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Risk-Informed Systems Analysis (RISA)

2024 LWRS Program Spring Review Meeting

April 30, 2024

Light Water Reactor Sustainability (LWRS) Program

LWRS Goal | Enhance the safe, efficient, and economical performance of our nation's nuclear fleet and extend the operating lifetimes of this reliable source of electricity

Plant Modernization

Enable plant efficiency improvements through a strategy for long-term modernization

Flexible Plant Operation & Generation

Enable diversification of light-water reactors to produce non-electrical products

Risk Informed System Analysis

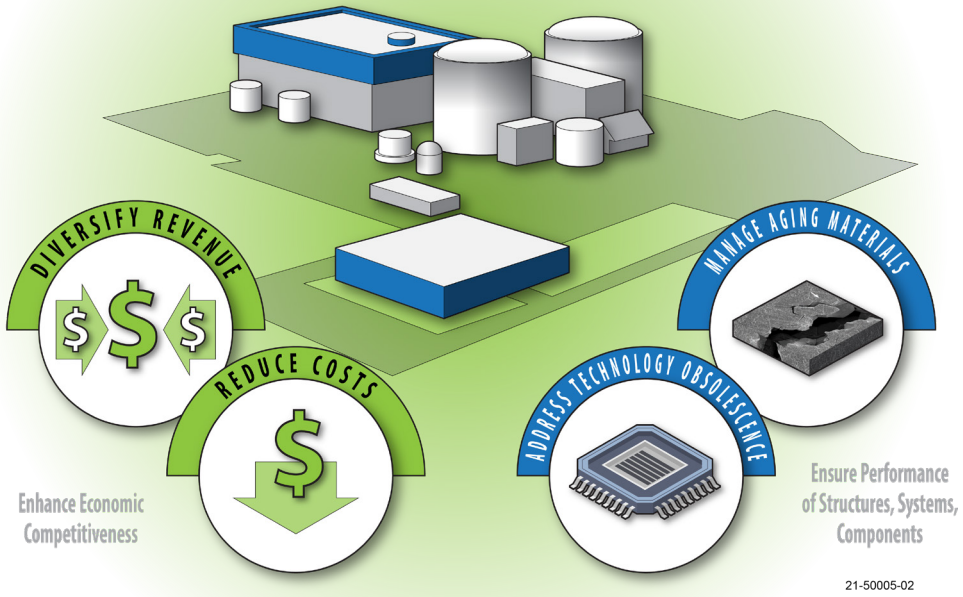
Develop analysis methods and tools *to optimize safety and economics*

Materials Research

Understand and predict long-term behavior of materials

Physical Security

Develop technologies to optimize physical security



LWRS
LIGHT WATER REACTOR SUSTAINABILITY

Risk-Informed Systems Analysis (RISA)

OBJECTIVE *(the what)*

- R&D to optimize safety margins and minimize uncertainties to achieve economic efficiencies while maintaining high levels of safety

APPROACH *(the how)*

- Provide scientific basis to better represent safety margins and factors that contribute to cost and safety

  Develop new technologies that reduce operating costs

RISA Framework

What About Risk?

RISK IS THE SUCCESS MEASURE AND THE GUIDING PRINCIPLE

REGULATOR

- Reactor regulations and oversight processes are being modernized through use of risk insights to enhance **safety + flexibility + efficiency** [**Be riskSMART** framework]

LICENSEES

- Risk information to focus on areas most important to safety
- Relaxation of programs and requirements for non-risk-significant areas ($$ savings)
- Risk-informed decisions (plant operations, compliance, modernization strategies)

