LWRS
LIGHT WATER REACTOR SUSTAINABILITY

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Risk-Informed Systems Analysis (RISA)

Pathway Overview

2024 Stakeholder Engagement Meeting

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

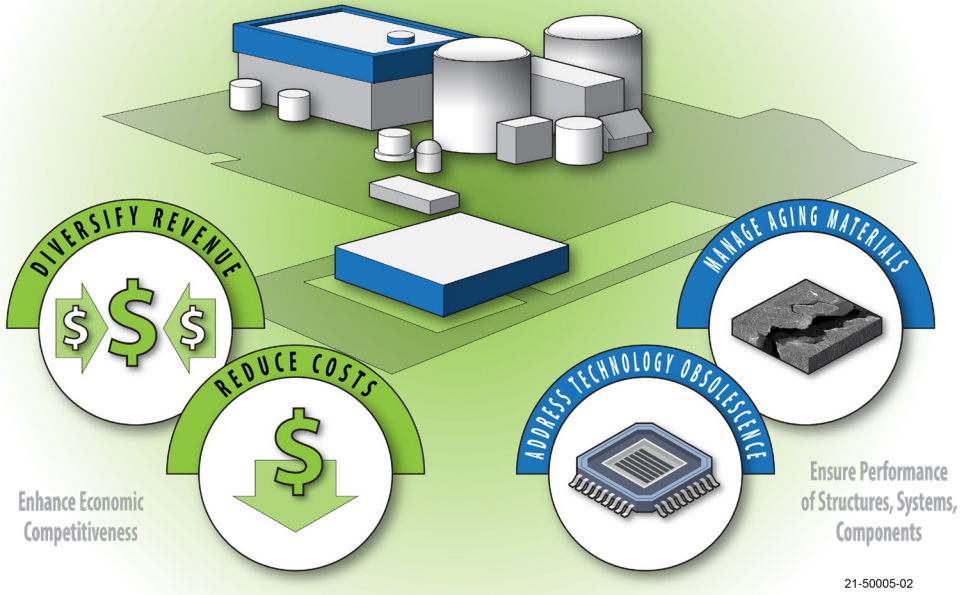
Develop analysis methods and tools *to optimize safety and economics*

Materials Research

Understand and predict long-term behavior of materials

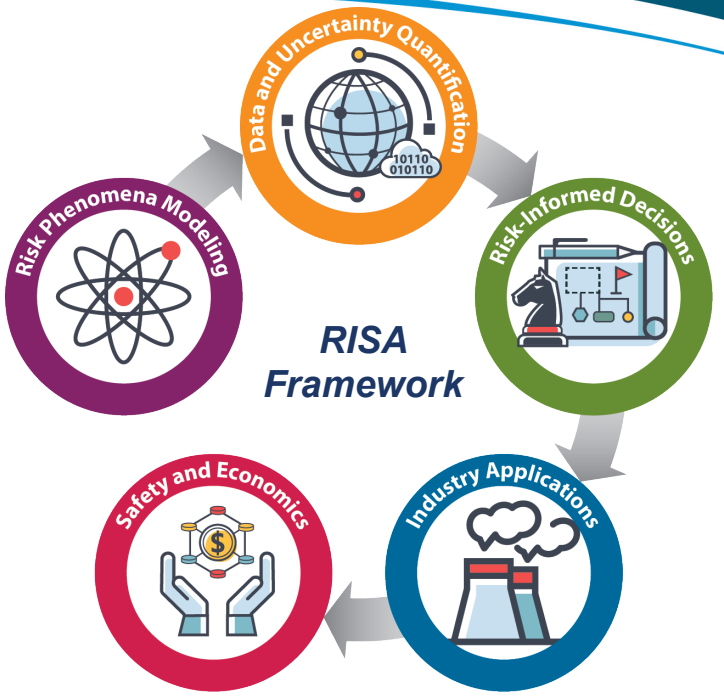
Physical Security

Develop technologies to optimize physical security



Risk-Informed System 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



Expanded RISA Objectives

- **Creating capabilities in advanced modeling and simulation**
  - Advanced modeling and data analytics to inform condition-based equipment maintenance
- **Improving plant capacity factor**
  - Outage optimization project addresses the risk of outage overruns ($1M-$2M for each additional outage day)
- **Mining for margin**
  - More accurate modeling and simulation allow to reduce conservatism leading to larger safety margins
  - Larger margins enable important initiatives supporting sustainability, e.g., larger power uprates, longer refueling cycles

