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Light Water Reactor Sustainability Program

Nuclear Power Plant Modernization Strategy and Action Plan

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ABSTRACT

The Plant Modernization Pathway is conducting a robust research program to enable performance improvement and economic sustainability for the U.S. nuclear operating fleet, as represented in this Action Plan. This Action Plan is built on years of technology development by the Pathway in each of the technical areas that is addresses. It is the product of a highly capable research staff that understand the challenges the operating nuclear plants are facing and have the needed experience, knowledge, and research skills to devise innovative solutions for these challenges.

The Pathway has a large number of collaborators who share these objectives, including nuclear utilities, industry support groups, suppliers, other research organizations, universities, and consultants/contractors. The collective knowledge and expertise of these collaborators is a significant factor in the success of the research. The participation of some of the nation's leading utilities underscores the confidence the industry places in this Department of Energy research program. Moreover, the Pathway works with suppliers to promote commercialization of these developments, where appropriate, such that they result in validated products for use by these utilities.

In addition, the Pathway regularly engages with the Nuclear Regulatory Commission to promote communications on emerging technologies and to understand any regulatory implications for the developments, thereby ensuring that they technology and process improvements can readily be implemented by utilities.

This Action Plan consists of 24 major developments over fiscal year 2020, which represent beneficial developments in four major areas of nuclear plant modernization: 1) Instrumentation and Control Modernization, 2) Control Room Modernization, 3) Plant Monitoring and Work Process Automation, and 4) Nuclear Plant Operating Model Transformation. These areas together comprehensively address the opportunities for performance improvement and cost reduction needed to ensure the long-term sustainability.

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ACRONYMS

BWR	boiling water reactor
CDM	Compact Digital Modernization
COG	CANDU Owners’ Group
COSS	computerized operator support system
DCS	distributed control systems
DEG	Digital Engineering Guide
DOE	Department of Energy
EPRI	Electric Power Research Institute
ESFAS	Engineered Safety Feature Actuation System
GPS	global positioning system
HFE	human factors engineering
HMI	human machine interfaces
HSSL	Human Systems Simulation Laboratory
I&C	Instrument and Controls
IAP	Integrated Action Plan
IFE	Institute of Energy Technology
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
ISG	Interim Staff Guidance
IT	information technology
LWRS	Light Water Reactor Sustainability
MWH	megawatt hour
NEI	Nuclear Energy Institute
NITSL	Nuclear Information Technology Strategic
NRC	Nuclear Regulatory Commission
O&M	operating and maintenance
OLM	online monitoring facility
OT	operations technology
RPS	reactor protection system
SE	Systems Engineering
SIL	Safety Integrity Level
TCO	total cost of ownership
TERMS	Technology-Enabled Risk-Informed Maintenance Strategy

UFSAR	Updated Safety Analysis Report
VCU	Virginia Commonwealth University
WFA	work function analysis

NUCLEAR POWER PLANT MODERNIZATION STRATEGY AND ACTION PLAN

1. Introduction

The Plant Modernization Pathway of the U.S. Department of Energy (DOE) Light Water Reactor Sustainability (LWRS) Program conducts a broad research and development (R&D) program that addresses the technical and economic sustainability needs of the U.S nuclear operating fleet. It is targeted to ensure that these nuclear plants are positioned for many additional years of operation in support of the national goals of energy and environmental security [1]. The Pathway conducts this research in collaboration with nuclear industry partners who share this sustainability objective, including nuclear utilities, industry support groups, suppliers, other research organizations, universities, and consultants/contractors.

Since the inception of the LWRS Program, the Plant Modernization Pathway has conducted research activities in a broad range of nuclear plant functional areas, addressing critical issues of technology obsolescence, plant reliability, plant worker efficiency, and operating and maintenance (O&M) cost reduction [2]. The development and demonstration of these technologies and related methodologies have been conducted with collaborating partners including nuclear utilities, nuclear industry suppliers, and other research organizations. The result is a set of proven technologies that together address the requirements for much needed modernization of the legacy plant systems and related operations and support processes in order to ensure long term sustainability and economic viability. To this end, a Strategy and Action Plan have been formulated to work with utility first-movers in each of the technology areas to enable the implementation of these technologies, obtain key lessons-learned and enhancement needs, and enable wide-spread adoption by the U.S. LWR nuclear operating fleet.

