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Light Water Reactor Sustainability Program

Plant Modernization Pathway

FY 2018 Summary Report on Industrial and Regulatory Engagement Activities

September 2018

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FY 2018 Summary Report on Industrial and Regulatory Engagement Activities

Ken Thomas

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Idaho National Laboratory
Light Water Reactor Sustainability Program
Idaho Falls, Idaho 83415

http://www.inl.gov

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Abstract

The Plant Modernization Pathway of the Light Water Reactor Sustainability (LWRS) Program conducts a vigorous engagement strategy with the U.S. nuclear power industry, including the nuclear operating companies, major support organizations, the Nuclear Regulatory Commission (NRC), and suppliers. The goal of this engagement strategy is to develop a shared vision and common understanding across the nuclear industry of the need for plant modernization, the performance improvement that can be attained, and the opportunities for collaboration to enact this vision.

In FY 2018, the vision, strategy, and project work was communicated to a number of key organizations, including the major industry support organizations, and a number of important industry conferences that are attended by leaders in nuclear plant modernization. This report presents the specific engagement activities that occurred in FY 2018 to promote awareness and participation by the nuclear power industry in the activities of the Plant Modernization Pathway.

Acknowledgements

Industrial and Regulatory Engagement is a shared activity among the research staff of the LWRS Program Plant Modernization Pathway, involving all of those who interact with utility partners, industry support groups, industry suppliers, Nuclear Regulatory Commission staff, and other industry stakeholders. In particular, the author would like to thank the following Pathway research staff members who were instrumental in making this engagement highly effective during FY 2018 and for their contributions to this report: Shawn St. Germain, Dr. Katya Le Blanc, Jeffrey Joe, Dr. Romald Boring, Dr. Vivek Agarwal, Dr. Ahmad Al Rashdan, Dr. Andrei Gribok, Casey Kovesdi, Zachary Spielman, Rachael Hill, and Johanna Oxstrand.

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Acronyms

ANS	American Nuclear Society
ASME	American Society of Mechanical Engineers
ASR	alkali-silica reaction
CAVE	Computer-Assisted Virtual Environment
CCF	common cause failure
CNEWG	Civil Nuclear Energy Working Group
COSS	computerized operator support system
CRADA	Cooperative Research And Development Agreement
DCS	distributed control system
DOE	Department of Energy
EdF	Electricité de France
EPRI	Electric Power Research Institute
FFRDC	Federally-Funded Research and Development Center
FOA	Funding Opportunity Announcement
HFE	Human Factors Engineering
HSSL	Human System Simulation Laboratory
IAEA	International Atomic Energy Agency
IAP	Integrated Action Plan
IFE	Institute for Energy Technology
I&A	Infrastructure and Applications
I&C	instrumentation and control
INL	Idaho National Laboratory
ISV	integrated system validation

IT	information technology
LWRS	Light Water Reactor Sustainability
NAE	Nuclear Automation Engineering, LLC
NDA	non-disclosure agreement
NDPD	Nondestructive Evaluation, Diagnosis and Prognosis Division
NEI	Nuclear Energy Institute
NITSL	Nuclear Information Technology Strategic Leadership
NLP	natural language processing
NRC	Nuclear Regulatory Commission
ORMI	Outage Risk Management Improvement
OSSREM	Outage System Status and Requirements Monitor
OSTI	Office of Scientific and Technical Information
PSAM	Probabilistic Safety Assessment & Management
PVP	Pressure Vessels and Piping
R&D	research and development
SHM	secondary health monitoring
SLR	subsequent license renewal
SMiRT	Structure Mechanics in Reactor Technology
SwRI	Southwest Research Institute
TERMS	Technology-Enabled Risk-Informed Maintenance Strategy
UGW	ultrasonic guided wave
USA	Utilities Service Alliance
VCU	Virginia Commonwealth University

1. Introduction

The Plant Modernization Pathway of the U.S. Department of Energy (DOE) Light Water Reactor Sustainability (LWRS) Program conducts a vigorous engagement strategy with the U.S. nuclear power industry, including the nuclear operating companies, major support organizations, the Nuclear Regulatory Commission (NRC), and nuclear industry suppliers. [1] The goal of this engagement strategy is to develop a shared vision and common understanding across the nuclear industry of the need for nuclear plant modernization, the performance improvement that can be attained, and the opportunities for partnerships to enact this vision.

During FY 2018, the activies of the Plant Modernization Pathway were communicated to a number of key nuclear industry organizations, including nuclear utiltiies, the major industry support organizations, and a number of important industry conferences that are attended by leaders in nuclear plant instrumentation and controls as well as human performance and process improvement.

This report presents the specific engagement activities that occurred in FY 2018 to promote awareness and participation by the nuclear power industry in the activities of the Plant Modernization Pathway.

All dates in this report refer to FY 2018 (October 2017 – September 2018) unless otherwise noted.

2. Nuclear Utility Engagement

2.1 Utility Working Group

The Plant Modernization Pathway conducts a variety of engagement activities with U.S. nuclear utilities through partnership in pilot projects, individual meetings on digital technology requirements, and distribution of project reports and other project products. The nuclear utilities that are engaged with the Plant Modernization Pathway in one capacity or another are collectively referred to as the Utility Working Group. Over the history of the Pathway, participating nuclear utilities include:

1. Arizona Public Service
2. Dominion Energy
3. Duke Energy
4. Entergy
5. Exelon Nuclear
6. First Energy Nuclear Operating Company
7. Luminant
8. Nebraska Public Power
9. NextEra
10. Pacific Gas & Electric
11. Public Service Electric and Gas
12. Southern Nuclear
13. South Texas Project
14. Tennessee Valley Authority
15. Utilities Service Alliance (USA)
16. Xcel Energy

During FY 2018, the primary means of engaging utilities was through focused areas of interest consisting of plant modernization, automated work packages, outage improvement, control room modernization and human factors, and on-line monitoring. In many cases, this consisted of their direct involvement in the technology development projects of the Plant Modernization Pathway or their expressed interest to learn more about these projects. In this manner, the utilities were engaged in their desired area of development. In addition, it promoted association and cooperation among utilities with similar technical interests. The utilities who served as project partners in the Plant Modernization Pathway research activities during FY 2018 are listed in the following table.

Table 1 FY 2018 Nuclear Utility Engagements

Nuclear Utility	Instrumentation and Control Architecture	Online Monitoring and Plant Automation	Advanced Applications and Process Automation
Arizona Public Service	X		X
Dominion	X	X	X
Duke Energy	X		
Exelon Nuclear	X		X
Luminant-Vistra		X	
Nebraska Public Power District			X
Southern Nuclear	X	X	X
Xcel Energy			X
Utilities Service Alliance		X	

In addition to these utilities who directly participate as pilot project partners, other utilities participated in conference calls, direct discussions, and industry meetings within the major focus areas.

Project reports are distributed to the Utility Working Group on an annual basis at the completion of the fiscal year as indicated in the table below. The next such distribution will be in October of 2018 and will use report access services provided by the Office of Scientific and Technical Information (OSTI). This distribution is in addition to the reports that are distributed during the year to interested utilities and other industry stakeholders on a request-basis.

