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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**

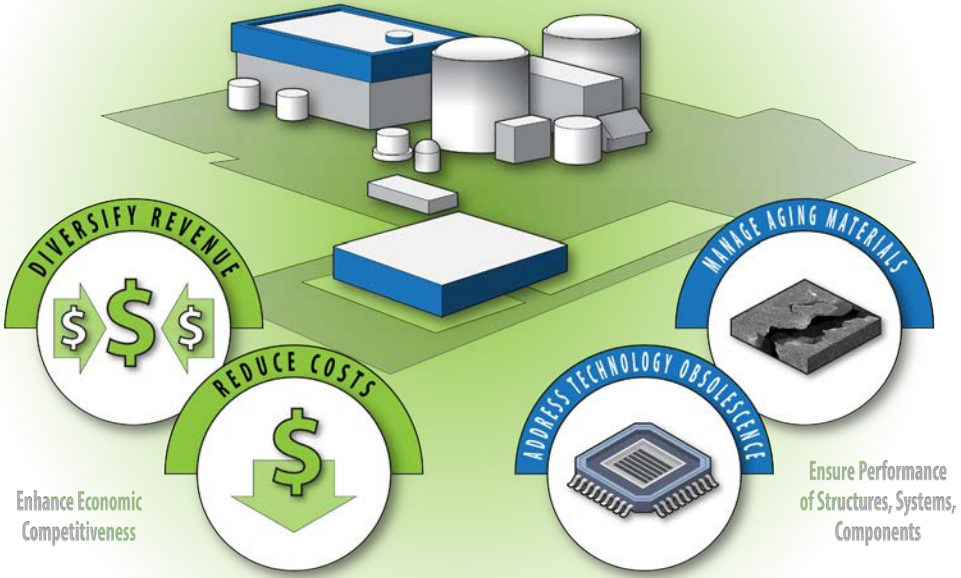
*Develop analysis methods and tools* to optimize safety and economics

**Materials Research**

*Understand and predict* long-term behavior of materials

**Physical Security**

*Develop technologies* to optimize physical security



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# 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



