GIF Webinar Series

2016-2026 EDUCATION AND TRAINING WORKING GROUP

IAEA

GEN IV International Forum

Expertise | Collaboration | Excellence

Artificial Intelligence Advances in the Nuclear Energy Sector

Your presenters:

Prof. Hany Abdel-Halik, Purdue University, USA

Mr. Shahab Dabiran, NEA

Prof. Pavel Tsvetkov, Texas A&M University, USA

Your moderators:

Dr. Alexei Miassoedov, IAEA

Dr. Patricia Paviet, PNNL

5 May 2026

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Click the Q&A buton in the zoom menu.

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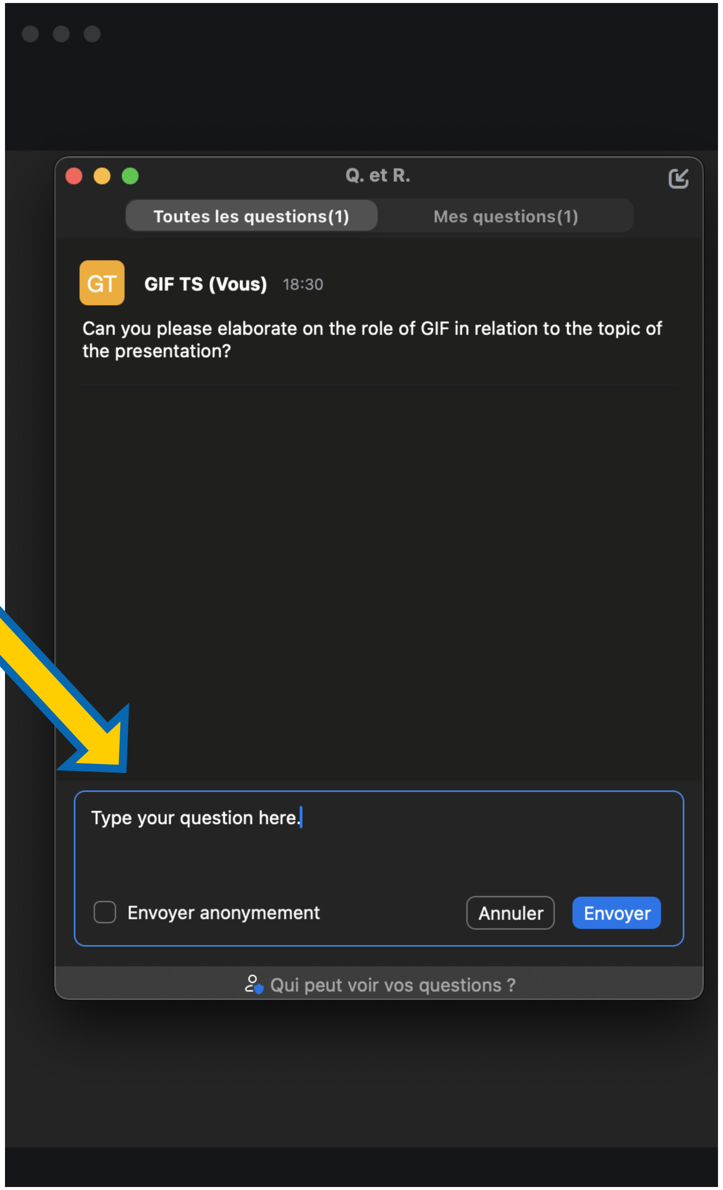

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Meet our Moderators

Dr. Patricia Paviet joined Pacific Northwest National Laboratory in October 2018 where she currently is a Senior Technical Advisor. Her 30-year expertise spans actinide and radionuclide chemistry, the PUREX process, waste form development, repository sciences, and molten salt systems for Molten Salt Reactor technology.

Since March 2021, she has been the National Technical Director of the Molten Salt Reactor program for DOE-Office of Nuclear Energy leading and managing groundbreaking research supporting the development of MSRs across seven US national laboratories with a focus on thermal properties of molten salts, off-gas management, safety, and modeling and simulation.

In addition, through the Generation IV International Forum (GIF), she plays a key role in global knowledge sharing, having organized and facilitated over 100 international GIF webinars, reaching thousands of experts across 84 countries. Her contributions continue to shape the future of nuclear energy and waste management. She received her PhD in radiochemistry from the University Paris-Saclay, France.

Email: Patricia.Paviet@pnnl.gov

Meet our Moderators

Dr. Alexei Miassoedov graduated in theoretical and experimental physics from the Moscow State Engineering Physics Institute in 1989 and joined the Kurchatov Institute, where he worked on modeling fission product release from irradiated fuel.

He earned his PhD in mechanical engineering from the Karlsruhe Institute of Technology in 1996 and subsequently joined its Institute for Materials Research at the KIT.

From 1996 to 2018, his work focused on reactor safety and severe accident research, including LWR fuel behavior under severe damage conditions, core melt progression, in- and ex-vessel melt retention, and related material behavior.

Since 2018, he has served as a Nuclear Engineer at the International Atomic Energy Agency (IAEA), specializing in the technology development of advanced light water reactors within the Nuclear Power Technology Development Section, Division of Nuclear Power, Department of Nuclear Energy.

Email: A.Miassoedov@iaea.org

Meet the Presenters

Dr. Hany S. Abdel-Khalik is a Professor in the School of Nuclear Engineering at Purdue University and the Founder of Covert Defenses LLC. He serves as Technical Lead of the IAEA Collaborating Centre on Artificial Intelligence for Nuclear Power and directs the CYNICS Research Group at Purdue, where his work focuses on advanced modeling, artificial intelligence, and resilient digital systems.

He earned his Ph.D. and M.Sc. in Nuclear Engineering from North Carolina State University and his B.S. in Nuclear Engineering from Alexandria University, Egypt. His professional experience includes academic appointments at Purdue University and North Carolina State University, joint faculty service with Idaho National Laboratory, and industry experience with AREVA-NP.

Dr. Abdel-Khalik's research brings together information theory, physics-informed modeling, uncertainty quantification, and digital twin methodologies. His work has contributed to the development of entropy-driven approaches to anomaly detection, industrial system resilience, and secure data architectures, with results documented in peer-reviewed publications and intellectual property disclosures.

He has received several recognitions for research, mentorship, innovation, and technology commercialization.

Email: AbdelKhalik@purdue.edu

Collaborating Centre
Artificial Intelligence for
Nuclear Power

Purdue's AI4NP

Exploring Opportunities & Challenges for AI Application

International Atomic Energy Agency
Collaborative Centre on Artificial Intelligence for Nuclear Power

Hany Abdel-Khalik, Purdue University, USA

Alexei Miassoedov, IAEA, Vienna, Austria

AI4NP @ Centre of Science of Information

Purdue University

Advancing New Frontiers in Nuclear Technology through Quantitative Understanding of AI4NP

1

Modelling & Simulations

High and low-fidelity simulation models using AI, automation, in-service inspection, real-time risk monitoring, reactor design, and predictive maintenance.

2

Validating AI Concepts for NPPs

Rigorous verification and validation (V&V) of AI/ML models. Confidence-building through UQ. Regulatory acceptance is critical to adoption.

3

Education & Training

Training the next generation of nuclear industry aspirants. Hosting researchers, IAEA MSCFP interns, and IAEA LMP fellows.

CC Activities

Collaborative Centre programme of work

Publications & Standards

Support advancements and innovations in nuclear power; contribute to development of technical and educational publications.

IAEA Joint Work

Reactor modelling/simulation, automation, nuclear digital twin, safety analysis, accident evolution prediction, and severe accident management using AI.

IAEA Mission

Contribute to safe, secure, and peaceful application of nuclear technology by training the next generation of aspirants in the nuclear industry.

Cutting-Edge Research

High/low-fidelity simulation models, automation, in-service inspection, structure/system/component defect evaluation, real-time risk monitoring, predictive maintenance.

IAEA Professional Support

Support IAEA professionals on implementing and incorporating AI for decision making.

Fellows & Researchers

Hosting of researchers, IAEA MSCFP interns, and IAEA LMP fellows.

AI Challenges

Four fundamental barriers in nuclear AI applications

01 **Complexity**

Nuclear systems produce heterogeneous high-dimensional data exhibiting varying degrees of nonlinearities.

02 **Scarcity**

Overparameterized models require an intractable number of samples to train.

03 **Integrity**

Model underspecification is vulnerable to adversaries and/or unexplained failure in real-world applications.

04 **Privacy**

Inherent risk in sharing NPP data and/or AI models — e.g., membership inference, privacy leakage.

Why This Matters

- Nuclear AI demands more than commercial ML, errors are potentially catastrophic
- Regulatory bodies (NRC, IAEA) require verifiable confidence before adoption
- Data scarcity and privacy constraints make standard deep learning approaches unsuitable
- Information theory provides a rigorous, mathematically defensible foundation for addressing all four challenges

AI4NP

AI requires big collaboration

Universities

Private Sector

Governments

Data Scientists

AI requires Big Collaboration

Highly Fragmented

Current AI/ML research in nuclear is scattered across institutions, with no shared benchmarks or standards.

Critical Benchmarking Need

Facilitated through structured collaboration within the community — open challenges and shared test cases.

Regulatory Acceptance

Critical to implementation and adoption. Current practices based on existing designs must evolve.

Rigorous UQ Required

Quantitative uncertainty accounting (UQ) for verification and validation (V&V) of all AI/ML models.

Why “Science of Information”?

Building on Shannon’s foundational principles

Claude Shannon

Laid the foundation of information theory — demonstrating that problems of data transmission and compression (i.e., reliably reproducing data) can be precisely modelled, formulated, and analyzed.

CSoI Mission

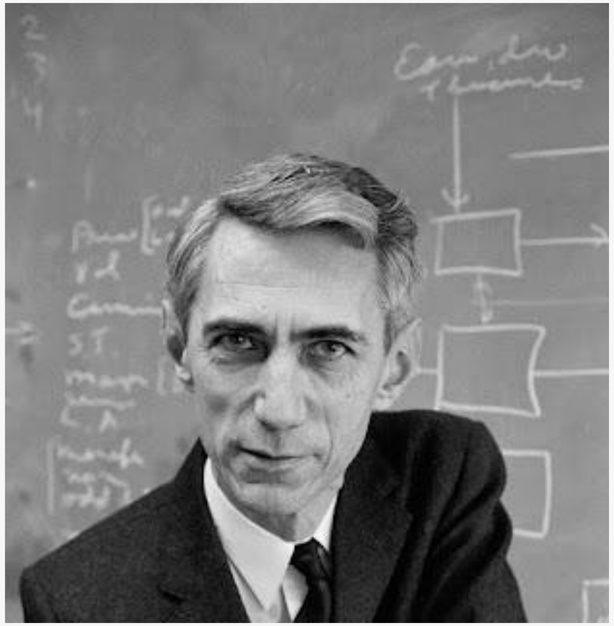
Advance science and technology through a new quantitative understanding of the representation, communication and processing of information in biological, physical, social and engineering systems.

SCIENCE OF INFORMATION

Builds on Shannon’s principles to address key challenges in understanding information that nowadays is not only communicated but also acquired, curated, organised, aggregated, managed, processed, suitably abstracted and represented, analysed, inferred, valued, secured, and used in various scientific, engineering, and socio-economic processes.

Information Theory Connection

Why Shannon entropy is the mathematical foundation of self-awareness



Claude Shannon

Father of Information Theory

Bell Labs · MIT · 1948

INFORMATION-THEORETIC FOUNDATIONS

01 Low-entropy pattern encoding

AI encodes data in low-dimensional representations (“patterns”) which have low entropy in the Shannon sense — this is what machine learning exploits.

02 Information Bottleneck Theory

Computer scientists proposed compressing data to the minimal representation necessary while preserving its knowledge value for AI inference.

03 Entropy-invariant transformations

Data can be mathematically transformed in infinite ways yet remain invariant to AI as long as information content and entropy are preserved.

04 GenAI as a communication mule

Generative AI is a perfect covert communication channel — entropy can be reallocated within generated content without altering its perceived meaning.

Information value quantified → Systems that adapt, conceal, detect, and self-heal

Essential AI Developments

Information Theory is cornerstone to all four capabilities

01 Pattern Recognition

Most efficient algorithms to rigorously quantify minimum number of degrees of freedom, and measure value of information.

02 Synthetic Data

Learning is data-hungry. Requires synthetic data that preserve information content in a mathematically defendable manner using information theory principles.

03 Data Masking

Protection against misuse scenarios essential to ensure meaningful collaboration. Secure embedding that preserves statistical properties.

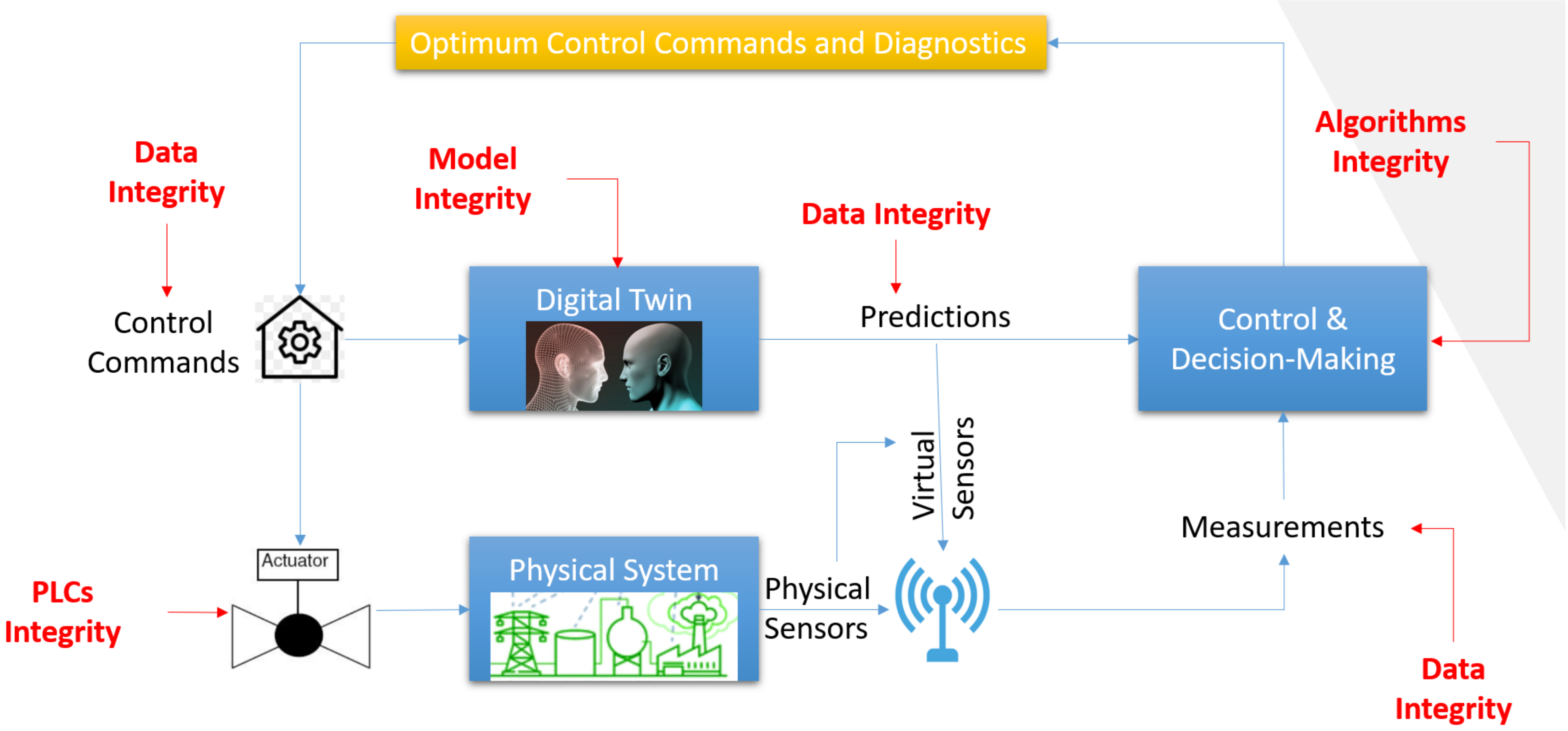
04 Self-Awareness

Self-awareness enables self-healing for operational resilience against intentional and non-intentional disruptions.

Information Theory is cornerstone to the development of these capabilities

Security Challenges in Autonomous Systems

Integrity threats across the digital twin ↔ physical system control loop



Collaborative AI Platform

Four-phase iterative cycle for trustworthy nuclear AI

01 BENCHMARK

Confidence-building exercises using VVUQ for AI/ML models. Establish shared performance standards.

02 ITERATE

Cat-and-mouse open-challenge using adversarial AI to stress-test models and surface failure modes.

03 EXPLORE

Determine future simulation and experimental needs based on identified gaps and uncertainties.

04 LEVERAGE

Collaborate and share data/models to improve quality, enable deployment, and accelerate adoption.

OECD/NEA – WPNCS Activity

New Sub-Group on Performance Benchmarking

A new Sub-Group (SG14) formed on Feb 14th, 2024:

“Performance Benchmark for Error Recovery and Experimental Coverage”

WHAT THIS MEANS

Error Recovery

Establishing benchmarks to assess how well AI/ML models recover from errors and edge cases in nuclear applications.

Experimental Coverage

Quantifying the degree to which available experimental data adequately covers the operational state space.

International Collaboration

Cross-institutional effort under OECD/NEA providing a globally recognised framework for regulatory acceptance.

Our International Blind Benchmark Showed AI Can Fail in Identifying Relevant Data

NEA/WPNCS Sub-Group 14 — Performance Benchmark for Error Recovery and Experimental Coverage

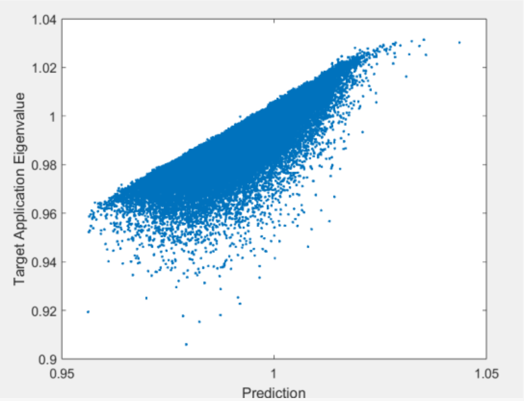
sg14.ornl.gov

International collaboration benchmarking AI/ML for nuclear data assimilation. Goal: characterise error sources and quantify impact on application-specific responses.

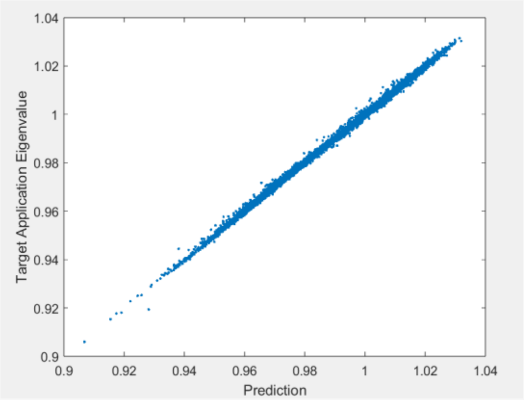
Key Finding

Conventional AI methods mis-classify experiment relevance — labelling valuable data as redundant and ignoring informative measurements.

FAILURE MODES IDENTIFIED



Deemed relevant — redundant



Ignored — valuable

PUBLICATIONS

Frontiers in Energy Research

The NEA Blind Performance Benchmark: Assessing Error Recovery and Experimental Coverage in Nuclear Data Assimilation

Mertyurek, Brady, Branco-Katcher, Cabellos, Delipei, Dorset, Hou, Houben, Hursin, Nguyen, Palmer, Shama, Wu, Xie, Sundaram, Abdel-Khalik et al.

