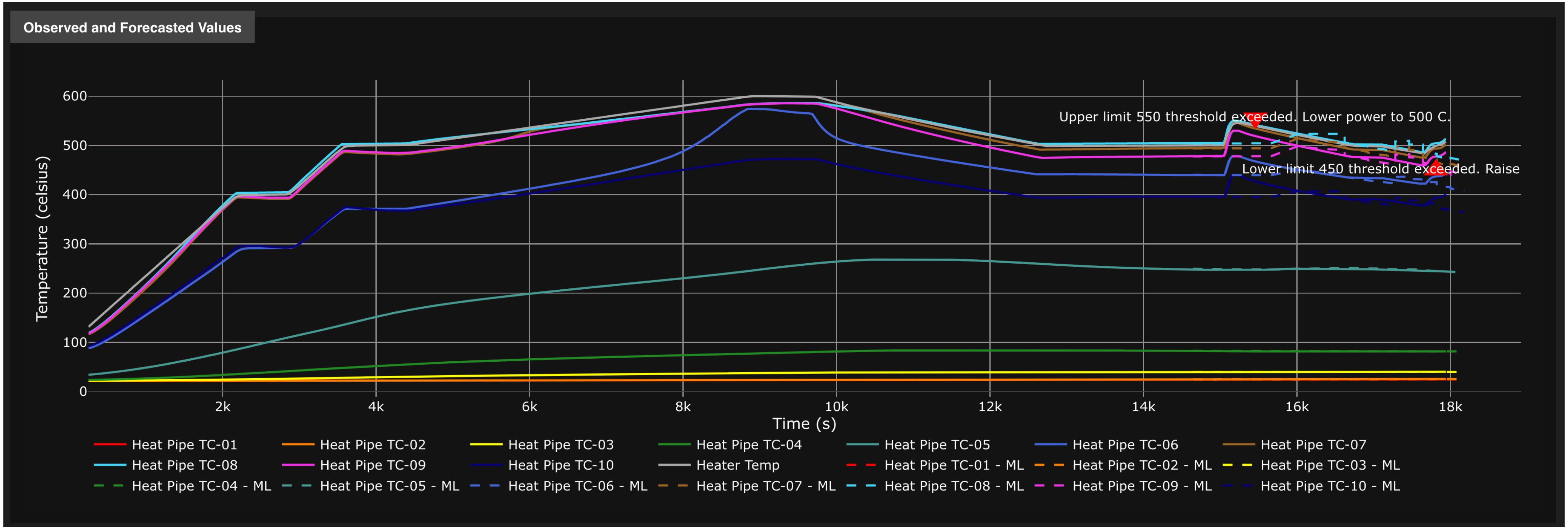
- Enhance readiness of public stakeholders, particularly DOE laboratories and the U.S. NRC, to design, operate, test, and license microreactor

Parameter	Value
Chamber Size	5 ft x 5 ft x 10 ft
Heat Removal	Liquid-cooled chamber walls, gas flow
Connections	Flanged for gas flow and instrumentation feed through and viewing windows
Coolants	Air, inert gas (He, N2)
Gas flow rates	Up to 43.7 ACFM at 290 psig
Design pressure	22 barg
Maximum power	250 kW
Max Temperature	750 C
Heat Removal	Passive radiation or water-cooled gas gap calorimeter

