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How to Flourish in the Age of Nuclear Renewal



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Nuclear power is more valuable today than it has ever been. While not a new notion among those who work in the domestic commercial nuclear power industry, the idea that nuclear power plants should and must continue safe, reliable, and economic operation has made significant inroads among policy-makers and experts nationwide. A brief look at the recent policy and regulatory events surrounding Diablo Canyon Nuclear Power Plant and the Inflation Reduction Act serve as an example of how far the nuclear industry has come in the eyes of governments and the public in the last two years.

With the future of nuclear power more secure now than it has been in decades, it is time to take a fresh look at business operating models in use in the United States (U.S.) commercial nuclear power industry. Over the last three years, Light Water Reactor Sustainability (LWRS) Program

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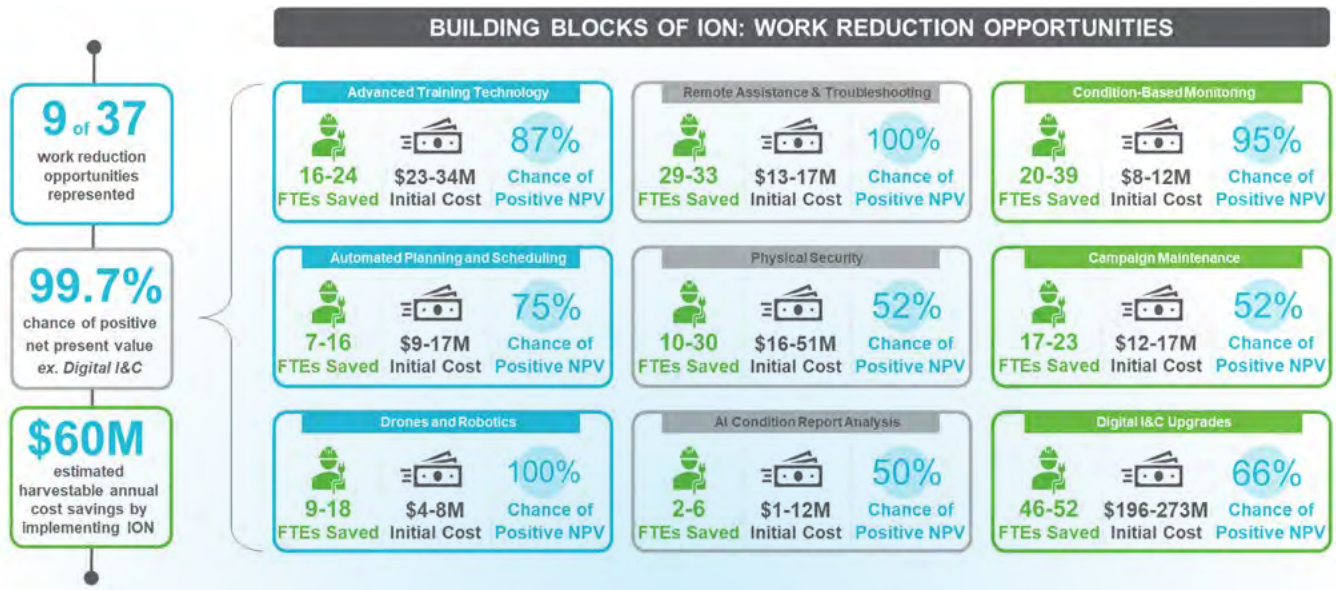

Figure 1. A sample of ION's work reduction opportunities and their benefits. The distribution of $60M is spread across all 37 items. The 99.7% mentioned, excluding Digital I&C, refers to the 9 out of the 37 items that we validated.

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researchers at Idaho National Laboratory (INL) have been doing just that. Business models for the operation of North Sea offshore oil platforms served as inspiration for research combining the capabilities and advantages of state-of-the-art technology, data, and automation into new organizational approaches to business operations when implemented at nuclear power plants and fleets.

Through this research, we are suggesting a new business operating model for domestic nuclear power plants called Integrated Operations for Nuclear (ION). ION achieves lower operation and maintenance costs by deploying digital technology and business process innovations.

The ION model represents an integrated, multi-year digital and operational transformation strategy that connects technologies building on capabilities of previously completed projects. This long-term integrated strategy is made possible by the significant policy support mentioned above, but also by the trend of license extensions that allow plants to operate for as many as sixty years or more.

Digital infrastructure and the modernization of plant systems and processes are not the only advantages of ION. The building blocks of the ION model are what researchers are calling work reduction opportunities. Each work reduction opportunity represents a category of changes to processes and potentially plant equipment. Automated planning and scheduling or training modernization are examples of two work reduction opportunities that focus on automating and digitizing existing plant processes making them more efficient and effective with fewer person-hours required.

The suite of thirty-seven work reduction opportunities, which constitute projects included in the ION business model, is described in *Process for Significant Nuclear Work Function Innovation Based on Integrated Operations Concepts* (INL/EXT-21-64134). This report, developed by LWRS Program researchers and the nuclear business experts at ScottMadden Management Consultants provide estimates of potential cost and expected savings for each work reduction opportunity.

