



ADVANCED REACTOR SAFEGUARDS & SECURITY

Remote Operation Feasibility of the MARVEL Microreactor

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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.

INL/MIS-26-92041



Background and Motivation



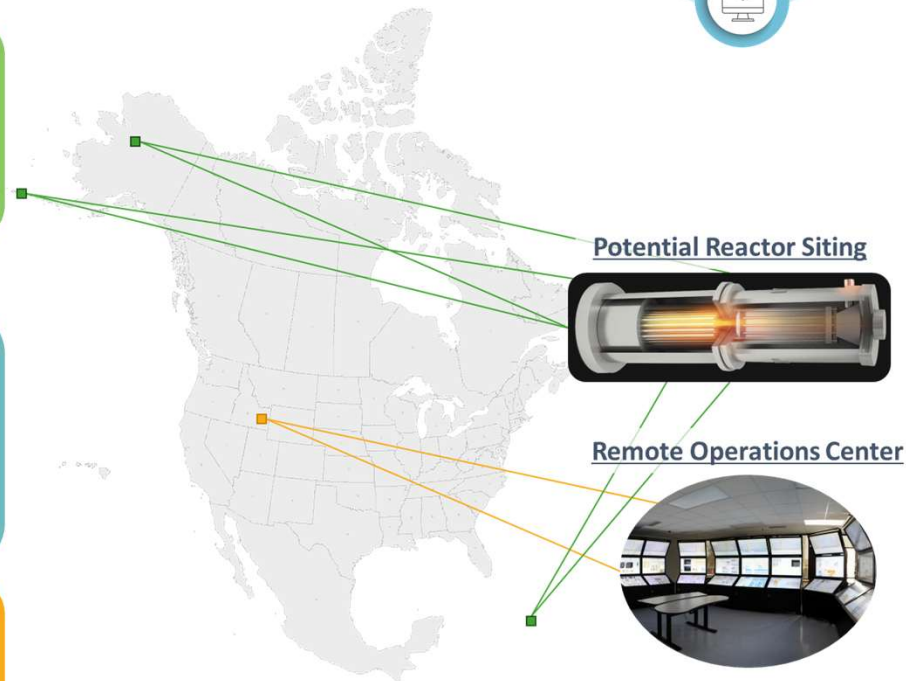
What:

This work aimed to assess the MARVEL microreactor currently under construction at Idaho National Laboratory (INL) for the suitability of remote operations under the remote operations class structure proposed in ARSS in FY25.

Why:

There is strong interest among advanced reactor developers in the integration of some level of remote operations in the concept of operations for their proposed reactor designs. Specifically, GE Vernova Hitachi has been selected to propose a first MARVEL end user experiment where they propose to demonstrate remote operations.

The remote operation of nuclear reactors is a new concept in the nuclear industry, and thus there are knowledge gaps in how, or if, remote operations could be implemented, especially in the areas of cyber and physical security.



Classification Of Remote Operations Based on Function and Access to Systems.



Amount of: Remote Control Functionality
Remote Access to Systems and Equipment
Required Security