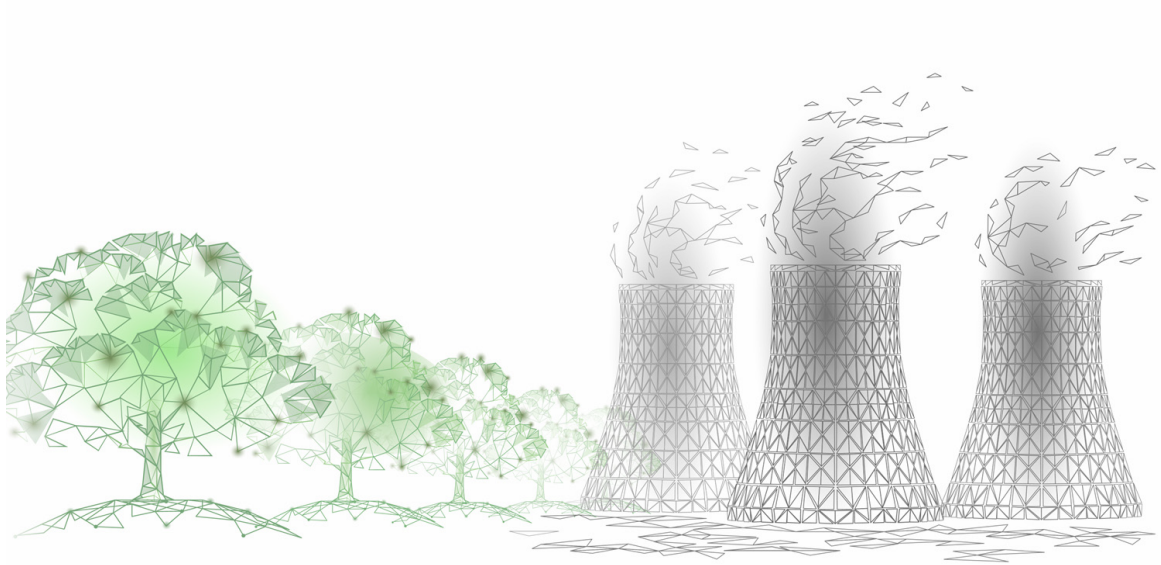
Power Uprates - Unprecedented Opportunity

DOE-NE Goal[1] – Enable continued operation of existing U.S. nuclear reactors

- Develop technologies that reduce operating costs
- Expand to markets beyond electricity
- Provide scientific basis for continued operation of existing plants

Historical Federal Legislation

- Infrastructure Investment and Jobs Act of 2021
  - Operating nuclear plant credit program
  - Advanced reactor demonstration funding
  - Large-scale H_2 demos
- Inflation Reduction Act (IRA) of 2022
  - Tax credits for existing reactors
  - Tax credits for all new clean generation
  - Tax credits for H_2 generation
  - Expanded federal loan guarantees



[1] *U.S. Department of Energy, Office of Nuclear Energy: Strategic Vision, 2021*

Sizable 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

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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 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

ADDITIONAL ASSESSMENTS

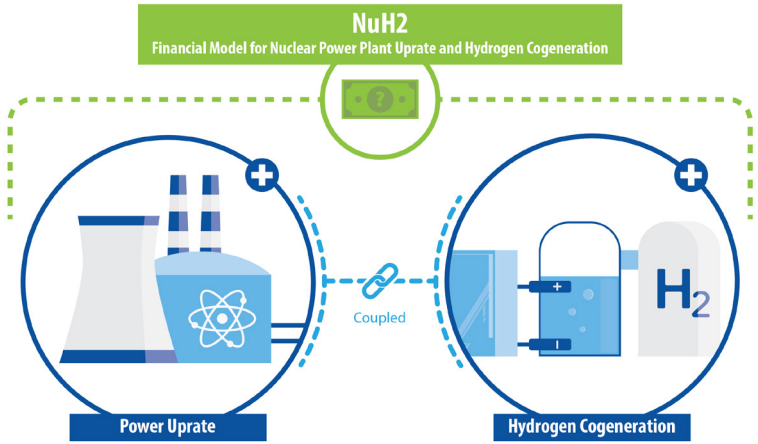
- Regional potential for hydrogen production using nuclear power added through uprates
- Opportunities to increase profits from captures CO_2 (byproduct of electrolysis)
- Explored opportunity to capitalize on IRA incentive for Direct Air Capture (DAC) of CO_2 with use of nuclear thermal energy and electricity.

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



NuH2 Tool: Financial model for nuclear power uprate and hydrogen cogeneration

Value of Sizable Power Uprates

Near-term delivery of substantial amount of clean power. Untapped available power*:

- BWRs: ~ 5,500 MWt, equivalent to ~ 2 large LWRs, or ~ 15-20 small modular reactors
- PWRs: ~11,000 MWt, equivalent to ~ 3-4 large LWRs, or ~ 30-40 small modular reactors

* Based on a generic approach used to establish uprate potential using historically-achieved power uprate levels