However, greater fidelity was needed for the cost and benefit estimates to assure the industry of sound analysis. Researchers verified initial costs and savings estimates with multiple utilities implementing these projects. Personnel were interviewed and project information was collected for efforts underway at Xcel Energy, Dominion Energy, Detroit Edison, Constellation, Duke Energy, Southern Company, Luminant, and NextEra Energy. LWRS Program researchers were also able to gather meaningful insights and data from industry sources such as the Nuclear Energy Institute, the Electric Power Research Institute, and Sandia National Laboratories.

Estimates and industry validation of these work reduction opportunities indicate significant operational and maintenance savings when implemented as a complete strategy. Figure 1 shows business cases and probabilities of a positive net present value for individual work reduction opportunities. It also shows the aggregate probability of achieving a positive net present value of the suite of projects. The full analysis and results of the research can be found in *Integrated Operations for Nuclear Business Operation Model Analysis and Industry Validation* (INL/RPT-22-68671).

As the domestic commercial nuclear power industry incorporates recent legislation into corporate strategies and business unit long-range plans, leaders will be thinking first and foremost of maintaining safe and reliable nuclear production for the decades to come. Thoughts of nuclear power plant cost-competitiveness, system obsolescence, and worker retention will dominate conversations and thoughts in the coming years as well.

The need for long-range planning will be even more important when considering a plant's approved or planned license extension to sixty and eighty years. The LWRS Program's ION business model can serve this scenario as a well-researched and vetted starting point for nuclear operators.

Safe, reliable, and financially sound nuclear generation is more important than ever. The ION business model is designed to facilitate an industry poised to flourish in this age of nuclear renewal.

References:

1. Remer, S. J., 2022, Integrated Operations for Nuclear Business Operation Model Analysis and Industry Validation, INL/RPT-22-68671, August 2022, Idaho National Laboratory, Idaho Falls, ID, USA.
2. Remer, S. J., K. Thomas, S. Lawrie, L. Martin, and C. O'Brien, 2021, Process for Significant Nuclear Work Function Innovation Based on Integrated Operations Concepts, INL/EXT-21-64134, August 2021, Idaho National Laboratory, Idaho Falls, ID, USA.

LWRS Program Hosts Halden Human Technology Organization (HTO) Project Annual Board Meeting, Uniting Worldwide Experts at Idaho National Laboratory

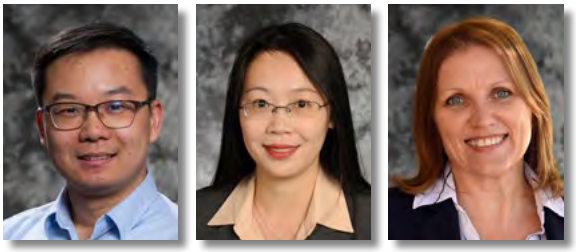
The LWRS Program hosted the annual Halden Human-Technology-Organization Project board meeting on May 9-10, 2023. This significant event brought together research program directors from various countries affiliated with Halden, facilitating valuable exchanges of ideas and expertise.

The meeting agenda encompassed a wide array of crucial subjects, including Human Performance, Control Room Design & Evaluation, Human-Automation Collaboration, Digital Systems for Operations & Maintenance, Digital I&C – Safety Assurance, and Cyber Security for Main Control Rooms. Notably, a demonstration conducted in the Human System Simulation Laboratory served as an integral part of the proceedings and a basis for an embedded workshop during the week.

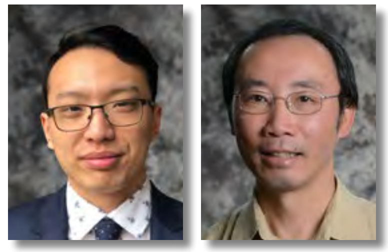
In addition to the technical discussions, participants also spoke about the most pressing issues in their respective countries or organizations. This included licensing and regulatory concerns, plant siting, water utilization and balancing electrical generation with energy production for industrial users.

Halden HTO Program Annual Board meeting included participants from 19 countries, both virtually and in-person.

Identification of Software Common-Cause Failures in Digital I&C Systems at Nuclear Reactors



Han Bao, Sai Zhang, Svetlana Lawrence
Risk-Informed Systems Analysis Pathway



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Most existing nuclear power plants in the U.S. were designed in the 1970s and 1980s using analog and relay components, as well as limited digital technology for monitoring, control, and protection functions. As the industrial base moves to digital systems for monitoring and control, the maintenance of analog systems at nuclear power plants has become challenging due to the lack of spare parts, increasing replacement costs, and limited vendor support. Compared with existing analog instrumentation and control (I&C) systems, digital I&C systems have significant functional advantages, such as reliable system performance in terms of accuracy and computational capability and high-capacity data-handling and storage capabilities to fully measure and display operating conditions. Therefore, in the last few years, the U.S. nuclear power industry has initiated the replacement of existing aging analog systems with digital I&C technology.