## 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

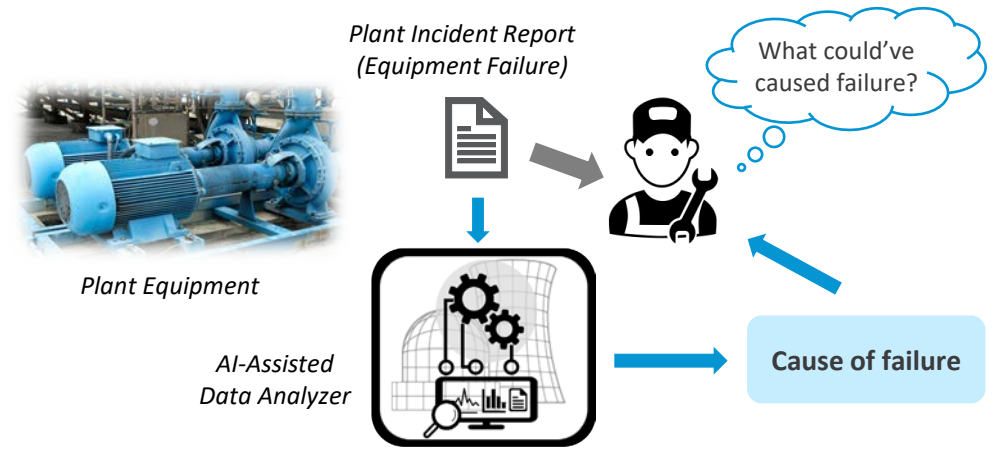
## Risk-Informed Asset Management

### 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

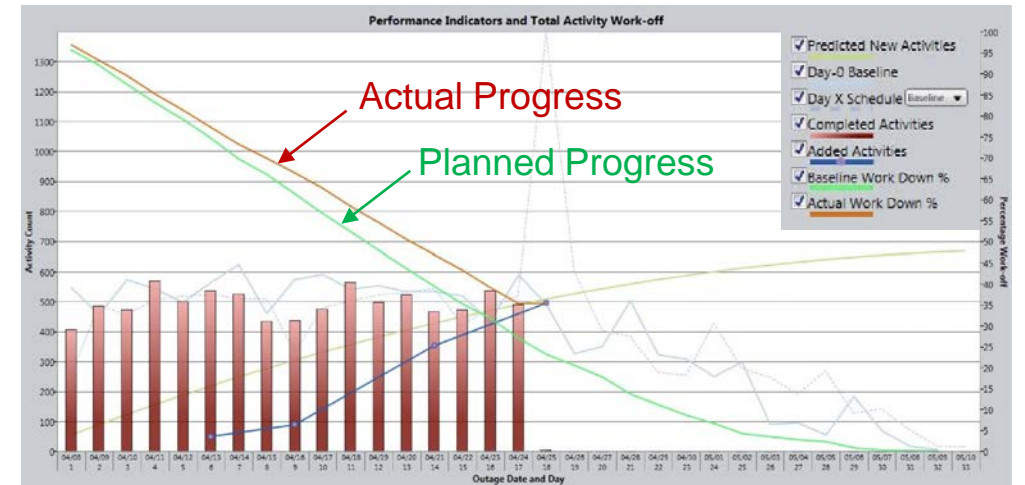
## Optimization of Plant Outage Activities

### OBJECTIVES

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

### COLLABORATION

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



Example of Outage Progress Monitoring

# Novel Approaches to Support Plant Activities (cont'd)

## Risk-Informed Compliance

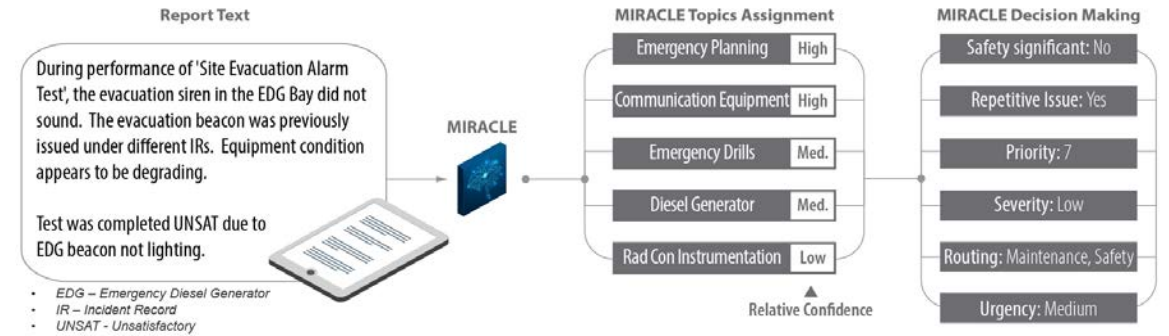
READY FOR COMMERCIAL USE!

### 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



**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)

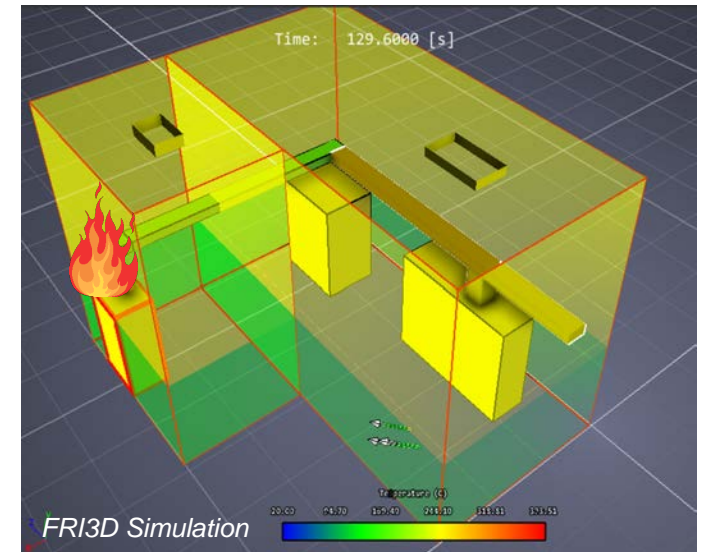
READY FOR COMMERCIAL USE!