The Strategy and Action Plan represents the major activities and associated research products for FY 2020 in the pursuit of plant modernization for the U.S. light water reactor (LWR)operating fleet. It has been formulated to address the most pressing needs of the industry in terms of advanced research that drives the near-term improvements for performance improvement and cost reduction. The products described in this action plan further relate directly to the enhancement priorities of these collaborating organizations, ensuring that the combined resources are tightly coupled and working to mutually beneficial objectives. The Strategy and Action Plan will be periodically updated to reflect new development and implementation priorities for plant modernization.

This Strategy and Action Plan first presents a digital strategy overview, describing a broad approach to plant modernization that ensures that long-term technical and economic viability is achieved by defining the future concept of operations, and then basing all modernization activities on this end-state vision.

The Pathway approach to research is then presented along with the roles and types of collaborators. Finally, the Action Plan is presented, addressing the major development areas of 1) Instrumentation and Control (I&C) Modernization, 2) Control Room Modernization, 3) Plant Monitoring and Work Process Automation, and 4) Nuclear Plant Operating Model Transformation. These areas together comprehensively address the opportunities for performance improvement and cost reduction needed to ensure the long-term sustainability.

2. Nuclear Power Plant Modernization Strategy

Digital technology is a cornerstone enabler of an optimized operations model that enhances nuclear plant economic viability. The term digital transformation" is used to describe implementation of this technology. Utilities have made, and continue to make, significant investments in digital technology.

Together with those in the planning stages, the implemented technologies can establish a foundational infrastructure upon which a larger digital transformation can build. As an example, recent industry efforts driving a pilot implementation of a digital Reactor Protection System (RPS)/Engineered Safety Feature Actuation System (ESFAS) replacement are intended to promote this digital transformation.

Some utilities have also experienced the difficulty that comes from making such digital I&C investments in an uncoordinated fashion. The result has been the increased cost of using existing electronic systems beyond their useful life, significant implementation delays and cost overruns in digital upgrades, and long-term lifecycle support strategies that are disjointed and inefficient. A piecewise approach to digital upgrades might also fail to provide utilities with expected benefits of lower system O&M costs and reduced workload.

This document proposes a nuclear digital transformation strategy to enable a technology centric operating model that minimizes nuclear plant total cost of ownership (TCO). This strategy addresses the intent of the EPRI Digital Engineering Guide (DEG) [3], Section 3.5.1 "Develop, Apply, and Maintain a I&C Strategy." It is intended that this strategy form the basis for a business case analysis of its implementation. A simplified view depicting the relationship between digital upgrades within a technology centric operating model is shown in Figure 1 below.