Oak Ridge NL · NC State · Oregon State · U. Politécnica de Madrid · Purdue University + 6 more

Frontiers in Energy Research

An Entropy-Based Debiasing Approach to Quantifying Experimental Coverage for Novel Applications of Interest in the Nuclear Community

Arvind Sundaram, Shiming Yin, Ugur Mertyurek, Hany Abdel-Khalik

Purdue University · Oak Ridge National Laboratory

** Correspondence: Ugur Mertyurek — mertyureku@ornl.gov*

EDIM: Physics-Informed ML Architecture for Trustworthy Inference

Unifying Physics Models, Data, and ML with Quantification Coverage (QC)

INPUTS

Physics Models

- Neutronics & depletion
- Process & transport models
- Detector response models
- Nuclear data & covariances
- Operational parameters

Multi-Modal Measurements

- Gamma spectra
- Neutron counts
- Radiochemical assay (RCA)
- Effluents / Process Data
- Seismic / Infrasound

Simulation Cloud

- Perturb physics parameters
- Preserve uncertainty structure
- Generate multi-modal synthetic responses
- Represent experimental & application domains

EDIM Algorithms (Toolset)

ROM	DF	QC	KM	SDG
Reduced Order Modeling	**Discriminative Feature**	**Quantification Coverage**	**Kernel Mapper**	**Synthetic Data Generator**
Identify active DOFs Preserve uncertainty propagation	Informative features Maximize QC	Maximum uncertainty reduction	Map → QoIs Posterior PDF	Generate realistic data Train robust ML

MISSION IMPACT

- Safeguards & NNSA
- Minimal Sensing
- Detector Optimization
- Multi-Modal Data Prioritization
- Bias-resistant Inference

REACTOR PHYSICS & VALIDATION

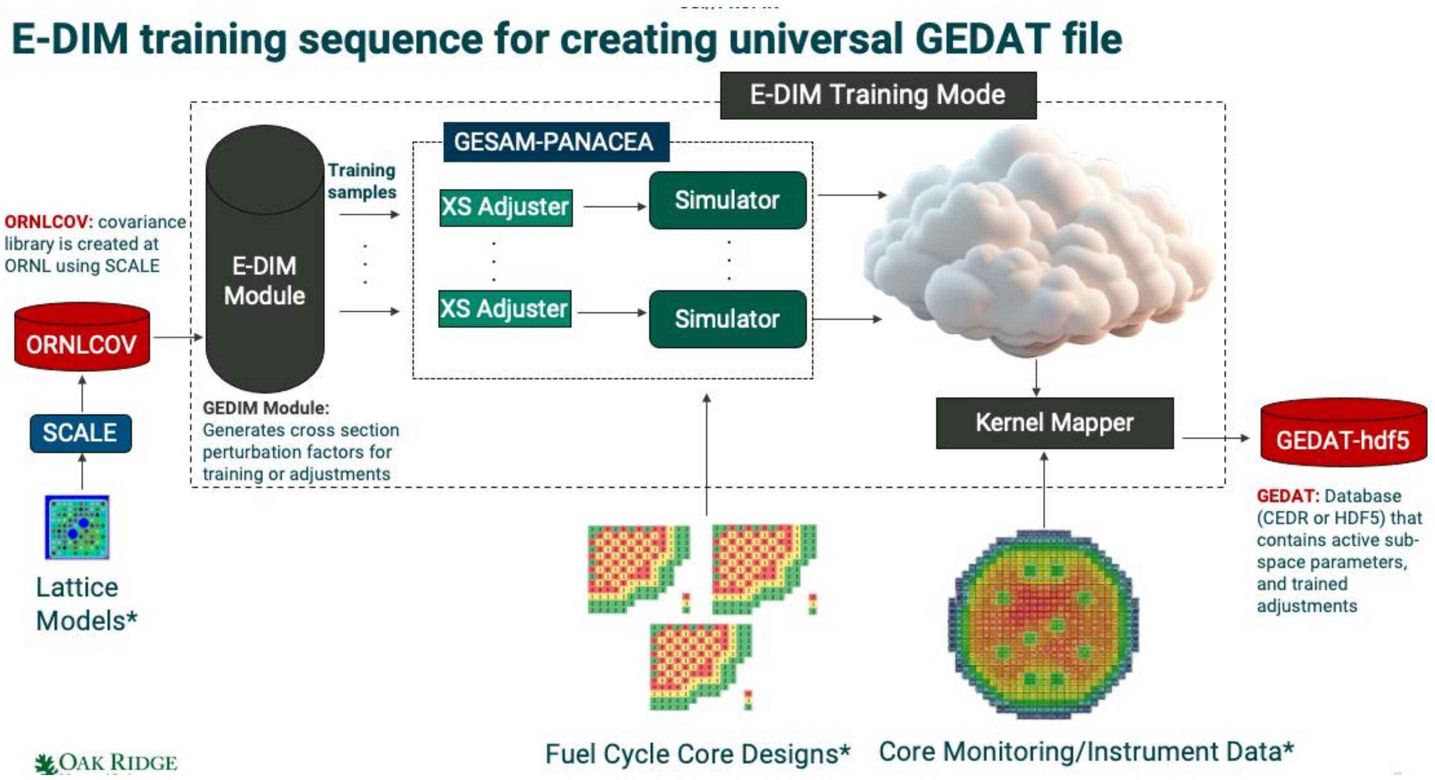
- Burnup reconstruction
- Criticality coverage
- Nuclear data guidance
- Experimental coverage quantification
- Digital twin confidence

EDIM → Information value quantified → Physics-consistent, defensible, regulator-trustworthy ML inference

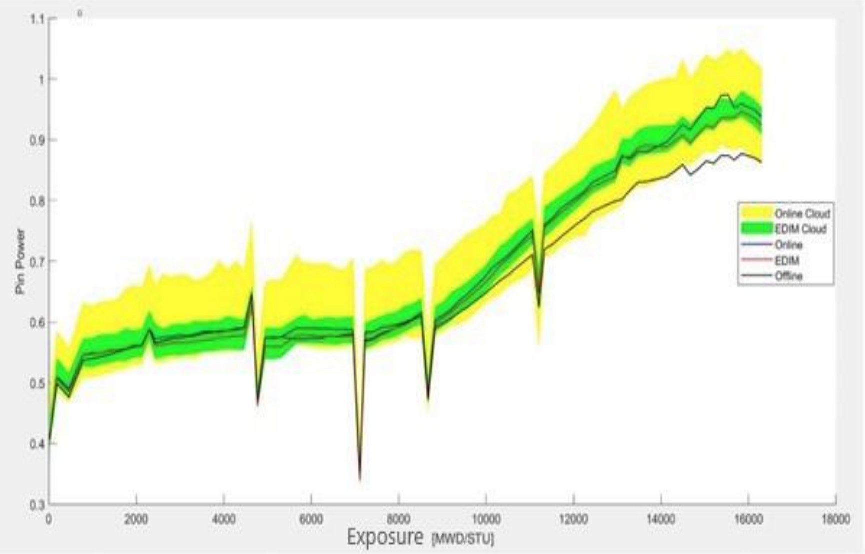
EDIM is Being Tested by Industry as a Solution to Digital-Twin Mispredictions

Improving Core Observables with Entropy-Based Debiasing Inference Methodology — Global Nuclear Fuel / Purdue

E-DIM TRAINING SEQUENCE FOR CREATING UNIVERSAL GEDAT FILE



PIN POWER PREDICTION — ONLINE VS OFFLINE VS EDIM CLOUD



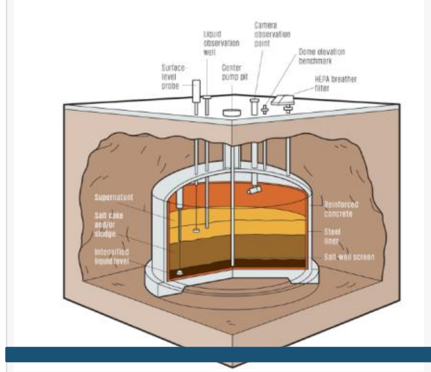
Improving Core Observables with Entropy-Based Debiasing Inference Methodology

Atul Karve[1,*], Ayden Cohn[1], Roger Doles[1], and Hany Abdel-Khalik[2]
[1]Global Nuclear Fuel, 3901 Castle Hayne Rd, Wilmington NC 28401 · [2]Purdue University, LMBS 5240, 363 Grant St, W. West Lafayette, IN 47907

- EDIM Cloud narrows uncertainty vs Online/Offline baselines
- Consistent prediction across full burnup exposure range
- Validated against Global Nuclear Fuel production data

Experiment Design with EDIM Leads to a Simpler and More Informative Experiment

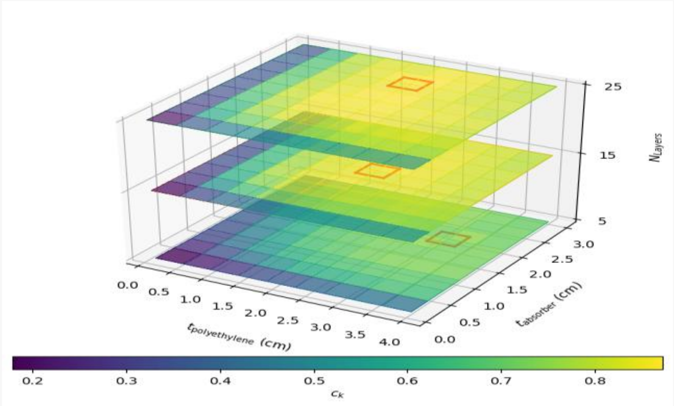
Achieving better experiment design through EDIM algorithms — TEX-Fe14 case study



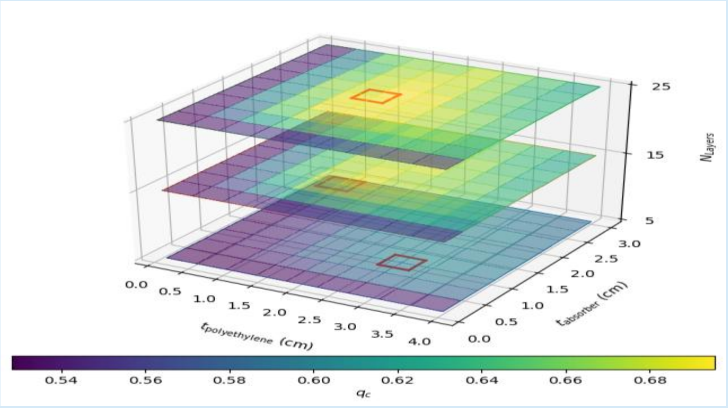
TEX-Fe14 experiment is optimized to provide a high c_k value (≈0.8)*

OPTIMISATION COMPARISON

Conventional Similarity-Based Optimisation



Qv-Based Optimisation (EDIM)



DESIGN PARAMETER COMPARISON

Design Parameters	c_k Optimised	Qc Optimised
Number of Layers	23	**12**
Absorber Thickness (cm)	1.36	**1.07** ↓
Moderator Thickness (cm)	1.97	**1.74** ↓

** EDIM Q^i-based optimisation reduces layer count by 48% while improving information coverage*

When Measurements Disagree: EDIM Pinpoints Correct Burnup via Power History Reconstruction

International isotope measurement programme — Samples E14-720 and E14-810

Sample E14-720

Calculated and measured nuclide concentrations deviate more than 50%. Burnup indicator nuclides have large uncertainties.

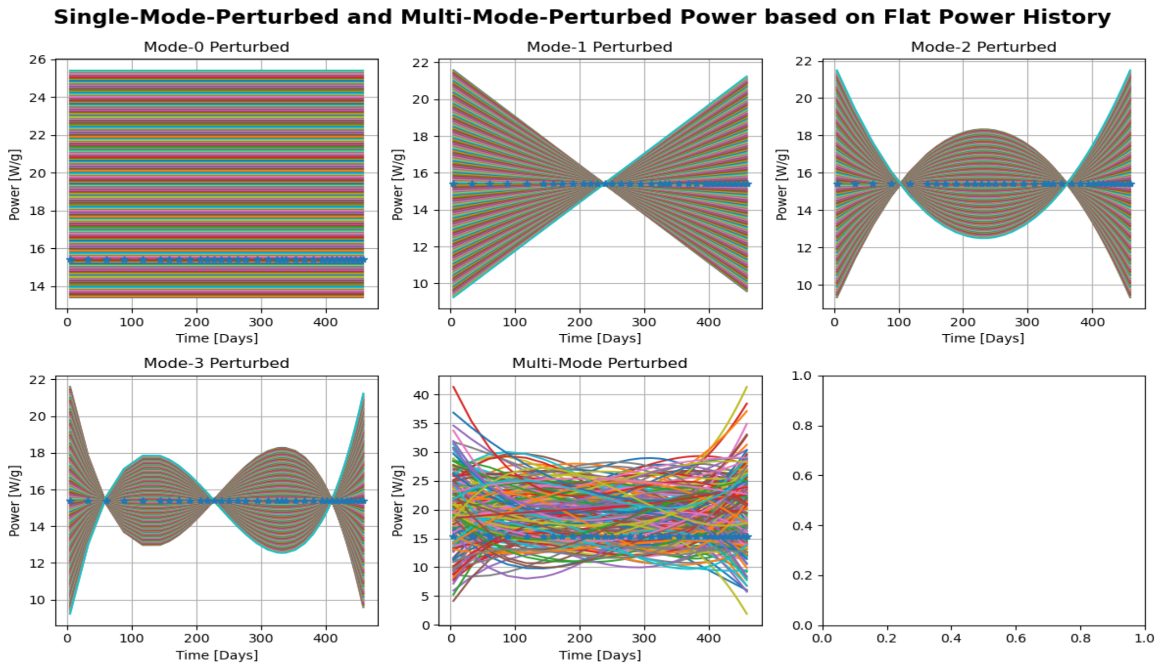
Reported Burnup:	**7.1 GWd/MTU**
EDIM Predicted Burnup:	**10.2 GWd/MTU**
Operator Corrected Burnup:	**10.4 GWd/MTU**

Sample E14-810

Cross-check for the sample showed large difference between laboratory measurements.

Lab 1 Reported Burnup:	**8.5 GWd/MTU**
Lab 2 Reported Burnup:	**8.1 GWd/MTU**
EDIM Predicted Burnup:	**8.17 GWd/MTU**

POWER HISTORY DECOMPOSITION — SINGLE & MULTI-MODE PERTURBED



Potential Burnup Indicator Identification Based on Power History Decomposition

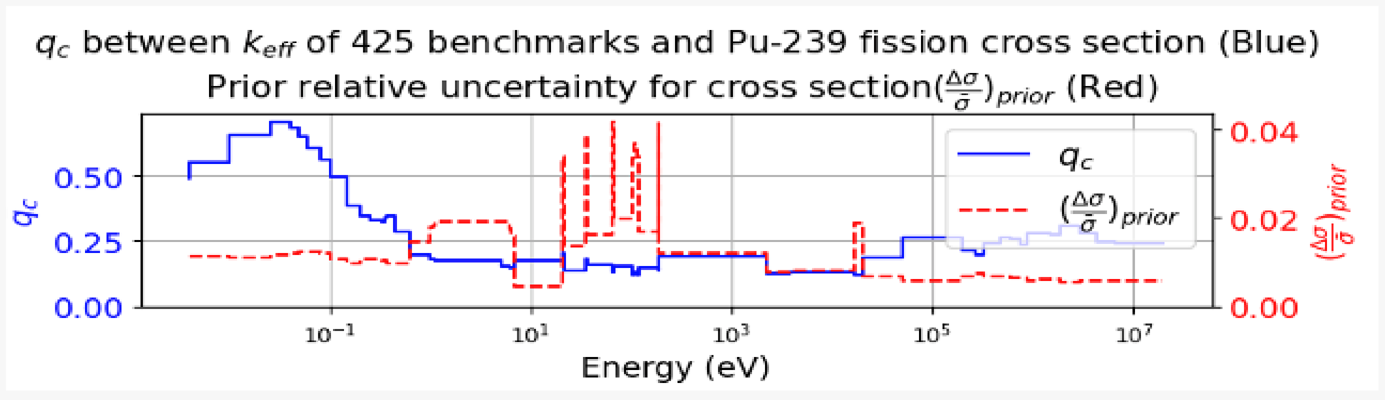
Shiming Yin[1], Tarikul Islam[1], Ugur Mertyurek[2], Germina Procop[2], Hany Abdel-Khalik[1,3]
[1]Purdue University · [2]Oak Ridge National Laboratory · [3]University of Texas at Austin

EDIM Can Identify Error Sources in the Input and Input Uncertainties

Correction of ^{239}Pu fission cross section — 425 and 100 critical experiments

CROSS SECTION UNCERTAINTY CORRECTION

Correction based on 425 critical experiments — q^i between k^{eff} and ^{239}Pu fission cross section



Correction based on 100 critical experiments — ^{239}Pu @E=0.0253 eV fission cross section

RELATED PUBLICATIONS & CONFERENCES

16th Nuclear Data Conference — ND2025

Application-relevant Uncertainty Coverage: qc Coverage Quantification for ND Adjustments

Ugur Mertyurek · Shiming Yin
Oak Ridge National Laboratory

June 22–27, 2025 · Madrid, Spain

PHYSOR 2026

Nuclear Data Adjustment Guided by Coverage Quantification Metric qc

Mertyurek, Yin, Sundaram, Islam, Abdel-Khalik
Oak Ridge NL · Purdue University

Physics of Reactors · Torino, Italy · April 19–23, 2026

The International Conference on Physics of Reactors

How Can EDIM Help Nuclear Energy Applications?

Entropy-driven innovation across secure, resilient systems

LLM

Secure LLM Weight Concealment

Embed tuned weights under unused entropy. Entropy masking to preserve utility.

COM

Private Communication

Embed signals via entropy reallocation. Latent-space / orthogonal-channel encoding.

RES

Ransomware Resilience

State stored as distributed entropy. Inference-based state recovery.

EDIM Core

Entropy · Mutual Information
Coverage · Constraint-based Inference

DX

Enadoxing (Data Devaluation)

Context-bound value degradation. Defensive friction post-exfiltration.

DF

Deepfake Detection

Mutual-information consistency tests. Entropy-flow discontinuity flags.

PPC

Privacy-Preserving Computing

Extract insight without exposing sensitive data. Inference on encoded latent projections.

EDIM → Information value quantified → Systems that adapt, conceal, heal, and survive

EDIM + ENADOX

A new paradigm for trustworthy autonomous DSRS operations

Information theory +
Context-bound security

EDIM — Decision Intelligence Layer

Solves the "unknowns" problem

- Quantifies information value of each sensor reading
- Measures coverage of the operational state space
- Flags missing measurements, redundant scans, high-risk uncertainty regions

In robotics:

- Adaptive sensing — robot decides where to measure next
- Real-time confidence: "Safe to proceed" vs "Insufficient knowledge"

✓ Fewer measurements, higher confidence

✓ Defensible decisions for regulators (IAEA/NNSA)

ENADOX — Security & Integrity Layer

Solves the "trust" problem

- Data & models only interpretable under correct operational context
- Useless if exfiltrated or tampered with
- Communications private and resilient in degraded environments

In robotics:

- Sensor streams encode integrity conditions
- AI models become non-actionable if stolen or misused

✓ Post-exfiltration resilience

✓ Tamper-resistant autonomy in adversarial environments

INTEGRATED ARCHITECTURE

Robot Platform — Sensors (radiation, vision, LiDAR) — **EDIM Layer** — AI/Robotics Control — **ENADOX Layer** — Operator / Regulator

DSRS is not just a robotics problem — it is a trust + uncertainty problem. EDIM makes decisions defensible. ENADOX makes systems resilient.

Thank You

We welcome your collaboration, questions, and feedback.

Please reach out:

abdelkhalik@purdue.edu

Hany Abdel-Khalik

Purdue University, USA

Alexei Miassoedov · IAEA, Vienna, Austria

IAEA

Collaborating Centre
Artificial Intelligence for
Nuclear Power

Meet the Presenters

Mr. Shahab Dabiran is a Nuclear Scientist at the OECD Nuclear Energy Agency (NEA), where he supports international research on advanced fuel cycles and supports collaborative technical projects on topics such as fuel cycle closure and Artificial Intelligence.
He has over 14 years of experience in the nuclear industry. Prior to joining the NEA, he spent nearly a decade at Ontario Power Generation (OPG), supporting the Pickering and Darlington Reactor Physics teams, as well as the Darlington refurbishment return-to-service projects, where he contributed to reactor physics commissioning tests. While at OPG, he developed multiple tools using data science, machine learning, and AI to enhance core surveillance, fueling strategies, reactivity management, and fuel defect identification.

