LWRS
LIGHT WATER REACTOR SUSTAINABILITY

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Extending reactor life, accurately measuring material stress

LWRS Program research develops tools to assess fracture toughness

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Materials Research Pathway

Components inside of a nuclear reactor pressure vessel must tolerate superheated water, stress, vibration, and an intense neutron field. Over the lifetime of these components, monitoring for degradation of materials is vital to ensuring the performance of the structures, systems, and components in a nuclear reactor vessel.

Extending service lifetimes of nuclear reactors to 60 years and beyond increases the stress on its materials. Light Water Reactor Sustainability (LWRS) Program is researching the behavior of materials inside of a nuclear reactor so that we can understand and predict how they

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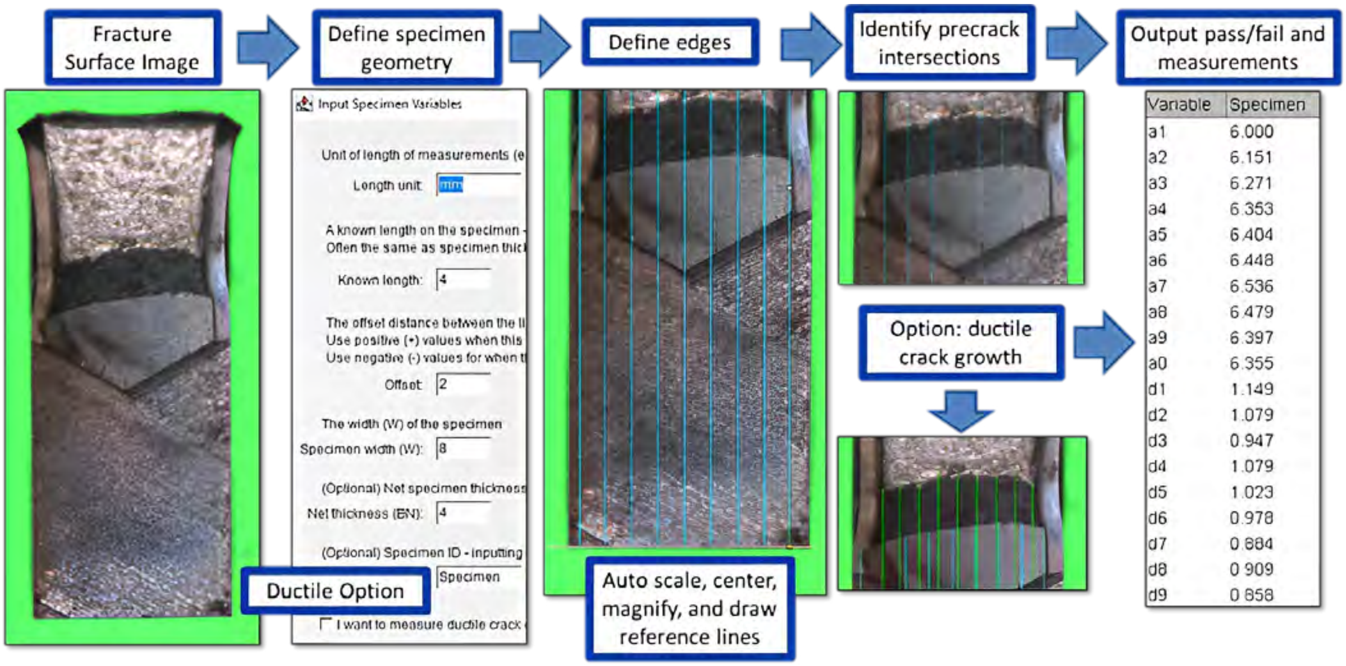

Figure 1. Interface of an automated crack length measurement software utilizing the ImageJ environment.

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will behave over time. The LWRS Program is developing mitigation and repair guidelines as well as new material alternatives for existing components.

Fracture toughness measures how well a material can withstand cracking when subjected to stress. Degradation can vary between the different systems, structures and components and it is very important to identify issues early, before catastrophic failure of the component occurs. The ASTM International test standards require precise crack length measurements to calculate fracture toughness. Historically, the crack length is measured from the fracture surface using a toolmaker microscope, which is a tedious and time-consuming process, and there is no open-source software available that meets the ASTM standards.

Fracture toughness values are a basis for structural flaw tolerance assessment. All commercial light water reactors have pressure vessels made of ferritic low alloy steels and its structural integrity relies upon our accurate understanding of the changes in the pressure vessel materials' fracture toughness over the time of operation. The analytical approach developed for ferritic steels, called the Master Curve method, can be used to directly measure fracture toughness properties of the irradiated pressure vessel. The data can then be more precisely used for assuring structural integrity during continued operation.

The Master Curve approach has been gaining acceptance throughout the world, and it is expected that nuclear power plant operating life can be extended by using this method. Researchers have developed an automated crack length measurement software macro using ImageJ software, an open-source Java-based image processing program originally developed at the National Institutes of Health, Bethesda, Maryland and the Laboratory for Optical and Computational Instrumentation at University of Wisconsin, Madison. User-written plugins, developed using a built-in editor and Java compiler, enable a wide range of image acquisition, processing, and analyses (Figure 1 and Figure 2).

A macro written in ImageJ automates tasks and performs complex operations on images. LWRS Program researchers developed a macro to automate crack length measurements, focusing on the following objectives:

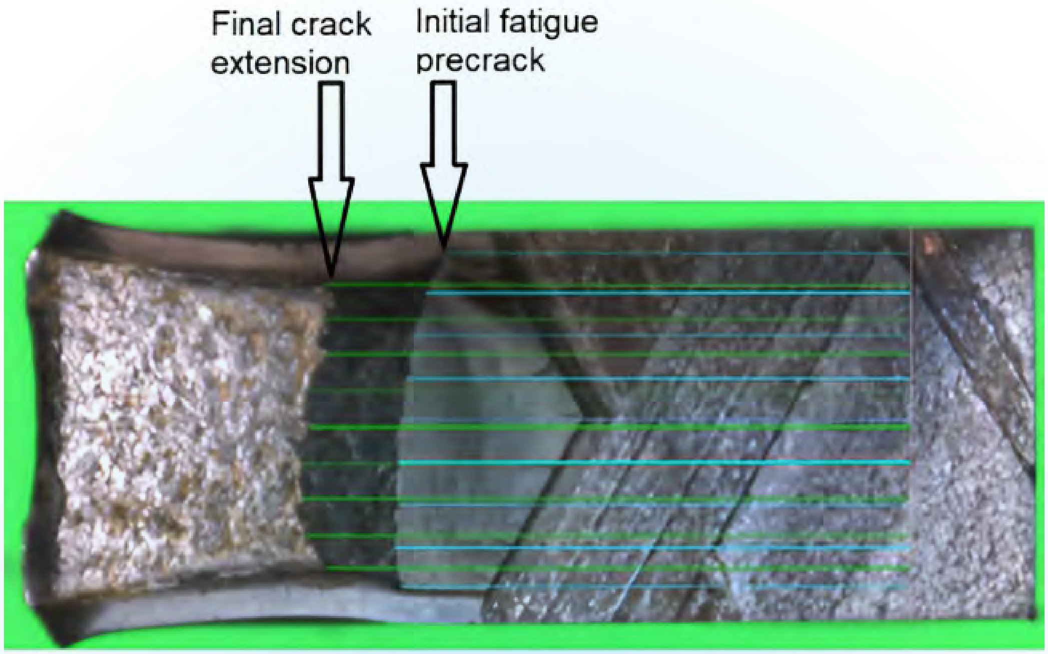


Figure 2. Optical image of a sample after fracture toughness testing with both initial and final crack length measurement.

