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Keeper: A Framework for Demonstrating Autonomous Operations

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy



Idaho National Laboratory

Current operations : What problems are we facing?

- Economic Pressures
 - High Operating Costs: Labor intensive operations with specialized workforce
- Workforce Challenges
 - 24/7 Staffing Demands: Continuous operations means continuous staff and backup personnel
- Operational Limits
 - Geographic: Difficulty for staffing in remote areas, where nuclear can potentially help most
- Deployment Barriers
 - Public Perception: Safety concerns and historical human-induced incidents



https://en.wikipedia.org/wiki/Control_room



<https://inl.gov/nuclear-energy/future-of-mining-is-microreactors-idaho-national-laboratory-sees-big-benefits/>

How are we planning on achieving autonomous operations?

Autonomous Operations

Hardware

Requirements

Integration

Control Algorithms

Human-Machine Interface

Simulator

Familiarization of reactor operators with Keeper

Hardware Testing

Keeper sends signals to move decoupled control rods

Autonomous Operations

Reactor operators provide desired state, and Keeper informs operators of actions after they have been taken

Human in the Loop

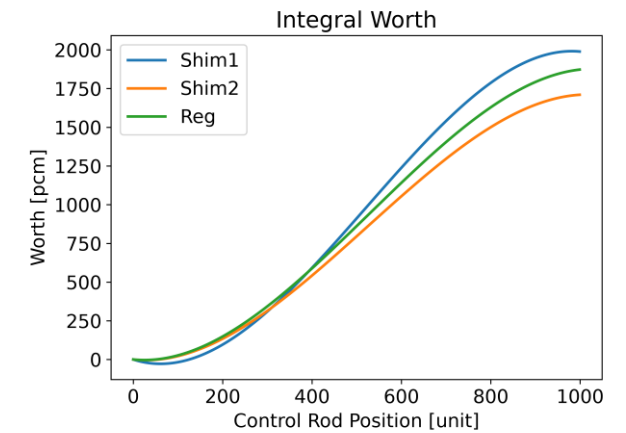
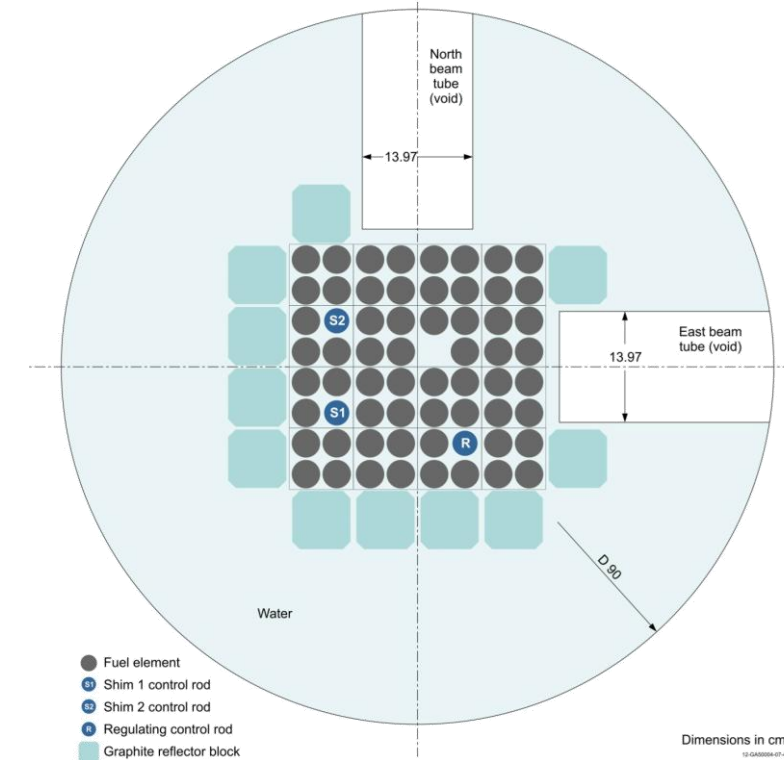
Real operational data ingested into Keeper, operators enact actions