Email: Shahab.Dabiran-Zohoory@oecd-nea.org

NEA
NUCLEAR ENERGY AGENCY

OECD Nuclear Energy Agency (NEA): Advanced Fuel Cycles and AI in Nuclear Research

Shahab DABIRAN

Division of Nuclear Science and Education

AIxpertise Team: Tatiana IVANOVA, Oliver BUSS, Shahab DABIRAN, Kenta INAGAKI, Annabel SANDERS

aixpertise@oecd-nea.org

Presentation Outline

Background

Advanced Fuel Cycles

AI/ML Initiatives:

- Ongoing activities
- AIxpertise Joint Project

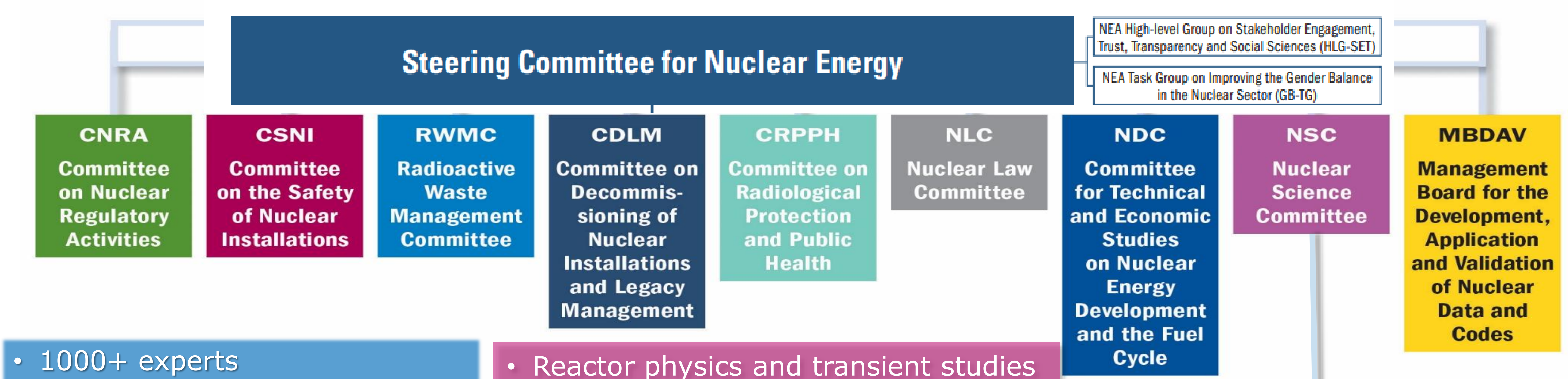
Membership of 34 countries

- **8** standing committees
- **80** working parties and expert groups
- **NEA Data Bank** - providing nuclear data, code, and verification services
- **23** international joint projects
- Growing global relationships with **industry** and **universities**

Together these 34 countries account for ~80% of the world's installed nuclear capacity

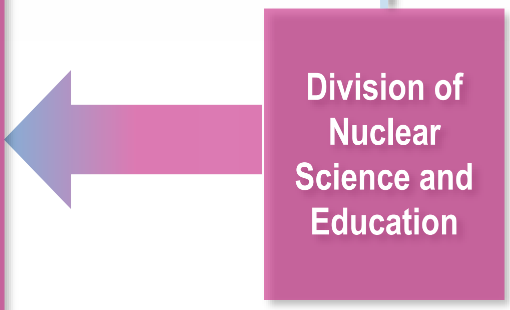
Nuclear Science Committee activities

NSC helps member countries identify, collect, compile, develop, preserve and disseminate the basic scientific and technical knowledge required to ensure the safe, reliable and economic operation of current and next-generation nuclear systems and to promote innovation.



- 1000+ experts
- 5 Working Parties/ 20+ Groups
- 7 databases
- 20+ benchmark studies
- 10+ publications/year
- 10+ workshops/year
- 6 joint projects
- The Global Forum

- Reactor physics and transient studies
- Radiation shielding
- Fuel cycle physics and chemistry
- Fuel and material science
- Nuclear criticality safety
- Nuclear data
- Nuclear knowledge management, education and training



Advanced Fuel Cycles

Working Party on Scientific Issues of Advanced Fuel Cycles (WPFC) – Overview

Innovative fuel design
Focusing on advanced fuel elements and cladding materials
Fabrication & Irradiation
Assessing new fabrication, characterization, fuel properties and irradiation techniques
International collaboration
Promoting international research and knowledge exchange
Advanced reactors
Supporting the development of fuel for advanced reactors

Reactor coolant technologies
Focusing on advancing technologies for reactor coolants (Na, Pb, and Pb-Bi) and components
Material & component evaluation
Evaluating materials & components under different coolant conditions
Safety & performance
Enhancing safety and performance of reactor coolant systems
Cross-cutting research
Supporting the development of coolant technologies for advanced reactors

Fuel cycle analysis
Studying advanced nuclear fuel cycle scenarios
Resource optimisation
Focusing on efficient use of nuclear materials and waste reduction
Scenario modeling
Developing models to assess advanced nuclear fuel cycle options, including for SMRs
Strategy support
Providing insight to guide nuclear strategy

Fuel recycling
Focusing on technologies for recycling spent fuel (hydro and pyro processes)
Waste management
Developing strategies for managing and reducing waste
International best practices
Sharing knowledge to improve fuel recycling and waste management
Process optimisation
Enhancing efficiency and safety in fuel recycling processes

Expert Group on Advanced Fuel Cycle Scenarios (EGAFCS) Overview

Scope

- Scenario studies to assess the potential of different options and the impact of uncertainties
- Needs associated with the transition from current to advanced nuclear fuel cycles
- Existing and future technologies, including transmutation and storage technologies

Current Initiatives

- Harnessing international co-operation for the management of transuranics: A comparative study
- Evaluating fuel cycle options for tripling nuclear energy capacity by 2050
- Development of portable surrogate neural networks for irradiation modelling in fuel cycle scenario codes

Past Reports

- Benchmark on Dose Rate Calculations for Irradiated Assembly
- The Effects of the Uncertainty of Input Parameters on Nuclear Fuel Cycle Scenario Studies
- Transition Towards a Sustainable Nuclear Fuel Cycle
- Benchmark Study on Nuclear Fuel Cycle Transition Scenarios Analysis Codes

Expert Group on Innovative Fuel Elements (EGIFE) Overview

Scope

- Technical issues associated with the development of innovative fuels (oxide, metal, nitride and carbide fuels, and special mechanical forms) targeted for use in advanced fuel cycles and Gen-IV systems
- Performance and properties of fuels dedicated to minor actinides (MA) transmutation considered for advanced fuel cycles and Gen IV systems

Current Initiatives

- Benchmark study on innovative fuels for fast reactors with fuel performance codes
- Standardisation of fuel properties for fuel performance codes

Past Reports

- Recommendations on Fuel Properties for Fuel Performance Codes
- Benchmark Study on Innovative Fuels for Fast Reactors with Fuel Performance Codes
- State-of-the-art Report on Innovative Fuels for Advanced Nuclear Systems

Expert Group on Fuel Recycling and Waste Technology (EGFRW) Overview

Scope

- Separation processes relevant to recycling technologies for spent nuclear fuel
  - Including reprocessing, waste treatment, recycling and reuse of spent fuel components
  - Excluding long-term (dry/wet) spent fuel storage technologies

Current Initiatives

- Perform technical assessments of separation processes in applications related to current and future nuclear fuel cycles
- Maintain and continue developing the international database of extractants (IDEaL)
- Conduct Critical EvAluation of fuel Management during and after MSR operation (CREAMM)

Past Reports

- Unlocking Hidden Value of Nuclear Fuel
- State-of-the-art Report on the Progress of Nuclear Fuel Cycle Chemistry
- Review of Operating and Forthcoming Experimental Facilities Opened to International R&D Co-operation in the Field of Advanced Fuel Cycles
- Spent Nuclear Fuel Reprocessing Flowsheet

Expert Group on Reactor Coolants/Components Technology (EGCoCoT) Overview

Scope

- Properties of liquid metal coolants (Pb, Pb-Bi, Na)
- Their effects on reactor components: structural materials, chemistry control, thermal hydraulics, component behaviour, safety issues, codes and standards

Current Initiatives

- Update of the Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal-hydraulics and Technologies
- Evaluation and assessment of sodium mixed-convection single phase flow thermalhydraulic correlations

Past Reports

- Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal-hydraulics and Technologies – 2015 Edition
- Structural Materials Data Management Survey

Ongoing AI/ML Activities

AI-related initiatives in the OECD/NEA

- **OECD.AI & Global Partnership on Artificial Intelligence (GPAI)**
- **NEA project "Nuclear Safety RegLab"**
  - Regulatory Sandboxing exercises in cooperation with EPRI and IAEA
- **NEA project "AIxpertise"**
  - Developing an AI Platform for Nuclear Research and Education

Announced during World Governments Summit on 11 Feb 2025

- **NEA data preservation projects**
- **AI&ML benchmarking activities**

Ongoing Benchmark Activities within the NEA Nuclear Science Committee related to AI/ML

Reactor Systems

- Critical Heat Flux (CHF) AI/ML benchmark + Interpretation, classification, and prediction of time series data from research reactors within the Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems (WPRS).

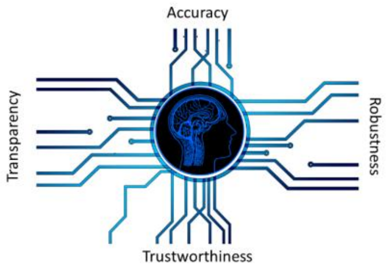
Materials

- Review current applications of ML/AI/UQ for **scale-bridging in multi-scale simulations of nuclear fuel performance** in Working Party on Materials Science Issues in Nuclear Fuels and Structural Materials (WPFM).

Criticality Safety

- **Data Assimilation Benchmark for Error Recovery** and Quantification of Experimental Coverage in Working Party on Nuclear Criticality Safety (WPNCS).

- Identify **benefits for research and development**
- Identify and mitigate **regulatory hurdles** in the domain of transparency, trustworthiness, and robustness

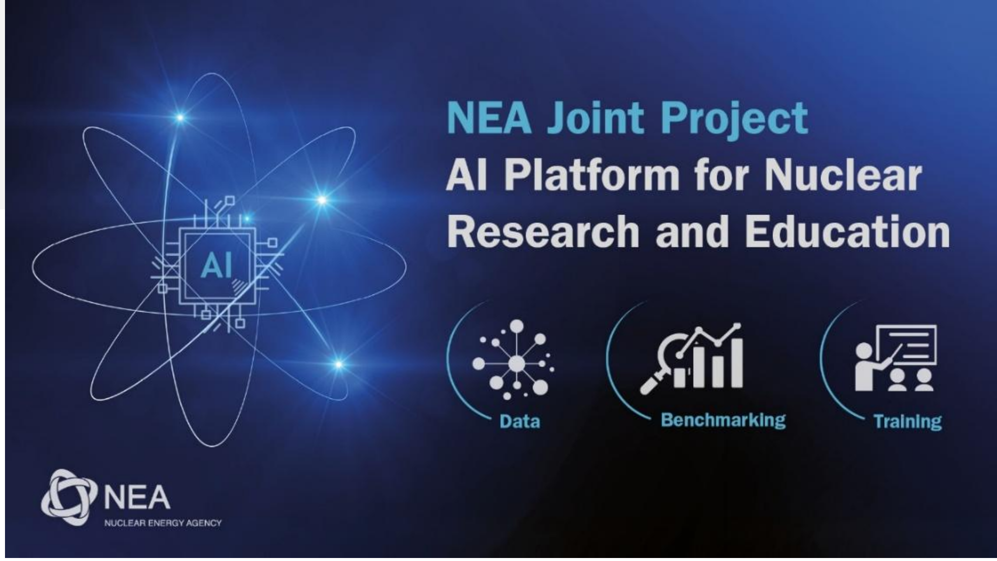


Requirements for Industry Wide AI/ML Deployment

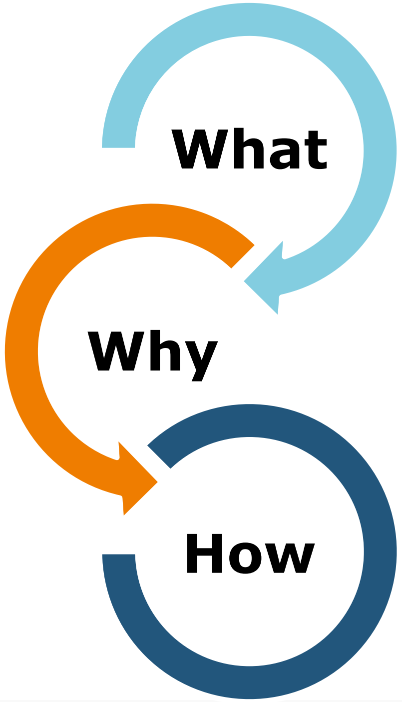
- Summary of needs per surveys, bi-laterals, RegLab #1, and tri-lateral “Considerations for developing Artificial Intelligence Systems in Nuclear Applications” report by CNSC, ONR and NRC:
  - **Collect and standardise data**
  - **Invest into verification and validation of AI & ML**
  - **Assess AI predictive power in application domains**
  - **Develop experience and hands-on training for users of AI & ML applications**

AIxpertise Joint Project

AIxpertise Project Objective



Establish a Joint Project within the Nuclear Energy Agency (NEA) to **harness the transformative potential of Artificial Intelligence (AI) and Machine Learning (ML)**



Why

- Keep pace with **fast-advancing innovations in AI/ML**
- Ensure **readiness for regulatory review** of AI approaches
- Support innovation in reactor **operation** and **SMR deployment**

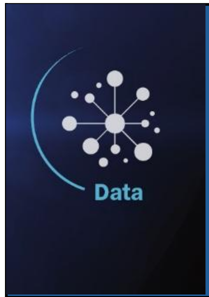
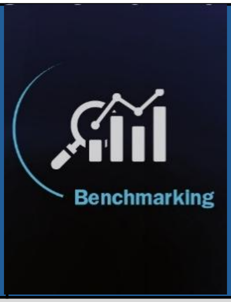
What

- **Demystify AI** solutions and **expand capacity**
- **Harness AI/ML** in a clear and defensible way

How

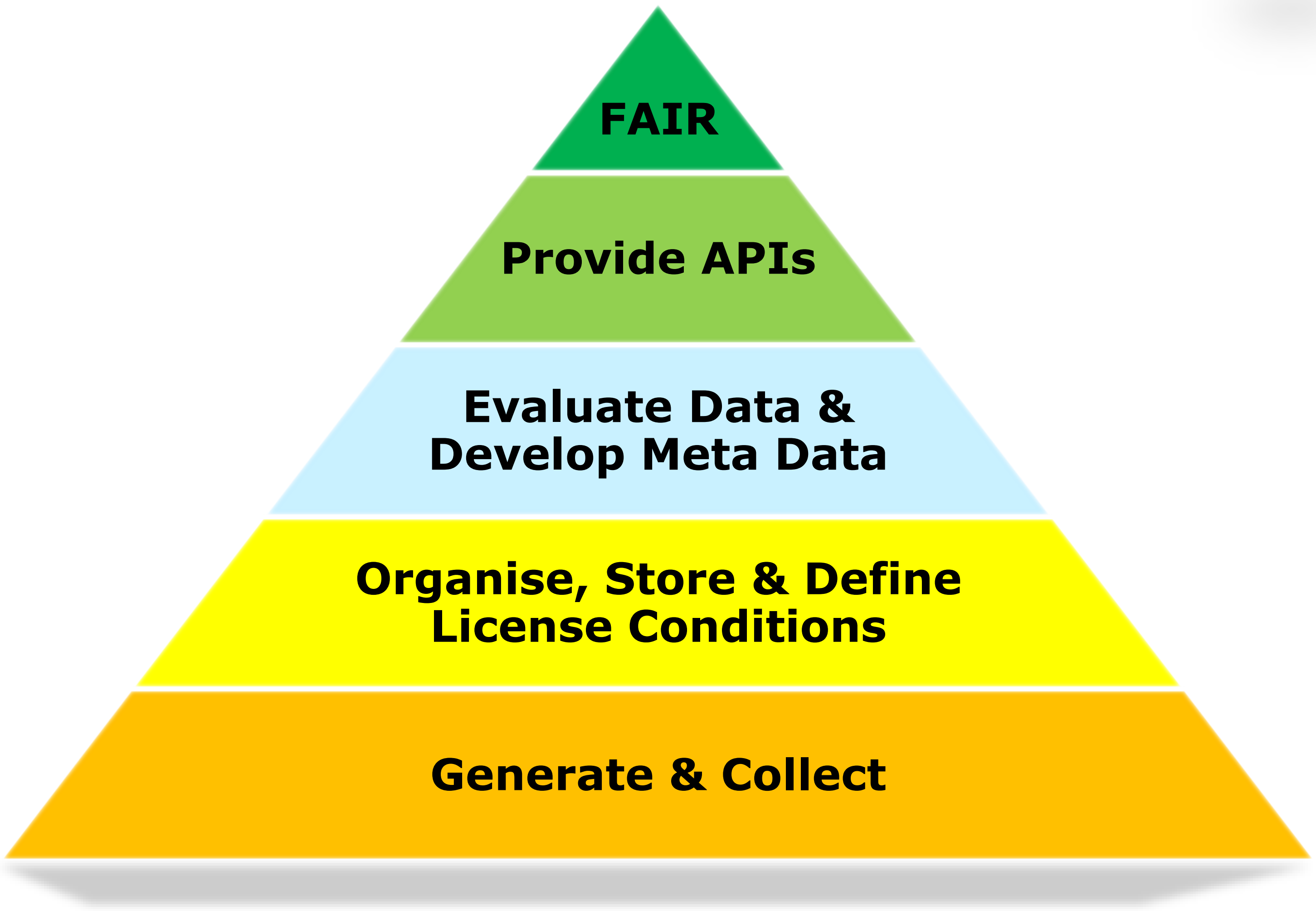
- Establish a **community-of-practice** ready to **learn by doing**
- Develop specific, structured deliverables

AIxpertise - Three Pillars of the Project

 Adapting/developing datasets for AI applications	 Building bridges between nuclear and AI domains to advance expertise	 Disseminating knowledge and training nuclear experts
Precursor NEA Activities		
40+ years of experience in collecting, preserving and disseminating experimental data in different domains.	Task Force on Artificial Intelligence and Machine Learning for Scientific Computing in Nuclear Engineering	20+ years of experience training in various fields, online and in-person for professionals, researchers and university and high school students.
AIxpertise Project Activities and Outputs		
AI-friendly internationally peer-reviewed, aggregated, and accessible datasets.	International benchmarks for assessing and training AI algorithms.	Hands-on trainings on the use of AI algorithm for nuclear research and education.
Online platform for collaboration of nuclear and AI experts for aggregated data, benchmark specifications, software, AI models, and interactive discussions and issue boards.		

AIxpertise Project: Data

- Build on **NEA expert groups** deliverables
- **Integrate data repositories** across various research areas
- Make the datasets machine-readable with **application programming interfaces (APIs)**
- Conduct **data mining** to provide new datasets and flag inconsistencies in existing datasets
- Extend and implement **continuous testing and improvement strategies**



*FAIR = Findable, Accessible, Interoperable, and Reusable

AIxpertise: Data related Activities Examples

	Dataset	Domain	Current Status of Data	Status after AIxpertise	AIxpertise improvements
1	**ICSBEP - International Criticality Safety Benchmark Evaluation Project**	Neutronics	Evaluated, meta data stored in a relational database (RDB), meta data queries possible via *DICE* graphical user interface (GUI)	**FAIR**	• Extend the datasets by including supplementary data (e.g. original raw data, CAD drawings of geometries, sensitivity analyses, code specific simulation models and results) • Extension of meta data. • Define hierarchical, machine readable data and meta data formats. • Design APIs
2	**IRPhE - International Reactor Physics Experiment Evaluation Database**	Reactor physics	Evaluated, meta data stored in a RDB, meta data queries possible via *IDAT* GUI		
3	**IFPE - International Fuel Performance Experiments Database**	Fuel performance	Partially evaluated, meta data stored in an RDB, queries possible via *DATIF* GUI		
4	**SFCOMPO - International Assay Data of Spent Nuclear Fuel Database**	Fuel	Partially evaluated, meta data stored in an RDB, queries possible via *SFCOMPO 2.0* GUI		
5	**SINBAD - Shielding Integral Benchmark Archive and Database**	Shielding	Partially evaluated, data and meta data stored in GitLab platform, API in proof-of-concept phase		
6	**Halden Reactor Project Legacy Database**	Fuel performance/ multi-physics	Generated	Evaluated data & developed meta data	• Investigate the performance of Generative AI/ LLMs for data mining to extract meta data, vision LLMs for the analysis of post irradiation examinations, integrate resulting (meta) data in IFPE and other NEA databases
7	**Time series data from research reactors**	Operational data	Generated	Organized, stored & defined license condions	• Share data with well-defined licensed conditions. • Define hierarchical, machine readable data formats.
8	**Subchannel and bundle test data**	Thermal-hydraulics	Generated, partially available as NEA DB packages (e.g.: NUPEC PSBT and BFBT)	Organized, stored & defined license condions	

AIxpertise Project: AI Algorithm Benchmarks

Collaborate	Collaboration among **industry, research, academia and regulators**.
Evaluate performance	Demonstrate the **performance**, **explainability** and **robustness** of algorithms.
Train AI Algorithms	**Assess and train** novel AI algorithms using well-defined international benchmark exercises.
Guide	Develop leaderboards, document **best practices and lessons learnt** to validate AI-driven scientific computing.

