INL/MIS-25-84500

Risk-Informed Systems Analysis (RISA)

LWRS Spring Program Review – Pathway Overview

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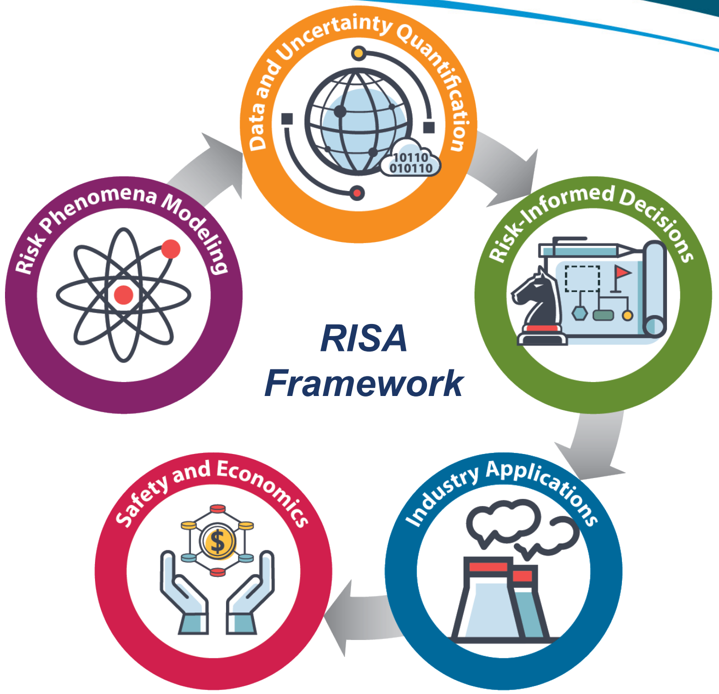
Risk-Informed System Analysis (RISA)



- **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

Near-term delivery of substantial amount of reliable baseload energy. Untapped available power (historical level of uprates):

- BWRs: ~ 1,800 GWe, equivalent to ~ 2 large LWRs, or ~ 15-20 small modular reactors
- PWRs: ~3,600 GWe, equivalent to ~ 3-4 large LWRs, or ~ 30-40 small modular reactors

Near-term, cost-efficient added power from existing nuclear fleet

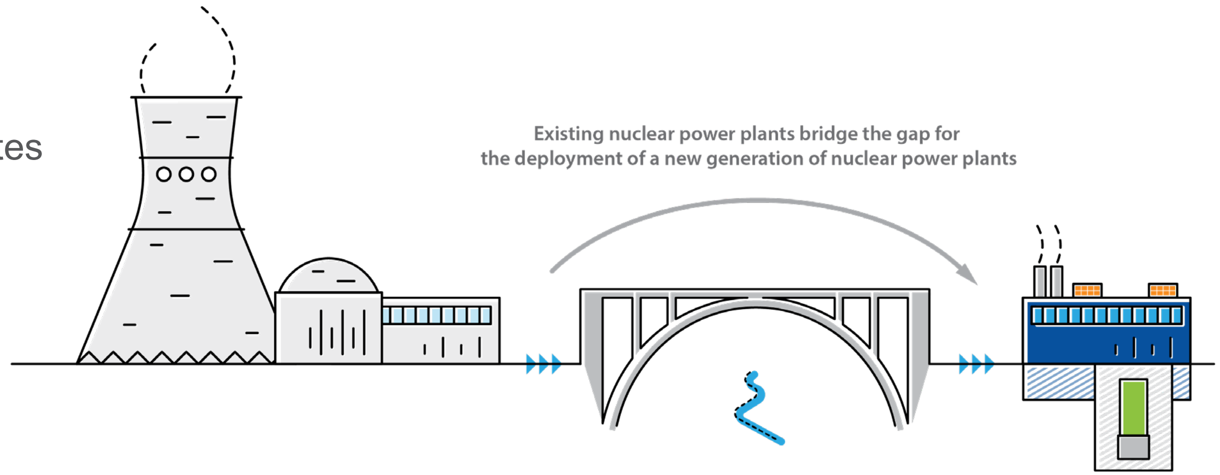
- Estimated costs of power uprates
  - Small uprates (MUR, < 2%): ~ $500 - $800 / kW
  - Medium uprates (SPU, 2%-7%) ~ $800 - $1,500kW
  - Extended power uprates (EPU, > 7%): ~ $1,500 - $2,500 / kW
  - Very large power uprates with large plant modifications: up to $5,000 / kW
    - Vogtle Units 3 &4: ~ $11,000 /kW,
    - New AP1000 estimates: $8,300-$10,375/kW, 6.5 – 8 years construction time[1]
- Improved economics of plant lifetime extension for another 20 years
- An opportunity to modernize