Table 2 FY 2018 Published Reports

Research Area	Report Title	Publication No.
Automated Work Packages	*Describe a strategy and plan to support a cooperative research project with industrial partners that delivers a risk-informed maintenance strategy which will reduces maintenance costs*	INL/LTD-18-51448

Research Area	Report Title	Publication No.
Automated Work Packages	*Describe the technologies that have the greatest impact for reducing work package operation and maintenance costs in the light water reactors fleet*	INL/EXT-18-51457
Automated Work Packages	*Describe a strategy and plan to support a cooperative research project with industrial partners that delivers a risk-informed maintenance strategy which will reduces maintenance costs*	INL/LTD-18-51448
Control Room Modernization	*Control Room Modernization End-State Design Philosophy*	INL/EXT-18-44739
Control Room Modernization	*The Influence of Individual Human-System Interface Display Features on Visual Information Processing during Naturalistic Process Control Tasks*	INL/JOU-18-45483
Control Room Modernization	*Submit a journal article documenting the research activities that serve as a technical basis for control room design.*	N/A
Control Room Modernization	*Development and evaluation of the conceptual design for a liquid radiological waste system in an advanced hybrid control room.*	INL/EXT-18-51107
Control Room Modernization	*Document the implementation of the end state concept for turbine control and feedwater systems*	INL/EXT-18-51582
Data Driven Condition Monitoring	*Process to move a plant from manual and analog to automatic and digital data acquisition which will be critical to enable data driven condition monitoring*	INL/EXT-18-51456
Digital Information and Control	*Strategy for Implementation of Safety-Related Digital I&C Systems*	INL/EXT-18-45683
Digital Instrumentation and Control Qualification	*Definition of the Methods, Tools, and Computing Resources for Instrumentation and Control Device Testability*	INL/EXT-18-51521
Fleet Based Control Room Modernization	Human Factors Engineering Evaluations of Planned Digital Instrumentation and Control System Upgrades at the Braidwood Nuclear Generating Station	INL/LTD-18-44295
Fleet Based Control Room Modernization	*A Human Factors Operator-in-the-Loop Evaluation of the Digital Control System Upgrades for the Braidwood and Byron Nuclear Generating Stations*	INL/LTD-18-44617
Fleet Based Control Room Modernization	*Connecting LWRS Human Factors Engineering R&D to NUREG-0711 Elements and Modification Activities in Nuclear Generating Plants*	INL/EXT-18-45149
Fleet Based Control Room Modernization	*Lessons Learned from Performing a Human Factors Engineering Validation of an Upgraded Digital Control System in a Nuclear Power Plant Control Room*	INL/LTD-18-51380
Fleet Based Control Room Modernization	*Planning and Analyses Performed to Install Halden's Advanced Control Room Concept in the Human Systems Simulation Laboratory*	INL/EXT-18-45966
Fleet Based Control Room Modernization	*Developing a Human Factors Engineering Program Plan and End State Vision to Support Full Nuclear Power Plant Modernization*	INL/EXT-18-51212
Fleet Based Control Room Modernization	*Summarize the human factors R&D performed in collaboration with Exelon*	INL/EXT-18-51365
Fleet Based Control Room Modernization	*Summarize the human factors studies conducted in support of the Control Room Modernization project.*	INL/EXT-18-51365

Research Area	Report Title	Publication No.
Fleet Based Control Room Modernization	*Document the development of a preliminary strategy for full nuclear plant modernization based upon digital technology deployment timelines to reduce costs and improve efficiencies*	INL/EXT-18-51366
Halden	*Development of Task Based Displays for the Fleet-Based Control Room Modernization Design Project*	INL/LTD-18-44296
Halden	*Summarize operator-in-the-loop studies conducted in support of the Fleet-Based Control Room Modernization project*	INL/EXT-18-51360
Industrial and Regulatory Engagement	*Industrial and Regulatory Engagement Activities*	INL/EXT-18-51462
Online Monitoring of Concrete Structures in Nuclear Power Plants	*Enhancement of the Structural Health Monitoring Framework by Optimizing Vibro Acoustic Modulation Technique to Localize Alkali Silica Reaction Degradation In Medium Sized Concrete Samples*	INL/EXT-18-45212
Online Monitoring of Concrete Structures in Nuclear Power Plants	*Uncertainty quantification methodologies developed to support the concrete structural health monitoring framework*	INL/EXT-18-51460
Online Monitoring of Concrete Structures in Nuclear Power Plants	*Document the progress of casting of reinforced concrete beam*	INL/EXT-18-51461
Online Monitoring of Secondary Structures in Nuclear Power Plants	*Describe performance of advanced signal processing and pattern recognition algorithms using raw data from ultrasonic guided waves transducers and provide recommendations on capabilities of advanced data analytics*	INL/EXT-18-51429
Outage Risk Management Improvement	*Prototype system for detecting interactions between status (configuration) states and concurrent component manipulations directed by in-use procedures including data integration and industry feedback*	INL/EXT-18-51474
Project Management	*Technical Program Plan for the Plant Modernization Pathway*	INL/EXT-13-28055 Rev 8
Risk-Informed Methodologies	*Describe the design basis for a resilient plant based on margin recovery and the application of new technologies to reduce the safety significance of design basis events*	INL/EXT-18-51531
Automated Work Packages	*Describe a strategy and plan to support a cooperative research project with industrial partners that delivers a risk-informed maintenance strategy which will reduces maintenance costs*	INL/LTD-18-51448
Automated Work Packages	*Describe the technologies that have the greatest impact for reducing work package operation and maintenance costs in the light water reactors fleet*	INL/EXT-18-51457

2.2 Duke Energy

The Plant Modernization Pathway has partnered with Duke Energy for a number of years in the area of control room modernization for the Brunswick, Harris, and Robinson Nuclear Plants. The human factors engineering (HFE) research and development (R&D) being conducted is through the strategic

partnerships (e.g., work-for-others) program, using a funds-in Cooperative Research and Development Agreement (CRADA). Even though this work is outside of the LWRS Program, the learnings from these activities are published from time-to-time in external-released Pathway reports for the benefit of the industry. In addition, the experience gained in these activities builds the expertise and experience of the researchers for application in Pathway activities.

The current work with Duke Energy is in performing integrated system validations (ISV) for the turbine control system upgrades, with the Brunswick ISV completed in December 2017, the Harris ISV completed in April 2018, and the Robinson ISV completed in August 2018.

LWRS Program staff, Jeffrey Joe and Ken Thomas, met with Paul Hunton, Duke Energy Project Manager for Instrumentation and Control Capital Projects, at the Harris Nuclear Plant near Raleigh, NC, to discuss the current project work in control room modernization and the possibility of extension beyond the currently-defined scope of ISVs for the Brunswick, Harris and Robinson Plants. Paul stated that he is very pleased with the LWRS Program work and wants to continue to contract INL for HFE activities in support of their continued build-out of the distributed control systems (DCS) systems at these three legacy-Progress plants. It is anticipated that the plant process computer will be the next system to be upgraded at these three plants, and that LWRS Program researchers at Idaho National Laboratory (INL) will be key HFE subject matter experts involved in this activity.

Results of the HFE R&D include developing industry guidance on how to develop an effective human factors program management plan, perform a quality operational experience review, evaluate the new advanced human-system interface when it is in the early stages of development, and perform the ISV. This guidance will be used to map these HFE activities to NUREG-0711 [2], which the nuclear industry can further use to understand and catalog the importance of the different phases in the HFE process.