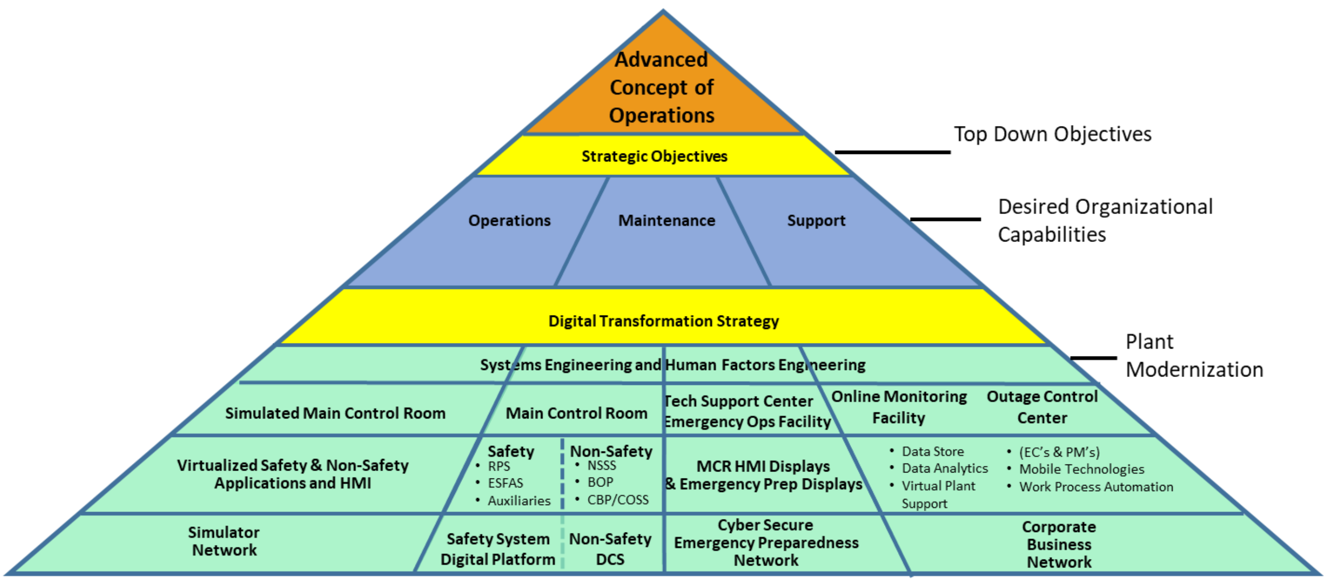

Figure 1. Technology Centric Plant Operations Model

The degree to which digital upgrades can enable a technology centric operating model is driven by a utility's approach to technology change and cost reduction. For those pursuing a system by system replacement strategy, the arrow on the "sliding scale of change/accountability" will move down. Accountability for these types of digital upgrades is typically driven lower in the utility's management structure (towards Engineering). This is more of a "digital modernization" than a "digital transformation." Cost reduction opportunities will be more limited.

For those utilities that are driving for truly transformative change, the arrow slides toward the top. The Advanced Concept of Operations is fundamentally changed across the enterprise (See Section 6.4.1). This drives digital upgrades up to support it. This level of digital transformation requires a higher degree of corporate accountability (typically championed by senior management) and takes a longer period of sustained commitment to achieve. It also requires an understanding of what technology can realistically provide. This Strategy provides insight into how this digital transformation is achieved.

A digital transformation is accomplished for a nuclear power plant by:

- Implementing a minimum set of foundational digital platforms to eliminate disparate, obsolete, legacy I&C equipment and the costs associated with them.
- Systematically consolidating the functionality of disparate, obsolete equipment to these platforms, moving beyond the like-for-like replacement model.
- Exploiting these platforms to perform higher order functions, such as control automation, plant monitoring, surveillances, system health monitoring, and problem diagnosis; thereby greatly reducing workload across the plant organization.
- Establishing a lifecycle support strategy for the foundational platforms so that technology investments are planned, executed, maintained, and refreshed in a continuous and deliberate manner.

In pursuit of this digital transformation, some utilities are changing how they manage digital upgrades. They are moving away from individual nuclear plants identifying, prioritizing, and executing digital upgrades. Rather, they are employing a multi-site project execution approach which provides an opportunity to employ common platform designs, processes, procedures, and support strategies/organizations across multiple nuclear units. This approach also supports multi-site planning, scheduling and implementation, which can significantly optimize both resources and the application of lessons learned. These utilities also realize additional savings by implementing the digital transformation as a single, corporate led activity.

3. Endpoint Vision, Technology Enablers, and Risk

To communicate how a digital transformation enables a technology centric operating model, it is helpful to consider a concrete endpoint vision of a digital transformation. The following sections describe a conceptual nuclear site digital infrastructure and the benefits that can be realized when fully exploited.

