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Structural Health Monitoring to Automate Monitoring and Condition-Based Inspection of Concrete Structures in Nuclear Power Plants

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Concrete structures in nuclear power plants may be affected by a variety of degradation mechanisms over time. Structural health monitoring (SHM) is an established approach to assess the condition of structures and provide high confidence, actionable information regarding structural integrity and reliability. Using a SHM approach may enable nuclear power plants to replace or augment current inspection-based aging management plans with online monitoring capabilities and condition-based inspections of concrete structures. Using an effective SHM approach will provide important information on structural integrity and reliability to support subsequent license renewal.

Currently, researchers from the Light Water Reactor Sustainability (LWRS) Program and Vanderbilt University are investigating alkali-silica reaction (ASR) in concrete, a chemical degradation process that occurs between the alkali hydroxides in the pore solution and the reactive non-crystalline (amorphous) silica found in many common aggregates in a moist environment. This reaction occurs

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over time and causes the expansion of the altered aggregate by the formation of a swelling gel of calcium silicate hydrate, referred to as ASR gel. In the presence of water, the ASR gel increases in volume and exerts an expansive pressure inside the material, thereby causing transition from micro to macro cracking. As a result, ASR reduces the stiffness and tensile strength of concrete, two properties that are particularly sensitive to micro cracking.

Typically, SHM consists of four stages: (1) detection; (2) localization; (3) assessment; and (4) prediction. An SHM approach based on vibro-acoustic modulation (VAM) testing is utilized to assess the condition of a medium-sized concrete specimen with dimensions of $2 \times 2 \times 0.5$ ft^3, as shown in Figure 1. The medium-sized concrete specimen was cast and cured at the Laboratory for Systems Integrity and Reliability at Vanderbilt University, and contained four types of aggregates at known locations, including three coarse aggregates known to be susceptible to ASR, as well as pure silica powder (see Figure 1). This specimen was placed in an environmental chamber maintained at 60°C and 95% relative humidity to accelerate ASR degradation.

In a VAM test (see Figure 2), the structural component of interest, which is the concrete specimen, is excited simultaneously at two frequencies, while the dynamic response (acceleration) is measured at various locations using sensors (accelerometers). A low-frequency input is termed the "pump" and a high frequency input is termed the "probe." The dynamic response of the structure is used to diagnose (detect) the presence or absence of any degradation. If the dynamic response contains side bands (see Figure 3), it is inferred that measurable degradation is present in the structure; otherwise, the structure has no measurable degradation.

The next step after detecting degradation is localizing the damage. To address this challenge, it was hypothesized that the spatial distribution of the relative magnitude of a sideband-based damage index, such as the sum of sideband amplitudes (AmpS1 + AmpS2), could be used to localize degradation sites on the concrete specimen.

This hypothesis was tested by performing a VAM test in the laboratory using different test parameters, including pump and probe frequencies, pump and probe excitation amplitudes, and their locations on the concrete sample. Accelerometers were distributed uniformly on the surface of the concrete sample to record the dynamic response of the structure for each test parameter setting during VAM testing. The data collected for different parameter settings was used to develop a set of damage maps.

Different test parameter combinations resulted in the identification of different possible ASR damage locations, thereby introducing uncertainty in the localization of the degradation site. To overcome this challenge, Bayesian data fusion was utilized to assimilate the diagnostic information from the VAM tests. Figure 4 shows two damage maps generated for two different test parameter settings and how the fused damage map using Bayesian

Figure 1. Casting of medium-sized concrete sample with pockets of reactive aggregates. Numbers in the red box indicate sites where visual cracks were seen after a year of curing and accelerated ASR degradation.

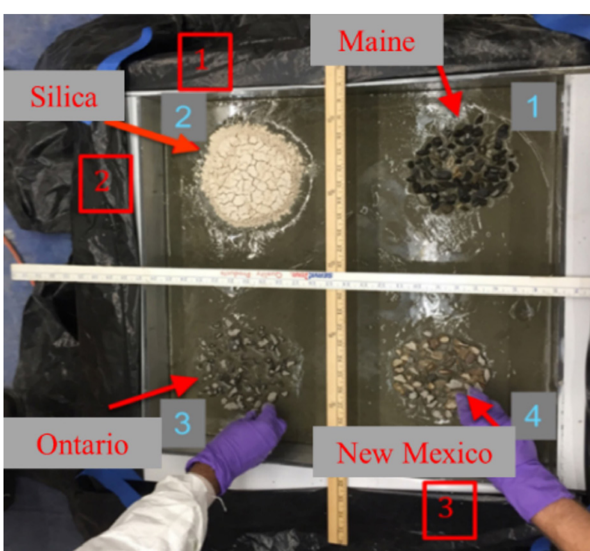
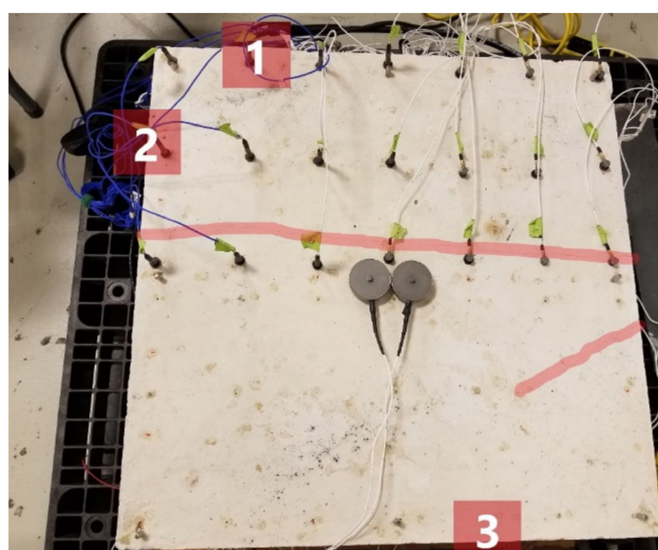


Figure 2. VAM experimental setup with degradation sites identified (marked in red).



