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Light Water Reactor Sustainability Program

Advanced Instrumentation, Information, and Control Systems Technologies Technical Program Plan

September 2012

U.S. Department of Energy

Office of Nuclear Energy

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Prepared by the
U.S. Department of Energy
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ACRONYMS

APR	advanced pattern recognition
DOE	Department of Energy
EPRI	Electric Power Research Institute
FW-PHM	Fleet-wide Prognostic and Health Management
HSSL	Human Systems Simulation Laboratory
II&C	instrumentation, information, and control
LWR	light water reactor
LWRS	Light Water Reactor Sustainability
NPP	nuclear power plant
OCC	outage control center
R&D	research and development
RUL	remaining useful life
UWG	utility working group

Advanced Instrumentation, Information, and Control Systems Technologies Technical Program Plan

1. BACKGROUND

Reliable instrumentation, information, and control (II&C) systems technologies are essential to ensuring safe and efficient operation of the U.S. light water reactor (LWR) fleet. These technologies affect every aspect of nuclear power plant (NPP) and balance-of-plant operations. In 1997, the National Research Council conducted a study concerning the challenges involved in modernization of digital instrumentation and control systems in NPPs. Their findings identified the need for new II&C technology integration.

Digital II&C technologies are deployed in a number of power generation settings worldwide. Current instrumentation and human-machine interfaces employ analog systems in the nuclear power sector. These systems, though generally considered by other industries to be obsolete, continue to function reliably, but do not enable utilities to take full advantage of digital technologies to achieve performance gains.

The NPP owners and operators realize that this analog technology represents a significant challenge to sustaining safe and economic operation of the current fleet of NPPs. Beyond control systems, new technologies are needed to monitor and characterize the effects of aging and degradation in critical areas of key structures, systems, and components. The objective of these efforts is to develop, demonstrate, and deploy new digital technologies for II&C architectures and provide monitoring capabilities to ensure the continued safe, reliable, and economic operation of the nation's 104 NPPs.

Today, digital technologies are implemented as point solutions to performance concerns with individual II&C components. This reactive approach is characterized by planning horizons that are short and typically only allow for 'like-for-like' replacements. This results in a fragmented, non-optimized approach that is driven by immediate needs. As a long-term strategy, this is inefficient in light of the evolution of II&C technology, the availability of skills needed to maintain this legacy technology, and the associated high costs and uncertainties.

To displace the piecemeal approach to digital technology deployment, a new vision for efficiency, safety, and reliability is needed that leverages the future potential of a range of digital options. This includes consideration of goals for NPP staff numbers and types of specialized resources; targeting operation and management costs and the plant capacity factor to ensure commercial viability of proposed long-term operations; improved methods for achieving plant safety margins and reductions in unnecessary conservatisms; and leveraging expertise from across the nuclear enterprise. This last point is especially noteworthy because mergers and acquisitions have redefined NPP ownership and nuclear energy supply in the United States and Europe. NPP ownership is spread across a smaller number of utilities due to mergers and acquisitions, and

ownership is no longer typically characterized by regional location or even national boundaries. Digital technology can enable plant owners to effectively manage the ongoing operations and support of the NPPs from wherever the owner resides.

A technology-driven approach in this research and development (R&D) area alone will be insufficient to yield the type of transformation that is needed to secure a long-term source of nuclear energy base load; a new approach is needed.[1] An effective R&D initiative must engage the stakeholders (i.e., plant owners, regulators, vendors, and R&D organizations) to initiate relevant R&D activities. This calls for development and execution of a long-term strategy for NPP II&C technology modernization based on the unique characteristics of the U.S. nuclear industry and its regulatory environment. In the near term, this strategy should lead to the ability to transition to a business model for NPP operation, employing a new technology base that becomes less labor intensive, facilitates greater digital application deployments, and can be deployed seamlessly across the operational enterprise. The execution of this R&D approach will lay the foundation for a technology base that is more stable and sustainable over the long term and assures the continued safety of power generation from nuclear energy systems.

2. RESEARCH AND DEVELOPMENT PURPOSE AND GOALS

The purpose of the research pathway is to enable the modernization of the legacy II&C systems in a manner that creates a seamless digital environment (Figure 1), encompassing all aspects of plant operations and support – building a three-dimensional information architecture that integrates plant systems, plant processes, and plant workers in an array of interconnected technologies as follows:

- Plant systems – beyond the monitoring and control functions of these systems, extend plant information within these systems directly into the processes that support the plant work activities and directly to the workers performing these activities.

- Plant processes – integrate processes with real-time plant information to enable task automation, plant status control, more accurate procedure and work package usage, enhanced risk management, and other such functions, based on actual plant configuration, performance, and operational constraints.

Figure 1. Seamless information architecture.

- Plant workers – immerse plant workers in an information-rich environment that provides immediate, accurate plant information and allows the workers to conduct plant processes directly at the plant location, using mobile technologies, augmented reality (e.g., "seeing" radiation fields), and real-time video, enabling virtual collaboration and collective situational awareness among all participants in a work activity, both at the job site and in remote locations.

This development will transform the current NPP operating model from one that relies on a large plant staff and predominately manual activities to one based on smaller, technology-empowered staff conducting largely automated activities. Such an operating model will significantly enhance nuclear safety, worker productivity, and overall plant performance. This digital transformation is critical to addressing an array of difficult issues currently facing the plants, including the aging of legacy II&C systems, the need for long-term plant asset management, a potential shortage of technical workers, susceptibility to consequential human error, ever-increasing expectations for nuclear safety improvement, and relentless pressure to reduce cost.

The development and collaborations through this pathway are intended to overcome the inertia that sustains the current status quo of today's II&C systems technology and to motivate transformational change by a shift in strategy – informed by business objectives – to a long-term approach to II&C modernization that is more sustainable. Accordingly, the Department of Energy (DOE) (through the Light Water Reactor Sustainability [LWRS] Program Advanced II&C Systems Technologies Pathway) recognizes the following issues and needs for a long-term R&D program in II&C technologies:

- II&C modernization is critical to the sustainability of the operating nuclear fleet.
- Because of its short-term operational focus, the U.S. commercial nuclear industry could replace its legacy systems and still miss the opportunity to transform its operating model, thereby missing out on efficiencies in the advanced technologies that could reduce the costs of plant operations and outages.
- A national research program is needed to develop the transformative technologies and implementation roadmap for a performance-based II&C modernization strategy.
- DOE's national laboratories maintain unique capabilities to develop and deliver a strategy for modernization that can be successfully deployed by the private sector:
  - A federally funded and industry cost-shared program is technologically and organizationally neutral.
  - Utilities must own the solution to a successful plant-specific licensing case for modernized II&C and monitoring technologies.
  - National laboratories will collaborate with utilities to overcome barriers to technology deployment.

An overriding objective of this pathway is to ensure that legacy II&C equipment does not become a limiting factor in the decisions on long-term operation of these NPPs. Goals for technology introduction are to enhance efficiency, safety, and reliability; improve characterizations of the performance and capabilities of passive and active components during periods of extended operation; and facilitate introduction of new advanced II&C systems technologies by demonstrating performance and reducing regulatory uncertainties. The R&D activities are intended to set the agenda for a long-term vision of future operations, including fleet-wide integration of new technologies.

3. PATHWAY RESEARCH AND DEVELOPMENT AREAS

3.1 Overview

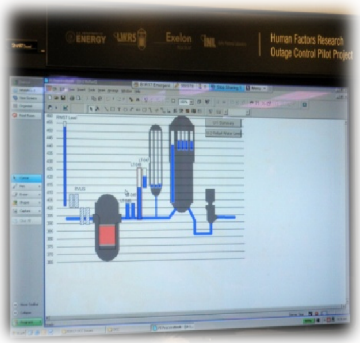
R&D activities are planned to develop needed capabilities through digital technologies to support long-term NPP operations and management. The supporting technologies will enable the large integrated changes that industry cannot achieve without direct R&D support. This includes comprehensive programs that achieve the following:

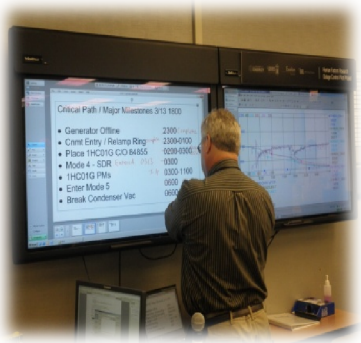
- Support creation of new technologies that can be deployed to address the sustainability of today's II&C systems technologies
- Improve understanding of, confidence in, and facilitate transition to these new technologies
- Support development of the technical basis needed to achieve technology deployments
- Create or renew infrastructure needed for research, education, and testing.

3.2 Advanced Instrumentation, Information, and Control Systems Technologies Research Program

This research program will address aging and long-term reliability issues of the legacy II&C systems used in the current LWR fleet by demonstrating new technologies and operational concepts in actual NPP settings. This approach drives the following two important outcomes:

- Reduces the technical, financial, and regulatory risk of upgrading the aging II&C systems to support extended plant life beyond 60 years.
- Provides the technological foundation for a transformed NPP operating model that improves plant performance and addresses the challenges of the future business environment.





The research program is being conducted in close cooperation with the nuclear utility industry to ensure that it is responsive to the challenges and opportunities in the present operating environment. The scope of the research program is to develop a seamless integrated digital environment as the basis of the new operating model.

The program is advised by a Utility Working Group (UWG) composed of leading nuclear utilities across the industry and the Electric Power Research Institute (EPRI). The UWG developed a consensus vision of how a more integrated approach to modernizing plant II&C systems could address a number of

challenges to the long-term sustainability of the LWR fleet.[2] A strategy was developed to transform the NPP operating model by first defining a future state of plant operations and support based on advanced technologies and then developing and demonstrating the needed technologies to individually transform the plant work activities. The collective work activities were grouped into the following major areas of enabling capabilities:

1. Highly integrated control room
2. Highly automated plant
3. Integrated operations
4. Human performance improvement for field workers
5. Outage safety and efficiency
6. Centralized online monitoring and information integration.

Within these areas of enabling capabilities, a series of 20 pilot projects were defined as the roadmap for industry to collectively integrate new technologies into NPP work activities. For online monitoring, two broad areas of development have been defined at the present, which will be further defined into a series of additional pilot projects.

A pilot project is an individual demonstration that is part of a larger strategy needed to achieve modernization according to a plan. It is small enough to be undertaken by a single utility, it demonstrates a key technology or outcome required to achieve success in the higher strategy, and it supports scaling that can be replicated and used by other plants.

The pilot projects are defined as the appropriate points to introduce enabling technologies across the spectrum of plant work activities. These technologies serve as the stepping stones to the eventual seamless digital environment that enables a transformed NPP operating model. In a September 2011 workshop, the UWG prioritized the pilot projects in terms of value to the utilities and validated the development order. The sequence of development is designed to achieve progressively greater benefits as the growing aggregate of integrated technologies enables higher degrees of automation and innovation. The pilot projects are scheduled over a 12-year period (i.e., 2010 to 2021) as depicted in Figure 2.

Prior to the time the individual pilot projects are scheduled to begin, members of the UWG are solicited to serve as host utilities for the R&D activities in which the new technologies are demonstrated and validated for production usage. This arrangement has a number of advantages as follows:

- It assures the end-state vision for plant modernization is shared by a significant portion of the LWR fleet.
- It assures the near-term technologies are immediately beneficial while they comprise the long-term building blocks of a more comprehensive digital environment.
- It greatly reduces the risk of implementation for any one utility and the oversight of the working group provides a competent peer review.
- It allows the utilities to move forward together in transforming their operating model to fully exploit these technologies, providing a transparent process for coordinated assistance from the major industry support organizations of EPRI, the Institute of Nuclear Power Operations, and the Nuclear Energy Institute.

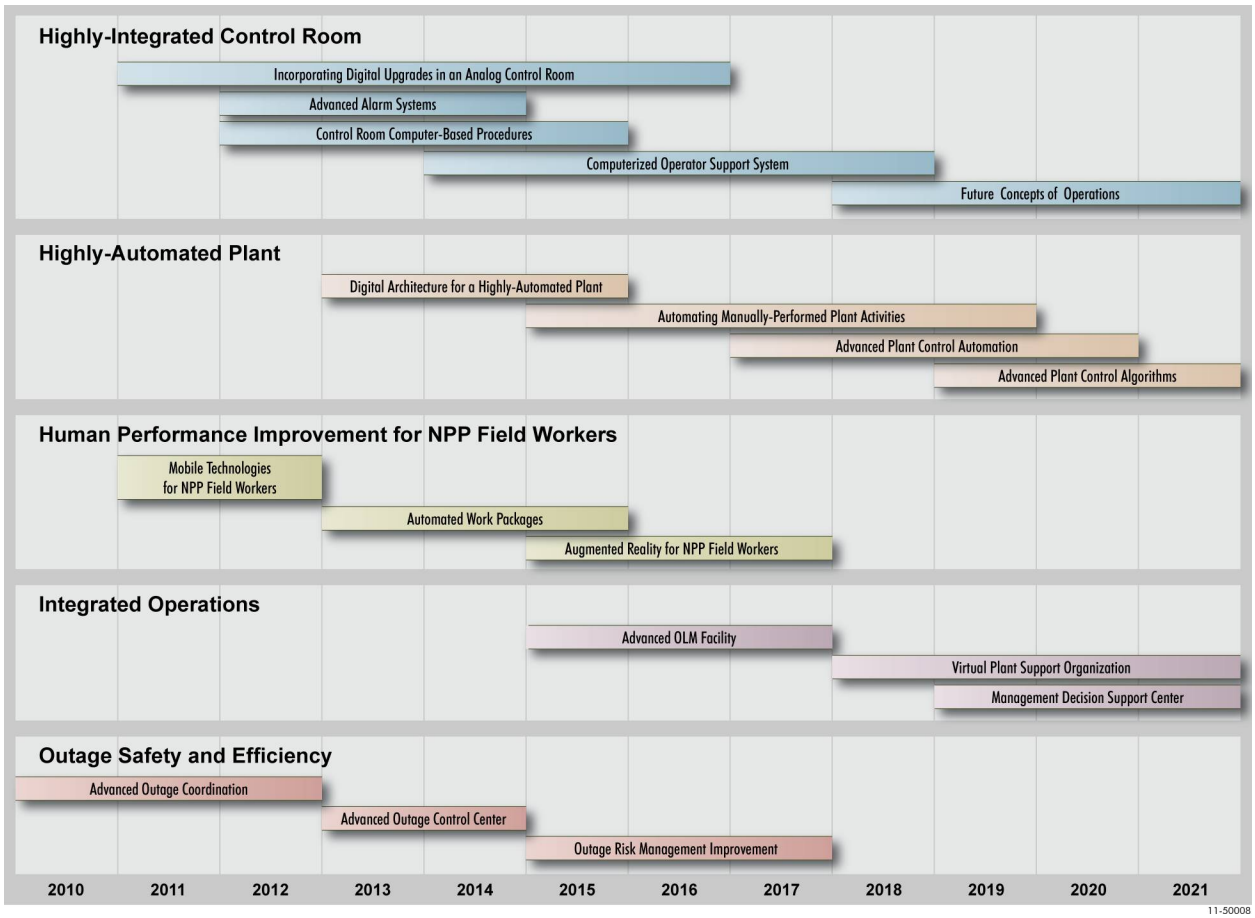


Figure 2. Pilot projects for the Advanced Instrumentation, Information, and Control Systems Technologies Pathway.

The LWRS Program provides the structured research program and expertise in plant systems and processes, digital technologies, and human factors science as it applies to NPP human performance. The utilities provide a cost share in the form of their time, expenses, expertise in plant functions, plant documentation, and access to plant facilities, including the plant simulator. The products of the pilot projects are technology demonstrations and technical basis reports that can be cited in regulatory filings, vendor specifications, and utility feasibility studies.

3.3 Product and Schedule Summary

3.3.1 Applying Digital Upgrades in an Analog Control Room

Full project description can be found in Section 5 subsection 5.1.1.

Schedule: FY 2011 to FY 2016

Milestones:

- (2012) Develop a digital, full-scale mockup in HSSL of a conventional NPP control room (Complete).

- (2013) Publish a reference human factors engineering plan for an optimized, human-factored control board layout for integrating digital operator interface screens with analog controls and indicators.

- (2014) Develop a strategy for migration of II&C functions from traditional control boards to compact operator control consoles.

- (2015) Integrate computer-based procedures for reactor operators into the hybrid control room concept, including soft controls and concepts for shared procedures among control room operators and field operators.

(2016) Develop an end-state vision and strategy, based on human factors engineering principles, for the implementation of both a hybrid and a full highly integrated control room as new digital technologies and operator interface systems are introduced into traditional control rooms.

