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Instrumentation & Control for Advanced Nuclear Reactors

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Yvotte Brits

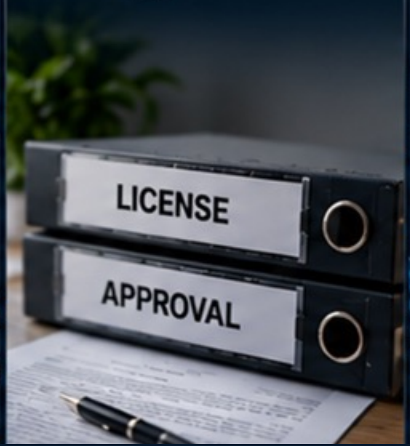
Chief Reactor Technology Officer

New Nuclear Power Plants must meet six challenges to remain competitive

1 Optimize their Levelized Cost of Electricity

2 Minimize CAPEX per MW and OPEX

3 Obtain licensing and regulatory approvals



4 Protect against physical and cyber threats

5 Safely maintain and evolve multiple systems

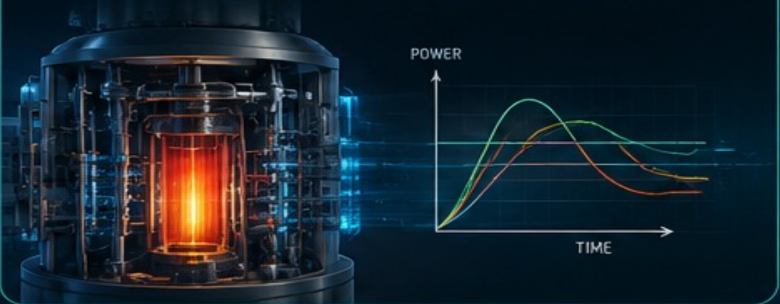
6 Manage and coordinate suppliers

Advanced reactor I&C is different

The biggest risk is not a cabinet or PLC – it is late discovery that the plant architecture cannot support licensing, operations, or security.

New physics & transients

New (VHTR, SMR, MSR, FHR) designs require reactor-specific models, setpoints, and protective actions.

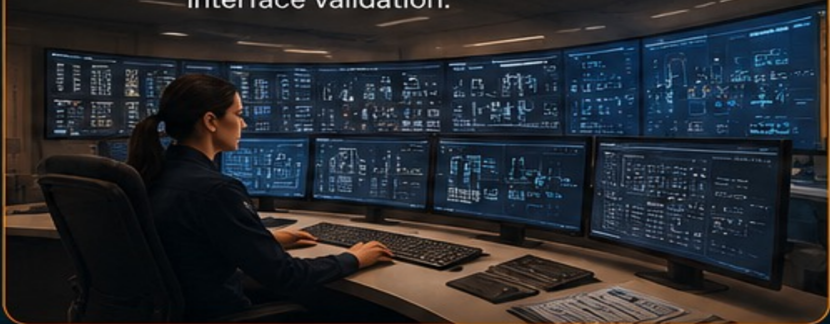


Digital safety licensing

Software/FPGA lifecycle, V&V, independence, diversity, and configuration control must be planned early.

Lean staffing & autonomy

Advanced reactors rely on automation, user trust, and human-system interface validation.



Multi-module operation

Shared systems and common-cause failures must be addressed in architecture and HFE.

Cyber + security

Digital assets, data flows, and physical security must be designed around the safety boundary.

Nuclear supply chain

NQA-1, commercial dedication, qualification, and long-lead procurement affect the critical path.

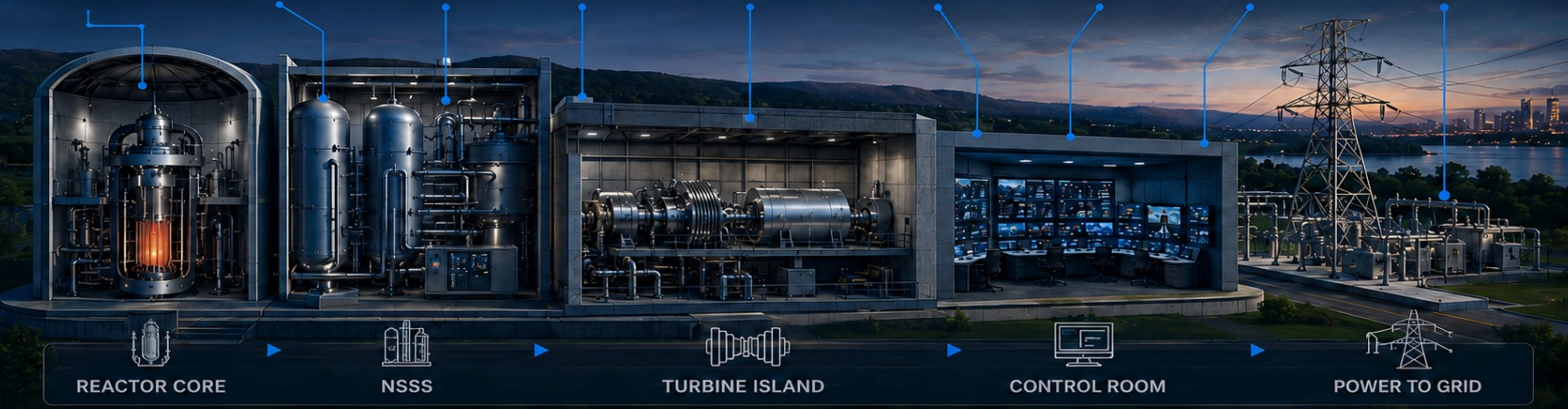
Bottom line: Success with advanced reactors comes from addressing these differences early, with an integrated I&C strategy that is safe, secure, operator-friendly, and licenseable.