A key challenge faced in the transition from legacy analog systems to digital I&C systems is the need to address and mitigate possible common-cause failures (CCFs). A CCF is the occurrence of two or more failure events due to the simultaneous occurrence of a shared failure cause and a coupling factor (or mechanism). Today, most safety-grade I&C systems at a nuclear power plant are designed with redundancy and/or various diversity types (e.g., design and functional diversity) to provide several ways of detecting and responding to a significant event, so that no common part and no single failure mechanism can result in a failure to detect or actuate a safety function when needed. But with a digital I&C system, the software could be employed in both primary functional areas, as well as the backup. Certain CCFs cannot be readily detected, as failures from analog systems are not directly transferable to digital systems, which impedes the licensing of advanced control systems. Existing failure identification approaches in conventional probabilistic risk assessment (PRA) lack the capability to assess why and how digital I&C systems can fail. Digital I&C systems can integrate previously separate analog systems [1], which makes it difficult to identify the source and evaluate potential consequences of CCFs. This has resulted in a disconnect between PRA model predictions and operational environments, where software failures may occur because the causes could not be anticipated and modeled.

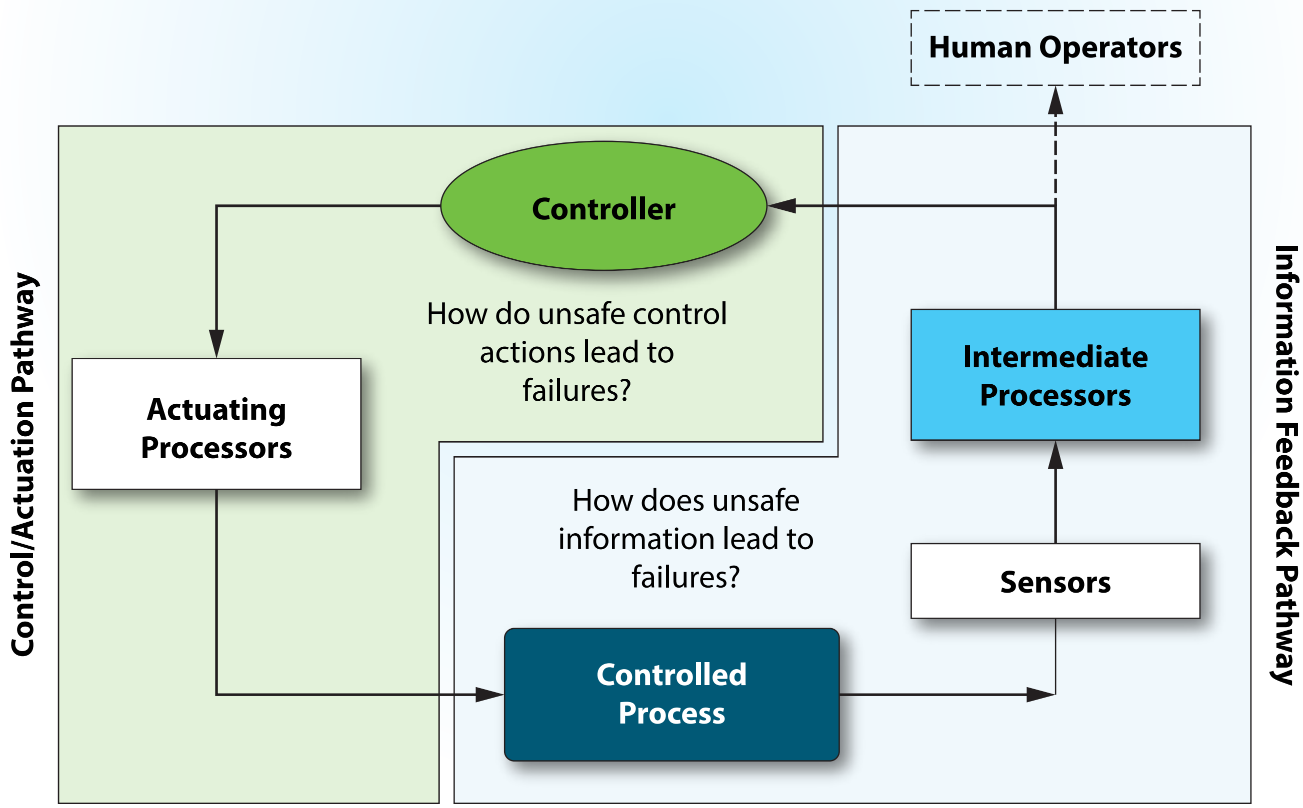
The LWRS Program Risk-Informed Systems Analysis (RISA) team is developing a framework for digital I&C risk assessment that provides a technical basis to identity and evaluate software CCFs in digital I&C systems due to unintended design or implementation defects [2]. The framework assesses such systems by considering the following: (1) in what ways can the system fail; (2) how likely is a failure event to occur; and (3) how does it impact stakeholder goals and ultimately the safe operation of a nuclear power plant. To assess how the system can fail, the framework focuses on the identification of failures and mechanisms leading to these failures, both when nuclear plant operators provide inputs to their controls (actuation pathway) and when the information is transmitted (information feedback pathway). Two types of software failure modes are possible. The first type of failure results in an errant controller action and is defined as an unsafe control action (UCA). The second type of failure is due to corrupted or counterfactual information from intermediate digital processors (e.g., analog-to-digital converters). This type of failure mode is defined as an unsafe information flow (UIF) [2]. In Figure 2, a model control loop is provided to show where UCA and UIF can be produced, as well as the flow of data.