Novel Approaches to Support Plant Activities

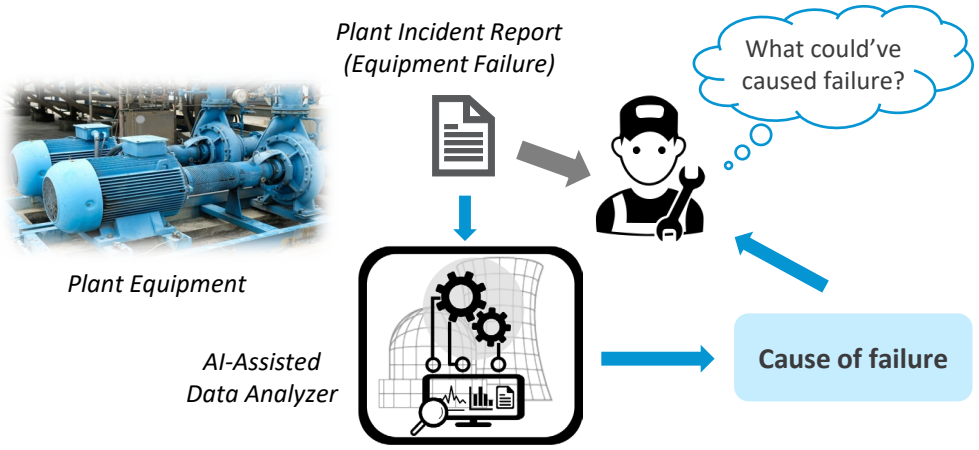
Risk-Informed Asset Management

OBJECTIVES

- Develop more effective and efficient analytical methods and tools for plant equipment reliability and asset-management programs
- Use novel methods to analyze plant record databases to extract knowledge on equipment failures and their causes
- Linking equipment reliability, performance, and health management to identify causal relationships between events

COLLABORATION

- Ontario Power Generation
- Westinghouse and PSEG



Schematic of AI-Assisted Causal Reasoning Approach

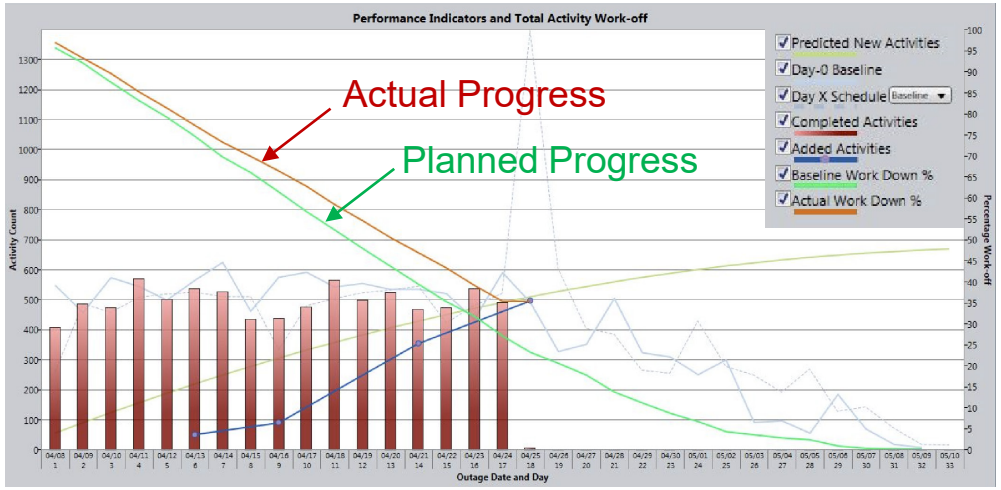
Optimization of Plant Outage Activities

OBJECTIVES

- Develop tools and methods to optimize plant outage activities
- Improve outage planning and execution
- Minimize unforeseen outage duration overruns

COLLABORATION

- Ontario Power Generation
- Arizona Public Service Co.
- INL's Advanced Test Reactor
- NextEra



Example of Outage Progress Monitoring

Novel Approaches to Support Plant Activities (cont'd)

Risk-Informed Compliance

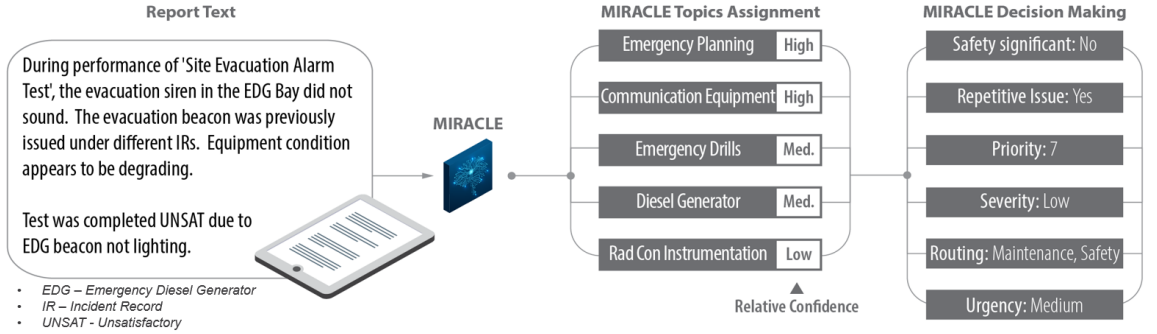
READY FOR COMMERCIAL USE!

