U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

ASI Advanced Sensors and Instrumentation

Advanced Sensors & Control Deployment

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ASI Advanced Sensors and Instrumentation

The US DOE Advanced Sensors and Instrumentation Program

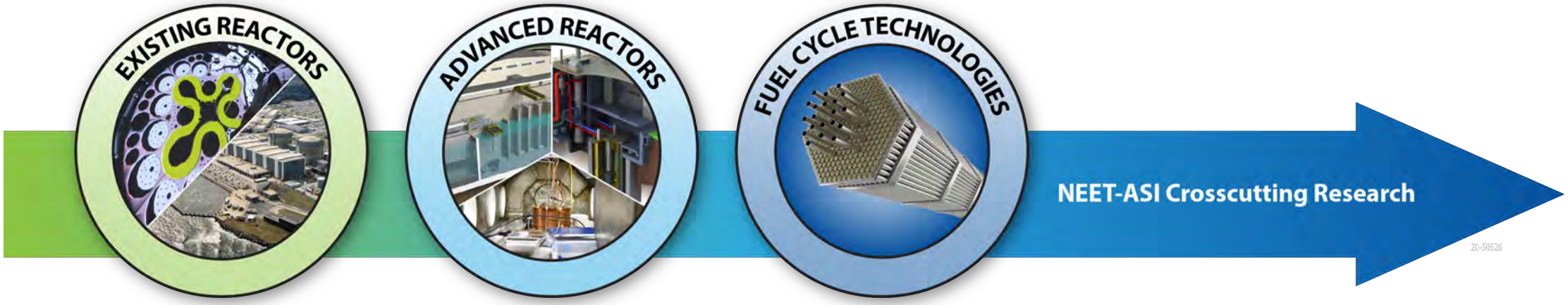
ASI Program Focus

Mission

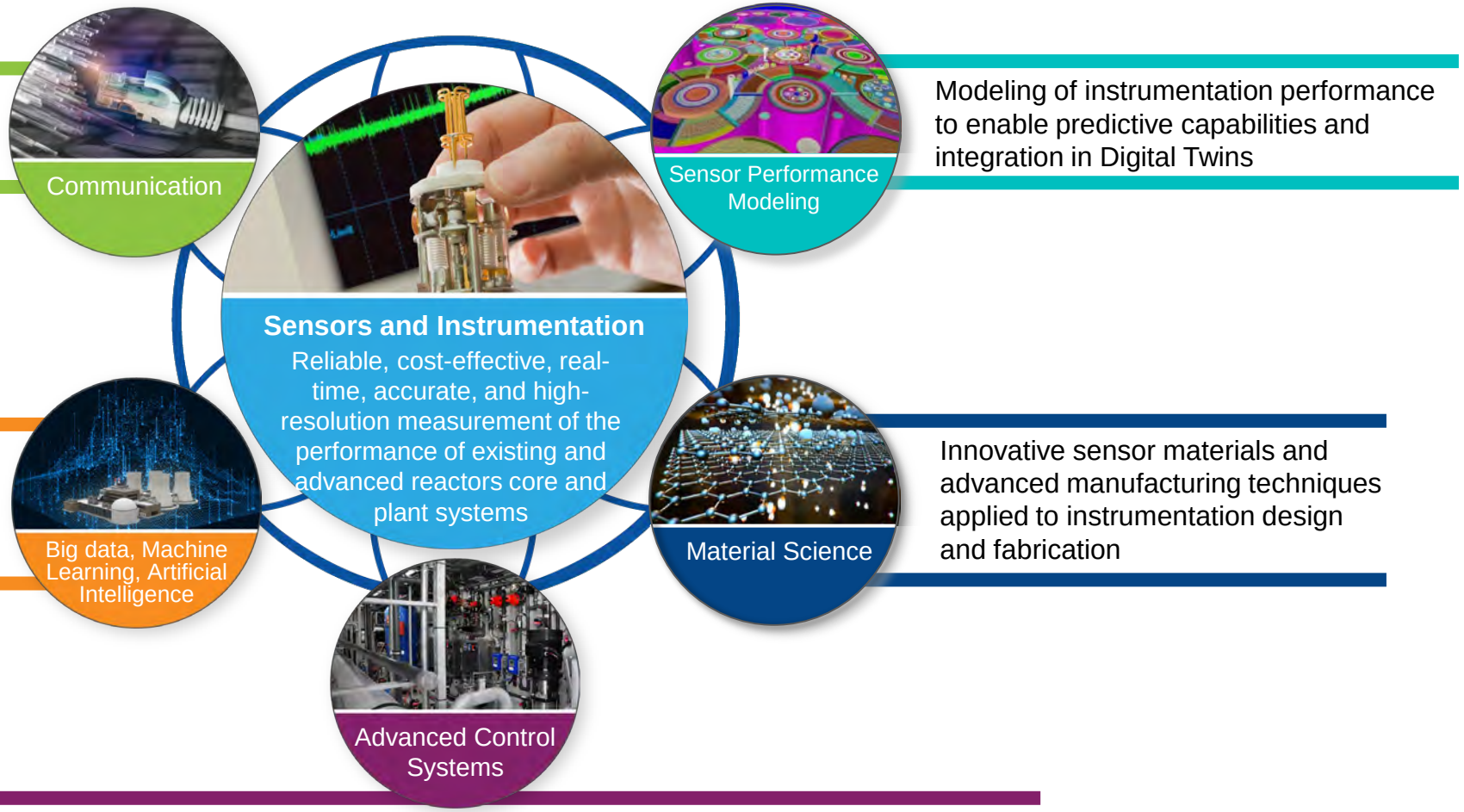
Develop **advanced sensors and I&C** that address **critical technology gaps** for monitoring and controlling existing and advanced **reactors** and supporting **fuel cycle** development