The introduction of UIF allows digital I&C designers and software engineers to describe how errant data can lead to undesirable behavior by controllers or human operators of the system. While both UCAs and UIFs are considered independent software failure events, they can also be used to identify errant CCF events within redundant digital I&C systems. This novel approach has been demonstrated in the qualitative assessment of the human system interfaces in nuclear power plant digital I&C systems. The areas of concern associated with these digital components can be mitigated by eliminating causal factors for independent and CCF events. Detailed findings can be found in [2]. In essence, by tracing relevant failures, this approach aims to: (1) systematically isolate areas of potential risk; and (2) provide targets for future risk quantification for reliability assessment. The latest research accomplishments were presented at the Pressurized Water Reactor Owners Group (PWROG) meeting in August 2022. In addition, the LWRS Program RISA team is currently collaborating on a PWROG project to identify and quantify potential CCF events.

References:

1. NRC, 2021, Guidance for Evaluation of Defense in Depth and Diversity to Address Common-Cause Failure due to Latent Design Defects in Digital Safety Systems, Branch Technical Position 7-19, U.S. Nuclear Regulatory Commission, Washington, D.C., USA.
2. Bao, H., S. Lawrence, J. Park, H. Ban, E. Chen, N. Dinh, A. V. Jayakumar, C. Elks, H. Zhang, E. Quinn, S. Zhang, and T. Shorthill, 2022, An Integrated Framework for Risk Assessment of High Safety-significant Safety-related Digital Instrumentation and Control Systems in Nuclear Power Plants: Methodology and Demonstration, INL/RPT-22-68656, August 2022, Idaho National Laboratory, Idaho Falls, ID, USA.

Figure 2. Information pathways in a digital I&C system.



Electrochemical Microprobes Reveal Irradiation Damage in Nuclear Alloys

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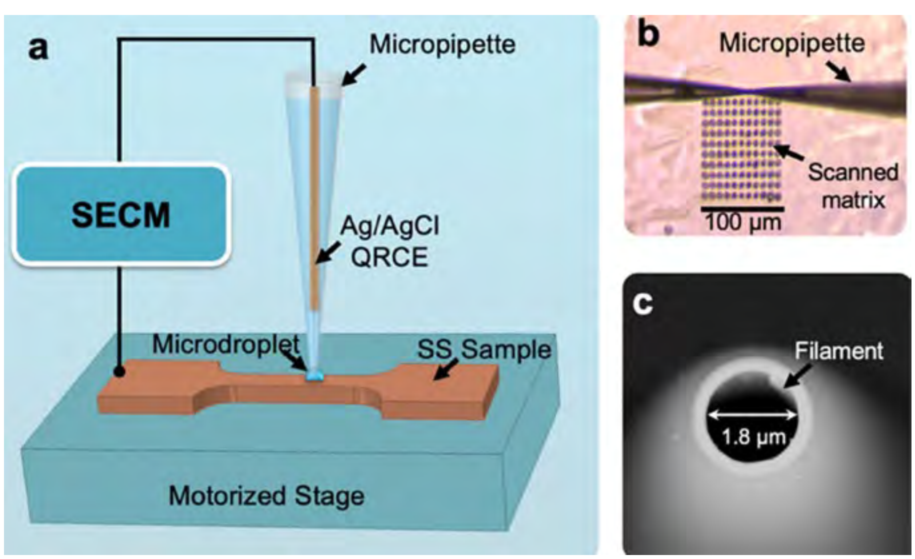
Los Alamos National Laboratory

Materials Research Pathway

Alloys have been developed to function in aggressive environments, such as nuclear power plants, nuclear waste disposal facilities [1], and others. In such environments, alloys may experience corrosion [2], irradiation, and deformation across scales [3, 4], or more uniquely, stress corrosion cracking (SCC) and irradiation-assisted stress corrosion cracking (IASCC) [5, 6]. Transformative damage detection technologies are needed not only to predict and prevent catastrophic failure in nuclear constituents, but also to screen next-generation alloys that are resistant to complex and aggressive environments.

Under the work scope of the materials research pathway, the University of California–Los Angeles (UCLA) has developed glass microprobes with nano-to-micrometer openings and filled them with electrolyte and filament electrodes, as observed in Figure 3. The microprobes were used to perform scanning electrochemical microscopy (SECM) and to profile corrosion activity in nuclear alloys. This technique, most significantly, discloses regions subjected to SCC and IASCC in scans take only seconds to minutes. For instance, as observed in Figure 4(a) and Figure 4(b), the microprobe resolved strain-induced microstructures and their enhanced corrosion activity; features that in general can lead to SCC initiation. Moreover, the microscope can also reveal irradiated microstructures that are of reduced corrosion resistance.

Figure 3 (a) A schematic of the microprobe setup developed using SECM. (b) An optical photo showing the matrix of microdroplets during a scan in progress. (c) A scanning electron microscopy (SEM) image of the filamented borosilicate micro-pipette used in this study.