- Compatibility with various image file formats (e.g., jpeg, gif, png, bmp, tiff, etc.).
- Automated image rotation and conversion of pixel distance to physical measurements.
- Flexibility to perform measurements from user-defined reference positions.
- Accordance with ASTM E1820 and E1921 standards.
  - ASTM E1820 testing determines the ductile fracture toughness of metals by testing a fatigue pre-cracked specimen.
  - ASTM E1921 testing covers the determination of a reference temperature to characterize the fracture toughness of ferritic steels that experience cleavage cracking.

To test the software, the LWRS Program researchers partnered with ASTM E08 committee members who were from Westinghouse Electric Co., the National Institute of Standards and Technology, the global industrial gases and engineering company, Linde PLC, University of Pittsburgh, VTT Technical Research Centre of Finland, Brazil's University of São Paulo, and COMTES FHT a.s., a privately owned Czech Republic research organization. Positive feedbacks with minor editorial changes were received from the ASTM E08 committee members.

The next steps will be to finalize the ImageJ macro, publish a software and user manual, and align it with ASTM E1820 and E1921 standards. The research and development of products developed from the LWRS Program will be used by utilities, industry groups, and regulators to help understand how materials in a reactor pressure vessel behave when subjected to long-term operation conditions.

It is expected that by using this method to test the integrity of materials used in reactors will help reduce the operating costs by offsetting maintenance costs due to better predictive models for component lifetimes, reduce costs for repairs, or extend the performance of plants through the selection of improved replacement materials.

Increasing Security Measures for Nuclear Power Plants and their Security Officers

Steven Sweet, Paul Zahnle, Christopher Skinner
Physical Security Pathway

If individuals or groups attack a nuclear power plant, their first targets may be the plant's security officers. Their officers safety, efficiency, and effectiveness could be improved by providing them with equipment to remotely detect intruders, and remotely operate their firearms.

Since 2019, LWRS researchers have been evaluating a Remotely Operated Weapon System (ROWS) that uses thermal imaging and optical cameras to identify intruders. ROWS allows a person in a control room, that is outside the line of fire, to aim a rifle at the target, and pull the trigger. The system would let a single security officer switch from one vantage point to another, almost instantly, by control from within a protected room.

Security officers make all the decisions. ROWS does not rely on artificial intelligence. Placing security officers in a secure location allows them to effectively respond in the event of an attack, while reducing the negative impact that their adrenaline can have when they are under fire.

Figure 3. A remotely operated "Single Sentry-II" installation, replacing a guard post. ROWS Configuration.

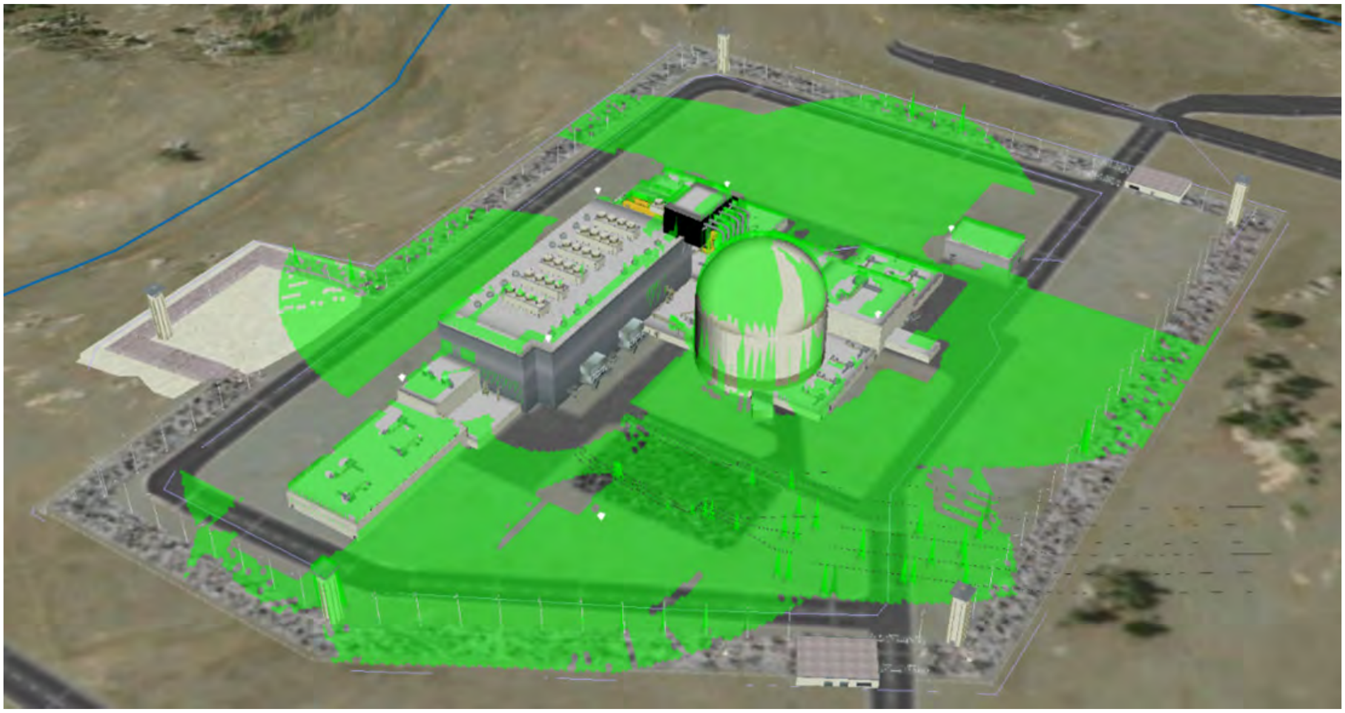


Figure 4. A computer-generated model of a hypothetical nuclear plant. Dante ViewShed schematic double coverage view of a notional nuclear power plant. Areas in green are covered by overlapping fields of fire from two or more remotely operated weapons.

Currently, security officers are stationed in bullet resistant enclosures (i.e., steel boxes), sitting on towers outside the plant, or in "hardened fighting positions," usually inside the plant. These have several shooting ports facing different directions from which the officers can fire.

A security officer can only be at one location at a time. A security officer stationed in a control room with access to multiple remote-controlled positions, i.e. ROWS, can promptly and effectively be at the scene almost instantly. If two officers are in the control room, they could quickly begin operating weapons with overlapping fields of fire.

ROWS has been tested in many applications and it has proven effective in these applications, and its applicability to nuclear power plants is clear, see Figure 3.

Researchers have modeled the performance of ROWS against the "design basis threat," the characteristics that the Nuclear Regulatory Commission presumes an attacking force will have. The details of the design basis threat are safeguarded, but the ROWS based security force generally has a higher success rate against the adversary force over a traditional security team.

