Research Plan for Advanced Controls Development as Part of ASI

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Advanced Reactor Objectives

Highly autonomous
Fabricated offsite

Profitability

Flexibility

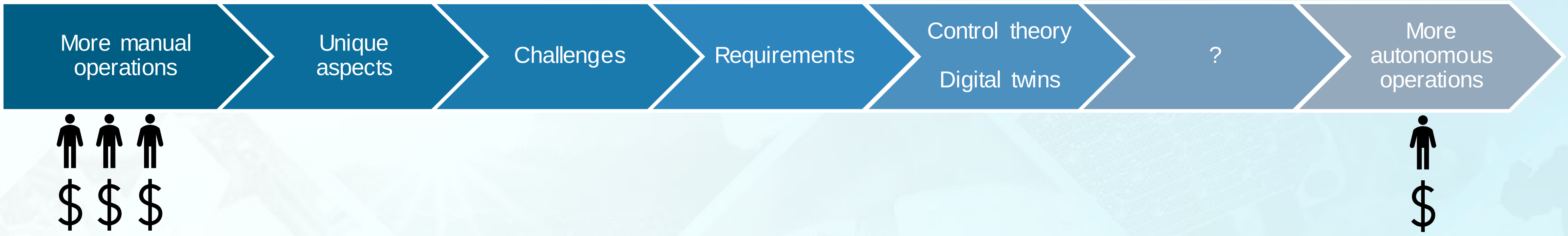
Variable power ratings
Rural locations

Non-electricity processes
Small footprint

Research Objectives and Impact

The objectives of this research are to:

- Identify control system requirements to enable more autonomous operations
- Assess how digital twins could be used to meet some of those requirements
- Identify remaining research gaps that need to be resolved



This effort provides a roadmap for advanced reactor vendors and researchers to transition from the current state of reactor operations to more autonomous operations

Types of Control

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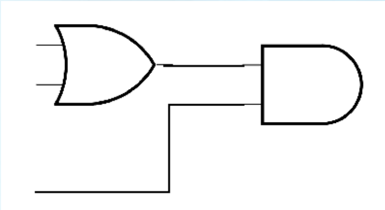
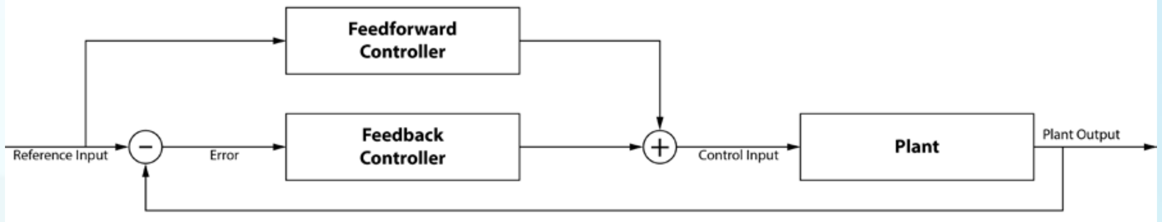
Logical Control

- IF, AND, OR, etc.