AIxpertise: AI Benchmarks Proposal Examples

	Benchmark title	AI domain	Data source	Benchmark challenge	AIxpertise goals
Data mining and knowledge management related benchmarking activities					
1	**Halden Reactor Project Data Mining**	Generative AI, image recognition, transfer Learning	Halden Reactor Project Legacy Database (NEA, 2024[10])	Auto-generate meta data for Halden experiments; Auto-evaluate experiments and extract metrics, which can be compared to fuel performance code results.	Extend validation basis for fuel performance codes.
2	**Bridging the gaps in validation databases**	VVUQ, data assimilation, data augmentation, transfer learning	ICSBEP, IRPhE, SINBAD, SFCOMPO	Validate modelling and simulations tools in domains of poor experimental coverage (e.g. for neutronics assessments of advanced reactors with HALEU fuel).	Foster VVUQ for advanced reactor designs
3	**Nuclear Science Chatbot**	Generative AI, guided learning	Publicly available reports	Build and benchmark a chatbot specialised on nuclear science. Evaluate benchmarking based on LLM-as-a-Judge methodology.	Provide a reliable chatbot for the given knowledge base

[1] All work involving data from the Nuclear Science Datasets will, at all times be subject to the terms and conditions of the Nuclear Science Dataset License Agreements reproduced in Appendix G of this Project Agreement.

AIxpertise: AI Benchmarks Proposal Examples

	Benchmark title	AI domain	Data source	Benchmark challenge	AIxpertise goals
Scientific computing related benchmarking activities					
4	**AI-enhanced scientific computing applied to subchannel thermal hydraulics (T/H)**	Convolutional neural networks, deep leaning, transfer learning	NRC critical heat flux database (NRC, 2016[11]), sub-channel bundle thermal hydraulic test data	Compare accuracy and robustness of novel AI methods to state-of-the-art T/H methods based on established benchmarks, e.g. the PSBT benchmark (NEA, 2015[12]).	Improve the critical power prediction for fuel assemblies
5 *	**Multi-scale AI/ML integration for nuclear fuel materials**	Surrogate modelling, reduced-order modelling, Bayesian inference, active learning	Halden Reactor Project Legacy Database, IFPE	Develop and validate ML approaches to accelerate atomistic simulations. Create surrogate models to replicate fuel performance simulations and experiments for various fuel properties (e.g. diffusion, creep, etc). Apply AI-enabled frameworks to quantify and propagate uncertainties in fuel material properties.	Enable AI-driven scale bridging from atomistic to engineering scale for reliable nuclear fuel performance modelling
6	**PINNs (Physics-informed neural networks) for AI-enhanced modelling of concrete degradation mechanisms.**	Surrogate modelling, PINNs.	(to be developed) Simulation generated data.	Comparison of PINNs with conventional numerical simulations, PINNs-based surrogate models. Proposed application case: Create surrogate models for THCM (Thermo-Hydro-Chemical-Mechanical) processes e.g. alkali-silica reaction, carbonation to enhance and speed-up simulation of concrete degradation mechanisms.	Evaluate PINNs suitability for modelling of physical phenomena (application case: concrete degradation mechanisms).

AIxpertise: AI Benchmarks Proposal Examples

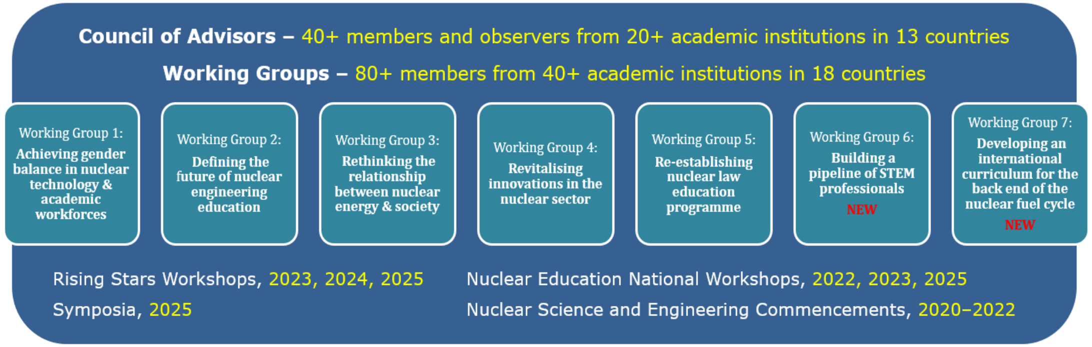
	Benchmark title	AI domain	Data source	Benchmark challenge	AIxpertise goals
Scientific computing related benchmarking activities					
7	**Improving nuclear data evaluations**	Bayesian inference, optimisation, model calibration, VVUQ	JEFF Nuclear Data, Integral data (ICSBEP, IRPhE, SINBAD, SFCOMPO)	Integrate macroscopic, integral experiment information in microscopic, nuclear data evaluations.	Improve nuclear data for enhanced accuracy of M&S tools.
9	**ML-enhanced computational fluid dynamics (CFD)**	Surrogate modelling	(to be developed) Simulation generated data	Provide new data driven turbulence and heat transport models.	Improve CFD modelling.
Health monitoring and reactor operation related activities					
9	**Reactor time series analysis**	Classification, time series forecasting	Research reactor or commercial reactor multi-variate time series data, e.g. PUR-1 data (William Richards, 2024[13])	Classify operational events, predict future reactor states, assess health of components and systems.	Assess the foundations for predictive maintenance and autonomous operations using real-world data
10	**Optimisation of nuclear power plant core reloading patterns**	Machine learning, optimisation	Simulation data for core loading patterns	Find optimum reloading patterns with respect to safety criteria, number of reshuffle operations, and other economical and operational considerations.	Support optimisation of NPP operations.

AIxpertise: Hands-on Training & Best Practices

- **Offer resources for training and education** including hands-on exercises based on data repositories to assess and train AI models.
- Organise **workshops for sharing best practices** to accelerate AI adoption in nuclear applications.
- Organise **AI/ML schools** tailored for nuclear engineers, scientists and students to foster skill development.
- Develop and implement **certified education programme** in partnership with the NEA Global Forum on Nuclear Education, Science, Technology and Policy, first of a kind international platform for academia

Supporting nuclear workforce development and continuous learning

3rd International School on Simulation of Nuclear Reactor Systems (SINUS) - Cambridge



Global Forum structure

AIxpertise: Hands-on Training & Best Practices

Workshop title	Workshop topics	Interested organisations (preliminary)
Data management for AI	• Best practises towards establishing FAIR data. • Data evaluation, meta data generation, data storage, API access.	Framatome, U Liverpool, proposed by CNL, EPRI, GRS, Imperial College
Deploying AI applications to the Cloud	• Technical basis for AI cloud computing and lessons learned by early adopters. • Export control and data residency considerations. • Contractual and operational non-disclosure safeguards .	EPRI, GRS, Imperial
Secure usage of AI in nuclear research	• Best practices for not exposing sensitive data while training AI models. • Non-proliferation aspects related to aggregating non-sensitive information to generate more complex information.	Framatome, Kinetrics, U Liverpool, CNL, , EPRI, GRS, Imperial College
Explainable AI for safety-relevant applications	• Implementing explainable AI for applications with safety relevance. • Regulatory acceptance.	Framatome, Kinetrics, POLIMI, U Liverpool, GRS, , EPRI, Imperial College, NRG
Machine Learning Hackathon	• Hands-on machine learning application event, specifically for an audience of computation, simulation, and software specialists from the nuclear field.	Framatome, Kinetrics, POLIMI, U Liverpool, GRS, EPRI, Imperial College, NRG
Hands-on Training	• Hosting and providing hands-on training	NCSU, POLIMI, Imperial College
AI for Nuclear Asset Management	• Basics and advances of the state-of-the-art AI for Prognostics and Health Management (PHM) in Nuclear Applications.	Proposed by POLIMI (NEW)

AIxpertise: How to Contribute?

Project members can contribute to AIxpertise in a range of ways, including:

- Contributing **computer resources**
- Sharing **existing tools or software**
- Providing **financial and/or staff support**
- Hosting **events and training**
- Providing **hands-on training and lectures**
- Sharing **relevant data or datasets**

Preliminary budget estimate:

- Expected financial contributions (depending on nature and size, and in-kind contribution)
- The financial contribution will support:
  - Hiring a data scientist
  - Providing and maintaining the IT platform
  - Covering NEA Secretariat support

AIxpertise - Project Development Timeline

11 Feb 2025: Announced during World Governments Summit

15-16 Oct 2025: AIxpertise Workshop, Remote

(45 organisations, 17 countries)

21 January 2026: AIxpertise 2nd virtual Workshop – Review PoW

(45 organisations, 16 countries, presentations by CNSC, GRS, NRC, RegLab)

01 March 2026: Feedback on legal agreement

April 2026: Final version of legal agreement & start of signing process

June 2026: AIxpertise Kick-Off Meeting

Early 2025: Surveys among NSC stakeholders including national laboratories, regulators, to define AIxpertise programme of work

Q4 2025: Development of the detailed program of work through bilateral discussion

Q1 2026: Prioritization and review of legal agreement

Conclusions

AIxpertise Programme of Work in mature state

Expect prioritisation by future AIxpertise Management Board

Gain AIxpertise, Tailor the Project to Your Needs

- **Set priorities that matter most** (e.g.: life-extension, new builds, SMRs and advanced designs, digital modernisation)

Contact

http://www.oecd-nea.org/aixpertise

aixpertise@oecd-nea.org

NEA
NUCLEAR ENERGY AGENCY

Questions?

AI in the nuclear energy domain - some simple questions

- What do we mean when we say “**AI**”?
- How to **validate** AI algorithms?
- AI is data driven - where do we find **trustworthy data**?
- Performance versus explainability - **what type of AI for which application**?
- How to **train our nuclear experts** for the ongoing and future deployment of AI tools?

AIxpertise Joint Project Agreement

- **Project steered by Management Board** consisting in members of participating organisations.
- **Programme of work and contributions of each organisation is defined by the participants.**
- **Clearly defined rules on intellectual property** rights.
  - ✓ All information disclosed in connection with the implementation of the Agreement is confidential and considered as such unless certain conditions are satisfied.
- **Clearly defined licensing rules for two types of datasets**: nuclear science datasets and datasets provided by AIxpertise members
  - ✓ Nuclear science datasets: Halden Reactor Project Legacy Database, ICSBEP, IFPE, IRPhE, SFCOMPO, SINBAD
  - ✓ Potential datasets provided by AIxpertise members: e.g., reactor time series
- **Role of NEA:** administrative and secretariat support, manages the contributions in accordance with the OECD Financial Statute

Meet the Presenters

Dr. Pavel Tsvetkov is a Professor of Nuclear Engineering at Texas A&M University and Director of the Graduate Program, where he leads the Advanced Energy Systems Laboratory. His work focuses on AI-enabled design, intelligent operations, and advanced reactor and fuel-cycle technologies, with applications spanning nuclear security, autonomous I&C, waste minimization, and resilient energy systems.

He is an active contributor to national and international nuclear security efforts and leads the data science and digital technologies thrust within the NNSA ETI Consortium.

Dr. Tsvetkov has published more than 300 peer-reviewed papers, conference proceedings, and technical reports, and has served as editor or major contributor to 15 books on energy, environment, and nuclear engineering. He holds multiple patents in advanced reactor technologies.

His professional service includes leadership roles such as Chair of the ANS Reactor Physics Division, Associate Editor of the ASME Journal of Nuclear Engineering and Radiation Science, and current Vice Chair of both the ASME Technical & Strategic Advisory Board and the ANS Publication Steering Committee, as well as Chair of the ANS Book Publishing Committee. He continues to serve on the ANS Reactor Physics Program Committee.

Email: Tsvetkov@tamu.edu

AI-Driven Evolution in Nuclear Engineering:
Meeting Modern Energy Demands through Advanced Research and Education

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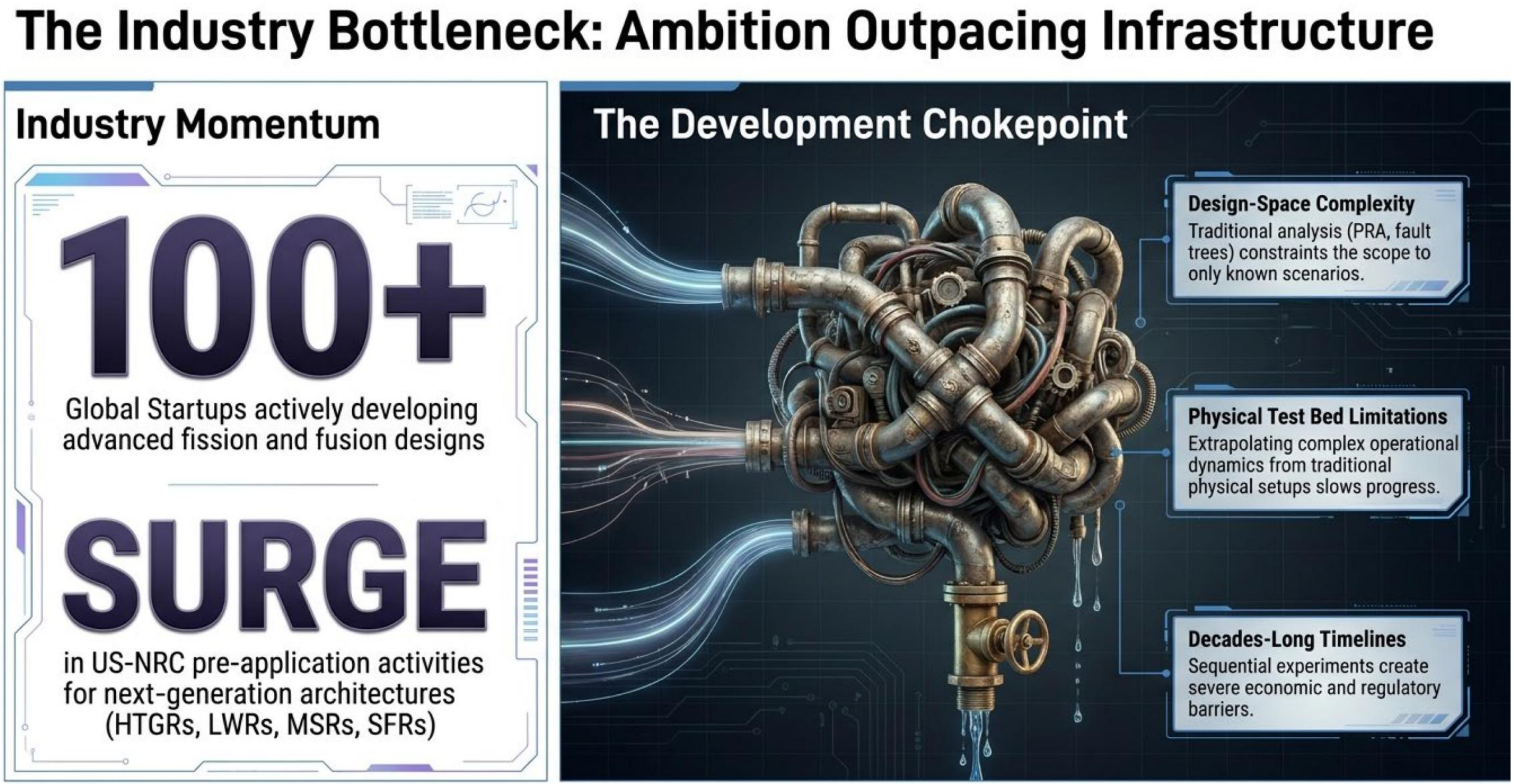

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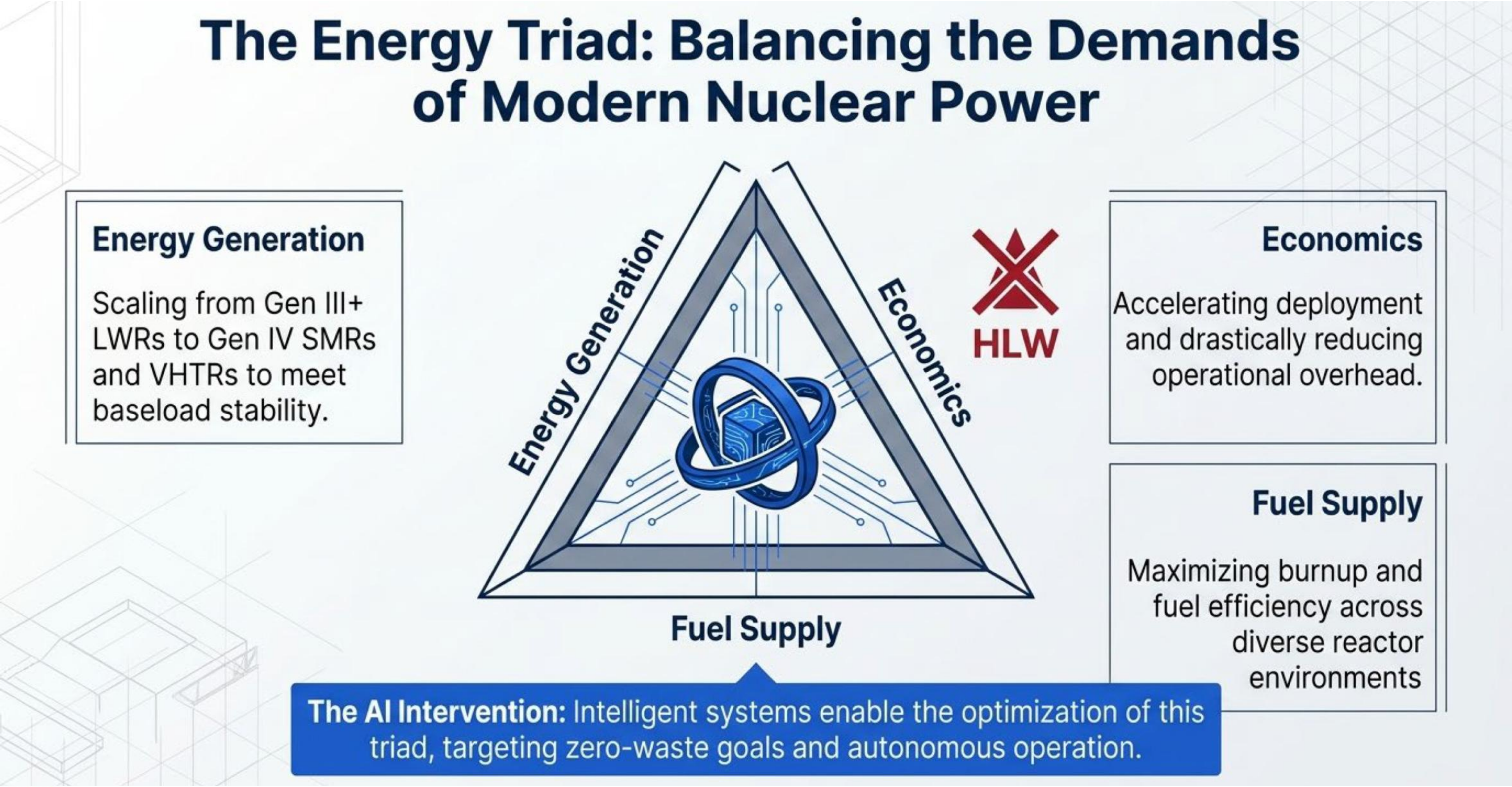

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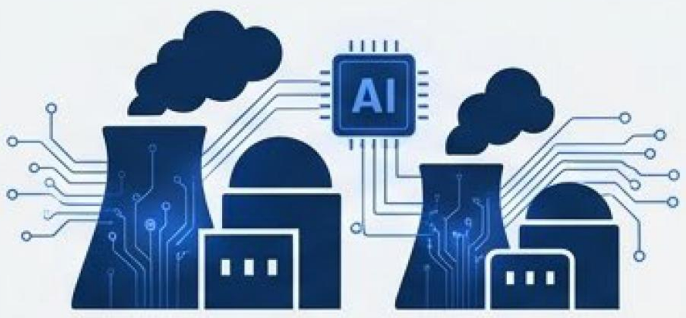
Scaling Intelligence: The Multi-Modal Reactor Portfolio

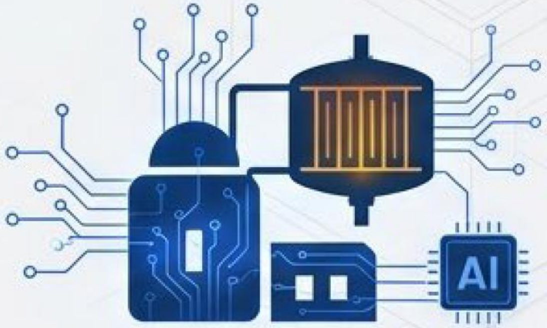


Large Power Plants & SMRs

Integration into critical infrastructure and grid baseload.