Class 1:
Remote
Monitoring
Only

Class 2:
Remote
Allowlisted
Commands

Class 3:
Remote
Control of
Non-Safety
Systems

Class 4: Remote
Control of
Safety-
Significant and
Important to
Safety Systems

Class 5:
Remote
Control of
Safety Related
Systems

MARVEL Microreactor Background

Microreactor Application Research, Validation and Evaluation Project

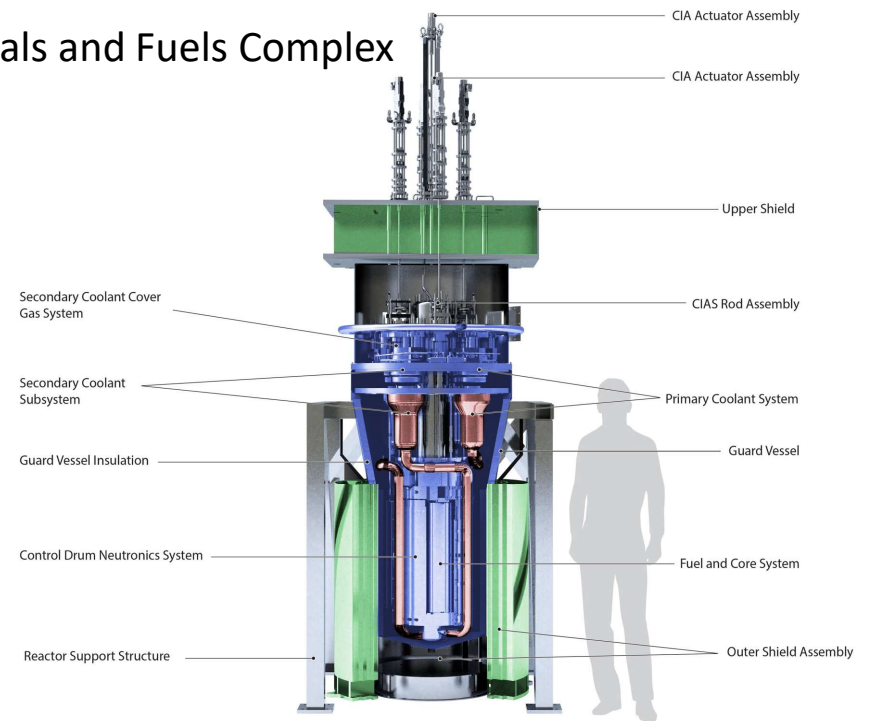


Dry Criticality: End of CY 2026

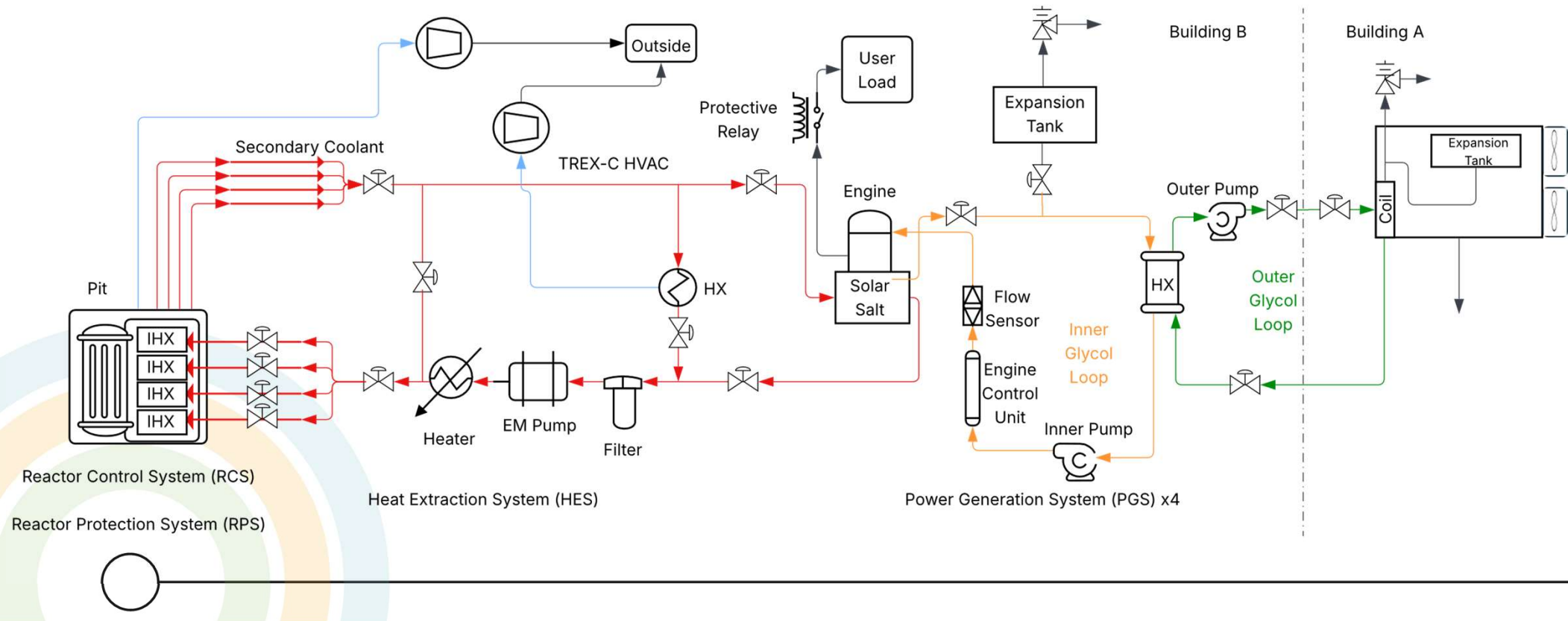
Full Power Operations: CY 2028

Location: Transient Reactor Test (TREAT) facility at the INL Materials and Fuels Complex

Key Design Features	
Thermal Power	100 kW (85 kW nominal)
Electrical Power	20 kWe
Weight	< 8 US ton
Primary Coolant	Sodium-Potassium eutectic
Coolant Driver	Natural Convection, single phase
Fuel	HALE(UZrH), 304SS clad, end caps
Moderator	Hydrogen
Neutron Reflector	Graphite, Beryllium (S200), Beryllium oxide
Reactivity Control	Radial Control Drums, Central Absorber
Primary Coolant Boundary	SS316H