Added power to produce hydrogen

- Explicitly allowed for IRA's §45V hydrogen production credit
- Hydrogen credits further strengthen the business case for power uprates

Bridging the gap to new nuclear

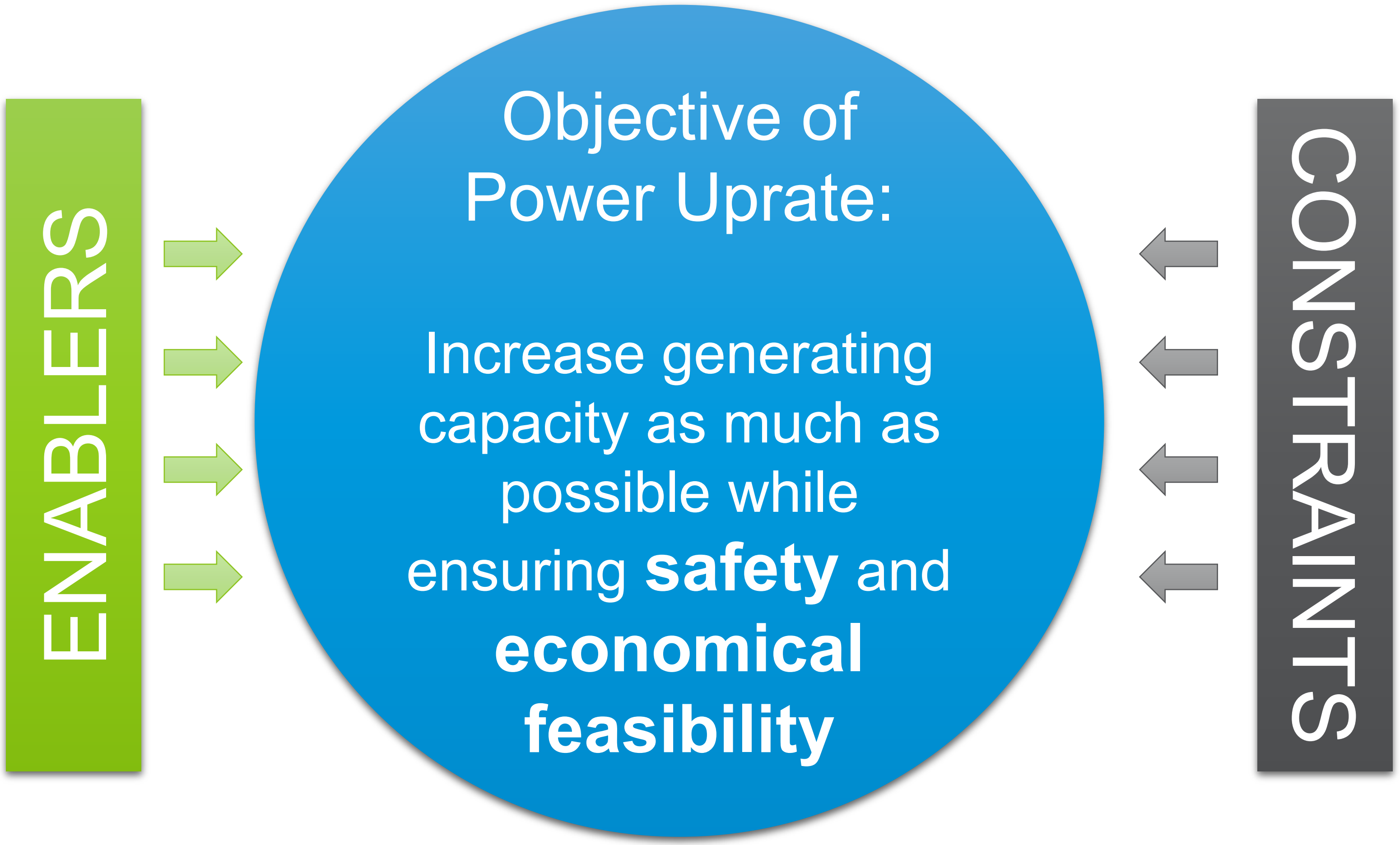
- U.S. nuclear energy to triple by 2050 – need to start with uprates
- Re-establishing U.S. nuclear capabilities and dominance:
  - Workforce
  - Supply chain for nuclear-grade systems and components
  - Scaled capacity of regulatory framework