2.3 Arizona Public Service

2.3.1 Control Room Modernization

Palo Verde Generating Station is a key partner partnering with the Pathway in developing an optimum end-state for control room modernization. The Pathway research team has developed the end-state main control room layout, alarm system design, and a human-system interface design for upgraded control systems, which is being adopted by Palo Verde Generating Station and is available to the nuclear industry as a roadmap for similar modernization efforts. In addition to the end-state design, Palo Verde Generating Station has participated in a detailed human factors analysis study. The results from these efforts will provide those nuclear plants considering a hybrid approach to control room modernization with an implementable upgrade plan providing consistent, advanced, and efficient control room design compared to a like-for-like replacement of components. Pathway researchers are conducting studies on the implementation of advanced visualizations for the chemical and volume control and turbine control systems at the station. This research demonstrates how incorporating advanced technologies, such as advanced human-system interface design, advanced alarms, and computer-based procedures can enhance operations in other areas of plant operation as well. This work serves as a proof-of-concept for digital technology migration and integration into prevailing analog environments, thereby enabling their adoption in other control room upgrade projects. The research is also considering new technologies for the main control room, such as how overview displays that are common in advanced LWR designs can be used in existing LWRs to efficiently support plant- and system-level operations, and illustrate how they can be used to provide advanced visualization in current control rooms.

Palo Verde Generating Station provides extensive operations and training support to the Pathway, enabling researchers to conduct evaluations and partial validations of the design concepts with licensed

operators. This research will inform control room modernization projects at other utilities and can reduce the uncertainty and risk associated with adopting beneficial, cost-saving technologies.

On March 19-23, 2018, a workshop was held at Palo Verde Generating Station in Phoenix, AZ, on the proposed design options for the radiological waste control room. Attending for the LWRS Program were Johanna Oxstrand, Rachael Hill, Casey Kovesdi, and Zachary Spielman. The workshop focused on a comparison of the end-state concepts provided by the project to those provided by the supplier of I&C upgrades for the radiological waste system. The LWRS researchers were able to obtain objective and subjective feedback from 21 auxiliary operators, including all of the operators currently trained to operate the LRS system. With this feedback, researchers were able to develop systematic criteria for design decisions in the LRS system and will translate that criteria to designs for the main control room.

A meeting was held with John Hernandez and Lorenzo Slay of Palo Verde Generating Station at INL on March 29 -30, 2018, to review progress on control room modernization work during FY 2018. The group also began the planning process for the next several years based on the status and progress of the Palo Verde Strategic Modernization Program, which is targeting digital upgrades for certain non-safety I&C systems and related control room modernization.

Senior executives from Palo Verde Generating Station visited the Human Systems Simulation Laboratory (HSSL) on Tuesday July 24, 2018. Pathway researchers demonstrated the variety of science-based methods used to support plant modernization to Palo Verde leadership and discussed the importance of industry collaboration to ensure effective plant modernization across the nuclear industry. Operators and engineers from Palo Verde also attended the meeting, and participated in a week-long workshop to support human factors input to control room and plant modernization.

Researchers from INL met weekly with Lorenzo Slay via teleconference during FY 2018 to discuss progress and challenges

2.3.2 Outage Improvement

The Plant Modernization Pathway has worked with Arizona Public Service at the Palo Verde Generating Station for several years in improving the management of refueling outages. Current work involves the reduction of outage risk by means of advanced data and information analytics. Shawn St. Germain visited Palo Verde on January 9-10 to discuss the Outage Risk Management Improvement (ORMI) project with Michael Grigsby. In addition, discussions were held with the current outage manager, Frank Chance, on the utility of proposed Outage System Status and Requirements Monitor (OSSREM) that is under development. Also Palo Verde provided example plant documents to support natural language processing (NLP) studies being conducted at Vanderbilt University in support of outage risk management by being able to extract information from commonly-used plant documents such as procedures.

2.4 Dominion

Mr. Ken Thomas was contacted on March 12th by Mr. Robert Atkinson of Dominion Energy in regard to possible collaboration on control room modernization for the Surry and North Anna Nuclear Stations as part of Dominion's pursuit of subsequent license renewal (SLR). Robert asked for background material on the work of the pathway, which was later sent. Mr. Atkinson requested a follow-up call or meeting with their SLR team, and then perhaps a visit to INL in late summer June to discuss how a potential partnership in plant modernization could be formulated. Their desire was to involve plant operators in

this visit for greater understanding in how control room modernization can improve operational performance.

Following this, Mr. Calvin Pugh, Dominion Energy Manager leading SLR for North Anna and Surry, visited INL on May 16th to learn about experience and capabilities in control room modernization. Dominion is considering significant I&C and control room modernization in support of their SLR efforts and has indicated they want to explore collaboration with the PM Pathway. The meeting resulted in an intent by Dominion to collaborate with the LWRS Program on control room modernization for the two nuclear stations. A number of action items were identified in the meeting and are now in progress.

Mr. Thomas visited Dominion Energy on July 19th in Richmond, Virginia, visiting Mr. Pugh and Mr. Atkinson. The purpose of the visit was to continue development of a potential collaboration in nuclear plant modernization. During the visit, a draft Statement of Work for a proposed CRADA was reviewed and accepted by Dominion. In addition, planning continued for a delegation from Dominion (representing North Anna Nuclear Power Station, Surrey Nuclear Power Station, and Dominion Fleet Engineering) to visit INL in August to learn more about plant modernization technologies developed under the Plant Modernization Pathway of the LWRS Program.

Dominion Energy visited INL on August 20-21 to conduct discussions on partnering in comprehensive plant modernization as part of their subsequent license renewal (SLR) project for the North Anna and Surrey Nuclear Stations. Dominion brought a 12-member multidiscipline team that included SLR project management, operators, engineers, and information technology (IT)/cyber security experts. The main focus of the meeting was on I&C and control room modernization, with presentations in the Human Systems Simulation Laboratory (HSSL) and the Computer-Assisted Virtual Environment (CAVE). In addition, technology presentations and demonstrations were made in the areas of on-line monitoring and mobile worker/process efficiency technologies. The results of the meeting were a stated intention of Dominion to serve as a utility partner in all of these areas as part of developing and pursuing their company strategy for broad plant modernization. A CRADA is being developed and the Plant Modernization Pathway is providing support information for the development of the Dominion plant modernization strategy.

2.5 Exelon Nuclear

2.5.1 Fleet-Based Control Room Modernization

The Plant Modernization Pathway has partnered with Exelon for several years in a fleet-based approach to control room modernization involving their Braidwood and Byron Nuclear Stations. This research will enables the creation of a strategic approach to perform large-scale digital upgrades for nuclear power plants. Along with participating in this research, Exelon is providing operational experience, lessons-learned, and implementation data related to their digital upgrades. This data is based on their non-safety related nuclear steam supply systems and the balance of their plant systems digital upgrades.

In FY18, LWRS Program staff engaged with individuals at Exelon regularly to execute a plant modernization R&D collaboration on control room digital enhancements of the Exelon fleet. Individuals at Exelon that met with the Pathway research staff include Mr. Mark Eyster, Mr. Charles Winters, Mr. Ryan Cragg, Mr. Mike Dahl, Mr. Mark Ristau, and Mr. John Connelly. In October 2017, LWRS staff travelled to the Braidwood training center to learn about Exelon's licensed operator requalification training process and how the scenarios the simulator instructors run to test operators are similar to, and different from, the simulator scenarios human factors experts run to evaluate human-system performance. LWRS Program researchers returned to the Braidwood training center in December 2017 to conduct a full

dynamic human factors workshop to evaluate the upgraded I&C systems that were installed in the Braidwood simulator. This workshop was an opportunity to verify and validate that the I&C system that would be installed in the Braidwood Unit 1 main control room in April 2018 was acceptable from a human factors engineering perspective. The findings from this dynamic workshop were supplemented with a visit to the Byron simulator in February 2018. The purpose of the Byron visit was to evaluate the human-system performance of the pre-modified control room. That is, the results from the Byron workshop allowed LWRS Program researchers to compare operator and overall system performance using the existing, analog I&C system still present in the Byron simulator to the upgraded, digital I&C systems installed in the Braidwood simulator. This further established the technical bases for the conclusions LWRS Program researchers made about the acceptability (from a human factors perspective) of the digital I&C upgrades that Exelon performed. As part of collaborative research with Exelon Nuclear for fleet-based control room modernization, a report was completed documenting the results of analyses to map and connect LWRS Program human factors studies to the associated regulatory guidance of the U. S. Nuclear Regulatory Commission.