Permission-Based Autonomous Ops

Keeper will seek permission for desired actions before executing them

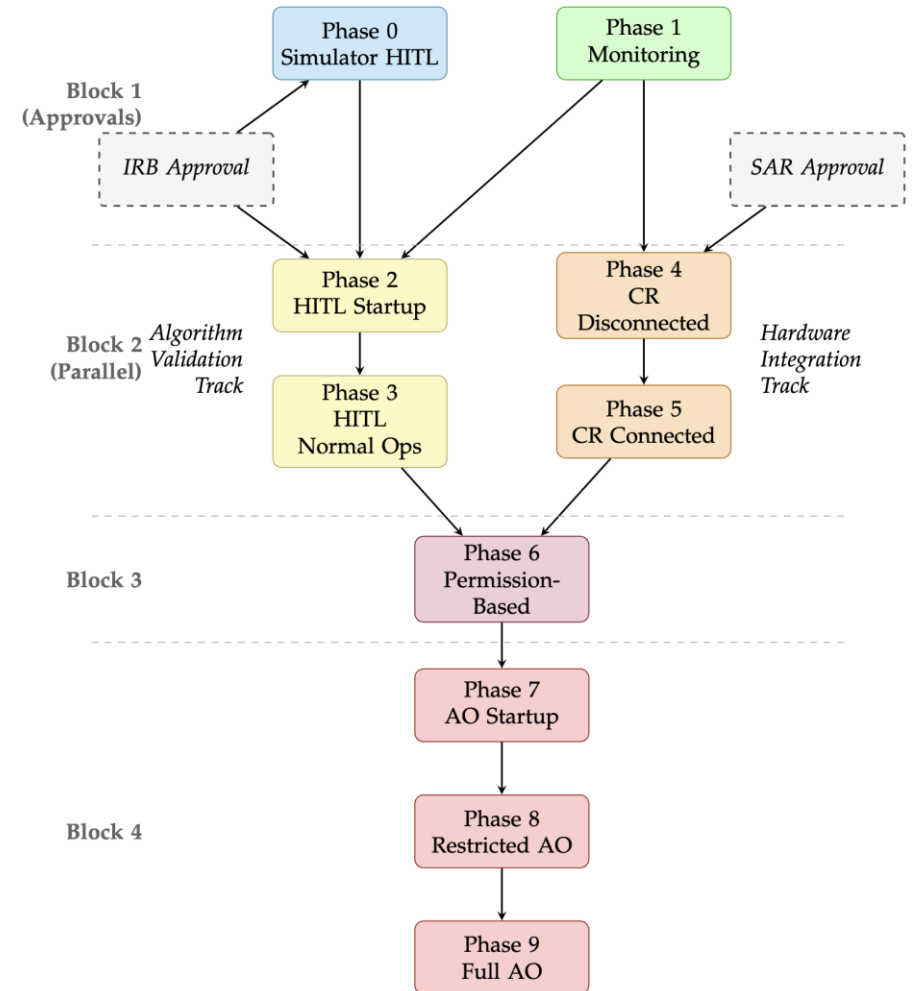
Hardware – What are we demonstrating on?

- TRIGA Mark II reactor.
 - Originally in Puerto Rico
 - Brought to Idaho and converted from HEU to HALEU
- Basic design facts:
 - Full-power 250 kW
 - Natural circulation in tank
 - UZrH fuel enriched to 19.75%
- 5+ years of historical data
- Magnetically coupled control rods to motorized drives
 - Autonomous control will *only* interact with motors
 - No interaction with safety system (magnets)