3.3.2 Advanced Alarm Systems

Full project description can be found in Section 5 subsection 5.1.2.

Schedule: FY 2013 to FY 2014

Milestones:

- (2013) Develop concepts and technologies for advanced alarm management in a hybrid control room.

- (2014) Publish a technical report for an advanced alarm management system in an NPP control room and a methodology for integrating diverse alarms and annunciators across all systems and digital platforms.

3.3.3 Computer-Based Procedures

Full project description can be found in Section 5 subsection 5.1.3.

Schedule: FY 2012 to FY 2015

Milestones:

- (2013) Complete evaluation of final Computer-Based Procedures prototype for field workers.

- (2014) Develop concepts for use of computer-based procedures in a hybrid control room.

- (2015) Publish a technical report for computer-based procedures that enhance worker productivity, human performance, plant configuration control, risk management, regulatory compliance, and nuclear safety margin.

3.3.4 Computerized Operations Support Systems

Full project description can be found in Section 5 subsection 5.1.4.

Schedule: FY 2014 to FY 2018

Milestones:

- (2014) Develop concepts for using NPP full-scope simulators as operator advisory systems in hybrid control rooms and complete a technical report on prototype demonstrations in HSSL.

- (2015) Develop concepts for a real-time plant operational diagnostic and trend advisory system with the ability to detect system and component degradation and complete a technical report on prototype demonstrations in HSSL.

- (2016) Develop an operator advisory system fully integrated into a control room simulator (HSSL) that provides plant steady-state performance monitoring, diagnostics and trending of performance degradation, operator alerts for intervention, and recommended actions for problem mitigation, with application of control room design and human factors principles.

- (2017) Develop an operator advisory system that provides plant transient performance monitoring with operator alerts for challenges to nuclear safety goals.

- (2018) Develop an end-state vision and implementation strategy for an advanced computerized operator support system, based on an operator advisory system that provides real-time situational awareness, prediction of the future plant state based on current conditions and trends, and recommended operator interventions to achieve nuclear safety goals.

3.3.5 Future Concepts of Operations

Full project description can be found in Section 5 subsection 5.1.5.

Schedule: FY 2018 to FY 2021

Milestones:

- (2018) Complete a technical report on operator attention demands and limitations on operator activities based on the current conduct of operations protocols. This report will identify opportunities to maximize operator efficiency and effectiveness with advanced digital technologies.

- (2019) Develop and demonstrate (in HSSL) prototype mobile technologies for operator situational awareness and limited plant control capabilities for NPP support systems (e.g., plant auxiliary systems operations and remote panel operations).

- (2020) Develop and demonstrate (in HSSL) new concepts for remote operator assistance in high activity periods (e.g., refueling outages) and accident/security events, allowing offsite operators to remotely perform low safety-significant operational activities, freeing the control room operators to concentrate on safety functions.

- (2021) Develop validated future concepts of operations for improvements in control room protocols, staffing, operator proximity, and control room management, enabled by new technologies that provide mobile information and control capabilities and the ability to interact with other control centers (e.g., emergency response facilities for severe accident management guidelines implementation).

3.3.6 Digital Architecture for a Highly Automated Plant

Full project description can be found in Section 5 subsection 5.2.1.

Schedule: FY 2013 to FY 2015

Milestones:

- (2013) Publish a technical report that provides a current state and gap analysis for integrating plant information residing in plant II&C systems, plant work processes, and information resources needed for mobile worker technologies.
- (2014) Develop a conceptual model for a digital architecture, integrating plant systems, plant processes, and mobile plant workers based on information exchange requirements that are established on open standards and consistent with design and licensing basis requirements (such as cyber security and Class IE separation). Develop a methodology for mapping NPP operational and support activities into the digital architecture.
- (2015) Publish a technical report on an advanced digital architecture, integrating plant systems, plant work processes, and plant workers in a seamless digital environment, with guidance on how to apply the architecture to an NPP's established data network systems.

3.3.7 Automating Manually Performed Plant Activities

Full project description can be found in Section 5 subsection 5.2.2.

Schedule: FY 2015 to FY 2019

Milestones:

- (2015) For NPP operations activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.
- (2016) For NPP chemistry activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.
- (2017) For NPP maintenance activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.
- (2018) For NPP radiation protection activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.

- (2019) Develop and publish a transformed NPP operating model and organizational design derived from a top-down analysis of NPP operational and support activities, quantifying the efficiencies that can be realized through highly automated plant activities using advanced digital technologies.

3.3.8 Advanced Plant Control Automation

Full project description can be found in Section 5 subsection 5.2.3.

Schedule: FY 2017 to FY 2020

Milestones:

- (2017) Develop concepts for advanced control automation for control room operators based on human technology function allocation developed in the pilot project for automating manually performed plant activities. Publish a technical report on candidate applications for automation reflecting design and human factors principles.

- (2018) Develop and demonstrate (in HSSL) prototype plant control automation strategies for representative normal operations evolutions (e.g., plant start-ups and shut-downs, equipment rotation alignments, and test alignments).

- (2019) Develop and demonstrate (in HSSL) prototype plant control automation strategies for representative plant transients (e.g., loss of primary letdown flow or loss of condensate pump).

- (2020) Develop the strategy and priorities and publish a technical report for automating operator control actions for important plant state changes, transients, and power maneuvers, resulting in nuclear safety and human performance improvements founded on engineering and human factors principles.

3.3.9 Advanced Plant Control Algorithms

Full project description can be found in Section 5 subsection 5.2.4.

Schedule: FY 2019 to FY 2021

Milestones:

- (2019) Conduct and publish a technical report on NPP control problems due to limitations in control algorithms and, specifically, lack of needed plant parameters (sensed or derived) that would improve plant control success in both normal and degraded conditions.

- (2020) Develop and demonstrate new control algorithms based on a prototype plant-wide database of sensed and derived parameters, which is built on the digital architecture for a highly automated plant.

- (2021) Develop the strategy and priorities and publish a technical report for improving plant control algorithms, based on greater availability of sensed and derived plant parameters through the advanced digital architecture, resulting in more anticipatory, adaptive, and resilient control functions.

3.3.10 Mobile Technologies for Nuclear Power Plant Field Workers

Full project description can be found in Section 5 subsection 5.3.1. This project will be completed at the end of FY 2012.

Schedule: FY 2011 to FY 2012

Milestone:

- (2012) Publish a technical report for implementing integrated mobile technologies for NPP field workers that provide real-time connections to plant information and processes, thereby reducing human error, improving human performance and productivity, enabling distance collaboration, and maximizing the "collective situational awareness."

3.3.11 Automated Work Packages

Full project description can be found in Section 5 subsection 5.3.2.

Schedule: FY 2013 to FY 2014

Milestones:

- (2013) Develop automated work package prototype technologies for NPP work processes with associated study of field trials at an NPP.
- (2014) Develop human factors evaluations and an implementation strategy for deploying automated field activity work packages built on mobile technologies, resulting in more efficient and accurate plant work processes, adherence to process requirements, and improved risk management.

3.3.12 Augmented Reality for Nuclear Power Plant Field Workers

Full project description can be found in Section 5 subsection 5.3.3.

Schedule: FY 2015 to FY 2017

Milestones:

- (2015) Develop and demonstrate augmented reality technologies for visualization of radiation fields for mobile plant workers.
- (2016) Develop and demonstrate augmented reality technologies for visualization of real-time plant parameters (e.g., pressures, flows, valve positions, and restricted boundaries) for mobile plant workers.
- (2017) Publish a technical report on augmented reality technologies developed for NPP field workers, enabling them to visualize abstract data and invisible phenomena, resulting in significantly improved situational awareness, access to context-based plant information, and generally improved effectiveness and efficiency in conducting field work activities.

3.3.13 Advanced Online Monitoring Facility

Full project description can be found in Section 5 subsection 5.4.1.

Schedule: FY 2015 to FY 2017

Milestones:

- (2015) Develop and demonstrate (in HSSL) concepts for an advanced online monitoring facility that can collect and organize data from all types of monitoring systems and activities and can provide visualization of degradation where applicable.
- (2016) Develop and demonstrate (in HSSL) concepts for real-time information integration and collaboration on degrading component issues with remote parties (e.g., control room, outage control center, systems and component engineering staff, internal and external consultants, and suppliers).
- (2017) Develop a digital architecture and publish a technical report for an advanced online monitoring facility, providing long-term asset management and providing real-time information directly to control room operators, troubleshooting and root cause teams, suppliers and technical consultants involved in component support, and engineering in support of the system health program.

3.3.14 Virtual Plant Support Organization

Full project description can be found in Section 5 subsection 5.4.2.

Schedule: FY 2018 to FY 2021

Milestones:

- (2018) For chemistry activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host NPP.
- (2019) For maintenance activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host NPP.
- (2021) For radiation protection activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host NPP.
- (2021) Publish human and organizational factors studies and a technical report for a virtual plant support organization technology platform consisting of data sharing, communications (voice and video), and collaboration technologies that will compose a seamless work environment for a geographically dispersed NPP support organization.

3.3.15 Management Decision Support Center

Full project description can be found in Section 5 subsection 5.4.3.

Schedule: FY 2019 to FY 2021

Milestones:

- (2019) Develop and demonstrate (in HSSL) concepts for a management decision support center that incorporates advanced communication, collaboration, and display technologies to provide enhanced situational awareness and contingency analysis.

- (2020) Develop and demonstrate (in HSSL) concepts for advanced emergency response facilities that incorporate advanced communication, collaboration, and display technologies to provide enhanced situational awareness and real-time coordination with the control room, other emergency response facilities, field teams, the Nuclear Regulatory Commission, and other emergency response agencies.

- (2021) Publish human and organizational factors studies and a technical report for a management decision support center consisting of advanced digital display and decision-support technologies, thereby enhancing nuclear safety margin, asset protection, regulatory performance, and production success.

3.3.16 Advanced Outage Coordination

Full project description can be found in Section 5 subsection 5.5.1. This project will be completed at the end of FY 2012.

Schedule: FY 2011 to FY 2012

Milestone:

- (2012) Publish a technical report for implementing digital technologies that facilitate communications, coordination, and collaboration in obtaining accurate outage activity status, managing the flow of information through the OCC, and enabling the resolution of emergent problems in an efficient and effective manner, resulting in improved work efficiencies, production success, and nuclear safety margins (Complete).

3.3.17 Advanced Outage Control Center

Full project description can be found in Section 5 subsection 5.5.2.

Schedule: FY 2013 to FY 2014

Milestones:

- (2013) Develop technologies for an advanced OCC that improves outage coordination, problem resolution, and outage risk management.

- (2014) Develop human factors studies and publish a technical report for an advanced OCC that is specifically designed to maximize the usefulness of communication and collaboration technologies for outage coordination, problem resolution, and outage risk management.

3.3.18 Outage Risk Management Improvement

Full project description can be found in Section 5 subsection 5.5.3.

Schedule: FY 2015 to FY 2017

Milestones:

- (2015) Develop and demonstrate (in the HSSL) technologies for detecting interactions between plant status (configuration) states and concurrent component manipulations directed by in-use procedures, in consideration of regulatory requirements, technical specifications, and risk management requirements (defense-in-depth).

- (2016) Develop and demonstrate (in the HSSL) technologies to detect undesired system configurations based on concurrent work activities (e.g., inadvertent drain paths and interaction of clearance boundaries).

(2017) Develop a real-time outage risk management strategy and publish a technical report to improve nuclear safety during outages by detecting configuration control problems caused by work activity interactions with changing system alignments.

3.3.19 Online Monitoring of Active Components

Full project description can be found in Section 5 subsection 5.6.1.

Schedule: FY 2012 to FY 2014

Milestones:

- (2012) Publish an interim technical report on the online monitoring technical basis and analysis framework for large power transformers.

- (2013) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for large power transformers, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

- (2014) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for emergency diesel generators, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

3.3.20 Online Monitoring of Passive Components and Structures

Full project description can be found in Section 5 subsection 5.6.2.

Schedule: FY 2012 to FY 2017

Milestones:

- (2012) Publish a summary report of strategy and technical plans for online monitoring technologies in support of nondestructive examination deployment.
- (2013) Publish an interim technical report on development of a formal information integration framework used to develop diagnostic and prognostic models for passive plant components.
- (2014) Develop diagnostic and prognostic models for large passive plant components based on the information integration framework.
- (2015) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for a large passive plant component/structure, involving nondestructive examination-related online monitoring technology development, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.
- (2016) Develop diagnostic and prognostic models for second large passive plant components based on the information integration framework.
- (2017) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for second large passive plant component structure, involving nondestructive examination-related online monitoring technology development, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

3.4 Human Systems Simulation Laboratory

The Human Systems Simulation Laboratory (HSSL) at the Idaho National Laboratory is used to conduct research in the design and evaluation of advanced reactor control rooms, integration of intelligent support systems to assist operators, development and assessment of advanced human performance models, and visualizations to assess advanced operational concepts across various infrastructures. This advanced facility consists of a reconfigurable simulator that supports human factors research, including human-in-the-loop performance, human-system interfaces, and analog and digital hybrid control displays. It is applicable to the development and evaluation of control systems and displays for complex systems such as existing and advanced NPP control rooms, command and control systems, and advance emergency operations centers. The facility also can be linked to a virtual reality system (known as the Computer-Aided Virtual Environment; Figure 3) for expanded overview displays, to perform virtual walkthroughs of work environments, or to evaluate human interaction in simulated virtual environments.

Figure 3. Human Systems Simulation Laboratory linked to the Computer-Aided Virtual Environment.

For this research project, HSSL will be used to study human performance in a near-realistic operational context for advanced NPP control room design. The facility is equally suitable for human performance measurement in other NPP control centers such as an outage control center, a centralized online monitoring center, and emergency response facilities. Assessment of human performance in a naturalistic setting includes studies in a range of the following focus areas:

1. Human-system performance relationships between the reliability of the operator, the time available to perform an action, performance success criteria, and the influence of the performance characteristics of the plant or system on task performance and outcome(s).

2. Usability of the human systems interface, which includes the effectiveness, efficiency, safety, and reliability with which an operator can perform specific tasks in a specific operational context (e.g., normal or emergency). This includes the effect on human performance with different technologies and different human-system interface configurations.

3. Human performance expressed as physical and cognitive workload under different operational conditions, including the following:

    a. Monitoring of plant status and system performance

    b. Human error, human reliability, and human error mechanisms

    c. Task completion (e.g., accuracy, speed, tolerance, and variability)

    d. Procedure following

    e. Problem diagnosis:

        1) Decision-making

        2) Response times.

4. Situational awareness with a given human-system interface and control configuration under different operational conditions.

5. Crew communication effectiveness with given technologies under different operational conditions.

6. Human performance with different staffing configurations and a given control room configuration.

HSSL provides the simulation, visualization, and evaluation capabilities needed for pilot projects involving development and evaluation of new technologies for the main control room and other control centers. As such, the new technologies will first be staged in HSSL for proof-of-concept prior to demonstration at host utility NPPs. HSSL facilities will be configured in a variety of settings according to the functional context of each type of plant control center (Figure 4).

Figure 4. Human Systems Simulation Laboratory used to evaluate advanced control room technologies.

The key advantage of mimicking current control rooms comes from the ability to implement prototypes of new digital function displays into the existing analog control environment.[3] Prior to full-scale deployment of technologies (such as control room upgrades), it is essential to test the performance of the system and the human operators' use of the system in a realistic setting. In control room research simulators, upgraded systems can be integrated into a realistic representation of the actual system and validated against defined performance criteria. The next phase of the simulator build-out to be completed in FY 2013 will feature 15 bench-board-style touch panel control bays (Figure 5). This will provide a more realistic representation of the panels found in the current LWR control rooms and will enable research on function allocation, task analysis, staffing, situational awareness, and workload in multiple-unit control rooms.

To meet the needs of other types of control centers (e.g., outage control centers), HSSL will be upgraded continually with new capabilities as the research program progresses. Over time, this will result in an HSSL of highly complex and sophisticated features that will enable realistic modeling of the tasks and functions required of the various plant control centers. It is envisioned that HSSL will be the leading facility in the United States for validation of new operational concepts and technologies for the LWR fleet, thereby ensuring that NPP modernization of II&C systems is based on demonstrated and validated scientific principles.