OBJECTIVES

- Develop an approach for mapping industry actions and events *(available as text-based data)* to plant risk model
- Enable prioritization of activities towards risk-important equipment and plant processes

COLLABORATION

- 50%+ of industry have contributed data and/or directly collaborate on this project *(e.g., Constellation, Xcel Energy, NextEra, Energy Northwest, TVA)*



Workflow of Data Processing Automation

2022 R&D 100 WINNER

MIRACLE *(Machine Intelligence for Review and Analysis of Condition Logs and Entries)* is an artificial intelligence tool developed to automate condition report handling with natural language processing and machine learning.

Enhanced Fire Probabilistic Risk Assessment (PRA)

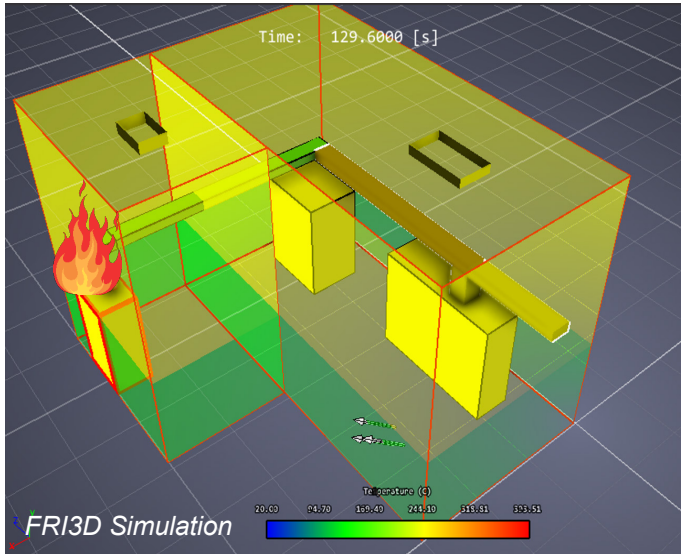
READY FOR COMMERCIAL USE!

OBJECTIVES

- Modernize fire simulations and PRA analyses to reduce labor and enhance clarity
- Streamline modeling and automate data handling and processing
- Integrate fire modeling tools already used by the industry → simplifies regulatory approvals, minimum training, seamless connection with existing analyses

COLLABORATION

- Callaway nuclear power plant and EPM (engineering consultant)
- Risk Spectrum provides FRI3D as part of their risk management portfolio tools



Advanced Modeling and Simulation

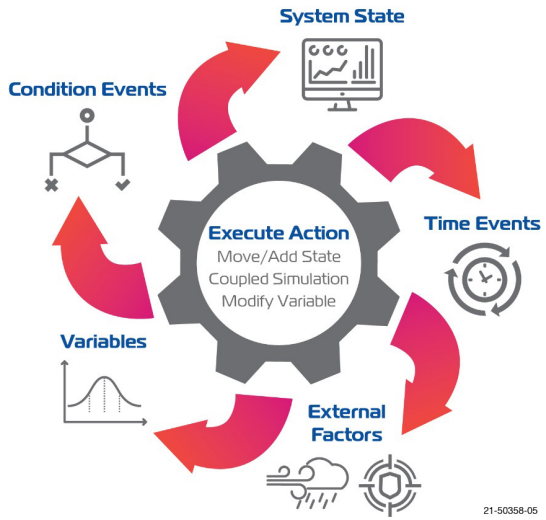
Simulation-Based Risk Assessment Using EMRALD

OBJECTIVES

- Flexible platform to quantify reliability, availability, resiliency, and maintainability
- Easy-to-apply to a wide range of scenarios and applications
- Coupling with traditional PRA tools SAPHIRE and CAFTA
- Coupling with HRA tool HUNTER

COLLABORATION

- PWROG
- APS



Conceptual Framework

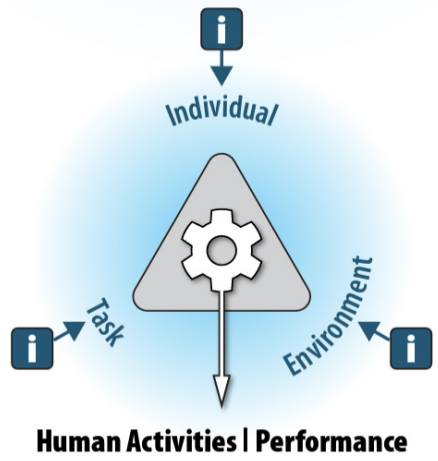
HUNTER for Enhanced Human Reliability Analysis (HRA)