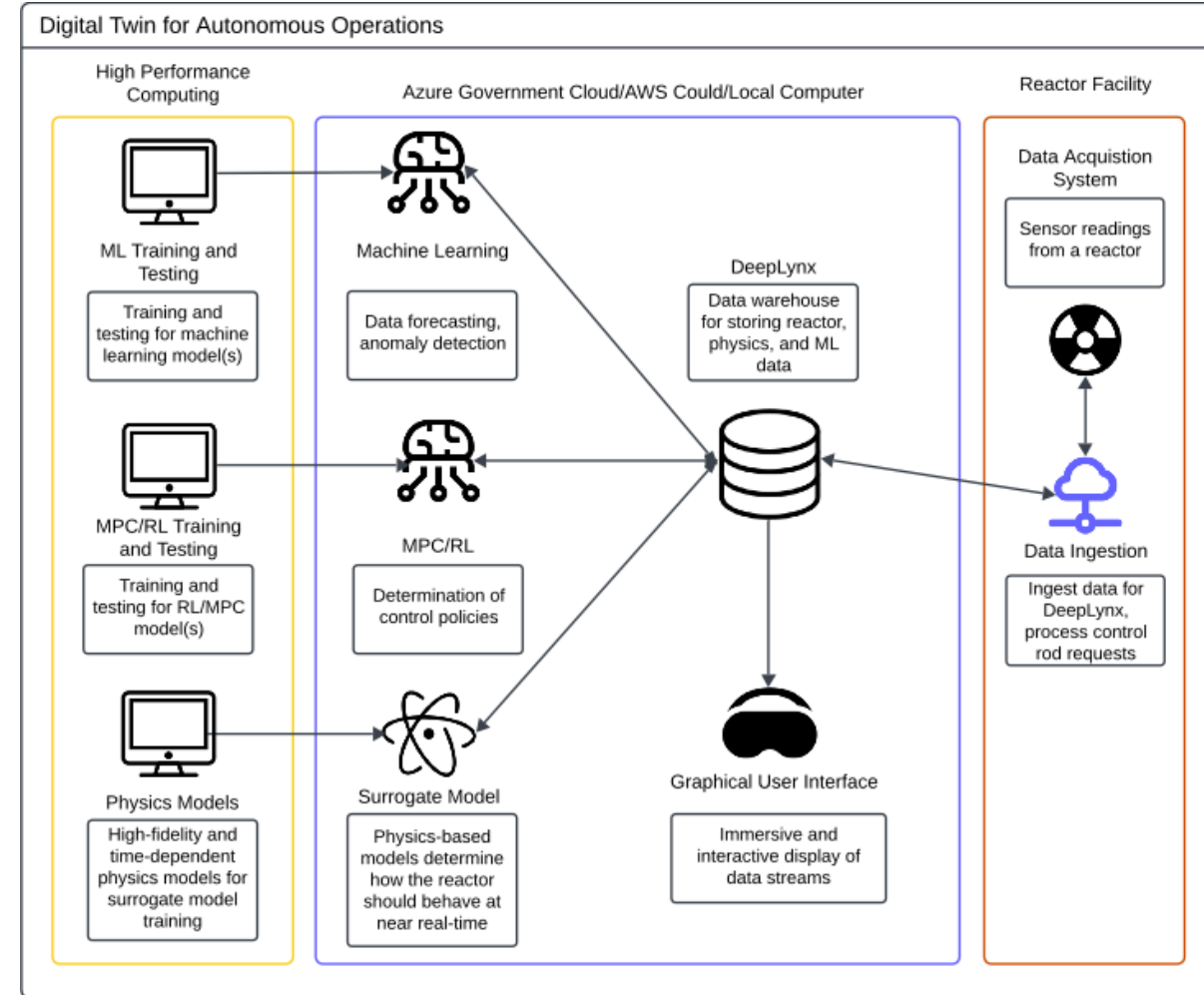
Requirements – How do we go about demonstrating autonomous operations?

- Requires an update to the Safety Analysis Report to allow for Keeper to interface with the console
- Development of a Concept of Operations (CONOPS)
 - Highlights how reactor operators will interact with Keeper
- Development of a Test Plan
 - Highlights how we plan to build on testing success to comply with DOE-STD-1271