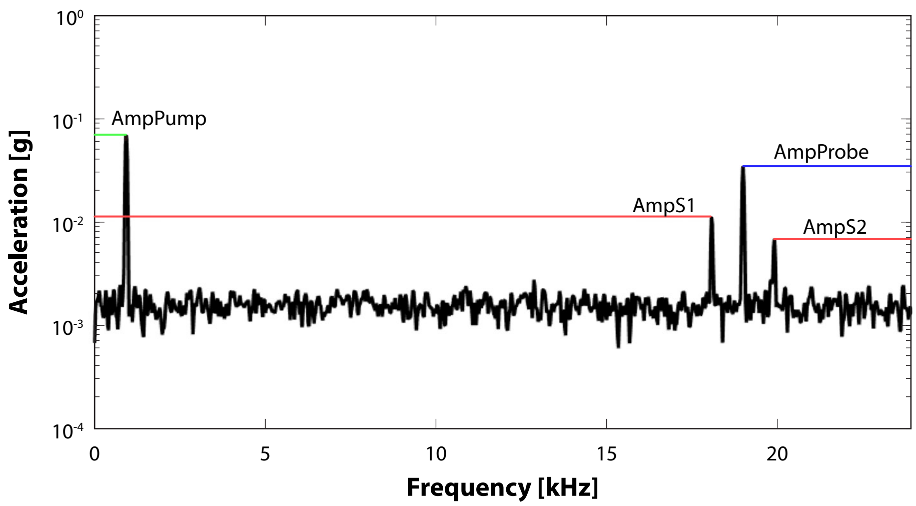


Figure 3. The dynamic response showing sidebands around the probing frequency.

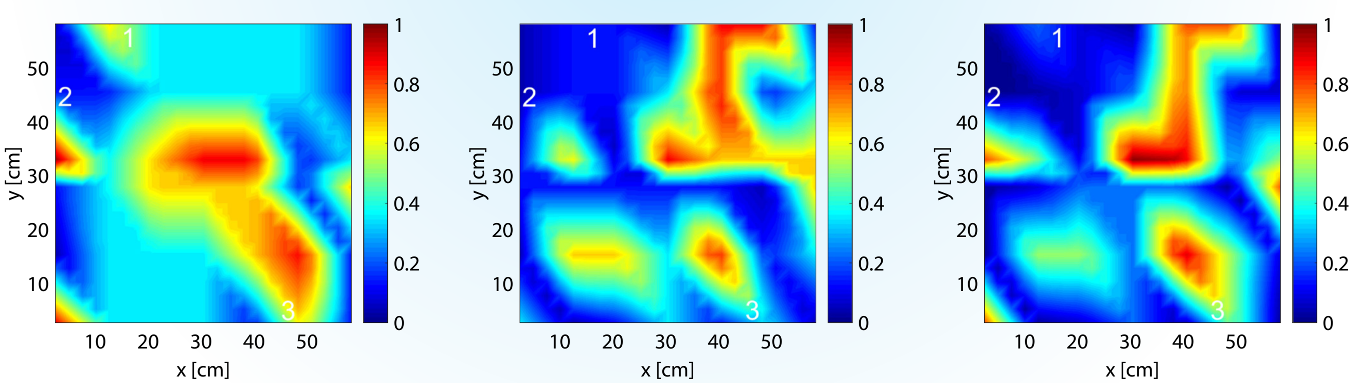
approach preserved the salient features from each damage map to generate an accurate degradation site localization. The degradation sites identified by the fused damage map were validated using the knowledge on known aggregate sites and visible degradation observed on the concrete specimen.

This example shows that the application of Bayesian data fusion enhances the assessment and prediction capability of the SHM approach. The progress achieved in the research and development of VAM based SHM approach to detect and predict concrete degradation has contributed significantly in enhancing the state of the art of monitoring structures. The approach is generic and can be extended to monitoring vital concrete structures in nuclear power plants with minor modifications and enable online monitoring to ensure performance assurance.

As path forward, for the degradation of interest (ASR in this case), develop a prediction capability, followed by a demonstration and an implementation strategy for concrete SHM to support automation and remote monitoring is required.

Establishing the extent of degradation at the identified site and predicting the future state of the concrete specimen are the topic of ongoing research in the current year.

Figure 4. Bayesian-fusion results for the different VAM test parameter settings for pump frequency set at 920 Hz and probe amplitude set at 250 mV. (Left): Probe frequency of 16 kHz. (Middle): Probe frequency of 20 kHz. (Right): Bayesian fusion of the results from (left) and (middle).