Sustainability of existing nuclear fleet

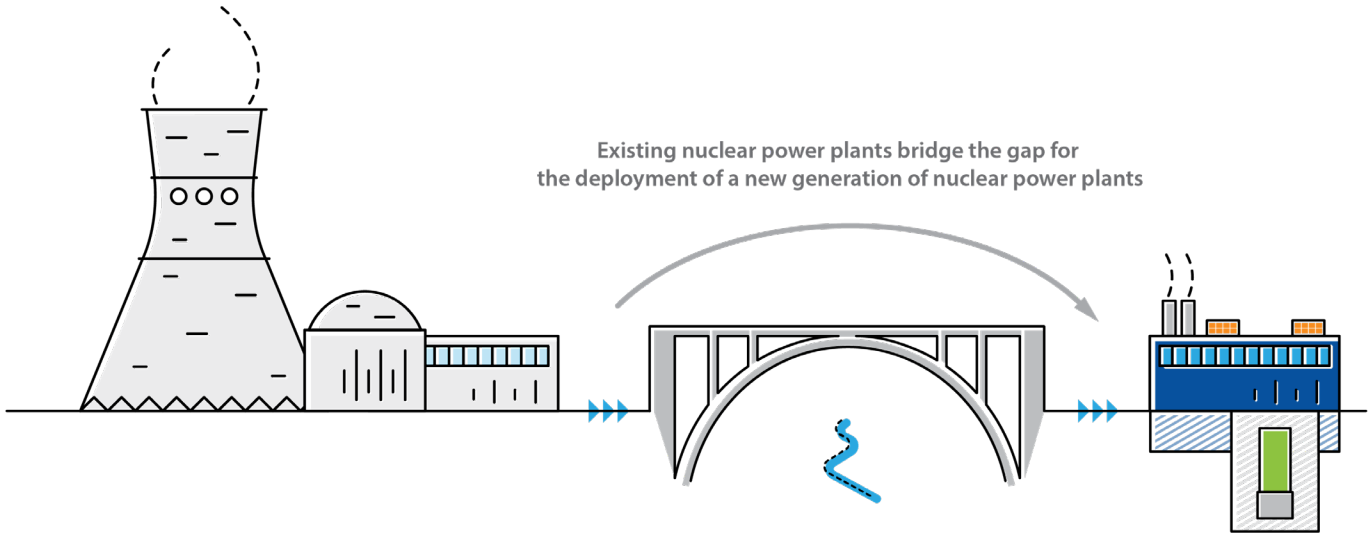
- Added profitability as soon as new power is produced
- Improved economics of plant lifetime extension for another 20 years
- An opportunity to modernize

Added power can be used to produce clean hydrogen

- Explicitly allowed in the draft rule* for §45V hydrogen production credit
- Hydrogen credits further strengthen the business case for power uprates

Bridging the gap to new nuclear

- U.S. nuclear fleet to scale from ~100GW to ~ 300GW by 20505
- Scaled capacity of existing nuclear plus added new nuclear – need to triple the current capacity
- Re-establishing U.S. Nuclear Sector Capabilities:
  - Workforce,
  - Supply chain for nuclear-grade systems and components
  - Scaled capacity of regulatory framework



Plant Modifications to Support Power Uprates

Ways to increase power output:

- Increased reactor thermal output
  - By increasing volume of fissile material in the core (by increased uranium enrichment or higher fuel density) and
  - Optimizing core design and operational conditions
- Improve electricity generation efficiency in the secondary side
- Combination of the two

Multiple plant systems must be upgraded / replaced to support higher power output

Safety analyses to support power uprates

- Re-evaluate performance of plant systems given power uprate and update requirements for accident mitigating systems
- Demonstrate adequate safety margins to ensure continues safety of NPP

Safety Analyses to Support Power Uprates

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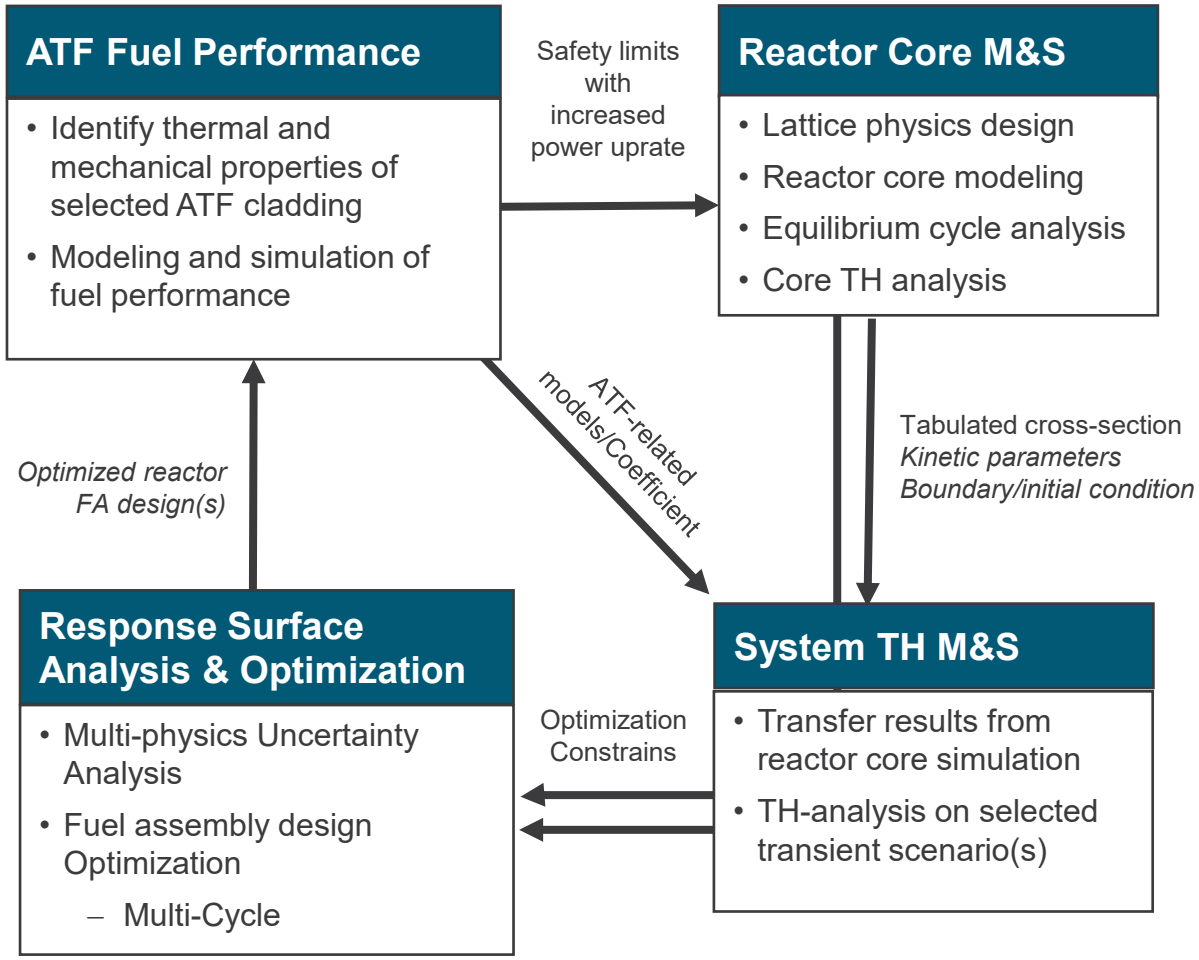
Project Description