High-Temperature Reactors (HTRs)

Optimized for process heat and electrical grid stability.



Molten Salt & Microreactors

Focused on nuclear waste minimization, sustainability, and isolated communities.

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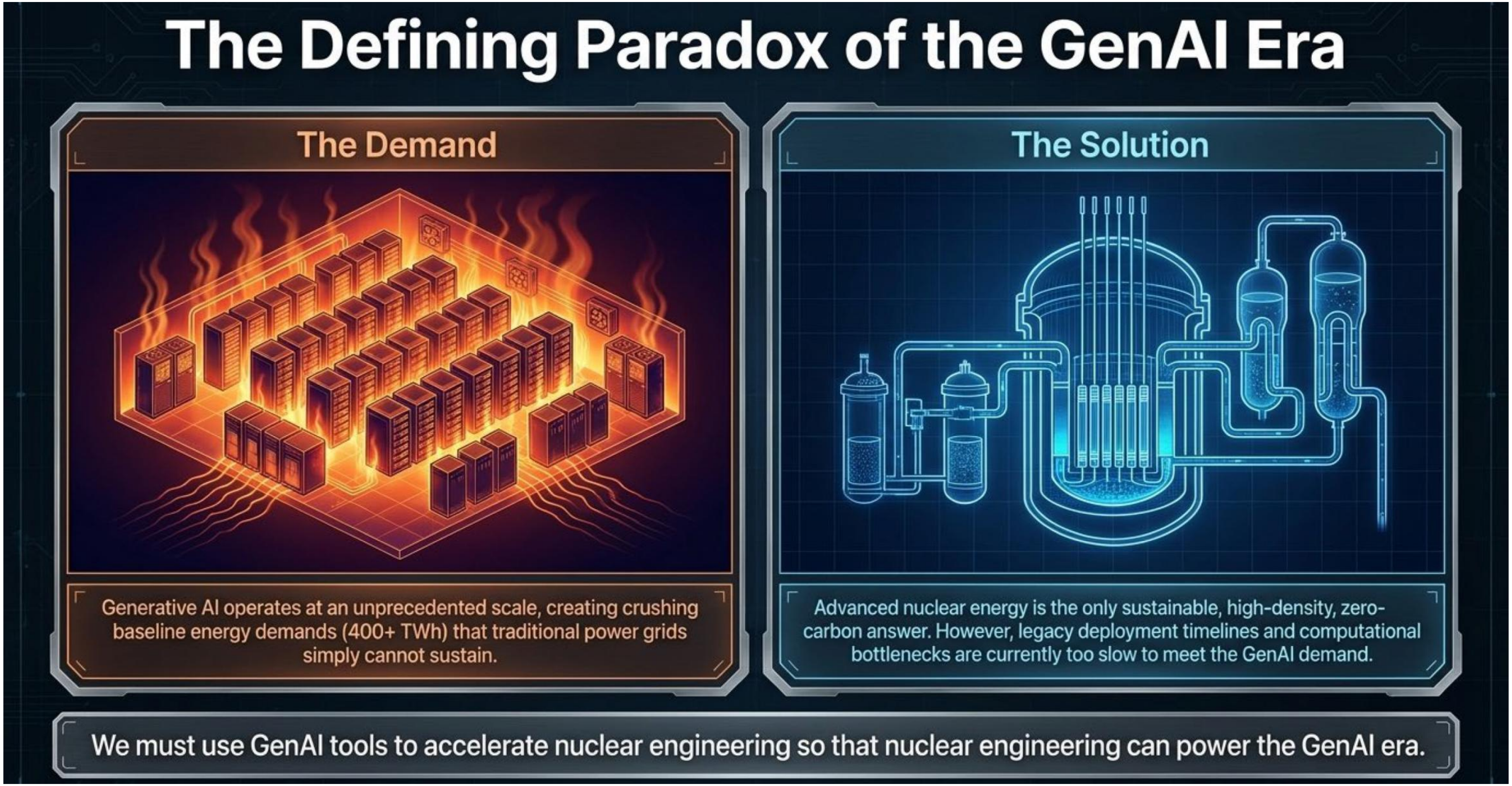

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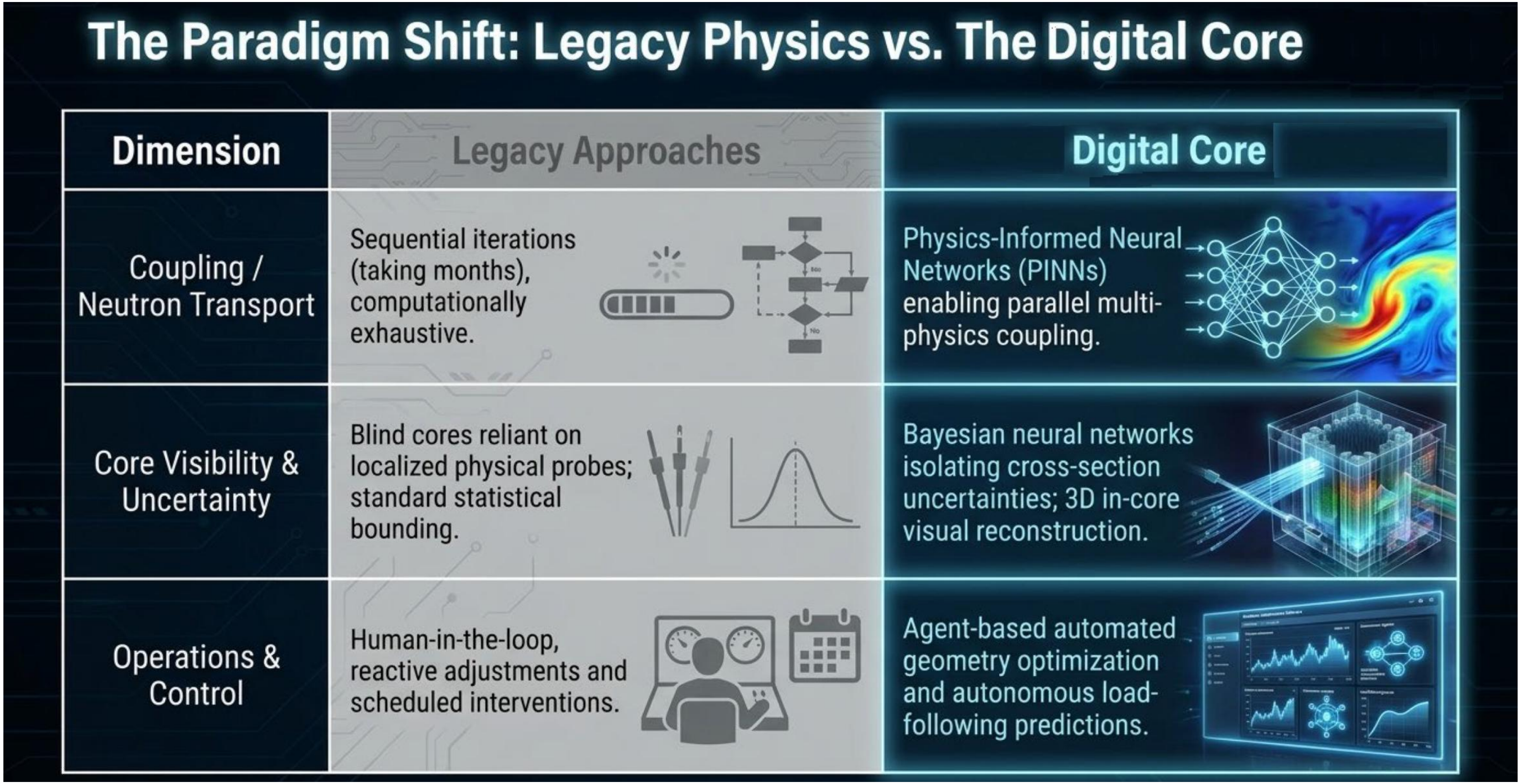

The Paradigm Shift: Legacy Physics vs. The Digital Core

Dimension	Legacy Approaches	Digital Core
Coupling / Neutron Transport	Sequential iterations (taking months), computationally exhaustive.	Physics-Informed Neural Networks (PINNs) enabling parallel multi-physics coupling.
Core Visibility & Uncertainty	Blind cores reliant on localized physical probes; standard statistical bounding.	Bayesian neural networks isolating cross-section uncertainties; 3D in-core visual reconstruction.
Operations & Control	Human-in-the-loop, reactive adjustments and scheduled interventions.	Agent-based automated geometry optimization and autonomous load-following predictions.

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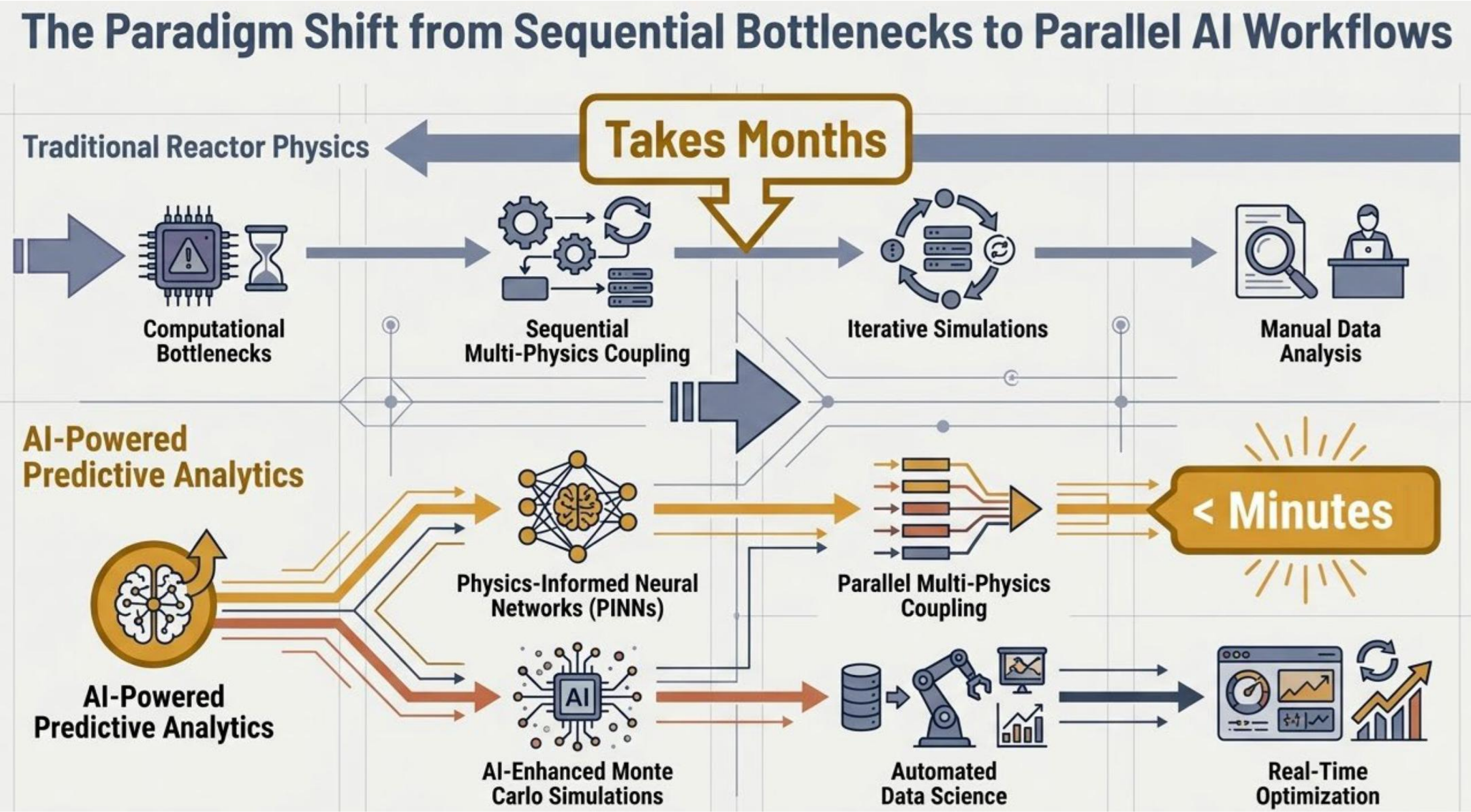

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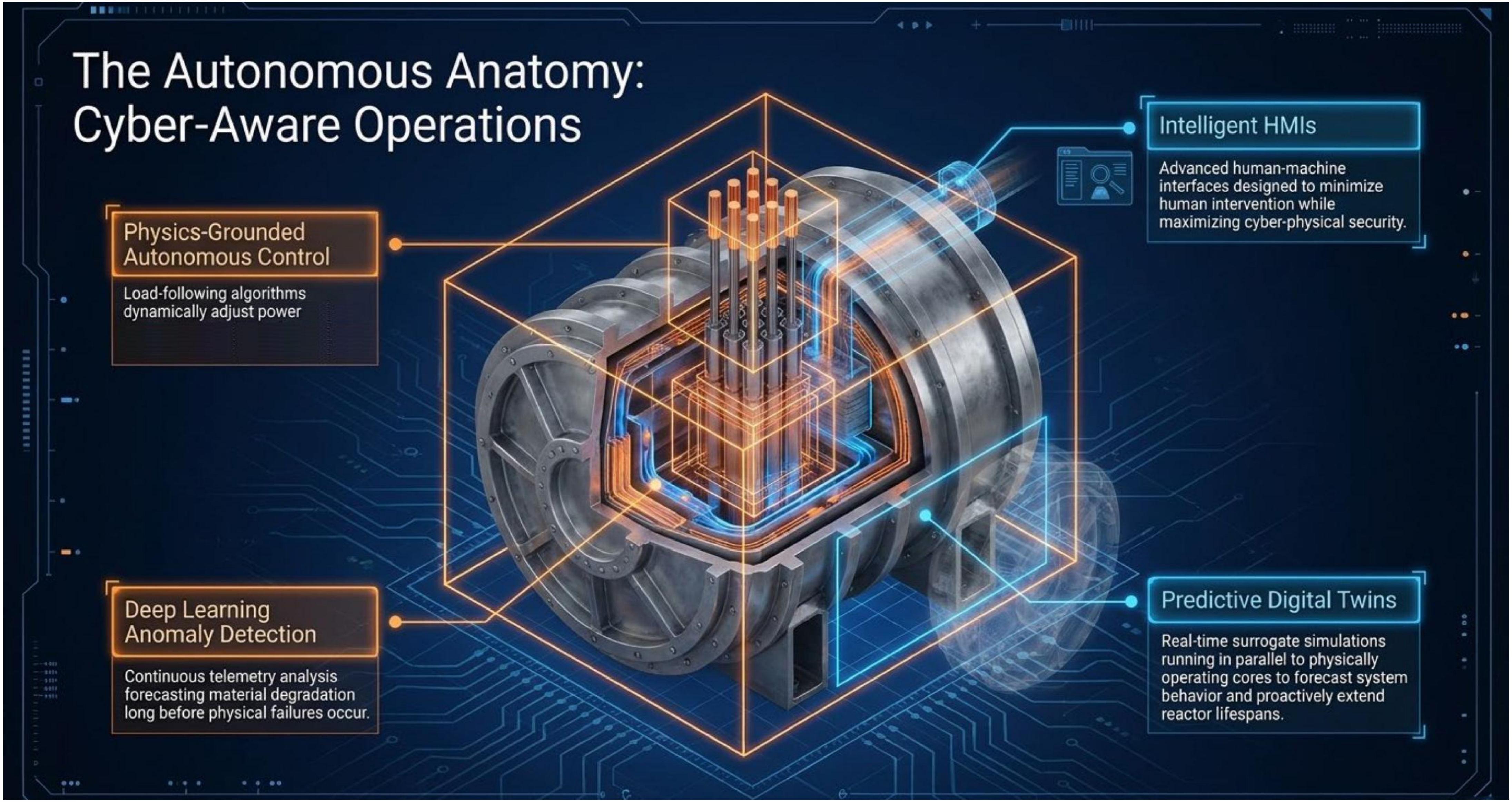

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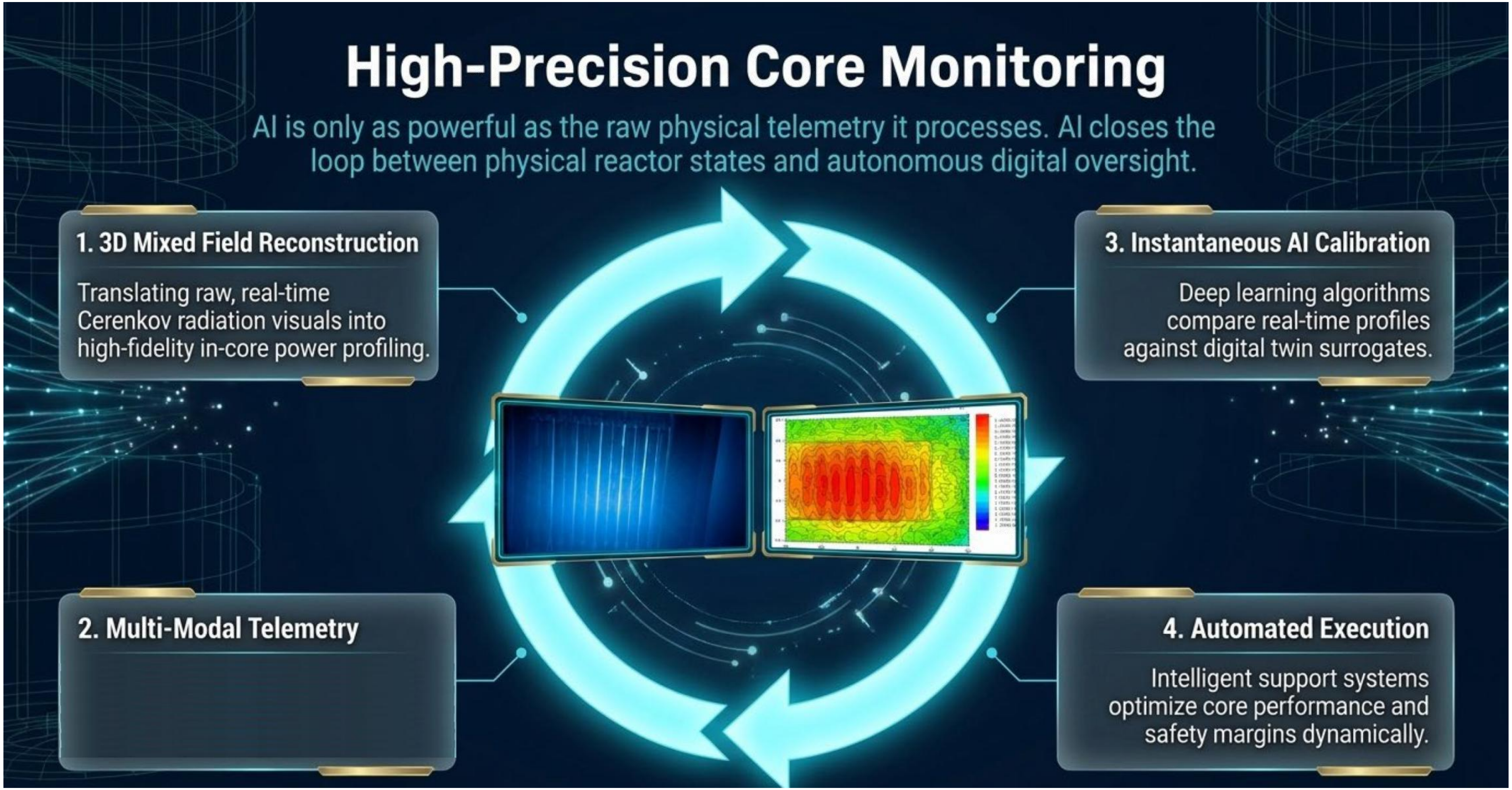