MARVEL System Architecture

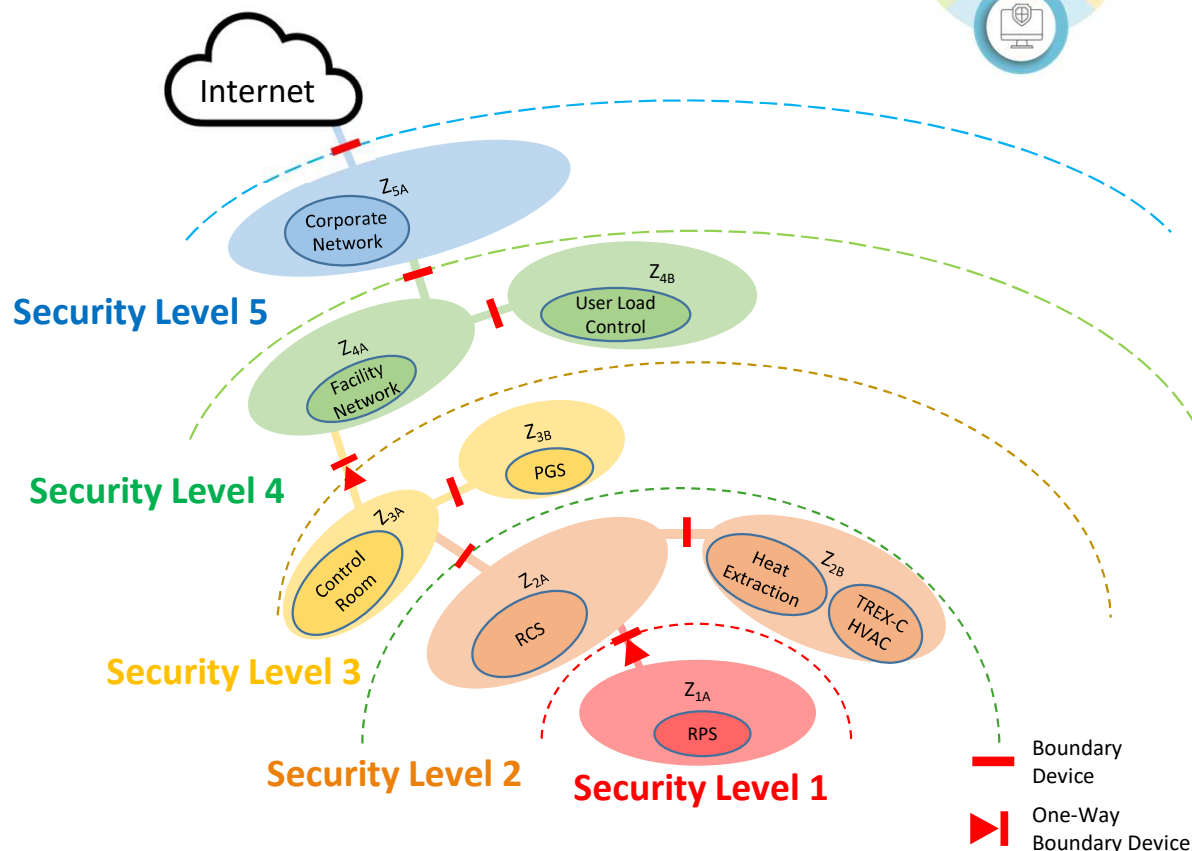


Sorting of MARVEL Systems Into a Defensive Cybersecurity Architecture (DCSA)



• MARVEL Systems

- Reactor Control System (RCS)
- Reactor Protection System (RPS)
- Heat Extraction System (HES)
- TREX-C HVAC
- Power Generation System (PGS)
- Plant Monitoring
- End User Load
- Corporate Network
- Facility Network