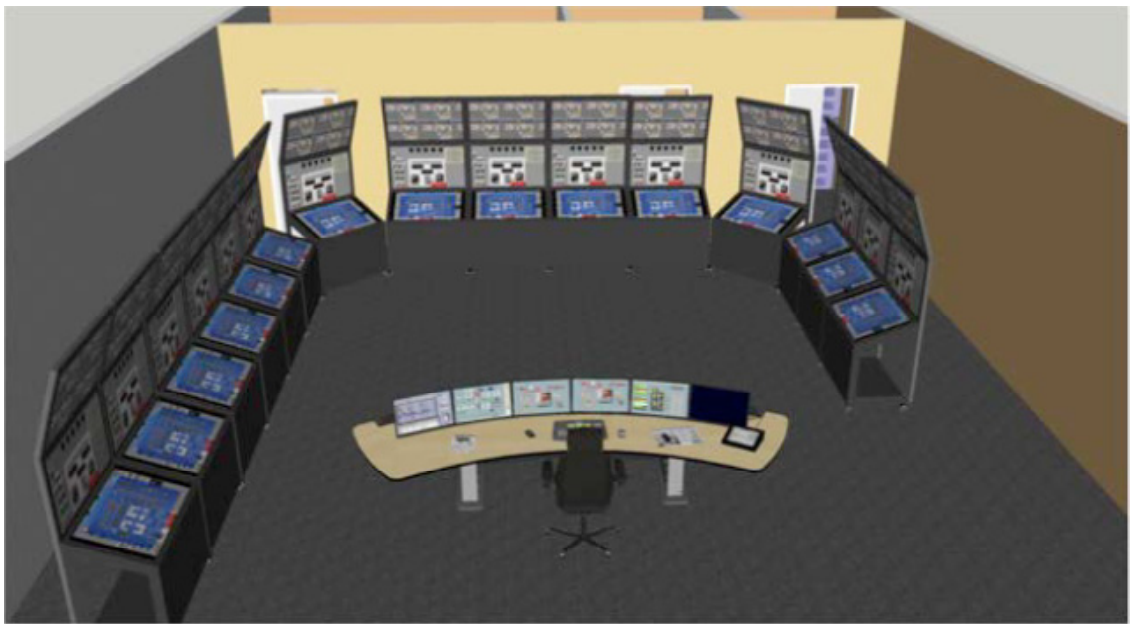


Figure 5. Representation of Human Systems Simulation Laboratory configured with bench-board style control bays for realistic simulation of current light water reactor control rooms.

Milestones:

- (2013) Implement an upgrade of HSSL, enabling research on function allocation, staffing, situational awareness, and workload in multiple-unit control rooms.
- (2014) Expand the HSSL capabilities to address an advanced outage control center.
- (2015) Expand the HSSL facilities and capabilities to address II&C integration and computerized operator support systems.
- (2016) Enhance the HSSL software to include simulation of online monitoring.

3.5 Cyber Security

Cyber security is recognized as major concern in implementing advanced digital II&C technologies in NPPs in view of the considerable security requirements necessary to protect these facilities from potential adversaries, as well as protect company-proprietary information. The members of the UWG have indeed expressed the need to ensure that cyber security vulnerabilities are not introduced through the adoption of these advanced digital technologies. Furthermore, these utilities have internal cyber security policies and regulatory obligations that must be upheld in implementing the project technologies.

To this end, a project task has been created to address cyber security issues arising from the technology developments in the pilot projects. DOE has significant cyber security expertise and resources that have been developed to address the security concerns of the laboratory, as well as those of many security-critical U.S. government facilities. DOE's experience in identifying, characterizing, and mitigating cyber security threats is highly applicable to the type of concerns that potentially would be created in technology areas of the pilot projects.

A cyber security plan assessment template will be developed to identify possible threat vectors introduced by the new technologies. An individual assessment will be conducted for each pilot project to identify the threats specific to its technologies, characterize the degree of cyber security risk, and recommend effective mitigation measures. The assessment will be discussed with the host utility for the pilot projects and the information will be provided to the UWG in general.

Responsibility for cyber security ultimately lies with the utilities that implement the technologies from this research program. They must ensure that their own policies and regulatory commitments are adequately addressed. However, the cyber security resources, expertise, and experience of DOE will provide a sound information basis to guide utilities in prudent technology implementation practices and mitigation measures.

3.6 Quality Assurance

Quality assurance requirements for this research program are defined in the *Light Water Reactor Sustainability Program Quality Assurance Program Document* (INL/EXT-10-19844). This Quality Assurance Program is based on the requirements in American Society of Mechanical Engineers NQA-1-2008, 1a-2009, "Quality Assurance Requirements for Nuclear Facility Applications." It covers all of the R&D activities of the program, including any quality assurance requirements applicable to the technologies and related concepts developed and implemented under the pilot projects.

A specific quality assurance plan is developed for the work package associated with each pilot project, employing an assessment matrix that examines each task in the project to classify it according to the type of research it represents: basic, applied, or development. These research types correspond to a graded approach to the quality assurance requirements, in which the quality assurance requirements appropriate to each type are applied.

4. RESEARCH AND DEVELOPMENT COOPERATION

A systematic engagement activity is underway with NPP owner/operators, suppliers, industry support organizations, and the Nuclear Regulatory Commission. Together, these engagement activities are intended to ensure that R&D activities focus on issues of challenge and uncertainty for NPP owners and regulators alike, the products of research can be commercialized, and roadblocks to deployment are systematically addressed.

4.1 Utility Working Group

The Advanced II&C Systems Technologies Pathway sponsors a UWG to define and host a series of pilot projects that, together, will enable significant plant performance gains and minimize operating costs in support of the long-term sustainability of the LWR fleet. At this time, the UWG consists of 12 leading U.S. nuclear utilities. Additional membership will be pursued for the UWG with the intent to involve every U.S. nuclear operating fleet in the program.

To achieve the full potential of digital technology to improve performance, the industry must work together to collectively transform the operating/support model, using these same practices of rapidly adopting proven innovations across the industry. The UWG will foster this digital transformation in a manner that reduces technical and financial risk, while providing a pathway to this new operating/support model. It also will cooperate with the major industry support organizations to facilitate all aspects of the transformation.

The UWG is directly involved in defining the objectives and research projects of this pathway. The UWG meets regularly several times annually. Criteria have been developed for identifying, prioritizing, and selecting potential advanced II&C pilot projects performed by this pathway.

The pilot project partner will make the results of the R&D available and accessible to other commercial nuclear utilities and participate in efforts to support deployment of systems, technologies, and lessons learned by other NPP owners. Host utilities regularly make presentations in key industry technical meetings to describe their motivations and efforts in the pilot projects and to communicate important findings to the industry.

The UWG sponsors four special interest groups in the areas of outage safety and efficiency, human performance improvement for NPP field workers, computer-based procedures, and control room modernization. The purpose of the special interest groups is to provide a means of focused engagement for utilities in the areas of their interests and provide the means of broad peer review of the technologies developed by the research program.

- The special interest groups hold separate conference calls and meetings to review specific technology developments, particularly in association with demonstrations at a host utility. This facilitates direct communication and collaboration among utility representatives with similar development responsibilities and provides a much broader base for identifying utility requirements, such that the developments will have broad applicability across the LWR fleet.

- Additional special interest groups will be formed as new areas of technology development are undertaken through future pilot projects.

4.2 Electric Power Research Institute

EPRI is both a member of the UWG and serves in a direct role in collaborative research with the II&C Pathway. EPRI has conducted numerous R&D activities over the past several decades in support of NPP digital implementation and related issues and has made relevant reports and guidelines available to this research pathway. EPRI technical experts directly participate in the formulation of the project technical plans and in the review of the pilot project results, bringing to bear the accumulated knowledge from their own research projects and collaborations with nuclear utilities. EPRI will assist in the transfer of technology to the nuclear utilities by publishing formal guidelines documents for each of the major areas of development (see Section 5.7).

EPRI also sponsors a utility advisory group on productivity improvements through advanced technology that is investigating digital technologies of interest to this program and has created an open dialogue for cooperation with the UWG through joint meetings and shared documentation.

4.3 Halden Reactor Project

The programs from the Halden Reactor Project extend to many aspects of NPP operations; however, the area of interest to this R&D program is the man-machine-technology research program that conducts research in the areas of computerized surveillance systems, human factors, and man-machine interaction in support of control room modernization. Halden has been on the cutting edge of new NPP technologies for several decades and their research is directly applicable to the capabilities being pursued under the pilot projects. In particular, Halden has assisted a number of European NPPs in implementing II&C modernization projects, including control room upgrades.

The II&C Pathway will work closely with Halden to evaluate their advanced II&C technologies to take advantage of the applicable developments. In addition to the technologies, the validation and human factors studies conducted during development of the technologies will be carefully evaluated to ensure similar considerations are incorporated into the pilot projects. Specific Halden developments of interest to the pilot projects are as follows:

- Advanced control room layout
- Computer-based procedures
- Advanced, state-based alarm systems
- Integrated operations
- Plant worker mobile technologies.

In addition, DOE will enter into a bilateral agreement in areas of research where collaborative efforts with Halden will accelerate development of the technologies associated with the pilot projects.

4.4 Major Industry Support Organizations

The LWR fleet is actively supported by major industry support groups; namely EPRI, the Nuclear Energy Institute, and the Institute of Nuclear Power Operations. All of these organizations have active efforts in the II&C area, including technical developments, regulatory issues, and standards of excellence in conducting related activities. It is important that these organizations be informed of the purpose and scope of this research program and that activities be coordinated to the degree possible. In the case of EPRI, even though they are a partner in development activities, there are opportunities to collaborate with other major programs they sponsor such as the Instrumentation and Control Program and the Nuclear Maintenance Application Center.

It is a task of this research program to engage these organizations to enable a shared vision of the future operating model based on an integrated digital environment and to cooperate in complementary activities to achieve this vision across the industry with the maximum efficiency and effectiveness.

There are additional industry support groups (such as the Pressurized Water Reactor and Boiling Water Reactor Owners Groups) that need similar engagement for more focused purposes. These groups sponsor II&C working groups that will similarly benefit from communications about the research program and coordination of activities where warranted.

4.5 Nuclear Regulatory Commission

Periodic informational meetings are held between DOE Headquarters personnel and members of Nuclear Regulatory Commission management to communicate about aims and activities of individual LWRS Program pathways. Briefings and informal meetings will continue to be provided to inform staff from the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research about technical scope and objectives of the LWRS Program.

4.6 Suppliers

Ultimately, it will be the role of the nuclear industry II&C suppliers to provide commercial products based on technologies developed under this research program. In the absence of an industry-wide II&C modernization strategy, products currently offered by these suppliers reflect the more limited approach of fragmented, like-for-like digital implementations as driven by the market. As a collective vision for an improved operating model based on an integrated digital environment takes hold within the LWR fleet, leading suppliers will seize the market opportunity to provide products that enact this vision.

An engagement strategy for nuclear industry II&C suppliers will be conducted with the following tasks:

- Communicate to suppliers the objectives of the research program and the specific technologies and operational concepts that are being developed and validated through the pilot projects.
- Obtain input from suppliers on how they are developing their products with respect to this market.
- Set up a mechanism for ongoing communications.
- Facilitate a long-term commercialization strategy for the program's developed technologies.

4.7 Department of Energy Nuclear Energy Enabling Technologies Program

The DOE Office of Nuclear Energy sponsors a crosscutting technology R&D program addressing common II&C needs in all Office of Nuclear Energy-sponsored programs. This program, the Advanced Sensors and Instrumentation crosscut, is conducting research that is intended to address gaps and needed capabilities for II&C technologies in all Office of Nuclear Energy-sponsored R&D programs.

II&C related technologies are or will be needed to meet some of the long-term sustainability goals that are beyond the scope of LWRS Program research activities today. This includes improved technologies to support fuels and materials research that are capable of providing higher quality data during in-pile irradiations (planned to be coordinated in other LWRS R&D pathways). It also includes technologies that will enable some of the vision elements of the II&C research pathway. Examples of these include digital technologies that can reduce the highly labor-intensive aspects of plant maintenance (such as inspections, tests, and surveillances of sensors and controllers). In addition, digital technology introduction still presents a challenge for most plants because of the considerable regulatory uncertainties – both real and perceived – to obtain approvals, creating significantly higher costs and schedule uncertainty.

The current fleet of LWRs still employs many of the same technologies and algorithms in balance of plant control as when the systems were originally commissioned. Because of the amount of system noise and measurement uncertainty, set point regulation imposes a high burden on plant margins and creates a control structure that is inflexible. Consequently, control system behavior is deterministic and cannot easily or rapidly account for small system disturbances or significant external transients without quickly reaching protection system set points. This results in more 'unavoidable' shutdowns and runbacks than would be necessary if installed control systems could be made more resilient and better able to cope with anticipated transients. Advances in control systems technologies would enable a range of operational

improvements that would support higher rates of plant availability and reduced thermal cycling on major plant components caused by rapid plant shutdowns.

Two significant issues confront the massive communications architectures that are required to transmit signal and control data from and between the more than 100,000 individual plant components. The first relates to the material aging of copper cables for medium and low-voltage cables, especially the performance of insulating material. Although research is underway to understand and propose mitigations to counter the effects of material aging and degradation, a diversification of communications approaches may reduce the amount of amelioration that is eventually necessary once a solution is found. In addition, many plant components are not physically 'wired' to the control system and exist outside the awareness of the control system and the operational staff. This introduces significant challenges in maintaining a desired plant configuration and requires substantial manual efforts to periodically assess and verify configuration status. In both cases, wireless communications technologies may one day be substituted for many physical cabling. In concert, power harvesting technologies would help realize the goal to have all components physically coupled to plant control systems without imposing additional requirements for power cabling.

Finally, the reactor accidents at Fukushima Dai-ichi have raised a number of issues regarding the ability of current II&C technologies to withstand the environmental and accident conditions of severe accidents. Currently, emergency operating procedures and severe accident management guidelines in U.S. NPPs require access to reliable information from sensors and controls in order to manage anticipated transients. However, the severe accidents at Fukushima Dai-ichi highlight the potential for loss of all instrumentation and the ensuing difficulties in implementing emergency actions as a consequence. Further research is needed to understand the root causes of instrument failures, alternative approaches to estimate plant conditions, and to determine alternatives to accident management and recovery.

5. RESEARCH AND DEVELOPMENT PRODUCTS AND SCHEDULES

For each of the areas of enabling capability, the current performance issues and needs are described, followed by a description of how technology developments can improve performance. Each of the pilot projects is then described in terms of activities and deliverables, including a concise summary of each project.

5.1 Highly Integrated Control Room

Control rooms for the LWR fleet reflect the technology that was available at the time they were designed. They consist of an expansive set of control boards to accommodate the hundreds of discrete controls and indications required by analog technologies. In addition, the control rooms are typically ringed with overhead alarm panels, consisting of hundreds of individual alarm windows each dedicated to a particular alarm condition. The complexity and sheer number of devices presents quite a challenge to the operators.

Digital technology has been slowly introduced into U.S. operating NPPs over the past couple of decades. However, it has had little impact on the design and layout of the control rooms themselves. Rather, it has been blended into the larger population of analog controls in order to preserve the general arrangement of functions that are familiar to the operators. A major upgrade of a control room has not yet been undertaken in the U.S. LWR fleet.

Research projects by the LWRS Program will be a significant national resource to guide the modernization of U.S. NPP controls rooms as the legacy II&C systems of these plants are inevitably converted to digital technology. HSSL is a world-class facility capable of supporting the technical and

human factors studies needed to ensure that new control room concepts are valid and will uphold all nuclear safety requirements. In addition, the LWRS Program has an agreement in place for access to control room modernization technology developed by the Halden Reactor Project, which has played a key role in several of the European control room upgrades. The LWRS Program is well-positioned to provide the enabling science behind a much needed modernization of the LWR fleet control rooms.

5.1.1 Applying Digital Upgrades in an Analog Control Room

More and more digital conversions of analog II&C systems will be undertaken by U.S. nuclear utilities as concerns over reliability and component aging continue to accrue. These new systems typically come with advanced operator interfaces that are quite different than the analog control devices of the legacy systems. This raises the questions of how to incorporate the new technology into the existing control room and what the impact on operator performance and regulatory requirements will be. One strategy has been to preserve the same operator interfaces of the old analog controls with the same or similar board-mounted discrete control and indication devices, in lieu of modern human systems interfaces. While this has minimized the cost of changes to operator procedures and training, it has diminished the value and potential benefits of the digital technology.

In other cases, dedicated human systems interfaces have been incorporated into the control boards in the general area where the former analog controls were located. However, this has sometimes introduced different types of operator interfaces, such as integrated flat-panel displays, large screen overview displays, touch panels, track balls, a standard computer mouse, and multiple keyboards. Obviously, this impacts control room human factors and can result in undesirable or unanticipated changes to operator and team performance if not properly implemented. Further, NPPs plan to implement these modifications over a long period of time, which will result in a progression of interim hybrid control room states that mix analog and digital human systems interfaces. Each of these interim states must be evaluated from a human factors perspective to ensure that operator performance is not diminished.

