INL/EXT-19-54520
Rev. 0

Light Water Reactor Sustainability Program

Stakeholder Engagement Meeting Summary Report

February 2020

U.S. Department of Energy

Office of Nuclear Energy

INL/EXT-19-54520
Rev. 0

Light Water Reactor Sustainability Program

Stakeholder Engagement Meeting Summary Report

February 2020

Idaho National Laboratory
Idaho Falls, Idaho 83415
http://www.inl.gov

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

SUMMARY

Nuclear energy is an important part of supplying our nation's electricity safely, dependably, and economically, with reduced carbon dioxide emissions, through the long-term safe and economical operation of current nuclear power plants. The United States (U.S.) Department of Energy–Office of Nuclear Energy (DOE-NE) supports a strong and viable domestic nuclear industry and preserves the ability of that industry to participate in nuclear projects both here and abroad. In combination with industry programs, the Light Water Reactor Sustainability (LWRS) Program provides the technical basis for extended safe, reliable, and economical operations of the existing commercial fleet of nuclear power plants.

This report describes the LWRS Program Stakeholder Engagement Review Meeting, which was held on January 17 and 18, 2019, in Rockville, Maryland. The purpose of the meeting was to provide information to participants on the accomplishments and plans of the LWRS Program and obtain input from stakeholders on priorities in order to identify needs for future research and development activities. The meeting was designed to be informative and provide opportunities for discussion on ways the LWRS Program can help sustain the existing fleet of U.S. light-water reactors. The meeting and discussions emphasized opportunities to increase engagement of the LWRS Program with the U.S. commercial nuclear power industry, vendors and suppliers, research organizations, and the regulator focusing on issues of sustainability, safety, and enhanced economic performance of the light water reactor industry.

CONTENTS

FIGURES

ACRONYMS

9/11	September 11, 2001
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ASME	American Society of Mechanical Engineers
ASR	alkali-silica reaction
BWR	boiling water reactor
CASL	Consortium for Advanced Simulation of Light Water Reactors
CIM	common information model
DLO	diffusion limited oxidation
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE–EERE	U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy
DOE–NE	U.S. Department of Energy–Office of Nuclear Energy
DRI	Direct-Reduced Iron
EPRI	Electric Power Research Institute
FCTO	Fuel Cell Technology Office
FOA	Funding Opportunity Announcement
I&C	instrumentation and control
IASCC	irradiation-assisted stress corrosion cracking
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
IT	information technology
LWR	light water reactor
LWRS	Light Water Reactor Sustainability
NDA	non-disclosure agreement
NDE	non-destructive examination
NEAMS	Nuclear Energy Advanced Modeling and Simulation
NEI	Nuclear Energy Institute
NEUP	Nuclear Energy University Program
NRC	U.S. Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PIDAS	Perimeter Intrusion Detection and Assessment System

PRA	probabilistic risk assessment
PWR	pressurized water reactor
R&D	research and development
RISA	Risk-Informed Systems Analysis
ROI	return on investment
RPV	reactor pressure vessel
SCC	stress corrosion cracking
SNL	Sandia National Laboratories
SSC	system, structure, and component
U.S.	United States

Light Water Reactor Sustainability Program

Stakeholder Engagement Review Meeting Summary Report

1. INTRODUCTION

Sustainability in the context of the Light Water Reactor Sustainability (LWRS) Program is the ability to maintain the safe and economic operation of the existing fleet of nuclear power plants now and in the future. It has two objectives with respect to long-term operations: (1) to provide science and technology-based solutions to industry to safely enhance the economical operation of power reactors; and (2) to manage the aging of systems, structures, and components (SSCs) so that nuclear power plants can continue to operate safely and cost-effectively.

The LWRS Program is focused on the following three goals:

1. Developing the fundamental scientific basis to understand, predict, and measure changes in materials and SSCs as they age in environments associated with continued long-term operations of existing nuclear power plants.
2. Develop and demonstrate methods and technologies that support the safe and economical long-term operation of existing nuclear power plants.
3. Researching new technologies to address enhanced nuclear power plant performance, economics, and safety.

The LWRS Program conducts research in the following primary technical areas of research and development (R&D):

- **Materials Research**: R&D to develop the scientific basis for understanding and predicting long-term environmental degradation behavior of materials in nuclear power plants. This work will provide data and methods to assess the performance of SSCs essential to safe and sustained nuclear power plant operations. The R&D products will be used to define operational limits and aging-mitigation approaches for materials in nuclear power plant SSCs subject to long-term operating conditions, providing key input to both regulators and industry.
- **Plant Modernization**: R&D to address nuclear power plant economic viability in current and future energy markets through innovation, efficiency gains, and business-model transformation through digital technologies. This includes addressing the long-term aging and modernization or replacement of legacy instrumentation and control (I&C) technologies by R&D and testing of new I&C technologies and advanced condition-monitoring technologies for more automated and reliable plant operation. The R&D products will enable modernization of plant systems and processes while building a technology-centered business-model platform that supports improved performance at a lower cost.
- **Risk-Informed Systems Analysis (RISA):** R&D to optimize safety margins and minimizing uncertainties to achieve high levels of safety and economic efficiencies. The pathway will: (1) deploy the method and tools of technologies that enable better representation of safety margins and the factors that contribute to cost and safety; and (2) conduct advanced risk-assessment applications with industry to support margin management strategies that enable more cost-effective plant operation. The methods and tools provided by the pathway will support effective safety margin management for both active and passive SSCs.

In addition to the previously listed primary technical areas (known as Pathways), the following new initiatives were kicked off in October 2018:

- **Flexible Plant Operation and Generation:** R&D to assess the technical feasibility, economic potential, and license considerations for dispatching thermal and electrical energy to diversify and increase revenue of light water reactors (LWRs) in the United States (U.S.). This includes evaluating the technical feasibility and economic benefits of operating LWRs as electric grid load-balancing plants versus baseload co-generation of electricity and one or more non-electrical energy intensive products, such as: (1) iron/steel; (2) ethylene and propylene for polymers and other chemical feedstocks; (3) transportation fuels; and (4) ammonia-based fertilizers. It also addresses energy storage in a way that could increase revenue for LWRs by shifting power dispatch to the grid during periods of highest demand when the selling price of electricity is higher. The benefits of LWRs to help regulate power grid stability is also evaluated under this R&D topic.
- **Physical Security**: R&D to provide the technical basis for the utilities, the regulator, and other stakeholders to optimize physical security postures while meeting their required security obligations. This initiative will include, but not be limited to, efforts in the following areas: (1) conduct R&D on aspects of risk-informed techniques for physical security to account for a dynamic adversary; (2) apply advanced modeling and simulation tools to better inform physical security scenarios; (3) assess benefits from proposed enhancements, novel mitigation strategies, and potential changes to best practices, guides, or regulation; and (4) enhance and provide a validated technical basis necessary for stakeholders to make the best security decisions possible.

Nuclear energy is an important part of supplying our nation's electricity safely, dependably, and economically, with reduced carbon dioxide emissions, through the long-term safe and economical operation of current nuclear power plants. The U.S. Department of Energy–Office of Nuclear Energy (DOE-NE) supports a strong and viable domestic nuclear industry and preserves the ability of that industry to participate in nuclear projects here and abroad. The LWRS Program provides, in collaboration with industry programs, the technical basis for extended safe, reliable, and economical operations of the existing commercial fleet of nuclear power plants.

This report describes the LWRS Program Stakeholder Engagement Review Meeting. Section 2 provides a brief overview of the meeting, while Sections 3 through 7 summarizes the outcome for each R&D area's parallel session.