- **Identify engineering design criteria of accident tolerant fuel (ATF) for power uprate**
- **ATF + Extended Enrichment + (possibly) HBU**
  - ATF can…
    - reduce oxidation kinetic
    - reduce hydrogen production and hydrogen pick up
    - improve post-quench ductility
    - improve corrosion resistance
  - Dopped Pellets has…
    - higher density
    - higher burnup support
    - higher plasticity at high temperature
    - better fission gas retention
    - improved PCI resistance
- **Utilize existing data/models/methods first for ATF safety evaluation**
  - Additional experiments in need can be performed



Advanced Methodologies

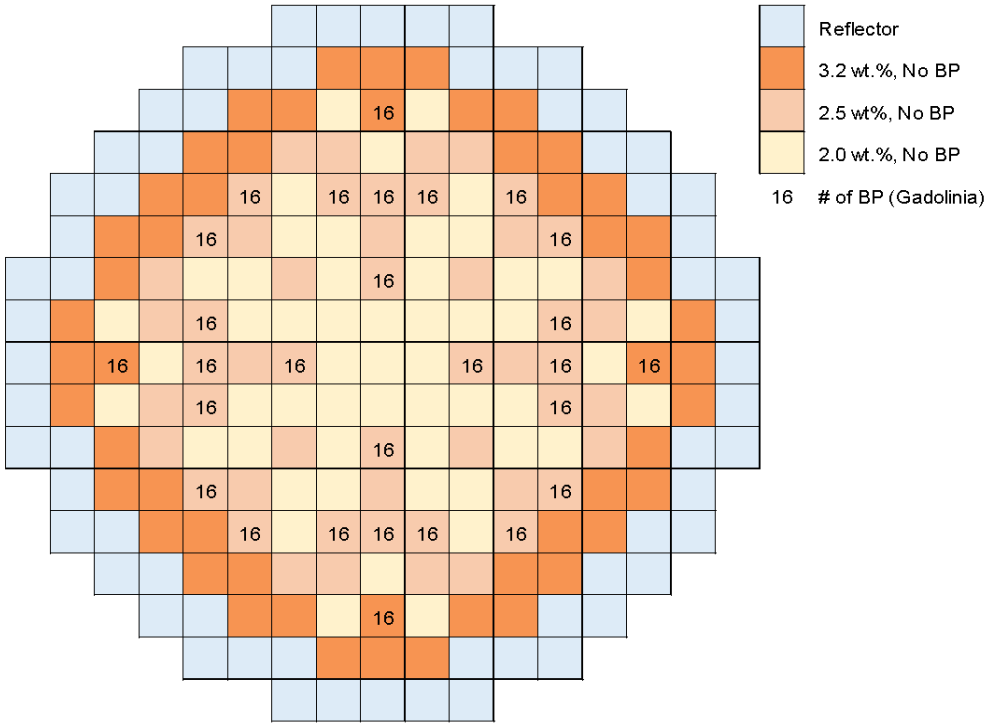
Plant Reload Optimization

OBJECTIVES

- Develop optimization methodology for multiple-objective optimization (e.g., minimize new fuel volume and maximize cycle length)
- An automated integrated multi-physics approach to core design