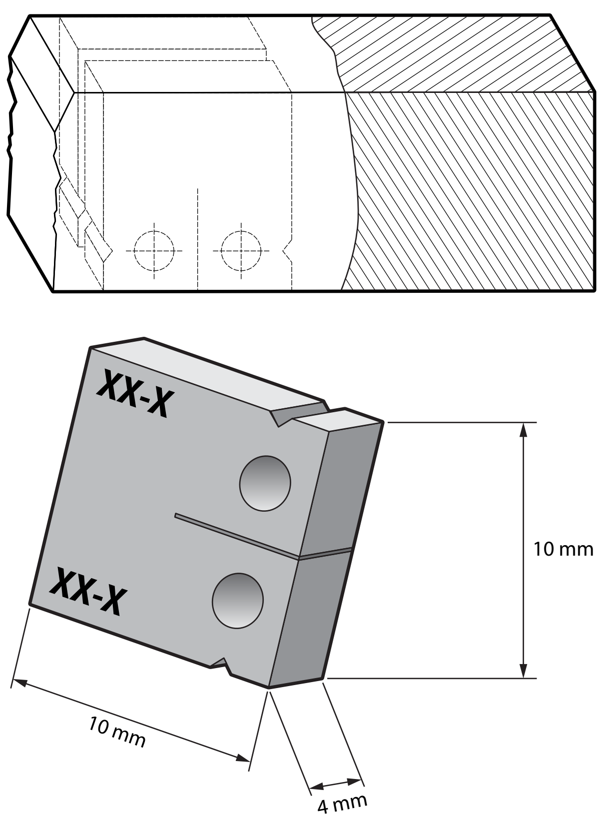
Validation of Mini Compact Tension Specimens for Fracture Toughness Characterization of Reactor Pressure Vessel Steels

Mikhail A. Sokolov
Materials Research Pathway

Surveillance capsules located inside the reactor pressure vessels (RPV) of commercial reactors can achieve faster radiation damage exposures than the wall of the RPV, providing insight into the future performance of the vessel ahead of the actual vessel. The Charpy V-notch specimen is the most commonly used specimen geometry in surveillance programs and most likely to be used in advanced reactors as per American Society of Mechanical Engineers (ASME) code. However, fracture toughness assessment of these materials requires indirect correlations to the Charpy impact specimens that may result in potential bias of the test data, especially at very high fluences that are of interest for extended operating life conditions.

Any fracture toughness specimen that can be made from the broken halves of standard Charpy specimens may have exceptional utility for evaluation of RPVs since it would allow one to determine and monitor directly actual fracture toughness. Mini-CT specimens are becoming an accepted geometry for use in the RPV community for direct measurement of fracture toughness in the transition region using the Master Curve methodology, as per American Society for Testing and Materials (ASTM) Standard E1921, for evaluating RPV integrity. The advantage of the Mini-CT specimen technique is coming from a similar net shape as the standard Charpy specimen and can be made from a broken half of a previously tested Charpy specimen, from a standard RPV surveillance capsule. Although it is a very small specimen, the thickness of this Mini-CT specimen is sufficient to fit in a very narrow validity limit window allowed by ASTM E1921. Figure 5 illustrates the layout of Mini-CT specimens within a broken Charpy half, as well as the overall dimensions of the Mini-CT specimen. In this example, it is shown that, typically, two Mini-CT specimens can be machined from one broken half of a surveillance weld metal Charpy specimen and four Mini-CT specimens of a surveillance base metal Charpy specimen.

Figure 5. Layout of Mini-CT within a broken Charpy half of surveillance weld metal and overall dimensions of Mini-CT specimen.



Up until now, the validation of Mini-CT specimens has been performed on non-irradiated base metals, and only recently has limited work been performed on weld metals, which can produce more sample variability and can be more sensitive to aging effects. Expanding on this early work, the LWRS Program set out to validate Mini-CT specimens uses on a weld material with reduced impact properties (low upper-shelf) in both unirradiated and irradiated conditions. This type of RPV beltline weld can be a limiting material for controlling the extended life of the current fleet of U.S. reactors. The low upper-shelf Linde 80 weld, designated WF-70, has been selected for this study. This weld was utilized in the Midland Reactor Unit 1 beltline weld and has been previously well characterized at the Oak Ridge National Laboratory (ORNL) with various conventional fracture toughness specimens in both unirradiated and irradiated conditions. The latter fact is critical because it made this study efficient by reducing the need to perform a large testing program with conventional specimens and without the need to perform an expensive irradiation campaign. To complete this task, an informal international partnership was formed, with acknowledged contribution from Drs. Masato Yamamoto from Central Research Institute of Electric Power Industry (CRIEPI), Robert Carter from the Electric Power Research Institute (EPRI), William Server from ATI Consulting, and Brian Hall from Westinghouse. Without their invaluable contributions, this project would have been hard to accomplish.