Larger Uprates Faster – the Urgent Need

Goals for the R&D:

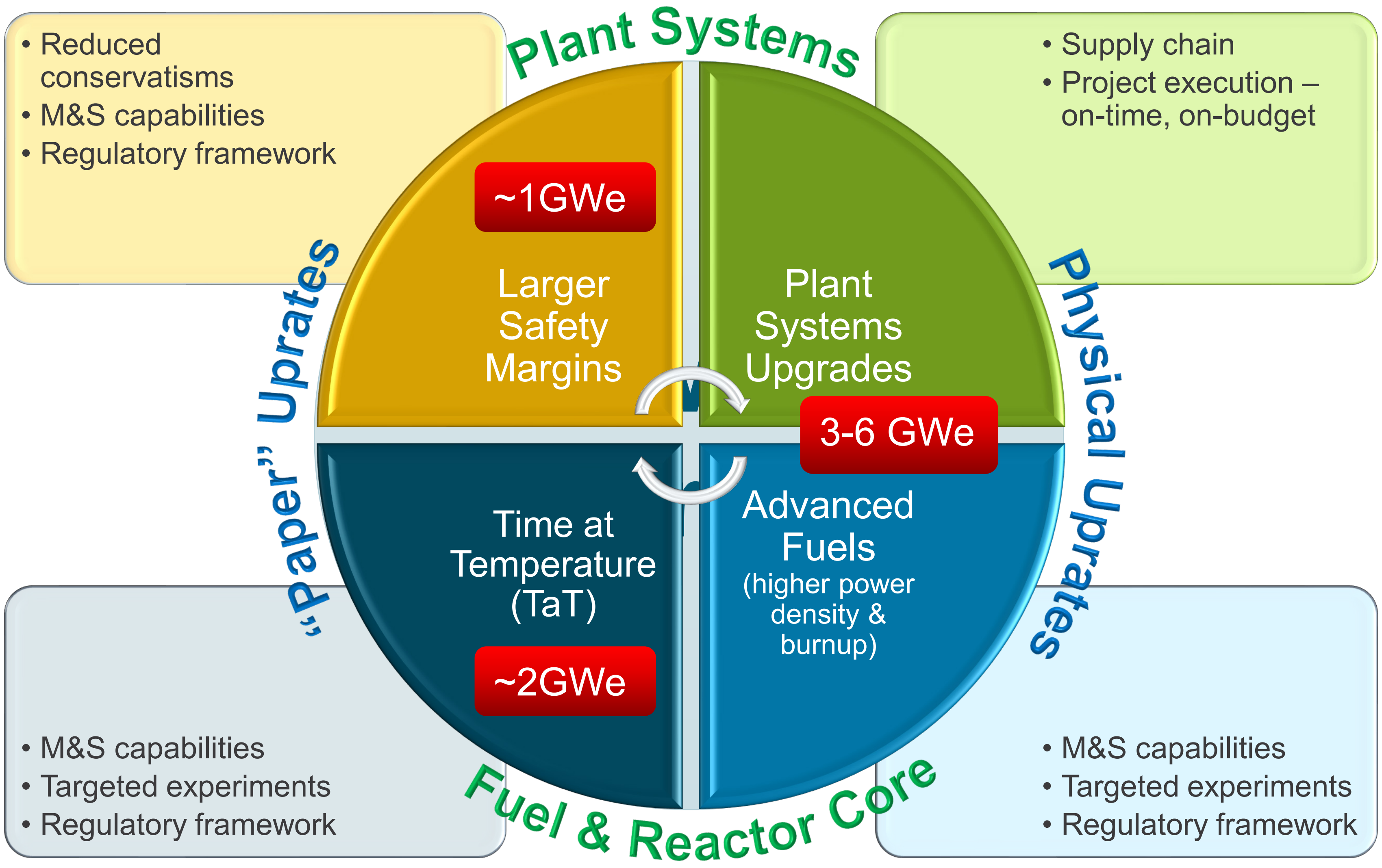
- Enable larger-size uprates
- Demonstrate safety of power uprates
- Support economic feasibility by efficiency gains