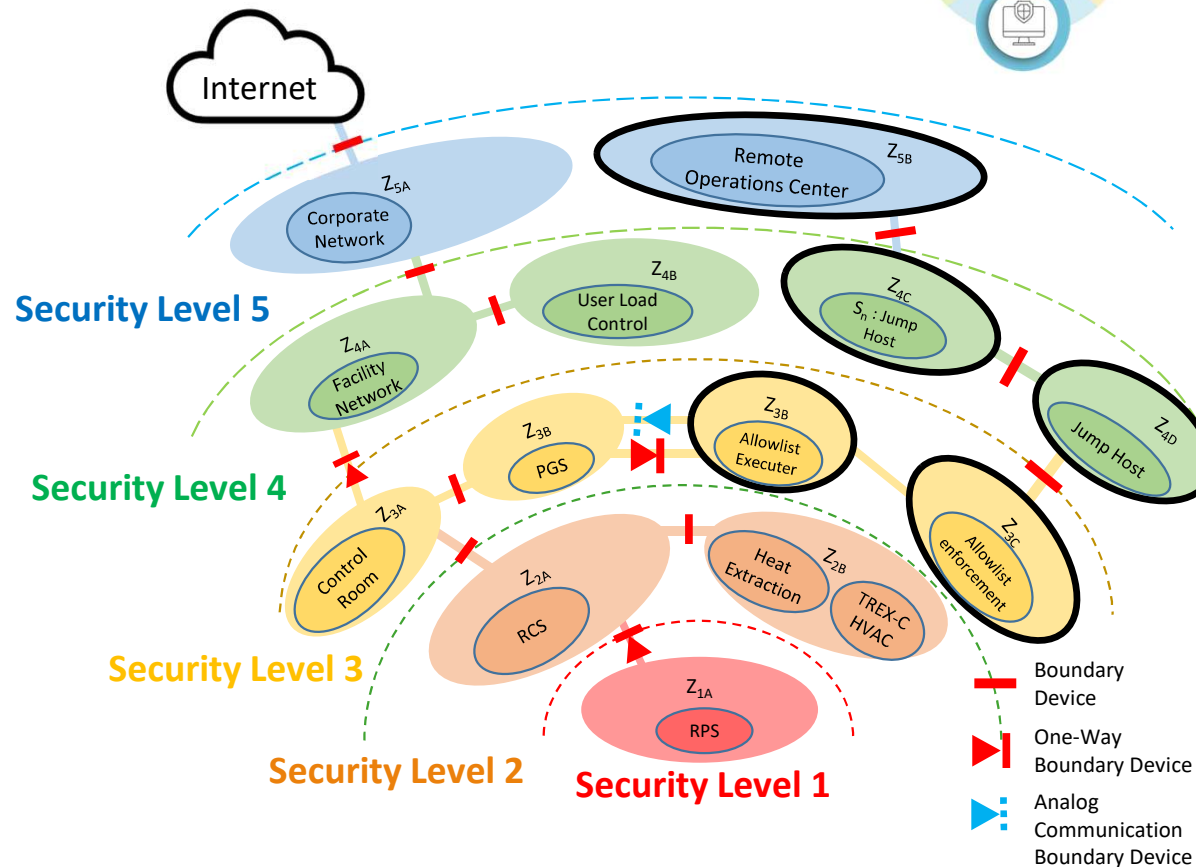


Adapted From IAEA – NSS 17-T

MARVEL Class 2 Remote Operations: Allowlisted Control



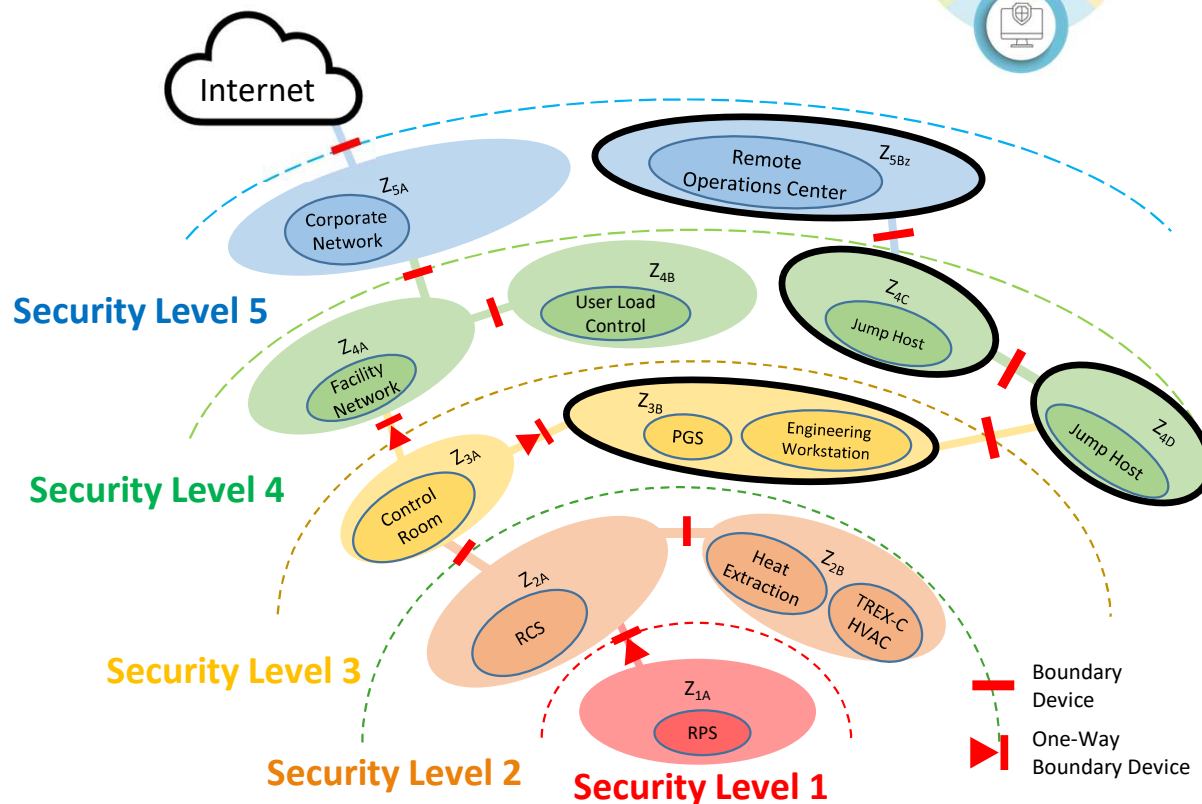
In a Class 2 remote operations architecture, a remote operations system would interface with the control room via an allowlist enforcement device, such as an analog or discrete connection, allowing the remote ops center to command specific, pre-defined and controlled actions.



MARVEL Class 3 Remote Operations: Control of Power Generation



In a Class 3 remote operations architecture, a remote operations system would interface over a networked only with non-safety systems designated for remote operation that are isolated from any other plant systems not designated for remote operations, regardless of safety categorization.