Therefore, the prospect of multiple, disparate digital interfaces in a hybrid control room will drive the need to readdress the control room layout in a more holistic manner in order to provide the operators with a consistent, uniform interface for the various digital systems. Such upgrades to will involve first-of-a-kind technical developments and regulatory submittals.

It is imperative that control room upgrades reflect the correct application of human factors principles. Expertise in human factors has been substantially lost in the nuclear utility staffs since the days of completing the TMI-2 Action Plan in the late 1980s. Furthermore, the understanding of human factors has substantially improved since that time and regulatory requirements and guidance have continued to evolve. DOE maintains considerable expertise in human factors principles and application and has HSSL as a laboratory of considerable capability to develop and validate technologies for control room modernization, including requirements for safety-related systems. DOE also is involved with leading international efforts (such as those conducted by the Halden Reactor Project) in order to leverage the expertise in modernizing control rooms that has been developed in other countries and, in particular, those that have been undertaken in Europe.

This pilot project will develop principles that can be used in guidelines for design and layout of a modernized analog control room and for standardized operator interface screens, each according to human factors engineering principles. It will develop standardized operator interface screens and control board layout guidelines based on human factors engineering principles and regulatory guidance. It also will develop a reference human factors engineering plan for control room modernization for use by industry based on the practical knowledge gained in this pilot project. It will involve workshops conducted in HSSL with utility licensed operators to address human factors issues such as functional requirements

analysis, function allocation, task analysis, and operator sequence analysis. These activities will lead to the ability to conduct integrated system validation, which looks at the total effect of hardware, software, and human factors changes to ensure that desired outcomes are indeed obtained without introducing undesirable factors.

This pilot project is currently underway with two host utilities: Southern California Edison (San Onofre Nuclear Generating Station) and Progress Energy (Harris Nuclear Station and Brunswick Nuclear Station).

Schedule: FY 2011 to FY 2016

Milestones:

- (2012) Develop a digital, full-scale mockup in HSSL of a conventional NPP control room (Complete).
- (2013) Publish a reference human factors engineering plan for an optimized, human-factored control board layout for integrating digital operator interface screens with analog controls and indicators.
- (2014) Develop a strategy for migration of II&C functions from traditional control boards to compact operator control consoles.
- (2015) Integrate computer-based procedures for reactor operators into the hybrid control room concept, including soft controls and concepts for shared procedures among control room operators and field operators.
- (2016) Develop an end-state vision and strategy, based on human factors engineering principles, for the implementation of both a hybrid and a full highly integrated control room as new digital technologies and operator interface systems are introduced into traditional control rooms.

5.1.2 Advanced Alarm Systems

Alarm systems in NPP control rooms today are facing reliability and aging issues, as well as being non-optimal for highest operator performance.

The annunciator window-based systems are capable of only indicating that a certain condition has been sensed and cannot put this information in the context of actual plant conditions and mode of operation. In a complex event or plant transient, many superfluous or low-priority alarms are triggered due to the large number of off-normal events throughout the plant. However, the majority of these alarm conditions are simply symptomatic of the event or plant mode and not the cause. Some of the alarms in any given event indicate the direct cause and some do require operator actions; however, most of them do not require action or at least not until later in the recovery.

An advanced alarm system would be capable of suppressing the non-essential alarms so the operator is not distracted with superfluous information during the time-critical phase of the event. These suppressed alarms would be preserved in a separate list that could be accessed any time the operator has a need for them. The advanced alarm system also could be state-based and operating mode-sensitive, meaning that alarms that are not meaningful in the present operating state would be suppressed.

Human factors studies will be conducted to measure operator performance for selected candidate alarm system displays and to determine which presentations of alarm information result in the optimum operator performance.

As another objective of this project, research will be conducted in advanced visualization techniques to improve operator recognition and comprehension of alarm states. Traditional alarm systems rely on brief word descriptions that are typically illuminated in a flashing annunciator window or flashing text alarm on an operator display. This type of presentation does not take advantage of a human's inherent abilities to process information conveyed in color, geometric patterns, and other visual clues. Human factors studies will be conducted to determine the optimum forms of alarms to maximize operator performance.

This pilot project will develop guidelines for selecting candidate alarm system displays and logic based on a needs analysis and technical requirements for an operating NPP.

HSSL will be configured to simulate control room functions and layout of the host utility control room. It will be used to conduct alarm design and validation studies on candidate alarm systems using operators from the host utility or those that are familiar with their systems and procedures. This will involve the logic of the alarms and the physical layouts of the alarm displays. Options for presentations will include use of HSSL and advanced visualization techniques, making use of human factors studies to determine the best information presentations for peak operator performance.

This pilot project will begin in FY 2013 with Southern California Edison (San Onofre Nuclear Generating Station) serving as the host utility.

Schedule: FY 2013 to FY 2014

Milestones:

- (2013) Develop concepts and technologies for advanced alarm management in a hybrid control room.
- (2014) Publish a technical report for an advanced alarm management system in an NPP control room and a methodology for integrating diverse alarms and annunciators across all systems and digital platforms.

5.1.3 Computer-Based Procedures

The commercial nuclear industry conducts virtually all plant activities using standard or special procedures. This includes operational activities, abnormal or emergency actions, maintenance, testing, security measures, plant chemistry control, and radiation protection. The quality of the procedures, refined by operating experience over decades, has been an important contributing factor to the overall success of plant operational excellence and nuclear safety. Strict adherence to written procedures is a key tenet of operational standards.

Unlike many other safety-critical industries, procedures in the commercial nuclear industry are almost always paper-based. As such, these procedures remain prone to certain human errors and process deviations that continue to challenge the plants. Typical problems are as follows:

- Applying the wrong procedure for the plant situation
- Unauthorized or unintentional deviations from procedure steps

- Unexpected results from procedure actions due to coincident plant conditions/configuration
- Copy errors in transcribing plant data into the procedures
- Computational errors in processing acquired data.

These types of problems can be largely prevented using computer-based procedures, which inherently enforce adherence expectations and perform data manipulations in a correct manner. Furthermore, in a well-connected computer-based procedure environment using wireless technology, it is possible to track the timing of real-time actions of procedure steps in order to detect unintended interactions among procedures or with the desired plant configuration. The following important benefits are possible with such a system:

- Integration with real-time plant data and system status
- Time monitoring for time-critical actions
- Detection of undesirable interactions
- State-based and mode sensitive context
- Sequencing of steps and other procedures (workflows)
- Place-keeping
- Seamless transitions to other procedures
- Computational aids and validation of results
- Embedded job aids – reference material, training material, and operating experience reports
- Automatic information insertion and verification of plant response
- Remote concurrences and authorizations
- Soft controls – platform for the future "highly automated" plant
- Real-time task status
- Real-time risk assessment.

DOE has considerable expertise in computer-based procedures, having produced papers and reference material for the Nuclear Regulatory Commission on this topic. Further, the DOE agreement with the Halden Reactor Project provides access to considerable research and products for computer-based procedures, including direct experience in implementing such systems.

In the longer run, full modernization of the NPP control rooms will require the use of soft controls based on a computer-based procedure platform. This will enable many advances in advanced controls and reduction in human error. Computer-based procedures are the foundation of many advanced operational concepts of benefit to the LWR fleet.

This pilot project will develop requirements and implementation models for application of computer-based procedures to operations and maintenance activities for an NPP. It will provide successive demonstrations of computer-based procedure capabilities as they are developed. It ultimately will integrate the technologies into the control room simulations for combined human factors studies with computer-based procedures used in hybrid and highly integrated control rooms.

This pilot project is currently underway with Arizona Public Service (Palo Verde Nuclear Generating Station) serving as the host utility.

Schedule: FY 2012 to FY 2015

Milestones:

- (2013) Complete evaluation of final Computer-Based Procedures prototype for field workers.
- (2014) Develop concepts for use of computer-based procedures in a hybrid control room.
- (2015) Publish a technical report for computer-based procedures that enhance worker productivity, human performance, plant configuration control, risk management, regulatory compliance, and nuclear safety margin.

5.1.4 Computerized Operations Support Systems

Situational awareness is critical to the safe operation of NPPs. It requires an accurate understanding of the current plant state and operating configuration, the intricacies of the plant process and control systems, the physics of the plant processes (nuclear, thermal, fluid, and electrical), and the current operating margins with respect to safety and regulatory limits. Today, this enormous amount of information has to be mentally integrated by the operators to arrive at an accurate understanding of how the plant is operating and where it is headed. This is a daunting task for even the most experienced operators and could become a significant concern in the future as a wave of new operators replaces the aging nuclear workforce.

As more and more plant information becomes available in a digital form, it will be possible to provide operators with advanced information systems that aid in assessing the current plant status, safety margins, and deviations from expected operations. Through advanced simulation techniques, it will be possible to predict where the plant is going operationally and how long the operators have to intercede in undesirable plant trends.

A computerized operations support system is a collection of capabilities to assist operators in monitoring overall plant performance and making timely, informed decisions on appropriate control actions for a projected plant condition. It could contain the following features:

- Advanced nuclear, thermal-hydraulic, and electrical models to assess actual plant performance relative to the predicted plant performance and report deviations and trends to the operators. It can use directly measured parameters and derived parameters to analyze plant performance. It can distinguish between real plant performance deviations and those due to failed instruments.
- A faster-than-real-time simulator that could predict the effect of operator actions prior to them being taken. This would detect interactions that might not be apparent to the operator due to unusual plant configurations and other operating restrictions. It could project the timing of the gradual effect of actions on reactor power such as boration and dilution. Depending on the fidelity of the simulator, it could be very helpful in off-normal conditions where the emergency procedures cannot anticipate every combination of component unavailability.
- Learning systems that become more robust as they experience a wider variety of operational conditions. This includes systems that employ advanced algorithms to monitor many sensors and other inputs to perform monitoring of plant and subsystem performance.
- Continual reinforcement of training within the control room by providing direct reference to training material when it would not be a distraction to operational duties. This form of embedded training has been used elsewhere in other industries (notably aviation) with beneficial effect.

This pilot project conducts research to build these aggregate plant models and connect them to current and new advanced sensors to obtain precise measurements of the current operating parameters. These models will be validated against actual plant performance at a host utility's NPP. They will be refined until they produced an accurate picture of the plant operating state and degree of deviation from expected performance.

It should be noted that this project will require a substantial cost-share on the part of the host utility. DOE's responsibility in the project will be to provide the computerized operations support system platform suitable for testing and demonstration. However, the largest portion of the work will be in modeling the host utility NPP to a degree of detail that will provide useful information to the operators. This would be the responsibility of the host utility.

Schedule: FY 2014 to FY 2018

Milestones:

- (2014) Develop concepts for using NPP full-scope simulators as operator advisory systems in hybrid control rooms and complete a technical report on prototype demonstrations in HSSL.
- (2015) Develop concepts for a real-time plant operational diagnostic and trend advisory system with the ability to detect system and component degradation and complete a technical report on prototype demonstrations in HSSL.
- (2016) Develop an operator advisory system fully integrated into a control room simulator (HSSL) that provides plant steady-state performance monitoring, diagnostics and trending of performance degradation, operator alerts for intervention, and recommended actions for problem mitigation, with application of control room design and human factors principles.
- (2017) Develop an operator advisory system that provides plant transient performance monitoring with operator alerts for challenges to nuclear safety goals.
- (2018) Develop an end-state vision and implementation strategy for an advanced computerized operator support system, based on an operator advisory system that provides real-time situational awareness, prediction of the future plant state based on current conditions and trends, and recommended operator interventions to achieve nuclear safety goals.

5.1.5 Future Concepts of Operations

The control room staffing and protocols for the current LWR fleet are based on operational concepts that go back to the beginning of the industry. They are largely based on staffing requirements to handle plant emergencies. They employ protocols that maximize command and control, rigorous formality, and operator attention-to-detail. They mandate minimum staffing present in the control room due to the need for physical proximity to the information displays and controls. These protocols are absolutely essential today because the operator is the point of integration for information about the current operating state of the plant.

While this operating model has been very successful in safe and productive operation of the LWR fleet, it drives a number of inefficiencies in staffing because operators who are monitoring the plant systems generally cannot be involved in other activities. Therefore, additional operators are required for work management functions, system tag-out developments, plant rounds and field operations, and monitoring special processes such as reactor refueling or dry cask storage loading.

In the future, it will be possible to gain significant efficiencies by employing new concepts of operation made possible by the combined technologies for control room modernization and enhanced operator performance. Specifically, there could be a reduction in the number of operators who are required to be either onsite or in the control room on a continual basis. In addition, the operating protocols could be substantially more flexible in allowing operators to conduct auxiliary tasks while maintaining adequate situational awareness of the operating units while being immediately available to take necessary control actions.

These future concepts of operations may alleviate the need for as large a physical presence to effectively control the plant; the new levels of automation may relieve the operators of performing tedious diagnosis and control functions, enhancing their roles to one of oversight of plant protection and control systems and intervening only as needed.

We have strong precedents for this concept in aviation today. For example, pilots do not have to actually be in the cockpit to fly an airplane (unmanned aerial vehicles have systems that can perform real-time flight control functions by responding to broader directions and objectives given by a remote pilot). A similar concept is employed in virtually all modern aircraft cockpits, where the flight controls, avionics, and navigation systems are coupled under a flight management system that automatically directs the flight according to the flight plan and pre-determined instructions of the pilot, freeing the pilot to stay in an oversight mode of ensuring all systems are operating correctly and the flight is proceeding as planned.

The idea of using technology to reduce control room staffing or to permit plant control from outside the control room using advanced display and communication technologies will be highly controversial, notwithstanding the potential efficiency gains. This concept will run against the grain of deeply held beliefs on the conduct of nuclear operations. However, there is already a provision for some of the control room staff to be out of the control room provided they can return within a set time (e.g., the shift technical advisor). Therefore, with no additional risk imposed, this concept can first be validated by giving these technologies to control room crew members that can already be out of the control room to determine their effectiveness in increasing situational awareness while away. The concept can slowly evolve from there as experience and human factors studies determine whether there are efficiency gains without undue concerns over loss of effectiveness of the control room crew.

These technologies and capabilities would include the following:

- Portable interface devices (e.g., tablets and heads-up displays) that will provide continual plant status and control capability anywhere in the plant.

- New control capabilities that automate large operational sequences such as power maneuvers and putting systems into service. Further, they could diagnose and manage (without manual operator actions) the early portions of transients and accidents for the time required for operators to return to the control room. These capabilities can transform required operator actions from long sequences of individual control actions to broad, high-level objective commands (e.g., “place alternate letdown in service”).

- Computerized operations support systems that detect deviations and trends very early and provide much more response time to operators to react to and intervene in the situation.

- Ability of qualified operators to assist with certain tasks from where they are (i.e., at home, in remote parts of the plant facility, or at a sister nuclear unit).

- For operators in the control room, technology would enable them to participate in activities that today would require them to be present in other parts of the facility (e.g., pre-job briefings). This capability would rely on real-time video, collaboration tools, and virtual meeting software to allow participation in these activities from their normal operating station.

The Halden Reactor Project is already experimenting with high-fidelity control room displays on portable devices (such as digital tablets) to study potential improvement in situational awareness for operators temporarily away from the control room. This effort, and other similar research studies, will provide insight into how these technologies can safely be used by control room crews.

This project will assess the capabilities beneficial to a modernized control room and develop concepts for operating the nuclear unit in a more flexible and efficient manner. This will include a minimum presence of staffing in the control room, assessment of the control room workload based on advanced technologies, and flexibility for crew members to conduct activities outside the control room while remaining "in-the-loop" through the technologies. A human factors study of crew dynamics would be conducted and would focus on collective situational awareness.

Other future concepts of operation would be explored, with the objective to enhance how the control room interacts with special-purpose control centers such as the outage control center, work execution center, technical support center, operational support center, and the emergency operations facility.

Schedule: FY 2018 to FY 2021

Milestones:

- (2018) Complete a technical report on operator attention demands and limitations on operator activities based on the current conduct of operations protocols. This report will identify opportunities to maximize operator efficiency and effectiveness with advanced digital technologies.

- (2019) Develop and demonstrate (in HSSL) prototype mobile technologies for operator situational awareness and limited plant control capabilities for NPP support systems (e.g., plant auxiliary systems operations and remote panel operations).

- (2020) Develop and demonstrate (in HSSL) new concepts for remote operator assistance in high activity periods (e.g., refueling outages) and accident/security events, allowing offsite operators to remotely perform low safety-significant operational activities, freeing the control room operators to concentrate on safety functions.