Larger Uprates Faster → SYSTEMS INTEGRATION

R&D AREAS:

- Enhanced modeling and simulation tools
    - Systems analyses
    - Fuel performance analyses
- Demonstration of adequate safety margins
    - Reducing conservatisms
    - Detailed analyses
    - Reducing uncertainties
- Artificial Intelligence and Machine learning (AI/ML) technologies
- Risk-informed licensing pathways
- Feasibility assessments
- Demonstrated case studies



LWRS
LIGHT WATER REACTOR SUSTAINABILITY

Novel Approaches to Support Plant Activities

Risk-Informed Compliance

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.

CHALLENGE

- Regulatory-required analyses of plant records are very labor-intensive with imprecise results due to human bias and errors.

RESEARCH

- Develop an approach for analysis of industry actions and events
- Develop AI-supported capability for automation of LAR preparation for large plant modifications (e.g., cycle extension, power uprate)

IMPACT

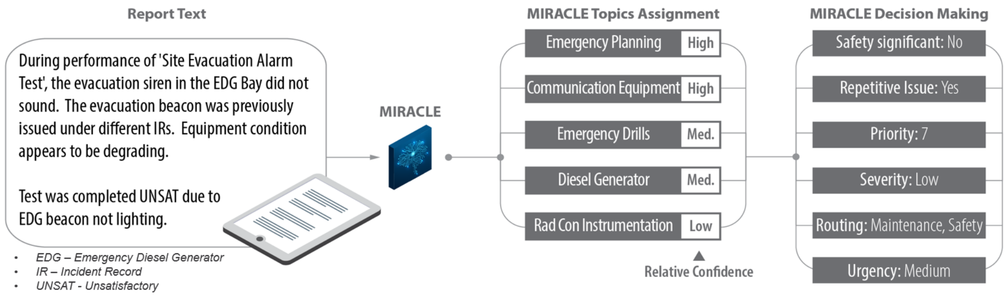
- Expedited and consistent process of reports preparation to support regulatory reviews → faster, cheaper LAR preparations and reviews

COLLABORATION

- Over 70% of the fleet contributed data to MIRACLE database

DEPLOYMENT TIMELINE

- FY20-24 – Methodology was developed and demonstrated with collaborators
- FY25 – Application for automation of LARs
- FY26 – Demonstrate LAR automation via a case study with collaborator



Workflow of Data Processing Automation

From 2000

From NRC website: https://www.nrc.gov/reactors/operating/licensing/power-uprates.html

Advanced Methodologies

Plant Reload Optimization

CHALLENGE

- Nuclear fuel is expensive ~ 20% of total O&M costs

RESEARCH

- Development of an automated integrated multi-physics approach to core design
- Methodology for multiple-objective optimization (e.g., minimize new fuel volume and increase safety margins)

IMPACTS

- Economic gains through reduction of volume of new and spent fuel and more efficient fuel use
- Enable larger power uprates
- Improve operational flexibility (fewer down power events)

