GEMINA—Generating Electricity Managed by Intelligent Nuclear Assets

PROJECT DESCRIPTIONS

GE Research – Niskayuna, NY

AI-Enabled Predictive Maintenance Digital Twins for Advanced Nuclear Reactors - $5,412,810

Advanced reactors must be designed to be financially competitive with fossil fuel power plants to gain a foothold in future energy markets. The GE Research team aims to reduce operations and maintenance (O&M) costs by moving from a time- to condition-based predictive maintenance framework, using GE Hitachi's BWRX-300 boiling water reactor as the reference design. GE will develop operational, health, and decision digital twins to enable continuous monitoring, early warning, diagnostics, and prognostics for the reactor systems. The team will develop a "Humble AI" framework—which defaults to a known safe operation mode when there is a situation the algorithms does not recognize—to ensure systematic handling of uncertainties, data and model assurance, and continuous learning for these twins.

Electric Power Research Institute, Inc. – Palo Alto, CA

Build-to-Replace: A New Paradigm for Reducing Advanced Reactor O&M Costs - $999,464

Major components in traditional nuclear design and construction are required to last many decades; replacing them can be technically complex and costly. The Electric Power Research Institute's (EPRI) proof-of-concept study will explore moving from the traditional "maintain and repair" to a "replace and refurbish" approach, in which components are intentionally designed and tested for shorter and more predictable lifetimes with the potential for game-changing O&M cost savings. EPRI's approach is similar to that adopted by the commercial airline industry, in which multiple refurbishments—including engine replacement—can keep a jet aircraft flying economically over many decades. The study will evaluate several advanced reactor designs with respect to cost savings and other important economic benefits, such as increased sustainability for suppliers.

X-energy, LLC – Rockville, MD

Advanced Operation & Maintenance Techniques Implemented in the Xe-100 Plant Digital Twin to Reduce Fixed O&M Cost - $6,000,000

X-energy's digital twin project aims to reduce the fixed O&M cost of its advanced nuclear reactor design to $2/MWh. The project will use human factors engineering, probability risk assessment, hazard analysis, and security and maintenance evaluations to identify areas for optimization. Further, X-energy will develop innovative ways to leverage advanced technologies—including automation, robotics, remote and centralized maintenance, and monitoring—to optimize staffing plans while ensuring optimal plant operation. The team will develop two modeling frameworks to evaluate and validate these solutions. X-energy's Immersive Environment Toolset is a multi-disciplinary 3D model that, when combined with virtual reality, will test techniques that optimize maintenance and security. The digital twin framework synthesizes information from the operating plant and assimilates data from across the fleet to provide a holistic understanding of the asset.

Argonne National Laboratory – Argonne, IL

Maintenance of Advanced Reactor Sensors and Components (MARS) - $2,200,000

Argonne National Laboratory (ANL) aims to reduce the O&M cost of the Kairos Power fluoride salt-cooled high temperature reactor through advanced sensing and automation. The team will develop advanced distributed sensing and data generation techniques to characterize critical components and systems. Further, the ANL project will increase sensor diversity and develop multi-functional sensors measuring several process variables simultaneously. Finally, the ANL team will develop machine learning-based signal processing algorithms for automated analysis of sensor data. Accomplishing these objectives will reduce the number of advanced reactor staff, as well as repair and replacement costs. The proposed methods are aimed to achieve $2/MWh O&M costs.

Framatome, Inc. – Lynchburg, VA

Digital Twin-Based Asset Performance and Reliability Diagnosis for the HTGR Reactor Cavity Cooling System Using Metroscope - $809,701

Framatome will develop two novel digital twins for use with Metroscope, a software package that connects digital twins and their associated fault libraries and monitors them with an algorithm to detect problems early on. The digital twins will simulate a passive cooling system with internal thermal hydraulic faults and a typical cooling circuit with different operating modes and control states. The twins will be paired with the reactor cavity cooling system of Framatome's Steam Cycle High-Temperature Gas-Cooled Reactor. Digital twins will allow for sensor sensitivity and reliability to be characterized and optimized.

Massachusetts Institute of Technology – Cambridge, MA

High-Fidelity Digital Twins for BWRX-300 Critical Systems - $ 1,787,065

The BWRX-300 is a small modular reactor designed to provide flexible energy generation that is cost-competitive with natural gas-fired plants. The Massachusetts Institute of Technology (MIT) will assemble, validate, and exercise high-fidelity digital twins of the BWRX-300 systems. MIT's work will advance and demonstrate predictive maintenance approaches and model-based fault system detection techniques. The digital twins address mechanical and thermal fatigue failure modes that drive O&M activities well beyond selected BWRX-300 components and extend to all advanced reactors where a flowing fluid is present. The role of high-fidelity resolution is central to the approach, as it addresses the unique challenges of the nuclear industry.

Moltex Energy USA, LLC – Wilmington, DE

SSR APPLIED - Automated Power Plants: Intelligent, Efficient, and Digitized - $3,500,000

Moltex Energy will develop a multi-physics plant digital twin environment for its Stable Salt Reactor - Wasteburner (SSR-W). SSR-W is a low overnight-capital plant design, targeting a <$2/kWe build cost. A non-nuclear separate effects test loop will support the digital twin development, to validate larger uncertainties in flow conditions providing a virtual test environment for showcasing/simulating operations and maintenance strategies in SSR-W. EPRI studies have identified the potential for a <$2/kWe advanced nuclear build cost to displace natural gas combined cycle power plants throughout the U.S. By further reducing the SSR-W O&M levelized cost of energy contribution from a current ~$11/MWh to a proposed $1.75/MWh, the potential for transformative energy cost reduction is significant.

University of Michigan – Ann Arbor, MI

PROJECT "SAFARI"- Secure Automation For Advanced Reactor Innovation- $5,195,000

The University of Michigan will develop physics-based, model-centric, and scalable capabilities to achieve unprecedented integrated state awareness for advanced reactor power plants. Individual modules include (1) a scalable digital twin, (2) a maintenance proactive evaluator to monitor usage and assess the health conditions and maintenance needs of advanced reactors; (3) an operations intelligent controller to achieve autonomous control during normal and accident conditions; and (4) an O&M deep supervisor to supervise O&M conditions. The team will first validate the product using a molten salt loop operating at the University of Michigan and apply it to the Kairos Power fluoride salt-cooled high temperature reactor design to demonstrate how the proposed capability can be used to optimize plant design.

Massachusetts Institute of Technology – Cambridge, MA

Generation of Critical Irradiation Data to Enable Digital Twinning of Molten-Salt Reactors - $899,825

Molten salt reactors (MSRs) produce radioactive materials when nuclear fuel is dissolved in a molten salt at high temperature and undergoes fission as it flows through the reactor core. Understanding the behavior of these radioactive materials is important for MSR design and for predicting and reducing O&M costs. The Massachusetts Institute of Technology (MIT) will use its nuclear research reactor to provide data to determine how radioactive materials are generated and transported in MSRs. Digital twins of MSRs will require this critical data, which is currently unavailable. MIT's project will irradiate molten salts containing fuel in materials planned for molten salt reactor construction while monitoring the released radioactivity.