- (2021) Develop validated future concepts of operations for improvements in control room protocols, staffing, operator proximity, and control room management, enabled by new technologies that provide mobile information and control capabilities and the ability to interact with other control centers (e.g., emergency response facilities for severe accident management guidelines implementation).

5.2 Highly Automated Plant

Perhaps, NPPs are the only remaining safety-critical operations that rely to a large degree on human skill to conduct routine and emergency activities. Adoption of digital technologies has transformed other high-risk industries (e.g., aviation, medical procedures, and high-precision manufacturing), with

tedious control functions performed by automation while the operator remains in an oversight, directory role.

This situation is largely due to the fact that the operating NPPs were designed in the 1970s and early 1980s and, because of technology limits at the time, most plant functions required manual control. While certain processes pertaining to reactor operations are automated (e.g., core power level with automatic rod control), the vast majority of plant controls for configuration changes or placing equipment in and out of service are manual. This over-reliance on tedious manual control on such a large scale challenges operators and results in human error rates that are unacceptable.

The concept of a highly automated plant is one where the most frequent and high risk control activities are performed automatically under the direction of an operator. Because of higher reliability in well-designed automatic control systems, improvements will be realized in nuclear safety, operator efficiency, and production. The chief impediment to the widespread implementation of this concept is the cost of retrofitting new sensors, actuators, and automatic control technology to the existing manual controls. The goal of this research will be to demonstrate that the resulting improvement in safety and operating efficiencies will more than offset the cost of making these upgrades.

5.2.1 Digital Architecture for a Highly Automated Plant

To automate operating NPPs to their full potential, integration of digital technologies must extend beyond plant control and information systems to that of the domain of plant work processes and plant worker activities. This will require a plant digital architecture that is more encompassing than currently is available to the industry.

Even in today's more advanced plants, the digital architecture typically extends only to the major protection and integrated controls systems. Data architectures to support plant work processes are intentionally separate due to cyber security concerns. No comprehensive data schema is available that relates all plant functions in the context of their real-world relationships, thereby defining the needed data interfaces to conduct plant functions and support activities in an integrated manner. This architecture would define the following:

- Systems that need to be integrated for robust plant protection and control
- Types of data busses and interfaces
- Cyber security requirements
- Failure and recovery requirements
- Necessary segmentation of the overall architecture to ensure independence of function and defense-in-depth
- Data relationships that are required to support plant functions, plant systems, plant processes, or plant worker activity
- External interfaces to enable remote operations and support activities, either at a fleet or industry level.

This pilot project will define an advanced information and control architecture that will accommodate the entire range of system, process, and plant worker activity to enable the highest degree

of integration, thereby creating maximum efficiency and productivity. This pilot project will consider a range of open standards that are suitable for the various data and communication requirements of the seamless digital environment. It will map these standards into an overall architecture to support the II&C developments of this research program.

Schedule: FY 2013 to FY 2015

Milestones:

- (2013) Publish a technical report that provides a current state and gap analysis for integrating plant information residing in plant II&C systems, plant work processes, and information resources needed for mobile worker technologies.

- (2014) Develop a conceptual model for a digital architecture, integrating plant systems, plant processes, and mobile plant workers based on information exchange requirements that are established on open standards and consistent with design and licensing basis requirements (such as cyber security and Class IE separation). Develop a methodology for mapping NPP operational and support activities into the digital architecture.

- (2015) Publish a technical report on an advanced digital architecture, integrating plant systems, plant work processes, and plant workers in a seamless digital environment, with guidance on how to apply the architecture to an NPP's established data network systems.

5.2.2 Automating Manually Performed Plant Activities

NPPs have a higher ratio of staffing to unit of power output than any other form of electrical generation. For example, an NPP will typically have ten times the amount of staffing as a similar-sized fossil generation station. Labor is the largest component of an NPP's operating and maintenance cost, typically accounting for 70% of the annual operating budget.

These high staffing requirements are due to the fact that NPPs have such a large number of systems and that most operations are manually performed. Because of nuclear safety concerns, most plant manipulations have to be verified by a second person and even a third person in high-risk situations.

As current components in the plants today approach end-of-life and are faced with reliability and component aging issues, an opportunity presents itself to upgrade the systems in a manner that can reduce dependence on manual activity. Whereas, this once would have been thought to be cost-prohibitive, new advances in technology now make this economically feasible. Some of these advances are as follows:

- Low-cost, highly reliable sensors and actuators (with low maintenance requirements)

- Wireless technology, avoiding the need for long runs of expensive instrument cable

- Easy-to-maintain control technologies such as field programmable gate arrays, programmable logic controllers, and other digital control devices

- Power harvesting from ambient energy (e.g., light, heat, and vibration).

To make this automation cost effective, plant activities must be transformed so that the cost of automation is offset by reductions in the size of the plant staff required to conduct these activities. Otherwise, the technology upgrade costs would simply be added to the cost of the present plant structure

of staffing and manual processes and no real efficiencies would be gained. Therefore, research is required to determine how to conduct these activities in a fundamentally different way, relying on automation to accomplish the end objectives rather than staff activity.

Examples of these kinds of opportunities are as follows:

- Replacement of stand-alone analog control loops with digital technology. A typical example would be a throttle valve control circuit, which would rely on an analog sensor/transmitter hard-wired to the control room, a controller with a set point or manual control, and an output circuit with a current loop connected to a pneumatic control loop connected to the valve's air operator. The objective would be to replace all of these analog technologies with digital equivalents, eliminating the frequent maintenance work required for these legacy technologies, while gaining improved accuracy and reliability of the digital technology.

- Elimination of manual gauges and displays that have to be locally read on a frequent basis by replacing them with wireless equivalents.

- Addition of low-cost, wireless component position indicators, thereby eliminating time-consuming and error-prone field walk-downs of valves, breakers, and dampers to verify they are in the correct position.

- Inline chemistry instruments, eliminating field samples that have to be transported to an analysis laboratory for processing.

- Replacing local control panels with highly automated soft controls that can be operated from more convenient locations.

- Conversion of protective relays to integrated digital relay systems that would eliminate tedious manual testing of these individual devices and greatly reduce the effort to replace or upgrade protective relay functions.

This project will analyze the NPP current staffing and cost model in a top-down manner to identify opportunities to significantly lower operating costs through selective automation of frequently performed manual activities. It will examine the technologies from a maturity perspective and a human factors perspective. It will make broad recommendations on gradually transforming the operating model of NPPs from one that is labor centric to one that is technology centric. In making this transformation, the underlying technologies that are deployed will enable a concept of integrated operations, which will greatly reduce dependence on in-plant staff in favor of out-sourced remote operations and maintenance.

Schedule: FY 2015 to FY 2019

Milestones:

- (2015) For NPP operations activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.

- (2016) For NPP chemistry activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and

human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.

- (2017) For NPP maintenance activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.

- (2018) For NPP radiation protection activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology with results published in a technical report.

- 2019) Develop and publish a transformed NPP operating model and organizational design derived from a top-down analysis of NPP operational and support activities, quantifying the efficiencies that can be realized through highly automated plant activities using advanced digital technologies.

5.2.3 Advanced Plant Control Automation

Because of the pervasive analog II&C technology in NPPs today, much of plant control is conducted by operators manually manipulating a large array of discrete control devices. The exceptions to this include the process control system for the reactor coolant system, heat transfer (steam generators for pressurized water reactors), and turbine-generator controls for power production. Also, the emergency core cooling system is typically auto-started on certain emergency signals, but has to be manually adjusted as the accident mitigation sequence progresses. Other plant systems are largely reliant on manual operator actions for normal and emergency operations.

By shifting the balance away from manual operator actions to more plant control automation, nuclear safety and plant production can be enhanced by reducing the opportunity for human error, while making it possible for the operator to stay in an oversight role of the changing plant conditions and the performance of the automatic control systems.

Building on work from the pilot project on automating manually performed plant activities, especially the portion concerning conversion of stand-alone control loops to digital technologies, it is possible to implement a distributed control system in a way that automates large sequences of commands in order to relieve the operators of tedious plant manipulations. This concept also will depend on converting currently manual components to automatic function and installing low-cost, highly reliable sensors and actuators.

Priorities for advanced plant control automation concepts would be those activities that are frequently performed, time and attention-intensive for the operators, and entail some nuclear safety or production risk. Examples of such activities are as follows:

- Plant heat ups and cool downs

- Automated management of plant transients

- Swapping operating trains where there are redundant systems

- Aligning systems to their test configuration

- Placing systems into service

- Conducting in-service maintenance activities such as backwashes of strainers.

Human factors evaluations would be a component of this project because there are significant concerns on how this level of automation will affect operator skills and knowledge. Operator performance studies would be run in HSSL to address the following issues:

- Would an over-reliance on the automation technology be created so operators would not maintain the skills necessary for performing the actions manually if the technology failed?

- Would operators have a sufficient understanding of what the automated systems were doing throughout any automated plant evolution?

- Would operators lose focus in monitoring the plant during long sequences of automated control?

- Would operators immediately recognize a control system failure even when there was no significant plant excursion?

Working with a host utility NPP, this project would use HSSL to develop a prototype of wide-scale control automation and conduct the human factors studies to answer these questions. The project would develop a prioritized list of plant control functions to be included in an advanced plant control implementation for a first-mover NPP. Also, the project would develop a technical report for applying advanced plant controls in a manner consistent with the human factors principles developed as part of the project.

Schedule: FY 2017 to FY 2020

Milestones:

- (2017) Develop concepts for advanced control automation for control room operators based on human technology function allocation developed in the pilot project for automating manually performed plant activities. Publish a technical report on candidate applications for automation reflecting design and human factors principles.

- (2018) Develop and demonstrate (in HSSL) prototype plant control automation strategies for representative normal operations evolutions (e.g., plant start-ups and shut-downs, equipment rotation alignments, and test alignments).

- (2019) Develop and demonstrate (in HSSL) prototype plant control automation strategies for representative plant transients (e.g., loss of primary letdown flow or loss of condensate pump).

- (2020) Develop the strategy and priorities and publish a technical report for automating operator control actions for important plant state changes, transients, and power maneuvers, resulting in nuclear safety and human performance improvements founded on engineering and human factors principles.

5.2.4 Advanced Plant Control Algorithms

Control algorithms for the current fleet of LWRs are certainly adequate and sufficient to maintain control of the plant in all operating conditions and to invoke protective actions when the allowable operating limits are exceeded. However, because of the state of technology at the time these plants were designed, the control parameters were limited to those that could be cost-effectively hardwired to the control devices of any particular plant function.

This meant that the controls of the plant were not as highly integrated as is desirable. In some cases, they are coupled only by the physics of the plant (e.g., controlling rod demand with turbine impulse pressure). As a result, certain downstream control functions do not respond until the physical plant has responded to some other input or control function. This introduces delay and insensitivity for the downstream control functions.

A fully-integrated digital plant would have access to any parameter captured by its sensors, instruments, and control functions. If properly organized in a plant-wide database, any parameter could be made available to any control function as a variable in the control software if it made logical sense to do so. This would provide the potential to have far more robust control functions for the plant, incorporating the following concepts:

- Adaptive controls to cope with sensor and control component failures
- Anticipatory signals for quicker plant responses to upsets
- New types of sensors to provide direct measures of key control parameters
- Derived values for desirable parameters that cannot be directly measured.

This project will conduct a study of critical control functions in both boiling water reactor and pressurized water reactor NPPs to determine how they can be made more robust and finely tuned by the addition of new control parameters. A source for each desired parameter will be identified as an available signal stored in the plant computer, a need for a new type of sensor, or a need for a derived parameter from other plant information. Also, an adaptive control scheme for each critical control function will be developed in consideration of these same available parameters. The result will be far more robust control schemes for critical plant control applications, improving plant reliability, minimizing plant transients, and enhancing nuclear safety.

This project will build on the work performed in the pilot project for the digital architecture for a highly automated plant, specifically in the structure of the plant-wide database to organize all of the sensor and derived parameters available to the II&C systems. A key consideration of this database design will be the update frequency required by the advanced plant control algorithms to keep pace with rapidly changing plant conditions.

Schedule: FY 2019 to FY 2021

Milestones:

- (2019) Conduct and publish a technical report on NPP control problems due to limitations in control algorithms and, specifically, lack of needed plant parameters (sensed or derived) that would improve plant control success in both normal and degraded conditions.

- (2020) Develop and demonstrate new control algorithms based on a prototype plant-wide database of sensed and derived parameters, which is built on the digital architecture for a highly automated plant.

- (2021) Develop the strategy and priorities and publish a technical report for improving plant control algorithms, based on greater availability of sensed and derived plant parameters through the advanced digital architecture, resulting in more anticipatory, adaptive, and resilient control functions.

5.3 Human Performance Improvement for Nuclear Power Plant Field Workers

Despite over a decade of strong emphasis on human performance improvement, the LWR fleet continues to be impacted by human error, resulting in plant transients, nuclear safety challenges, and equipment damage. While consequential error rates are relatively low (typically measured in the range of 10-4 consequential errors on a base of 10K hours worked), the sheer number of work hours accumulated by the plant staff over time means that errors impacting plant safety and reliability still occur too frequently.

The traditional approach to improving plant worker human performance has been to focus on correcting worker behaviors. This has indeed produced substantial improvement since the time this emphasis began in the mid-1990s. Up to that time, there were frequent plant trips and transients due to human error (such as working on the wrong component or even the wrong operating unit). These types of errors have been gradually reduced until they presently are relatively rare. However, other types of errors continue to cause or complicate nuclear safety challenges. The commercial nuclear industry received somewhat of a wake-up call in the first half of 2010 when there were a series of incidents at different NPPs, many of which were considered to be among the industry's best performers. These incidents were documented in the Institute of Nuclear Power Operations Significant Operating Experience Report (SOER) 10-2, "The Thinking, Engaged Organization," which assigned a significant portion of the causes to human error and lack of operator fundamental knowledge.

The focus on correct worker behaviors typically involves analysis of the inappropriate worker actions and implementation of corrective actions in the form of additional training, procedure upgrades, job and memory aids (i.e., acronyms and neck strap cards), additional peer checking, management job observations, and so forth. While some improvement is usually obtained from these corrective actions, there has been a cumulative negative effect in adding complexity to work activities that make work tasks slow and cumbersome. To the operators, the focus seems to be more about the human error prevention tools (job aides) than the actual task or activity being conducted. Job satisfaction has been eroded and the added complexity has become an enticement to take short-cuts with these additional requirements, further perpetuating the cycle of human error. Much frustration on the part of workers and their managers has resulted from the ever-increasing job expectations added to work activities with, in actuality, diminishing returns in terms of error-free performance. Some industry observers believe that a saturation point has been reached, where the added complexity is contributing to the rate of human error (due to divided attention) and that we have reached the practical limits of human reliability at the present error rates.

To further improve human performance for NPP field workers, a fundamental shift in approach is needed. Digital technology can transform tedious error-prone tasks in NPP field activities to a large degree, leaving the worker in more of a cognitive role. It has the potential to eliminate human variability in performing routine actions such as identifying the correct components to be worked on. In short, the

technology can perform tasks at much higher reliability rates, while the plant worker remains in a role of correctly applying the technology and validating the results.

5.3.1 Mobile Technologies for Nuclear Power Plant Field Workers

Virtually all plant work activities are conducted under the control of rigorous work processes that convey the required job quality and technical requirements. Up until now, these work processes have generally relied on printed paper to present information to the plant workers and to serve as the medium to direct execution and recording of the specific tasks of the work activities. However, paper (as a medium) has the obvious limitations of not being interactive with real-time information sources; it is inflexible in its usage, leaves room for interpretation; and is incapable of enforcing its printed requirements. Technologies that have replaced the use of paper processes in the office environment have not been as easily adapted to field worker requirements.

The primary difficulty in providing plant workers with technology to improve their performance has been the fact that sometimes the workers must move about the plant in relatively inhospitable environments for digital technology (e.g., temperature extremes, radiation, radio frequency interference, and confined spaces). Also, there has been no practical way to connect these devices for real-time interactions to assist mobile workers.

Outside the nuclear industry, the use of mobile technologies to improve human performance is far more pervasive. A rapid transformation is in progress in the use of mobile technologies to revolutionize how humans conduct their routine personal and work-related activities. These technologies range from the applications in the latest smart phones to the hand-held business technologies used to receive and track mobile objects such as overnight packages, rental cars, and warehouse inventories. What these technologies have in common is that they correctly identify the intended work object, apply the correct process, guide the worker through the correct process steps, validate information, and post real-time work status to the corporate process systems – all from the job location.

These devices rely on wireless networks, digital processing devices, object identification capabilities (e.g., bar codes and radio frequency identification), voice command capability, and information processing software. In other words, many different technologies can be bundled in a single mobile device to address all aspects of a particular work activity. These technologies also have been "hardened," such that they are rugged and can perform reliably in challenging environments, including those found in an NPP.