2.5.2 Plant Modernization

Working under the DOE Light Water Reactor Sustainability Program – Plant Modernization Pathway, INL has partnered with the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI) and Exelon Nuclear to define the elements of a plant modernization strategy. This effort began in July of 2017 with direct discussions between Exelon and the Pathway on potential partnership for full plant modernization, specifically targeting Exelon's Braidwood and Byron Nuclear Stations.

This was followed by a two day working meeting held at Exelon Nuclear corporate offices in Warrenville, IL on November 8-9, with INL, NEI, EPRI, and invited consulting firms participating. Mr. Ken Thomas represented INL at the meeting. One of these consulting firms, Nuclear Automation Engineering (NAE), presented a highly-integrated digital I&C architecture referred to as a "compact digital modernization." NAE had developed this concept for the Pathway in another research project. A direction was set in this meeting for these industry leaders to pursue full plant modernization assuming that technical, business case, and regulatory issues could be successfully resolved. It was further decided that, based on the urgency of many operating plants to reduce substantially operating costs, the modernization would be implemented in a single step (future extended outage) in the reasonable near term rather than as an evolutionary implementation over a 10-15 year time frame.

During this working meeting, there were over four hours of presentations on the work of the Plant Modernization Pathway relevant to the scope of this modernization. Discussion at the meeting and follow-up discussions after the meeting, indicated many common objectives. It was ultimately decided that this would be expanded to an industry effort led by EPRI and that funding would be pursued through a new Department of Energy funding opportunity. A description of this continuing industry engagement for plant modernization is found in Section 3.1.4.

2.6 Xcel Energy

Dr. Ahmad Al Rashdan continued to work with Xcel Energy through a CRADA that started in FY17 and continued in FY18. The collaboration focused on piloting automation technologies developed in the automated work packages project at Xcel Energy, the potential for work package data mining research, and future collaboration on image recognition and comprehension application at the nuclear industry. Discussions were held with Xcel Energy on possible use of computerized operator support system (COSS) technology for health monitoring of plant systems. This would include use of the PRO-AID software developed by Argonne National Laboratory. Further discussions are planned with Xcel Energy and Argonne on this possible project.

2.7 Luminant-Vistra Energy/Utilities Service Alliance

Luminant-Vistra Energy and Utilities Service Alliance (USA) approached the Plant Modernization Pathway about participating in an effort to obtain DOE funding under Funding Opportunity Announcement (FOA) DE-FOA-001817 or research and demonstration of fleet-wide nuclear plant monitoring. Luminant-Vistra Energy operates the Comanche Peak Nuclear Station. USA is a consortium of eight U.S. nuclear utilities that operate 14 plants at nine sites, including Comanche Peak. Luminant–Vistra Energy has substantial experience in operating a centralized on-line monitoring center known as the Power Optimization Center, which uses current-state technology to monitor plant components for degradation and efficiency losses.

INL provided assistance to the USA team in the development of the FOA proposal, including the potential benefits for LWRS research activities. A two-day meeting with the USA team was held at INL where it was decided that INL would serve as a Federally-Funded Research and Development Center (FFRDC) sub-recipient to USA responsible for the on-line monitoring business case and for technology development in the area of data analytics.

Dr. Ahmad Al Rashdan visited Luminant-Vistra Energy in Dallas in July to continue the discussion between the LWRS program and Luminant as a representative of the Utilities Service Alliance (USA). The visit resulted in the identification of the current state in online condition motioning for USA and the research needs to systematically move the industry from labor intensive and costly manual inspections to a state where the whole online monitoring process is data-driven for automated and continuous decision making.

In late July, it was learned that DOE had not accepted the proposal due to certain stated concerns; however, the team was encouraged to resubmit it with appropriate revisions. A series of conference calls were organized to address the revised proposal, leading to a meeting held on September 14th at Luminant-Vistra Energy headquarters in Irving, TX. Mr. Craig Primer attended this meeting to support the proposal development and to reconfirm a desire to partner in related research for business case development, sensor development, and related data analytics. The current intent is to resubmit the proposal for the next DOE FOA submittal date of October 31st.

2.8 Utilities Service Alliance

Dr. Bruce Hallbert and Dr.Ahmad Al Rashdan participated in the USA Executive Summit in Seattle, Washington on the July 17-18, 2018. Dr. Hallbert presented the LWRS program mission, objectives, and current research and development efforts to a large audience of the senior executive management of the USA nuclear power plants. The summit was also attended by members of the nuclear STARS Alliance. Dr.Al Rashdan engaged the participants at a dedicated LWRS booth, discussed the details of the LWRS program efforts, and established new contacts for future partnerships.

2.9 Nebraska Public Power District

LWRS researchers Dr. Ahmad Al Rashdan and Shawn St. Germain visited Cooper Nuclear Station in Nebraska in July to discuss possible partnering in on-line condition monitoring with the Plant Modernization Pathway online condition monitoring. Cooper nuclear power station discussed their specific needs and requirements in such a partnership in online condition monitoring and arrangements were made for a follow-up visit.

Dr. Al Rashdan and Mr. St. Germain again visited Cooper on August 24-25 to discuss the preventive maintenance challenges faced by Cooper and the potential for partnering with the Plant Modernization

Pathway on migrating the current manual inspection processes to an automated approach. During the visit, the Pathway team met the engineering and maintenance management and exchanged information on the high cost activities and labor intensive tasks that the LWRS research can target. The visit also addressed aligning Cooper efforts with the overall plans for data-driven condition monitoring of the Utilities Service Alliance discussed in Section 2.7.

3. Collaboration with Major Industry Support Groups

3.1 Electric Power Research Institute

3.1.1 General Research Coordination

Periodic conference calls are held with EPRI to coordinate research activities under the Memorandum of Understanding between the LWRS Program and the EPRI Long-Term Operations Program [3]. These calls are used to update each party on the status and progress of ongoing research, to coordinate research activities where there are mutual objectives such as on-line monitoring, and to review future planned research activities where there might be opportunities to coordinate efforts.

A review meeting with EPRI was held in Washington DC on August 16th to review research plans for the coming year. Attending for the Plant Modernization Pathway were Mr. Craig Primer and Mr. Ken Thomas, and for EPRI, Mr. Robert Austin, Mr. Matt Gibson, Mr. Fernando Ferrante, and Mr. Sam Harvey. Each organization in turn presented its research plans, with opportunities for coordination identified in the areas of plant modernization, I&C modernization, and on-line monitoring. Follow-up conference calls will be conducted to connect the specific research teams of each organization in these project areas.