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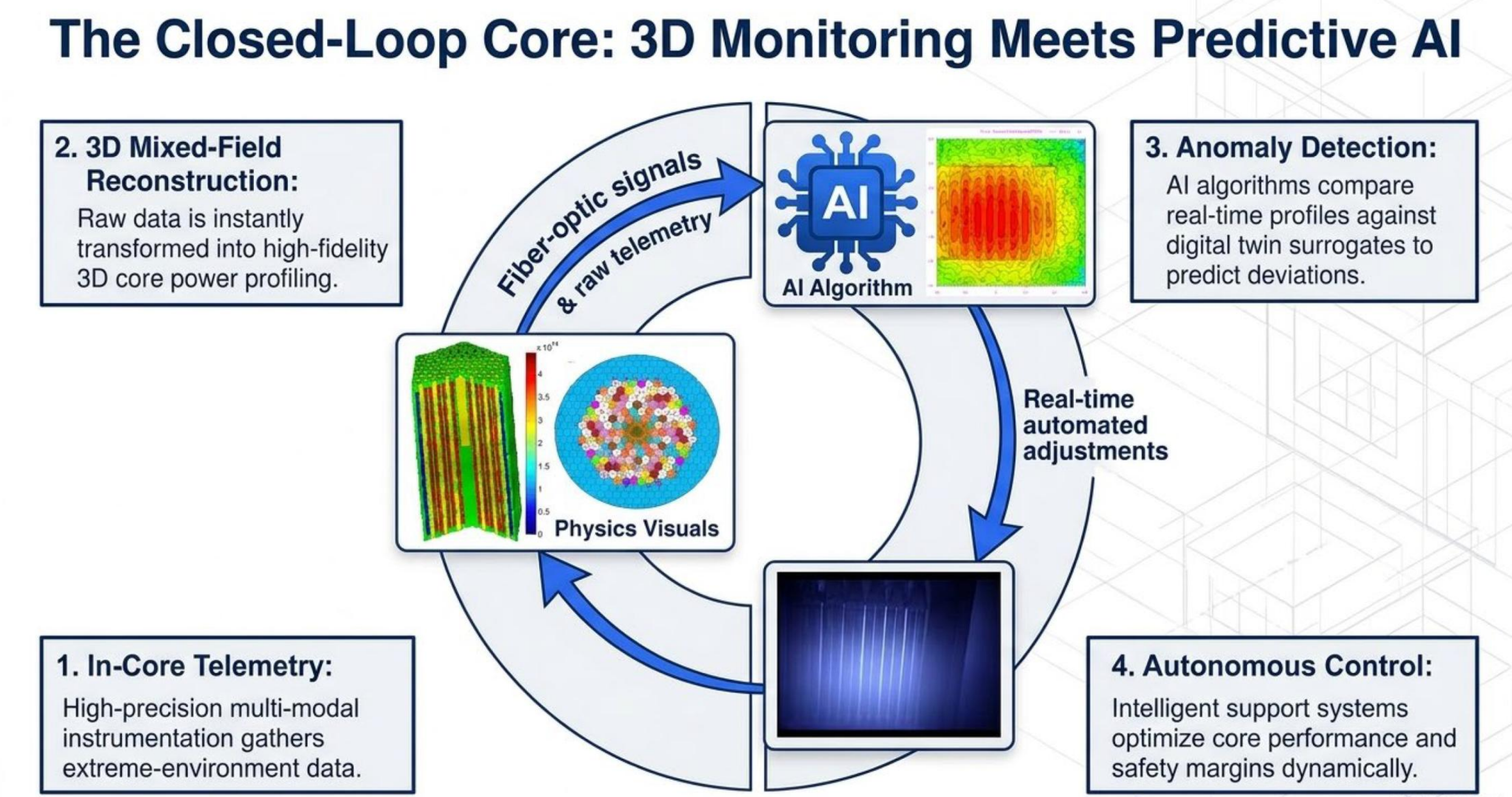

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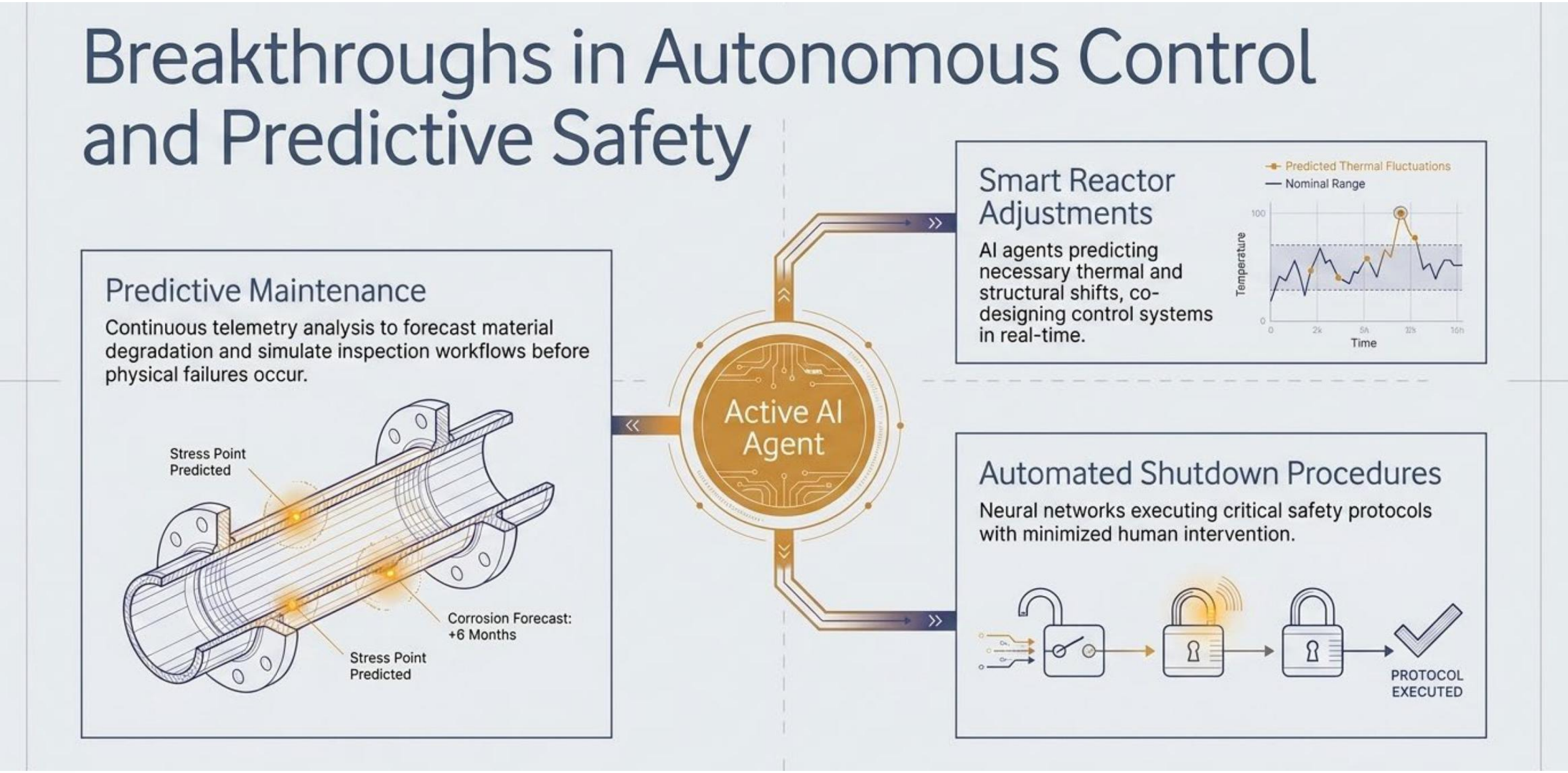

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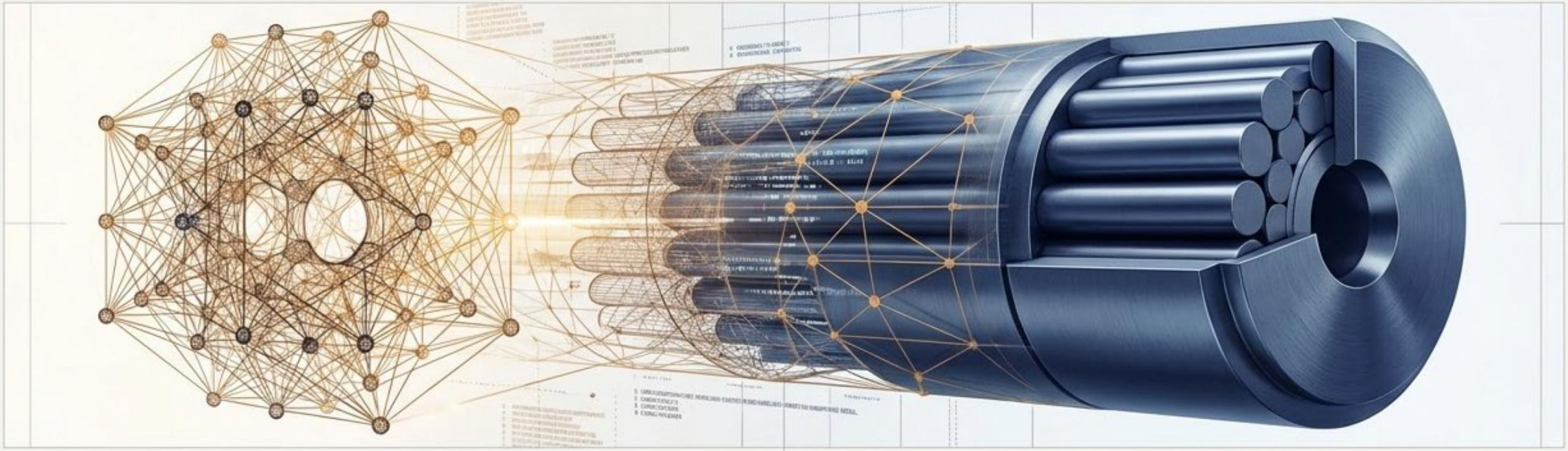
AI-Assisted Materials Discovery and Geometry Optimization



High-Efficiency Fuels

Machine learning identifying novel material compositions that withstand higher temperatures and burnup cycles.

Reactor Geometry

Algorithmic optimization of structural layouts to ensure maximum energy conversion efficiency.

Passive Safety Integration

Designing physical architectures that naturally integrate with AI-driven passive safety systems, functioning without active human oversight.

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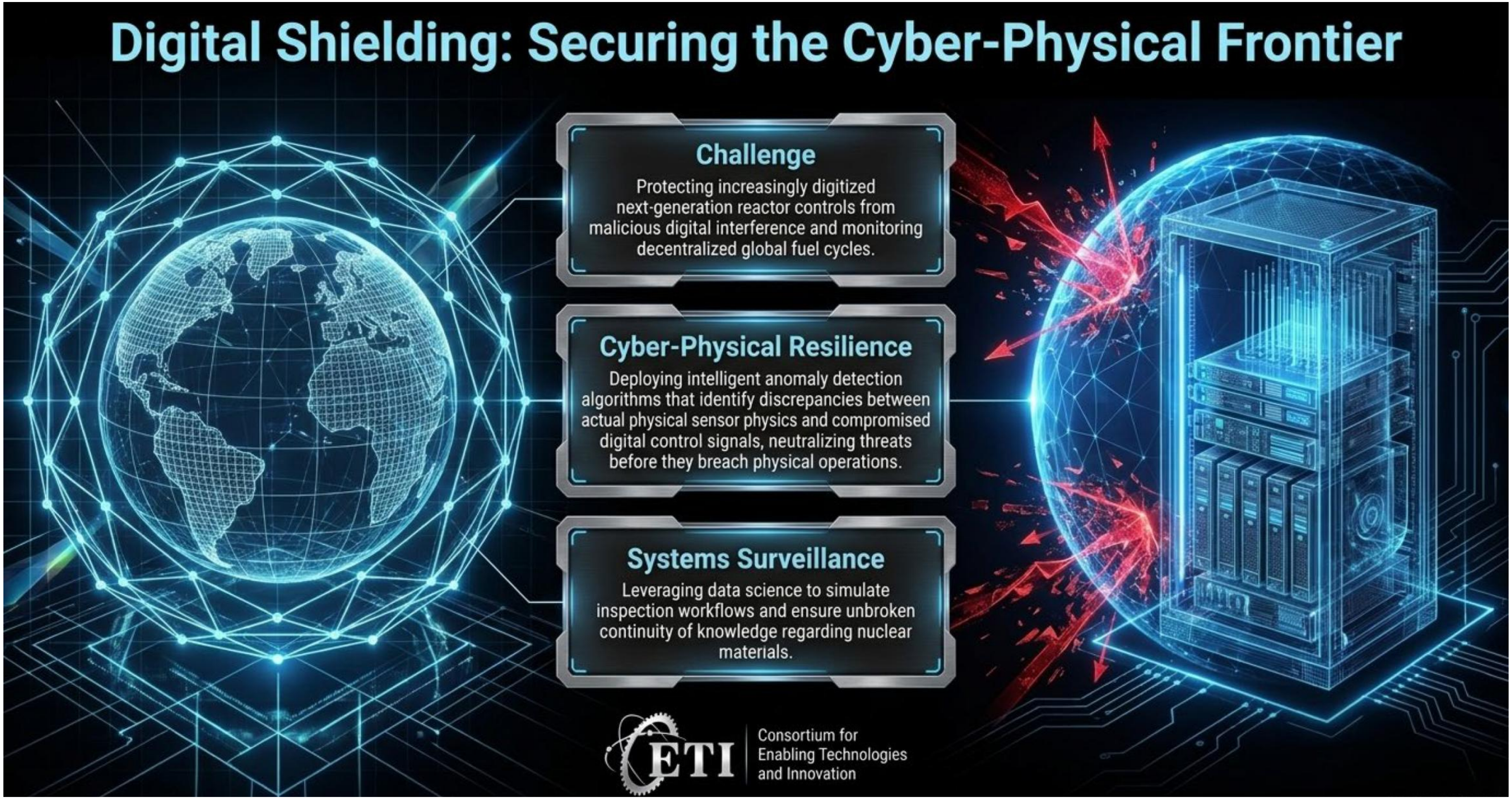
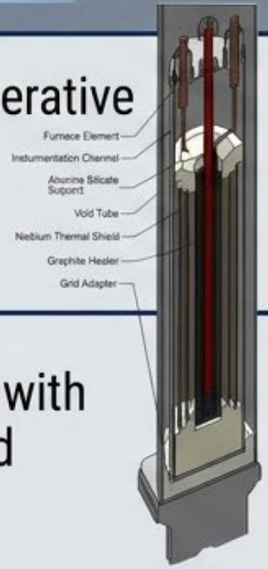


The AI Advantage: Moving from Physical Constraints to Digital Agility

	Traditional Nuclear Paradigm	AI-Driven Paradigm
Design & Licensing	Highly reliant on costly, iterative physical test beds and analog high-temperature furnaces.	**AI-enhanced high-fidelity surrogacy and automated design optimization, slashing development timelines.**
System Operations	Human-centric oversight with reactive maintenance and analog thresholds.	**Autonomous I&C,** integrating AI with **Human-Machine Interfaces (HMIs)** for **predictive reliability.**
Security Posture	Physical perimeter defense and isolated analog sensors.	**Proactive, cyber-physical defense mechanisms analyzing multi-modal data streams in real-time.**



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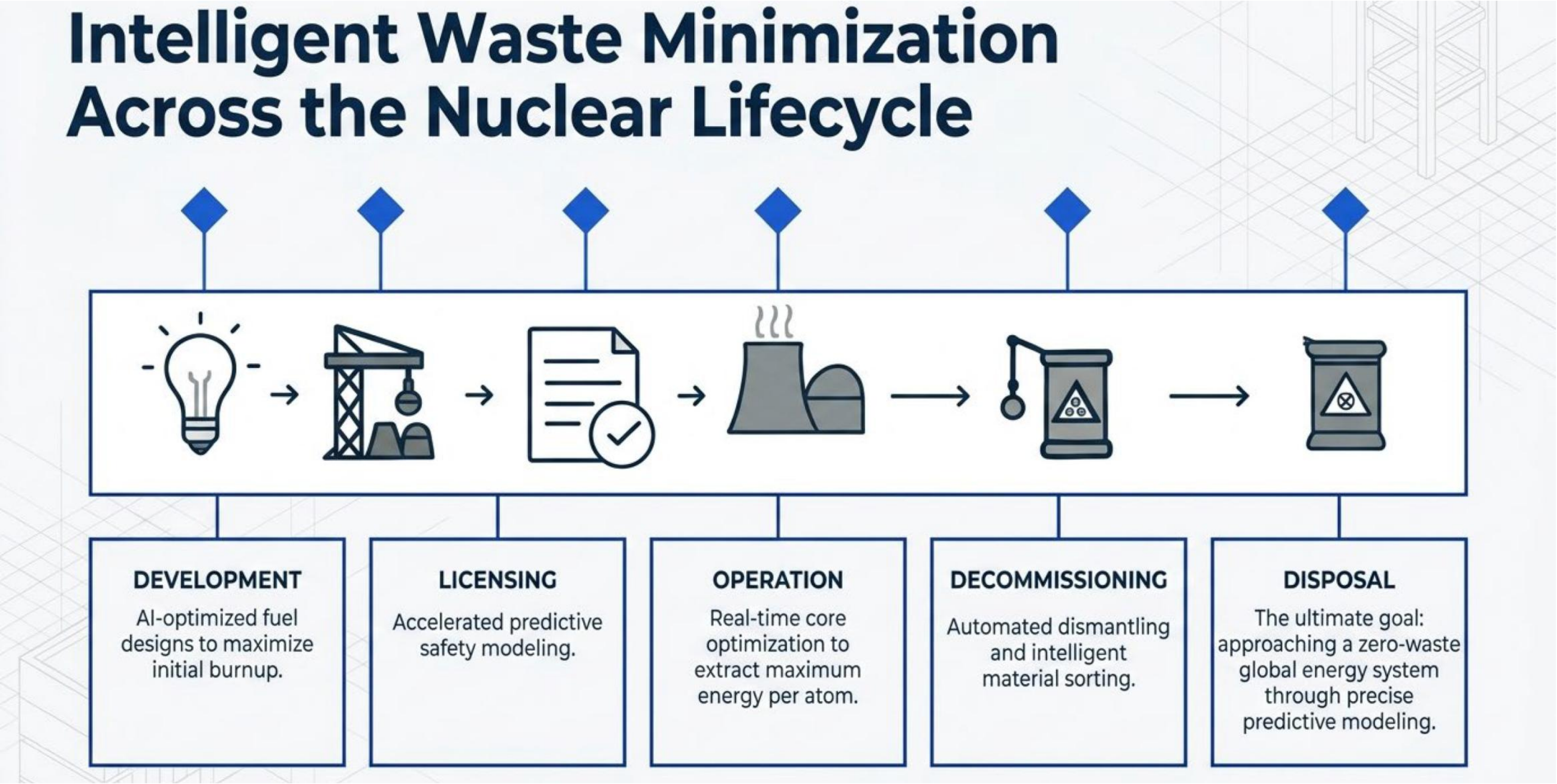