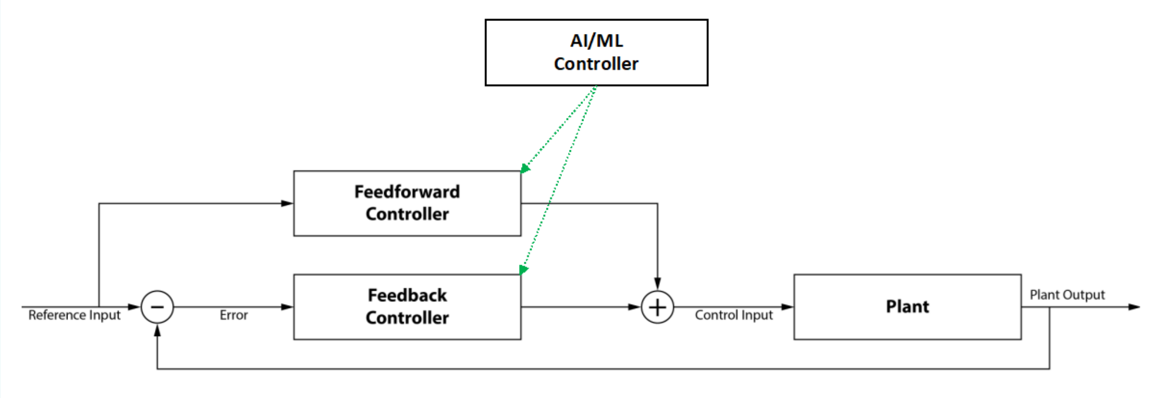
High Performance (HP) Control

- Continuous tracking of a process



AI/ML Control

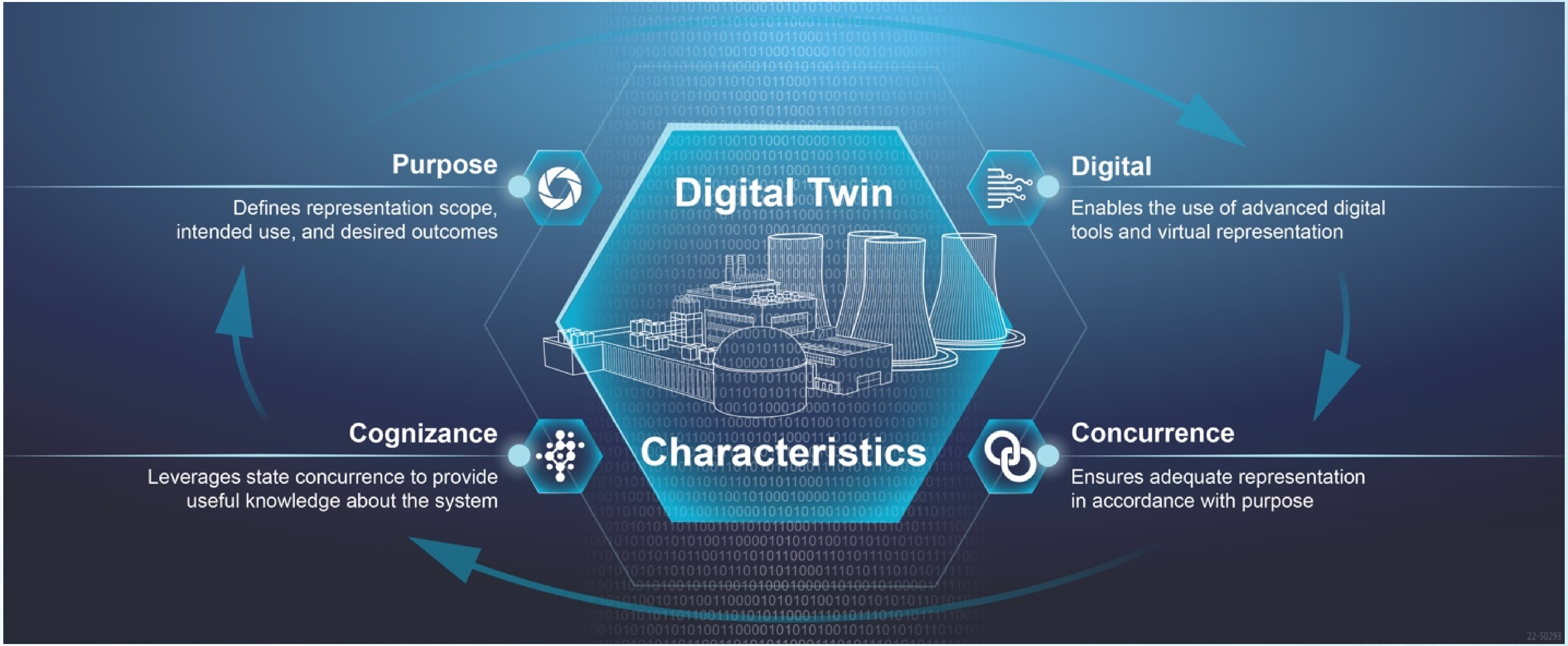
- Like HP control or as supervisory control