2. STAKEHOLDER ENGAGEMENT REVIEW MEETING OVERVIEW

The U.S. Department of Energy (DOE)-sponsored LWRS Program Stakeholder Engagement Review Meeting was held on January 17 and 18, 2019, in Rockville, Maryland. The purpose of the meeting was to provide information on the accomplishments and plans of the LWRS Program and obtain input from stakeholders on priorities in order to identify needs for future R&D activities. More than 130 individuals from over 41 organizations were represented at the meeting, including representatives from the U.S. commercial nuclear power industry, vendors and suppliers, regulators, and research organizations.

The remainder of this section is a high-level summary of the meeting.

DOE-NE Deputy Assistant Secretary for Reactor Fleet and Advanced Reactor Deployment, Shane Johnson, welcomed meeting participants.

He was followed by an Industry Overview and Direction presentation given by Senior Vice President and Chief Nuclear Officer, Xcel Energy, Tim O'Connor, who provided compelling remarks on reinventing and repurposing nuclear plants to ensure their competitiveness as the key to their long-term sustainability. He also presented a need for a new vision for nuclear power, as well as a roadmap for transformation that is tied to Xcel's plans for its nuclear fleet going forward.

LWRS Program Technical Integration Office Director, Bruce Hallbert, then described the goals, objectives, and R&D focus areas of the LWRS Program. He also discussed the LWRS Program 2017 Accomplishments Report and Integrated Program Plan.

Former Westinghouse Chief Technology Officer and Senior Vice President, and current Director of Energy and Technology Consulting at Key Source, Kate Jackson, reported on the results of a recent LWRS Program external review.

Following all of these presentations, a panel discussion entitled, "Industry Challenges and Perspectives for Long-term Operation," was then moderated by Jack Cadogan, senior vice president of Site Operations, Arizona Public Services, Palo Verde Generating Station (see Figure 1). The panel consisted of the following leaders in nuclear energy:

- Scot Greenlee, Exelon Nuclear Senior Vice President, Engineering and Technical Support
- Paul Harden, FirstEnergy Nuclear Operating Company Senior Vice President/Chief Operating Officer
- Brad Adams, Southern Nuclear Vice President Engineering
- Robert Coward, MPR Associates Principal Officer.

The panelists shared their perspectives on industry challenges for the long-term operation of the existing nuclear fleet. Panelists noted that the best outcomes for industry from the LWRS Program's R&D are: (1) digitization of the entire plant; (2) risk-informed approaches that have been accepted by the U.S. Nuclear Regulatory Commission (NRC) and the Institute of Nuclear Power Operations (INPO); (3) continued long-term R&D, such as in the areas of materials, as well as executing near-term results; and (4) research in the areas of physical- and cyber-security.

After the panel discussion, Senior Vice President and Chief Nuclear Officer of the Nuclear Energy Institute, Doug True, gave a presentation regarding current industry initiatives to sustain the existing LWR fleet. His presentation highlighted the value of nuclear energy and some recent performance achievements of the industry. He described the Nuclear Energy Institute's (NEI's) targeted outcomes to achieve meaningful cost reductions and described a call to action in the near-term to ensure the viability of the existing nuclear fleet.

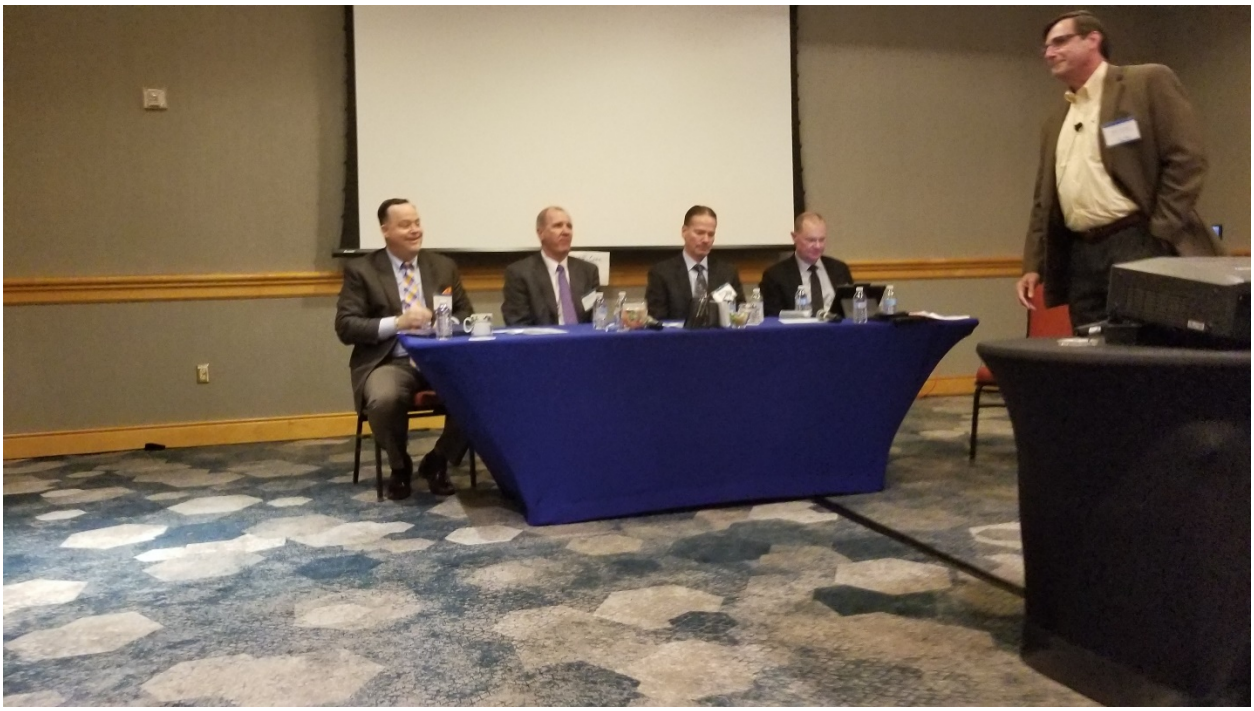

Figure 1. Panelist: (from left to right) Brad Adams, Robert Coward, Paul Harden, and Scot Greenlee. Moderator: Jack Cadogan.

During the afternoon session on Day 1, attendees met in parallel sessions that were conducted to address the gaps and opportunities for the LWRS Program R&D to enable improved plant performance and address industry needs. These sessions were chaired by the following LWRS Program leaders in their respective areas of R&D:

- Keith Leonard, Materials Research Pathway Lead
- Craig Primer, Plant Modernization Pathway Lead
- Curtis Smith, Risk-Informed Systems Analysis Pathway Lead
- Mitch McCrory, Physical Security Initiative Research Lead
- Richard Boardman, Flexible Plant Operation and Generation Research Lead.

Meeting participants highlighted the needs and opportunities and provided fresh perspectives on needed timeframes for results that are needed to have the types of impacts required to sustain and achieve improved performance of the existing U.S. nuclear fleet. A summary of the outcomes from these parallel sessions are described in Sections 3 through 7 of this report.

NRC Director of Nuclear Regulatory Research, Raymond Fursteneau, also gave a presentation during the meeting (see Figure 2). In summary, he noted that the NRC will continue to: (1) collaborate with DOE and the Electric Power Research Institute (EPRI) on aging management research to reduce regulatory uncertainty; (2) build on the successful cooperation that has established the technical basis for long-term operation of nuclear power plants; and (3) conduct regulatory research supporting operational safety to support the revision of aging management guidance and associated aging management plans.