Vision

NEET ASI Research results in advanced sensors and I&C technologies that are **qualified, validated, and ready to be adopted by the nuclear industry**



ASI R&D Components

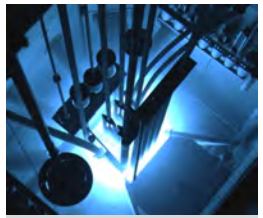


Technology Maturation Using DOE Testing Infrastructure

Irradiation test requirements and technology maturity largely determine the appropriate facility for testing

Low sensor TRL Technology
Easier Access
Lower Cost Tests
Separate effects testing

OSUR
University Reactor



PULSTAR
University Reactor

MITR
University Reactor

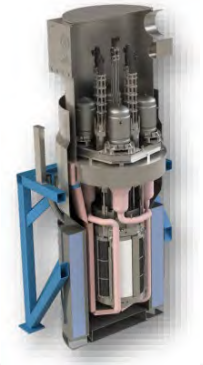
High sensor TRL Technology
Limited Access
Higher Costs, High Dose
Controlled Prototypic Environment

DEVELOPMENT → *PROTOTYPIC DEPLOYMENT*

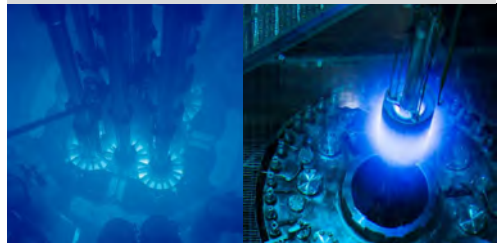
TREAT (INL)

NRAD (INL)

MARVEL ?



ATR/HFIR (INL/ORNL)



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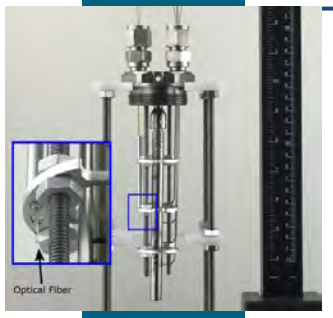
FY23 Program Directed Research Activities

Sensors for Advanced Reactors

Reactor power monitoring
Thermometry
Fiber optic sensing
Structural health monitoring
Rad-hard electronics



Sensors for Irradiation Experiments

LVDT
Passive monitors
Material properties characterization
Sensor qualification test

Sensors I&C integration

Advanced controls
Communication

4 guide tubes inserted into the air gap between the guard vessel and the reactor shielding house BF_3 and B-10 neutron detectors for MARVEL power control

The ASI program has interest in demonstrating neutron sensors in MARVEL for the following objectives:

1. Benchmarking commercial neutron sensors for low fluence rate environments.
2. Developing an advanced control algorithm using a neutron sensor array.