However, it is not enough to simply provide field workers with mobile technologies. These technologies must be integrated into the plant work processes and must be able to access real-time plant information. Further, they must provide the ability for real-time interaction and collaboration with workers in other locations, in particular those who are coordinating overall plant operations, such as the NPP control room or outage control center. The idea is to literally embed the field worker in the plant processes and plant systems with wearable technologies, such that the worker is an integral and connected part of the seamless digital environment supporting plant operations and related activities.

These integrated technologies must first be validated using human performance evaluations to ensure they are not introducing negative factors into the work setting. It is essential that they be packaged and used in a manner that is intuitive, promotes situational awareness, and does not distract the worker from key job requirements or safety hazards in the area.

This research project will develop the basic mobile technology capabilities needed by an NPP field worker in performing typical plant work activities (Figure 6). It will include general work process

instructions, component identification capability, wireless communications to transmit and receive real-time information, audio, picture and video streaming, and use of heads-up, hands-free displays for workers involved in hands-on work. It also will include human factors evaluations to ensure the technology does not introduce negative factors that are detrimental to the job outcomes or well-being of the workers.

Figure 6. Operator at Catawba Nuclear Station using hand-held technology for component identification.

The initial applications of this technology will address safety tagging of components and conducting valve line-up checklists. These two initial applications typify many other plant activities such that the technology can easily be expanded into these other uses. The project also will develop a prototype of a simplified computer-based procedure to test the suitability of the technologies to handle interactive and shared content.

This pilot project currently is underway with Duke Energy (Catawba Nuclear Station) serving as the host utility. It will be completed at the end of FY 2012.

Schedule: FY 2011 to FY 2012

Milestone:

- (2012) Publish a technical report for implementing integrated mobile technologies for NPP field workers that provide real-time connections to plant information and processes, thereby reducing human error, improving human performance and productivity, enabling distance collaboration, and maximizing the "collective situational awareness."

5.3.2 Automated Work Packages

Work packages for NPP field activities are typically bulky and cumbersome. They are expensive and wasteful of paper to print, and the volume of paper can be overwhelming to transport to the job site and manage while there. Further, for activities in the radiation control zone, there is always a trade-off between taking the necessary paperwork to the job site and the amount of potentially contaminated waste that could be generated.

Moreover, the paper-based work processes rely on human performance to correctly obtain data, enter it into the work packages and procedures, successfully complete the steps of the process in the right sequence, and ultimately validate that the correct activity results have been obtained. Because of the

complexity of these activities and the sheer bulk of the paperwork, errors frequently occur that cause incorrect final results, rework, time delays, excessive safety system unavailability, and, if errors are undiscovered, latent nuclear safety issues.

Based on mobile technologies for NPP plant workers developed in the first pilot project of this enabling area, it will be possible to automate large portions of plant activities in a manner that enhances nuclear safety by reducing the opportunities for active and latent failures, improves human performance, and makes workers more productive. Specific capabilities would include the following:

- Organize and control the sequence of all tasks performed under the work package.
- Retrieve documentation directly from the utility's document management system, eliminating reference material from the work package that proves to be unneeded.
- Obtain plant data inputs directly from the plant systems and components, eliminating reading and transcribing errors. This data could be obtained wirelessly from the plant computer and locally by connecting directly to smart devices such as digital transmitters.
- Insert results directly into plant work processes and plant systems. This would include system health applications, data historians, plant computer, and the work package and procedure archival system.
- Obtain real-time concurrences and verifications from remote locations.
- Directly download updates and deviation approvals if revisions are needed to complete the work package.
- Directly access supplemental information such as training videos, operating experience, similar historical work packages, and corrective action reports.
- Provide real-time task status available to relevant stakeholders, eliminating the need to call field workers to obtain updates.
- Validate results based on real-time plant data, historical results, and engineering acceptance criteria.

This project will develop prototype work packages that can be executed on the mobile technologies for field workers. Target work packages will be selected from the areas of operations, maintenance, chemistry, radiation protection, and security. The work packages will be tested in a host utility NPP, exercising all of the capabilities of the mobile technology and interconnectivity to that technology. Human factors evaluations will be conducted during these tests to determine the gains in productivity and human performance, as well as identifying any negative human factors that are introduced and how to mitigate these concerns. The final product will be a technical report on how to deploy this concept for a wide range of work package-based plant activities using mobile technologies.

This pilot project will begin in FY 2013, with Duke Energy (Catawba Nuclear Station) serving as the host utility.

Schedule: FY 2013 to FY 2014

Milestones:

- (2013) Develop automated work package prototype technologies for NPP work processes with associated study of field trials at an NPP.
- (2014) Develop human factors evaluations and an implementation strategy for deploying automated field activity work packages built on mobile technologies, resulting in more efficient and accurate plant work processes, adherence to process requirements, and improved risk management.

5.3.3 Augmented Reality for Nuclear Power Plant Field Workers

NPP field workers are often in a plant environment where information critical to successful completion of their activities and even their well-being is not visually available, including the following:

- Temperature of surrounding components
- Whether a valve is open or closed
- Proximity to reactor trip-sensitive equipment
- Proximity to temporary hazard boundaries (e.g., radiography or overhead load paths)
- Plant data (pressure, flow, and set points) concerning nearby components
- Strength of radiation fields and location of hotspots
- Oxygen-deficient environments.

Therefore, plant workers must have this information already provided in their work packages or they have to rely on others to supply this information during the activity through the available communication channels. This is time-consuming and often results in an inadequate understanding of the actual field conditions.

Technologies are emerging that will connect the field worker to this information in a dynamic and context-based way. These technologies will allow the worker to "see" otherwise invisible information that will enable them to make informed decisions about their activities and their personal proximity to hazards. For instance, this might include smart safety glasses that can superimpose a transparent color-shaded representation of a radiation field directly into the worker's field of view. Similarly, plant data could be superimposed directly onto the components in the field of view, allowing the worker to "read" the data by merely looking at the components.

This capability would be made possible through use of wireless communications to supply information from the plant computer and other sources, in combination with technologies that can determine the worker's location, orientation, and field of view. Further, the information provided would be context based because the worker's purpose for being in that location would be known to the information system. In this way, only data relevant to that purpose would be automatically pushed to the worker. However, the worker could request any other information desired. In addition, it would be possible to remotely monitor personal physiological data, when necessary, such as workers in

high-temperature work environments or during confined space entries with the potential for hazardous gases.

These capabilities would create a whole new dimension in the concept of an "intelligent plant worker." They could be combined with the concept of automated work packages to produce extraordinary efficiencies in conducting plant activities and keeping the worker safe. There would be secondary benefits to knowing the location and surrounding environment of each worker. For example, this would greatly simplify accounting for personnel in emergency situations such as containment evacuations and security events. It could enable remote monitoring of radiation dose and allow for optimized dispatch of field workers supporting concurrent work activities such as quality control inspectors. It could enable the concept of "picture procedures" in which images of the actions required by a procedure step are superimposed on the equipment being manipulated via the worker's heads-up display.

This project will develop the needed technologies to create augmented realities for NPP field workers and will test these technologies in HSSL and, ultimately, in a host utility NPP. Studies during testing will include both technical and human factors evaluations. The final product will be a technical report on how to implement these technologies in conjunction with the previously developed mobile technologies for NPP field workers. It also will provide guidance for integrating the augmented reality technology with compatible automated work packages.

The Halden Reactor Project is already developing these types of technologies, including those that can determine the location and orientation of a field worker. The pathway will work closely with Halden to take full advantage of the augmented reality technologies as they are developed.

Schedule: FY 2015 to FY 2017

Milestones:

- (2015) Develop and demonstrate augmented reality technologies for visualization of radiation fields for mobile plant workers.
- (2016) Develop and demonstrate augmented reality technologies for visualization of real-time plant parameters (e.g., pressures, flows, valve positions, and restricted boundaries) for mobile plant workers.
- (2017) Publish a technical report on augmented reality technologies developed for NPP field workers, enabling them to visualize abstract data and invisible phenomena, resulting in significantly improved situational awareness, access to context-based plant information, and generally improved effectiveness and efficiency in conducting field work activities.

5.4 Integrated Operations

Many industries have taken advantage of new digital technologies to consolidate operational and support functions for multiple production facilities to improve efficiency and quality. This concept is sometimes referred to as integrated operations. It basically means using technology to overcome the need for onsite support, thereby allowing the organization to centralize certain functions and concentrate the company's expertise in fewer workers. These workers, in turn, develop higher levels of expertise because they are exposed to a larger variety of challenges and issues than if they supported just a single facility. It allows them to outsource functions, where beneficial, while maintaining immediate access to the services even if provided remotely. The concept also enables standardized operations and economy of scale in maintaining a single organization instead of duplicate capabilities at each location.

The Halden Reactor Project has been quite active in this concept for the Norwegian off-shore oil platforms. The oil companies have developed integrated operations to move large parts of their platform operations and support functions to centralized on-shore locations. This has resulted in dramatic improvement in the efficiency of operations and the quality of life for participating workers. While there remains a need for sufficient staff on the platforms to conduct the hands-on work, virtually any activity that can be controlled or monitored through a digital system is a candidate for integrated operations.

Likewise, for years, airlines have maintained centralized flight monitoring centers, recognizing the impracticality of providing this as an onboard service. Data links are used to stream in-flight performance data to the centers, where they are monitored by systems experts. The experts then can confer directly with the pilots on any immediate operational concerns. Otherwise, minor issues can be documented and addressed at the next convenient opportunity.

NPPs have a similar opportunity to improve support functions by developing an integrated operations concept. Indeed, some steps in this direction have already been taken by utilities that have implemented a centralized online monitoring center for plant components equipped with remote monitoring capability. However, there are many more opportunities to consolidate support services across the fleets using digital technologies that enable work to be performed just as effectively as if it were onsite. Furthermore, the concept can extend beyond the utility organization to create seamless interfaces with suppliers, consultants, and original equipment manufacturers. In this way, an operating company could build a virtual organization of trusted partners rather than providing all services in-house.

5.4.1 Advanced Online Monitoring Facility

Sustainability for the U.S. LWR fleet is dependent on the preservation of plant assets far beyond the original life of 40 years. With most utilities pursing life extension to 60 years (with the possibility of 80 years), long-term plant asset management will have to be a prominent focus of the utility's technical staff.

Technologies are being rapidly developed that can provide early indication of component degradation in progress. Moving beyond empirical models of the degradation factors, physics-based models are now being developed that can mimic the effects on the overall component in response to degradation in one of the subcomponents. This provides capability to move beyond mere monitoring of the condition to diagnosis of the degradation mechanism and prognosis of the remaining useful life of the component and give the utility a window of opportunity to take remedial actions. These types of technologies are being developed under pilot projects described in Section 5.6.

The purpose of this project is to integrate these new monitoring capabilities into a concept of fleet asset management based on a centralized online monitoring facility. The underlying information structure would be part of the digital plant architecture as described in Section 5.2.1.

The architecture would support the real-time acquisition of condition monitoring data from every type of source. This would include fixed sensors embedded in components such as in "smart pumps." It also would collect data streamed from mobile technologies used by field workers (see Section 5.3.1). This would include data from hand-held condition monitoring technologies such as thermal imaging, vibration monitors, and acoustic probes.

The architecture would organize the information in a manner that could be used for a variety of purposes. In addition to being available for the centralized asset management facility, it would be made available to the plant engineering system health program, troubleshooting and root cause teams, original

equipment manufacturers and technical consultants involved in component support, and the data historian and plant records function.

This project will develop a prototype advanced online monitoring facility based on the state-of-the-art information technologies and collaboration facilities, and will provide the following:

- Employ new visualization capabilities to create a better understanding of the condition of degrading components
- Have video conferencing capability for direct collaboration with plant staff in a variety of settings (e.g., the control room, the outage control center, or engineering support groups)
- Have access to industry databases on failure signatures and associated component data to assist in diagnosing component degradations
- Support the concept of integrated operations in that it will be able to remotely support a number of operating plants as effectively as if it were onsite.

The prototype advanced online monitoring facility initially will be developed in HSSL, where technology developments and human factors studies can be conducted in a test environment. Following that, a production facility would be developed at a host utility location for actual production testing. Based on this initial experience, a technical report will be written to provide recommendations for industry-wide implementation.

Schedule: FY 2015 to FY 2017

Milestones:

- (2015) Develop and demonstrate (in HSSL) concepts for an advanced online monitoring facility that can collect and organize data from all types of monitoring systems and activities and can provide visualization of degradation where applicable.
- (2016) Develop and demonstrate (in HSSL) concepts for real-time information integration and collaboration on degrading component issues with remote parties (e.g., control room, outage control center, systems and component engineering staff, internal and external consultants, and suppliers).
- (2017) Develop a digital architecture and publish a technical report for an advanced online monitoring facility, providing long-term asset management and providing real-time information directly to control room operators, troubleshooting and root cause teams, suppliers and technical consultants involved in component support, and engineering in support of the system health program.

5.4.2 Virtual Plant Support Organization

Because of the complexity of plant systems and the large number of components in NPPs, utilities maintain a very large staff of highly trained operators, engineers, technicians, and other types of specialists to ensure safe and successful operations. Considerable ongoing investment in the form of training and development is made in this workforce to enable them to maintain the unique and aging technologies in the plants. Like the technologies, the workforce as a whole is aging (i.e., a large portion of the workers began their careers in the early days of commercial nuclear power).

At present, the nuclear industry has arguably the most experienced workforce in its history. This is undoubtedly a significant factor in the operational success the industry has enjoyed over the last decade or so. However, this is an unsustainable path because, like the aging II&C systems that plants must be replaced, the aging workforce is on the brink of a substantial retirement wave in which a significant portion of the workforce will have to be replaced in a relatively short amount of time.

Going forward, there are concerns whether the commercial nuclear industry will be able to attract the needed engineers and technicians given the looming shortage of technically trained workers in this country. In addition, the model of having career-long employees who develop deep expertise will likely be less successful in the future with a new generation of workers who will be more prone to change jobs.

A better model would include the ability to build a virtual plant organization that is seamlessly connected through advanced II&C technologies. A virtual support organization is a combination of an NPP's own organization plus external organizations that have been delegated direct support roles in operating and maintaining the plant. The term "virtual" implies that the organization is interconnected through a digital architecture for data exchange, communications, and collaboration as opposed to having to be located onsite. This allows the NPP to tap into far greater resources and expertise than practically can be maintained at the NPP facility.

In general, this is an extension of the concept introduced with the advanced centralized online monitoring facility. It will allow specialty organizations, both within the utility and with outside companies, to assume full responsibilities of portions of the ongoing operations and support of the plants. Some examples of these types of operational and support roles would be as follows:

- An onsite, demineralized water production plant could be owned and remotely operated by the original equipment manufacturer of the equipment, with minimum onsite support for hands-on maintenance.

- Condition monitoring could be performed by remote experts in vibration analysis, oil sample analysis, and loose parts monitoring analysis rather than having to maintain this specialized expertise within the general plant engineering staff.

- II&C system monitoring and diagnostics could be performed by the manufacturers of the system, with a small onsite support staff to replace circuit boards once faults were isolated to the specific component.

- Radiation monitoring could be performed remotely using data-linked monitors and video cameras to observe workers in the radiation control zones.

- Chemistry analysis could be performed remotely using in-line instruments that take either batch or continuous samples.

- System test results could be reviewed and validated by a remote engineering staff that directly receives data from system performance tests.

- Portions of the plant support systems could be monitored, or even operated remotely, by a centralized staff. This would exclude safety-related systems and those systems that are major transient initiators such as the main feedwater system. There could be a significant reduction in burden on the control room for having many of the auxiliary systems under centralized operations. Examples would include auxiliary steam systems, hydrogen purification skids, oil purification skids, chemistry systems, and radwaste systems.

A virtual support organization would be a significant step toward the concept of integrated operations for the LWR fleet. The workforce required to conduct the plant work activities could be appreciably reduced in number, resulting in a secondary proportional reduction in organizational support functions (e.g., number of supervisors, human resources specialists, trainers, and recruiters). This concept would move the NPP operating model away from a labor-centric model to a technology-centric model. This could greatly enhance LWR fleet cost competitiveness because technology is generally a declining cost factor while labor is always an increasing cost factor. By purchasing only the services a plant needs, rather than maintaining a full-time staff for all technical functions, considerable cost savings could be obtained.

The following are examples of specific benefits of a virtual organization:

- Specialty organizations could attract and maintain experts much more effectively than could individual operating companies. The experience base of a specialty organization would be much deeper in that they would see phenomena and problems across the entire industry and not just a few plants.