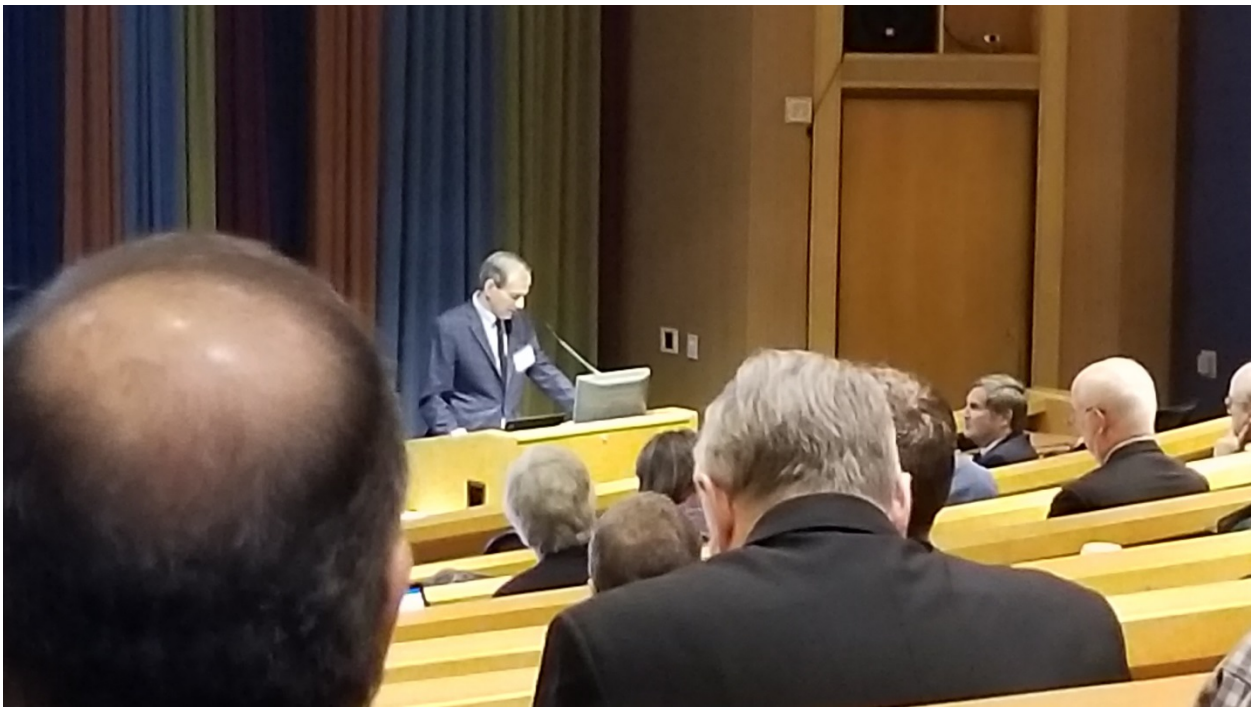

Figure 2. Ray Fursteneau, U.S. NRC Nuclear Regulatory Research Director.

In his closing comments, Southern Nuclear Vice President Engineering, Brad Adams, noted that the nation's nuclear plants are valuable national assets and encouraged those of us in the industry to believe in what we do and be proud of it. He provided a positive outlook on the construction progress of Vogtle Units 3 and 4, as well as optimism regarding their future operation; shared his perspectives that current plants will bridge to next generation plants; and that next generation plants with advanced designs will be built and begin operations in the future. He said that some in the industry may be skeptical of those plans, but that we should maintain a positive attitude because attitude makes a difference.

Alison Hahn, DOE Federal Program Manager, thanked the meeting participants for providing valuable information and contributions during the presentations and parallel sessions. The meeting and discussions emphasized opportunities to increase LWRS Program engagement with the U.S. commercial nuclear power industry, vendors and suppliers, research organizations, and the regulator focusing on issues of sustainability, safety, and enhanced economic performance of the LWR industry.

3. MATERIALS RESEARCH PATHWAY

3.1 Overview

Materials research provides an important foundation for managing the long-term, safe, and economical operation of nuclear power plants. Aging mechanisms and their influence on nuclear power plant SSCs are predictable with sufficient confidence to support planning, investment, and continued operation of existing plants. Understanding, predicting, controlling, and mitigating materials degradation processes will remain key priorities during periods of extended plant operation. The strategic goals of the Materials Research Pathway are to develop the technical basis for understanding and predicting long-term environmental degradation and behavior of materials in nuclear power plants and to provide data and methods to assess the performance of SSCs that are essential to safe and economically sustainable nuclear power plant operations. This includes methods for monitoring and measuring degradation, to understand the aging mechanisms, and to model materials and component performance towards developing strategies to mitigate the effects of aging.

The parallel session for the Materials Research Pathway began with a short, high-level overview of the pathway activities to ensure that people new to the pathway were informed of the pathway's objective and its current research directions and goals. This also included information on the coordinated and collaborative research efforts engaged with stakeholders of the pathway.

3.2 Industry Needs and Priorities

The Materials Research Pathway has been proactively engaged with stakeholders through hosted workshops, pathway level external reviews, attendance and interaction with industry staff at topical national and international meetings and workshops, codes and standards meetings, and user group and owners group meetings. In general, the panel members and parallel session attendees found the scope of the current research projects to be of great benefit to the stakeholders. Some of the main points addressed as stakeholder needs or priorities include:

- Cognizance that scope of research, including program milestone goals and timelines, should support industry aging management, operational improvements, and return on investment.
- Completion and validation of a radiation-induced concrete damage model to reduce uncertainties in long-term licensing of reactors.
- Completion and validation of radiation-induced embrittlement of reactor pressure vessel (RPV) models at extended lifetime to reduce uncertainty and margins.
- Evaluating the response and mechanisms of irradiation-assisted stress corrosion cracking (IASCC) in austenitic stainless steels found in core internals.
- Identifying the underlying mechanisms controlling stress corrosion cracking (SCC) initiation in Ni-base alloys, as well as understanding and modeling the fundamental processes causing crack nucleation, which is a key step in predicting and mitigating SCC in the primary and secondary water systems of LWRs.
- Assessing mechanisms of environmentally assisted fatigue of reactor components to provide plant operators a tool that reduces uncertainty and overly conservative approaches in estimating fatigue life.
- Identifying alloys that are more resistant to radiation-induced degradation than those being used today. This will provide plants with options to minimize degradation of internals, avoid unexpected shutdowns, increase plant reliability, and reduce the cost of nuclear power to the utilities and their customers.

- In collaboration with EPRI, developing and demonstrating advanced welding technology for repair applications to provide industry with techniques to overcome welding problems associated with highly irradiated components and thereby reduce operational costs.
- Completing the assessment of the development of alkali-silica reaction (ASR) expansion and induced damage of large-scale specimens that are representative of structural concrete elements found in nuclear power plants. This includes extensive monitoring and non-destructive techniques and destructive testing to address the question of the shear capacity. This work will provide guidance for aging management and operational improvements.
- Continuing to address the identified knowledge gaps in cable system aging and the evaluation of condition-monitoring techniques will have a significant impact on plant decisions for cable lifetime predictions.
- Aging effects and changes to non-destructive examination (NDE) evaluation of rejuvenated cables.
- Completion of predictive mechanistic model for submerged cables.
- Examination of harvested materials to assess the accurate mode and extent of degradation in specific components towards improved prediction of aging effects in extended operation of existing plants and model validation.