IMPACTS

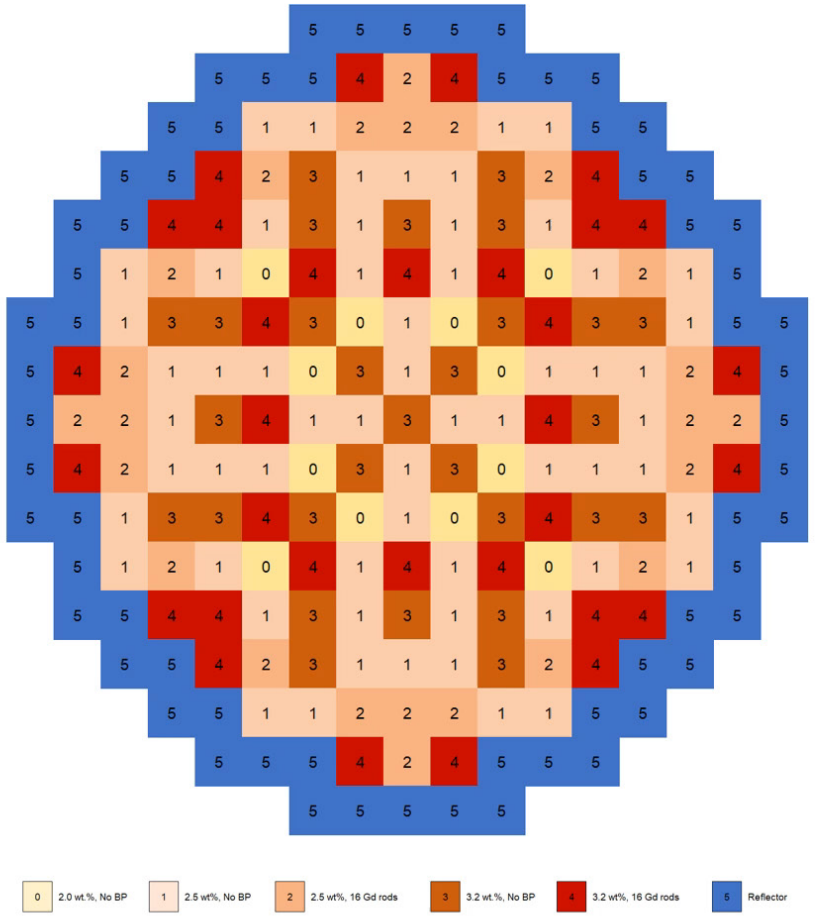
- Economic gains through reduction of volume of new and spent fuel – fuel costs are ~ 20% of total O&M costs
- Increase operational flexibility