OBJECTIVES

- Create a usable and adaptable standalone software tool for dynamic human reliability analysis
  (HRA) **HUNTER** [*Human Unimodel for Nuclear Technology to Enhance Reliability*]
- Couple HUNTER with EMRALD, a dynamic risk analysis tool, for advanced scenario modeling
  and simulations (e.g., risk-informed physical security)
- Use HUNTER for HRA studies in support of new digital system implementation

COLLABORATION

- Industry (via Pressurized Water Reactor Owners Group [PWROG]), engagement with EPRI, coordination of efforts with the NRC



HUNTER Conceptual Framework

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Advanced Modeling and Simulation (cont'd)

Evaluations of Accident-Tolerant Fuel (ATF) With Higher Burnup

OBJECTIVES

- Economic gains via extended refueling cycle, lower volume of new and spent fuel
- Support of evaluations required for extended power uprates
- High burnup ATFs allow larger uprates (up to 20%) as compared to uprates using traditional fuel

COLLABORATION

- Industry via ATF deployment task force (DOE / EPRI / Utilities / NEI / Academia)
- DOE Advanced Fuels Campaign program
- Academia – via Nuclear Energy University Program (NEUP) engagements

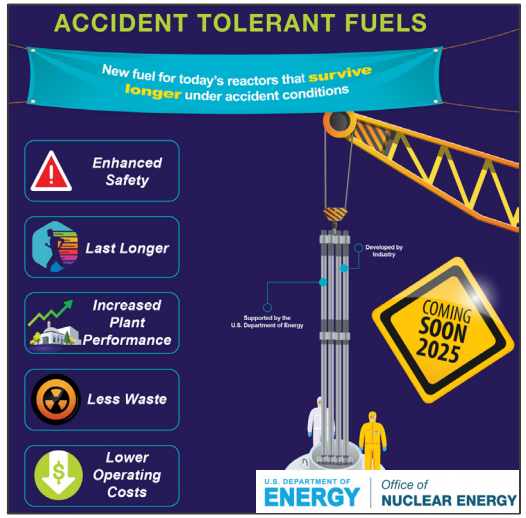


Image Credit: U.S. Department of Energy (link)

Plant Reload Optimization

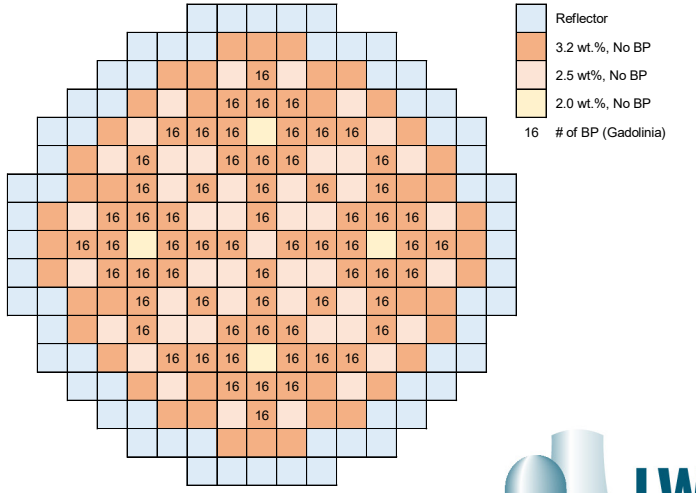
OBJECTIVES

- All-inclusive integrated framework for fuel reload analyses
- Optimization of core configuration to minimize amount of new fuel
- Support of refueling cycle extension (with High Burnup ATFs)
- Support of evaluations required for power uprates

COLLABORATION

- A project with Constellation with participation of Framatome, Westinghouse, and Studsvik