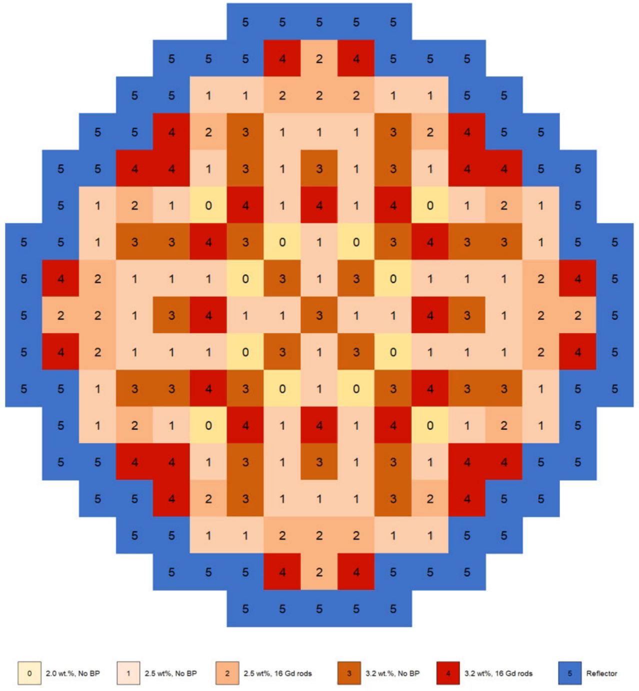
COLLABORATION

- Constellation Nuclear, planned Westinghouse

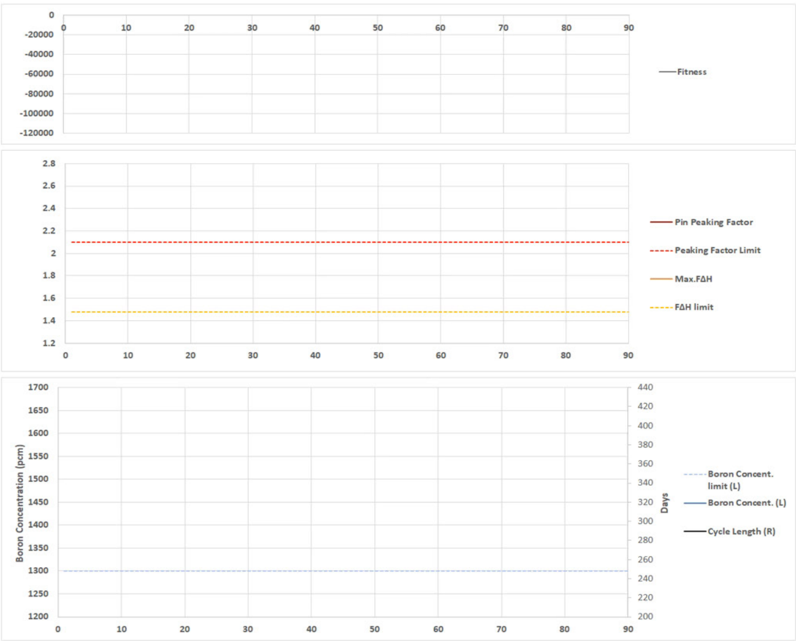
DEPLOYMENT TIMELINE

- PWR: already operational, fully-integrated integrated multi-physics approach – end of FY26
- BWR: ~ end of FY28

Reactor Core Fuel Pattern



Fitness of Pattern, Constraints, Objective



Novel Approaches to Support Plant Activities

Automated knowledge extraction from plant records to optimize maintenance

CHALLENGE

- Expensive operations and maintenance (O&M) of plant systems and highly-consequential equipment failures require advanced diagnostic and prognostic techniques to reduce O&M costs and preclude unexpected failures.

RESEARCH

- Create an Artificial Systems Engineer – enabled reasoning not just data processing
- Automate knowledge extraction from numerical and textual data for integrated knowledge base that mimics the process of human knowledge collection, retention, and use

IMPACTS

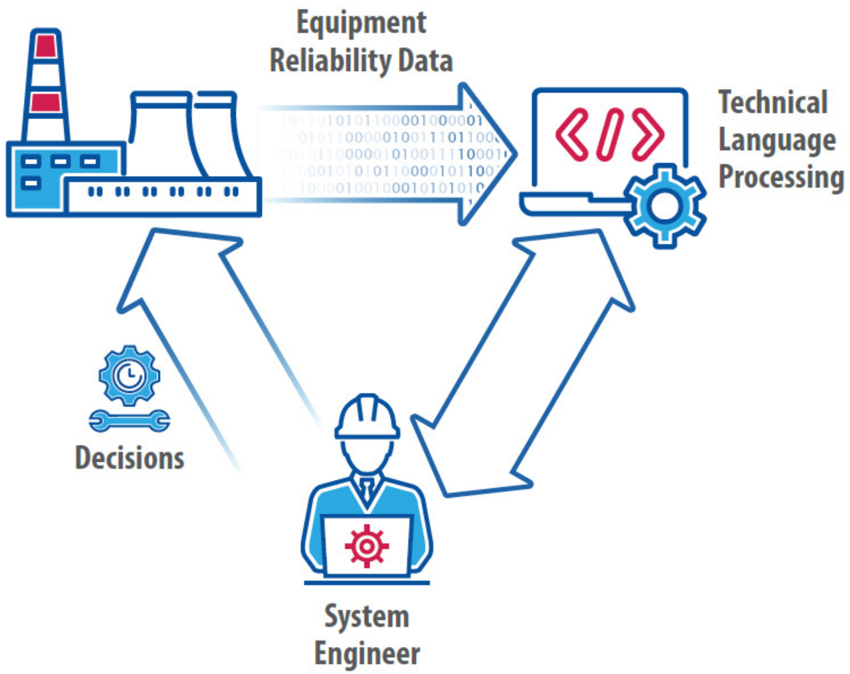
- Ability to detect failures before they occur → cost savings and safety improvements
- Knowledge retention and transfer to expedite workforce training and improve retention