FULL SCOPE NEW NUCLEAR I&C DEVELOPMENT

ONE STOP SHOP

One Integrated Partner. One Complete Solution. Every Stage of Your Plant Lifecycle.

1. Safety I&C
2. Non-Safety I&C (Special-Treatment)
3. Non-Safety I&C
4. Security & Safeguards
5. Cyber Security
6. Human Factors Engineering
7. Simulator Development
8. Control Room Development
9. Licensing & Regulatory Support



SUPPORTING THE ENTIRE PLANT LIFECYCLE

DESIGN > LICENSE > BUILD > COMMISSION > OPERATE > MODERNIZE

MIRION TECHNOLOGIES

SAFEGUARDING TODAY.
POWERING TOMORROW.

ONE PARTNER. ONE SOLUTION. COMPLETE PEACE OF MIND.

Turnkey I&C Discipline Solution
for New Nuclear Plant Life Cycle

MIRION TECHNOLOGIES

One Partner. One Integrated Solution. Delivered Across Every Stage.

Plant-Wide I&C Design & Licensing → Equipment Supply → Installation Support → O&M Support & Spares

PROJECT LIFE CYCLE

- **DEFINITION PHASE** – Define the right solution
- **DEVELOPMENT PHASE** – Design & engineer with confidence
- **EXECUTION PHASE** – Build, commission & deliver
- **UTILIZE** – Operate & optimize

Definition Phase	Pre-Concept	Pre-Concept	Business objectives & initial I&C strategy
Definition Phase	Conceptual Design	C1	Regulatory framework & requirements
Definition Phase	Conceptual Design	C2	System architecture & boundaries
Definition Phase	Conceptual Design	C3	I&C technology selection
Definition Phase	Conceptual Design	C4	Vendor strategy & evaluation
Definition Phase	Conceptual Design	C5	I&C concept & validation
Development Phase	Preliminary Design	B1	Architecture & system integration approach
Development Phase	Preliminary Design	B2	Complete functional design
Development Phase	Preliminary Design	B3	Detailed I&C specifications & standards
Development Phase	Preliminary Design	B4	Interface & data management strategy
Development Phase	Preliminary Design	B5	Verification & validation planning
Development Phase	Final Design I (System Level)	D1	System architecture & network design
Development Phase	Final Design I (System Level)	D2	Detailed engineering & I/O definition
Development Phase	Final Design II (Product Level)	D4	Cybersecurity & functional safety analysis
Development Phase	Final Design II (Product Level)	D6	Factory acceptance & test packages
Execution Phase	Construction	R1	I&C installation & preparation
Execution Phase	Construction	R2	Loop checks & pre-commissioning tests
Execution Phase	Construction	R3	System integration & functional testing
Execution Phase	Construction	R4	SAT & site acceptance
Execution Phase	Commissioning	R5	System commissioning & dynamic testing
Execution Phase	Commissioning	R6	Handover to operations
Utilize	Operations	U1	Performance monitoring & optimization
Utilize	Operations	U2	Lifecycle support & upgrades

INTELLIGENT DESIGN

RELIABLE TECHNOLOGY

EXPERT INSTALLATION

SEAMLESS COMMISSIONING

LIFETIME SUPPORT

- Safety & Compliance Built In
- Proven Methodology & Standards
- Integrated Team & Expertise
- Risk Reduction & Schedule Confidence
- Optimized Cost of Ownership

**ONE PARTNER.
ONE SOLUTION.
COMPLETE PEACE OF MIND.**

170+ new nuclear reactor designs and concepts can be grouped into four main technology families

This creates a huge need for simulator-based design validation, training and licensing readiness.

170+
new nuclear reactor designs & concepts

4
main technology families

HTGR
High temperature gas-cooled
TRISO fuel • high outlet temp

LWR
Pressurized / boiling / integral
Most familiar licensing basis

Molten Salt
Low pressure salt systems
High temperature heat applications

Fast Reactor
Sodium / lead / lead-bismuth
Fast spectrum advanced designs

IAEA ARIS and industry tracking show a broad and growing advanced reactor pipeline. Paragon focuses on the four families most relevant to near-term commercialization.