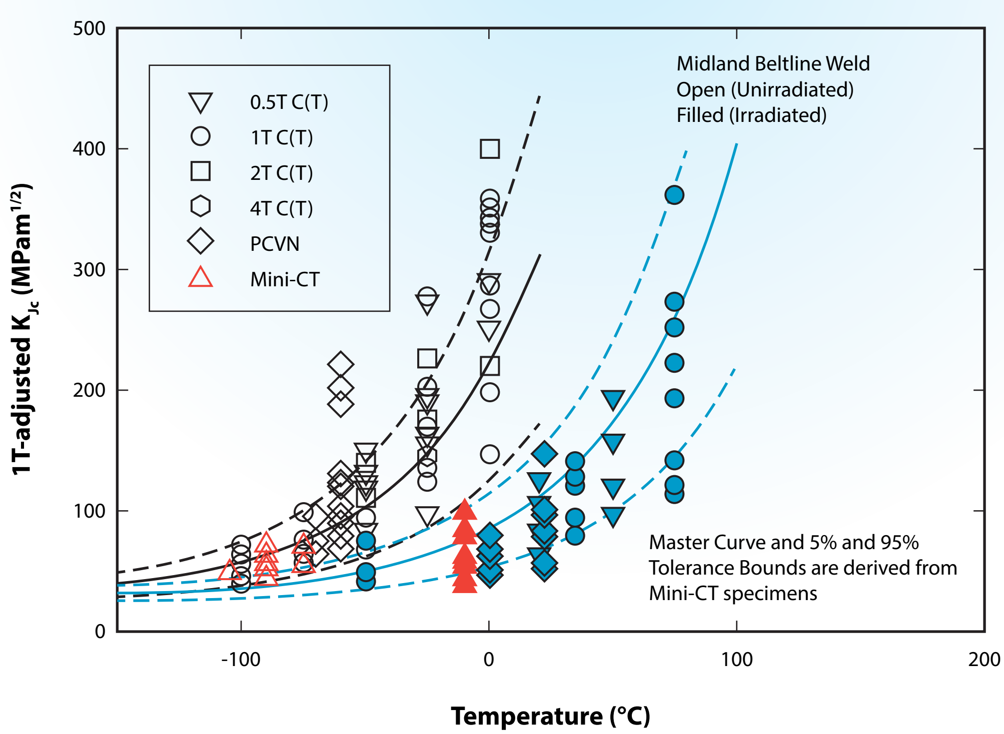
Figure 6 illustrates 1-T adjusted fracture toughness data of a Midland beltline weld WF-70 from the present studies with larger specimens in the unirradiated and irradiated conditions and compared with data as derived using Mini-CT specimens. These results (see the red color) are superimposed on the fracture toughness database for the Midland WF-70 weld previously produced by LWRS Program researchers at ORNL using conventional specimens in both the unirradiated and irradiated conditions. Overall, the transition temperature (To) values derived from a relatively small number of Mini-CT specimens in this study are in remarkable agreement with values from previously reported fracture toughness data. The Master Curve and 5% and 95% tolerance bounds are based on current study Mini-CT data and envelop the scatter exhibited on a large set of variously sized conventional specimens over a wide temperature range. At the same time, this study indicated areas that need to be addressed in the current ASTM E1921 Standard, which require future development and/or clarification for adopting this small specimen for wide use in surveillance specimen testing such that the Mini-CT specimen would provide a powerful tool for direct fracture toughness characterization of RPV material using already available Charpy surveillance specimens, thus enabling industry to better assess RPV integrity through reducing potential bias and uncertainties. The lessons learned from the Materials Research Pathway study also have application to other industries where important decisions are needed, but only limited material is available for testing.

Reference

1. D. E. McCabe, R. K. Nanstad, S. K. Iskander, R. L. Swain, "Unirradiated Material Properties of Midland Weld WF-70," NUREG/CR-6249 (ORNL/TM-12777), 1994.

Contact Mikhail A. Sokolov (sokolovm@ornl.gov) for more information and full list of references.

Figure 6. Fracture toughness data of unirradiated and irradiated Midland beltline weld from the present study using Mini-CT specimens and conventional specimens in [1]. Master Curves and Tolerance bounds are derived from Mini-CT data only.



Study Finds LWR Electricity–Hydrogen Hybrids May Improve Profitability

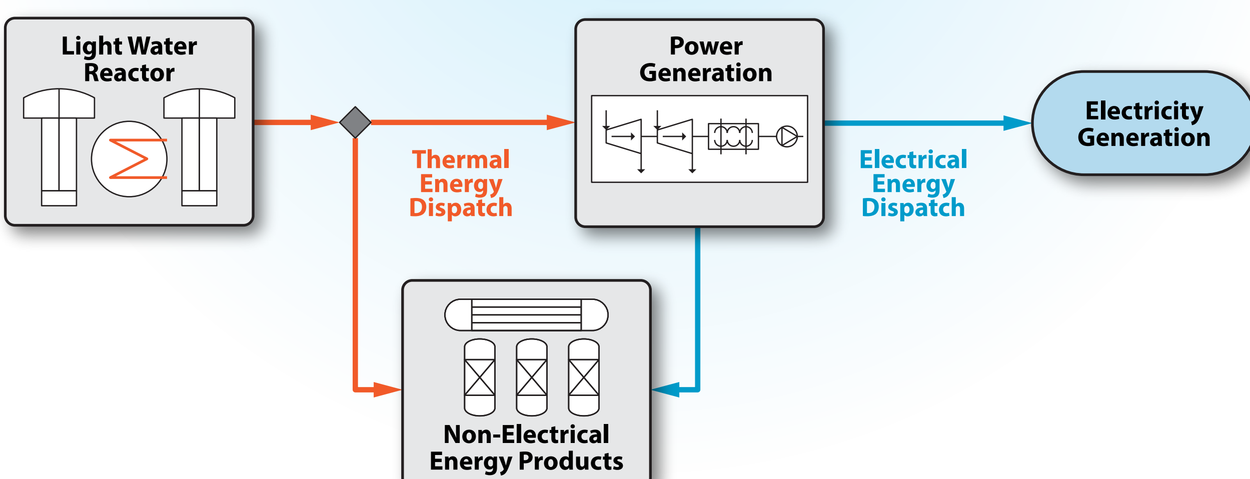
Richard D. Boardman
Integrated Energy Systems Initiative