By the end of next year, researchers will determine where to put ROWS equipment, inside and outside a plant, and develop the simulator's scenarios to train defenders, and verify the system's effectiveness.

The current research is being conducted at two commercial nuclear power plants. Tabletops and high-fidelity modeling and simulation are the main basis of the research. The tabletop exercises are being conducted with Sandia's Scribe3D tool, where security personnel can make decisions with the tool that allows them to explore states and decisions over an attack with a human-in-the-loop. The high-fidelity modeling and simulation is being conducted with Sandia's Dante tool suite, where over two decades of high-fidelity physics, behavior engine, path planning, and many other libraries are melded together to evaluate several thousand iterations of different scenarios of adversary and security force tactics in a Monte Carlo batch analysis, see Figure 4.

Security officers at nuclear power plants conduct routine "force-on-force" exercises, in which attackers and defenders are given what resembles laser tag equipment, while human observers monitor and evaluate the exercises. Researchers plan to use ROWS in such an exercise in 2025. In 2026, the program would include a full-scale deployment execution plan of ROWS at an operational reactor site.

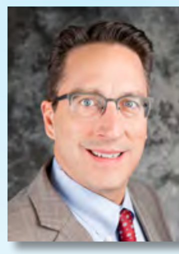
Affordable Nuclear-Powered Hydrogen Production Within Reach, Studies Suggest

Paving the Way for a Sustainable Energy Future




Tyler L. Westover, Thomas A. Ulrich, Richard D. Boardman, Dan S. Wendt
Flexible Plant Operation and Generation

Jason M. Marcinkoski
Department of Energy



Alan Wilson
Sargent & Lundy

Brian D. James
Strategic Analysis Inc.

Competition from fossil fuels and renewable energy presents a challenge for nuclear power plants as they try to remain profitable. Nuclear-powered hydrogen production could provide plant operators with a good way to diversify their products while increasing profits.

The LWRS Program is helping evaluate the technical feasibility and economics of electrolysis systems that harness electricity and heat from nuclear power plants to split water into oxygen and hydrogen.

These systems not only provide utilities with additional revenue from the sale of hydrogen, but also a means to ramp electricity generation up or down to match variable demand on the grid. Hydrogen serves as a storage medium for a nuclear power plant's excess power. Hydrogen can then be sold to a number of industries or can even be turned back into electricity during times of high grid demand.

Recently, utilities worked with LWRS Program researchers at Idaho National Laboratory (INL) to locate small-scale electrolysis systems at operating light water reactor plants. The nation's first nuclear-powered clean hydrogen production facility, a 1.25-MWe, low-temperature electrolysis system, is producing hydrogen at Constellation's Nine Mile Point plant in New York state. Another low-temperature system is planned for Vistra's Davis-Besse plant in Ohio, and a 200-kWe high-temperature electrolysis system will be installed at Xcel Energy's Prairie Island plant in Minnesota.

Researchers have developed conceptual designs and a cost analysis for combining nuclear plants with larger-scale high-temperature electrolysis systems—100MW and 500MW, respectively.

The analysis showed that, by 2026, combined nuclear-hydrogen systems could produce hydrogen with no significant carbon emissions for under $2/kg. Market studies show that at that price, clean hydrogen could compete in some markets with steam methane, reforming a process that consumes fossil fuels and emits greenhouse gases.

The clean hydrogen produced by these electrolysis systems could help support decarbonizing industries from chemicals production to steel manufacturing, while bolstering clean technologies such as fuel-cell vehicles and sustainable fuels that could replace petroleum fuels.

Researchers developed the hydrogen system designs for a 4-Loop Westinghouse pressurized water reactor, which is the most common design used currently operating U.S. nuclear power plants. A similar effort for boiling water reactors is expected in late 2024. The design could also be adapted for low-temperature electrolysis systems (Electrolysis systems split water into hydrogen and oxygen using electricity in the presence of a catalyst. Low-temperature systems split liquid water, whereas high-temperature systems split steam, which is more efficient).

To develop the conceptual design, researchers collaborated with Sargent & Lundy, an architectural engineering company, and Strategic Analysis, Inc., a consulting firm, with support from Westinghouse Electric Company. The addition of the electrolysis system requires changes to the power plant design, but those changes are minor (see Figure 5).

The studies explored technical questions such as how to size the steam extraction components and pipes to ensure no adverse consequences to the operation of the power plant, where and how to establish control capabilities and how to tap electricity from the nuclear plant's power transmission station. Direct current electricity would be tapped from the high-voltage side of the generator step-up transformer, then transported via a 345-kV transmission line to the hydrogen production facility.

The studies also looked at how and where to extract high-temperature steam from the nuclear power plant. High-temperature steam electrolysis systems require heat at approximately 150°C.

In a pressured light water reactor, heated water is carried to the steam generator in a closed pipe. Inside the steam generator, the heated water in the pipe vaporizes the water outside of the pipe, creating high-pressure, high-temperature steam (300°C) that is routed to the first turbine, which makes most the plant's electricity because this is where the water has the most energy. After the first turbine, the steam has cooled to about 190°C and is routed to a second turbine before it returns to the steam generator as water.

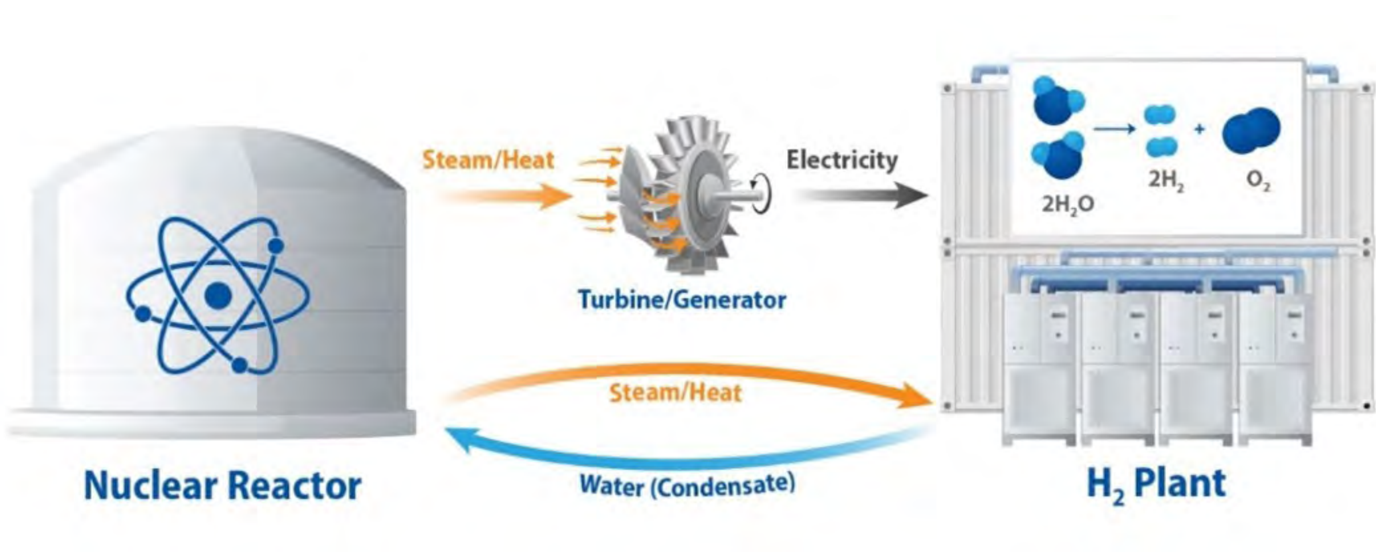
Researchers found that extracting cooler steam before it enters the second turbine was the most cost-effective way to transfer thermal energy to a high-temperature steam electrolysis system to produce hydrogen. Researchers estimated that using this cooler steam for hydrogen production would cost approximately $9/MWhth (megawatt-hours of thermal energy) for a 500 MW hydrogen plant, compared with $13/MWh for steam extracted from the main steam line and $30/MWh for steam from an electric boiler.