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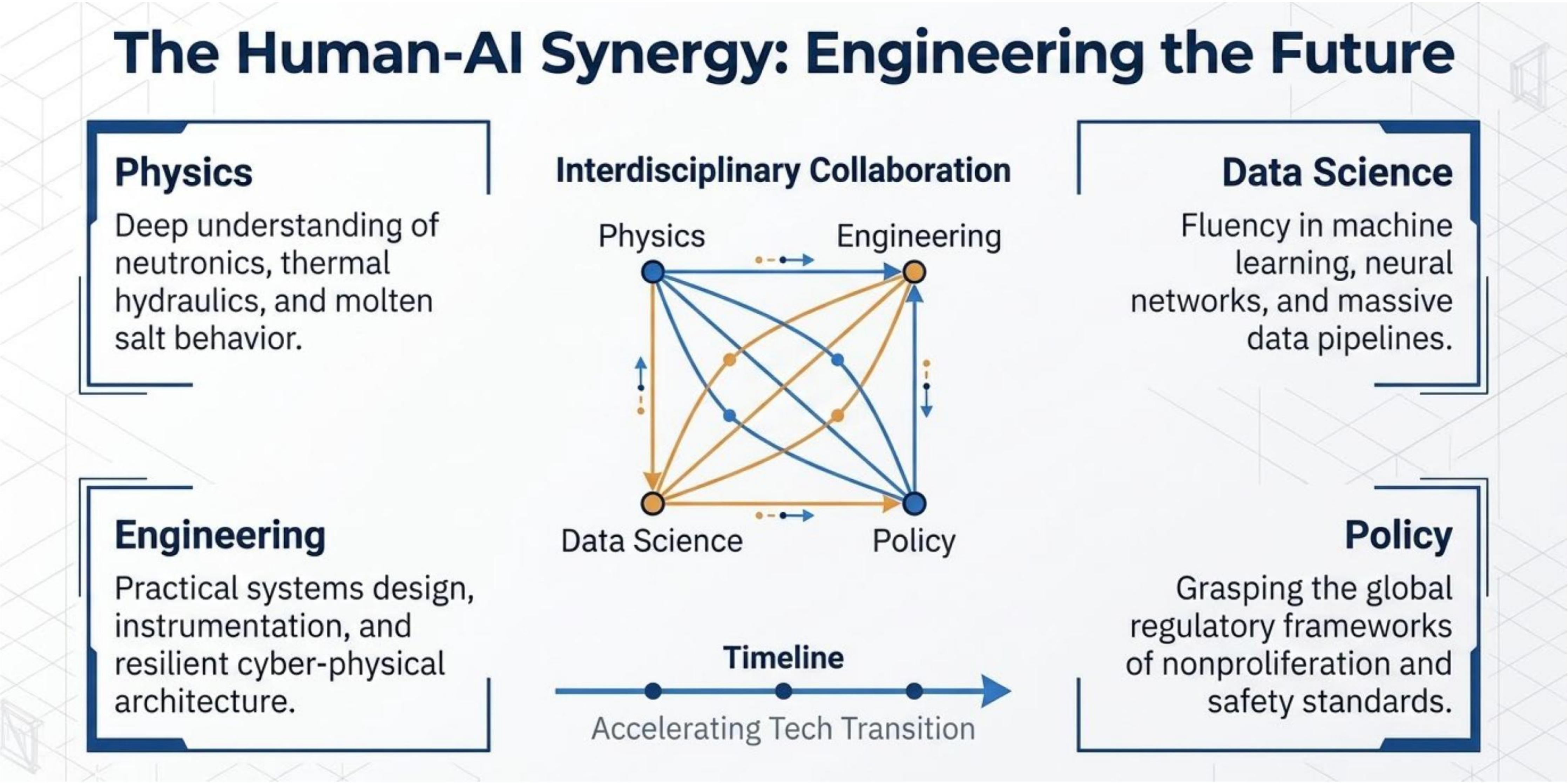

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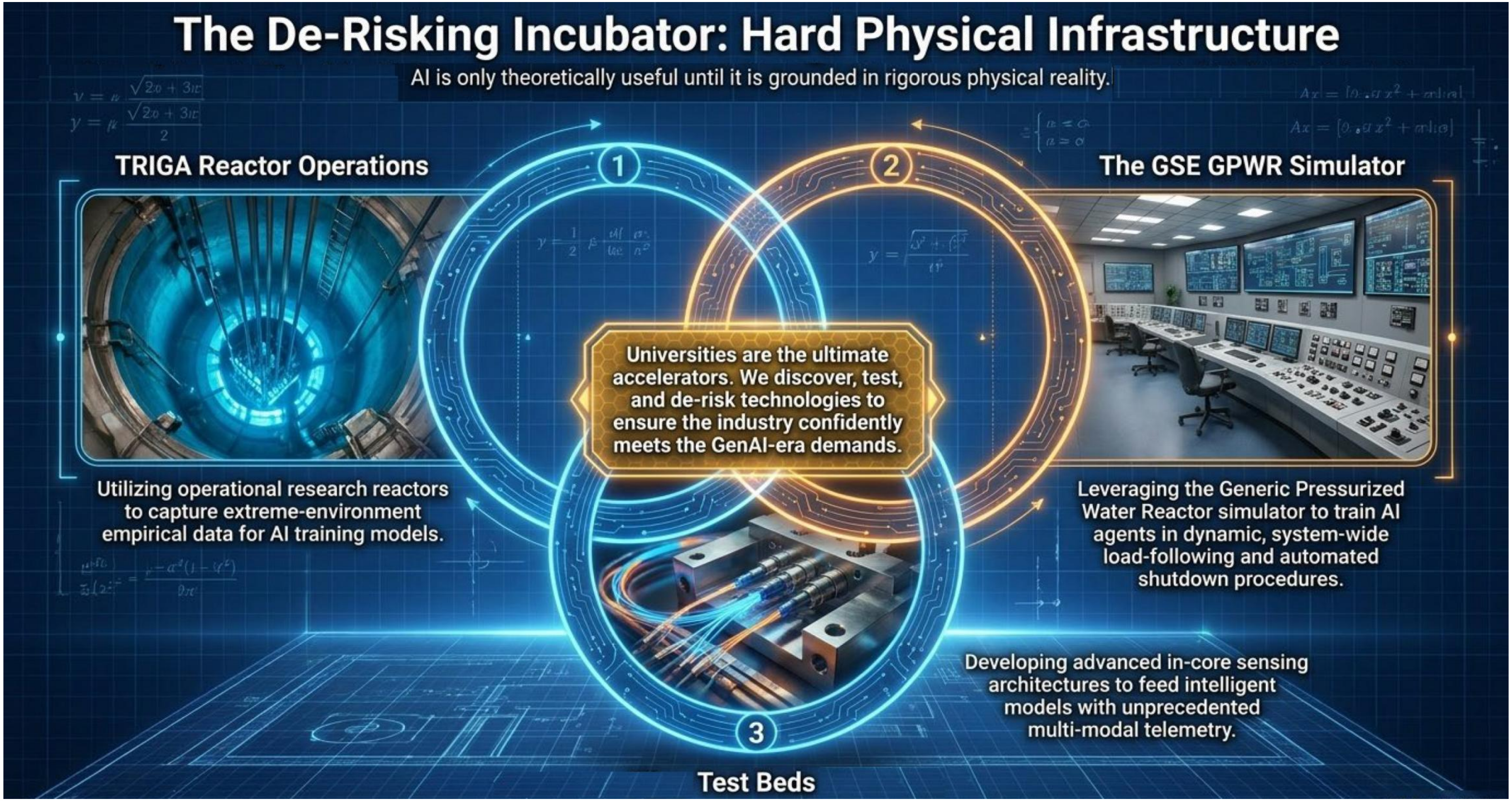

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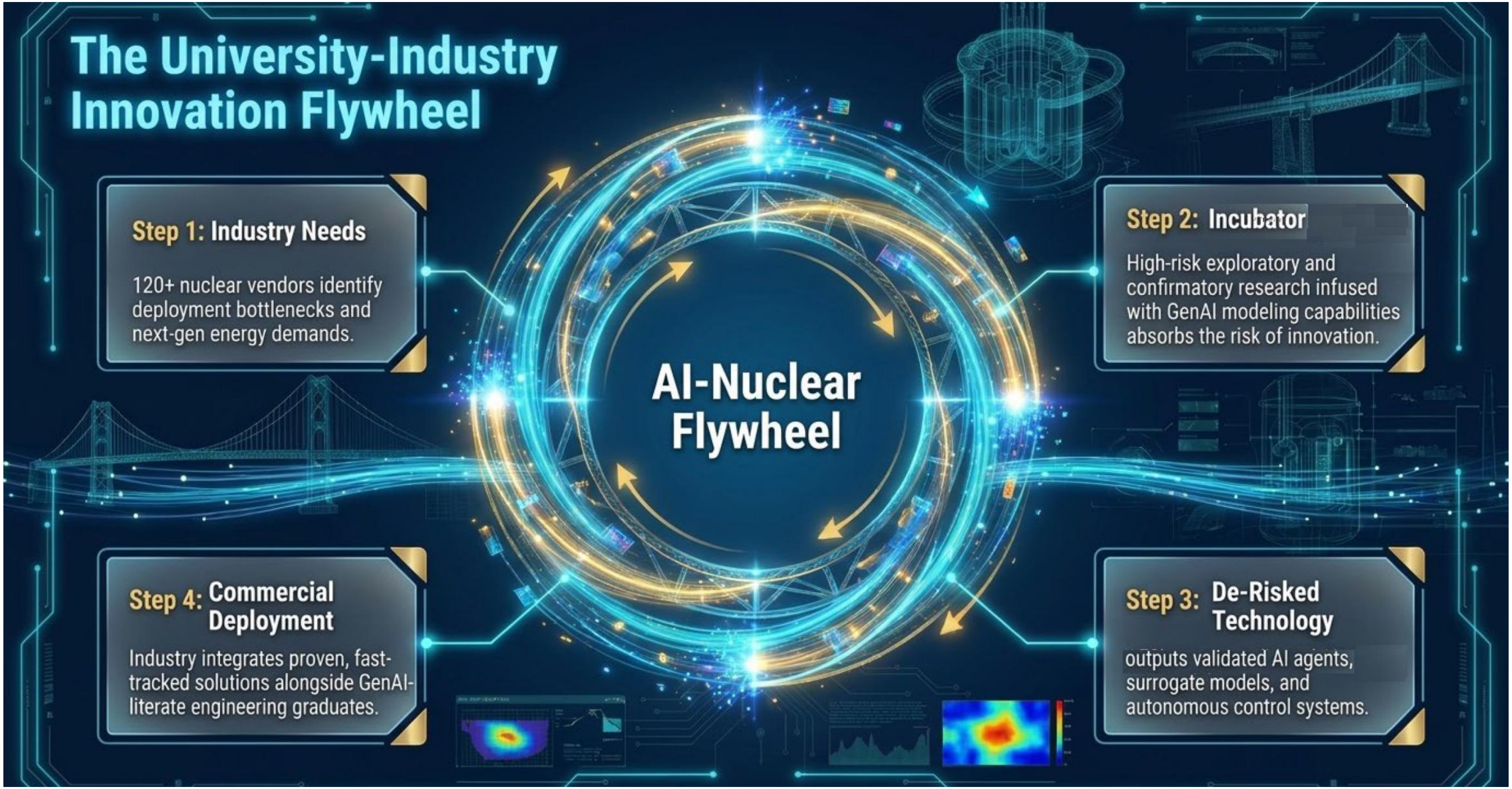

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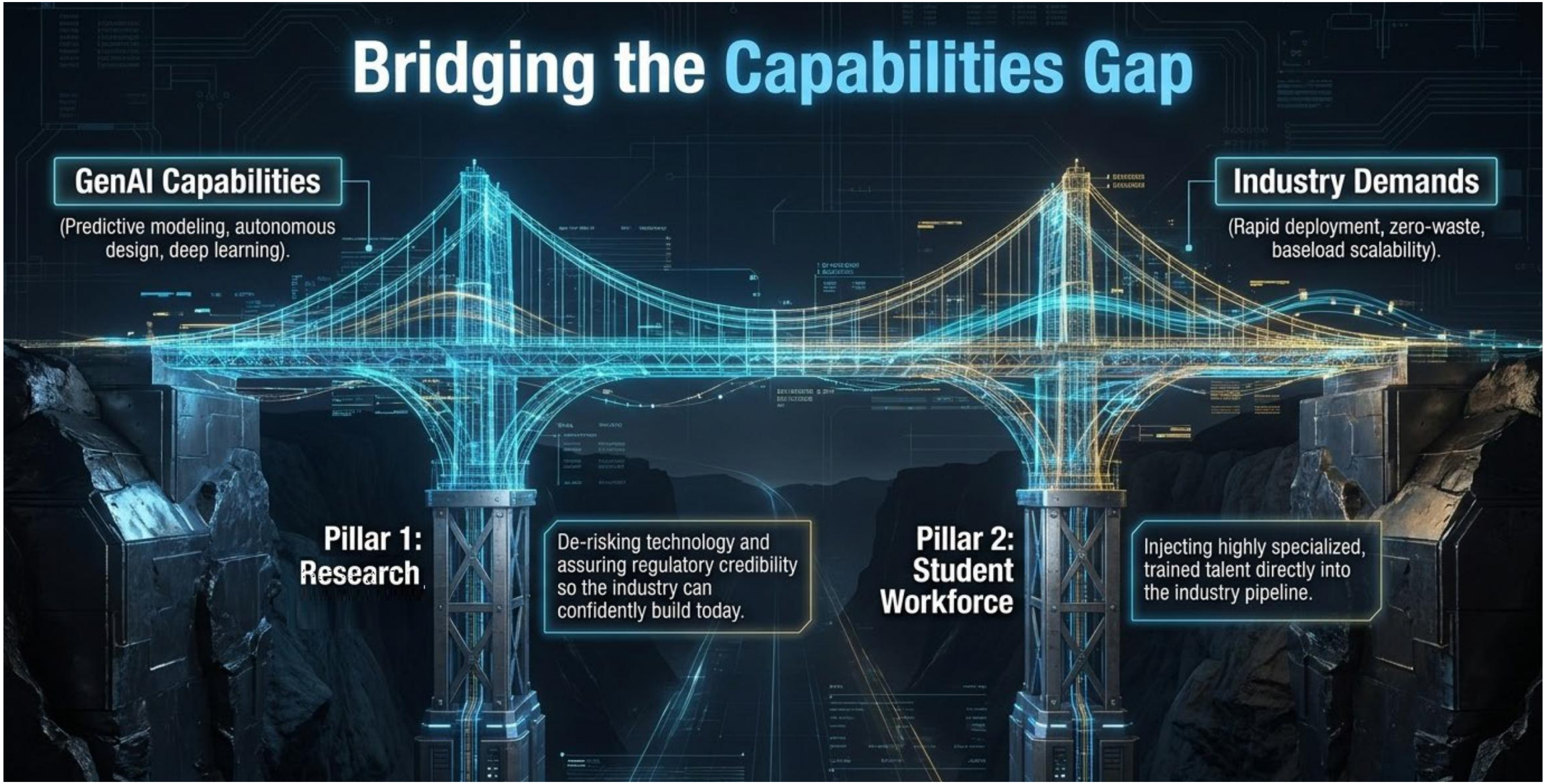

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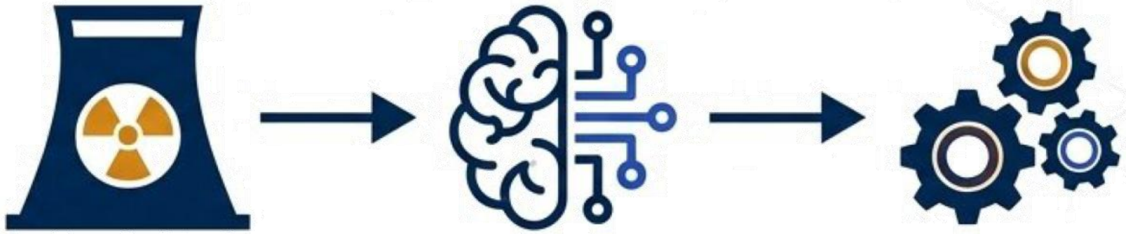
NUCLEAR ENGINEERING
TEXAS A&M UNIVERSITY

Training the "Bilingual" Nuclear Engineer



The Texas A&M Nuclear Engineering Graduate Program, driven by AESL, is bridging the critical skills gap. We are forging a new class of professional fluent in both nuclear physics and applied machine learning.

HANDS-ON EXPERIENCE

- Hands-on experience with surrogate modeling and real-world reactor deployments

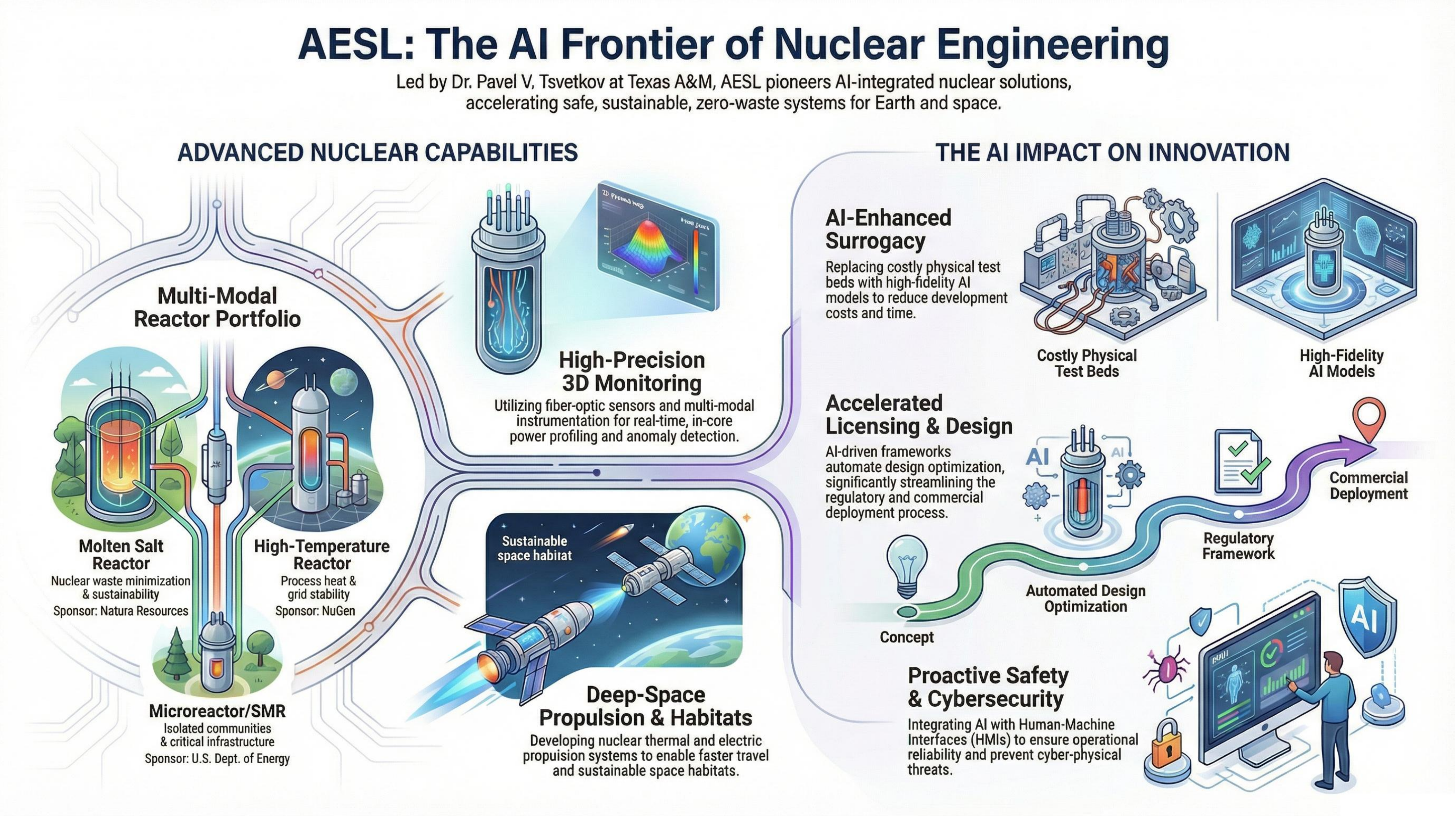
INDUSTRY INTEGRATION

- Direct integration with National Laboratories and commercial industry partners.

PIONEERING SOLUTIONS

- Pioneering AI-integrated solutions for sustainable systems on Earth and in deep space.