- The monitoring capabilities of a third party (or even a fleet-centralized service) would be more uniform over time because it would not depend on the work schedules of one or two experts onsite.

- The NPP would be relieved of continual hiring, transferring, and training of replacement workers for these positions as inevitable attrition occurred.

- In the case of having some plant auxiliary systems monitored or operated remotely by support organizations, there would be a net safety benefit in allowing the control room and onsite operations staff to concentrate more on the safety-significant portions of the plant.

This project will develop the underlying technologies that will enable development of a virtual support organization. The information structure to do this will be built into the digital architecture for a highly automated plant (see Section 5.2.1). Human and organizational factors will be incorporated into a technical report for integrating external organizations directly into the line functions of the plant organization, as enabled by data sharing, communications (voice and video), and collaboration technologies that will compose a seamless work environment. These technologies will first be created and studied in the HSSL reconfigurable simulator, where it will be possible to evaluate the dynamics of a remote organization conducting a key plant support function. An open standard and data sharing technology will be developed for this architecture to promote a fair and competitive market for external services.

The project will identify which plant functions are priorities for outsourcing using the virtual plant support organization concept. The project will work with a host utility NPP to implement some trial instances of remote support. Evaluations of these initial examples will be the basis for a guideline document on how to implement the virtual plant support organization on an expanded scale.

Schedule: FY 2018 to FY 2021

Milestones:

- (2018) For chemistry activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host NPP.

- (2019) For maintenance activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host NPP.

- (2021) For radiation protection activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host NPP.

- (2021) Publish human and organizational factors studies and a technical report for a virtual plant support organization technology platform consisting of data sharing, communications (voice and video), and collaboration technologies that will compose a seamless work environment for a geographically dispersed NPP support organization.

5.4.3 Management Decision Support Center

Operational decision-making is a foundational element of safe nuclear operations. Processes for decision-making are formal and rigorous in all levels of the nuclear utility management structure. Nuclear managers are required to be technically competent and actively engaged in the issues facing their nuclear facilities, such that they can effectively participate and be held accountable in the ongoing operational decisions.

Plant functional managers typically serve in both standing and special-purpose decision review boards that are formally invoked for significant plant issues. One such example required by a nuclear utility's Quality Assurance Program is the plant operational review committee, or a similarly titled group. The plant operational review committee is required by the facility license to have a broad range of technical expertise and competence in plant issues and is required to review a number of different types of plant issues and provide a recommendation to the plant manager on the advisability of recommended actions. There are similar groups that are appointed for other special purposes (such as to provide oversight of operational decision-making and risk management).

On a more informal basis, the plant management typically meets early every weekday morning to review current operational concerns and to ensure that all work plans are well-coordinated and meet risk management expectations. This is yet another forum for operational decision-making on the adequacy of the daily work plan and the response to emergent problems. A similar daily management meeting is held during outages to address the issues arising from the ongoing work.

Another category of management decision-making pertains to the emergency response organization. These are the decisions on how to classify, mitigate, and provide protective actions in a nuclear emergency. These deliberations occur in the dedicated emergency response facilities, namely the technical support center, the operations support center, and the emergency operations facility, the latter of which is offsite and sometimes serves the entire fleet.

What all of these decision-making processes and forums have in common is the critical need for accurate, timely information on which to base the operational decisions made by the plant managers. There are many examples in the industry where a plant management team made decision errors, not due to lack of competence among the managers, but simply because the managers did not have an accurate picture of what actually was happening at the time and what was at stake.

To improve understanding in these settings, technology will be introduced that provides a better visual picture of the situation (such as real-time video taken at the location of the problem). In other cases, where pictures of the problem are not practical (e.g., core power imbalances due to dropped rods), simulations and symbolic presentations of the issues will be developed.

The concept of a management decision support center would address these needs by employing advanced digital technologies to improve the quality of operational decision-making. It would be a dedicated facility where all regular and special management oversight meetings would be held. (The exception to this would be the emergency response facilities, which have to be maintained in a state of readiness. The technologies of the management decision support center also would be separately implemented in the emergency response facilities.) The following are examples of the types of technologies that would be implemented:

- Multiple large screen displays that can handle many different data sources at a time
- Video streaming capability directly onto any of the large displays, including video conferencing
- Access to all data and displays of the plant computer and Safety Parameter Display System
- Real-time images of the main control room control boards, with real-time data refreshing
- Ability to run the plant simulator for the scenario of concern
- Real-time plant risk assessments and defense-in-depth measures
- Severe accident management guidelines and extensive damage mitigation guidelines
- Access to all plant process applications (e.g., technical specification logs, operator logs, schedules, work orders, and test results)
- Access to all plant documentation through the electronic document management system
- Access to NPP field worker mobile technologies for streaming of activity-related information
- Access to outside data sources such as weather, media, regulatory information, and external databases
- Decision support and resource allocation software
- General presentation capabilities.

This concept also could be applied at the fleet level where decisions involve multiple NPPs or involve decision processes between the plant and fleet-level management. Collaboration tools would allow information views to be pushed to other participating centers so that there would be a shared context for discussions and decisions.

Obviously, this project will build on many of the capabilities that are developed in other pilot projects, but will focus them on the unique aspects of nuclear management decision-making. The project will team with a host utility to identify the needed capabilities in such a facility. The digital architecture pilot project will address the information requirements of this facility. The facility will be prototyped in HSSL to demonstrate and evaluate the various capabilities. Human factors studies will be a key part of the

evaluation to ensure the information presentations are well designed for comprehension and do not result in an information-overload situation. Protocols for managing the information resources during a management decision-making meeting also will be developed. Following the laboratory demonstration, a management decision support center will be implemented at the host utility NPP for trial usage. Field studies will assess any needed corrections to the concept or implementation. A technical report will be developed for industry-wide implementation.

Schedule: FY 2019 to FY 2021

Milestones:

- (2019) Develop and demonstrate (in HSSL) concepts for a management decision support center that incorporates advanced communication, collaboration, and display technologies to provide enhanced situational awareness and contingency analysis.

- (2020) Develop and demonstrate (in HSSL) concepts for advanced emergency response facilities that incorporate advanced communication, collaboration, and display technologies to provide enhanced situational awareness and real-time coordination with the control room, other emergency response facilities, field teams, the Nuclear Regulatory Commission, and other emergency response agencies.

- (2021) Publish human and organizational factors studies and a technical report for a management decision support center consisting of advanced digital display and decision-support technologies, thereby enhancing nuclear safety margin, asset protection, regulatory performance, and production success.

5.5 Outage Safety and Efficiency

Nuclear plant refueling outages are perhaps the most challenging periods of time in the ongoing operations of the facilities. There are usually more than 10,000 activities to be accomplished in a typical duration of 20 to 30 days. Enormous expenses are incurred related to the cost of the outage work, including supplemental workforce, which sometimes totals over 1,000 contractors. Schedule delays drive these costs up proportionately. In addition, the utilities incur additional costs for replacement power for the time NPPs are out of service. Nuclear safety is a particular challenge during outages due to the degraded configurations an NPP is sometimes in to accommodate work on the systems. In fact, the majority of the annual planned incremental core damage frequency of the plant's probabilistic risk assessment is incurred during outages. There also is a special regulatory risk because the plants are challenged to meet shutdown technical specifications and "maintenance-rule" risk mitigation measures. Finally, an outage is especially challenging from the standpoint of industrial safety in that the risk of plant workers getting hurt is highly elevated due to the types of activities that are conducted.

Managing nuclear outages in a safe and efficient manner is a very difficult task. In fact, the early history of refueling outages was one of significant cost and schedule overruns, as well as troubling nuclear safety challenges. This led utilities to develop formal outage organizations dedicated to planning and executing both their refueling and forced outages. They also built outage control centers that co-locate the activity managers for all of the major site organizations so that they can closely coordinate their activities. In addition, they maintain a number of other work execution centers that control critical elements of the work, such as safety tagging for system and component isolations, nuclear risk management coordinators, and similar functions needed to address other constraints on how the outage is conducted.

As a result of these practices, today's outage performance is greatly improved from what it once was. Outage cost and durations are considerably lower than in the past. Nuclear safety also is greatly improved. However, there remain some significant opportunities and challenges for the industry and are as follows:

- Further reducing the duration of refueling outages remains the largest opportunity to improve plant capacity factors and increase the economic value of the facilities.

- In spite of impressive gains in shutdown safety, there are still too many serious safety challenges (such as loss of residual heat removal and unintended additions of positive reactivity).

- Regulatory violations continue to occur due to subtle configuration control issues that result from unintended interactions among concurrent work activities.

In spite of the impressive organizations and facilities that have been implemented to improve outage performance, outage management generally relies on the very basic technology of radios, telephones, and stand-alone computer applications. There is some growing usage of remote video for point applications and activity monitoring. Utilities have not made widespread usage of mobile technologies for controlling field work, collaboration technologies for coordinating issues across the broad organization, or advanced configuration management technologies to improve safety and regulatory performance.

There is no question that improved technology for outage management would provide a step change in a utility's ability to conduct outages in a safe and efficient manner. DOE is well positioned with its HSSL, human and organizational factors expertise, and knowledge of NPP outage practices to demonstrate and provide guidance for application of advanced digital technologies in order to achieve substantial economic value and nuclear safety improvement through outage performance improvement.

5.5.1 Advanced Outage Coordination

The amount of information that must be processed by the outage control center (OCC) is staggering. OCC managers must obtain the status of ongoing work activities, project the expected progress of the activities, and then adjust near-term activities for gains or losses in the overall schedule. Accurate work status is difficult to obtain due to communication barriers with field work, particularly in hard-to-access areas of the plant. Also, work status sometimes reflects an overly optimistic outlook by those performing the work. The term "real-time truth" is sometimes used by outage managers to refer to this need for the true status of the work-in-progress.

The outage managers also deal with a continual stream of emergent issues caused by deviations in the expected progress of the planned activities or new problems that arise (e.g., equipment failures, unexpected interactions between work activities, and other unanticipated outage conditions). The outage managers have to quickly assess the impact of the new issues on the overall outage plan and schedule, consult with knowledgeable individuals on the nature of the problems and possible solution options, determine the solution that results in the least impact on the overall outage objectives, and communicate changes to plans and schedules to the affected activity managers.

These typical outage management activities rely on telephone calls, impromptu meetings, "white board" solution sessions, manual transcribing of agreed-upon changes into a number of work process systems (e.g., work orders, schedules, risk management, radiation work permits, safety tagging, and warehouse parts), and communication throughout the organization using outage status meetings, email, and direct telephone contact. This process is repeated tens of times per shift for the duration of the outage.

This pilot project will assess the needs of outage management and identify technologies that will greatly improve communications, coordination, and collaboration activities that are needed to minimize the impact of challenges to the outage plan and schedule. It will focus on capabilities that facilitate natural human interaction, while ensuring a high degree of situational awareness and shared understanding. Further, the technologies will be integrated in a way that minimizes the effort to keep all work management systems synchronized with changing plans.

The project also will develop dynamic interfaces for information coming from mobile field workers, the plant control and information systems, and the fluid information developed in the OCC (and other control centers) as the greater organization develops solutions to emergent outage problems (Figure 7). Human factors assessments of the use of the technology will be conducted to validate that the benefits are actually obtained and new problems are not introduced by technology usage. The results of the project will be a demonstration of the integrated technologies and a technical report for industry-wide implementation.

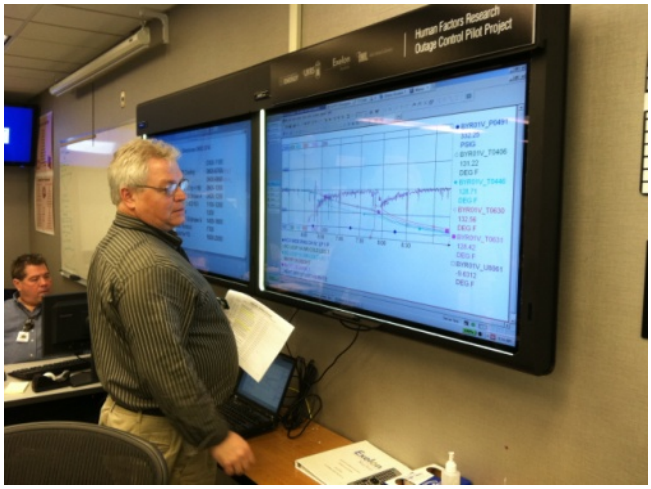


Figure 7. Remote collaboration technology in use at the spring 2011 Byron Nuclear Station refueling outage.

This pilot project currently is underway with Exelon Nuclear (Byron Nuclear Station) serving as the host utility. It will be completed at the end of FY 2012.

Schedule: FY 2011 to FY 2012

Milestone:

- (2012) Publish a technical report for implementing digital technologies that facilitate communications, coordination, and collaboration in obtaining accurate outage activity status, managing the flow of information through the OCC, and enabling the resolution of emergent problems in an efficient and effective manner, resulting in improved work efficiencies, production success, and nuclear safety margins (Complete).

5.5.2 Advanced Outage Control Center

The OCC is the central command and control point for executing NPP outages. It is staffed 24/7 during outages and accommodates 15 to 20 managers and coordinators from the site and fleet organizations supporting the outage. These positions are typically grouped according to organization and

informally interact with one another to coordinate their specific work activities and problem resolutions. Various types of meetings are held on a regular schedule each shift to communicate outage status, share information on upcoming activities and emergent issues, and verify with each organization that they are prepared to support the upcoming activities.

Many of the organizations represented in the OCC also maintain a functional support center at their own site locations to provide the specific services they conduct. For example, radiation protection operates a center to develop and assign radiation work permits and authorize and brief workers who enter radiation control zones. Operations maintains centers to prepare safety tagouts, conduct risk assessments, and track plant configuration changes. There are similar functional support centers set up in the other organizations such as chemistry and engineering. One of the key tasks of the OCC coordinators is to ensure these functional centers are aware of changing needs as determined in the OCC and are responding accordingly. The coordinators typically have to leave their positions in the OCC several times a shift to attend coordination meetings back in their functional support centers and are not available for coordination with other OCC positions during those times.

In considering all of these coordinating activities, there is a significant need for advanced technologies to facilitate the information flow into, across, and out of the OCC. These include technologies to conduct interactive meetings with participants in other locations. They will allow the entire OCC to share information as it develops in response to an emergent issue. They will allow the OCC coordinators to meet electronically with their respective functional support centers without having to leave the OCC. They will update all affected work management systems as decisions are made on how to resolve a problem. Finally, they will provide the overall outage managers with the true status on the progress of work and the implementation status of outage plan changes from the OCC managers and coordinators.

These technologies will be integrated into an advanced OCC specifically designed to accommodate and maximize the value of the technologies, while preserving the features of the existing OCCs that facilitate human interaction. Where appropriate, these features will be extended to the functional support centers to accommodate their interface with the OCC.

This pilot project will integrate these technologies into a prototype advanced OCC using HSSL. It will be set up to facilitate the display and processing of information and collaboration within the OCC or with parties remote to the OCC. This prototype facility will be used to simulate outage coordination functions so the technology and associated human factors can be evaluated. It will test interaction with all required sources of information needed by the OCC, including mobile technology operated by NPP field workers, plant control and information systems, other control and functional support centers, and information sources external to the plant. As a final product, a technical report will be developed for industry-wide implementation of the advanced OCC.

This pilot project will begin in FY 2013, with Arizona Public Service (Palo Verde Nuclear Generating Station) serving as the host utility.

Schedule: FY 2013 to FY 2014

Milestones:

- (2013) Develop technologies for an advanced OCC that improves outage coordination, problem resolution, and outage risk management.

- (2014) Develop human factors studies and publish a technical report for an advanced OCC that is specifically designed to maximize the usefulness of communication and collaboration technologies for outage coordination, problem resolution, and outage risk management.

5.5.3 Outage Risk Management Improvement

Significant efforts are expended to manage the nuclear risk of an outage. The utilities conduct pre-outage risk assessments, based on a very detailed review of the outage schedule, to identify where combinations of outage work and equipment out-of-service would result in degraded conditions with respect to nuclear safety or regulatory compliance. Probabilistic risk assessment studies are conducted to quantify the incremental core damage frequency as a result of the outage activities and system unavailability. These studies are usually presented to site and fleet management, the site plant operational review committee, and the NPP's independent Nuclear Safety Review Board for concurrence that the outage is planned safely and that reasonable measures have been taken to reduce the added risk of conducting the outage.