For a 500 MW hydrogen plant, cooler steam contributes approximately \$0.066/kg-H_2, compared with \$0.10/kg-H_2 for steam from the main steam line and \$0.22/kg-H_2 for steam from an electric boiler. The cost savings of using steam from the cold reheat of a nuclear power plant could be as much as \$0.16/kg H_2. During times of low electricity prices, the cooler steam could prove more valuable for making hydrogen than making electricity.

These demonstration projects help to reduce risks for utilities as they consider adopting these hybrid nuclear-hydrogen technologies. While projected cost of hydrogen at $2/kg depends on the establishment of a robust electrolysis manufacturing industry, advancements in hydrogen technology could reduce that price even further to $1/kg by 2031. The $1/kg price meets the Department of Energy's (DOE) Hydrogen Earthshot objective.

The lessons learned apply not only to the nation's current reactor fleet, but also to the next generation of advanced reactors that have the potential to supply industries with heat at even higher temperatures.

Figure 5. Nuclear power plants can provide heat and electricity for high-temperature water electrolysis.



'Future proofing' the Fleet

LWRS Program supports nuclear plant modernization efforts

Casey R. Kovesdi, Jeremy D. Mohon, Paul J. Hunton, Craig A. Primer
Plant Modernization Pathway

The nation's existing nuclear power plants fleet produced more than 800 million kilowatt hours of electricity in 2021. This clean energy is indispensable to curbing greenhouse gas emissions.

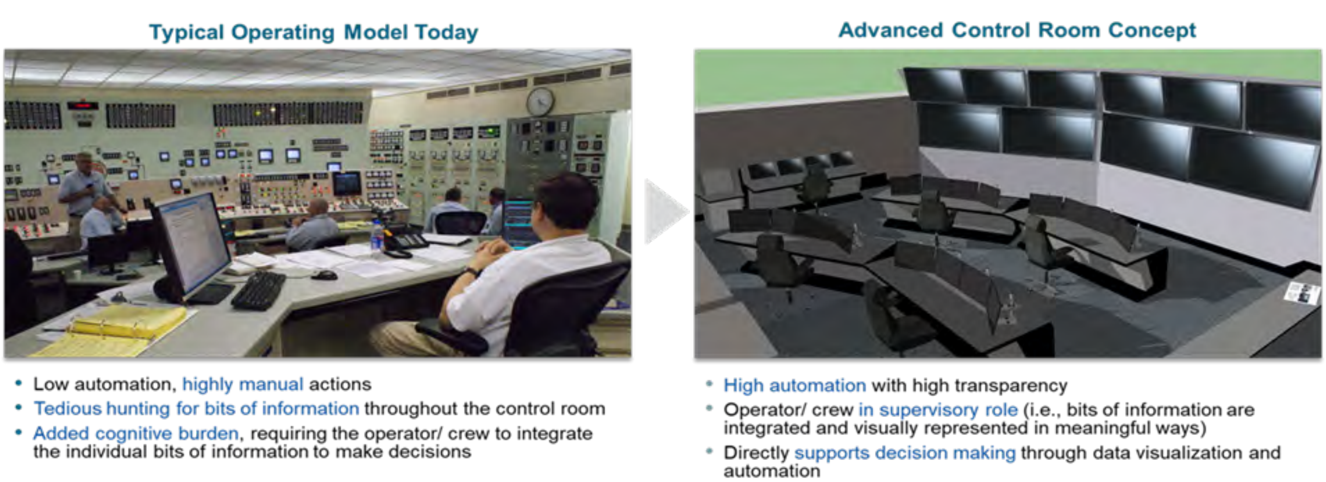
Updating aging infrastructure is a major and continuing challenge. The oldest operating nuclear plant in the U.S. is New York's Nine Mile Point Unit 1 which is 54 years old, and many more are approaching the half-century mark. Parts for some plant components are, or will become unavailable and operating systems will become obsolete. Utilities have long recognized the need for modern advanced digital systems. Automation can eliminate tedious, error-prone tasks, provide near-instant integrated plant data, and reduce training burdens.

Engineering challenges - Most of the light water reactors that make up the U.S. fleet were originally designed and constructed with analog instrumentation and control systems. Digitalization offers huge advantages (Figure 6), but poses new engineering challenges for plant owners and operators. The LWRS Program is a source of solutions for modernizing, digitalizing, and streamlining operations at U.S. nuclear power plants.

LWRS Program researchers have developed methodologies and tools that can help the nuclear industry identify and implement the need for advanced digital technologies. The goal is "obsolescence management." With some plant owners applying for license extensions that could extend operations as long as 80 years, the LWRS Program aims to "future proof" the process as it looks ahead at new capabilities and automation.

Human and Technology Integration (HTI) - For continued safe and reliable operations, it is essential to understand how people will use the new technology, identify situations in which operators would be likely to make

Figure 6. Comparison of existing control rooms to advanced control room.



mistakes and developing approaches for their mitigation. HTI applies human factors engineering (HFE) methods and tools while focusing on the application of technology to reduce operation costs. The methodology extends from known standards and guidelines and is based on original LWRS Program research in advanced alarm systems, computer-based procedures, model-informed decision support and advanced human-system interface displays.

Viewed more widely, HTI ensures safe, reliable use of advanced digital technology by leveraging the capabilities of people and technology. The new digital technologies minimize training demands, eliminate human error, reduce workload, enable automation transparency, and provide meaningful information to support organizational effectiveness and decision-making. These benefits result in safer, more timely decisions and improve people's trust and adoption of advanced digital technologies.

Industry partners Constellation Energy and Southern Nuclear have taken the lead in partnering with the U.S. DOE's LWRS Program. The Limerick Generating Station in Pennsylvania, has entered a cost-sharing project with DOE, which is providing $50 million toward the first fully digital safety system upgrade at a U.S. nuclear power plant. The main control room will be enhanced with digital instrumentation and control (I&C) systems, digital displays, and alarm systems.