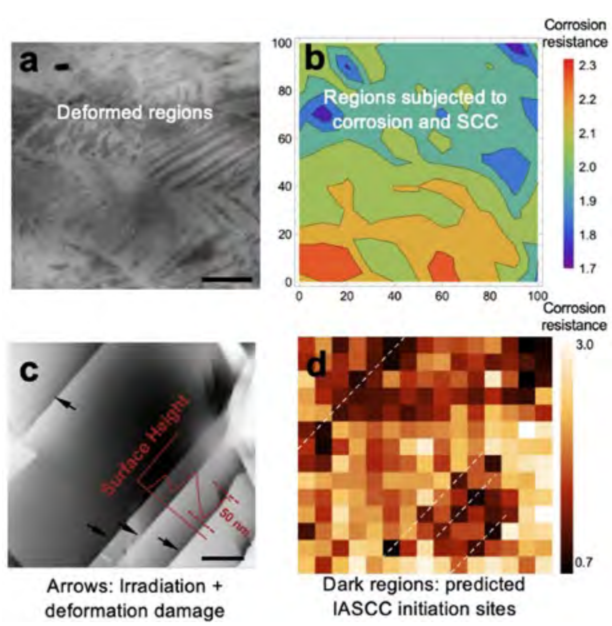
In other words, it is discovered that the more an alloy has been exposed to radiation, the less resistant to corrosion it is. Therefore, the technique can be used to forecast IASCC initiation in alloys that are deformed and damaged under irradiation, as observed in Figure 4.

Currently, the team has been pushing the resolution limit of this microprobe technique to interrogate nanoscale features, such as grain boundaries and dislocation channels, as indicated in Figure 4(c) and Figure 4(d). By doing so, very early stage irradiation-induced damage and cracking can be resolved. Furthermore, due to the high-throughput and high-resolution nature of this technique, in-reactor probes to survey reactor components during maintenance shutdowns are being developed. Finally, the microprobe technique can be used to provide accurate corrosion examinations with fast turnaround times, as well as to screen next-generation nuclear alloys for new, advanced reactor designs.

References:

1. Cattant, F., and D. Crusset, 2008, "Corrosion issues in nuclear industry today," Materials Today, 11(10), 32–37.
2. Chen, X., M. Gussev, M. Balonis, M. Bauchy, and G. Sant, 2021, "Emergence of micro-galvanic corrosion in plastically deformed austenitic stainless steels," Materials & Design, 109614.
3. Gussev, M. N., and K. J. Leonard, 2019, "In Situ SEM-EBSD analysis of plastic deformation mechanisms in neutron-irradiated austenitic steel," Journal of Nuclear Materials, 517, 45–56.
4. Gussev, M. N., K. G. Field, and J. T. Busby, 2014, "Strain-induced phase transformation at the surface of an AISI-304 stainless steel irradiated to 4.4 dpa and deformed to 0.8% strain," Journal of Nuclear Materials, 446 (1–3), 187–192.
5. Matsubara, N., T. Kobayashi, K. Fujimoto, Y. Nomura, N. Chigusa, and S. Hirano, 2011, "Research programs on SCC of cold-worked stainless steel in Japanese PWR NPP," In International Symposium Fontevraud, Vol. 7, p. A099.
6. Takakura, K., K. Nakata, M. Ando, K. Fujimoto, and E. Wachi, 2007, "Lifetime evaluation for IASCC initiation of cold-worked 316 stainless steels' BFB in PWR primary water," In Proceedings of the 13th Int. Conference on Environmental Degradation of Materials in Nuclear Power Systems.
7. Was, G. S., D. Farkas, and I. M. Robertson, 2012, "Micromechanics of dislocation channeling in intergranular stress corrosion crack nucleation," Current Opinion in Solid State and Materials Science, 16(3), 134–142.

Figure 4. The scanning microprobe technique reveals: (a) strain localization; and (b) corrosion susceptibility in a deformed nuclear alloy. (c)-(d) The same technique was applied to predict IASCC susceptible regions [7] in a nuclear alloy that was deformed and damaged under irradiation. The scale bars are 20 µm in length.



CARBON – Ensuring Availability of Wireless Networks

John Anthony B. McVay
Physical Security Pathway

There is a growing need for modern, robust protective networks to guard critical infrastructure or other assets from physical intrusion and attack. These networks must often be deployed where location or time constraints make it impractical to install hardwired data communications by trenching and burying cable. Notable examples include remote or temporary locations and sites with difficult or inaccessible terrain.

A goal of the LWRS Program's Physical Security Pathway is to enable a wireless capability that can provide the framework for continuous, jam-proof, remote-monitoring, and ultimately remote operations of digital systems for both physical security (e.g., sensors, cameras, communications) and safety (e.g., remote-monitoring and operations) at nuclear power facilities. LWRS Program researchers at Sandia National Laboratories have developed a secure and robust communications networking solution, CARBON, which provides highly reliable wireless communications. Just as adding carbon to iron makes hardened, robust steel in networking, joining CARBON network processors to commercial off-the-shelf wireless technologies creates hardened and robust networks. CARBON is ideal for a wide range of applications, including ad hoc wireless networks with limited mobility, fixed-site physical security systems, and rugged-terrain applications.

CARBON supports any communications technology that can send and receive data via a standard Ethernet cable (wired or wireless), enabling the platform to meet a wide range of site-specific needs, as observed in Figure 5. CARBON processors carry large data volumes, such as high-definition live video feeds, as well as different types of sensor and assessment data. Platform-specific alarms, events, and logs provide situational awareness of network health. CARBON can offer the following benefits when it comes to security, versatility, and efficiency.