3.1.2 On-Line Monitoring for Concrete Degradation

The Plant Modernization Pathway is conducting research in on-line monitoring of concrete structures, and in particular, the detection of alkali-silica reaction (ASR). Dr. Vivek Agarwal periodically updates Ms. Maria Guimaraes of EPRI about important research highlights on the structural health monitoring research performed at INL and Vanderbilt University, providing to her the recent published milestone report and presentations. Vanderbilt University hosted a joint meeting between the Plant Modernization and Material Aging and Degradation Pathways on concrete along with participants from EPRI and other Universities on December 12-13, 2017. During the workshop, EPRI presented a joint roadmap on ASR and Irradiation of concrete in collaboration with DOE, NRC, and other entities. Dr. Agarwal and Prof. Sankaran Mahadevan (Vanderbilt University) presented the progress on concrete structural health monitoring and Ms. Dianna Ezell presented the nondestructive evaluation (NDE) research progress at Oak Ridge National Laboratory. Other universities funded under the DOE's Nuclear Energy University Program (NEUP) on online monitoring of concrete structures also presented their respective research progress. The outcome of the meeting was to develop a comprehensive joint research plan to support the research, development, and demonstration in the area of concrete health monitoring research.

On August 2nd, EPRI organized a webinar on Concrete NDE Roadmap attended by Ms. Emma Wong, Mr. Sal Villalobos, Ms. Maria Guimaraes, Mr. Joe Wall, and Mr. David Scott from EPRI, Ms. Dianna Ezell, Mr. Tom Rosseel, Mr. Keith Leonard, and Mr. Yann Le Pape from ORNL, Mr. Mitch Farmer from Argonne National Laboratory, and Dr. Vivek Agarwal from INL. The purpose of the meeting was to get a status update on ongoing project at EPRI and National Laboratories and plan for future. One of the

outcomes of the meeting was to develop a short-term research goal and a long-term research goal in three areas of interest. The three areas of interest include: Physical NDE and need for advancement; Structural health monitoring; and Model development to capture degradation mechanisms. The group met at Oak Ridge National Laboratory in Knoxville, TN, on September 26th to continue planning of the activities.

3.1.3 Secondary Piping On-Line Monitoring

LWRS Program researchers are collaborating with EPRI in areas related to both concrete and secondary piping secondary health monitoring (SHM). In the area of concrete structural health, EPRI is collaborating with Plant Modernization and Materials Pathways researchers to develop methods for full-field imaging and other techniques to detect and monitor chemical degradation in concrete structures caused particularly by ASR. EPRI participates in periodic inter-pathway collaboration and technical exchange meetings; provides regular updates on research activities, plans, and results; and provides input to LWRS Program planning personnel to facilitate the most efficient use of funding and human resources. In the areas of secondary piping SHM, the research activities conducted with EPRI allows access to unique facility, instrumentation, and research expertise in this area. A multi-year joint R&D plan, INL/INT-16-38821, "Joint Research Plan on Structural Health Monitoring with the Electric Power Research Institute," has been developed between the Plant Modernization Pathway and EPRI for secondary piping SHM. The collaboration with EPRI has also facilitated access to industry data, as well as proprietary diagnostic software, which is being used by Pathway researchers to develop new signal processing algorithms for monitoring in situ changes to pipe wall thickness.

EPRI has provided technical reports used to develop the testing regime conducted through LWRS Program research for guided-wave signal processing algorithm development. The information provided on Magnetostrictive Sensor SHM for feedwater heat exchanger shells, along with information on Piping Degradation Mechanisms other than flow-assisted corrosion, validated and informed the testing performed by Pathway researchers. EPRI also facilitated transfer of guided wave monitoring data from Southwest Research Institute (SwRI) to the LRWS Program.

3.1.4 Plant Modernization

On December 7, 2017, DOE provided Funding Opportunity Announcement (FOA) DE FOA 0001817, U.S. Industry Opportunities for Advanced Nuclear Technology Development. One of the industry application pathways was for First-of-a-Kind Nuclear Demonstration Readiness Projects.

Several organizations had previously met at Exelon Nuclear on November 8-9 on a potential partnership for comprehensive plant modernization, including Exelon, NEI, EPRI, and INL (see Section 2.5.2). To pursue more substantial funding for this effort, these organizations agreed to submit an application to the FOA for this modernization strategy, with EPRI as the lead organization for the submittal and INL serving as a FFRDC sub-recipient. Weekly phone calls to develop the proposal were held from mid-December 2017 through January 2018, with a two day working meeting held at EPRI in Charlotte, NC, on January 9-10., with Mr. Ken Thomas representing the Plant Modernization Pathway.

The purpose of the meeting was to formulate a joint proposal for the FOA. Other participants were Exelon, Luminant (later withdrew from the proposal), and the Nuclear Energy Institute (NEI). The results of this planning meeting were that INL and Exelon would have the role of for defining the end state I&C architecture, NEI would have the role for regulatory strategy, and EPRI would have the role for the business case and the implementation plan. Exelon would provide support for these activities as well. Follow-on work was conducted to prepare INL's portion of the proposal as a sub-recipient of the award if successful. This input was completed in the week of January 22 with the proposal being submitted by EPRI on January 31st.

In April of 2018, it was learned that this plant modernization application was not successful in regard to an award of funding. However, the industry decided to continue to pursue the full nuclear plant modernization strategy due to the pressing needs to lower operating costs for the nuclear fleet. At the time of this report writing, discussions are underway among these same partnering organizations to pursue this comprehensive plant modernization strategy.

3.2 Nuclear Energy Institute

3.2.1 Digital I&C Working Group

The Digital I&C Working Group was established in 2015 with a representative of the Plant Modernization Pathway represented by Mr. Ken Thomas and Mr. Gordon Clefton (consultant to the Plant Modernization Pathway). This Working Group is tasked by the chief nuclear officers of the NEI member nuclear utilities to work with the NRC to find resolutions to certain long standing regulatory barriers to implementing digital technologies. The focus on the effort is in the areas of treatment of digital common cause failure, digital modifications under NRC regulation 10 CFR 50.59 [4], and improvements to the NRC license amendment review process for digital modifications.

Activity for the Working Group in FY 2018 consisted of participating in conference calls and providing comments on a number of documents and presentations used in the resolution of these issues. There were no formal meetings of the entire Working Group during the year in favor of working meetings on the specific issues. The Working Group planned to visit the Plant Modernization Pathway research team at INL during August of 2018 to hear more of the work of research activities. However, that meeting was postponed to October. Involvement with this Working Group will continue as the technology and methodology developments of the Pathway are helpful to improving the regulatory basis for implementing digital technologies for plant modernization.

3.2.2 Plant Modernization Coordination

Preliminary discussions were held with Mr. Jerud Hanson and Mr. Jason Remer of the Nuclear Energy Institute (NEI) on getting their perspectives on the issues addressed in this report and their thinking on what new developments would be useful to the industry and complementary to the NEI work in this regulatory area.

Additional discussions of the strategy were held with Mr. Remer during an unrelated DOE workshop at Argonne National Laboratory. The four key elements of the full nuclear plant modernization strategy (end-state architecture, cost-benefit analysis, regulatory approach, and implementation sequence plan) were discussed with Mr. Remer and he stated that this was compatible with NEI thinking on the subject.

3.3 Southwest Research Institute

To assist the Plant Modernization Pathway research in secondary piping on-line monitoring (see Section 3.1.3), Southwest Research Institute (SwRI) provided guided-wave data recorded by their corrosion monitoring system on the shell of a low-pressure feedwater heater at Exelon's Braidwood Nuclear Generating Station. The system collected daily monitoring data for 747 days between January 27, 2011, and February 12, 2013, from 17 ultrasonic guided-wave sensors. SwRI also provided analysis reports on the continued monitoring and analysis of data collected on the heat exchanger, which was also analyzed using new guided wave techniques created by Pathway researchers.