3.1 Site Digital Infrastructure and Systems Engineering

To achieve the maximum aggregate benefit enabled by this digital transformation, the digital infrastructure for a nuclear plant must be designed as an integrated set of systems that together enable a technology centric operating model. A simplified view of this integrated set is shown in Figure 2.

Such an integrated systems design is achieved by a Systems Engineering (SE) process. SE in this context is the art and science of developing this digital transformation system infrastructure so that it is capable of meeting its requirements within opposing constraints. SE is an integrative activity where the contributions of many different disciplines are balanced along with opposing constraints to produce a coherent whole. Utilization of SE is a key enabler for producing an aggregate digital infrastructure that minimizes development and lifecycle costs while maximizing support workload and cost reduction. Use of the SE process as developed in the EPRI Digital Engineering Guide (DEG) [3] is the preferred approach to achieving this end. A graded human factors engineering methodology compliant with the U.S. Nuclear Regulatory Commission (NRC) NUREG-0711 Human Factors Engineering Program Review Model [4] within the larger DEG process results in optimized human machine interfaces (HMI) using a process familiar to utilities and to the NRC.

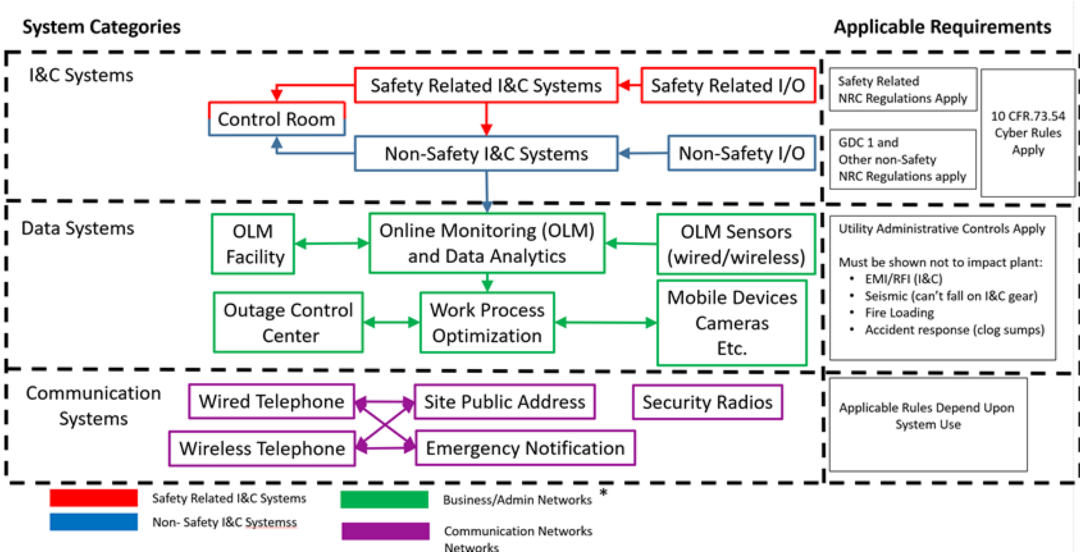

Figure 2. Digital Transformation System Infrastructure

Within the digital transformation system infrastructure, significant technical synergy can be leveraged to lower costs. As an example, a properly controlled, single fiber optic cable infrastructure can be installed and shared to meet the communications needs for all depicted system categories in Figure 2. Different systems use different fibers to segment their functions since there is no physical mechanism for signal coupling between the separate fibers.

3.2 Instrumentation and Control Systems

Modern, expandable, I&C system platforms are installed as a digital backbone onto which the functions of obsolete monitoring and control systems are migrated. The obsolete systems are then eliminated. Separate safety and non-safety platforms are utilized so that each platform is properly sized and designed to meet the scope of the need in each area and to meet the different requirements that govern each. The following are key concepts for a transformed I&C digital infrastructure.

1. Use of modern, common platforms

   The number of disparate technologies that need to be supported collapses over time so that when all functions are migrated to the appropriate platform, only two platforms need to be supported going forward. This reduces the need to maintain the knowledge and documentation base for a multitude of disparate systems. This also reduces training costs, spare parts inventory requirements, maintenance of supply chains (contracting), and other lifecycle support related items.