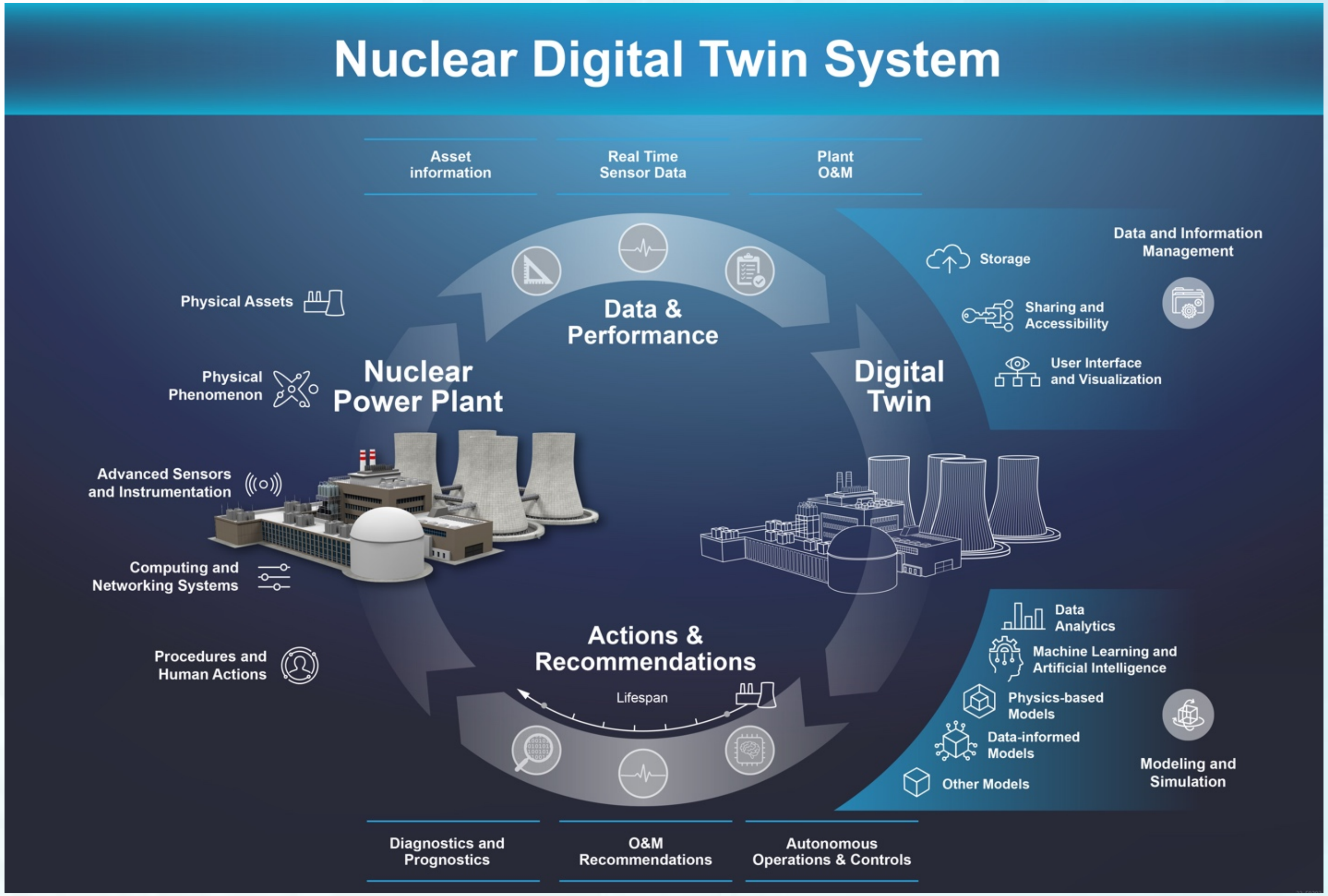
Requirements

Unique Aspect	Challenge	Control Requirement
Regulatory Requirements	AI/ML control may not meet regulatory requirements, such as deterministic and explainable behavior	Include an interface control layer between any AI/ML decision making and the plant
Operating Environment	I&C equipment will endure harsh environments for extended periods, increasing probabilities of failures	Identify and compensate for sensors, communications, and electronics failures
High Consequence	Manual investigation may not be feasible to reduce uncertainty and avoid shutdown	Incorporate risk elements to prevent unnecessary loss of generation
Highly Coupled	Compact and simpler designs will produce strongly coupled systems, making “isolated” control less feasible	Integrate highly coupled control loops and state-awareness methods
Evolving Knowledge	Novel concepts of physics and operation will be used that may not be fully understood or validated	Incorporate robustness into the control loop
Operating History	There will be limited operating history with which to make operational decisions	Use software models to identify, react, and track unanticipated physical phenomena Define the human role and allowable human interventions