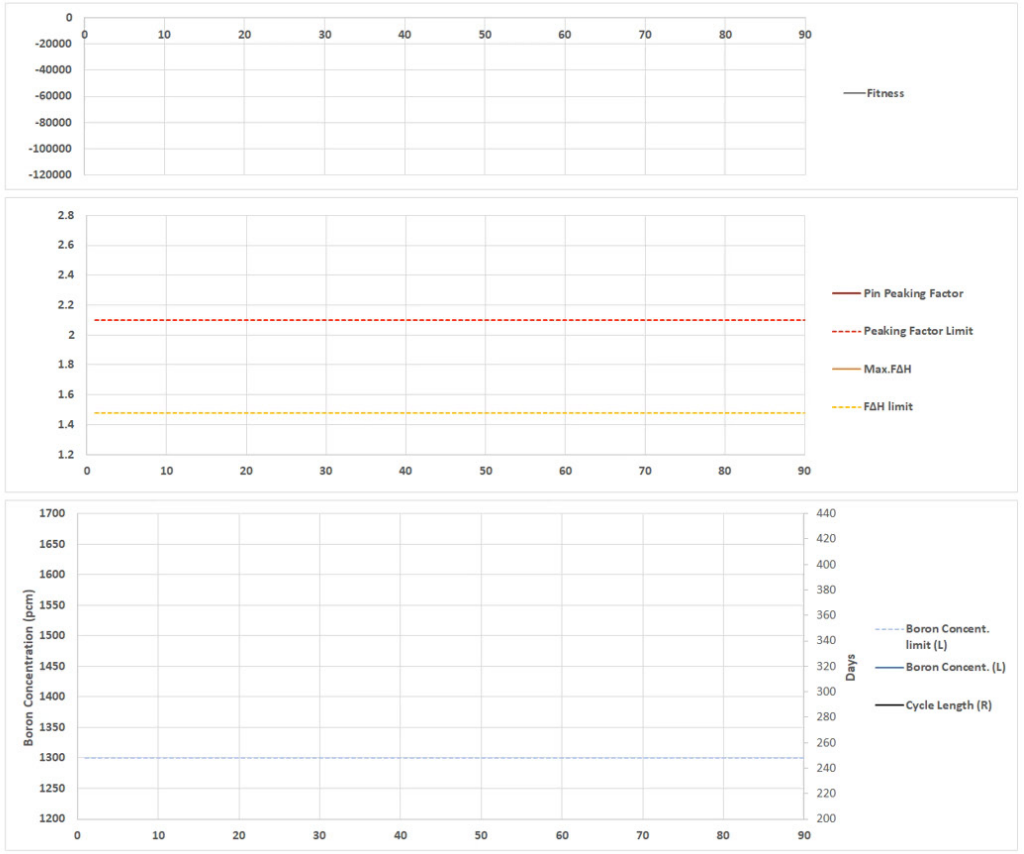
Randomly generated PWR Core

Demonstration of Optimization of Core Design

Reactor Core Fuel Pattern



Fitness of Pattern, Constraints, Objective



Novel Approaches to Support Plant Activities

Automated knowledge extraction from plant records to optimize maintenance

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OBJECTIVES

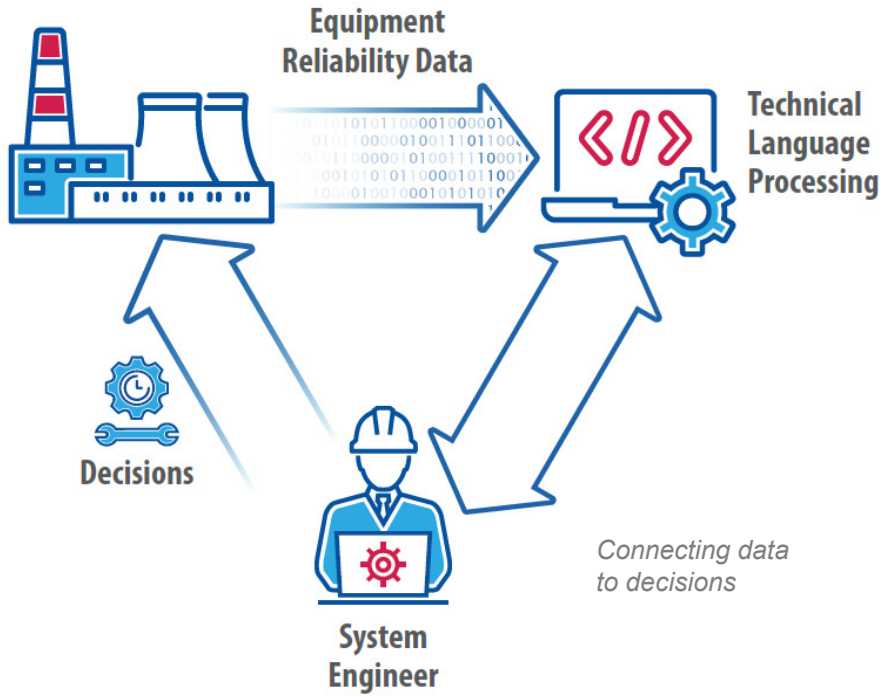
- Develop methodology to automate knowledge extraction from numerical and textual data for integrated knowledge base
- Knowledge base mimics the process of human collection, retention, and use of knowledge

IMPACTS

- Improved capability to detect precursors for failure
- Knowledge retention and transfer to expedite work force training and improve retention

INITIAL OPEN-SOURCE RELEASE

- DACKAR: Digital Analytics, Causal Knowledge Acquisition and Reasoning for Technical Language Processing https://github.com/idaholab/DACKAR



Novel Approaches to Support Plant Activities

Optimization of Plant Outage Activities

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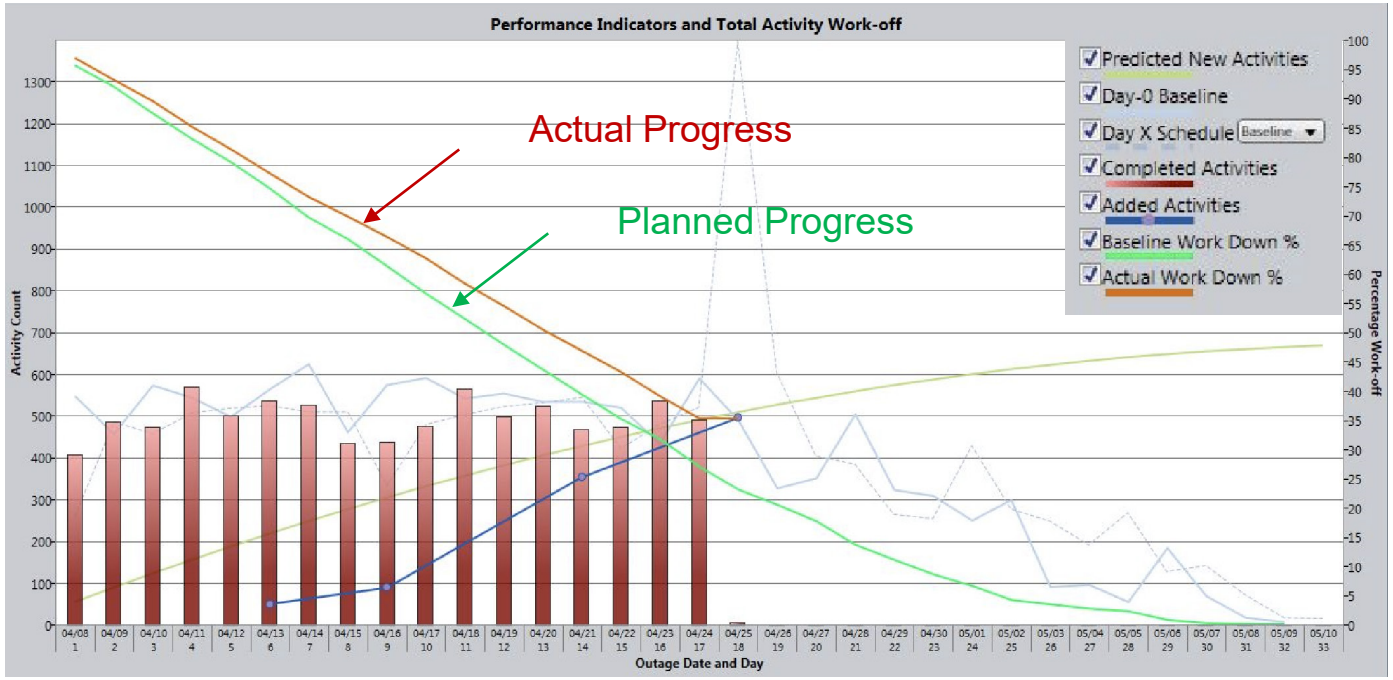
OBJECTIVES