### 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 EMERALD

### 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

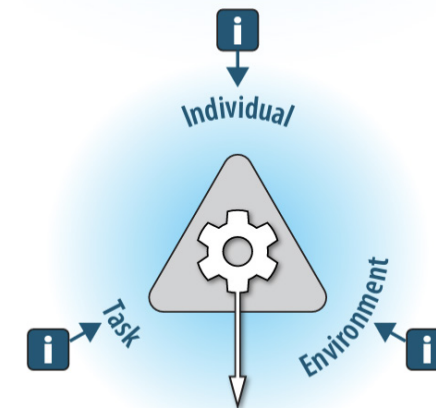
## HUNTER for Enhanced Human Reliability Analysis (HRA)

### 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 EMERALD, 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



Human Activities | Performance

HUNTER Conceptual Framework



# Advanced Modeling and Simulation (cont'd)

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

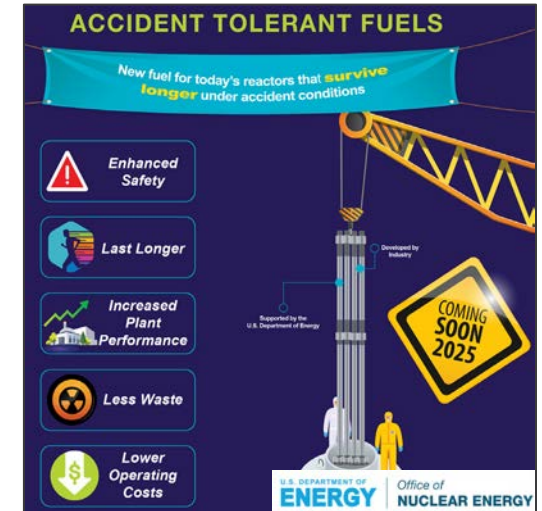
### OBJECTIVES

- 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

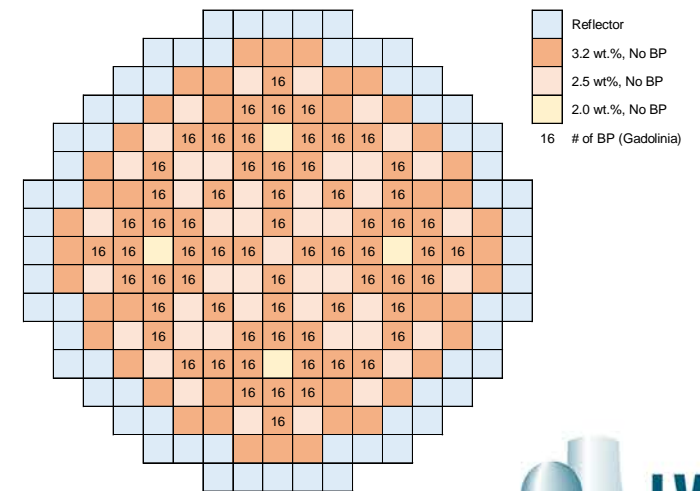
### OBJECTIVES

- 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



# Transitioning to Digital Systems

## Digital I&C Risk Assessment

### OBJECTIVES

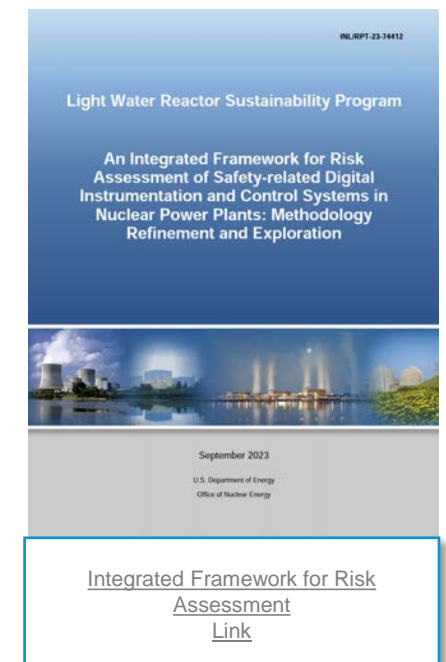
- Provide an objective, systematic, verifiable and reproducible approach for qualification of DI&C systems
- Develop an integrated platform that addresses the risk triplets: *what can go wrong, how likely is it, and what are the consequences* in DI&C systems