3.3 Gaps and Opportunities to Enable Improved Performance

Gaps (not currently being addressed or funded) include:

- Assessing the in-situ repair of medium- and low-voltage cables—i.e., rejuvenation. Key items include the effect of further aging on the lifetime of rejuvenated cables and their environmental qualification. This also includes establishing the trends for different local and global types of NDE testing on repaired cables.
- Understanding the mechanisms associated with core shroud cracking, mechanical-property changes, and expected conditions with further aging.
- Understanding the impact of long-term thermal and low-fluence aging of the hot-leg nozzle section and pressurizer components.
- Validating predictive models through harvested materials (e.g., from MOSAIC, Grizzly, Consortium for Advanced Simulation of Light Water Reactors [CASL and the NEAMS Program], Virtual Polymer).

A discussion was conducted on the effective ways the program has engaged with industry and future activities that could be planned. These items include the following:

- Maintaining engagement with existing roadmaps with EPRI and NRC on cables, concrete, and metals and expanding to include industry contributions (particularly for engagement in DOE-NE Funding Opportunity Announcements [FOAs]).
- Conducting periodic, highly focused technical workshops with stakeholders to maintain engagement, review research, and address emerging issues and needs, such as:
  - NRC hosting an international workshop on “metals” in May 2019
  - International Group on Radiation Damage Mechanisms in RPVs in May 2019
  - International Committee on Irradiated Concrete in November 2019
  - International workshop on cables in January 2020, which coincides with the EPRI Cable Users Group meeting
  - Harvesting workshop with dates and hosting to be arranged

- Increased engagement in attending the pressurized water reactor (PWR) and boiling water reactor (BWR) owners group meetings.

3.4 Stakeholder Recommendations for the LWRS Program

Materials research is critical for the effective aging management of commercial nuclear power-generation and will require continued updated, quantitative materials-degradation information.

To ensure viability of long-term operation, an assessment of the impact of future funding levels on the ability to meet stakeholder needs for aging management is needed. It is highly important that the high-priority tasks the LWRS Program has are not diverted from current roadmaps to examine issues that have a far lower impact on plant economics or operational readiness by:

- Conducting road-mapping exercises where there is a clear value for areas of collaborative and coordinated research not currently covered (e.g., core internals, vessel integrity, pressure boundary components)
- Maintaining engagement through workshops and attendance at industry meetings
- Continuing to explore engagement with EPRI's Integrated Life Cycle Management Program as a conduit towards faster integration of LWRS Program materials-research data and models into industry
- Examining where DOE can effectively address buried-piping research without duplicating current EPRI or vendor-based activities.

3.5 Parallel Session – Additional Details

The selected panelists were from organizations that represent current LWRS Program Materials stakeholders including the regulator, industry research organizations, nuclear companies and vendors, and the utilities. A larger number of engineers from the utilities were invited to participate in the parallel sessions but could not make the meeting due to previous engagements. The large number of panel members ensure representation of all stakeholders and to cover all the materials-related topic areas of high importance (i.e., RPV, core internals and piping, structural concrete and cable systems) to industry and regulator stakeholders. See Appendix A for full list of meeting participants.

3.5.1 Parallel Session Focus, Objectives and Outcomes

The panel members and audience were asked a number of questions, with the following statement as the primary focus area for discussion: "What are the research areas that need to be addressed or research products developed that will provide a near term positive economic impact on plant operations and which DOE national laboratories are best capable of addressing."

3.5.1.1 Parallel Session Objectives

- Ensure that LWRS Program research products (i.e., data, models, techniques, and materials) positively impact plant economics through reducing uncertainties in materials performance and inform both plant operation decisions and regulatory guidelines.
- Ensure that LWRS Program research plans are developed with industry and regulatory collaborators to ensure the appropriate direction of research goals and timelines will have the most meaningful impact on the nuclear power industry.
- Strengthen industry/regulatory cooperation in LWRS Program research activities.
- Outcomes of the parallel session were intended to:
  - Recognize stakeholder needs and priorities
  - Identify gaps or opportunities to enable improved performance

- Develop opportunities for engagement with LWRS Program activities
- Gain stakeholder recommendations for the LWRS Program.

3.5.2 Panel Discussion Topics

The panel discussions covered several topics, which are summarized in the following subsections by subject area.

3.5.2.1 Cables

- An overview of the cable aging conditions and test plans were discussed in context of addressing research gaps, including diffusion limited oxidation (DLO) effects that may skew accelerated aging test data towards cable insulation lifetimes longer than those observed during in-service aging. The effects of DLO on experimental testing are of concern and represent a focus for the LWRS Program.
- Mechanisms of submerged cable degradation and development of a predictive model was an issue raised by the NRC. This is the focus of a current Nuclear Energy University Proposal (NEUP).
- Aging effects on rejuvenated cable was discussed as a gap area for needed research and will be incorporated into future year planning. This includes understanding the change in response to NDE between aged, rejuvenated, and further aged cable sections.

3.5.2.2 Concrete

- Agreement by attendees that the LWRS Program work on developing a damage model for irradiated concrete was of high importance in addressing near term support for licensing applications, as well as for aging management.
- Discussions of current LWRS Program work on ASR testing and NEUP work on creep of concrete.

3.5.2.3 Reactor Metals and Piping

- Discussion of potential areas in which the Grizzly advanced modeling tool could be used to address other materials related issues, including evaluation of BWR core shroud crack development.
- Discussions on how cracks behave as a function of time, long-term aging at higher temperatures, and comparisons of cracking and the behavior of cold leg cracking and durability versus hot legs.
- Buried pipe degradation from corrosion or leaching mechanisms were an issue raised from the utilities perspective and discussed relative to what gaps research could be applied.

3.5.2.4 Harvesting

- There was general agreement by participants in the parallel session as to the benefits that harvesting and the assessment of materials from decommissioned plants will have on aging management and operational improvements. This was an issue of high-priority, for reasons that include:
  - The accurate identification of mechanisms responsible for known degradation events appearing in specific components that are difficult to simulate under laboratory test conditions (i.e., multivariable influences, flux effects, etc.).
  - Assessment of the extended operation of current plants in evaluating the potential for unknown degradation phenomenon to become active.
  - Validation of materials degradation models.

- Some of the materials of interest for harvesting [a]include, but are not limited to:
  - Concrete samples from various locations that have seen different environmental conditions.
  - Low neutron flux, long-term thermally aged components of the RPV, such as the hot-leg nozzle and weldment, or from the pressurizer.
  - More substantial harvesting of material from the BWR core shroud that can permit greater levels of testing and evaluation.
  - Dissimilar metal welds located in high flux regions.
  - High fluence/long service time core internal structural elements.

3.5.2.5 Miscellaneous Discussion Points

- Assessment of current cross-program collaborations to optimize resources for the most beneficial impact for industry.
- Discussion of effective collaboration methods (i.e., workshops, roadmaps, etc.).