   The physical footprint and number of components needed to support I&C functions can be also be significantly reduced. This is achieved by employing available technology from the input/output devices (e.g. Foundation Field Bus and Profibus enabled devices) up through supervisory control and HMI devices (e.g. using server hosted virtual machines to perform these functions instead of separate physical hardware).

   Modern I&C platforms are also increasingly designed to permit the direct migration of application software from obsolete hardware. This protects the intellectual property investment made on that application software by largely decoupling it from hardware obsolescence.

2. Automation of complex and operationally challenging tasks

Plant operational performance improvements and reductions in operator workload can be obtained by automating control room tasks. For example, utilities have demonstrated where events such as plant trips when transitioning to automatic feedwater regulating valve control of steam generator level during plant startup have been eliminated through automation. Automation of main turbine startup and warmup has also reduced operations workload. By properly identifying and implementing automation through function allocation and task analysis, operators can transition from component control to plant state control.

3. Enhanced HMI and digital control rooms

   Integrated operator displays can be deployed based on advanced human factors engineering (HFE) principles, enabling proper supervision of automated control functions while eliminating certain classes of operator error. Properly human-factored operator aids such as alarm management, trend displays, task-based displays, integrated plant overview displays, computer-based procedures, and computerized operator support systems can be used to significantly improve operational performance and reduce operator workload. Maximizing these capabilities, the main control room would approach being fully digital much like the Westinghouse AP1000® control room pictured in Figure 3 below.

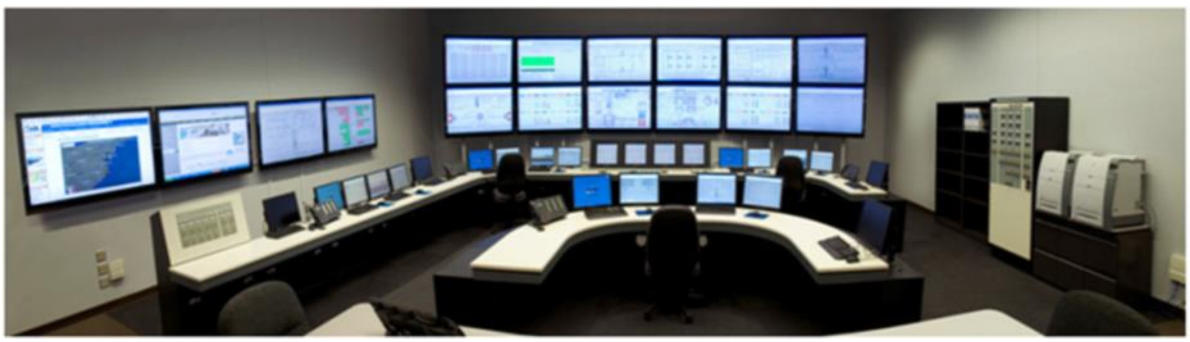

Figure 3. AP1000® Control Room

   Such a control room is much more intuitive to operate than the current bench board style control rooms of the operating nuclear plants today. It has the potential to significantly reduce the necessary training required for plant operators to maintain their proficiency as compared to current training, which in many cases is focused on overcoming human factors issues associated with the legacy control room designs. This supports reductions in both operator and training support workload. Also, activities currently performed by auxiliary operators can be shifted to the main control room to further reduce overall operations workload.

4. Reduction/elimination of manual surveillances and calibrations

   Digital systems have advanced self-diagnostic features that significantly reduce or eliminate the need for operators and technicians to perform surveillances and calibrations. Mechanisms can also be employed to test active components online (e.g. turbine trip circuits and actuators) using automated routines initiated from the control room without risk of operational upset.