The LWRS Program recently completed a comparative study that finds existing nuclear power plants located in the Midwest can increase their profitability by switching between electricity production and hydrogen (H_2) generation. Figure 7 illustrates how a H_2 plant could be coupled to an existing nuclear plant. This may help nuclear power plants increase their revenue at a time when wholesale electricity prices have fallen to historically low levels. Together with significant contributions from collaborating national laboratories and Strategic Analysis, Inc, the LWRS Program recently completed an in-depth technical and economic assessment of a new business model for a candidate light-water reactor (LWR). The assessment focuses on developing a new market from LWR operations based on coproduction of non-electrical-based products, such as H_2 or other valuable chemicals, by directly using the steam or electricity produced by the nuclear reactor. During periods when the wholesale price of electricity is high, the nuclear power plant can shift to selling electricity to the grid, while reducing the production of H_2 or the other chemicals. This mode of dispatching energy for the production of more than one energy commodity is referred to as a hybrid plant. The idea is to maximize the profitability of the nuclear power plant by selling electricity or steam directly to the secondary user on a schedule that allows both the nuclear power plant and the associated energy user to be profitable.

This study evaluated the market case for producing H_2 in the Upper Midwest. Currently, there is a growing market for clean-burning fuel-cell-powered vehicles. H_2 fuel cell forklifts are becoming popular for warehouse and cargo distribution centers where combustion engine emissions can be a problem. And because H_2 fuel cell vehicles can operate for longer periods of time than electric-battery vehicles, both cars and heavy-duty trucks powered by fuel cells are starting to emerge as society desires to transition clean energy from wind and solar farms to the transportation sector. Nuclear power plants that produce H_2 can also produce clean, zero-emissions energy for the transportation and other sectors. The study found that nuclear power plants can produce H_2 for under \$2.00 per kilogram once emerging electrolysis technology becomes commercially available. Each kilogram of H_2 has the equivalent energy of one gallon of gasoline; however, a typical fuel cell car may be driven 60–70 miles on one kilogram of H_2. The overall U.S. Department of Energy (DOE) goal is to produce, deliver, and sell H_2 at filling stations for around \$4.00 to \$7.00 per kilogram for fuel-cell vehicles to be competitive with the gasoline-fueled automobiles driven today.

Large industrial users of H_2 could also reduce their emissions using H_2 from nuclear power plants. These include fertilizer producers, petroleum and synthetic-fuels producers, and steelmakers. H_2 is combined with nitrogen to make ammonia-based fertilizers, such as ammonium nitrate and urea. Millions of tons of H_2 are used by refineries to produce gasoline and diesel fuel. H_2 can also be used to convert carbon dioxide into important chemicals like methanol or to make synthetic lubricants and fuels. In addition, it can also be used to reduce iron ore to a form of iron that can be refined in an electric arc furnace to produce high-quality iron and steel materials. These are just some examples of H_2 markets that are growing as domestic and foreign demand for each of these

Figure 7. Nuclear Power Plant Hybrid Concept.



chemical products and materials continues to rise. The H_2 price target for these industries ranges from about $1.00 per kilogram for competitive steelmaking up to $2.00 per kilogram for fertilizers produced with clean-energy sources.

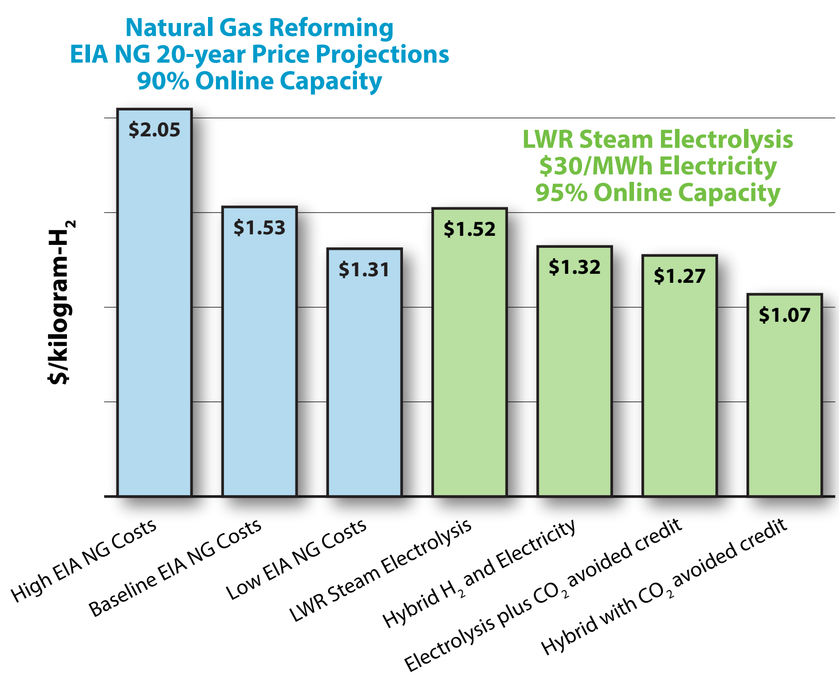
The approach taken by the study was to compare the cost of producing H_2 using the energy from an LWR against a conventional process that converts natural gas into H_2 through natural-gas reforming with steam. The latter uses up to one-third of the natural gas to produce the required steam and heat necessary for the process; the remaining two-thirds goes into the H_2 product. The nuclear electricity-H_2 hybrids could use either low-temperature alkaline, polymer electrolyte membrane, or high-temperature steam electrolysis to split water into H_2 and oxygen. Natural-gas reforming results in carbon dioxide emissions. Water or steam electrolysis with electricity and steam provided by the nuclear power plant would be free of pollutant emissions.