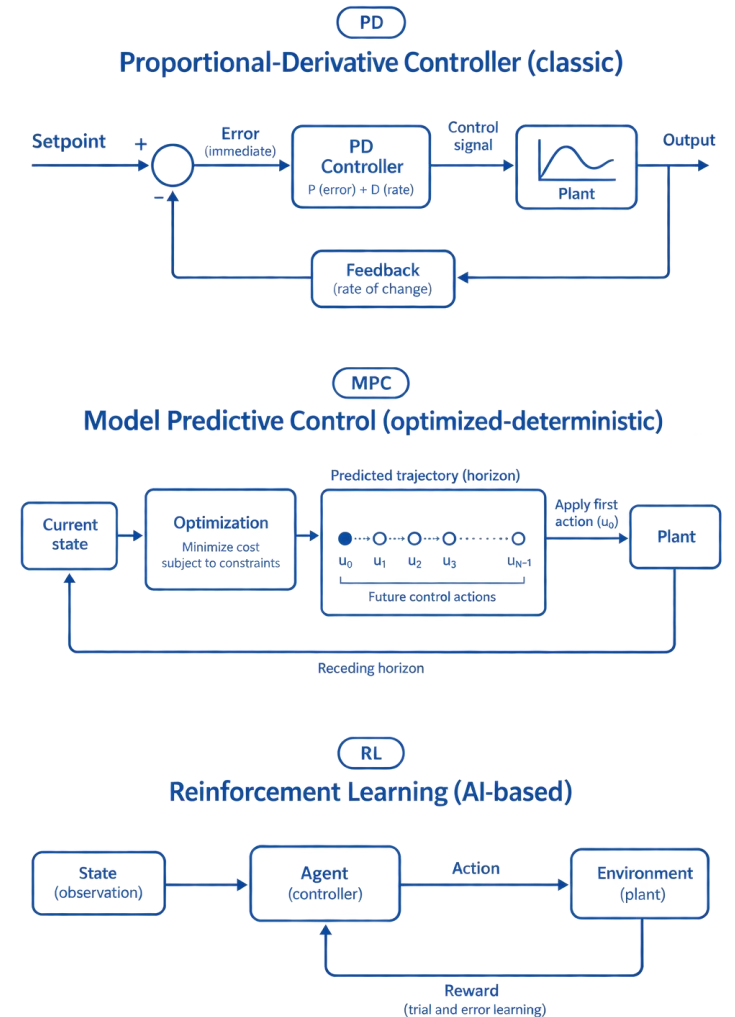
Integration – How do we connect the physical and virtual?

- Digital twin ontology has been developed
 - Generic reactor digital twin
 - Autonomous operations digital twin
- Initial integration with DeepLynx Nexus
 - Imported NRAD ontology
 - Identified how to push and pull data
- Initial integration with COMMAND for synchronization
 - Can pull and push data to DeepLynx
 - Can run initial ML and control models