March 30 2022 Test

3D Model of MAGNET

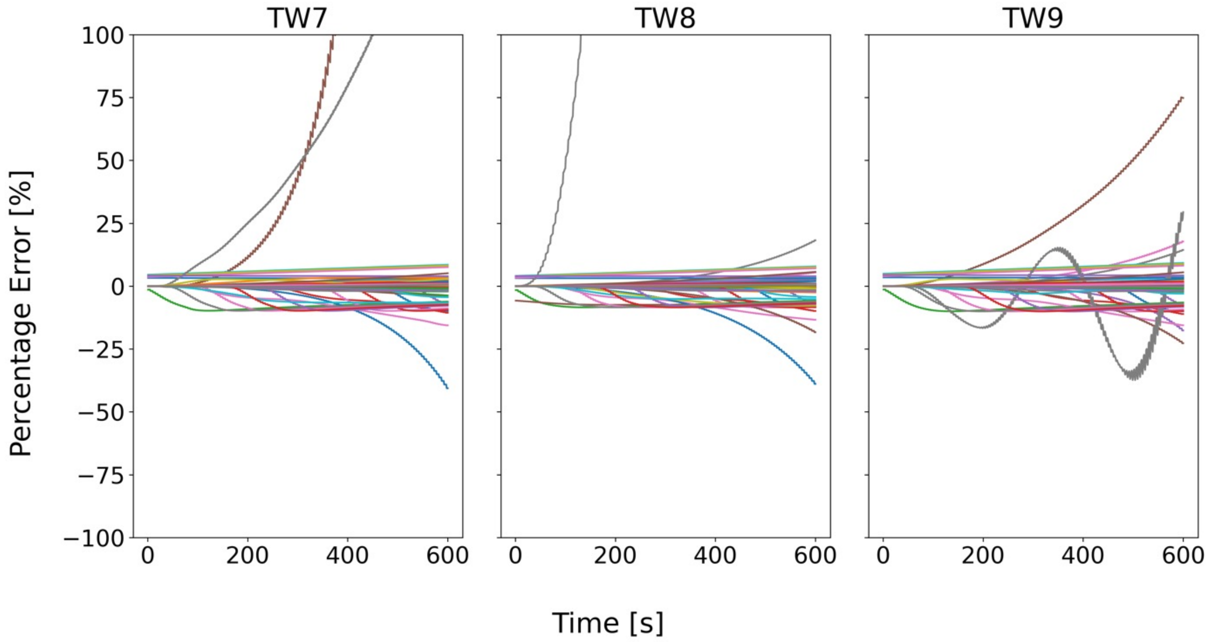
MAGNET Temperatures, Forecasts, and Control



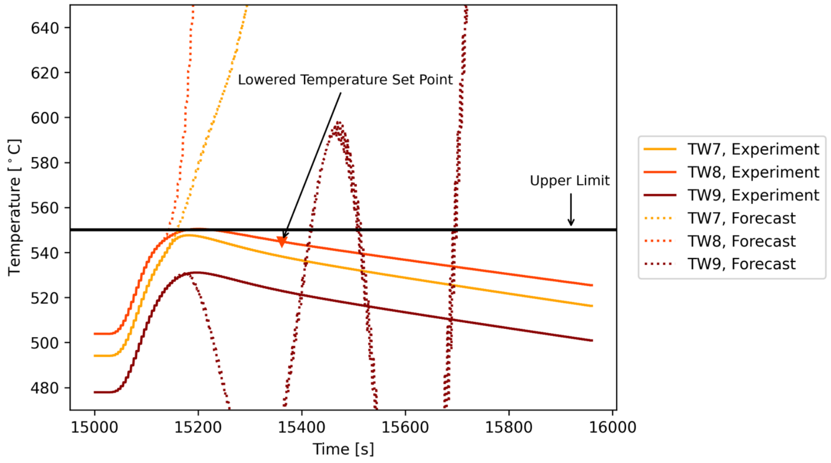
Machine Learning Approach

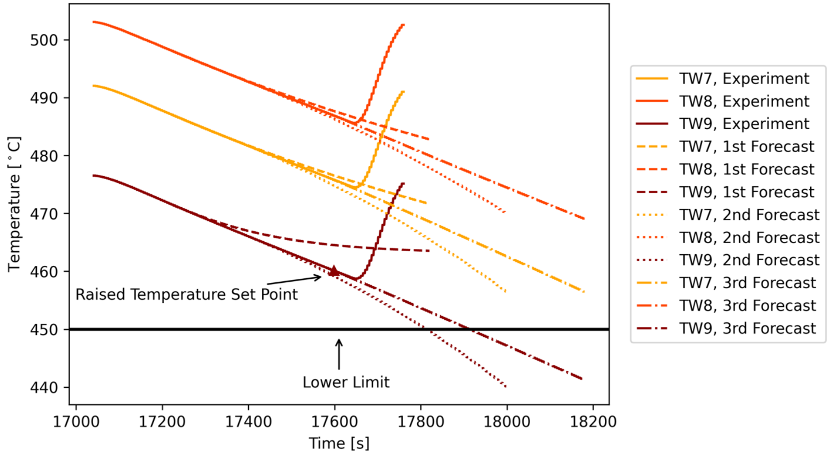
- Inference-based methods to determine anomaly correlation
  - Robust statistics:
    - Problem: Anomalies may come in leverage points or groups of outliers
    - Solution: Nonconvex penalized regression for describing groups of mean shifts in the data
  - Explainability:
    - Problem: Deep Neural Nets provides an estimation via a black box approach
    - Solution: Tailored penalized regression models to MAGNET that perform variable selection on features generated by physics-based models.
- Application: Tailored Local Interpretable Model-agnostic Explanations (LIME) with robust mean shift detection