Definition of Digital Twins



Capabilities of Digital Twins



Digital Twins in Control

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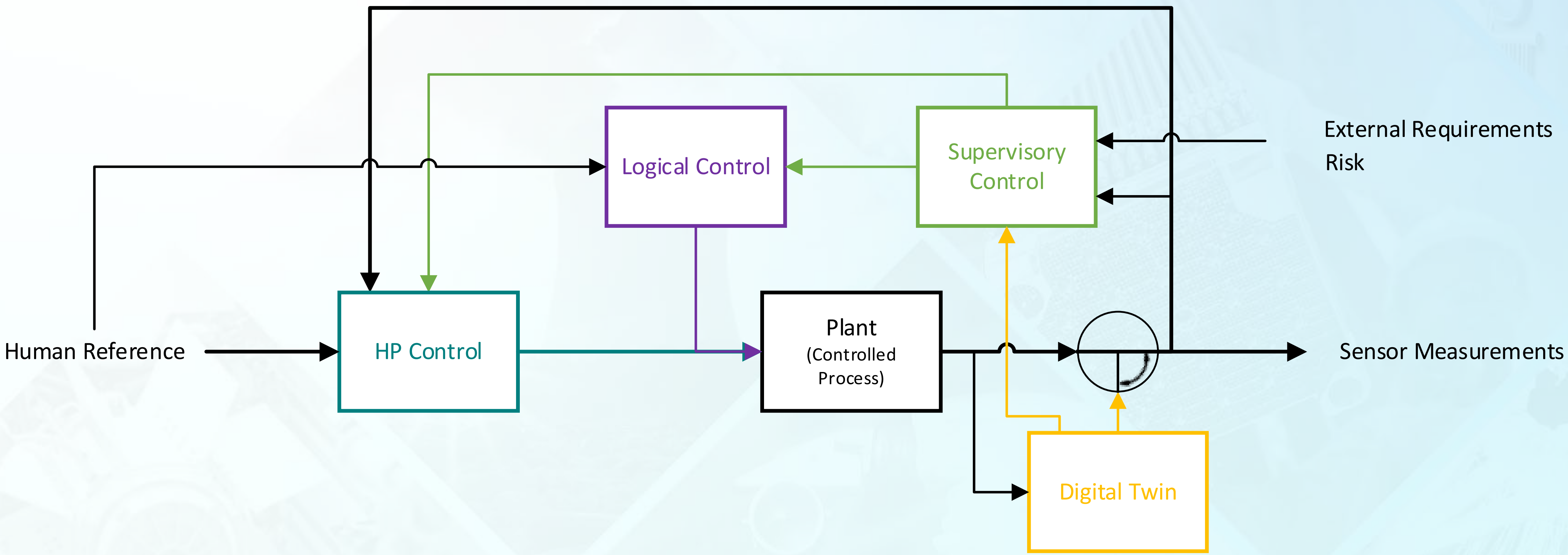
Design	• Create virtual sensors • Optimize the controller
Testing	• Assess control response to design-basis accidents • Assess control response to beyond design-basis accidents
Operations	• Determine the external operational state • Estimate the internal system state • Understand and react to beyond design control scenarios
Maintenance	• Evaluate impact of changes to control functions in case of failures • Reoptimize control response (e.g., from aging or maintenance)

Integrating Controls and Digital Twins

Operational Approach (Abstract)