- Develop tools and methods to optimize plant outage activities
- Improve outage planning and execution

IMPACTS

- Minimize unforeseen outage duration overruns
- Optimize utilization of resources during outages



Example of Outage Progress Monitoring

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

Risk-Informed Compliance

Ready for Commercial use

OBJECTIVES

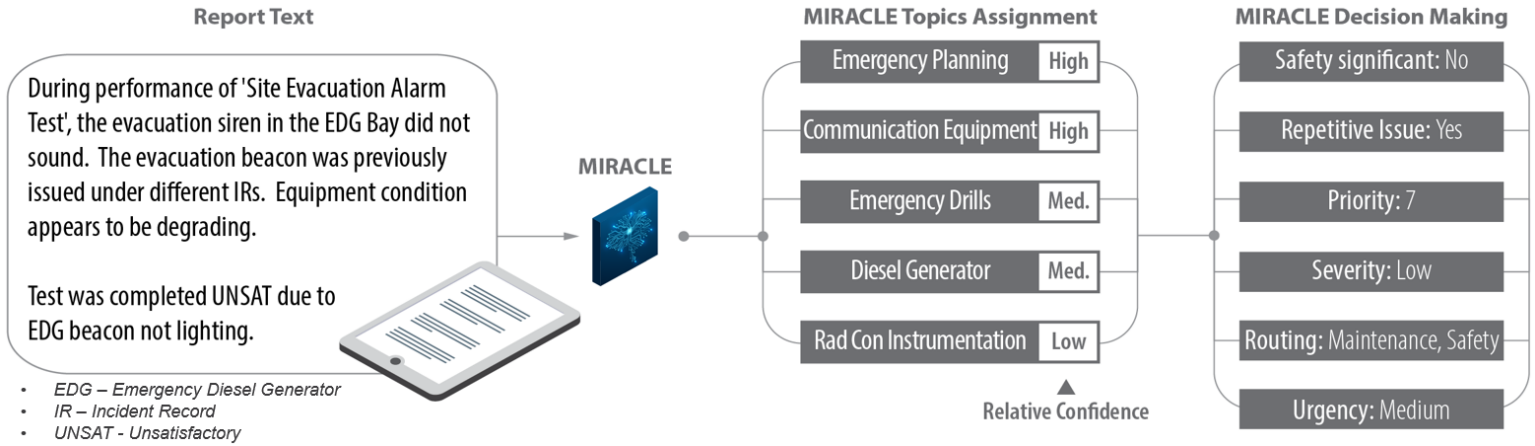
- Develop an approach for mapping industry actions and events *(available as text-based data)* to plant risk model
- Enable prioritization of activities towards risk-important equipment and plant processes

IMPACTS

- Improved process of collecting data needed for risk assessments

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.



- *EDG – Emergency Diesel Generator*
- *IR – Incident Record*
- *UNSAT - Unsatisfactory*

Workflow of Data Processing Automation

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

Enhanced Fire Probabilistic Risk Assessment (PRA)

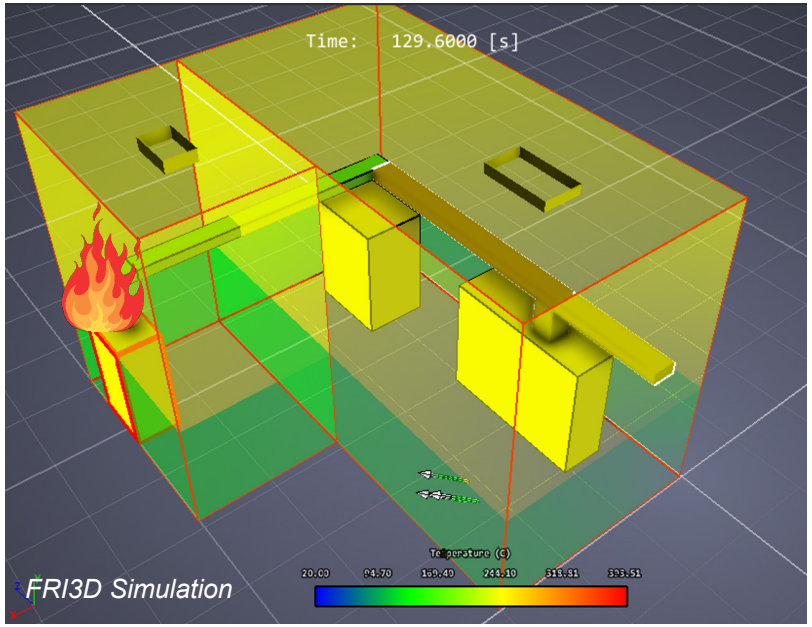
Ready for Commercial use

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

IMPACTS

- Significant improvements of the complicated process of fire analyses allowing plant staff focusing on results rather than manual processes
- Conservatisms are greatly reduced