### 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





# 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

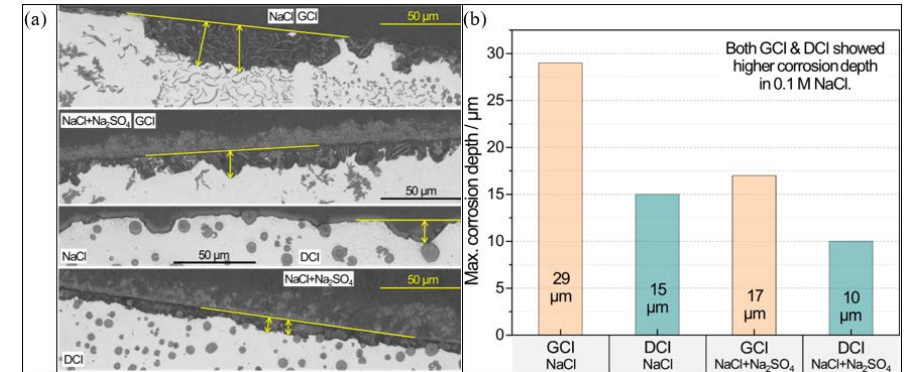
## TASK 4

### A Simplified Cost-Benefit Analysis of SLR Commitments

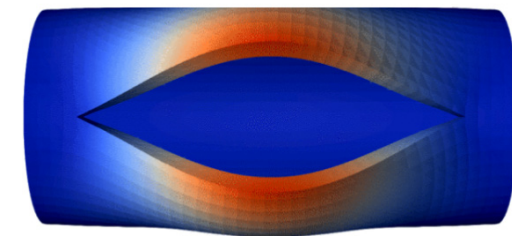
- Identified the most burdensome SLR commitments and opportunities for using risk-informed performance-based approaches to reduce costs

### REMAINING NEEDS AND GAPS

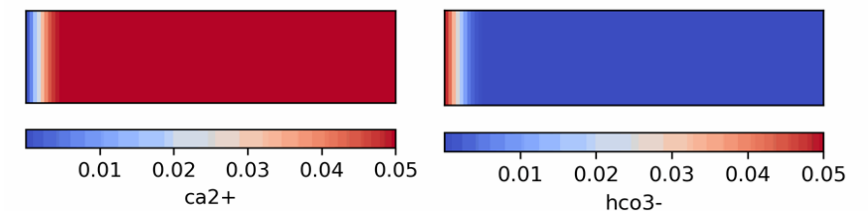
- Expand assessment of degradation rates (application of alternative methods to accelerate degradation)
- Improve finite element modeling: increase confidence in results, include evaluation of uncertainties
- Evaluate opportunities for remote condition monitoring



a) Micrographs of cross sections of GCI (top two micrographs) and DCI (bottom two micrographs) showing extent of corrosion in NaCl and NaCl + Na<sub>2</sub>SO<sub>4</sub> 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 (Ca<sup>2+</sup>) and bicarbonate (HCO<sub>3</sub><sup>-</sup>) 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

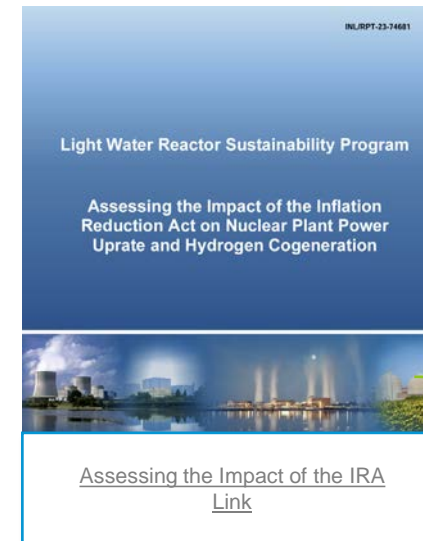
- Developed financial models and overall business case for power uprate
- Demonstrated the financial viability of power uprate and hydrogen generation

## THE FINANCIAL TOOL IS AVAILABLE FOR INDUSTRY USE

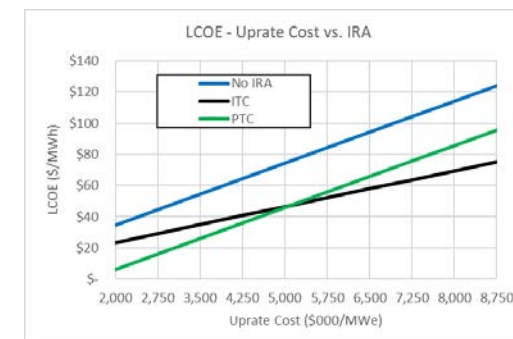
- **NuH2: Financial Model for Nuclear Power Plant Uprate and Hydrogen Cogeneration**
- Email [agradmin@inl.gov](mailto:agradmin@inl.gov) to request access

## COLLABORATION

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



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



## 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](http://lwrs.inl.gov)*