Integrating Controls and Digital Twins

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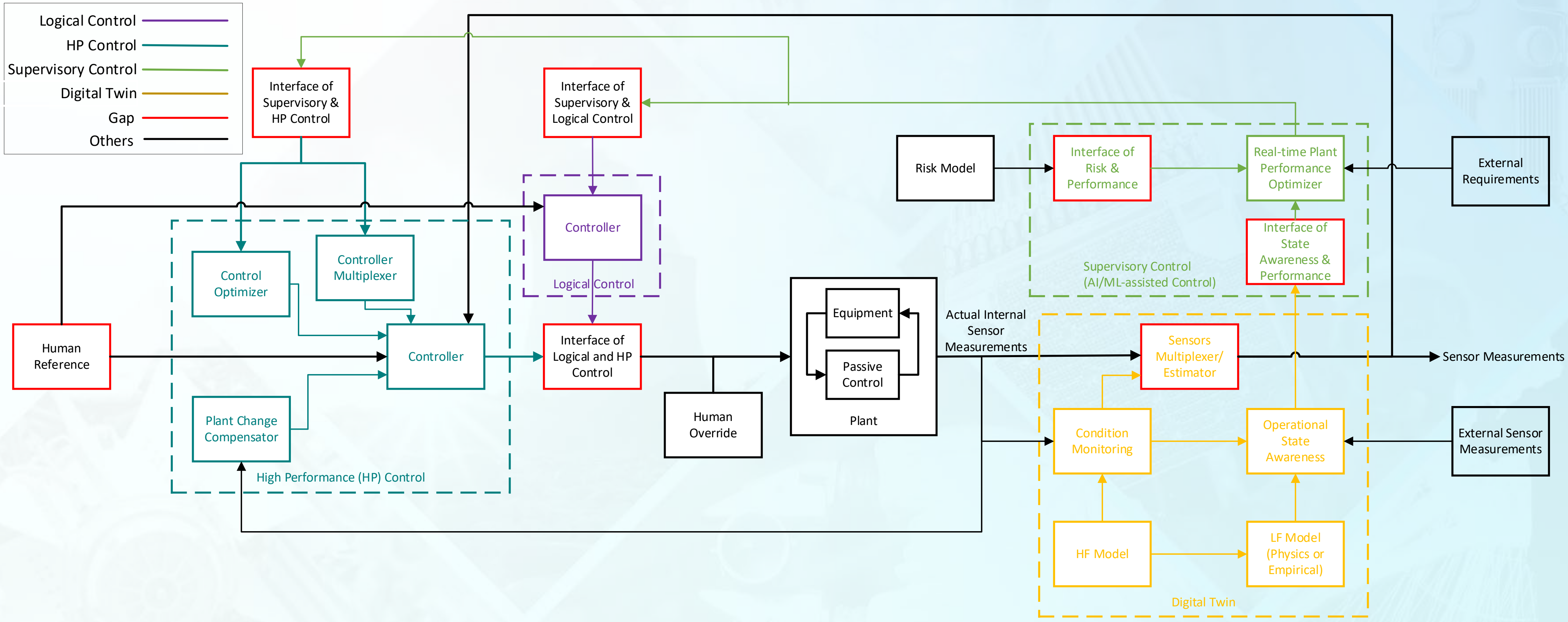
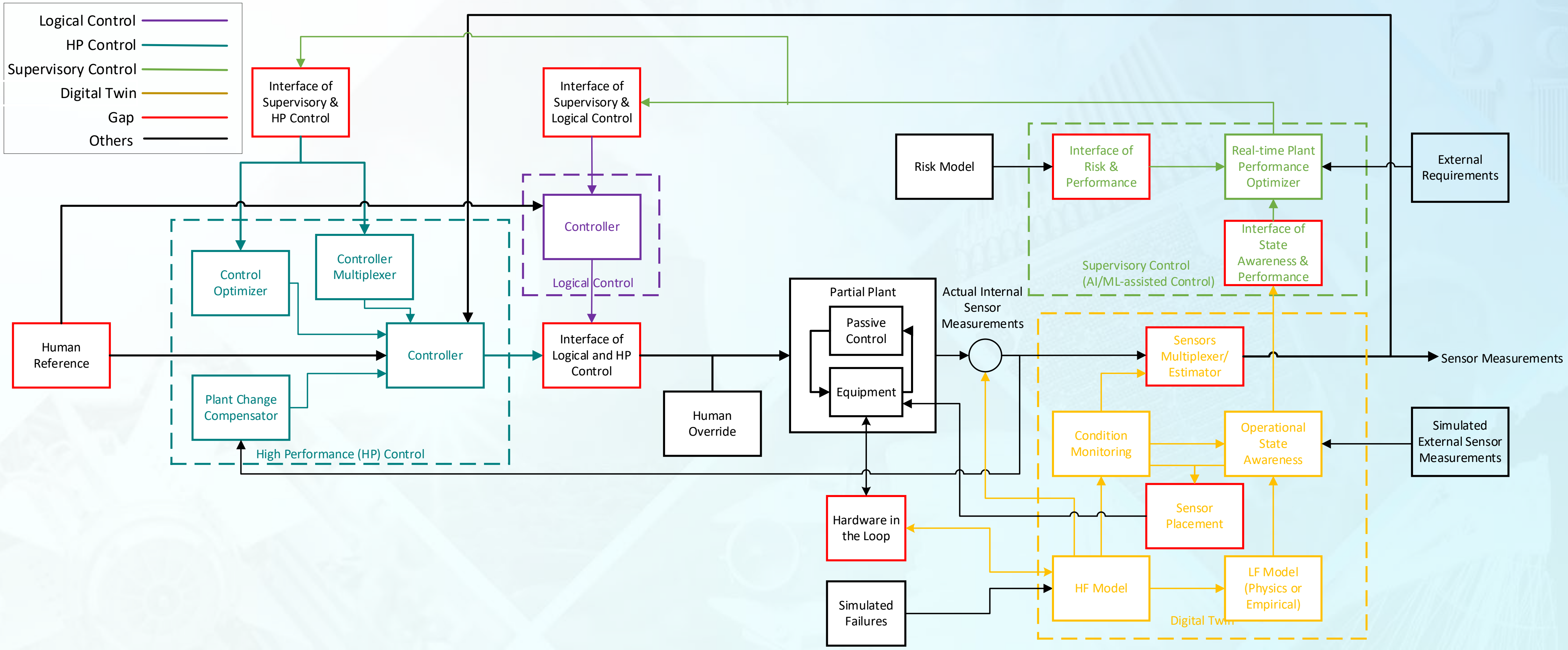
Operational Approach (Detailed)