4. Collaboration with Universities

4.1 Vanderbilt

LWRS Program researchers are collaborating with Vanderbilt University to develop methods for monitoring the structural integrity of concrete structures (see Section 3.1.2 for information on the research this university engagement supports). The collaboration is aimed at developing advanced data analytic capabilities to process and integrate heterogeneous data and extract features for diagnosing concrete degradation. Vanderbilt University will periodically interrogate the large concrete sample at University of Tennessee-Knoxville, which is being operated by the LWRS Program, using the digital image correlation technique and analyze the data to detect any deformation due to ASR. This support is critical to develop science-based approaches to understand, detect, characterize, and monitor changes in concrete that may affect its structural health.

An industry meeting was held at Vanderbilt University the week of December 11, 2017, to coordinate research activities among the participating national laboratories and universities. Also, in the online monitoring area, a nondisclosure agreement was completed in November 2017 to enable the Plant Modernization Pathway to receive data sets from Southwest Research Institute. These will be used in research on extending the range of guided wave sensor arrays to monitor the condition of secondary plant piping.

Vanderbilt University provides results of their research on 3-D Chemo-Mechanical Degradation State Monitoring, Diagnostics, and Prognostics of Corrosion Processes in Nuclear Power Plant Secondary Piping Structures used in developing evaluation techniques based on various degradation mechanisms.

4.2 University of Nebraska – Lincoln

Plant Modernization Pathway researchers are collaborating with the University of Nebraska–Lincoln to provide several additional samples, each with unique reactive aggregates (see Section 3.1.2 for information on the research this university engagement supports). These samples, as well as access to independent university research results, are very useful in assisting to develop methods for full-field imaging and other techniques, which are the main goal of this research effort.

4.3 University of Pittsburgh

University of Pittsburgh provides results of their research on secondary health monitoring of nuclear pipe pomponents using high spatial resolution fiber sensor-enabled artificial intelligence, which is providing initial understanding and influencing the scope of Plant Modernization Pathway research using fiber-optics.

The Pathway initiated a joint project with University of Pittsburg on application of fiber optics to elbow monitoring in secondary piping. In this project, the University of Pittsburgh will explore artificial intelligence and high spatial resolution fiber sensors as tools to reduce influence of both human and hardware factors and improve pattern recognitions for corrosion-induced defect identification. Through high spatial resolution data gathering using distributed fiber sensors (acoustic, temperature, and strain) and deep neural network machine learning, the objective is to significantly improve cost effectiveness and measurement efficacy for multi-modal sensing systems for pipeline monitoring.

4.4 Virginia Commonwealth University

Virginia Commonwealth University (VCU) is providing technical analysis and device architecture descriptions for investigation into the feasibility of exhaustive testing of digital devices for software defects.

Discussion were held with Dr. Carl Elks of VCU on the feasibility of 100% testing of digital component software as a means of qualifying a digital device for safety-related applications. This comprehensive testing is endorsed by the NRC as a qualification method, however, a practical method of doing this has never been found. Dr. Elks offered to provide additional insights into how such a comprehensive test might be conducted. Further discussions on this will be held in April.

Additional discussion were held with Dr. Elks on the feasibility of 100% testing of digital component software as a means of qualifying a digital device for safety-related applications. Dr. Elks provided some preliminary information on considerations for 100% testing of a representative digital device such as a digital pressure transmitter. This information will be used in the description of a potential research project.

Mr. Ken Thomas visited VCU on July 18th, meeting with Dr. Elks and his graduate student staff, to discuss a potential collaboration project in exhaustive (100%) testing of a digital device typical of what is used in field applications in nuclear power plants. The results of the meeting were that VCU is very well suited to conducting such work and a contract is now in place to conduct the next steps of this testing, which are to determine the methods, tools, and computing resources for such a test, and to develop a test specification.

VCU will continue to research methods for achieving the testability of a typical nuclear plant digital device into FY 2019 through this contract.

5. General Industry Meetings and Conferences

5.1 2015 Procedure Professional Association Workshop

During the Procedure Professionals Association's annual conference in Charleston, South Carolina, June 19-21, 2018, Ms. Rachael Hill and Ms. Johanna Oxstrand facilitated a workshop titled "Writing the Future: Workshop on the Procedure Writer’s Perspective on Authoring Dynamic Procedures". The workshop had 25 participants representing procedure writers from multiple nuclear power plants. Ms. Oxstrand is a member of both the Procedure Professionals Association's steering committee and the standards committee. As a member of the steering committee, Ms. Oxstrand supports the planning and organizing the Procedure Professionals Association's annual conferences.

5.2 2015 NITSL Workshop

Mr. Shawn St. Germain attended the Nuclear Information Technology Strategic Leadership (NITSL) 2018 meeting in West Palm Beach, FL this year for the Automated Work Package and Digital Architecture projects. Mr. St. Germain made a presentation on the work we have done on automated work packages and electronic work packages titled “Electronic Work Packages”. He also attended a NITSL Infrastructure and Applications (I&A) working group meeting to discuss topics for presentation at the next NITSL meeting. The Pathway is continuing to participate as a member of the I&A working group, which is currently identifying utility members to support the DIRECTOR initiative (a utility group to define requirements for authoring electronic work packages).

5.3 2018 ASME Pressure Vessels & Piping Conference

Dr. Vivek Agarwal is a Secretary of the ASME Nondestructive Evaluation, Diagnosis and Prognosis Division (NDPD) and was a technical representative of the NDPD at the 2018 ASME Pressure Vessels and Piping (PVP) Conference program committee. As part of his duties, he chaired, participated, and presented at the 2018 ASME PVP Conference in Prague, Czech Republic, July 16-21, 2018. The PVP Conference is a recognized forum for fruitful exchange of ideas with participants from over 40 countries in Europe, Africa, the Middle East, Asia, the Americas, and the Oceania islands. Dr. Agarwal was awarded with the certificate of recognition for his contributions to the division. He presented the research progress on concrete structural health monitoring at the conference.

Dr. Andrei Gribok presented paper "Advanced Signal Processing Techniques for Guided Waves Corrosion Monitoring System in Secondary Circuits of Nuclear Power Plants" at the ASME Pressure Vessels & Piping Conference (PVP). The paper was published in the ASME official proceedings.

5.4 2015 ANS Utility Working Conference

Dr. Bruce Hallbert and Ms. Cathy Barnard participated in the ANS Utility Working Conference from August 5-8, 2018 at Amelia Island, Florida. This is an important industry conference that many nuclear utility managers attend to obtain information on performance improvement good practices and innovations. It is also well-attended by the major nuclear industry technology and service suppliers to provide information on new nuclear plant technologies and work methods. The LWRS Program sponsored a booth which attracted considerable interest and engagement. Information on technology developments of the Plant Modernization Pathway was distributed to interested attendees.

5.5 Westinghouse Outage Optimization Workshop

Mr. Shawn St. Germain presented the ORMI project at the Westinghouse Outage Optimization Workshop in Pittsburgh, PA on July 29- August 1. The meeting was attended by approximately 45 outage managers and utility work management professionals. Feedback on the Plant Modernization Pathway technology developments for outage improvement was very positive.

5.6 Probabilistic Safety Assessment & Management Conference

Mr. Shawn St. Germain presented the ORMI project and OSSREM application to the Probabilistic Safety Assessment & Management (PSAM) Conference in Los Angeles, CA, on September 16-21. PSAM is a conference focused on risk management, reliability and safety. The objective of this presentation was to continue to generate interest in and solicit ideas for future capabilities for the OSSREM concept.