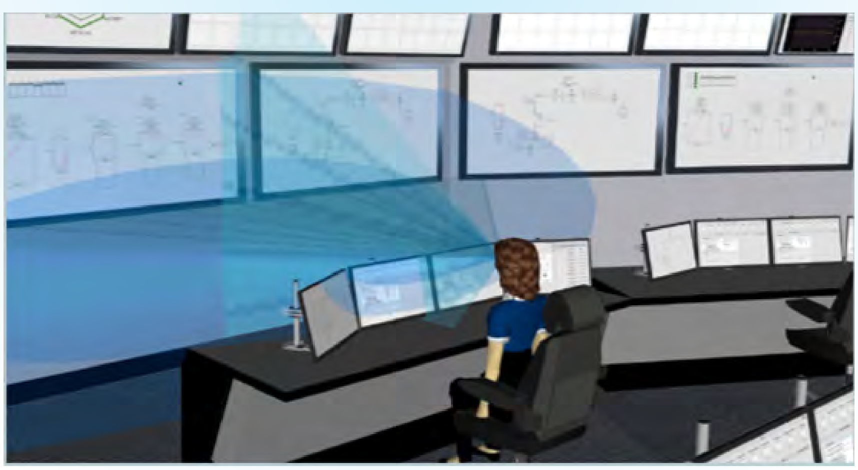
Researchers applied the HTI methodology during the detailed design phase of the Limerick Generating Station project. At INL, the Human Simulation Systems Laboratory (HSSL) offers an environment that can digitally simulate any number of control rooms. To address information and task requirements, they have used advanced HFE tools, methods, and frameworks, including performance-based tests in the HSSL for digital human modeling (Figure 7) and cognitive task analysis. INL collaborated with Constellation, Westinghouse and CORYS to prepare a near-full scope simulator and coordinated the execution of preliminary validation. To integrate the three key components of any modernization -- hardware, software, and people -- and to determine whether performance and safety requirements are met during the upgrade, researchers will continue to use performance-based tests.

Southern Nuclear, researchers applied the HTI methodology in the initial scoping phase of Southern Nuclear's fleet-wide modernization project by developing the vision and new concept of operations for the Farley plant.

Southern Nuclear collaborated with Sargent & Lundy to develop new control room requirements and the conceptual layout of a new control room. This was done using the HSSL and the Advanced Visualization Laboratory at the Center for Advanced Energy Studies, at INL. The demonstrations led to human factors considerations for large overview displays, computer-based procedures, advanced alarms, and compact workstations providing complete, transparent, and usable information. Continued HTI methodology demonstration will expand into defining fleet-wide requirements for Southern Nuclear.

The lessons learned from both projects will offer industry guidance on HTI, reducing the technical, financial, and regulatory risk of upgrading the aging I&C systems. Ultimately, this should support extended plant life up to and beyond 60 years. The work will expand the vision scope and concept of operations across other utility plant sites to ensure that they are safe, reliable and include state-of-the-art digital technology that ensures economic viability.

Figure 7. Use of digital human modeling to perform human factors analysis.



Learning to Spot Trouble Before It Starts

Modernizing Plant Monitoring with Machine Intelligence

Ahmad Al Rashdan, Jacob A. Farber
Plant Modernization Pathway

The control room operators in a nuclear power plant are well prepared to handle any issues that arise, but they generally only act when they are alerted that something is wrong. By the time an alarm is triggered, and the control room operators respond to it, the nuclear power plant may have initiated an automatic shutdown, resulting in the loss of valuable energy production. Additionally, a piece of equipment may have been damaged, complicating the repair process.

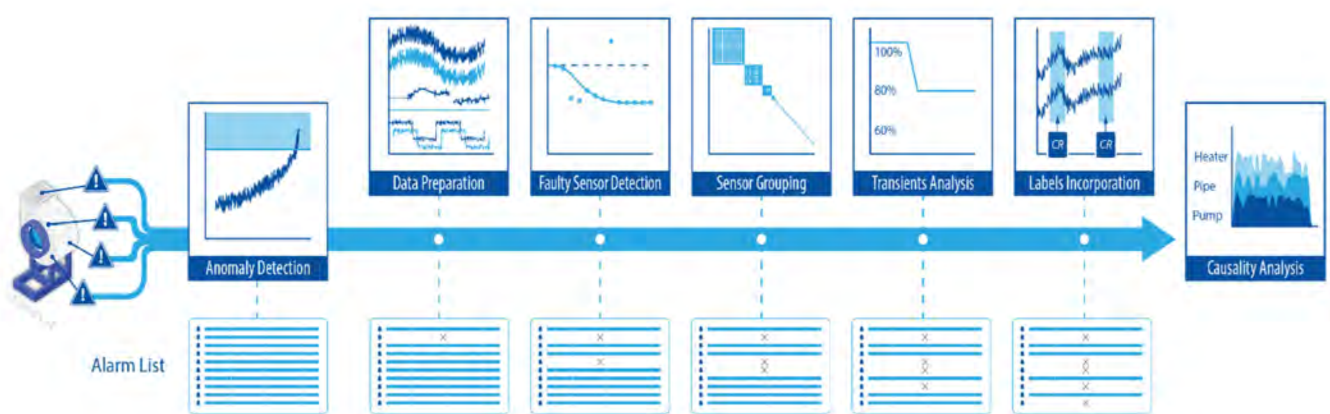
The solution is to not have to wait for alarms to happen. With assistance from a computer system that monitors the numerous sensors in the nuclear power plant, the operators could spot anomalies before they lead to problems.

The idea that historical data patterns could be used to detect anomalies early enough to prevent shutdowns or damage is not new. Engineers have long used computers to detect when a group of sensors gives readings that depart from a known pattern. But it is hard to execute at a nuclear plant, because of its immense size. With thousands of embedded sensors, it produces a plethora of data, which can be hard to analyze.

To overcome this, machine learning is used to analyze historical data and detect subtle changes. It determines what is a significant change in plant conditions to alert the operators accordingly. LWRS Program researchers at INL call it the ALARM software, for Automated Latent Anomaly Recognition Method. It is essentially an algorithm that establishes correlations between sensor readings and off-normal conditions, in a way that smooths out the operations of a plant and saves money.

An example of how ALARM can smooth out operations and save money is detecting cooling fan degradation before the onset of failure. Cooling fans are used in boiling water reactors (BWR) to help limit temperature in the drywell, a structure that dissipates excess heat from the reactor. In a BWR, two cooling fans failed within a four-week timeframe, forcing the reactor to be shut down. One of the challenges was that there were no vibration sensors or other readings on the cooling fans that could be used to detect their degradation more directly. However, if fans were beginning to fail, places in the plant near the fans would show odd temperature readings. ALARM would monitor something broader than the fans themselves: the whole environment, from which the condition of the fans can be inferred. Two fans failed within four weeks, and the reactor had to be shut down for repairs. No vibration sensors or other readings could be used to detect this ahead of time. But if the fans were beginning to fail, places nearby in the plant would show odd temperature readings. The innovation is to monitor something broader than the fans themselves: the whole environment, from which the condition of the fans can be inferred.

Figure 8. The ALARM software consists of several anomaly detection modules that significantly reduce the number of false alarms (from the alarm list), ensuring effective use of anomaly detection.



Two main categories of errors make any machine intelligence less useful. The first one is when it fails to detect an anomaly while the second involves triggering unnecessary alerts, alerting the control room operators so often that they become desensitized to the warning.