3.5.2.6 Stakeholder Needs and Priorities

The Materials Research Pathway has been proactively engaged with stakeholders through hosted workshops, pathway level external reviews, attendance and interaction with industry staff at topical national and international meetings and workshops, codes and standards meetings, and user group and owners group meetings. In general, the panel members and parallel session attendees found the scope of the current research projects to be of great benefit to the stakeholders. Some of the main points addressed as stakeholder needs or priorities include:

- Cognizance that scope of research, including program milestone goals and timelines, should support industry aging management, operational improvements, and return on investment.
- Completion and validation of radiation-induced concrete damage model to reduce uncertainties in long-term licensing of reactors.
- Evaluating the response and mechanisms of IASCC in austenitic stainless steels found in core internals.
- Identifying the underlying mechanisms controlling SCC initiation in Ni-base alloys, as well as understanding and modeling the fundamental processes causing crack nucleation, which is a key step in predicting and mitigating SCC in the primary and secondary water systems of LWRs.
- Assessing mechanisms of environmentally assisted fatigue of reactor component to provide plant operators a tool that reduces uncertainty and overly conservative approaches in estimating fatigue life.
- Identifying alloys that are more resistant to radiation-induced degradation than those being used now. This will provide plants with options to minimize internals degradation, avoid unexpected shutdowns, increase plant reliability, and reduce the cost of nuclear power to the utilities and their customers.
- In collaboration with EPRI, developing and demonstrating advanced welding technology for repair applications to provide industry with techniques to overcome welding problems associated with highly irradiated components and thereby reduce operational costs.
- Completing the assessment of the development of ASR expansion and induced damage of large-scale specimens that are representative of structural concrete elements found in nuclear power plants. This includes extensive monitoring and non-destructive techniques and destructive testing to address the

[a] In addition to LWRS-specific harvesting needs discussed, the Office of Nuclear Energy leads the Nuclear Science User Facilities (NSUF) program that offers opportunities for researchers to access facilities, technical capabilities, and materials for research in nuclear energy. This program is described at https://nsuf.inl.gov/

question of the shear capacity. This work will provide guidance for aging management and operational improvements.

- Continuing to address the identified knowledge gaps in cable system aging and the evaluation of condition-monitoring techniques will have a significant impact on plant decisions for cable lifetime predictions.
- Aging affects and changes to NDE evaluation of rejuvenated cables.
- Completion of predictive mechanistic model for submerged cables.
- Examination of harvested materials: assessing the accurate mode and extent of degradation in specific components towards improved prediction of aging effects in extended operation of existing plants and model validation.

3.5.3 Opportunities

- Maintaining engagement with existing roadmaps, expanding to include industry contributions (particularly for engagement in DOE-NE FOAs)
- Conducting periodic, highly focused technical workshops with stakeholders to maintain engagement, review research, and address emerging issues and needs. This includes hosting BWR and PWR owners group meetings.

4. PLANT MODERNIZATION PATHWAY

4.1 Overview

Plant Modernization research is addressing the urgent need to modernize the U.S. nuclear fleet. The LWRS Program is conducting R&D in new digital technologies that provide significant improvements in operational efficiencies through their broad deployment. These transformational concepts and technologies enable transition from labor- to technology-centric plant operations, significantly reducing operations and maintenance (O&M) costs of the LWR fleet. Pathway research prioritizes direct collaborations with nuclear utilities and its suppliers to ensure direct and meaningful impact in the U.S. nuclear industry with results that reduce technical, financial, and regulatory risk of full plant modernization, while ensuring the safe reliable long-term performance of operating nuclear power plants.

The LWRS Program Plant Modernization Pathway break-out session was a roundtable-type discussion where approximately 20 attendees, representing the U.S. commercial nuclear power industry, vendors and suppliers, regulators, and research organizations discussed priorities and identified needs for future R&D activities.

To facilitate the discussions, breakout session organizers asked several stakeholders to present what they saw as high priority R&D opportunities. The presenters were asked to (1) describe the R&D opportunity; (2) estimate its value; (3) identify the existing technology or methodology gaps; and (4) prioritize which of the existing gaps should be addressed by the LWRS Program Plant Modernization Pathway. The goal of these presentations was to facilitate a conversation among stakeholders, with participants commenting on proposed ideas, as well as asking questions of the presenters. After the presentations, all stakeholders were asked to describe additional R&D opportunities. The breakout session concluded with all participants prioritizing the R&D opportunities in terms of their value and urgency.

4.2 Industry Needs and Priorities

The results of the prioritization of R&D opportunities discussed during the break-out session are:

1. End State Vision for Digital Transformation:
    - Not just digital modernization, but digital transformation. A key challenge has been establishing a vision of a Full Nuclear Plant Modernization that is ambitious and transformational, rather than a modest upgrade that falls within the current regulatory and operational mindset.
2. Value Proposition for Digital Transformation:
    - Business case with scalable timeline for implementation. One challenge with Full Nuclear Plant Modernization has been how to cost-justify the expense of modernization relative to the expected return on investment.
3. Implementation Plan/Roadmap:
    - Lessons learned/operational experience. It is important to analyze relevant information and past events to identify lessons learned that should be used as a technical basis for modernization decisions and activities that are made in later stages.
4. Integrated Industry Mobilization Plan:
    - Communication, coordination, and a drive towards effective collaboration. How can the LWRS Program play an effective role in facilitating needed interactions among utilities, regulators, vendors, and other researcher entities (e.g., EPRI, Halden/Institute for Energy Technology) to communicate and coordinate on collaborative R&D efforts in this area?

Accelerate the research, development, demonstration, and deployment of digital transformation and communicate results as soon as possible.

Top research, development, and demonstration priorities:

- End State Vision. Get an outside perspective on staffing a transformed plant.
- Technical Challenges:
  - R&D to resolve common cause failures
  - R&D to develop advanced online monitoring and value-based maintenance.
- Organizational Challenges:
  - Integrate information technology (IT) into transformation effort
  - Product/output as a strategy/technology roadmap to manage IT risk
  - Develop a technically informed risk management transformation approach.

4.3 Gaps and Opportunities to Enable Improved Performance

There are a number of specific opportunities that stakeholders identified for consideration by the LWRS Program Plant Modernization Pathway to enable improved LWR fleet performance and achieve the LWRS Program mission. They include:

- Developing disruptive technology to enable advanced online monitoring and value-based maintenance.
- Determine how nuclear power plant work functions are related from the standpoint of modernization technologies. Map this integration.
- Develop a multi-party agreement, which will allow for the flow of information among utilities and other stakeholders collaborating on plant modernization activities.
- Produce a business case for wireless communication technologies (i.e., identify the technologies it enables, and how they can they be credited together to maximize the return on investment [ROI] for wireless deployment).
- Enable new business models that benefit the industry from a cost standpoint that leverage technology to enable suppliers to support the industry more effectively. An example of this is the business-model used by some suppliers of jet engines to the aviation transportation industry.
- Virtualization of I&C hardware (possibly cloud-based) to address obsolescence concerns of digital systems.
- Use of block chain technology for nuclear record keeping, as well as securing information for cybersecurity concerns.
- Support development of a common information model (CIM) to integrate all of the work functions and associated technologies for seamless data sharing across the organization. Support development of new use cases for the CIM.
- Develop, demonstrate, and support deployment of digital technologies that reduce initiating events.
- Develop a comprehensive economic model for plant modernization that can be used as the basis for investment decisions.
- Streamline training for new nuclear operators for the use of new digital training technologies.
- Use of augmented reality for nuclear plant field inspections.
- Identify or develop an easy process for porting plant data to a central repository.
- Conduct a global study on obsolescence that considers the implications of a reduced U.S. supply chain for obtaining outdated technologies.

4.4 Opportunities for Engagement with LWRS Program Activities

Opportunities for engagement include both internal and external LWRS Program activities. Examples of internal opportunities include developing risk-informed methodologies for gaining safety-margin and reducing O&M costs using FLEX portable equipment. The research effort spans across multiple LWRS Program Pathways, including the Plant Modernization Pathway and the RISA Pathway. This research integrates the innovative methodologies developed within the Plant Modernization Pathway with the probabilistic risk assessment models developed for FLEX portable equipment in the RISA Pathway.

External opportunities were identified as well. Rolls-Royce requested that the Pathway explore beneficial business models for the nuclear industry based on technologies that enable real-time collaboration by remote parties. This is a concept that has been proven in Rolls-Royce's jet engine business and could result in a number of important technical and business advantages for the LWR fleet.

It was noted that the Plant Modernization Pathway and EPRI would continue their collaboration in the development of a CIM as a means of sharing data across the many work functions of an operating nuclear power plant. This will involve the development of new use cases based on the findings of the Pathway's research activities.