Machine Learning Results



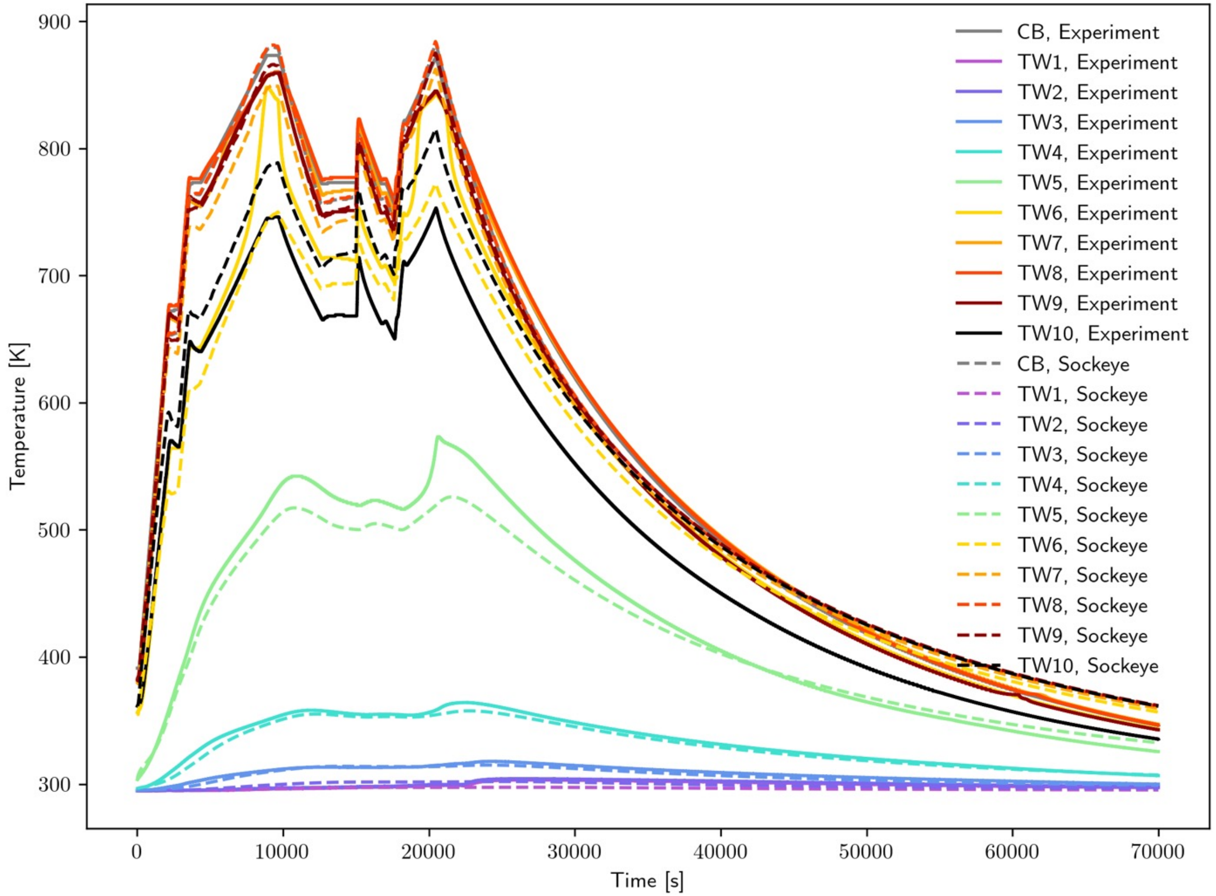
Thermocouple ML Error. Within 0.25% except for two inflection cases due to ramp rate changes.





Upper and Lower limit control requests sent by the DT.

Sockeye Physics Results



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