The study identified two business opportunities for LWR-supported electrolysis. One case is for smaller plants that could produce H_2 for fuel-cell-vehicle filling stations. In this case, low-temperature electrolysis plants are competitive with natural-gas reforming plants. The second case is for industrial plants that use a large amount of H_2. In this case, steam electrolysis was shown to be competitive with large-scale natural-gas reforming plants. The study assumed that H_2 produced near a nuclear power plant would be compressed and put into a pipeline to be sent to end users as far away as 15 miles.

Figure 8 presents H_2 production costs for a large scale, 500 tonne per day, plant based on natural gas reforming versus steam electrolysis. The study found that H_2 can be produced for just over $1.50 per kilogram by either steam electrolysis or a natural-gas reforming plant based on cost projections by the Energy Information Agency (EIA) for high, baseline, and low natural gas price scenarios. The value of H_2 produced by electrolysis with steam and electricity provided by the nuclear power plant considered the value of reducing carbon emissions, as well as a modest capacity payment for sending electricity to the grid during periods when electricity demand is relatively high. A $25 credit for each tonne of CO_2 avoided relative to natural-gas reforming could reduce the cost of H_2 produced by electrolysis by $0.25 per kilogram. For the grid conditions used for this evaluation, a hybrid plant sending electricity to the grid just less than 2% of the year, with a realistic capacity payment, could independently reduce the price of H_2 by $0.20 per kilogram. The combined benefits could reduce the cost of the H_2 produced by the nuclear power plant to around $1.07 per kilogram. This would be game-changing for H_2 markets and would provide incentive to build LWR electricity H_2 hybrids in several places.

This study aligns with Crosscutting Technology Development Integrated Energy Systems research and development activities under the DOE Initiatives Program Offices for Nuclear Energy and Energy Efficiency/Renewable Energy. It complements analysis activities being conducted by the Energy Efficiency and Renewable Energy Fuel Cell Technology Office under an initiative referred to as H_2@ Scale. The LWRS Program is presenting detailed results of this study to LWR owners and operators, H_2-using industries, and electrolysis-technology providers to help promote partnerships that can demonstrate the technical feasibility of the hybrid systems.

Figure 8. Cost of hydrogen production and delivery 500 tonne per day plant.



Overview of Light Water Reactor Sustainability Physical Security Initiative

F. Mitch McCrory
Physical Security Initiative

The LWRS Program initiated a nuclear power plant Physical Security Initiative in August 2018.

Physical security of nuclear power plants is an important aspect of maintaining a safe, secure, and reliable nuclear energy fleet. Physical security programs at U.S. nuclear sites started to ramp up to meet changes in their design basis threat (DBT) in the early to mid-1980s. The events of September 11, 2001 saw more changes to the DBT and significant increases of physical security at nuclear power plant sites. As U.S. nuclear power plants modernize their infrastructure and control systems to move past their original operating licenses, an opportunity exists to apply advanced tools, methods, and automation to modernize their physical security programs leveraging their benefits. These benefits include higher fidelity models that should remove some conservatisms in their security models, leverage automation as force multipliers, improve the optimization of their security postures, and risk-informed methods for use in evaluating security changes.

Figure 9. Sensor configurations evaluated by Sandia National Laboratories for the U.S. Government.

This initiative will leverage advances in modeling and simulation, sensor technologies, risk management tools, automation, and other technologic advances to advance the technical bases necessary to modernize and optimize physical security capabilities. This initiative will include efforts in the following areas:

- Conduct research and development on aspects of risk-informed techniques for physical security to account for a dynamic adversary.
- Apply advanced modeling and simulation tools to better inform physical security scenarios.
- Assess benefits from proposed enhancements, novel mitigation strategies, and potential changes to best practices, guides, or regulation.
- Enhance and provide a technical basis for stakeholders to employ new methods, tools, and technologies to achieve physical security.

To ensure that the LWRS Program Physical Security Initiative is focused on stakeholders' outcomes, the program is creating a working group, which is scheduled to meet September 10–11, 2019, at Sandia National Laboratories (SNL) in Albuquerque, New Mexico.