Example Configuration of Reactor Core



LWRS LIGHT WATER REACTOR SUSTAINABILITY

Transitioning to Digital Systems

Digital I&C Risk Assessment

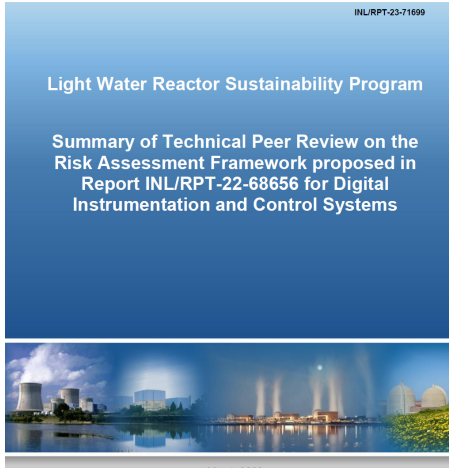
OBJECTIVES

- Provide an objective, systematic, verifiable and reproducible approach for qualification of DI&C systems
- Develop an integrated platform that addresses the risk triplets: *what can go wrong, how likely is it, and what are the consequences* in DI&C systems

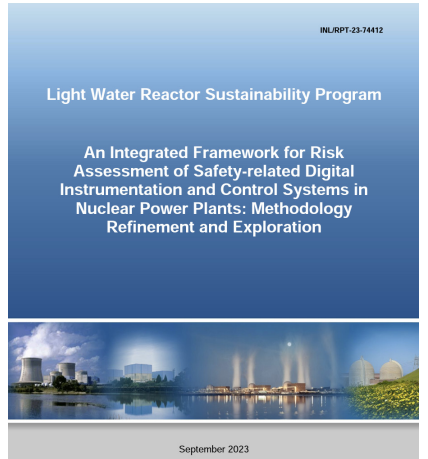
COLLABORATION

- Collaborative project with Westinghouse and Southern Nuclear Company (via PWROG engagement)
  - A case study using industry data for risk-informed DI&C systems is completed
  - Industry via NEI-lead Digital I&C Working Group
  - Halden project
- Completed Industry Peer Review
  - US NRC, Industry, EPRI, Academia à very positive feedback
- Latest improvements of the framework
  - Further advancements in hazard analysis of DI&C systems
  - More robust software risk assessments
  - Evaluation of reliability of Machine Learning algorithms integrated in I&C systems

Transition from Analog to Digital Control Systems



Summary of Technical Peer Review on the Risk Assessment Framework
Link



Integrated Framework for Risk Assessment
Link

Risk-Informed Aging Management

TASK 1

Experimental Testing (In Close Collaboration With EPRI)

- Conducted experiments to identify methodologies for assessing degradation rate by accelerating selective leaching mechanisms
- Investigate degradation rates for Grey Cast Iron (GCI) and Ductile Cast Iron (DCI)

TASK 2

Finite Element Analysis Model Using MOOSE

- Built finite element model that can be used to predict the effects of a given state of degradation on the fit-for-service condition

TASK 3

Evaluated Techniques Using Sensors & Data Processing

- Explored existing evaluation methods / techniques and their applicability to underground metallic structures and associated degradation mechanisms

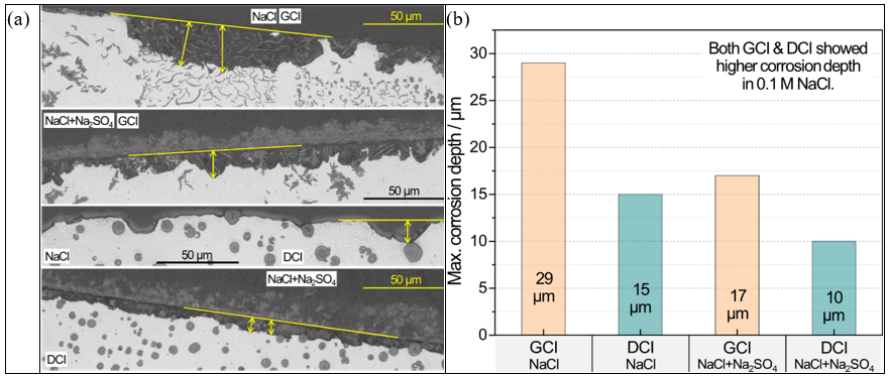
TASK 4

A Simplified Cost-Benefit Analysis of SLR Commitments

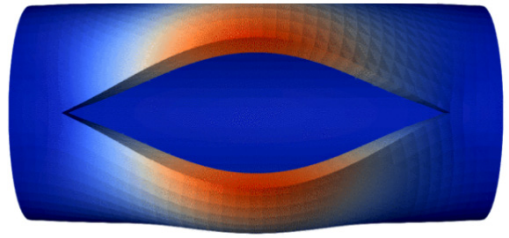
- Identified the most burdensome SLR commitments and opportunities for using risk-informed performance-based approaches to reduce costs