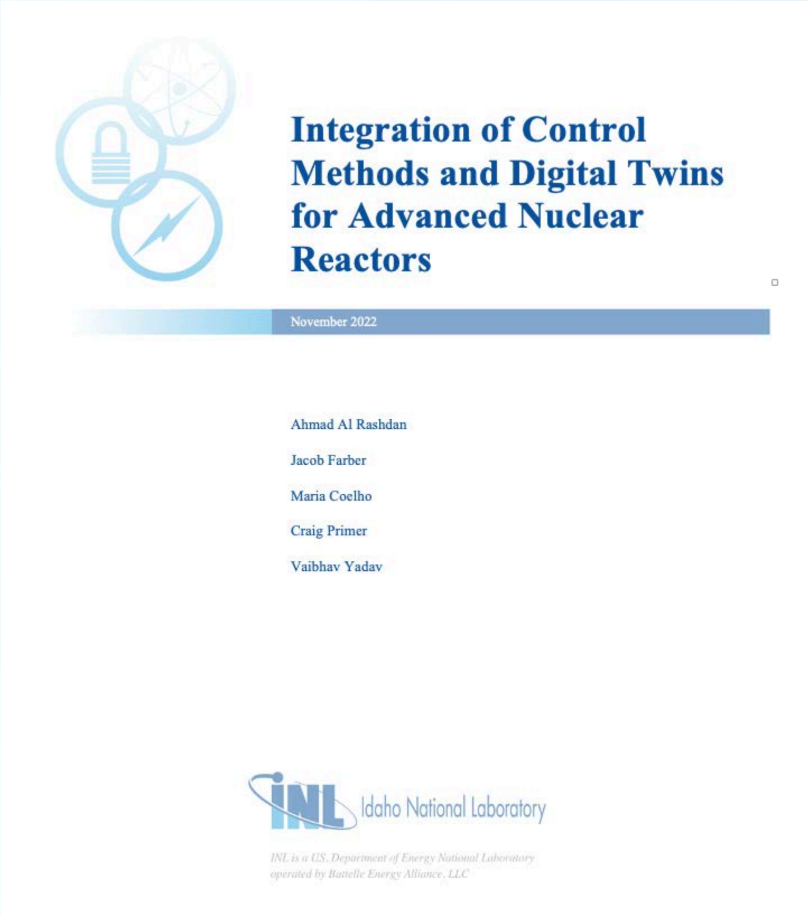
Integrating Controls and Digital Twins

Design Approach (Detailed)



Concluding Remarks

- The unique aspects and challenges of highly autonomous operations were assessed, which resulted in a set of control system requirements
- To meet the requirements, a layered approach was proposed that interfaced a supervisory control system with a digital twin
- This led to gaps that can serve as a roadmap for future research on controls in advanced reactors



Integration of Control Methods and Digital Twins for Advanced Nuclear Reactors

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Thank You