COLLABORATION

- Ontario Power Generation, PSEG

DEPLOYMENT TIMELINE

- FY24 – Initial methodology was developed and demonstrated with collaborators
- FY25 – Refinement of methodology and development of tool DACKAR 1.0 (Digital Analytics, Causal Knowledge Acquisition and Reasoning for Technical Language Processing) https://github.com/idaholab/DACKAR
- FY26 – DACKAR 2.0 deployment with added features if automatic problem identification and explanation using Large Language Model Artificial Intelligence (LLM AI)



Connecting data to decisions

Novel Approaches to Support Plant Activities

Optimization of Plant Outage Activities

CHALLENGE

- Outages are consistently longer than scheduled causing lower capacity factors and profit loss (a day of plant not-operating costs ~ $1M-$2M).

RESEARCH

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

IMPACTS

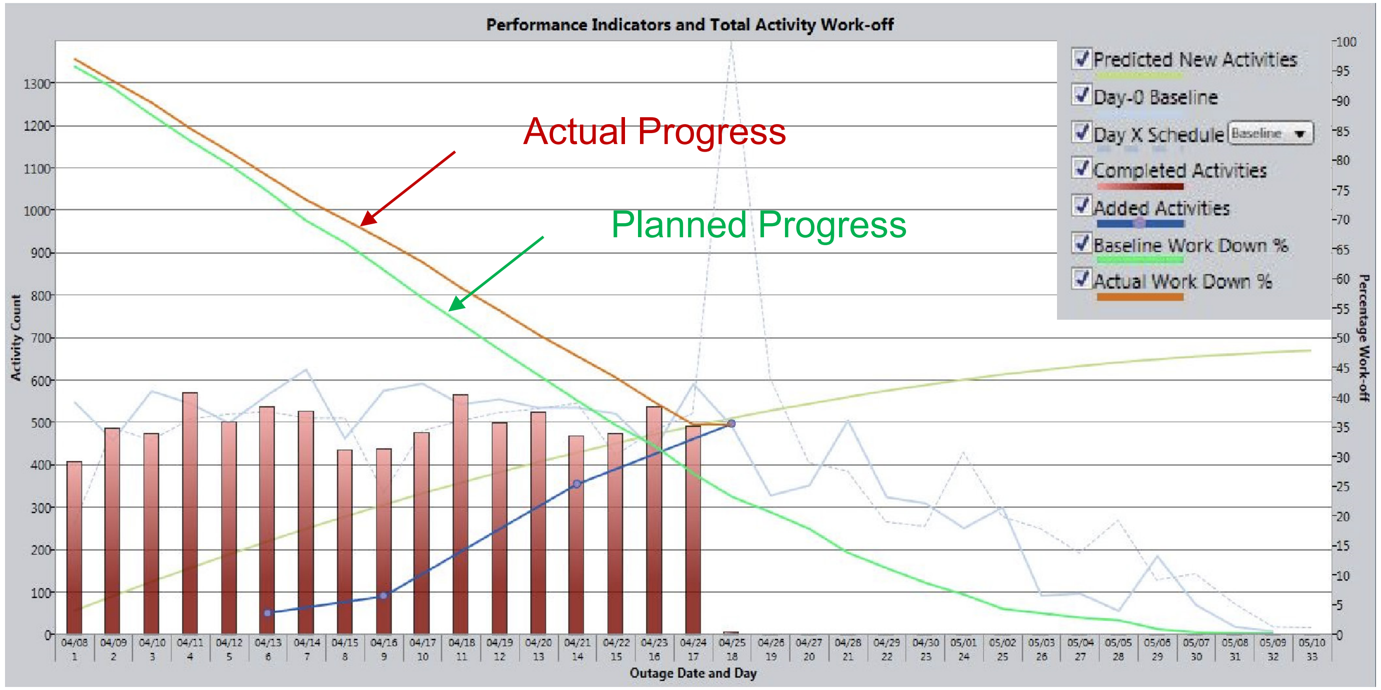
- Minimize unforeseen outage duration overruns
- Optimize utilization of resources during outages