Minor design mod to accommodate 8 more guide tubes is under consideration

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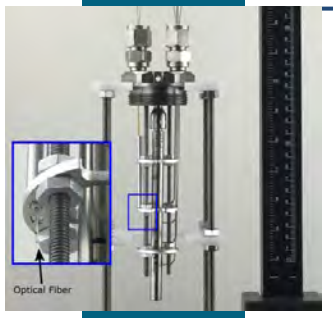

Sensors for Irradiation Experiments

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Proper mechanical compliance between sensors and components is an essential aspect of SHM and a major challenge for nuclear applications.

Embedding sensors through advanced manufacturing techniques is a key enabling technology for SHM. ASI is assessing two pathways complementing the work implemented at ORNL under MRP (ultrasound assisted sintering):

- Electric Field Assisted Sintering (INL)
- Hot confined rolling (PNNL)

A workshop (Aug 27-29, PNNL) will bring together ASI, AMMT and MRP experts to prioritize coordinated DOE efforts in this area (Chris Petrie for MRP).

FY23 Program Directed Research Activities

Sensors for Advanced Reactors

Reactor power monitoring
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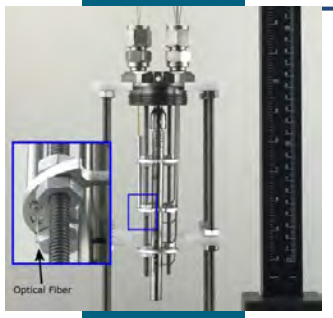
Rad-hard electronics



Sensors for Irradiation Experiments

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Example Program Effort: Advanced Controls for Advanced Reactors