To reduce those errors, the ALARM software consists of several modules (Figure 8) that enhance anomaly detection. The first module detects deficiencies in sensor data and focuses on identifying indicators such as prolonged periods of unchanging data or apparent delays in data transmission. By identifying weaknesses in sensor readings, the software effectively minimizes false alarms.

Some of those readings will come from sensors giving incorrect data. Their readings may drift, or show spikes or other noise in the data, or they may simply fail. A second module looks for those sensors because fixing a sensor is easier than fixing an actual mechanical problem in a plant.

Scaling anomaly detection for a whole plant requires analyzing clusters of related sensors simultaneously, and then drawing inferences. The thousands of sensors within the plant can be divided into groups, treating each group as a single system or process, which is the focus of the next module. In addition to improving anomaly detection performance, this technique reduces computational requirements, because correlations need to be established only among a smaller group of sensors.

The next module looks for changes that will occur when the reactor operates at less than full power. A sensor reporting reduced temperature or pressure might trigger an alarm, but the reading might be normal for a reactor operating in that mode.

As alarms are generated in cases where they were justified, human operators can provide feedback to the automatic software as part of an ALARM module. By labeling the data, humans will help the machine logic get smarter.

In the complex and tightly coupled systems of a nuclear power plant, when multiple alarms sound simultaneously, human operators may require time to determine the root cause. Learning to recognize the source of an anomaly is the focus of the final module.

The goal of all these modules is to sort anomalies that represent problems from anomalies that do not. Software that can reduce the number of times it issues false alarms can increase the quality of information going to the operators, and the operators' confidence in the software. Ultimately this results in a lower number of unexpected outage and enormous cost savings with minimal distraction of operators.

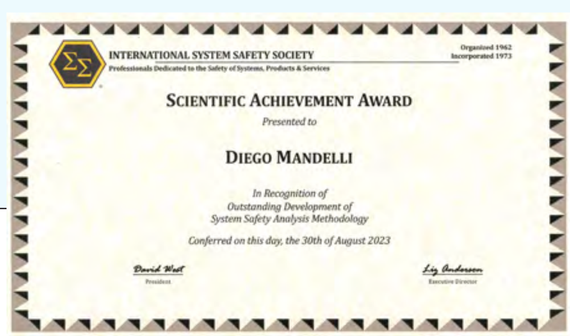
Diego Mandelli honored with International Safety System Society Scientific Achievement Award

Diego Mandelli was recently recognized at the annual International System Safety Summit and Training Conference as a distinguished expert in the field of Risk-Informed Asset Management. He received the prestigious 2023 International System Safety Society Scientific Achievement Award. This esteemed award recognizes individuals or groups who have significantly advanced the realm of system safety by dedicating their efforts to pioneering research and development programs.

Mandelli received this award in recognition of his outstanding accomplishments in the development of data analytical methods for equipment reliability analysis and advancing model-based system engineering tools.

Diego Mandelli

Mandelli's dedication to improving system safety through innovative R&D is a major asset to the Light Water Reactor Sustainability Program. His contributions continue to shape the landscape of Risk-Informed Asset Management, providing invaluable insights and tools for extending the lifetime of the existing fleet of nuclear reactors.



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David West
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Better Together: EMRALD-HUNTER

LWRS Program Software Tools Linked for Better Modeling of Hardware and Human Risk





Ronald L. Boring, Thomas A. Ulrich, Stephen P. Prescott, Jooyoung Park
Risk-Informed Systems Analysis Pathway

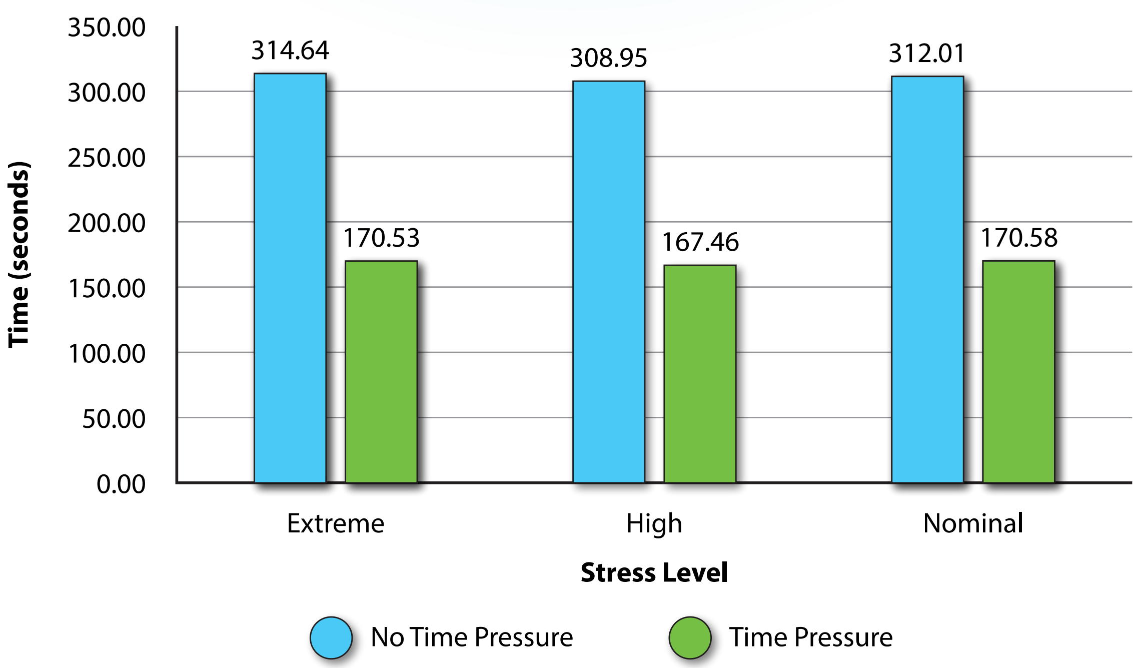
Roger Lew
University of Idaho

Legacy risk assessment methods are widely used in the nuclear industry to help ensure the overall safety and reliability of the U.S. commercial operating fleet of nuclear power plants. However, these methods are largely static approaches to risk, meaning they operate on a fixed or well understood set of plant and operational conditions. For example, static risk approaches might anticipate failure to initiate safety injection of coolant following a plant trip, but they might not fully consider risk changes resulting from delaying the injection. It is not an all-or-nothing condition with only a single success or failure outcome.

In contrast, dynamic risk assessment uses Monte Carlo techniques to explore a wider range of outcomes, enabling "what-if" modeling. Such modeling is especially important in the context of plant upgrades, novel plant strategies like hydrogen production, and advanced reactors. In those contexts, there is not yet a large base of operating experience to understand system interdependencies or new operational contexts. Dynamic risk assessment can provide this information.

LWRS Program Risk-Informed Systems Analysis (RISA) Pathway researchers have developed two tools that

Figure 9. Example EMRALD-HUNTER output in terms of overall time duration as a function of time pressure and stress.



support emerging needs for dynamic risk assessment:

- Event Modeling Risk Assessment using Linked Diagrams (EMRALD) is a dynamic probabilistic risk assessment (PRA) software tool to help model causes and mitigations for hardware failures .
- Human Unimodel for Nuclear Technology to Enhance Reliability (HUNTER) is a dynamic human reliability analysis (HRA) software tool to help model operator performance including human errors .