One simulator platform across all four reactor families

Paragon has already modeled HTGR, LWR, Molten Salt and Fast Reactor configurations on a common simulation platform.

HTGR
High-temperature gas-cooled

LWR
Light water reactor

Molten Salt
Primary/secondary salt systems

Fast Reactor
Sodium / fast spectrum

I&C design accelerator for an advanced reactor customer

Focused early engagement can de-risk licensing, architecture, simulator, cyber, and budget before the program locks into expensive choices.

1 Design basis intake

Collect plant description, PFD/P&IDs, key parameters, modes/states, preliminary transients, and licensing strategy.

2 Architecture workshop

Define safety / non-safety boundaries, NMS, RPS, DCS, HSI, and simulator interfaces, plus data flows and partner roles.

3 RPS + NMS concept

Develop protective functions, detector approach, block diagrams, trip matrix skeleton, and equipment assumptions.

4 HFE + simulator roadmap

Define control room concept, staffing assumptions, simulator fidelity, training objectives, and validation path.

5 Cyber / security / safeguards

Develop CDA methodology, network zones, physical security assumptions, safeguards framework, and gap list.

6 Commercial plan

Class 4/5 budgetary estimate, schedule, procurement path, risks, assumptions, and next-phase SOW.

Deliverable: integrated I&C roadmap that connects licensing, design, simulator, operator readiness, and equipment supply.

Latest new nuclear technology themes that drive I&C requirements

Different reactor technologies force different decisions on automation, monitoring, protection philosophy and operator support.

1 High-temperature heat applications

Higher outlet temperatures, advanced materials and heat-transfer chains increase the need for thermal monitoring and coordinated protection.

2 Smaller crews & more automation

Many advanced reactors are designed for smaller operating staffs, driving stronger HSI, alarm management and simulator-based training.

3 Factory-built modules & microreactors

Compact modular plants increase the value of standardization, remote monitoring, repeatable logic and package-level qualification.

4 Digital engineering & digital twin

Simulators, controls logic, setpoint basis and digital safety cases increasingly need to evolve together.

5 Hybrid energy / load following

Grid support, process heat and hybrid energy integration place new demands on flexible control and plant optimization.

6 Integrated cyber posture

New nuclear plants need cybersecurity designed into systems, networks and lifecycle governance from day one.

SAFE BY DESIGN | OPERATIONAL EXCELLENCE | SUSTAINABLE FUTURE | PEOPLE EMPOWERED

Inputs needed from reactor developers

If inputs are not mature yet, Mirion + Paragon can generate assumptions and close gaps through structured workshops.

1 Plant basis

- Top-level requirements
- Reactor description / SDOs
- PFDs / P&IDs
- Layouts and equipment locations

2 Analysis basis

- Open-loop transients
- Unprotected / protected transients
- PRAs / LDEs
- Modes and states

Controlled Baseline

Defended, updated, and traceable

3 Process parameters

- Power, flux, temperature
- Pressure, flow, steam conditions
- Setpoint assumptions
- Flux maps / detector constraints

4 Program basis

- Licensing pathway
- Cybersecurity assumptions
- Quality / qualification requirements
- Schedule and procurement constraints

Objective

Not to have perfect information on day one; it is to create a controlled baseline **that can be defended, updated, and traced.**

Defend → Update → Trace

Regulatory strategy and the digital safety case must be designed into the architecture

Licensing success depends on one consistent story: plant functions and hazards → I&C requirements → logic and setpoints → testing → verification.

Part 50 / 52 path

Traditional commercial framework

- Strong safety classification and defense-in-depth
- High software quality and V&V rigor

Part 53 opportunity

Technology-inclusive pathway for advanced reactors

- Better fit for highly automated and non-light-water designs
- Still requires disciplined systems engineering

Digital safety case

Maintain the evidence digitally

- Requirements traceability
- Model-based evidence
- Hazard, cyber and design-basis rationale

Do not separate licensing from design — the fastest programs develop both together.

Use simulation and evidence — prove trip logic, protected transients, control philosophy and operator actions.