Acknowledgements

Project Team

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Pattrick Calderoni

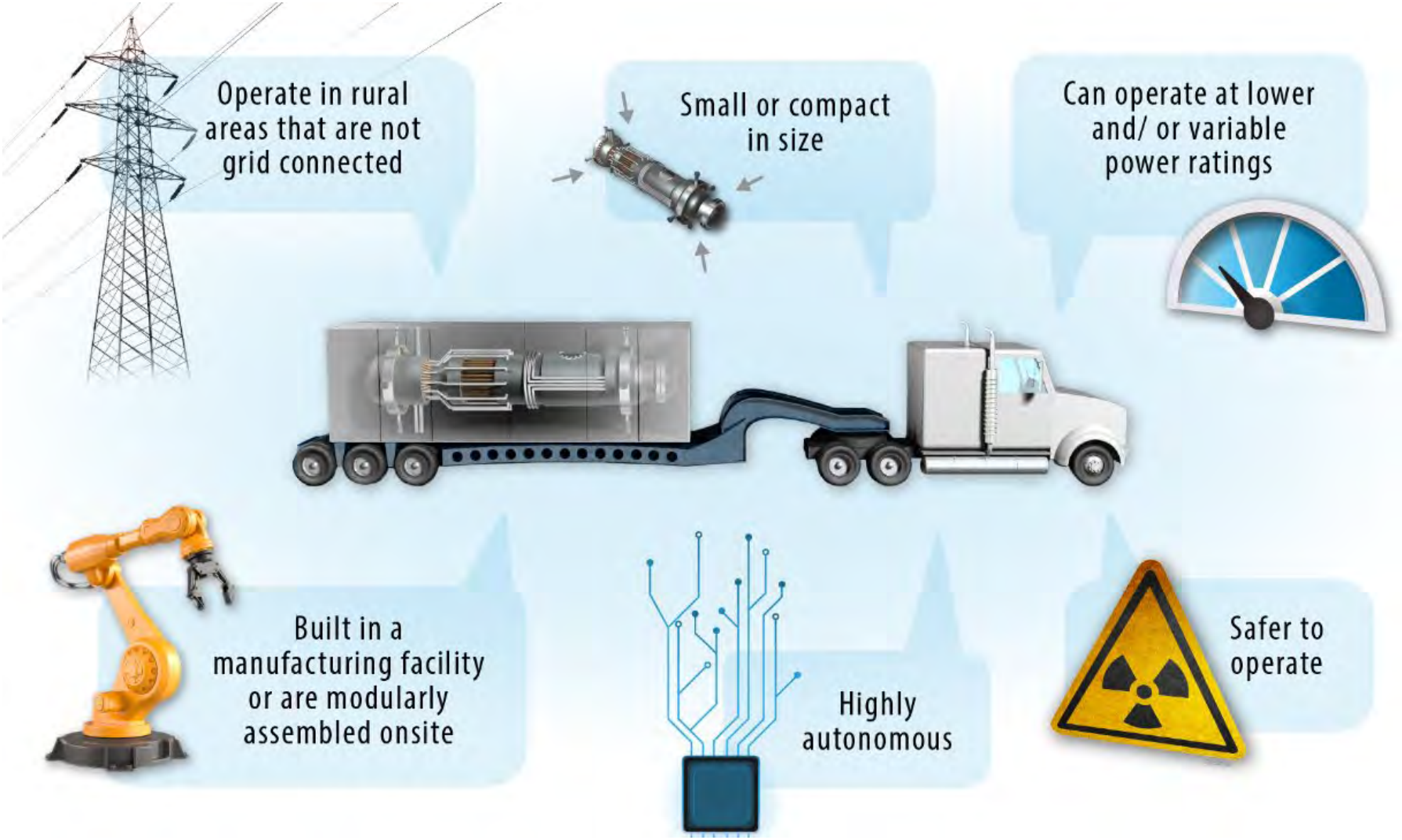
Coordination Team

Richard Vilim

Pradeep Ramuhalli

Roberto Ponciroli

Example Microreactor Characteristics



Gap Analysis

Unique Aspect	Gap	Control Requirement
Regulatory Requirements	AI/ML control requires the development of a special form of model that meet regulatory requirements.	Introduce layered approach of control that enables AI/ML-assisted control but cannot compromise the main control role that meets regulatory requirements
Operating Environment	Given the high autonomy requirement, it is necessary to deploy methods that introduce better awareness of the plant and compensate for sensors failure	Couple to low and high-fidelity digital twins that create a virtual knowledge of lost plant information and indirectly feeds into the control function of the reactor
High Consequence	Need to understand the broader plant condition and challenges, and make a risk-informed decision on the best action to take.	Incorporate risk elements into control methods to achieve optimal performance
Highly Coupled	Multi-input and multi-output control need to handle high level of non-linearity and interface continuous and discrete states.	Interface the various means of control including AI/ML-assisted control methods that can handle multi-input multi-output high level of non-linearity and digital control for discrete states control.
Evolving Knowledge	Control methods performance is dependent on the accuracy associated with the estimated control model	Interface the various means of control including AI/ML-assisted control methods that can empirically and gradually model the process and adjust the control method as knowledge is gained.
Lack of Operating History	Useful history to feed into optimization the control methods design and development does not exist.	Leverage hybrid systems (using digital twins and hardware in the loop) to generate synthetic operating history. This requires a provision to interface with a pool of software and physical technologies. Enable a limited provision for human intervention, especially during the initial operation of reactors.

In July 2023, the DOE NEET ASI hosted its first control-focused workshop at ANL.

Motivation: Industry has been focusing more on core reactor design problems. Control is rarely mentioned in discussions of advanced nuclear reactor design as it is assumed that when needed, the solution would be available.

Approach: Convene subject matter experts and stakeholders in control methods and technologies for a comprehensive discussion on challenges and research and development needs to focus the program research.

Participation: Three national laboratories, eight industry representatives, the Nuclear Regulatory Commission, and several universities.

The need for advanced control:

- There seemed to be a disagreement of what the control and human role would be in autonomous systems, which is potentially due to the different types of reactors being developed.
- Autonomous control in nuclear reactors has not been demonstrated for advanced nuclear reactors and there could be challenges that we are not aware of yet.

Challenges and current state (One Example):

- The changing environment: Controllers that can adapt to changing environments have not been demonstrated.
- Testing and demonstration: The research community lacks a platform to freely manipulate, disturb, and validate methods to develop control methods and digital twins, and a standard set of benchmark datasets and scenarios that can be used for validation.