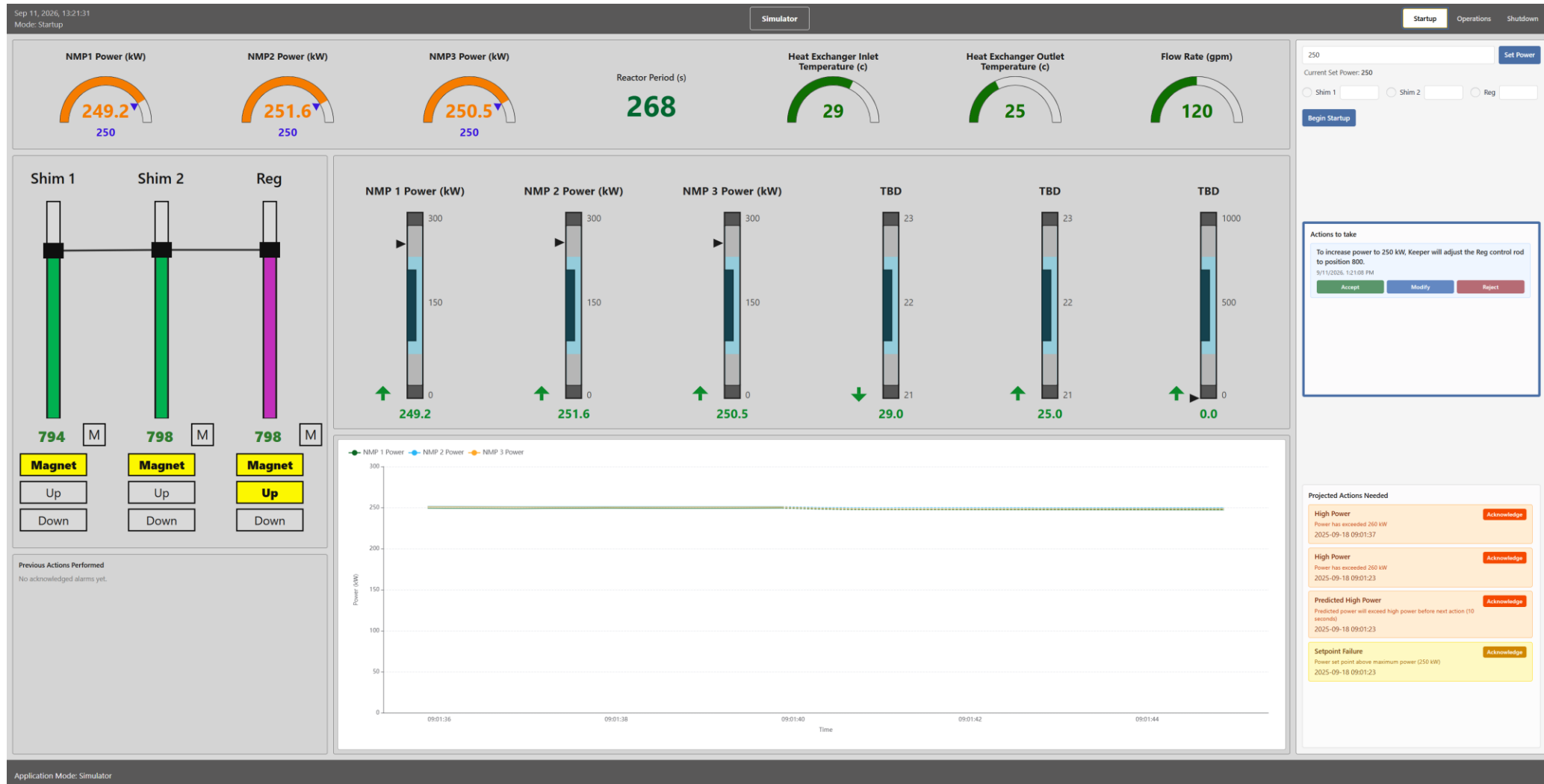


Control – How do we change the state of the reactor?

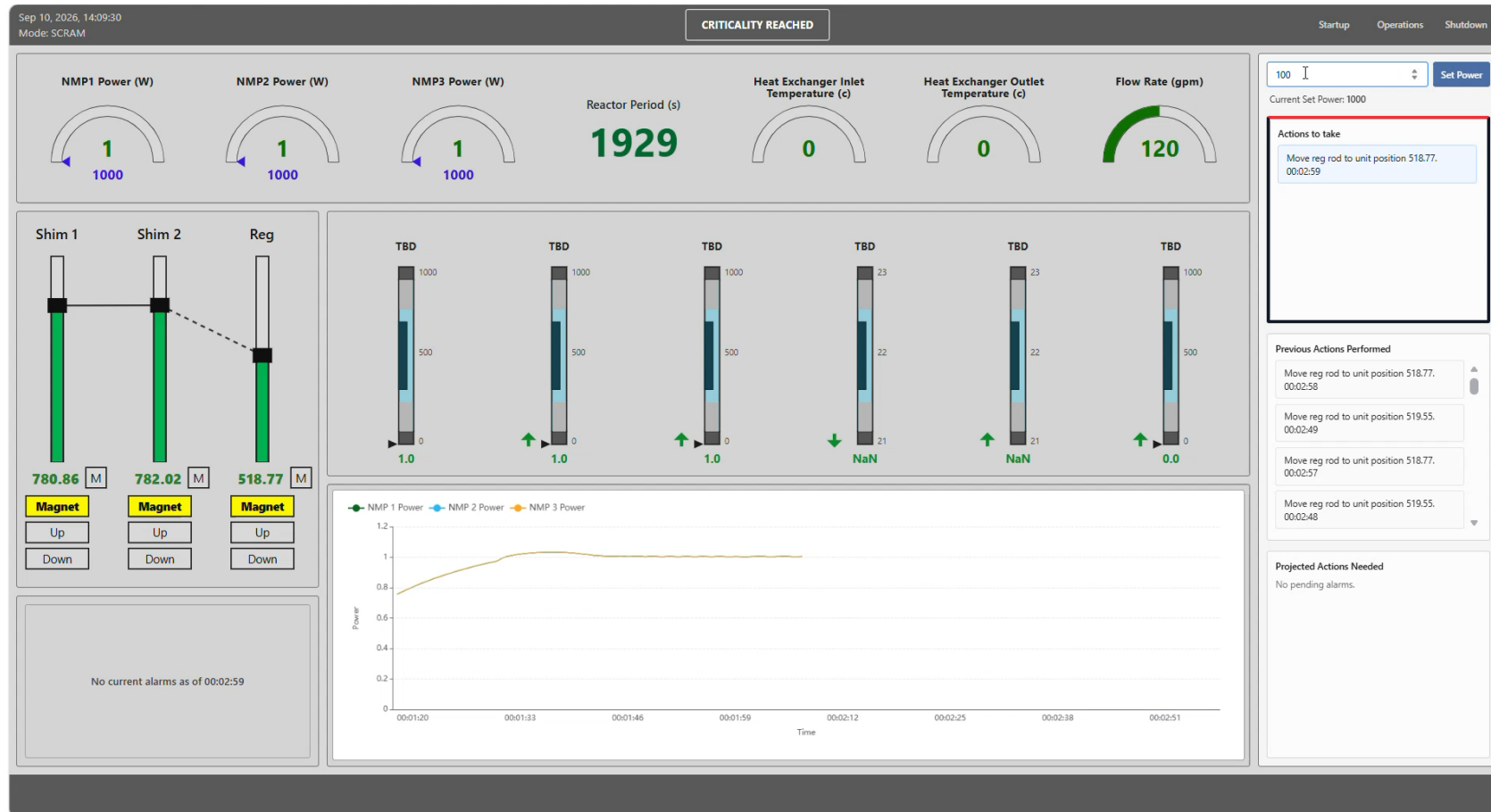
- Developed three operations regimes: startup, at-power, shutdown
- Keeper can be controlled using three control algorithms in at-power operations
 - Proportional-derivative controller (classic)
 - Model predictive control (optimized-deterministic)
 - Reinforcement learning (AI-based)
- Algorithms will provide control action(s) to take (i.e., new control rod positions)
 - An action should arise every N seconds; this is an area of **discussion** and feedback