5.7 2018 EPRI Mobile Work Management

A team of LWRS researchers lead by Dr. Ahmad Al Rashdan participated in the 2018 EPRI Mobile Work Management conference in Charlotte, North Carolina on August 7-8. The team presented the ongoing and completed LWRS program efforts on automated work packages, computer based procedures, and outage optimization to a large audience from the work management organizations of the participating nuclear power plants. This engagement resulted in discussions with several potential utility partners, including partnering with South Texas Nuclear Generating Station to pilot the Bluetooth-triggered tablet

actions application developed in FY17 by the Automated Work Package project, and partnering with Diablo Canyon Power Plant on the demonstration of radio frequency identification applications, also developed in FY17 by the Automated Work Package project.

6. Engagements with Nuclear Industry Suppliers

6.1 Atos

Atos is a large-scale multi-disciplinary systems integrator and industry partner of multiple international entities, and has worked with several nuclear utilities outside the United States on large scale condition monitoring efforts. Atøs has performed efforts to migrate plants towards data-driven condition monitoring in both the nuclear and fossil industries. This collaboration provides the Plant Modernization Pathway researchers with good practices and lessons-learned from these previous projects, which are being incorporated into the Pathway research projects. Atøs will be providing resources and information to achieve this mission.

Atos participates with Plant Modernization Program researchers in developing outage applications to improve outage risk management through a combination of data visualization, natural language text mining, and logic models to detect potential conflicts between ongoing and upcoming work activities during outages. Atos provides data scientists and software experts with the ability to collaborate on research in developing state-of-the-art data analysis systems and data management techniques for outage information technology.

Mr. Shawn St. Germain contracted Atos during FY2018 to provide software coding services for the development of the OSSREM application under a sub-contract. They delivered a functional software platform that we can use to test additional concepts related to information integration.

A team of LWRS researchers led by Dr. Ahmad Al Rashdan visited Atos in Dallas in July 2018 to define the scope of collaboration between the LWRS program and Atos. The visit aimed at discussing mechanisms of using Atos international experience to benefit the United States nuclear industry.

6.2 Rolls Royce

Mr. Craig Primer and Mr. Ken Thomas visited Rolls Royce on May 21st to define a collaboration opportunity for risk-informed maintenance optimization for nuclear plant cost reduction. Actions were outlined to define a project for this purpose known as Technology-Enabled Risk-Informed Maintenance Strategy (TERMS). Rolls-Royce Nuclear is a world leader in the area of asset monitoring and predictive asset maintenance. They have expertise in risk-informed maintenance and access to a broad range of equipment data with which to develop, test, and validate advanced equipment monitoring techniques. Rolls-Royce will also provide access to proprietary analytic tools, allowing researchers expanded testing capabilities during this research project.

Dr. Vivek Agarwal met with Rolls-Royce North America collaborators to discuss the research scope of the TERMS project at INL, Idaho Falls, ID July 23-25, 2018. The outcome of the meeting was a proposal that was submitted to the DOE Industry FOA for consideration. Also, the Pathway and Rolls-Royce are developing a CRADA to support the scope of research that is not covered in the submitted FOA proposal.

6.3 Westinghouse Electric Corporation

6.3.1 Control Room Modernization

Through our partnership with Arizona Public Service, Westinghouse Electric Company has provided screenshots of turbine control system graphics, standard display design examples, and human-system interface style guides. This information was used to develop a basis for comparison between the proposed Westinghouse systems, the existing analog controls, and other concepts developed by LWRS Program researchers and collaborators.

6.3.2 Secondary Piping Health On-Line Monitoring

Dr. Andrei Gribok conducted a conference call with Mr. Frank Gift, Westinghouse Product Manager, and Lead Engineer, Mr. Paul Sirianni, Lead Engineer, and Ms. Doris Doyle, Project Manager, about application fiber optic in for secondary piping health on-line monitoring. The discussion focused on identifying fiber optic applications in the nuclear industry.

6.3.3 I&C Modernization Business Case Analysis

In July, discussions with Westinghouse were initiated on potential cooperation in business analysis for safety-related I&C modernization. Specifically, the Plant Modernization Pathway plans to conduct some research with nuclear utility partners to determine the long-term costs of maintaining the current analog safety systems in the face of increasing obsolescence issues and the task of maintaining a competent workforce for the declining analog technologies. Westinghouse has proprietary information on the cost of new digital replacement systems and insight into the cost of implementing these systems. A Non-Disclosure Agreement (NDA) was completed and forwarded to Westinghouse on September 13th to enable the exchange of proprietary information to these ends. The information will be collected and exchanged by the respective organizations through the second quarter of FY 2019, with the possible development of a CRADA if mutually-beneficial research is identified through this work.

6.4 Nuclear Automation Engineering

Nuclear Automation Engineering (NAE), LLC was contracted to assist with the Digital I&C Qualification Project, which consists of research to identify new methods of qualifying digital I&C systems, especially with respect to digital common cause failure (CCF).

Two new methods were identified that will be recommended for future Pathway research projects: 1) finding an acceptable method for 100% testability of digital devices, and 2) elimination of concurrent triggers of software faults as a means of preventing CCF. NAE also contributed to the development of a strategy for comprehensive nuclear plant modernization.

7. Regulatory Engagement

7.1 General NRC Engagement

Mr. Ken Thomas conducted discussions with Dave Desaulniers of the NRC on a possible meeting in FY 2018 on human factors issues for control room modernization from the NRC perspective. One

possibility was whether there would again be an informal interface meeting of industry and the NRC following the March Regulatory Information Conference.

Dr. Bruce Hallbert and Mr. Thomas attended the 2018 NRC Regulatory Information Conference in Rockville, MD, on March 13-15 (morning). The conference subject matter provided relevant information on how changing regulatory positions and directions impacts the work of the Plant Modernization Pathway, particularly in the area of digital I&C upgrades. This was an opportunity to conduct discussions with nuclear utility managers on the work of the pathway.

This was followed up with a technical exchange with the NRC in their headquarters building the afternoon of the 15th and supported the discussion on pathway work for I&C and control room modernization, with Mr. Craig Primer and Mr. Thomas representing the Plant Modernization Pathway.

7.2 NRC Discussions on Digital I&C Qualification

Discussions were held with Dr. Steven Arndt and Mr. Mike Franovich of the NRC on the issues and difficulties in using PRA methods to qualify software. They both provided their assessments on the efforts to date on the application of PRA methods to address digital common cause failure. Dr, Arndt provided two technical papers he had authored describing the difficulty in modeling software to determine its reliability.

7.3 NRC Digital Integrated Action Plan

The Plant Modernization Pathway conducts regular engagement with the NRC on the Digital Integrated Action Plan (IAP) [5] through participation in the NEI Digital I&C Working Group (see Section 3.2.1). The IAP maintains the Staff Requirements Memorandum (SRM) to SECY-15-01062 direction to develop an integrated strategy to modernize the NRC's Digital I&C regulatory infrastructure. The engagement consists of periodic public meetings and conference calls sponsored by the NRC, with opportunities to comment on technical materials developed for these meetings.

Mr. Gordon Clefton has been the primary Pathway representative in this engagement, with support from Mr. Ken Thomas. Contacts for the NRC include Mr. David Rahn, Mr. Dinesh Tanejo, Mr. Eric Benner, Mr. Harold Chernoff, Mr. Paul Rebstock, Mr. Richard Stattel, amd Mr. Rossnyev Alvarado. This engagement is ongoing as the NRC works through the tasks of the IAP in cooperation with the NEI Digital I&C Working Group.