5. Plant data capture for analysis

   As obsolete I&C functions are migrated to digital platforms, data that was previously isolated becomes available and can be forwarded to plant data systems for analysis. (see Section 3.3)

6. Full simulator integration with plant digital I&C upgrades

Proper integration of digital I&C technology into the simulators enables a "design once, build twice" capability. Once this is accomplished, the same software and HMI developed for the plant can be directly integrated into the simulator for training. In fact, simulator functionality can be further replicated at low cost and be used as a conceptual design tool for developing control system changes, HMI changes, and for procedure development. It can also be used to help validate final system software and HMI designs before they are installed in a plant. These uses have already been demonstrated in the nuclear industry as depicted in Figure 4 below [5].

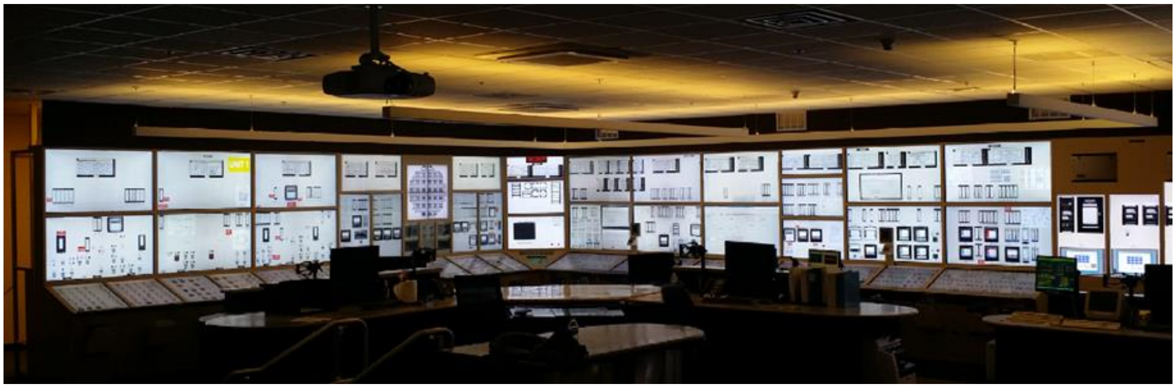

Figure 4. Brunswick Nuclear Plant Control Room Glasstop Simulator

Such simulators have also been used to perform NUREG 0711 based HFE Integrated System Validations on digital control room upgrades [6] following a holistic, graded approach to support I&C Modernization [7].

7. Standardization of a simplified cyber security defensive architecture

   A generic, integrated cyber security defensive architecture can be employed for the safety related and I&C platform architectures. As functions are migrated from legacy equipment to the appropriate platform, those functions would inherit the cyber security attributes of the respective platform. All cyber security activities associated with the legacy equipment are eliminated as it is decommissioned/removed.

The items listed above provide opportunities for significant workload reduction. Integration of them all in a comprehensive SE-enabled strategy provides a technology multiplier that enables a result that is more than the sum of its parts. Plant data collected by digital systems can be automatically stored and distributed. The amount of equipment needed to perform I&C functions can be drastically reduced (e.g. removing duplicate sensing, indicating, control, and local logic devices). In fact, some I&C systems like the Plant Process Computer and Plant Annunciator panels can be eliminated.

There are a number of key challenges associated with deploying this technology and methods to address them, including:

1. I&C migration strategy

   Current plant health processes are biased to identify and approve system I&C sustaining/modernization activities in a piecemeal manner that is not informed/driven by an integrated and optimized endpoint vision. After establishing direction for a digital transformation, I&C technology investments should be identified, prioritized, and implemented as dictated by the technology-centric operating model which the digital transformation enables.

2. Phased implementation

   The scope of a holistic digital transformation is such that it is unlikely that a utility would accomplish it in one step. A phased implementation approach provides an opportunity to minimize plant operations impacts, to level needed implementation resource over a longer period as well as providing mechanisms to leverage lessons learned. A properly executed phased approach also provides for a controlled cultural transition to a technology-centric operating model. Such a phased approach requires a sustained focus to attain the endpoint vision coupled with a long-term commitment to achieve it. Interim states on the path to the endpoint vision need to be carefully defined to minimize rework. It should be noted that partial implementation of the endpoint vision can produce a result which exacerbates TCO challenges instead of ameliorating them.