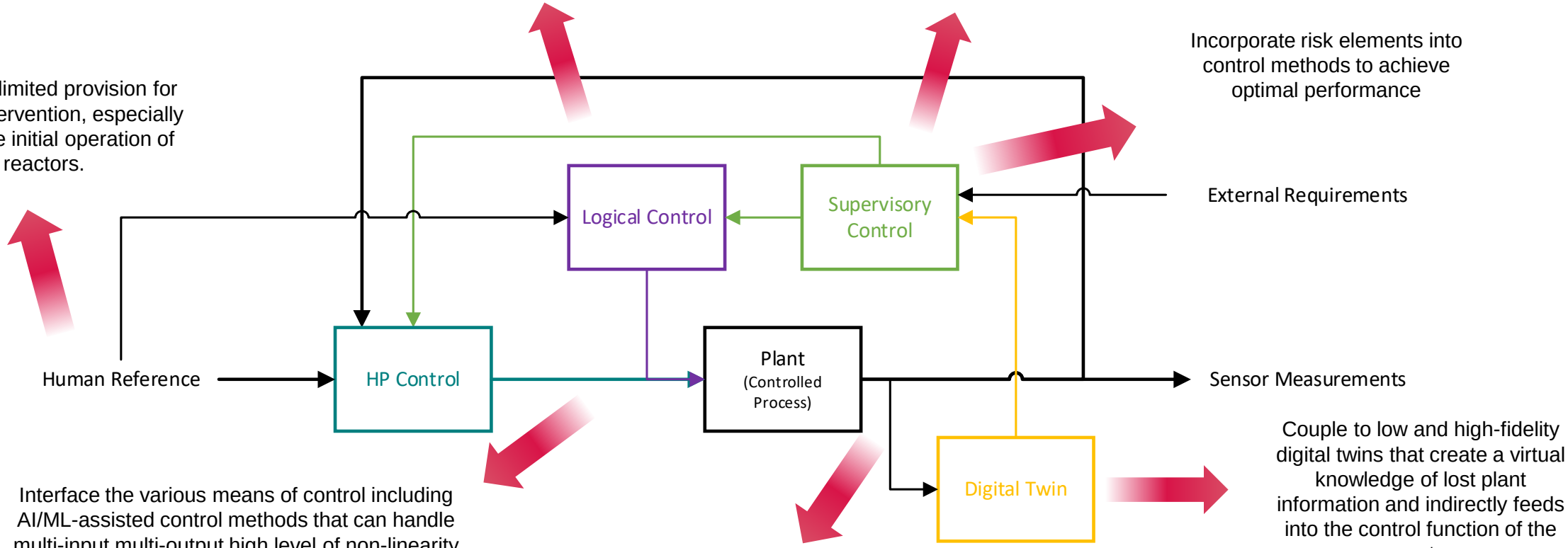
Approach to Meet the Control Requirements

Introduce layered approach of control that enables AI/ML-assisted control but cannot compromise the main control role that meets regulatory requirements

Interface the various means of control including AI/ML-assisted control methods that can empirically and gradually model the process and adjust the control method as knowledge is gained.

Incorporate risk elements into control methods to achieve optimal performance

Enable a limited provision for human intervention, especially during the initial operation of reactors.



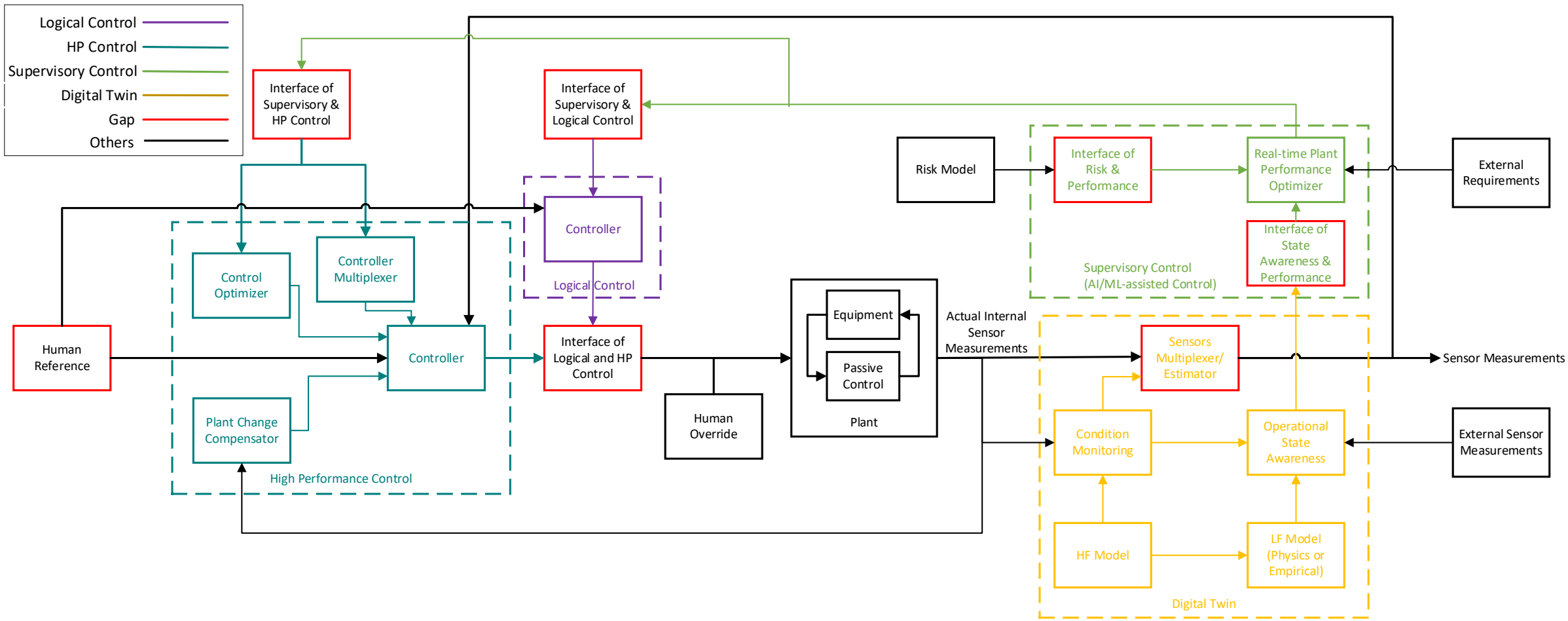
Interface the various means of control including AI/ML-assisted control methods that can handle multi-input multi-output high level of non-linearity and digital control for discrete states control.