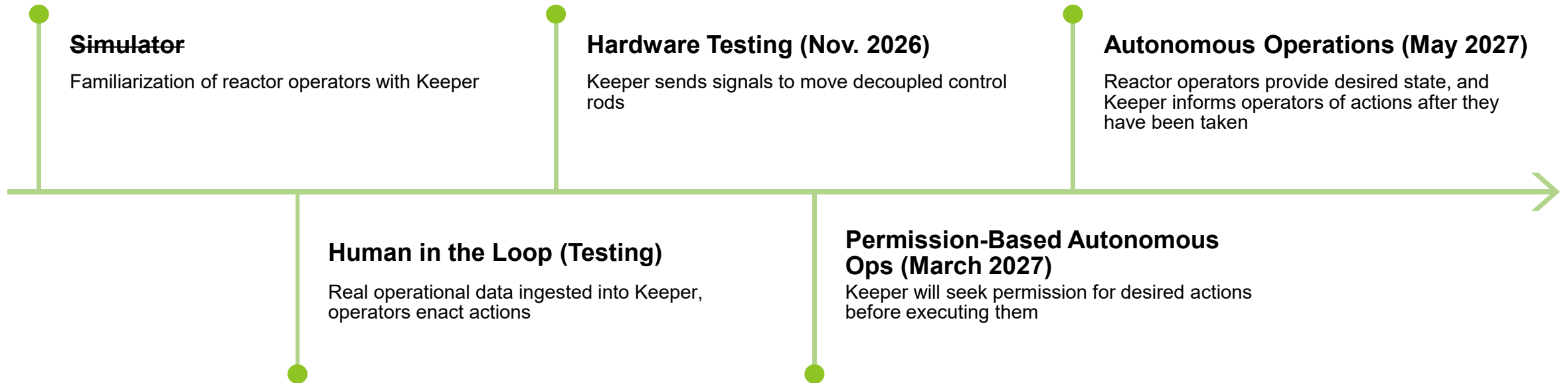
Human Machine Interface – How do we decide what happens?



Putting it all together



Where are we going?



Acknowledgments and Questions

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