8. International

8.1 International Atomic Energy Agency

Dr. Ronald Boring supported the International Atomic Energy Agency (IAEA) work to publish a supplemental guideline to standard DS492 on human factors issues for nuclear power plants, traveling to working meetings in Vienna, Austria in February and Madrid, Spain, in September. The supplemental guideline on "Instrumentation and Control Aspects of Human Factors Engineering for Design and Analysis" was developed by nominated participants from member countries and will serve as practical implementation level guidance for the instrumentation and control of monitoring and control locations at nuclear power plants. Participation from the Plant Modernization Pathway was sought due to its hands-on experience working with utilities on modernizing control rooms under LWRS. In developing field guidance for the application of human factors and human performance as part of the IAEA tasking, this helps identify key human performance measures that should be considered as part of instrumentation and

control development for nuclear plants. Participation by the Pathway team member affords the opportunity to ensure that the Pathway approaches and practical experience are incorporated and acknowledged in the guideline.

8.2 IFE Halden Reactor Project

Under contract to the Plant Modernization Pathway, the Institute for Energy Technology (IFE, sponsor of the Halden Reactor Project) developed a flexible software platform for conducting micro-tasks to support control room design activities with our utility partners. This platform can be used to collect data in small-scale studies where operators respond to focused questions about a static interface example with stand-alone dynamic micro-simulations and with the interfaces developed for full-scale plant interfaces. This software collects user interactions and synchronizes eye-tracking data. IFE also adapted their "Synopticon" platform to the HSSL to enable eye tracking studies requiring a minimal amount of data post-processing.

IFE provided a key expert with experience in developing simulator facilities and in developing new I&C interfaces for legacy nuclear power plant control rooms. They also provided nuclear human factors and operations experts with experience in performing large-scale digital upgrades of European nuclear power plant control rooms to facilitate LWRS Program researchers' efforts to use the HSSL as a research tool to conduct early design-phase operator-in-the-loop studies. Halden experts also supported control room validation studies performed at the utility's control room simulator.

Mr. Robert McDonald of IFE participated in a meeting at INL with Dominion Energy on August 20-21 as part of a series of presentations and demonstrations of control room modernization technology and human factors engineering methodologies. This is representative of the valued relationship the Pathway has with IFE in seamlessly working together to support plant modernization for the US LWR fleet.

8.3 Electricité de France

In support of improving LWR performance, Dr. Bruce Hallbert, LWRS Program's Technical Integration Office Director, and Ms. Alison Hahn, LWRS Program's U.S. DOE Federal Program Manager, visited several facilities in France during the week of February 25, 2018. These facilities are owned and operated by Electricité de France (EdF). Atos, a nuclear industry services corporation (refer to Section 6.1), has been selected as the architect, engineer, and supplier of advanced technologies for plant modernization projects by EdF. The scope of these projects includes technologies to enable plant-wide monitoring of components and the supporting analytics to extract information and "intelligence" to optimize plant performance and gain greater operational efficiencies and cost performance. A key aspect of these meetings is that they occurred at several EdF locations and were largely led by EdF plant representatives. This enabled the attendees to learn, from an owner-operator perspective, the incentives and motivations behind the investments, the focus of targeted outcomes throughout the modernization projects, the selection process for determining initial projects, EdF's future plans, and whether the company is currently obtaining the expected returns on investments in the expected time periods. Several briefings were given to EdF and Atos on the LWRS Program by Dr. Hallbert and Ms. Hahn.

8.4 US-India Bilateral Civil Nuclear Energy Working Group

INL hosted the US-India bilateral Civil Nuclear Energy Working Group (CNEWG) Meeting in Idaho Falls, ID, July 31-August 02, 2018. The meeting is supported by the U.S Department of State to promote research collaboration between two countries to advance civil nuclear research. As part of the 2018

meeting, Dr. Vivek Agarwal presented on the health monitoring of assets at nuclear power plants with specific focus on concrete structures. The delegation of scientists from India presented their portion of research on concrete health monitoring. The two presentations were complementary and the excellent synergy between two presentations was noted by representatives from both of the countries. The outcomes from this meeting was agreement to develop a joint research plan to pursue combined impact of corrosion and ASR degradation on concrete health. Also, a joint conference publication will be submitted to 2019 Structure Mechanics in Reactor Technology (SMiRT) Conference in Charlotte, NC, August 5-9, 2019. The two countries agreed to hold monthly teleconference to advance the joint research plan.

9. Other Communications

9.1 Journal Articles

A journal article entitled, "Application of Eye Tracking for Measurement and Evaluation in Human Factors Studies in Control Room, Modernization" was published in *Nuclear Technology* in June. This paper discusses the value of using eye tracking as an objective method that can be used in human factors measurement and evaluation. A brief description of eye tracking technology and relevant eye tracking measures is provided. Additionally, technical considerations and the unique challenges with using eye tracking in full-scale simulations are addressed. Finally, this paper shares preliminary findings regarding the use of a wearable eye tracking system in a full–scale simulator study. These findings should help guide future full–scale simulator studies using eye tracking as a methodology to evaluate human-system performance.

A journal article entitled, "Automated Work Packages: Capabilities of the Future" was published in *Nuclear Technology* in July. This paper resulted from work performed through the LWRS Program. The paper evaluated areas of weakness in the work package process of nuclear power plants and researched the means for available and futuristic automation technologies to overcome them. This resulted in shaping the LWRS Program-generated Automated Work Package concept.

A journal article entitled, ""The Strategic Value of Human Factors Engineering in Control Room Modernization, Progress in Nuclear Energy" was published in *Progress in Nuclear Energy* in August. When planning for control room upgrades, plants have to deal with a multitude of engineering, operational, and regulatory impacts. This will inevitably include several human factors considerations, such as workstation ergonomics, viewing angles, lighting, seating, new interaction modalities, new communication requirements, and new concepts of operation. In helping nuclear power utilities to deal with these challenges, this paper discusses research-based human factors design and evaluation methods to be used in the development of end-state concepts for modernized control rooms and to manage the various phases of the upgrade life cycle.

9.2 LWRS Newsletter Articles

Dr. Andrei Gribok authored a LWRS Newsletter article for the May issue entitled "Online Monitoring of Passive Components and Structures: From Offline Periodic Inspection to Continuous Online Surveillance." The article described the research of the Secondary Health Monitoring project to enable continuous monitoring of pipe and component structures by applying advanced signal processing techniques capable to extend the detection range and sensitivity of ultrasonic guided wave (UGW) technology. This project is partnering with EPRI and SwRI in acquiring data recorded using UGW systems at one of the utilities in US, as described in Sections 3.1.3 and 3.3 respectively.

Ms. Rachael Hill authored a LWRS Newsletter article for the September issue entitled "Energizing the Nuclear Industry through Innovation and Collaboration." The article described the benefits of the engagement the Plant Modernization Pathway has with Arizona Public Service and their Palo Verde Generating Station in control room modernization. The article further highlighted a visit to INL by a senior management team from the station to observe first-hand how their development team participates in human factors engineering research activities in the DOE Human Systems Simulation Laboratory at INL. Included in the article were positive comments from the management team on the results of the research and the value to Palo Verde. The article also noted that management team took the opportunity to record their weekly management video for Palo Verde employees, which conveyed a strong endorsement of the partnership with the Plant Modernization Pathway and the positive effect it is having on I&C modernization for them.

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