Practical Limitations of Implementing Remote Operations on MARVEL



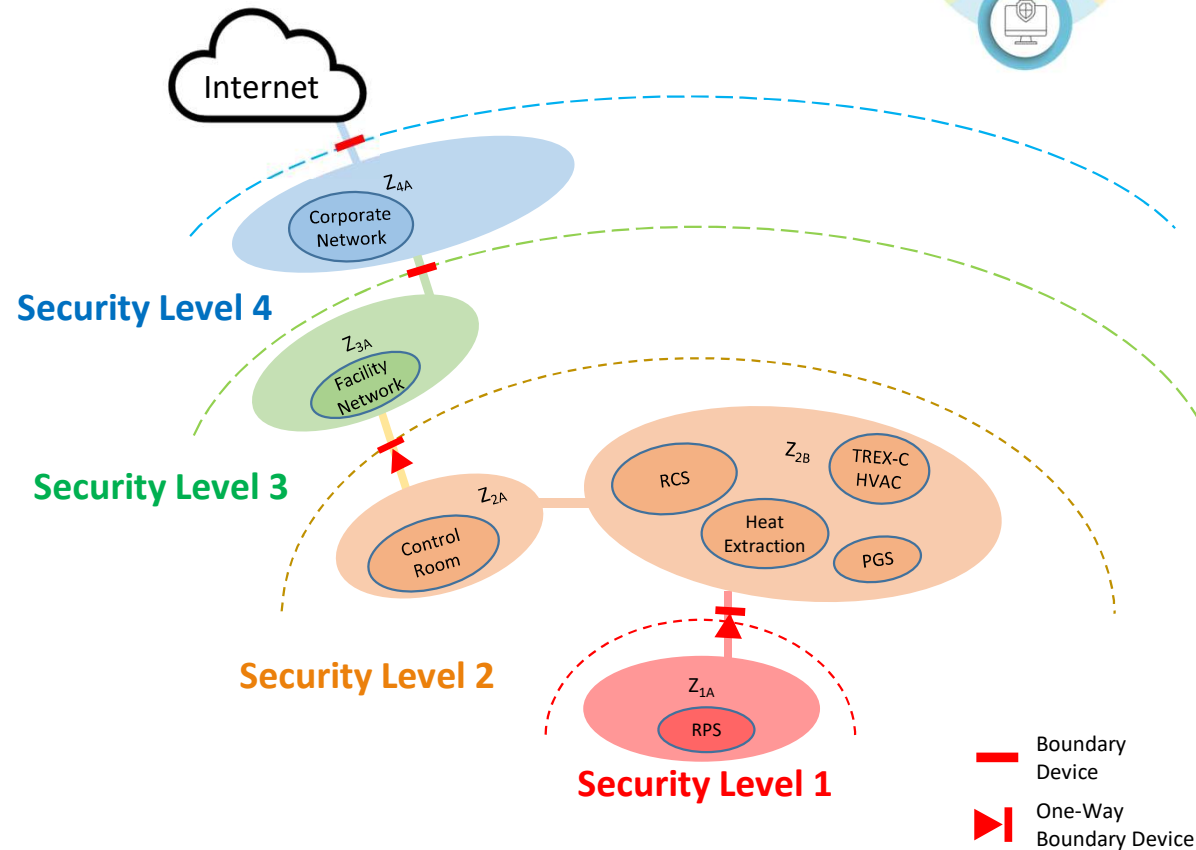
- Regulatory
 - Compliance with DOE-1271-2025.
 - Compliance with internal INL policy.
- Location
 - MARVEL is located within the TREAT reactor facility, therefore impacts to TREAT must be considered.
- Design
 - MARVEL was not designed with remote operations in mind; therefore, a remote operations system must adapt to MARVEL and not visa versa.
 - The eventual implementation of remote operations for MARVEL may not be the solution that would be used if remote operations was a requirement from the beginning.



How is MARVEL Actually Architected?