An opportunity for follow-up was suggested by Arizona Public Service for work involving safety-related digital I&C systems and cybersecurity practices. The issue arises from desired use of computer-based procedures for safety-related system and component O&M. The computer-based procedures and the safety-related systems and components are in separate layers of the cybersecurity scheme and two-way communication between these layers is prohibited. This is a generic problem that needs to be resolved for the industry.

The NRC representatives expressed a desire to work with the Plant Modernization Pathway on regulatory aspects of new digital I&C and control room technologies that are likely to be pursued by licensees in their I&C modernization projects. It was noted that there was a meeting with NRC I&C staff this past fall at INL and that the Pathway was continuing to support the NRC's Integrated Action Plan through its association with the Nuclear Energy Institute (NEI) Digital I&C Working Group. There will be follow-up to see if additional direct discussions between the NRC and the Pathway would be helpful.

4.5 Stakeholder Recommendations for the LWRS Program

The key message from the stakeholders was the urgent need to accelerate the research, development, demonstration, and deployment of digital transformation. They are specifically looking for an end-state vision that goes beyond digital modernization and supports transformation in the nuclear power industry. This includes developing an integrated industry mobilization plan that communicates, coordinates, and ultimately enables effective collaboration in the transformation effort.

5. RISK-INFORMED SYSTEMS ANALYSIS PATHWAY

5.1 Overview

The Risk-Informed System Analysis (RISA) Pathway conducts R&D to enhance safety and improve plant economics. The objectives of its activities are to develop technologies, new risk assessment methods, and other solutions that will afford high levels of safety and economic efficiencies that can be used to support the continued operation of the U.S. nuclear fleet. The RISA Pathway uses a combination of deterministic and probabilistic techniques applied together in a risk-informed approach to better characterize safety margins, reduce unnecessary conservatisms, and allow for greater flexibility in managing new technologies and operations within current safety margins. The RISA Pathway focuses on developing and delivering enhanced capabilities for analyzing and characterizing LWR systems performance by demonstrating and deploying methods, tools, and data with industry and other stakeholder collaborators to enable improved risk-informed safety and economics margins management.

The RISA breakout session included 19 participants, 14 of whom were external to the LWRS Program. See Appendix A for the full list of participants. The session started with an overview presentation of the RISA Pathway by Dr. Curtis Smith, who described the goals, objectives, and current pilot projects in the pathway. The meeting then progressed to discuss industry needs in the area of risk-informed applications and to recommendations for the direction of RISA Pathway research. Some of the more significant areas related to industry needs include demonstrating—by using existing reliability data—that 50.69 relaxation of requirements doesn't reduce reliability. Tools created by the LWRS Program could be used to support the 50.69 evaluations, which could help identify "non-traditionally risk-informed" processes where risk insights may reduce time or cost for regulatory activities, such as physical security, aging analysis, or tools to support engineering walk downs. The team noted that probabilistic risk assessment (PRA) analysis is very expensive and that a need exists to reduce the cost. Industry needs the capability to reduce the conservatism in analyses. Some specific examples of expensive-to-perform risk assessments included seismic-fragility analysis, fire PRAs, and PRA updates and maintenance.

5.2 Industry Needs and Priorities

To help better support industry through the activities of the RISA Pathway, it was suggested that a mixture of existing and advanced risk-informed tools be developed and demonstrated through industry applications in the near term that with a focus on the intersection of safety and economics. Specific suggestions for future pathway activities include:

- Industry and LWRS Program researchers may use different PRA tools, which may slow collaboration; we could make it easier to work together by using commonly employed tools.
- The pathway pilot projects should evaluate new PRA tools and methods against PRA standards and NRC NUREG 1.200 requirements in order to judge suitability and acceptance within the regulatory framework used for risk-informed applications.
- Pathway activities should consider research to develop time-reliability models for real-time risk analysis, taking advantage of big data methods.
- Encourage involvement by the NRC in research activities to obtain feedback, promote regulatory familiarity, and endorse acceptance of developing methods and tools.
- Consider forming a RISA Pathway Industry Working Group to promote continued involvement and feedback from stakeholders and to host periodic reviews of plans and accomplishments.
- The pathway should engage with the Risk Informed Steering Committee Support Group (of NEI/NRC), and with standards committees (American Society of Mechanical Engineers [ASME], American Nuclear Society [ANS], etc.) to promote awareness of research and the new methods that are being developed through the RISA Pathway.

- Industry, DOE, and the NRC should evaluate the potential for jointly supported testing activities and consider the data that could be obtained from decommissioned or decommissioning plants to validate models and tools, especially where limited data today forces conservative assumptions in practice.
- The pathway should identify a target for an early win application of new methods (or new applications of existing tools) that could be demonstrated for the NRC's acceptance.
- The pathway needs to more effectively advertise opportunities to participate in pilot projects to ensure all who want to participate or follow pilot project activities have the opportunity to do so, as well as to communicate the results of research more frequently.
- The pathway should continue to ensure efforts related to risk-inform tools and methods are coordinated with external stakeholders (LWRS Program/EPRI/Industry) and with other DOE projects in order to provide a path forward for industry use of the R&D outcomes.
- The pathway could consider providing training and information about how to use or apply new risk tools and methods developed within the pathway.
- Consider using existing reliability data and a demonstration application to show that 50.69 relaxation of requirements doesn't reduce reliability of an important SSC.
- Determine how to identify "non-traditionally risk informed" processes where risk insights may reduce time and cost for regulated activities, such as in the areas of:
  - Physical security
  - Aging analysis
  - Other qualitative analysis from existing tools
  - Tools to support engineering walk downs (i.e., laser scans with digital models).

5.3 Gaps and Opportunities to Enable Improved Performance

During the session, technical gaps and opportunities were identified.

- Meeting participants identified the need to reduce the cost of conservatisms in the analysis in the following areas:
  - Seismic fragility analysis
  - Fire PRA
  - PRA updates/maintenance.
- The pathway should investigate tools and methods that could facilitate enhanced work-flow and integration of tools that are currently not designed to work together.

5.4 Opportunities for Engagement with LWRS Program Activities

Several potential opportunities for outreach from the RISA Pathway to industry organizations were identified, including:

- The formation of a RISA Pathway Industry Working Group to ensure continued involvement and feedback from industry practitioners into the LWRS Program. Nominally, this should be an annual review meeting.
- Engage with the Risk Informed Steering Committee Support Group (of NEI/NRC).
- Engage with various industry standards committees to support awareness of new methods and to help standards development and related pilot applications.

- Industry/DOE/NRC should look more carefully at testing/data that could be harvested from decommissioned/decommissioning plants. For example, to validate models and tools that are being developed, especially where limited data forces conservative assumptions in risk models.

5.5 Stakeholder Recommendations for the LWRS Program

There were several recommendations regarding what the LWRS Program should consider in the area of risk and risk applications. In summary:

- Identify a target for an early win application of new methods (or new applications of existing tools) that gets through NRC acceptance.
- Advertise opportunities to participate in pilot projects more effectively to ensure all who want to participate or follow have the opportunity to do so.
- Communicate results of the research more effectively/frequently via multiple mechanisms.
- Develop a plan for accelerated industry implementation and NRC approval of advanced tools.
- Coordinate efforts related to the development and application of risk tools and methods with industry.
- Investigate supporting security risk analysis by leverage existing spatially related models rather than traditional internal events models.
- Provide training and better information about how to use and apply new risk tools and methods.

6. PHYSICAL SECURITY INITIATIVE

6.1 Overview

In this session, session leaders introduced a new thrust of the LWRS Program focused on physical security. 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.