COLLABORATION

- Ontario Power Generation

DEPLOYMENT TIMELINE

- FY24 - Methodology was developed and demonstrated with collaborators
- FY25 – Methodology improvements and development of a tool supporting outage performance, to be released at the end of FY
- FY26 – Small addition of the capability of resource management in addition to the traditional schedule management



Example of Outage Progress Monitoring

Advanced Methodologies

Digital I&C Risk Assessment

CHALLENGE

- Urgent need for an efficient and quantified approach to risk assessment of digital I&C systems to support control room upgrades

RESEARCH

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

IMPACTS

- Support of DI&C systems regulatory approvals
- Elimination of the need for redundant systems

COLLABORATION

- Pressurized Water Reactor Owners Group (PWROG), Westinghouse, GE Hitachi, Framatome

DEPLOYMENT TIMELINE

- Methodology – developed and demonstrated with collaborators
- FY25 – methodology and tool refinements
- FY26 – develop a software tool to support user-friendly, efficient process of risk assessments of digital I&C systems

Transition from Analog to Digital Control Systems

Advanced Modeling and Simulation

Virtual Assessments of Human Actions

CHALLENGE

- Digitalization of plant operations require assessment of human actions under the new operating conditions.

RESEARCH

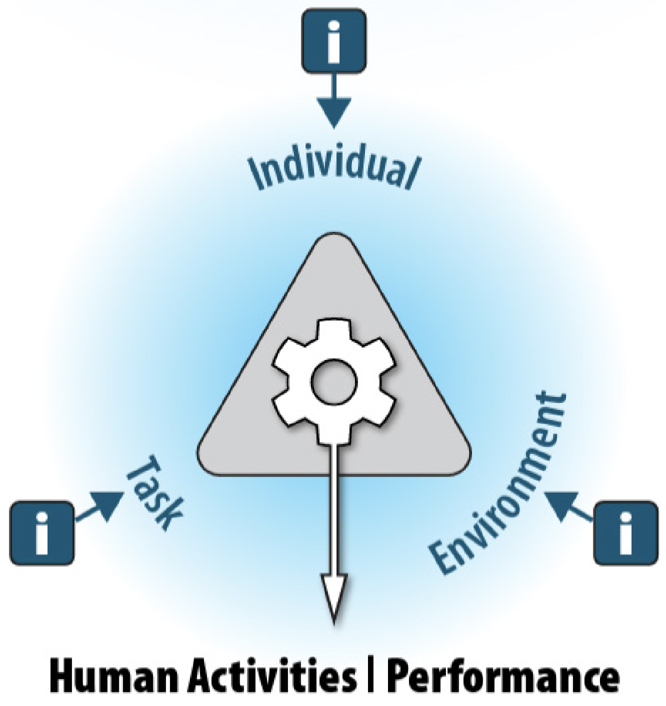
- Demonstrate human performance with an upgraded digital system in the control room

IMPACT

- Expedite regulatory approvals of digital upgrades of safety-related systems

COLLABORATION

- Utilities (Duke Energy, Southern, APS, Constellation) and vendors (Westinghouse, Curtiss-Wright)



HUNTER Conceptual Framework
HUNTER: Human Unimodel for Nuclear Technology to Enhance Reliability

DEPLOYMENT TIMELINE

- FY25 – Couple HUNTER to full-scope plant simulator in the Human Systems Simulation Laboratory (HSSL) at the Idaho National Laboratory
- FY26 – Evaluation of virtual operator performance of existing plant against upgraded plant to identify changes in important human actions
- FY27 – Development of software tools for consistent approach to evaluate human performance in digital environment or for novel applications (e.g., collocated hydrogen generation)

LWRS

LIGHT WATER REACTOR SUSTAINABILITY

Sustaining National Nuclear Assets

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