The Physical Security Initiative started its outreach to U.S. nuclear power plant stakeholders in January 2019 with a site visit to a nuclear power plant by LWRS Program-sponsored physical security and reactor system subject matter experts and held a first-of-its-kind industry training on security provided by the U.S. DOE National Laboratories. This training was held in March 2019 at SNL (see Figure 9) and provided a week-long physical security training course that included participants from the Nuclear Energy Institute, the Electric Power Research Institute, staff from operating nuclear utilities, and other DOE National Laboratory security experts. The course included instruction, hands-on examples, and field exercises for physical security technologies, modeling, and DOE security enhancements. This inaugural training was attended by representatives from 14 U.S. utilities. This training course was adapted from an SNL security course that has been provided to other physical security experts for over ten years. The training also introduced the new LWRS Program Physical Security Initiative to many of the stakeholders and was used as an opportunity to obtain feedback from course participants.

Meet the New Materials Research Pathway Lead

I am pleased to announce that Dr. Thomas M. (Tom) Rosseel has agreed to serve as the Materials Research Pathway Lead. He is a Senior Research Staff Member and Senior Program Manager in Oak Ridge National Laboratory's (ORNL's) Materials Science and Technology Division, as well as a member of the Nuclear Structural Materials Group. Tom received his Ph.D. in Physical Analytical Chemistry from the University of Wisconsin, where he used synchrotron radiation to explore the oxidation states of transition metal oxides. He was awarded a Wisconsin Alumni Research Foundation Fellowship for this research. He also received his B.S. in Chemistry at the University of Michigan, where he was twice awarded the Moses Gomberg Undergraduate Chemistry Prize.

Thomas (Tom) M. Rosseel
ORNL

Dr. Rosseel, who has worked at ORNL for more than 30 years, has managed numerous research projects and programs—including serving as the Deputy Materials Research Pathway Lead for concrete, cable, non-destructive evaluation, and Zion Unit 1 harvesting research tasks. He also managed the U.S. Nuclear Regulatory Commission Heavy-Section Steel Irradiation Program. He has performed research in a number of areas including heavy-ion-induced x-ray studies; positron spectroscopy; the effects of radiation on minerals, aggregates, cement, and concrete; and the effects of radiation on (RPV) steels. As a member of the Materials Research Pathway, he led the effort to harvest RPV base and weld metal from the decommissioned Zion Unit 1 nuclear power plant to study the attenuation of radiation-induced embrittlement. Tom also led the formation of the International Committee on Irradiated Concrete, an organization that provides a forum for broad technical interactions on the effects of irradiation on concrete used in nuclear facilities, storage, and disposal sites, and promotes international collaborations to accelerate efforts to understand and model radiation effects on concrete.

Bruce P. Hallbert
Director, LWRS Program Technical Integration Office

U.S. Energy Department invests in Advanced Remote Monitoring Project

Eric Williams
Plant Modernization Pathway

How do you simultaneously modernize several power plants that all have unique characteristics, are highly regulated, produce mountains of data that's typically drawn from multiple distinctive analog plant systems and not uniformly organized, and operate on razor-thin margins?

In short, you combine technological advancements with human cooperation, executed by a really smart team with a passion for improvement.

That's the essence of the Advanced Remote Monitoring (ARM) project undertaken by the Utilities Service Alliance, Inc. (USA) and Idaho National Laboratory, under the Department of Energy's U.S. Industry Opportunities for Advanced Nuclear Technology Development program. DOE is investing more than $9 million in the effort, while USA will contribute more than $4 million over three years.

"Huge amounts of data exist in a nuclear power plant," explained Ahmad Al Rashdan, LWRS Program senior research and development scientist at INL. "You can use it to automate manual activities. It can improve performance. It can also allow operators to predict plant issues or equipment failure way ahead of time. You can plan for failures and use this knowledge to optimize plant work activities and reduce operating cost."

The nation's current nuclear power reactor fleet was built on processes and technologies from several years ago, said Clint Carter, who ran Luminant's groundbreaking Power Optimization Center and is now a loaned executive to USA in charge of Fleet Modernization. "Meanwhile, contemporary technologies are providing opportunities to automate data collection, analytics and reporting, and help us automate our traditional business processes in a way to improve their efficiencies – all while preserving nuclear safety."

John Christensen, USA's president and CEO, credits Luminant and Carter for laying the groundwork. "They're as experienced with applying this type of technology as any nuclear operator in the world, and they've worked

Figure 10. The Advanced Remote Monitoring project was co-developed by Ahmed Al Rashdan, an LWRS Program senior R&D scientist, working in INL's Human Systems Simulation Laboratory.

a lot of the bugs out," he said. In particular, Luminant used this general approach to problem-solving at its generating plants over the last 15 years, including its one nuclear station, Comanche Peak in Texas. "We're primarily single-unit operators – we aren't part of a large nuclear fleet," Christensen said of USA, a nonprofit membership organization based in Kansas.