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 R&D 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.

The focus of discussions in this new area during the stakeholder engagement meeting was to obtain input from stakeholders on developing the LWRS Program Physical Security Initiative R&D based upon participants' perspectives on current issues and challenges related to physical security and needed R&D to improve the ways it can be achieved. The meeting was attended by a cross-section of the current stakeholder community, including representatives from DOE-NE, the NRC, EPRI, NEI, industry, security software vendors, Sandia National Laboratories (SNL), Idaho National Laboratory (INL), and nuclear industry physical security experts (see Appendix A for the full attendance list). A summary of the physical security breakout session follows.

6.2 Industry Needs and Priorities

This workshop engages industry directly and will help create the basis for a vision and strategic goals for the Physical Security Initiative, provides initial engagement with industry to inform them of the initiative, and starts a continuing dialog with industry. Some of the feedback from the workshop identified some immediate

areas where leveraging DOE tools and physical security R&D efforts from other customers might have near-term impacts for the industry. These include:

- Evaluating existing DOE technologies, identifying applications to commercially licensed nuclear power plant physical security regimes, and providing an agreed upon technical basis for the fleet and the NRC.
- Making an effort to revise and update an open source document-based nuclear power plant facility (Lone Pine) for physical security force-on-force modeling with linked reactor plant system response. This work will leverage the SNL-developed Scribe-3D software for facility visualization of force-on-force modeling.
- Initiating efforts towards risk-informed security aimed at ensuring that cost reduction and optimization of physical security does not compromise risk and enable licensees and regulators to make risk-informed decisions.

6.3 Gaps and Opportunities to Enable Improved Performance

Under the gaps and opportunity discussion, the breakout group discussed creating a vision on when or how to reduce costs. While improved performance would be desirable, the group was more focused on reducing costs without impacting performance, and subsequently improved performance. The following were suggested by consensus discussion within the breakout session as opportunities to achieve improved performance in the LWR fleet through research activity outcomes:

- 10 CFR 73.55 defines the minimum size for a security force. Currently, every nuclear power plant has significantly larger security forces than required by regulation. It was suggested by participants that the Physical Security Initiative develop a vision and implementing activities to help provide the tools and technical basis to reduce staffing to minimum numbers as required by 10 CFR 73.55. Comments from the working group on this topic include:
  - Identifying real cost drivers for site specific security
  - Applying current technologies, leveraging advanced modeling, and providing technical basis
  - Identifying the ROI necessary for implementation.
- Current adversary timelines are thought by participants to be overly conservative. DOE and the U.S. Department of Defense (DoD) are thought to have realistic timelines for use in their security models. In some cases, participants believed that the conservative timelines used by the nuclear industry force-on-force models result in needing to add security personnel to mitigate a particular threat scenario. Comments from the working group on this topic include:
  - Evaluating the use of DOE and DoD adversary timelines for use with NRC-regulated facilities
  - Integrating travel speeds to compliment the information in NUREG/CR-7145
  - Consideration of adversary ‘tool kit’ and delay tactics.
- Risk-informing physical security can provide the technical basis to support physical security decisions, which is currently an effort the NRC is advocating for to support physical security decisions. R&D is needed in this area as the human aspects of physical security prevent many risk methodologies from being effective or valid in this domain. Comments from the working group on this topic include:
  - It is important to develop a consensus definition of what risk-informed security means
  - Qualitative and semi-quantitative models may be useful
  - Performance and effectiveness metrics will be needed for risk-informed security analysis
  - Confidence bounds on assessment criterions will also be needed.
- The nuclear industry representatives noted that surveillance on physical security systems seemed to be excessive relative to other critical systems. They expressed interested in exploring the technical

basis driving physical security maintenance and equipment surveillance. Comments from the working group on this topic include:

- The need for a risk-significance metric if technology failed
- Current technical basis to identify margins
- Offsite response is an area that could potentially decrease the number of physical security personnel onsite by using an offsite force to supplement. Comments from the working group on this topic include:
  - The kind of "active delay" tactics that could be employed.
  - Integrated offsite and onsite response.
  - Options of offsite response.

- Comments from the working group regarding potential areas of exploration by the Physical Security Initiative include:
  - Global entry kiosks for visitor processing (akin to airport security), including a re-evaluation of key duties, fire watch, and other collateral duties by the security force.
  - Integration with cybersecurity (while we discussed this is out-of-scope currently for this session, there was a lot of discussion about needing work in this area and that physical can't be separated for cyber).
  - Human-reliability modeling and risk analysis for detection and response.
  - Detection within Perimeter Intrusion Detection and Assessment System (PIDAS) to notify operators to start response actions.
  - Exploration of current research of insider threat and its applicability.
  - Exploration of the use and taking credit for offsite responders.
- Viable early detection technology that can be credited, including:
  - An agreed upon pedigree (technical basis) for the fleet and the NRC
  - The method to determine how much early detection is needed to be of benefit
  - Exploration of the development of a new standard that licensees and regulators can agree upon.
- The working group discussed the use of online integrated safety and security risk models to interface with out-of-service security and safety equipment or components to get a better picture of what is important and to explore:
  - Identifying conjoint influences of safety and security
  - Enabling the ability to justify a lower number of personnel in the security posture
  - Allowing the identification of when compensatory measures are required.

A key takeaway from the meetings that the group wanted captured was that while the current NRC regulation, 10 CFR 73.55, postulates the existing physical-security regime at U.S. commercial nuclear power plants, the design and personnel of specific utilities differ significantly from each other.

6.4 Opportunities for Engagement with LWRS Program Activities

With very strong engagement from the LWR physical security community, a lot of different engagement opportunities exist. Some of the more significant opportunities include:

- ANS/ASME Joint Committee on Nuclear Risk Management Meeting on Physical and Cybersecurity (January 23-24, 2019)
- NRC Public Meeting on Risk-Informing Physical Security (February 20, 2019)
- NEI and EPRI Physical Security Training at Sandia for utilities (March 11-15, 2019)

Engagement with the NEI Physical Security Working Group (June 12-13, 2019)

- NEI National Security and Emergency Preparedness Summit (August 19-22, 2019)
- Updates to Pressurized Water Reactor Operators' Group and Boiling Water Reactor Operators' Group on the LWRS Program Physical Security Initiative, including their impact on risk, procedures, and licensing committees
- Site visits to nuclear utilities to explore their physical security environment and operating conditions in detail.

6.5 Stakeholder Recommendations for the LWRS Program

Stakeholders provided a number of recommendations regarding the types of activities and direction for future research in physical security within the LWRS Program. The Physical Security Initiative for the LWRS Program was recently initiated at the time of the meeting, so the program plan at that time was under development. This input from stakeholders was timely for the team in that it could be used to support developing the long-term program plan and R&D activities for LWR physical security. The information derived from the workshop will be utilized in developing the program plan. One of the key recommendations from meeting participants was to define an ambitious vision for the Physical Security Initiative with results that the industry can use in the next two to three years. Suggestions include:

- Define the vision:
  - Determine short-term and long-term strategic goals.
  - Consider how R&D activities could impact the ultimate financial target for physical security, based upon input from owner-operators.
- The working group suggested that the Physical Security Initiative address the relationship with cybersecurity as part of their activities as most physical security systems include a significant digital presence in their technology and are included in the NRC rule on cybersecurity (e.g., 10 CFR 73-54). Additionally, cybersecurity is another regulated environment that is currently impacting facility costs. The organizers noted that DOE-NE also has a separate program specifically addressing cybersecurity R&D for nuclear enterprises, which would include LWRs.
- Meet NRC-established requirements for public safety and protecting the environment.
- A frequently expressed common theme is 'risk-informing' security:
  - There was no common definition offered by participants of what 'risk-informing' means, though efforts are underway to develop guidance in this area, which could be used as a basis.
- Integrate or roll-up cybersecurity with physical security:
  - Multiple interests expressed on where cybersecurity resides within the LWRS Program.