A recent RISA Pathway research effort integrated HUNTER into EMRALD to enable plant and human operational risk modeling in a single tool. This assists industry risk analysts to cover both hardware and operational risk, provides the existing wider user base for PRA with greater HRA functionality, and provides missing functions required for holistic risk modeling of hardware and human interactions.

The integration of HUNTER into EMRALD is informed by earlier efforts and the challenges that were incurred in modeling HRA without a specific human module in EMRALD. For example, many human actions are repeated across procedures, but repeated human actions had to be separately coded for each instance in EMRALD. To enable HUNTER integration, EMRALD's process, structure and interface were extended. This new functionality allows modeling operator procedures to include repeated human actions. The speed and choice of operator actions is determined by contextual events in the EMRALD simulation and human influences modeled within HUNTER, creating a realistic simulation of operator performance.

HUNTER benefits from dynamic PRA functions via EMRALD, while EMRALD acquires HRA support from HUNTER. This integration is more efficient than adding the redundant functions separately to HUNTER and EMRALD.

Integrating HUNTER into EMRALD is an effective way to handle routine dynamic PRA applications needing HRA. An example of one of the outputs for a steam generator tube rupture for 1,000 scenario runs in EMRALD-HUNTER is shown in Figure 9. Novel applications such as rare events or human factors design tasks to establish the risk of new human-machine interfaces may require a more in-depth understanding of human operational phenomena, and the standalone version of HUNTER remains available for such applications.

The initial implementation benchmarks successfully to previous standalone HUNTER simulations and to operator performance data . As such, EMRALD-HUNTER holds considerable promise to help industry model risk for novel plant applications.

Welcome Sue Goetz, the New Light Water Reactor Sustainability Federal Program Manager

Sujata (Sue) Goetz is the new Light Water Reactor Sustainability Program Federal Program Manager within the Reactor Optimization and Modernization Team. Sue brings a wealth of experience and knowledge to this role. Sue holds an undergraduate degree in Biology with an emphasis in Microbiology, from Virginia Tech, a master's degree in environmental science and policy from Johns Hopkins University, and certificate in National Environmental Policy Act from Duke University.

Throughout her career, Sue has consistently demonstrated a commitment to environmental stewardship and innovation within the energy sector. Sue began her career as a biologist, working in a laboratory doing research on carcinogens. Then she worked at the U.S. Department of the Air Force, Headquarters (HQ), Pentagon, where she was an intern, At Fort Belvoir, she began her federal service as the Environmental Program Manager for the installation. She was then promoted to the US Army HQ Pentagon, where she continued to serve as an Environmental Program Manager.

She left the Department of the Army to serve as a general engineer at the US Nuclear Regulatory Agency in the office of New Reactors, where she reviewed license applications for the construction and operation of new nuclear reactors, including Vogtle and VC Summer. She has also served as a regulator for operating reactors, where she issued amendments for nuclear power plants such as Comanche Peake, Fermi, Prairie Island, Susquehanna, Beaver Valley, and most recently, Calvert Cliffs.

Sue's diverse background and expertise will be invaluable as we work to advance the sustainability of light water reactors.

Recent Highlights

Six outstanding projects that have demonstrated the success of the Light Water Reactor Sustainability Program

A New Approach to Evaluate Work Reduction Opportunities in Nuclear Power Plants

LWRS Program researchers introduced a novel Technical, Economic, and Risk Assessment framework to evaluate work reduction opportunities in nuclear power plants, with the goal of improving efficiency and long-term cost-effectiveness. This framework assists stakeholders in making informed decisions, reducing investment risks, and optimizing costs in the nuclear sector. Working alongside Southern Nuclear Company and Sargent & Lundy, LLC, they assessed work week planning and condition reporting processes as potential areas for efficiency improvements. POC: Ryan.Spangler@inl.gov, Vivek.Agarwal@inl.gov

A depiction of the Technical, Economic and Risk Assessment framework showing process model and output.

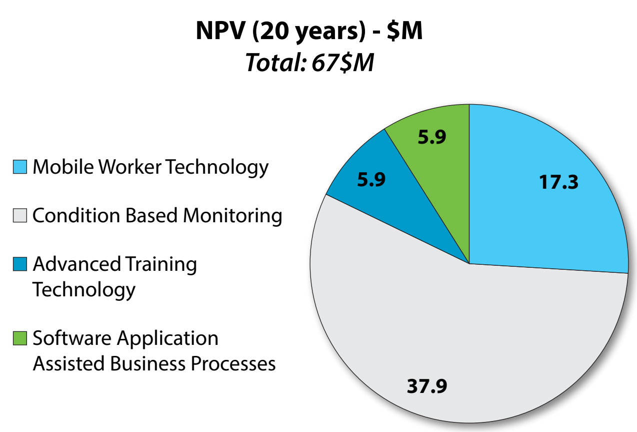
Improving Trust Between Operator and Artificial Intelligence Technologies for Decision-Making

The nuclear industry's adoption of Artificial Intelligence (AI) and Machine Learning (ML) must address performance, explainability, and trustworthiness. To secure operators' trust in AI/ML technologies, Light Water Reactor Sustainability Program researchers conducted research on approaches and applications to demonstrate how specific metrics, user-centric visualization and human-in-the-loop evaluations addressed these issues. POC: Vivek.Agarwal@inl.gov, and Cody.Walker@inl.gov

Aspects of AI technologies essential for decision-making

LWRS Program Successfully Demonstrates an Inspection Data Portal for Nuclear Power Plants

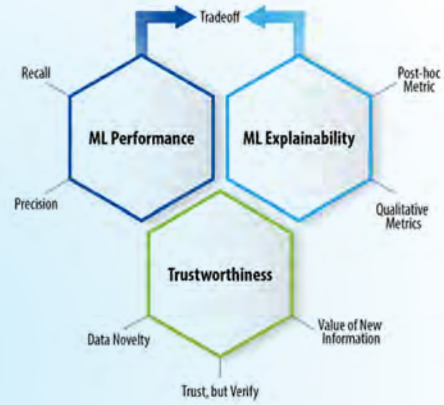
The LWRS Program developed a data portal for use by nuclear-industry-related organizations to facilitate coordination, data sharing, and reviews regarding compliance verification and demonstration. The portal uses MIRACLE to analyze plant performance using natural language processing and machine learning. In July 2023, the portal was demonstrated with real plant data from Xcel Energy. The Nuclear Regulatory Commission and the Nuclear Energy Institute provided feedback. The portal may be used to support an actual NRC inspection at Xcel Energy in 2024. POC: Ahmad.AlRashdan@inl.gov



An inspection data portal stores and processes data from nuclear power plants to enable efficient regulation by the NRC and assessment by other stakeholders.