Example of 3D Model of Fire Zone in FRI3D

Advanced Modeling and Simulation

Simulation-Based Risk Assessment Using EMRALD

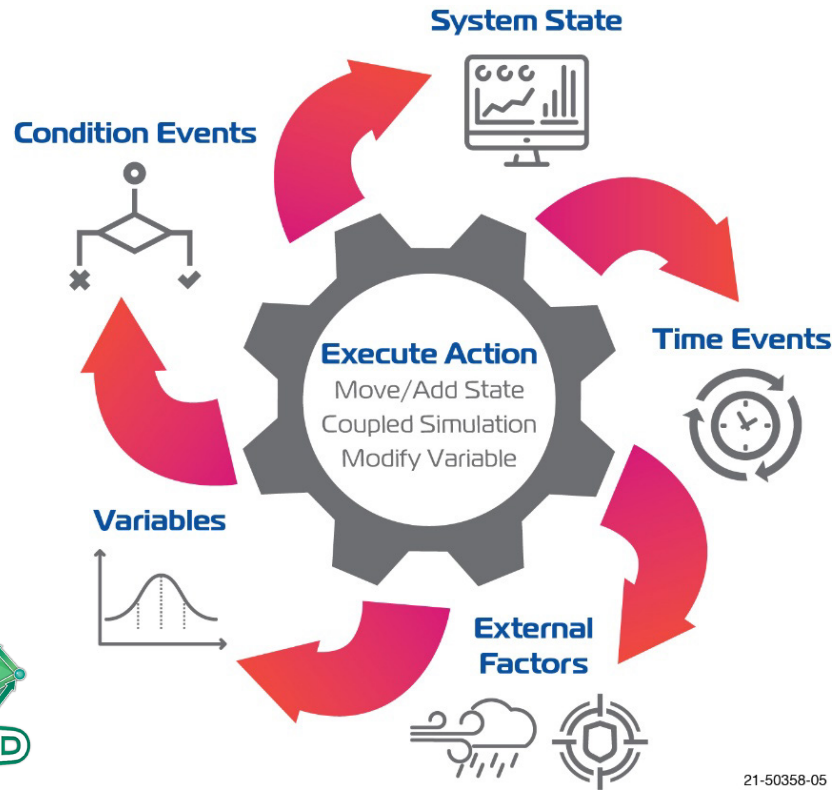
Ready for Commercial use

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

IMPACTS

- Simulations that are much more detailed to provide better insights of the scenario progression
- Capability to evaluate novel scenarios that have not happened before



Dynamic PRA Conceptual Framework

Advanced Modeling and Simulation

HUNTER for Enhanced Human Reliability Analysis (HRA)

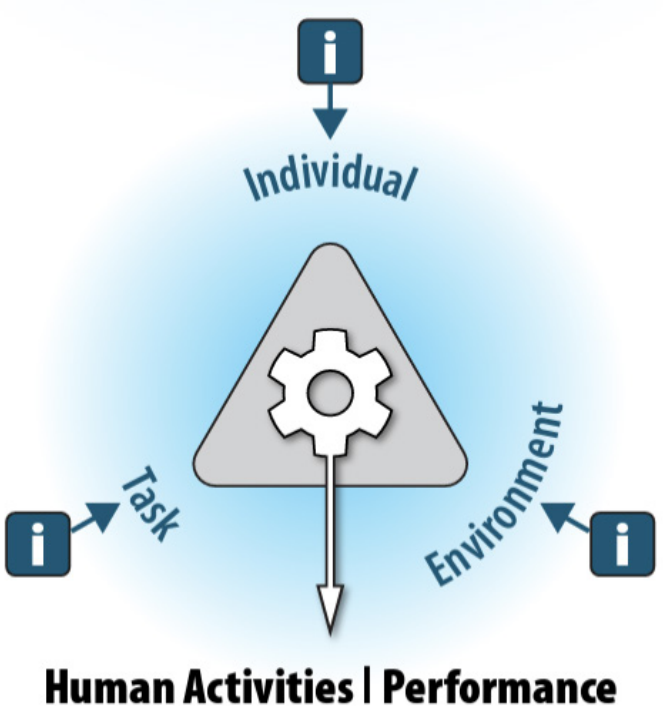
Ready for Commercial use

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

IMPACTS

- Enables dynamic simulation of operator actions
- Human psychology is explicitly integrated to allow a better-refined evaluation of human performance



HUNTER Conceptual Framework

Advanced Methodologies

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 in DI&C systems: what can go wrong, how likely is it, and what are the consequences

IMPACTS

- A first comprehensive approach for quantified software failures
- Quantified approach to DI&C failures is by the NRC to support licensing approvals

Transition from Analog to Digital Control Systems

Sustaining National Nuclear Assets

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