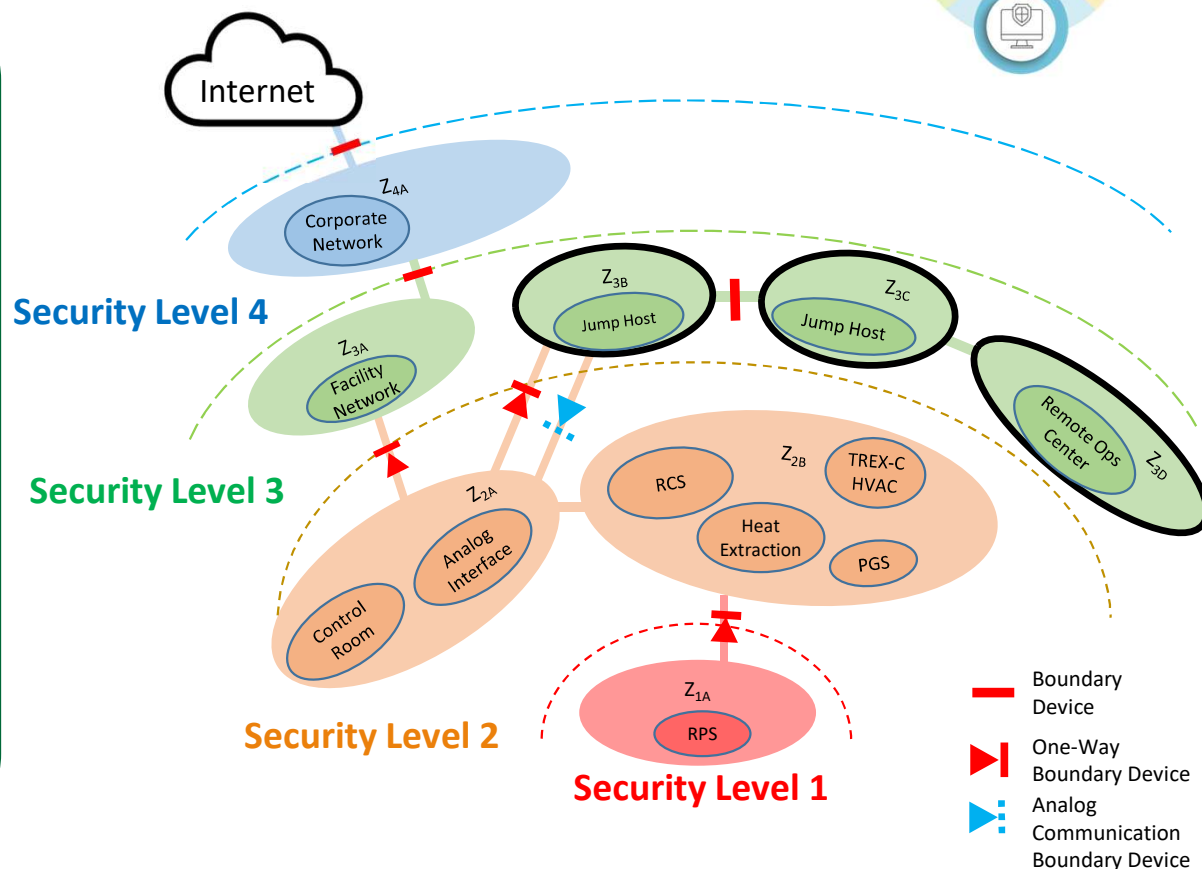
MARVEL is designed as a largely flat network that is isolated from any external networks.



Possible Architecture for MARVEL Remote Operations



- Because of facility restrictions, its is unlikely an external system, even within INL network boundaries, will be allowed to digitally interface with the MARVEL control system, eliminating the possibility of a Class 3 remote operations architecture.
- It may be tenable to use the analog interface method proposed in Class 2 remote operations, provided the remote operations center is within INL network boundaries even if at a geographically disparate facility, e.g. Idaho Falls.



Conclusions and Next Steps



- If MARVEL had remote operations considered from the start of the design, both Class 2 or Class 3 remote operations may have been possible.
- However, because of choices made early in MARVEL design regarding network boundaries, only a Class 2 architecture may be possible moving forward.
- Next steps for the remainder of FY26:
 - DOE authorization considerations for MARVEL remote ops as being constructed.
 - DOE authorization considerations for MARVEL remote ops if remote ops considered from start of design.
 - Goal is to provide lessons learned to industry.





Questions?

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