One of USA's strengths is examining a complicated challenge and developing a systematic approach to tackling it. "We started by selecting pilot programs from the industry Efficiency Bulletin document list, selecting items identified as easy, medium, and hard to implement," he said. Under Carter's direction, USA has assembled a 10-person team from across its membership to work with scientists and professionals at INL for three years focusing on four stations, along with Luminant's Power Optimization Center:

- Talen Energy's Susquehanna Station, Pennsylvania
- Xcel Energy's Monticello Plant and Prairie Island Plant, Minnesota
- Energy Northwest's Columbia Station, Washington
- Luminant's Comanche Peak Nuclear Power Plant, Texas

While those stations will be the first to reap the benefits – and to go through the process of working the bugs out – Christensen stressed the learnings will be deployed across USA's membership. INL will analyze and develop the technologies to collect and analyze plant data and share the experience and outcome of the effort with the nation's nuclear power fleet.

Examples of factors being examined abound, with one being thermal performance. "Nuclear power plant operators know they're losing energy or revenue because of thermal losses. This loss can be tracked and reduced," Al Rashdan said. Another area of focus is the process of facility workers doing their rounds. "The operator has to walk around, visually monitor plant activities or equipment and instruments (much of it analog instruments), and report back," he said. "It's a significant amount of time."

Also in the equation is finding an array of sound, safe ways to cut costs and thus ensure the nuclear generators are competitive – and continue running. Of course, automation can be accompanied by staff reductions, and the USA-INL team is keenly attuned to having the ARM project be part of a smooth transition as large numbers of employees in this sector near retirement.

"It's far better for people to retire through normal means than for a plant to shut down and everyone loses their jobs all at once," Christensen said.

And a good way to do that "is to look at all the data they already have in their plants, optimize their operations using this data, and perhaps save millions of dollars a year," Al Rashdan noted.

"I am firmly convinced that nuclear power can compete head-to-head with any other electric generating source through the application of advanced technologies," said Carter. "We owe it to our nation and to future generations to preserve this most phenomenal source of safe, clean and reliable energy."

PECASE Announcement

Plant Modernization Pathway Researcher Vivek Agarwal at Idaho National Laboratory won the Presidential Early Career Award for Scientists and Engineers (PECASE). Agarawal had his LWRS Program research and development highlighted as part of his application for this award.

White House news release

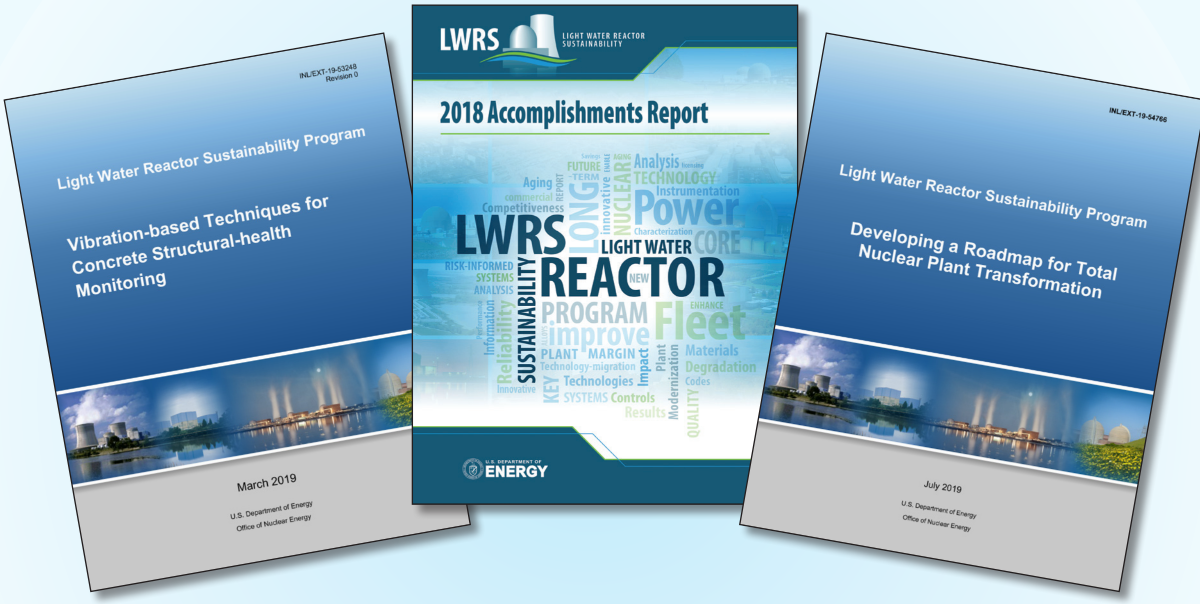
Vivek Agarawal
Plant Modernization Pathway

Fellow Announcement

Materials Research Pathway researcher Zhili Feng at Oak Ridge National Laboratory was elected fellow of the International Institute of Welding last spring. Feng's election was in recognition of his "lifetime achievement through distinguished contributions to the field of welding science and technology" and for supporting the field's stature.

Zhili Feng
Materials Research Pathway

Recent LWRS Program Reports



Technical Integration Office

- *Light Water Reactor Sustainability Program 2018 Accomplishments Report*

Materials Research

- *Material Condition Effects on Stress Corrosion Crack Initiation of Cold-Worked Alloy 600 in PWR Primary Water Environments*

Plant Modernization

- *Vibration-based Techniques for Concrete Structural-health Monitoring*
- *Developing a Roadmap for Total Nuclear Plant Transformation*

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

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