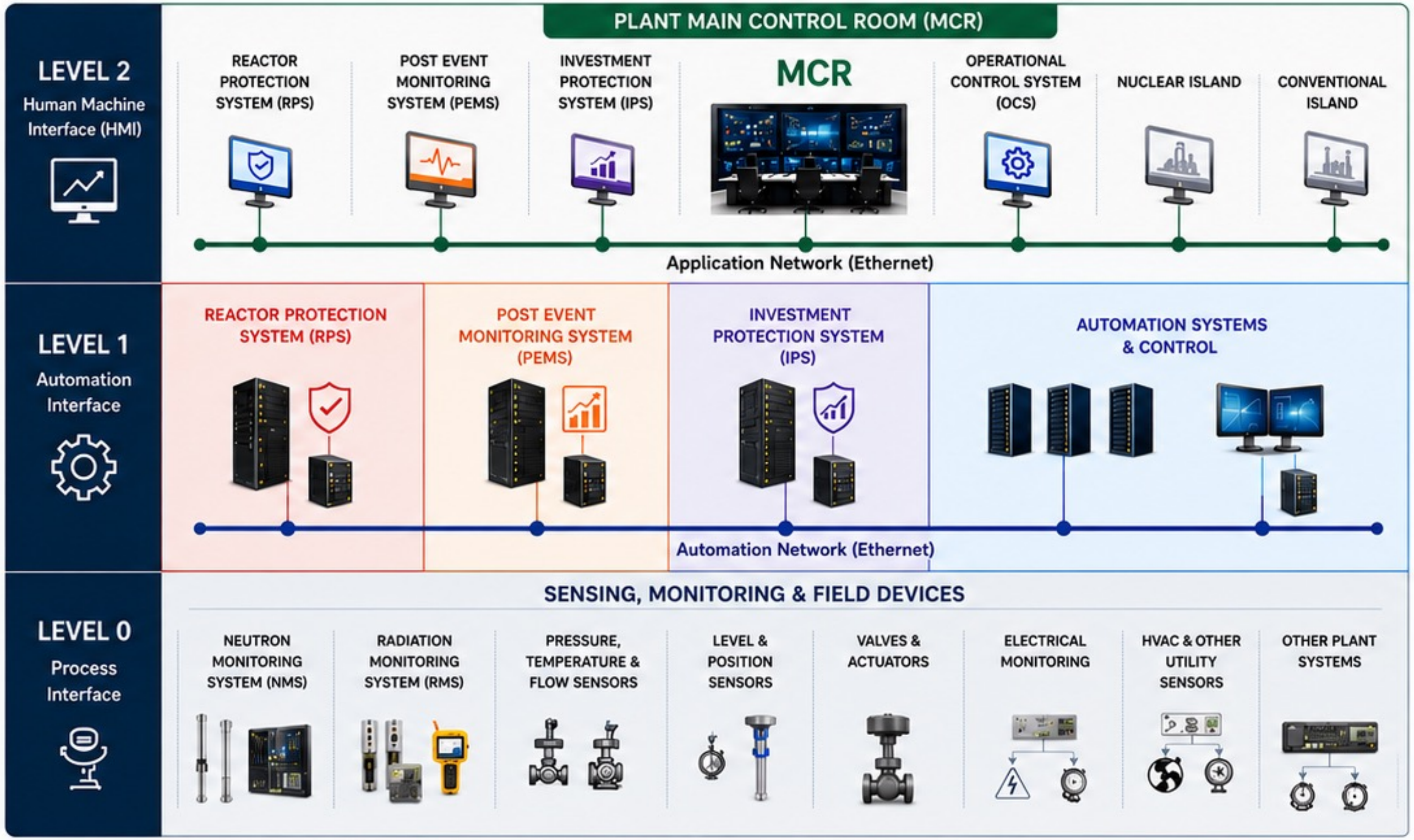
Make cyber and HFE native to the design — bolting them on late creates licensing and program risk.

Punch line: **The fastest path to license is a single digital thread from architecture to evidence.**

GENERIC SMR I&C ARCHITECTURE
DEVELOPMENT OVERVIEW

MIRION TECHNOLOGIES

Integrated. Secure. Scalable. Delivered Across Every Level.



I&C SYSTEMS & SAFETY CLASSIFICATION (NEI 18-04)

I&C System	Safety Classification (NEI 18-04)
Reactor Protection System (RPS)	Safety-Related
Post Event Monitoring System (PEMS)	Non-Safety-Related with Special Treatment
Investment Protection System (IPS)	Safety-Related with Special Treatment
Automation Systems & Control	Non-Safety Related
Main Control Room & Training Simulator	Non-Safety Related
Sensing, Monitoring & Field Devices	Safety / Non-Safety Related

MIRION I&C & NUCLEAR TECHNOLOGY SOLUTIONS

- **NMS** – Core Monitoring
- **RMS** – Radiation Monitoring
- **RPS / IPS** – Protection Systems
- **PEMS** – Monitoring & Diagnostics
- **SENSING, SENSORS & FIELD DEVICES**