During the outage, the plant configuration is monitored continuously to ensure that it conforms to the approved safety plan. Deviations must be assessed and approved by management committees and, in some cases, the plant operational review committee. In virtually all outage meetings and job briefings, the current nuclear safety status of the plant is communicated, including information on the specific equipment that is being relied on to meet the requirements of the nuclear safety plan. In addition, operations and the outage organization implement several layers of physical and administrative barriers to prevent unintended interaction with the systems and equipment credited for nuclear safety.

In spite of all these efforts, nuclear safety challenges still occur too frequently in outages. While some of these are due to failure of equipment credited for safety, the majority occur because of human error. These typically involve some form of interaction between work activities and plant configuration changes. Some of them are very subtle and are extremely challenging to detect in advance. Nevertheless, they are not acceptable and represent clear opportunities to improve nuclear safety during outages.

This pilot project will investigate methods to improve real-time plant risk management and configuration control during outages as a function of work activities and plant system alignments. It will develop a means for combining actual plant status information with intended component manipulations embedded in procedures and work packages that are underway. This information will, in turn, be compared to design information (e.g., piping and instrumentation diagrams and one-line diagrams) to identify the set of possible interactions. Finally, the information will consider the technical specifications (and other licensing basis requirements), probabilistic risk assessment information (e.g., accident precursors), and ongoing risk mitigation plans to report possible interactions of concern. The project will demonstrate the techniques and underlying technologies to perform this type of outage safety analysis. The project deliverables will include the new technologies and guidance for integrating them into outage preparation and execution activities.

Schedule: FY 2015 to FY 2017

Milestones:

- (2015) Develop and demonstrate (in the HSSL) technologies for detecting interactions between plant status (configuration) states and concurrent component manipulations directed by in-use procedures, in consideration of regulatory requirements, technical specifications, and risk management requirements (defense-in-depth).

- (2016) Develop and demonstrate (in the HSSL) technologies to detect undesired system configurations based on concurrent work activities (e.g., inadvertent drain paths and interaction of clearance boundaries).

- (2017) Develop a real-time outage risk management strategy and publish a technical report to improve nuclear safety during outages by detecting configuration control problems caused by work activity interactions with changing system alignments.

5.6 Centralized Online Monitoring and Information Integration

As NPP systems begin to be operated during periods longer than originally anticipated, the need arises for more and better types of monitoring of material and component performance. This includes the need to move from periodic, manual assessments and surveillances of physical components and structures to centralized online condition monitoring. This is an important transformational step in the management of NPPs. It enables real-time assessment and monitoring of physical systems and better management of active components based on their performance. It also provides the ability to gather substantially more data through automated means and to analyze and trend performance using new methods to make more informed decisions concerning component health. Of particular importance will be the capability to determine the "remaining useful life (RUL)" of a component to justify its continued operation over an extended plant life.

The foundation for monitoring in the U.S. nuclear industry is built around signal processing techniques and advanced pattern recognition (APR) programs that are technically mature and commercially supported. The application of this technology is in the early stages of implementation by leading nuclear utilities. The implementation rate is slow due to the required funding and infrastructure development for integrating monitoring programs within the operating and business environment.

APR provides highly sensitive anomaly detection of current condition or behavior for targeted components. Much of the value of online monitoring comes from early warning of imminent component failures. Commercial APR products rely on the continuous input of well-correlated plant data to provide this early warning. (These products typically are only available for active plant components). After the initial warning, an investigative review identifies the actual failure mode and cause and then suggests appropriate corrective actions. The investigative review can involve plant staff, consultants, and field experts in predictive maintenance. In these cases, the diagnostic process can be manually intensive and can consume available warning time and extend damaging operating conditions. While APR systems are effective at identifying equipment operating in conditions that may shorten the equipment's RUL, they are well suited to identifying operating data values that are "not normal" in comparison to a historical baseline. Commercially available APR products cannot perform the next essential step of diagnosing the underlying cause for the abnormal data values. This diagnosis step *relies entirely* on a staff of highly trained specialists to troubleshoot and diagnose the underlying problem and to recommend a corrective action response. Furthermore, the RUL of the monitored asset cannot be determined by APR technology. In addition, there are long-term failure modes that are not detectable with APR technology.

Hence, current APR products are not capable of providing directly useful information to life-cycle management and long-term asset management. Commercially available APR technologies in their current form are unable to detect long-term failure modes, thereby making them unsuitable for long-term monitoring and management of nuclear assets and, in particular, for passive assets evaluated on an intermittent basis using nondestructive evaluation measurement techniques.

The development of diagnostics and prognostics capability would provide automated capability to directly identify the equipment condition from the "signature" of the initial warning. This would support

analysis of long-term component behavior, related risk, and RUL. Further, it would provide verification of asset condition as evidence of design qualification and economic viability. This will enable early detection of degradation conditions that can be addressed before they significantly contribute to life-limiting damage. This early detection of degradation is one of the more significant factors in extending component lifetime. A more timely response to the causes of degradation also can significantly improve nuclear safety and prevent collateral damage to other nearby components and structures. Finally, these new capabilities will reduce costs for manual diagnostic work.

EPRI is active in various research and demonstration projects for maturing prognostic and health management technology to help assure the long-term, reliable operation of the nation's fleet of NPPs. EPRI's current research includes developing a Fleet-wide Prognostic and Health Management (FW-PHM) Suite software solution designed for compatibility with existing NPP troubleshooting and asset management processes while leveraging tools already used for online monitoring (Figure 8). No commercial products are available that perform the full functionality intended for the FW-PHM Suite. The Suite's four primary functional modules are built on a common reference database of diagnostic and life models for power generation assets.

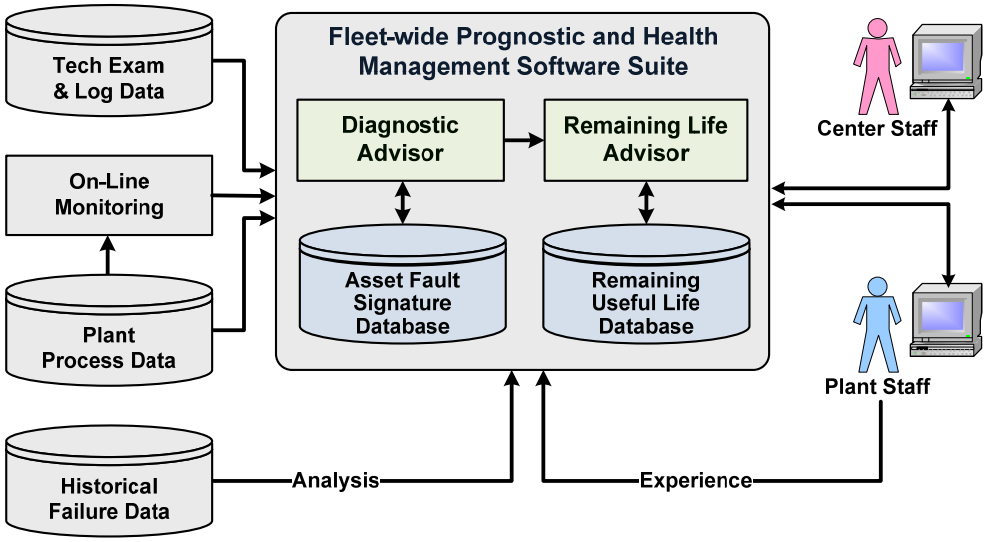


Figure 8. Fleet-wide Prognostics and Health Management in an Online Monitoring Environment (diagram courtesy of EPRI).

The FW-PHM Suite includes specific knowledge capture capabilities that learn diagnostic and prognostic information from in-service experience in industry-deployed applications and structure this information for pooling and analysis by EPRI, government, and industry experts. This information can be used by experts in combination with EPRI's extensive library of reference documents to create and maintain an industry-wide database of verified diagnostic and RUL models for NPP assets.

The FW-PHM Suite software is, at present, a research grade product available to EPRI members that have sponsored its development. The Suite's databases are populated with limited knowledge derived from various preliminary pilot applications involving a small set of nuclear and fossil plant equipment and from technology demonstration projects. EPRI has identified the long-term need for ongoing research to develop the diagnostic and remaining life prediction models for power generation assets that will populate this industry-shared database of models, because no one utility or vendor alone could compose such a comprehensive model reference collection. In fact, collaboration among the industry, EPRI, the national laboratories, and universities is needed to accomplish the R&D effort to identify a model or a set

of models as required for a particular component to create verified diagnostic and prognostic models to support PHM processes and to provide accurate, substantiated input to life-cycle management and long-term asset management capabilities. In particular, diagnostic and prognostic models for passive nuclear assets require significant future research, which should include formulating the resulting diagnostic and prognostic models and their basis information for inclusion in the FW-PHM Suite's knowledge database.

A gap exists between the current state of technology development and the effective application of diagnostics and prognostics to nuclear plant assets. To address this gap, the following research tasks have been defined.

1. Complete development of a monitoring infrastructure at the operating and management levels of the nuclear power industry.

2. Develop an organizational structure that defines the contributing research organizations, their roles, resource availability, and utility hosts. This includes EPRI, national laboratories, universities, utilities, and technology developers.

3. Continue R&D of the diagnostics and prognostics technology for adaption to the nuclear power industry.

4. Develop the component-specific models, analytical methods, and the supporting data requirements needed to support diagnostics and prognostics analysis.

5. Obtain access to the real physical assets in service in an NPP and determine the critical measurements needed to support the analysis.

6. Develop additional monitoring methods (such as transient analysis) to support RUL analysis.

7. Identify environmental conditions detrimental to aging mechanisms, including fatigue monitoring and assessment.

8. Identify component-specific failure and aging mechanisms/precursors.

9. Identify measurement and sensor requirements to support analytical methods.

An effective means to accomplish portions of the above research tasks is through conduct of pilot projects. These projects will be structured around a narrowly defined set of objectives to accomplish specific tasks that require access to real-time plant assets and operational data. There are significant limitations to bench-top modeling and scaled-down component behavior analysis in the progression of technologies from proof-of-concept to real-world component applications. The utilization of real physical components and operational data is required to develop the technologies beyond the laboratory. The process of applications engineering and research is not within the capabilities of the utilities or the engineering staff at NPPs. Host utilities are required to support the needed research to provide access to major components in actual service.

EPRI will provide the lead role in providing online monitoring capabilities through their continued development and support of the FW-PHM Suite software, in addition to their other online monitoring research activities. The LWRS Program will support EPRI by conducting the pilot projects to develop the diagnostic and prognostic analytical framework for representative active and passive component/structures whose extended life supports LWR sustainability.

In regard to the "centralized" aspect of the project concept, it is expected that utilities will find that a central monitoring function within their nuclear fleet will be the most efficient way to implement this technology. Indeed, this has been the practice of some of the early movers for online monitoring using the APR technology. This concept work for centralized monitoring will be accomplished through the pilot project on the advanced online monitoring center (as described in Section 5.4.1). The LWRS Program also will serve the role of integrating the online monitoring information into the overall digital information architecture such that it will provide information beneficial to other plant activities.

5.6.1 Online Monitoring of Active Components

A pilot project will be conducted involving two active components representative of those for which extended life is highly important to LWR sustainability. An early task of this pilot project will be to select two components for which sensor technology is either already typically installed or can be readily added in the timeframe of the project. Candidate components include main turbines, main electric generators, main feed pumps, reactor cool pumps, and reactor coolant motors.

The objective will be to develop the diagnostic and prognostic analysis framework for these components, including the ability to predict RUL. These capabilities will enable industry to implement online monitoring for these components and will establish the methodology for industry to extend the concept to other active plant components where aging and degradation mechanisms must be managed for extended life.

Using the EPRI FW-PHM Suite software, the pilot project will develop the databases and analytical models needed to process sensor signals to derive parameter estimates of specific aging and performance features and to characterize the state and condition of materials. The databases include the asset fault signature database and the RUL database. The analytical models will be those needed for the diagnostic and RUL advisors. The project also will include identification of additional sensor development and monitoring capabilities needed to enhance the monitoring capabilities for these components.

For each of these component types, a technical report will be published that describes the technical basis and analysis framework to enable online monitoring for these components. These technical reports, along with the results and experience from the pilot projects, will be used to develop guidelines for utilities to implement centralized online monitoring and information integration for the components/structures important to plant life extension.

This pilot project currently is underway with two host utilities: Exelon Nuclear (Braidwood Nuclear Station) for emergency diesel generator monitoring and Progress Energy (Harris Nuclear Station) for large power transformer monitoring.

Schedule: FY 2012 to FY 2014

Milestones:

- (2012) Publish an interim technical report on the online monitoring technical basis and analysis framework for large power transformers.
- (2013) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for large power transformers, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

- (2014) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for emergency diesel generators, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

5.6.2 Online Monitoring of Passive Components and Structures

A pilot project will be conducted involving two passive components/structures representative of those for which extended life is highly important to LWR sustainability. The passive components or structures will target large and economically important plant assets for which the science of managing long-term material degradation is yet unsolved. Candidates would include the reactor vessel, containment structure, and containment concrete base mat. In this effort, the LWRS Program and EPRI will work with the LWRS Program's Materials Aging and Degradation Pathway to select a suitable component or structure based on importance to utility decision-making in pursuing additional life extension (beyond 60 years) and the prospects for research success within the timeframe of this project. The Materials Aging and Degradation Pathway would be responsible for developing the scientific basis for modeling the degradation mechanisms and determining the types of sensors needed to monitor the degradation. It is possible that new types of sensors will have to be fabricated for this purpose. The LWRS Program would devise the signal processing capabilities to convey the sensed parameters to the monitoring system. The LWRS Program also will develop the technologies needed to enable utilities to retrieve, store, process, and integrate the large volumes of nondestructive examination information collected through the online monitoring systems installed on these passive plant components.

The objective of the pilot project will be to develop the diagnostic and prognostic analysis framework for these components, including the ability to predict RUL. These capabilities will enable industry to implement online monitoring for these components and will establish the methodology for industry to extend the concept to other passive plant components, where aging and degradation mechanisms must be managed for extended life.

For each of these component types, a technical report will be published that describes the technical basis and analysis framework to enable online monitoring for these components. These technical reports, along with the results and experience from the pilot projects, will provide guidance for utilities to implement centralized on- monitoring and information integration for the passive components/ structures important to plant life extension.

Schedule: FY 2012 to FY 2017

Milestones:

- (2012) Publish a summary report of strategy and technical plans for online monitoring technologies in support of nondestructive examination deployment.

- (2013) Publish an interim technical report on development of a formal information integration framework used to develop diagnostic and prognostic models for passive plant components.

- (2014) Develop diagnostic and prognostic models for large passive plant components based on the information integration framework.

- (2015) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for a large passive plant component/structure, involving nondestructive examination-related online monitoring technology development, including the

diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

- (2016) Develop diagnostic and prognostic models for second large passive plant components based on the information integration framework.

- (2017) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for second large passive plant component structure, involving nondestructive examination-related online monitoring technology development, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.

5.7 Publications of Guidelines

To ensure appropriate transfer of technology to the nuclear power industry, guidelines documents will be published for each of the areas of enabling capabilities, incorporating the specific technologies and technical reports produced under each of the pilot projects for the respective areas. EPRI has agreed to assume responsibility for development and publication of these guidelines, using their standard methods and utility interfaces to develop the documents and validate them with industry. The LWRS Advanced II&C Pathway will support this effort by providing the relevant information and participating in the development activities.

The following milestones have been established to produce the guidelines for each area of the enabling capability:

Highly Integrated Control Room

- (2016) Publish interim guidelines to implement technologies for a highly integrated control room.
- (2019) Publish revised interim guidelines to implement technologies for a highly integrated control room.
- (2022) Publish final guidelines to implement technologies for a highly integrated control room.

Highly Automated Plant

- (2017) Publish interim guidelines to implement technologies for a highly automated plant.
- (2021) Publish final guidelines to implement technologies for a highly automated plant.

Human Performance Improvement for NPP Field Workers

- (2014) Publish interim guidelines to implement technologies for human performance improvement for NPP field workers.
- (2016) Publish revised interim guidelines to implement technologies for human performance improvement for NPP field workers.
- (2018) Publish final guidelines to implement technologies for human performance improvement for NPP field workers.

Integrated Operation

- (2018) Publish interim guidelines to implement technologies for integrated operations.
- (2020) Publish revised interim guidelines to implement technologies for integrated operations.
- (2022) Publish final guidelines to implement technologies for integrated operations.

Outage Safety and Efficiency

- (2015) Publish interim guidelines to implement technologies for improved outage safety and efficiency.
- (2018) Publish final guidelines to implement technologies for improved outage safety and efficiency.

Centralized Online Monitoring and Information Integration

- (2015) Publish interim guidelines to implement technologies for centralized online monitoring and information integration.
- (2018) Publish final guidelines to implement technologies for centralized online monitoring and information integration.

6. REFERENCES

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