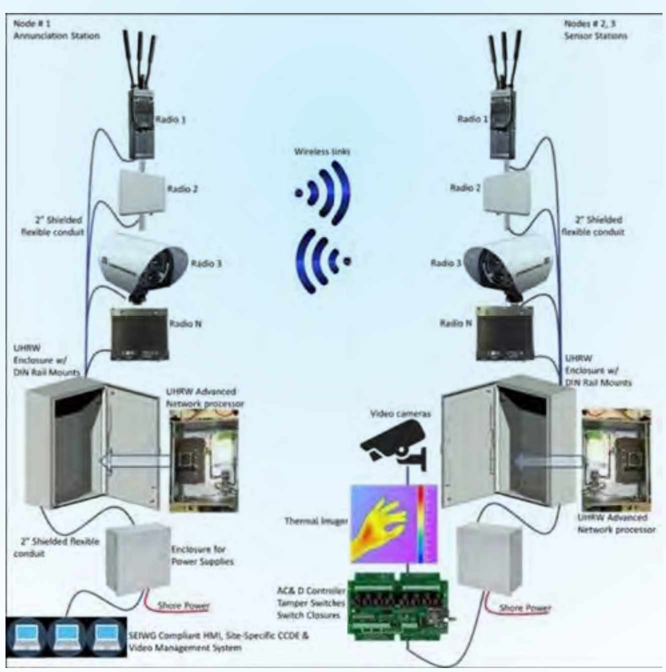
Security

The main goal of CARBON is to approach the security and reliability associated with hardwired communications. CARBON is highly reliable and jam-resistant through its deployment of multiple, redundant, and widely diverse communication layers. CARBON data is protected using the latest Commercial National Security Algorithm Suite encryption, which protects not only against eavesdropping on transmitted data, but also provides mitigations against cyber-threats.

Versatility

Because CARBON supports multiple, redundant wireless technologies, CARBON is adaptable to all terrain types, and

Figure 5. Commonly deployed network components.



supports communications over rocky, mountainous terrain, as well as in, around, and over bodies of water. CARBON-specific information, such as state of network health or firewall violations, are output in a Security Equipment Integration Working Group (SEIWG)-compliant format meaning that CARBON-specific alarms are plug-and-play with any SEIWG compliant command and control alarm station, and thus, no further system integration would be necessary. CARBON supports various radio types and topologies (e.g., radio-frequency, optical, mesh, point-to-point, point-to-multipoint), and can even support wired infrastructure, such as copper or fiber, where such hardwired infrastructure might already exist.

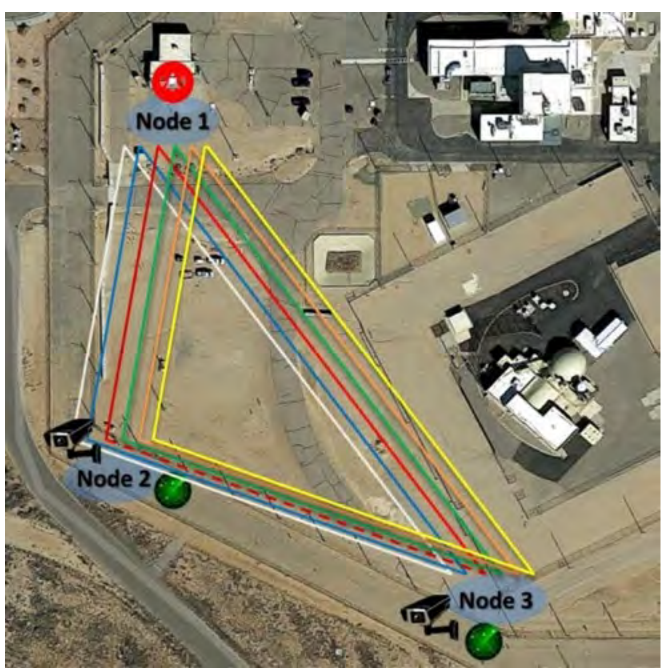
Efficiency

Since CARBON supports wireless infrastructures, it can provide lower initial installation costs, as well as recurring maintenance and upgrading costs to that of buried infrastructure. Adding redundancies or upgrading equipment can be accomplished simply and effectively. CARBON's ability to provide Power-over-Ethernet (PoE) to the utilized equipment reduces complexity when employing PoE-compliant equipment. CARBON provides the capacity to integrate future technologies and capabilities. Additionally, CARBON can offer unique features including:

- Redundant underlay networks mitigate against communication jamming/interference and denial-of-service attacks, as can be seen in Figure 6.
- Monitoring underlay networks for situational awareness.
- Support of multiple mesh radios, point-to-multipoint, optical, and radio-frequency point-to-point wireless links actively transmit and receive video and alarm data, as well as CARBON-specific data and alarms.
- Reporting when a network is jammed, congested, or is otherwise interfered with.
- Reporting unauthorized traffic attempts on the network (i.e., cyber-attack attempts).
- Reliable communications in RF-denied environments (e.g., during counter-unmanned arial system mitigations).
- Reducing potential insider threat vulnerabilities through containerized admin configuration access.
- Configurations via industry-standard Network Configuration Protocol.
- The capability of meeting site-specific needs related to radio-frequency spectrum backgrounds, data rates, topologies, and configurations.

Through further research and development, LWRS Program could apply CARBON to provide a range of highly reliable wireless communications along with other advantageous capabilities, such as continuous health monitoring of security systems. An initial pilot study of the CARBON wireless capability will be conducted at a collaborating nuclear power plant site in 2023, which will help better understand current issues and constraints.