DELIVERING VALUE ACROSS THE PLANT LIFECYCLE

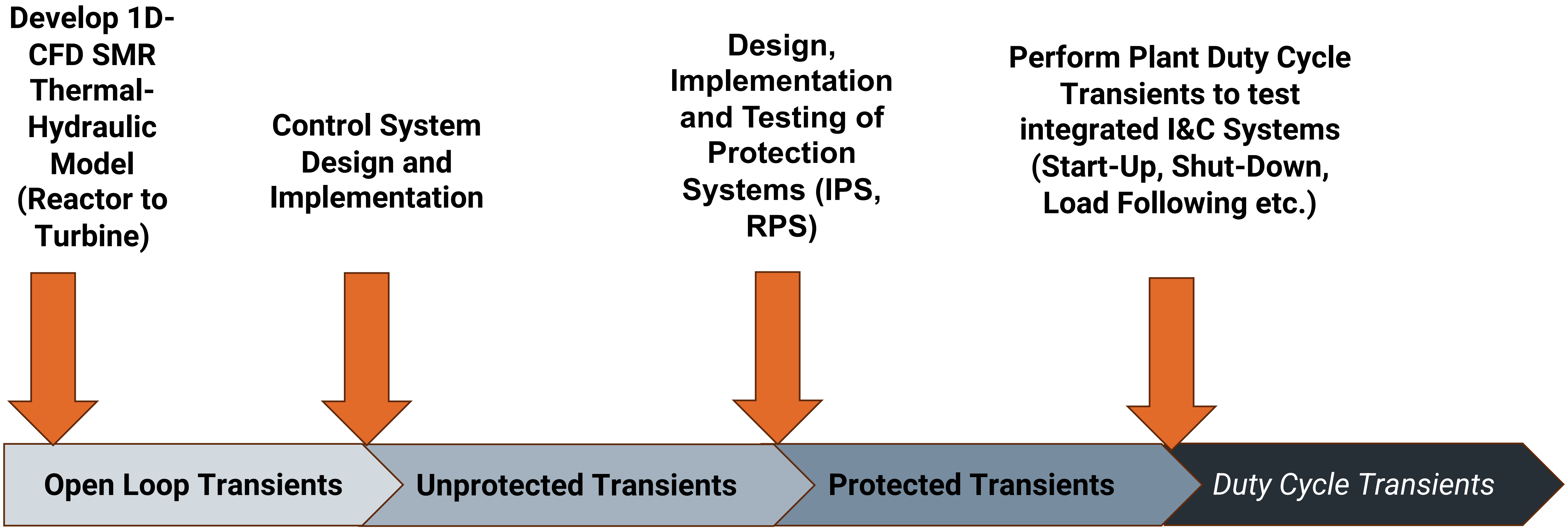
- **INTEGRATED ARCHITECTURE** – Seamless system integration across all levels
- **SAFE & RELIABLE** – Defense-in-depth with proven nuclear I&C solutions
- **SCALABLE & FLEXIBLE** – Designed for SMR deployment and future expansion
- **OPTIMIZED PERFORMANCE** – Improved operability, availability and reduced lifecycle cost
- **ONE PARTNER. ONE SOLUTION.** – Complete peace of mind across the plant lifecycle

Additional Mirion Offerings

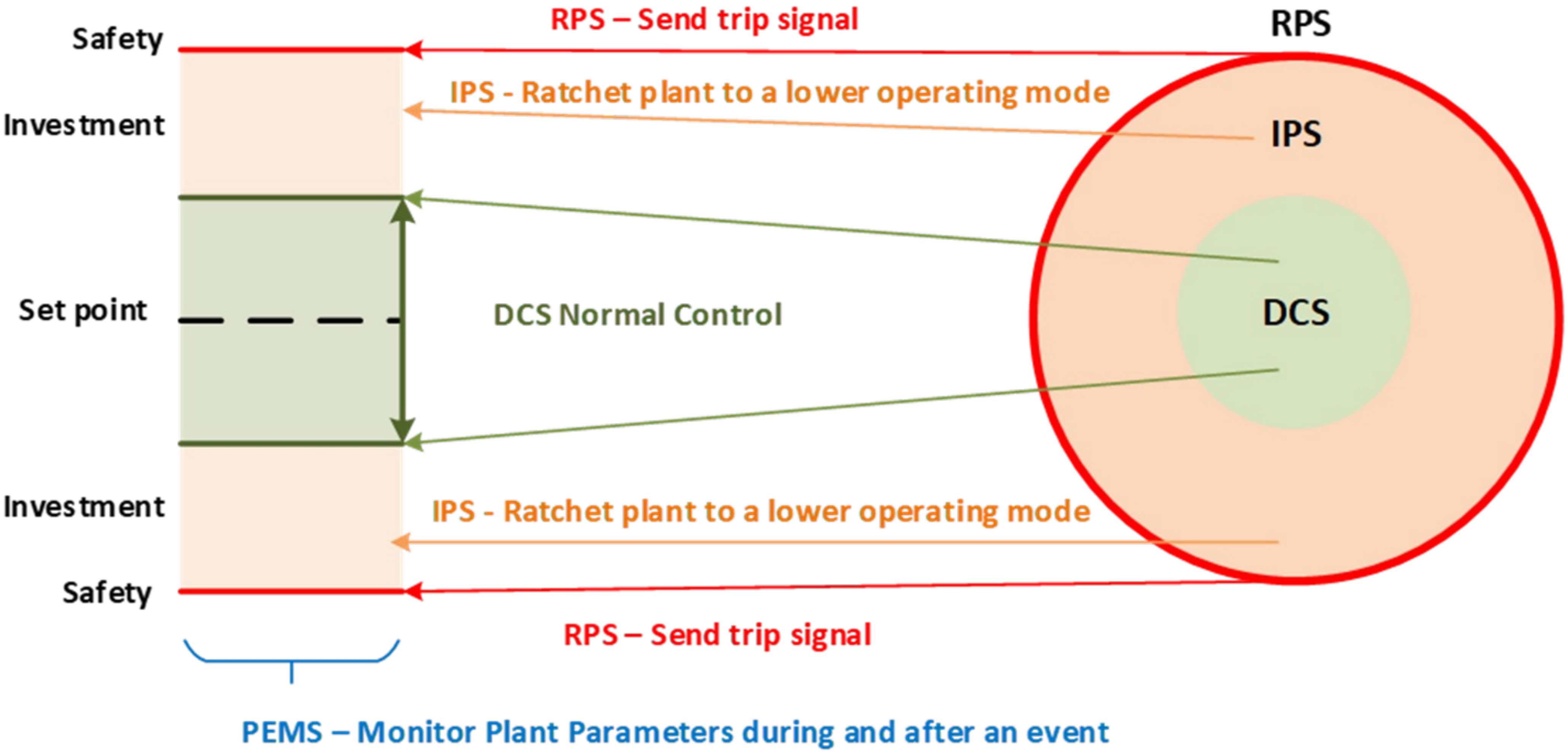
- Neutron Detectors
- Gamma Detectors
- Environmental Monitors
- Area & Process Monitors
- Cybersecurity Solutions
- Services & Support