REMAINING NEEDS AND GAPS

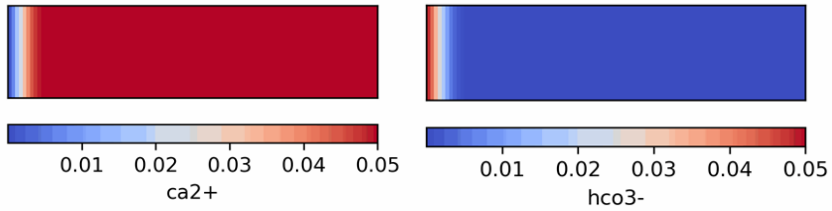
- Expand assessment of degradation rates (application of alternative methods to accelerate degradation)
- Improve finite element modeling: increase confidence in results, include evaluation of uncertainties
- Evaluate opportunities for remote condition monitoring



a) Micrographs of cross sections of GCI (top two micrographs) and DCI (bottom two micrographs) showing extent of corrosion in NaCl and NaCl + Na2SO4 solutions and b) plot of maximum measured corrosion depth of the two materials in the two solutions.



Pipe crack propagation modeling in MOOSE



MOOSE modeling of corrosion due to calcium (Ca2+) and bicarbonate (HCO3-) by coupling thermodynamic databases with MOOSE chemical module

Feasibility of Power Uprates

Project Objectives

- Demonstrate the value of the Inflation Reduction Act (IRA) carbon free generation and hydrogen production tax credits including consideration of advanced fuels
- Provide a deliverable utilities can use to assist in assessing the financial gains of power uprate

MARKET ASSESSMENT

- Economic gains via extended refueling cycle, lower volume of new and spent fuel
- Support of evaluations required for extended power uprates
- High burnup ATFs allow larger uprates (up to 20%) as compared to uprates using traditional fuel

CAPABILITY ASSESSMENT

- Demonstrated the technical viability of power uprate considering the plant modifications needed to upgrade the plant

BUSINESS MODEL ASSESSMENT

- Developed financial models and overall business case for power uprate
- Demonstrated the financial viability of power uprate and hydrogen generation

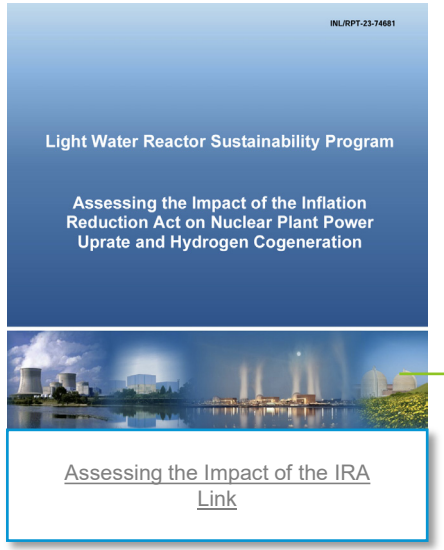
THE FINANCIAL TOOL IS AVAILABLE FOR INDUSTRY USE

- **NuH2: Financial Model for Nuclear Power Plant Uprate and Hydrogen Cogeneration**
- Email agradmin@inl.gov to request access

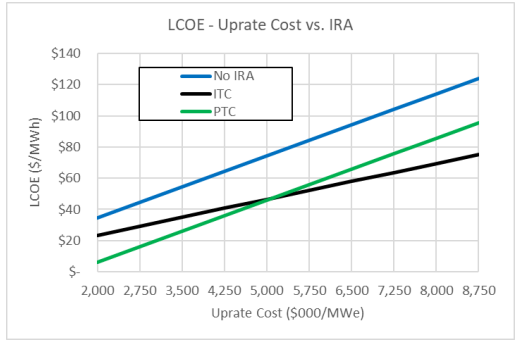
Impact from investment and production tax credits on LCOE depending on size of power uprate

COLLABORATION

- NEI, utilities, fuel vendors, DOE programs, NRC
- **Industry power uprate workshop hosted by EPRI – May 29-30**



Assessing the Impact of the IRA Link



LWRS' FEASIBILITY STUDY

- Business case assessment of practicality of power uprate with consideration of IRA credits

RESULTS

- Positive and competitive levelized cost of electricity (LCOE) supporting the business case for power uprates
- A stronger business case if added power is used to produce clean hydrogen

Sustaining National Nuclear Assets

lwrs.inl.gov