Figure 6. Multiple, redundant underlay networks.



Cleaning the Transportation Sector with Hydrogen from Nuclear Power Plants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Flexible Plant Operation and Generation


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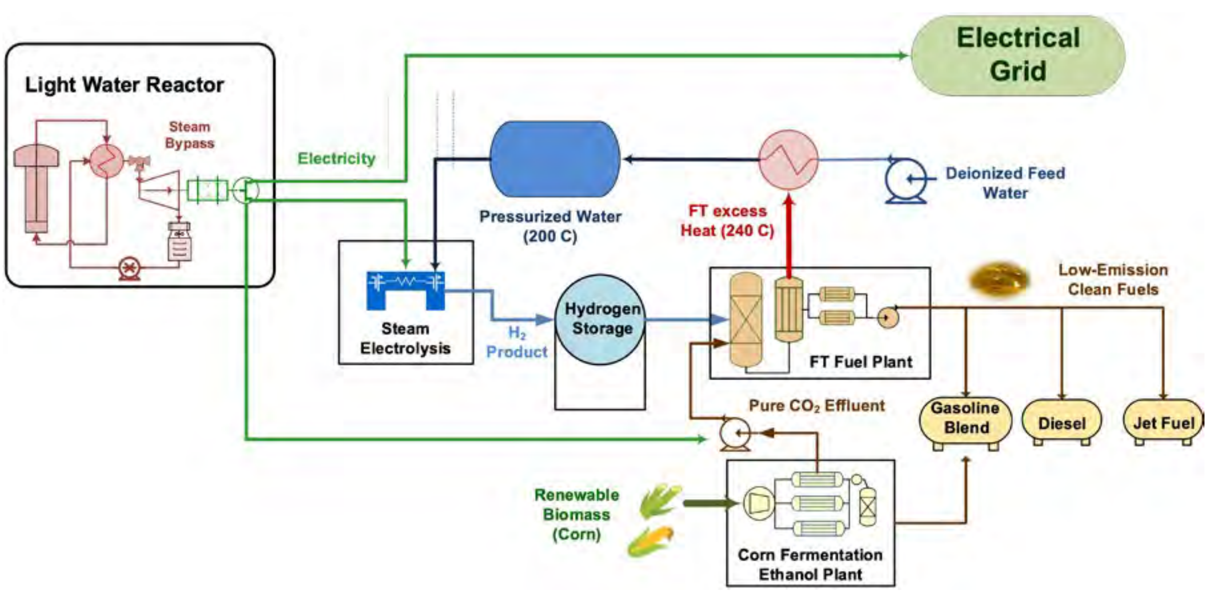
In 2019, the LWRS Program embarked on technical and economic assessments of hydrogen (H_2) production by directly coupling nuclear power plants to a new technology referred to as high-temperature electrolysis (HTE). These assessments indicate nuclear plants will eventually be able to produce H_2 at DOE's 2026 target for under $2 per kilogram when purchasing electricity for around $30 per megawatt-hour (MWh e) and when using HTE [1]. Unlike low-temperature water-splitting electrolysis, HTE splits steam into molecular H_2 and oxygen (O_2). The steam for HTE can be conveniently produced from water using heat provided by a nuclear power plant. Each kg of hydrogen produced using HTE requires approximately 37 kWh of electric power and 6.4 kWh of thermal energy. Therefore, approximately 15% of the energy required for HTE can be provided in the form of heat, which reduces the quantity of the more expensive electrical power required to produce H_2 and O_2 via electrolysis. A preliminary design for thermal energy extraction and electrical power distribution to a commercial-scale HTE plant was recently completed by an architecture/engineering firm [2].

The Inflation Reduction Act (IRA) provides up to a $3 per kilogram production tax credit for clean H_2 for the first ten years of operation for a project beginning before 2033. This will help stand up the first commercial H_2 projects that are connected to a nuclear plant. This, in turn, will help reduce the cost of manufacturing electrolysis modules so future projects can be competitive with conventional H_2 production from natural gas. Water-splitting electrolysis produces pure H_2, which can then be used for many applications, such as electricity production through fuel cells and ammonia production—an important chemical used to manufacture fertilizer. Clean H_2 is being pursued as an approach to help decarbonize the manufacturing and transportation sectors too. Not only is H_2 required to refine petroleum fuels, but it can also be used to convert carbon sources, such as biomass and CO_2 into transportation fuels. And it can be used to replace most of the fossil fuels that are used to produce iron, steel, and glass.

A recent economic study by Argonne National Laboratory (ANL) and INL evaluated the potential for using the H_2

Figure 7. Nuclear hydrogen and associated FT fuels plant.