I&C Design by Analysis Process

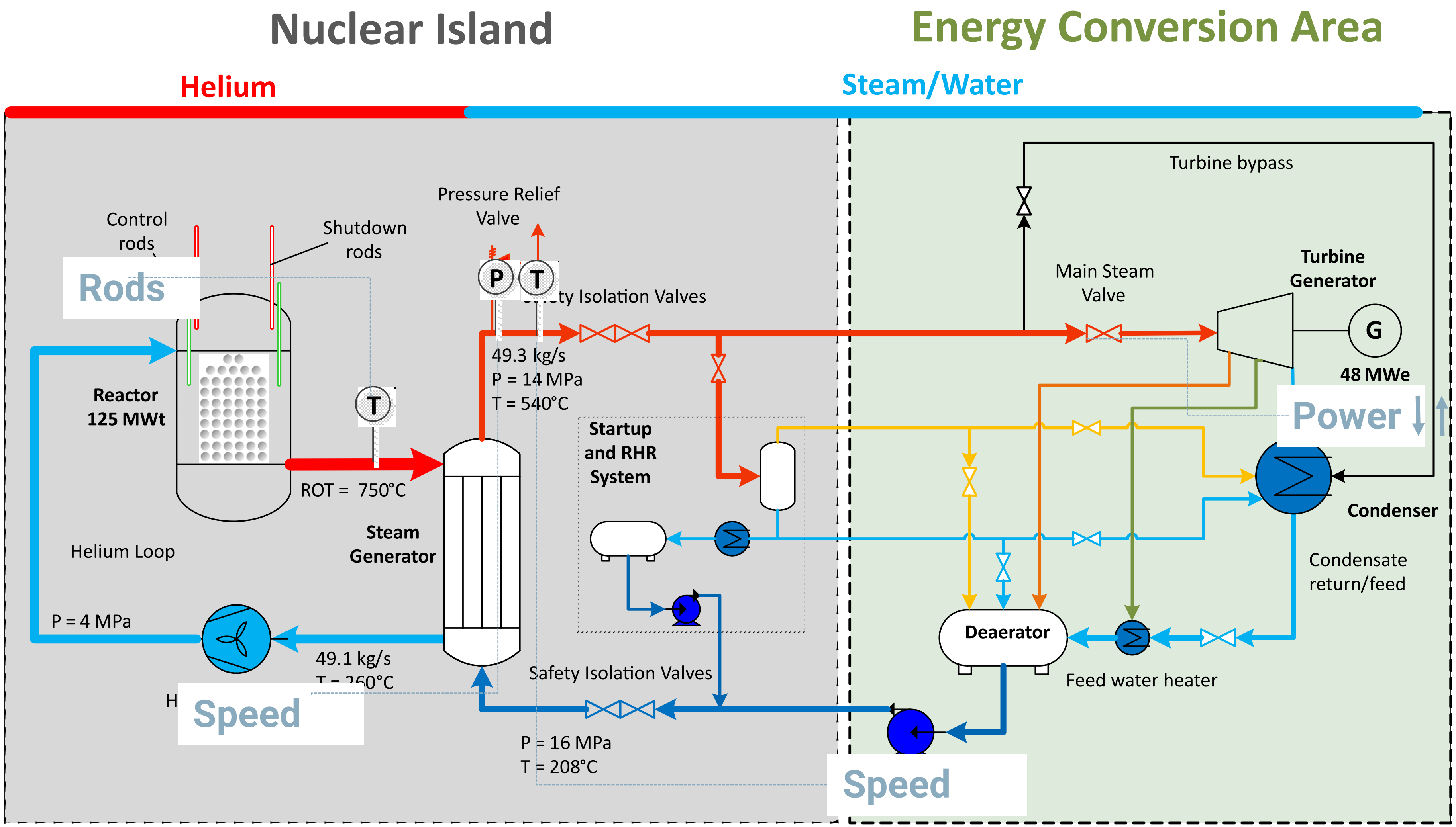
Paragon



Generic SMR I&C Architecture: System Synergy Across Plant Operations



Example Control Approach on a HTGR

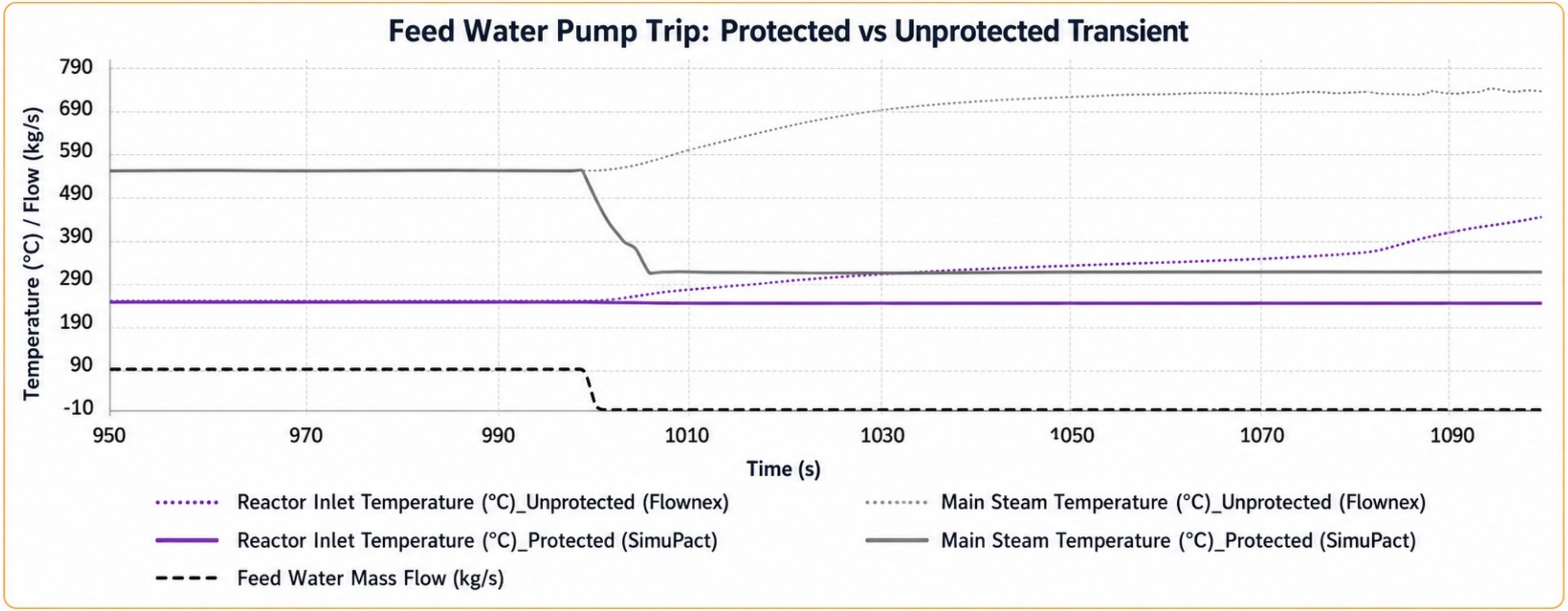


Controlled Variable	Set point	Manipulated Variable
Steam Generator Inlet Temperature	750°C	Control Rod Position
Main Steam Pressure	14 MPa	Helium Circulator Speed
Main Steam Temperature	540°C	HP Feed pump Speed
Electrical Load	25 – 100%	Turbine Throttle Valve Position

Example Unprotected, Protected Transient to develop trip actions with setpoints

Paragon

PROTECTION SYSTEM	PROTECTION SYSTEM INITIATING SIGNAL	PROTECTION SIGNAL & ACTION
Reactor Protection System	• Reactor Inlet Temperature >= 300°C • Main Steam Temperature >= 593°C • Main Steam Pressure >= 19.8 MPa • Reactor Outlet Temperature >= 800°C	Trip Circulators, Insert control rods



Plant-wide I&C architecture: one connected stack

Design the safety boundary, data boundary, operator interface, and simulator boundary together.