Leverage hybrid systems (using digital twins and hardware in the loop) to generate synthetic operating history. This requires a provision to interface with a pool of software and physical technologies.

Couple to low and high-fidelity digital twins that create a virtual knowledge of lost plant information and indirectly feeds into the control function of the reactor

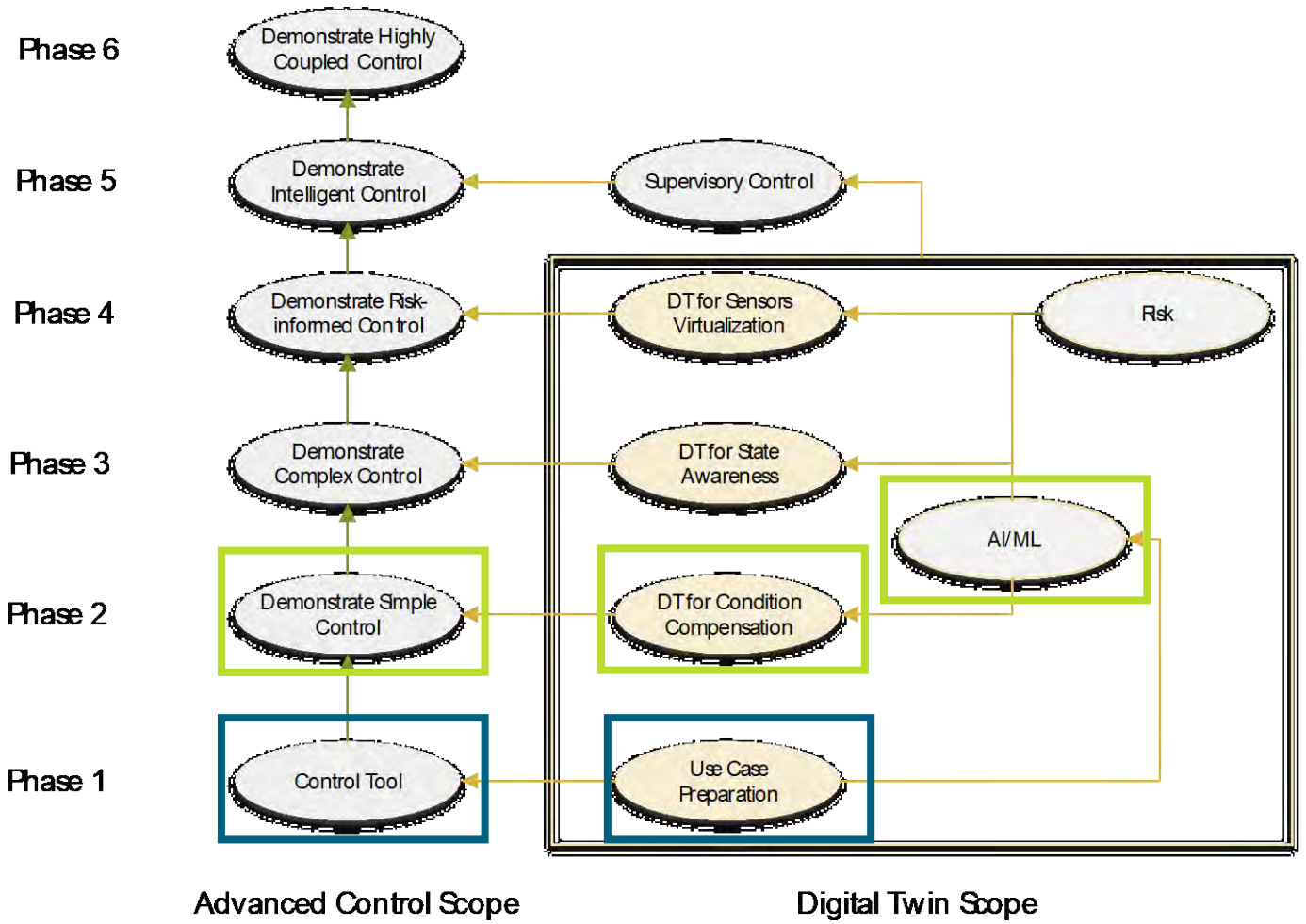
Source: Al Rashdan, A., J. Farber, M. Coelho, C. Primer, V. Yadav, Integration of Control Methods and Digital Twins for Advanced Nuclear Reactors, INL/RPT-22- 69937. Idaho National Laboratory.