Integrating new operation concepts and digital technologies to reduce nuclear plants costs

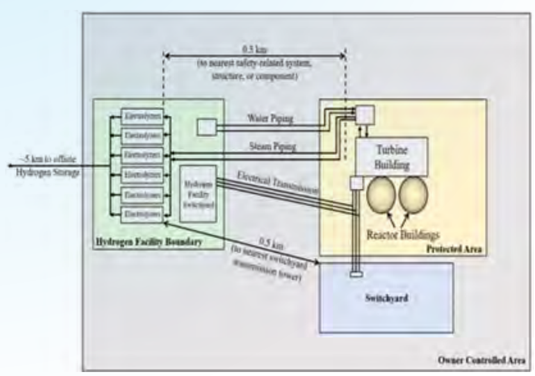
LWRS Program researchers led a Digital Infrastructure (DI) Business Case Analysis with Luminant Generation at Comanche Peak. Existing safety and non-safety instrumentation and control (I&C) systems were evaluated, including the impact of not upgrading these systems. The team is also integrating ION (Integrated Operations for Nuclear) with DI research. By integrating ION concepts into the DI, Luminant Generation was able to identify priority work reduction opportunities, that will result in significant cost reductions. POC: Ahmad.AlRashdan@inl.gov



Net Present Value of Priority Work Reduction Opportunities (Luminant Generation's Comanche Peak plant).

Hydrogen Regulatory Research and Review Group – Updated Results Nuclear Integrated Hydrogen Production

The group assessed a 500 MW hydrogen facility compared to a 100 MW facility previously assessed. Key findings concluded that: (1) there are minimal risk changes between the two cases, (2) designs above 500 MW may require a modified steam supply, (3) the safe separation distance between the nuclear power plant and the hydrogen facility could be significantly reduced, compared to current analysis methodologies. POC: Sherman.Remer@inl.gov



Layout of the nuclear power plant and hydrogen production facility.

RAVEN–Computational Platform Performing Stochastic Analyses Wins R&D 100 Award

RAVEN is an open-source software platform that facilitates and enhances a variety of model exploration, risk analyses and design optimizations for nuclear reactors, energy grids and other complex systems. Development of RAVEN has been funded by the Light Water Reactor Sustainability and Integrated Energy Systems Programs. POC: Diego.Mandelli@inl.gov

RAVEN

2023 R&D 100 WINNER

RAVEN is an open-source software platform that facilitates and enhances a variety of model exploration, risk analysis and design optimizations.

Recent LWRS Program Reports

Materials Research

- *Spread Spectrum Time Domain Reflectometry and Frequency Domain Reflectometry for Detection of Cable Anomalies Using Machine Learning*
- *Extended Bandwidth Spread Spectrum Time Domain Reflectometry Cable Test for Thermal Aging, Low Resistance Fault, and Water Detection*
- *The Mechanism of Irradiation Assisted Stress Corrosion Cracks in Stainless Steels*
- *Effect of thermal aging on microstructure and stress corrosion cracking behavior of Alloy 152 weldment*
- *Applying grain-boundary sensitive electrochemical scanning probe techniques to evaluate intergranular degradation of irradiated and deformed stainless steels*
- *Complete the first phase of the comprehensive characterization of repair welding performed on irradiated Ni alloy182 using stress improved laser welding in collaboration with EPRI*
- *Comprehensive Characterization of Helium-induced Degradation of the Friction Stir Weld on Neutron Irradiated 304L Stainless Steel*
- *FY23 Progress on Stress Corrosion Crack Testing of Ni-Base Alloys in PWR Primary Water*
- *Survey of Aging and Monitoring Concerns for Cables and Splices Due to Cable Repair and Replacement*

Plant Modernization

- *Assessment of Cloud-based Applications Enabling a Scalable Risk-informed Predictive Maintenance Strategy*
- *Digitalization Guiding Principles and Method for Nuclear Industry Work Processes*
- *Complete Evaluation of ION Cost Reduction Opportunities for LWRS Program Pathways*
- *Development of a Technical, Economic, and Risk Assessment Framework for the Evaluation of Work Reduction Opportunities*
- *Applying the ION Business Model to a Domestic Nuclear Plant: Assessment and Transformation Implementation Plan*
- *Development of Analysis Methods that Integrate Numeric and Textual Equipment Reliability Data*
- *Integrated Operations for Nuclear: Work Reduction Opportunity Demonstration Strategy*
- *Human and Technology Integration Evaluation of Advanced Automation and Data Visualization*
- *Pilot Business Case Analysis for Digital Infrastructure*
- *Human and Technology Integration Evaluation of Advanced Automation and Data Visualization*
- *Optimizing Information Automation Using a New Method Based on System-Theoretic Process Analysis: Tool Development and Method Evaluation*
- *FY23 ION-Based Approaches to Address Labor and Knowledge Retention*
- *Extending Data-Driven Anomaly Detection Methods to Transient Power Conditions in Nuclear Power Plants*
- *Explainable Artificial Intelligence Technology for Predictive Maintenance*
- *Technical Specification Surveillance Interval Extension Using Self-Diagnostics*
- *Optimizing Information Automation Using a New Method Based on System-Theoretic Process Analysis*

Risk-Informed Systems Analysis

- *Assessing the Impact of the Inflation Reduction Act on Nuclear Plant Power Uprate and Hydrogen Cogeneration*
- *Safety Analysis of FeCrAl Accident-Tolerant Fuels with Increased Enrichment and Extended Burnup for PWR*
- *Novel Approaches and Technologies for Aging Management*
- *An Integrated Framework for Risk Assessment of Safety-related Digital Instrumentation and Control Systems in Nuclear Power Plants: Methodology Refinement and Exploration*
- *Pressurized-Water Reactor Core Design Demonstration with Genetic Algorithm Based Multi-Objective Plant Fuel Reload Optimization Platform*
- *Tools and Methods for Optimization of Nuclear Plant Outages*
- *Methods and Feature Enhancements for Industry Use of EMRALD*
- *Development of Analysis Methods that Integrate Numeric and Textual Equipment Reliability Data*

Flexible Plant Operations & Generation

- *Preliminary Analysis and Evaluation of Thermal Stress Induced by High-Capacity Thermal Energy Delivery*
- *Evaluating Energy Storage Options and Costs for Consistent Energy Supply to Non-Electric Sectors*
- *Technical Economic Assessment of LWR-Supported Hydrogen Markets in Gulf Coast Regions*
- *Advancements in Development and Testing of Thermal Power Dispatch Simulators*
- *Comparison of Energy Storage and Arbitrage Options for Nuclear Power*
- *Impacts of Extracting 30% of Reactor Power from a Pressurized Water Reactor*
- *Expansion of Hazards and Probabilistic Risk Assessments of a Light-Water Reactor Coupled with Electrolysis Hydrogen Production Plant*
- *Report on the Creation and Progress of the Hydrogen Regulatory Research Review Group*
- *Estimating the Value of Nuclear Integrated Hydrogen Production and the Dependency of Electricity and Hydrogen Markets on Natural Gas*
- *Risk Analysis of a Hydrogen Generation Facility near a Nuclear Power Plant*

Physical Security

- *Special issue on Nuclear Physical Security Risk and Uncertainty Analysis*
- *Plant-Specific Model and Data Analysis using Dynamic Security Modeling and Simulation*

(Click on the report title to download the document.)

Editor: Gordon Holt
Designer: David Combs

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