AI-Driven Evolution in Nuclear Engineering:
Meeting Modern Energy Demands through Advanced Research and Education



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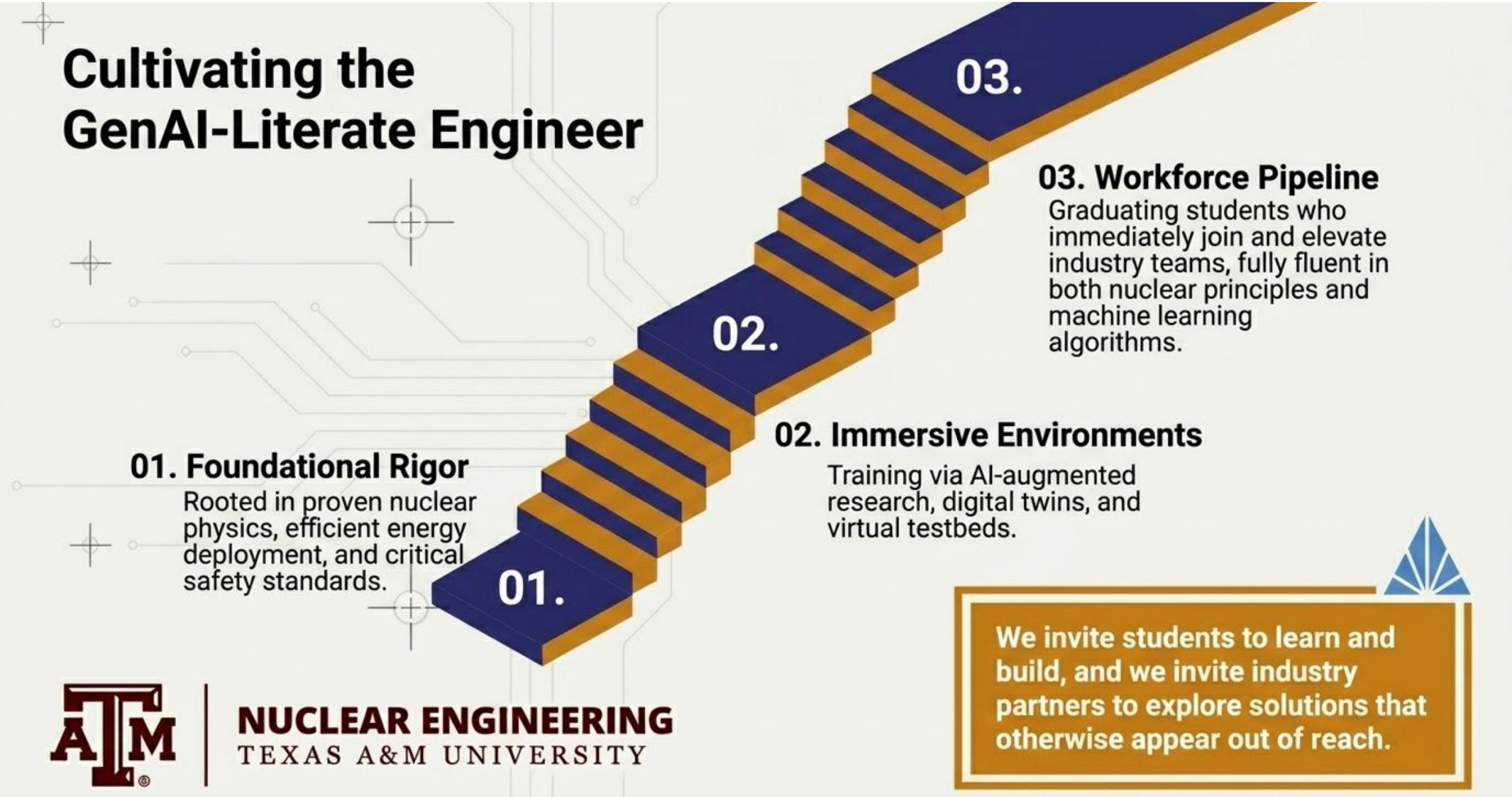
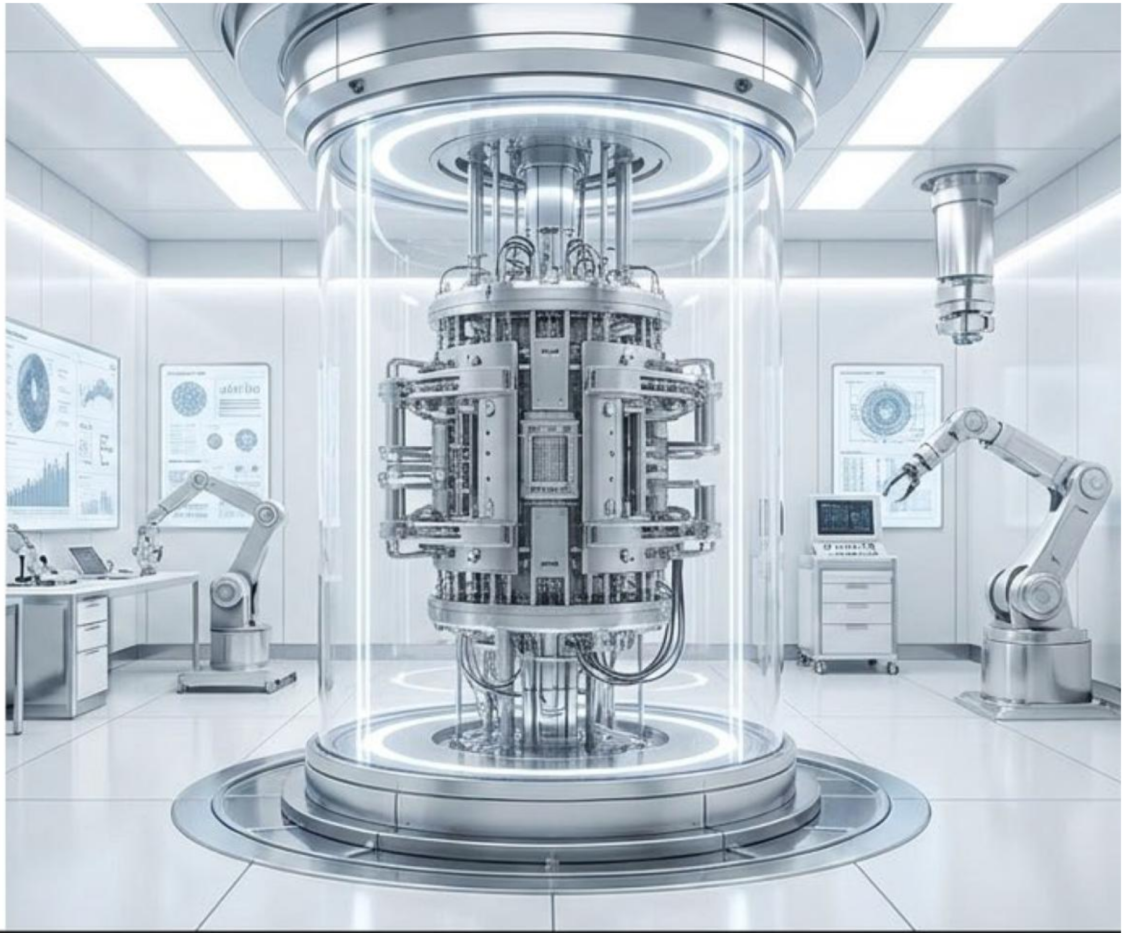


The Next Evolutionary Epoch

- **Quantum Synergies**
  What's next? Forging new pathways between artificial intelligence, quantum computing, and advanced nuclear science.

- **Interdisciplinary Convergence**
  Erasing the boundaries between AI data scientists and reactor physicists to solve global energy bottlenecks.



"There is no project today that does not use AI to deepen discovery and amplify impact. This is an exciting and enabling time for nuclear."

AI-Driven Evolution in Nuclear Engineering:
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AESL
Advanced Energy Systems Laboratory

https://aesl.engr.tamu.edu/

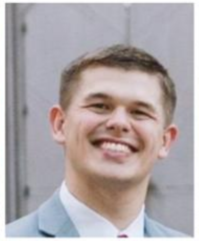
Acknowledgements


Dr. Pavel V. Tsvetkov
Professor, Graduate Program Director (NUEN)


Dan Watson
PhD Candidate


Dr. Jason Hearne
Research Engineer


Dahvien Dean
Research Engineer


Ryan Brownfield
Research Engineer


J. Tyler Gates
PhD Candidate


Hui-Yu Hsieh
PhD Candidate


M. Scott Walls
PhD Student


Michael Parnell
Aviles Johnson Fellow
PhD Student


Ryan Kelly
Rickover Fellow
PhD Student


Rowan Johnson
Horizons Fellow
PhD Student


Seray Cerezo
PhD Student


Matthew Johnson
PhD Student (INL)


Claire Lewis
Undergrad (26')


Chris Walk (GT)
Undergrad Intern (27')


Timothy Davila
Undergrad (26')


Harrison Herndon
Undergrad (26')


Sydney Ballard
Undergrad (26')


John Ludwick
Undergrad (26')

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Acknowledgements

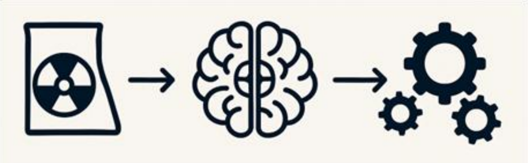

Image created with Microsoft Copilot Pro and xAI SuperGrok

- Reactor physics
- Experimentation
- Nuclear security and nonproliferation
- Design
- Sensors
- Applications

Dr. Anna Erickson

Professor

Georgia Institute of Technology

https://sites.gatech.edu/lanns/

Mr. Daniel Watson

Researcher

Texas A&M University

https://aesl.engr.tamu.edu/

NUCLEAR ENGINEERING
TEXAS A&M UNIVERSITY

AI-Driven Evolution in Nuclear Engineering:
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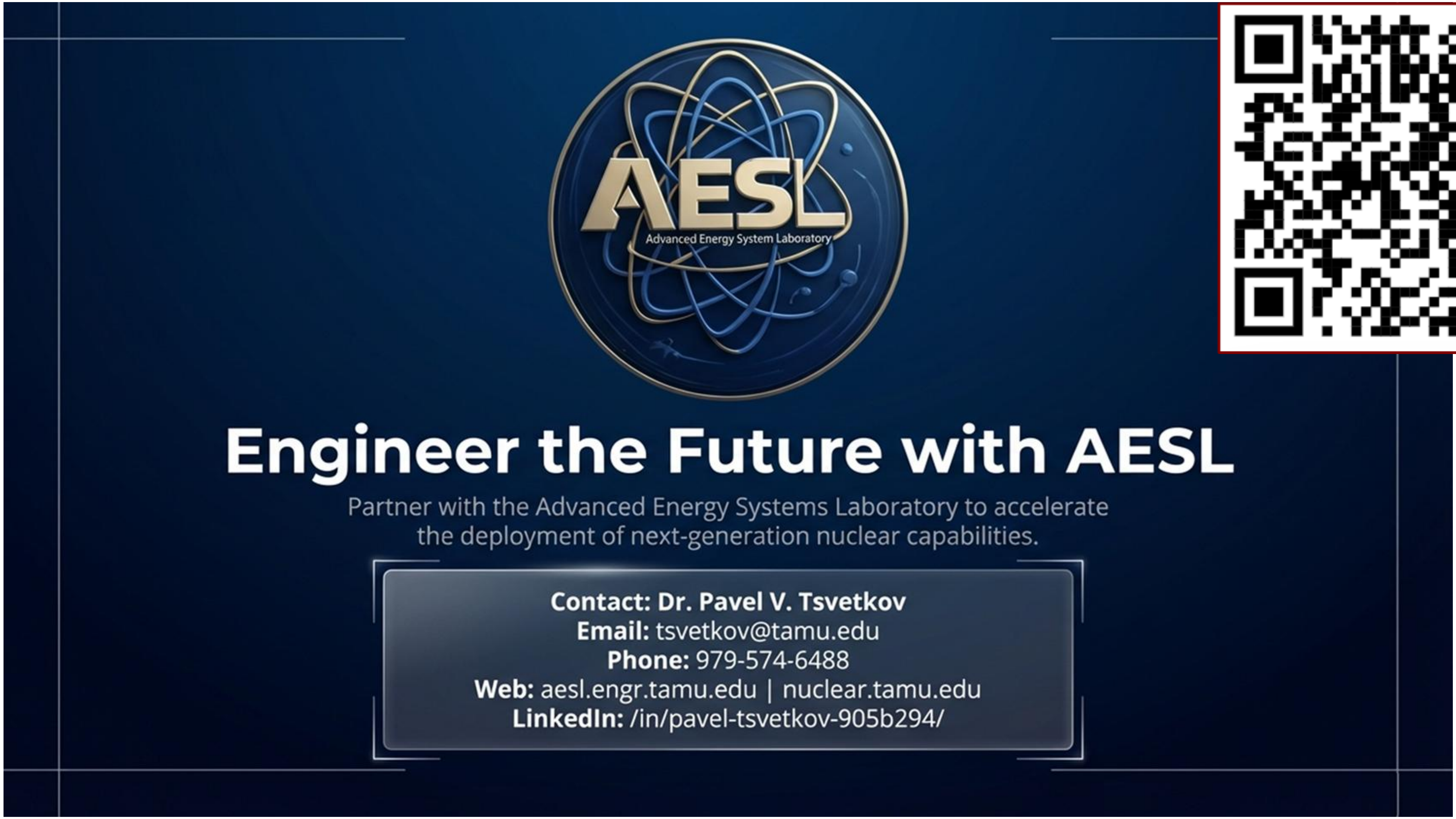
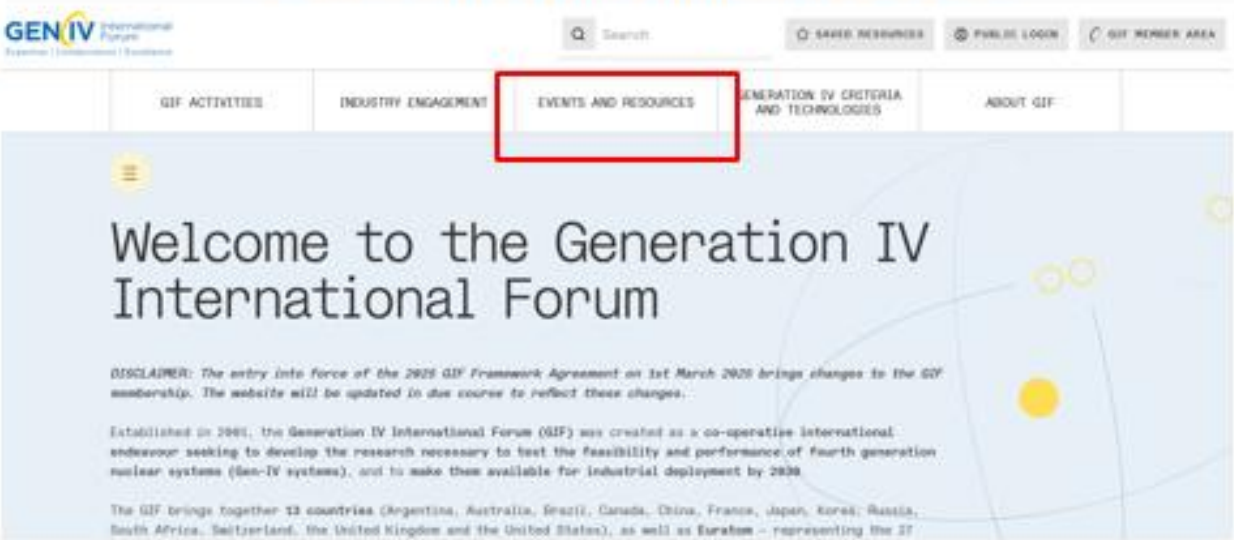


Upcoming GIF ETWG Webinars

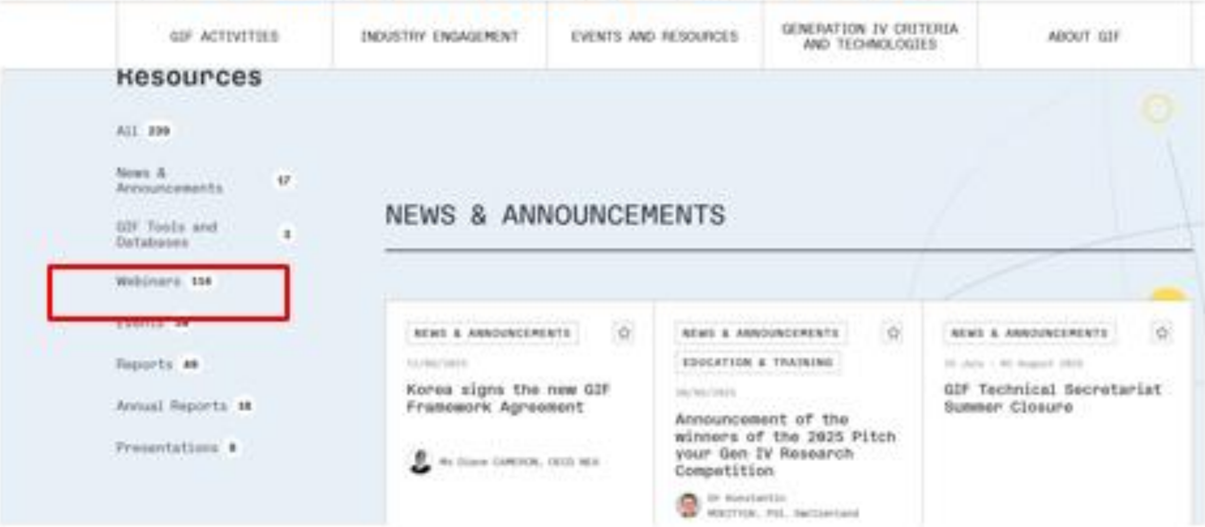
Date	Title	Presenter
22 June 2026	Defensive Cyber Security Architecture and Impact on GenIV Reactors	Dr. Rick Bodner, Canadian Nuclear Laboratories, Canada
8 July 2026	The Wider Role of Nuclear in the Energy System – Engagement and education activities to enable	Mr. Robert Alford, UKNNL, United Kingdom
12 August 2026	Diamonds are a Reactor's Best Friend: Novel Sensor to Investigate High-Valence Actinides in Molten Salts	Dr. Hannah Patenaude, Los Alamos National Laboratory, USA

How to find the recorded GIF Webinars – www.gen-4.org

1- Click on "Events and Resources Tab



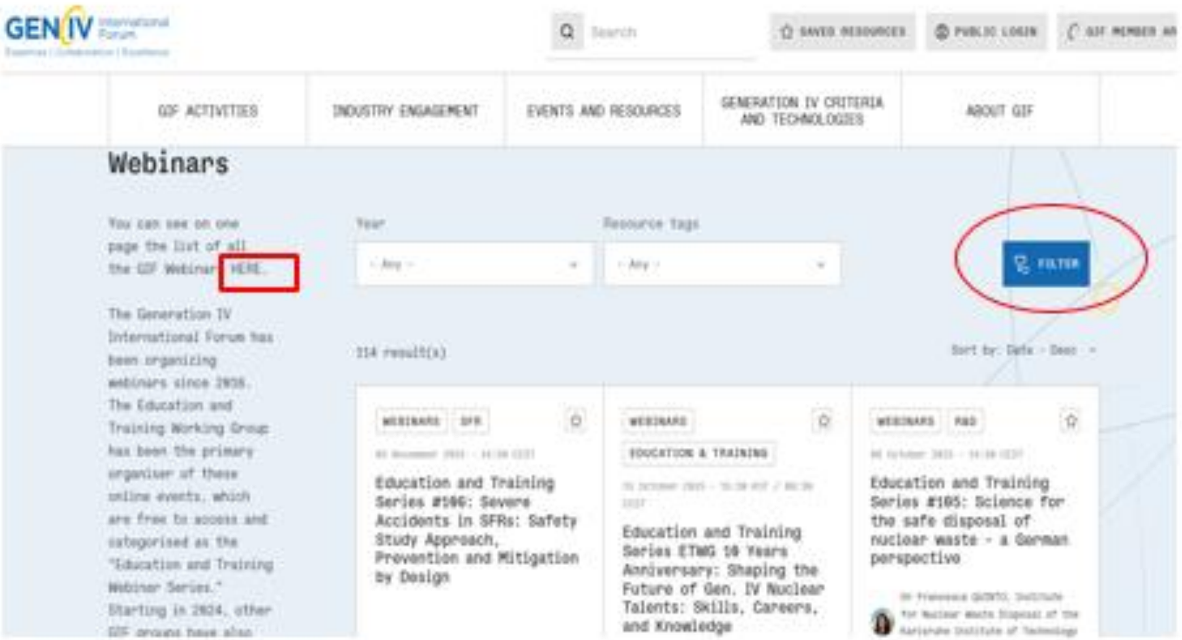
2- Click on "Webinars" tab on the left



3- Click on "HERE" to see all the webinars

Or

4-Use the Year and Resource tag and click on Filter



Thank you!
Questions?

All GIF webinars can be found here: https://www.gen-4.org/list-gif-webinars

A feedback survey will be circulated following this webinar. Please kindly take the time to fill it to help us improve this series of webinars.