Sensors, detectors & actuators — Neutron flux, process variables, radiation, control rods, breakers, valves, pumps

CoreVision / NMS — Detector power, signal processing, range monitoring, flux indication

HIPS / RPS — Safety-related logic, 2oo4 voting, trip matrix, protective actuation

IPS / PEMS / NSRST — Investment protection, accident monitoring, special treatment functions

DCS / BOP control — Plant control, turbine island, balance-of-plant, data historian

HSI, control room & simulator — Operator interface, instructor station, training scenarios, digital twin

Architecture rule: safety-related systems remain simple, independent, deterministic, and protected; optimization and plant performance functions live outside the safety boundary.

Safety-related I&C — HIPS provides the deterministic protection backbone

Advanced reactor developers need a safety system that is licensable, testable, configurable and easy to integrate with the broader plant architecture.

Real HIPS hardware

HIPS strengths

Deterministic logic, safety actuation, online testability, redundancy and strong separation from non-safety control.

Trip & actuation logic

Reactor trip, interlocks, voting logic, setpoint implementation and response validation.

Licensing support

Supports the safety case with traceable requirements, design basis and testable logic.

Integration

Interfaces to neutron monitoring, field instrumentation, DCS, simulator and digital safety case tooling.

Mirion
Nuclear I&C
Paragon

Trip matrix: where the safety case becomes hardware

The trip matrix is the bridge from transient analysis and licensing basis events to RPS logic, actuation, testing, and operator response.

Initiating signal	Condition / setpoint	RPS action	Non-safety response	Traceability
Reactor outlet temp	> high-high limit	Trip reactor / circulators	Alarm + cooldown sequence	LBE-01
Neutron flux	> overpower / rate	Insert rods	Power runback	LBE-02
Primary flow	< low flow	Trip reactor	Pump diagnostics	LBE-03
Steam pressure	> high pressure	Turbine / isolation logic	Bypass / dump controls	LBE-04

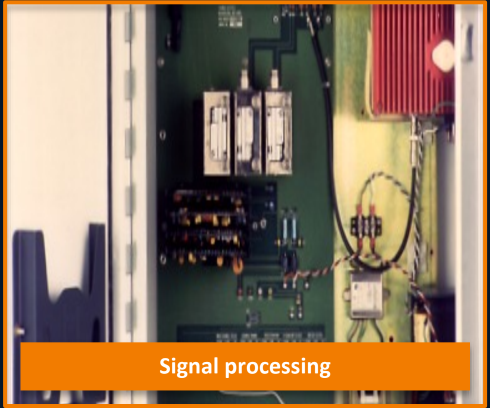
Design principle: keep safety-related trip functions short and deterministic; put diagnostics, optimization, and operator aids outside the safety boundary.

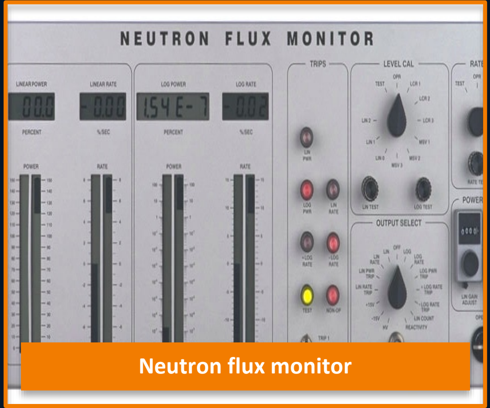
Requirements | Setpoint calc | Logic diagrams | Test cases | Operator actions

Neutron instrumentation — from detector to processing to operator display

Neutron monitoring is not one box; it is a chain of qualified hardware, signal processing, algorithms, displays and lifecycle support.


Detector


Signal processing



Neutron flux monitor

CoreVision

CoreVision / ProTK value
A technology-adaptable neutron monitoring solution for source, intermediate and power range needs.

Advanced reactor fit
Supports diverse core geometries, operating envelopes and monitoring concepts.

Engineering fit
Can be integrated into the broader I&C architecture, digital twin and operator displays.

Lifecycle fit
Qualification, configuration control, test and long-term support from one team.

Best practice: keep the detector arrangement, processing chain, trip logic basis and operator display philosophy aligned from the start.

Instrumentation & Control for Advanced Nuclear Reactors

Integrated I&C is the key enabler for safe, licensable, secure and competitive advanced nuclear deployment.

1 Safety & Protection

Reliable protection systems and defense-in-depth architectures

2 Licensing & Compliance

Supports regulatory approval, validation and operator readiness

3 Cyber & Physical Security

Protects critical digital assets and plant operations

4 Performance & Reliability

Precise monitoring, control and optimized plant performance

5 Simulation & Training

High-fidelity simulators and digital twins for operational excellence

6 Delivery & Lifecycle Support

One-stop integration from design through commissioning and operation

From concept to operations, world-class I&C *turns advanced reactor ambition into bankable reality.*

Paragon delivers the integrated I&C discipline solution for the full advanced reactor life cycle.

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