7. FLEXIBLE OPERATION AND GENERATION INITIATIVE

7.1 Overview

This session was organized around the emerging need for new nuclear energy markets at a time when existing LWRs are experiencing diminishing revenue in many electricity markets. Based on the growing interest for producing hydrogen, a session based on the hybrid operation of LWRs and the associated role of the LWRS Program to conduct needed research to support the development and deployment of integrated energy systems was arranged.

The LWRS Program has initiated efforts to evaluate operations that can increase the revenue of LWR power-generation stations. One alternative would be to evaluate operationally repurposing these plants during some periods by directly selling electricity and/or steam to a large industrial process. A second option would be to optimize revenue through hybrid operation by dynamically apportioning thermal energy and electricity between an industrial process and the electricity grid. Some manufacturing industries, such as refineries and petrochemical processes, consume a large amount of energy that is on an LWR scale. Unfortunately, these industries are not typically located adjacent to power plants. In order to incentivize a large capital investor to couple a new industrial process to an existing LWR, the new manufacturing process must be competitive with existing manufacturing plants or any new plants that are or could be entering the market place during the period of capital paydown of the industrial plant.

Based on the focus of LWR hybrid electricity/hydrogen plants, this session gathered the following organization and experts to discuss technology gaps and R&D needs that can be addressed by the LWRS Program:

- Utility Sector—particularly utilities with nuclear power plants in both regulated and de-regulated markets and regions where renewable wind or solar capacity is on the rise and where natural gas power plants are being built to take advantage of the historically low cost of natural gas. EPRI's Flex-Ops working group was also represented in this group.
- Hydrogen Electrolysis Businesses—mainly U.S. developers and providers of electrolysis technology, including commercially proven alkaline electrolysis, polymer electrolyte membrane electrolysis (PEM), and solid-oxide high temperature steam electrolysis cells.
- Hydrogen User Industry—represented by a company developing an iron ore reduction process referred to as Direct-Reduced Iron (DRI).
- DOE and National Laboratories—specifically the U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy (DOE–EERE) Fuel Cell Technology Office (FCTO), INL, SNL, Argonne National Laboratory (ANL), and the National Renewable Energy Laboratory (NREL).

Presentations were given by DOE and the National Laboratory participants, followed by discussion on the topical guidelines for the meeting. Key recommendations or comments were captured in the report-out session and are listed for the categories that follow.

7.2 Industry Needs and Priorities

The need to expand the value proposition of LWRs was recognized and stated as a clear need and priority by stakeholders. This issue needs to be addressed and the development and execution of a path forward that supports achieving broad market viability of the operating fleet within five years was emphasized by the utilities and the nuclear reactor operating companies. All participants agreed that alternative revenue sources need to be explored. This should be accomplished by completing technical/economic assessments to establish market cases that support raising the revenue of LWRs. Hydrogen was recognized as a product that could be produced and sold into the merchant market or to a single, large hydrogen user, such as an ammonia plant or a DRI plant.

Based on the presentations of the representatives from FCTO and the National Laboratories, the utilities and LWR representatives strongly encouraged the LWRS Program to focus on hydrogen markets in the near term, and not to "spread the work over too many options." The consensus was to first consider hybrid operations that would enable a currently operating LWR to apportion energy between electricity production for the grid and a hydrogen plant. This would enable the plant to produce the products of the highest value to different markets, demonstrate the viability of these technologies, and identify gaps and needed R&D to support near-term technology development and deployment.

Assuming that the value proposition of hybrid operations can be affirmed through focused technical and economic assessments, the group strongly encouraged moving ahead with first-of-the-kind demonstration projects as soon as possible. The opportunity to apply for DOE assistance under the DOE/NE Industrial FOA was also discussed.

7.3 Gaps and Opportunities to Enable Improved Performance

The main gaps that need to be addressed were distilled down to completing case-specific technical and economic assessments to provide the business case for hybrid operations and then to proceed with needed research, development, and demonstration activities supported by the LWRS Program. Some of the near-term needed R&D includes developing plant interfaces with these systems, including electrical connections, thermal connections, and monitoring and control systems that are important to incorporating these systems into nuclear plant operations.

In addition, the team agreed that it would be important to test the ramp rate and dynamic performance of hydrogen production to reduce the commercial risk of connecting larger systems to nuclear plants. Opportunities to improve performance included evaluation of energy storage systems, reversible solid-oxide high temperature steam electrolysis cell systems that can produce power using the stored hydrogen, and dynamic operation of the solid-oxide high temperature steam electrolysis cell plants to understand the possibility of participating in reserve capacity markets. Plans for raising the Technology Readiness Level of high temperature electrolysis technologies and the interface connections were recommended as key R&D needs.

7.4 Opportunities for Engagement with LWRS Program Activities

The LWRS Program was encouraged to develop a Roadmap (or Plan) leading to first pre-commercial demonstrations. This should begin with the case-specific/reactor-specific technical/economic assessments that are carried out by the LWRS Program with engagement by utilities and LWR operators and engineers. A detailed list of the steps and coordinated efforts was developed for presentation during the report-out meeting.

7.5 Stakeholder Recommendations for the LWRS Program

In summary, the stakeholder recommendations for DOE sponsored efforts were to maintain a focus on hydrogen markets, establish partnerships to help develop impetus for technology development and commercialization, and to plan out and execute small commercial projects as soon as possible. Relative to the LWRS Program operations, the stakeholders encouraged the LWRS Program to develop and prove control systems and communications interfaces with LWR plant and/or electricity dispatch controllers.

Setup and testing of alkaline electrolysis, polymer electrolyte membrane electrolysis, and solid-oxide high temperature steam electrolysis cell at designated LWR power plants is recommended in order to begin addressing physical integration with the electrical (first) and thermal (second) systems of the plant. In addition, fire safety codes and standards, as well as the LWR reactor license basis, should be evaluated to ensure the ability to integrate these systems without substantial licensing or amendments.

Appendix A

Stakeholder Engagement Review Meeting Attendees

Appendix A
Stakeholder Engagement Review Meeting Attendees

Company
Analysis and Measurement Services
ARES Security Corporation (ASC)
Argonne National Laboratory
Arizona Public Service Company
Curtiss-Wright
Department of Energy
Dominion
Electric Research Power Institute
Energy Impact Center
Exelon Corp
Exelon Nuclear
FENOC
FirstEnergy Nuclear Operating Company
FirstEnergy Solutions Generation Companies
Framatome Inc.
FuelCell Energy Inc.
GE Hitachi Nuclear Energy
Howard - Johnson Associates
Idaho National Laboratory
Jensen Hughes
KeySource
LPI, Inc.
Luminant
Midrex Technologies Inc.
MPR Associates, Inc.
National Renewable Energy Laboratory
Nel Hydrogen
Nexceris, LLC

Company
Nuclear Energy Institute
Nuclear Regulatory Commission
Oak Ridge National Laboratory
OxEon Energy, LLC
Pacific Northwest National Laboratory
Pressurized Water Reactor Owners Group (PWROG)
Remer Consulting
RhinoCorps Ltd.Co.
Rolls-Royce
Sandia National Laboratories
Southern Nuclear Company
Tennessee Valley Authority
USA Nuclear
UT-Battelle, LLC
Westinghouse Electric Company
Xcel Energy, Inc