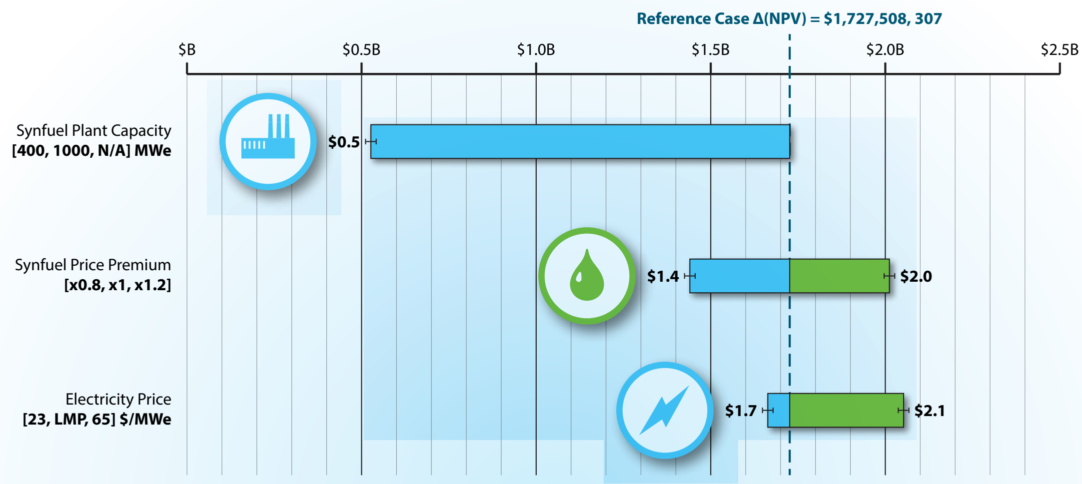


Figure 8. Nuclear based synfuel production sensitivity analysis of NPV.

to synthesize clean fuels to replace diesel and jet fuel produced by petroleum crude [3]. The basis for this study is the well-proven Fischer-Tropsch (FT) synfuels process for synthesizing liquid hydrocarbon fuels from hydrogen and a carbon source. The FT process was first developed by Germany and has more recently been implemented in South Africa and Qatar. Figure 7 shows how the H_2 produced by the nuclear plant is fed to an FT plant. In this case, excess heat from the FT plant can be used to produce the steam feed stream that is split into H_2 and O_2 by HTE. The ANL/INL study evaluated the cost of collecting and transporting the CO_2 that is normally released from corn ethanol plants as the carbon source for the synfuel production process [4]. The study assumed a nuclear power plant would sell heat and electricity to the FT plant at the same price it would get for selling electricity to the electricity grid market. This is referred to by the power industry as the Locational Marginal Price. The sale of FT fuels was set at the projected price of regular gasoline and diesel fuels for the next 20 years. Finally, the increase in profit for the nuclear plant was calculated with a term referred to as the Net Present Value (NPV). The NPV includes the cost of interest paid to an investor willing to fund the project. A typical 10% weighted average cost of capital representing the combined cost of interest to service debt and the rate of return to equity investors was used in this study.

By taking advantage of the clean hydrogen production tax credits available from the recently passed IRA, the analysis shows a 1,000 MWe nuclear-powered H_2 and synfuels plant that collects CO_2 from regional ethanol plants to produce over 10,000 barrels of synthetic fuel daily could reap approximately $1.7 billion more profit over the life of the project as compared to only selling electricity, as observed in Figure 8. The net profit increase would drop to around $0.5 billion for a smaller plant that uses only 400 MWe of power and produces 4,400 barrels of fuel per day. The net profit could be slightly higher or lower depending on the states where the fuel is sold. California and a few other states currently award credits to clean fuels; however, in the Southeast where most refineries are located, the selling price of fuels is generally lower. The sensitivity to both the fuel and electricity market prices is shown in Figure 8.

Because the transportation fuels market is large and could take decades to transition completely to electrical vehicles and hydrogen fuel cell trucks, there appears to be a strong market opportunity in the foreseeable future to produce non-petroleum clean transportation fuels.

References

1. Wendt, D., and L. T. Knighton, 2022, High Temperature Steam Electrolysis Process Performance and Cost Estimates, INL/RPT-22-66117, March 2022, Idaho National Laboratory, Idaho Falls, ID, USA.
2. Sargent & Lundy, Nuclear Power Plant Pre-Conceptual Design Support for Large-Scale Hydrogen Production Facility, Report SL-016181, Project No. A14248.005, November 2022.
3. Zang, G., P. Sun, H. E. Delgado, V. Cappello, C. Ng, and A. Elgowainy, 2022, The Modeling of the Synfuel Production Process: Process Models of Fischer-Tropsch Production with Electricity and Hydrogen Provided by Various Scales of Nuclear Plants, ANL/ESD 22/8, March 2022, Argonne National Laboratory, Lemont, IL, USA.
4. Wendt, D., M. Garrouste, W. D. Jenson, Q. Zhang, M. S. Roni, F. Joseck, T. H. Bhuiyan, and R. D. Boardman, 2022, Production of Fischer-Tropsch Synfuels at Nuclear Plants, INL/RPT-22-69047, September 2022, Idaho National Laboratory, Idaho Falls, ID, USA.

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Technical Integration Office

- *Light Water Reactor Sustainability Program Overview and Accomplishments Report - 2022*

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- *Dose Rate Effects on Degradation of Nuclear Power Plant Electrical Cable Insulation at a Common Dose*
- *Frequency Domain Reflectometry (FDR) Simulation Techniques for Digital Twin Representation of an Electrical Cable*

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- *Integrated Operations for Nuclear Business Operation Model Analysis and Industry Validation*

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- *Summary of Technical Peer Review on the Risk Assessment Framework proposed in Report INL/RPT-22-68656 for Digital Instrumentation and Control Systems*

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