Approach to Meet the Control Requirements



Source: Al Rashdan, A., J. Farber, M. Coelho, C. Primer, V. Yadav, Integration of Control Methods and Digital Twins for Advanced Nuclear Reactors, INL/RPT-22- 69937. Idaho National Laboratory.

Full Demonstration of an Autonomous Reactor



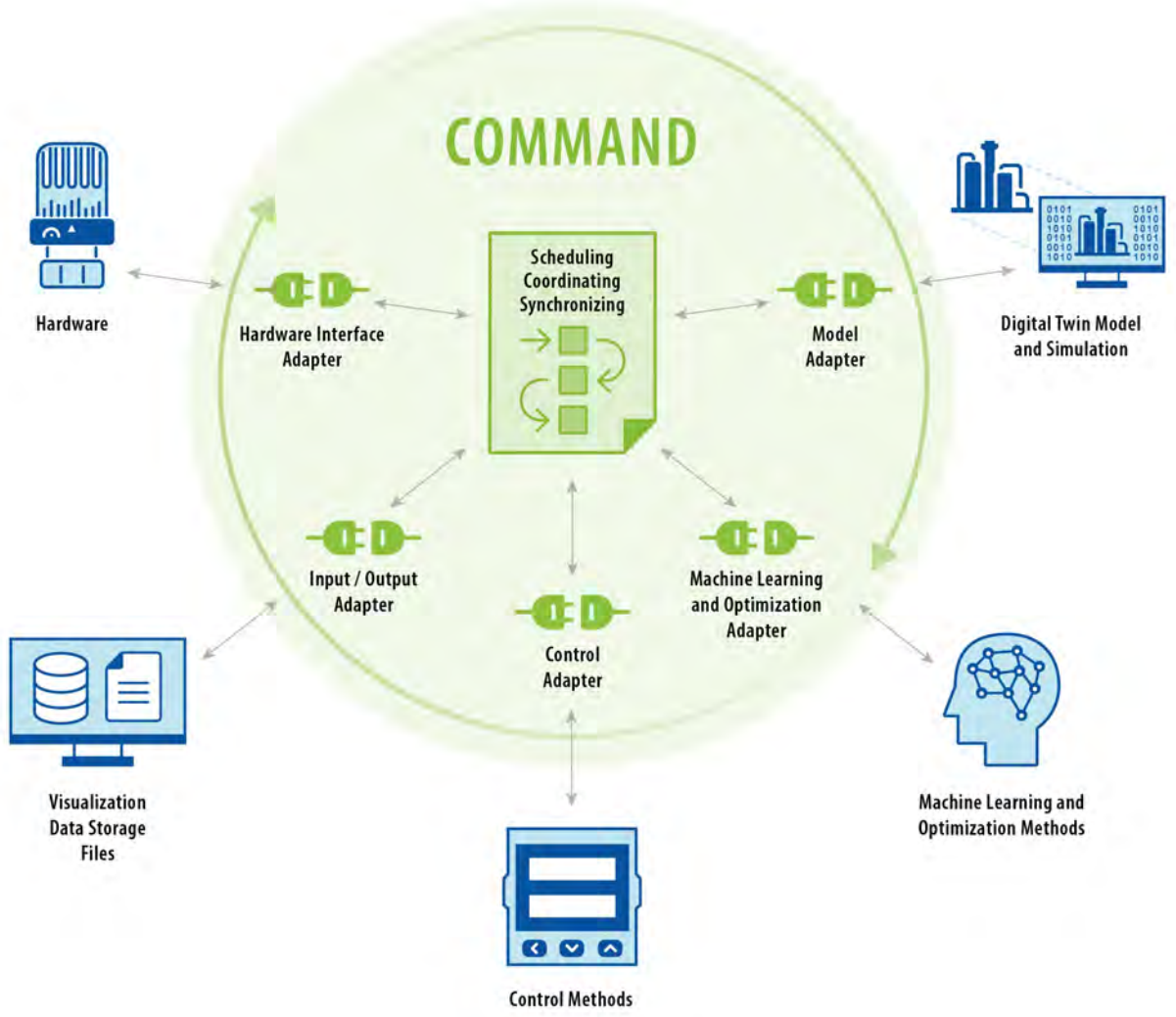
FY23

FY24

Control and Optimization Modular Modeling Application for Nuclear Deployment (COMMAND)

COMMAND is a flexible simulation platform designed to be:

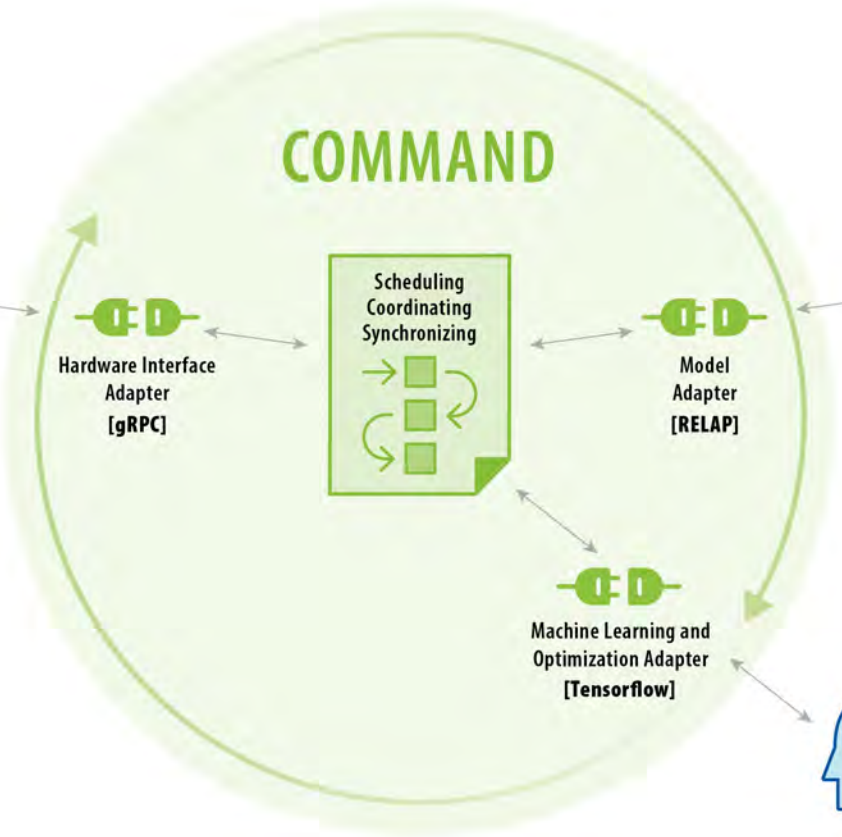
- Accessible: the intent is to make it open-source and publicly available
- Modular: the software "pieces" all inherit from generic building blocks and can be combined and connected to create complicated simulations
- High performing: designed for parallel processing, enabling simulations to take advantage of multi-core computers, servers, and nodes



FY24 Accomplishments

Developed adaptor to gRPC, an industrial communication protocol

MACS



Updated MARVEL RELAP model to accommodate MCNP inputs

RELAP5-3D

MARVEL Model

Developed pipeline to connect hardware running locally to COMMAND running on INL's High Performance Computing ecosystem

Ran MARVEL MCNP simulations and developed surrogate models to capture spatial power distribution

Surrogate Models

MCNP6

MARVEL Model

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.