3. Regulatory licensing strategy

   Previous commitments to the NRC must be addressed in the implementation of the digital transformation strategy. While many commitments are explicitly defined, many others are implicit in the legacy technology used to implement them as described in a particular plant's design basis documents and its Updated Safety Analysis Report (UFSAR).

   The most efficient technical solution may not be the best overall solution for minimizing TCO because of licensing considerations of that solution. An example of this is functional segmentation. Implementing the most efficient technical solution may result in a complete "re-rack" of the functional segmentation as captured in a plant's design basis documents and described in the UFSAR. In digital design, unrelated I&C functions might share a computer processor and thereby have a common failure source. Segmentation in this sense is not necessary with analog I&C functions because each circuit depends on its own set of hardware. Using segmentation in the plant's design when performing digital upgrades may require some additional equipment, but it could completely mitigate the risks described above and provide the best TCO solution.

   License amendments will be required for some safety system upgrades and all Technical Specification surveillance reductions. A structured, holistic approach for addressing licensing issues must be developed coincident with this digital transformation. Early and frequent regulatory engagement where specific principles, attributes, implementation techniques for the full digital transformation system infrastructure are presented will help mitigate licensing risk. Leveraging the Interim Staff Guidance (ISG-06) Alternate Approach for performing safety-related I&C modification for a pilot digital RPS/ESFAS replacement provides an early opportunity to foster this engagement.

4. Leveraging vendor capabilities and technology as built

   In most cases, currently available vendor capabilities and technology provide the needed expertise and functionality to enable the digital transformation. Nuclear utilities have been reluctant to fully leverage these, resulting in increased implementation and lifecycle support costs. Utility implementation and support processes/procedures need to be evaluated to enable leveraging vendor capabilities and technology to minimize TCO as other industries do. The nuclear industry could thereby simplify design and implementation processes/procedures, leverage innovative design techniques, and eliminate large portions of current nuclear-specific test programs, while improving overall system quality and reliability. Associated costs could be significantly reduced.

   In specific instances where current vendor products do not provide features that are major benefit enablers, they would be best obtained by teaming with the vendor to make those features part of their standard offering. The vendor would shoulder most if not all of the cost to develop these features if there was a larger market for them. They would also be supported by the vendor going forward, thus reducing obsolescence risk.

5. Establishing a technology lifecycle support program

A digital transformation strategy involves a continuous technology support and refresh plan from initiation to the end of plant life. Installed digital systems require day-to-day support activities such as software patch management. For the longer term, industrial operations technology (OT) digital system hardware typically has a seven- to ten-year technology lifecycle compared to the three- to five-year lifecycle for the information technology (IT) systems they leverage. Using 30 years as a baseline for remaining plant life (for a plant pursuing Second License Renewal), it is expected that after initial installation, a minimum of two platform technology hardware refreshes may be required. Safety systems may require fewer. These need to be planned for and managed much like other regularly scheduled key infrastructure support activities (e.g., reactor coolant pump refurbishment). A key aspect of this technology lifecycle program is selection of a system technology that allows for retention of initial software application intellectual property investments to minimize refresh costs. Leveraging practices accepted in industrial control outside of nuclear (such as technology migrations for non-safety platforms during plant operating periods) can also significantly reduce plant operation impacts and associated costs.

6. Standardization

   Performing I&C modernization activities as standalone projects that provide like-for-like functional replacements is inefficient. Standardization of digital platform designs and processes to migrate obsolete I&C equipment functions to those platforms and sustain them through plant life provide benefits for individual plant implementations. These benefits can be magnified when standardization is applied to multiple plants or to a fleet of them. Phased function migrations to selected platforms become repetitive and leverage processes and lessons learned from previous ones. Documentation for these migrations follows a standard format with a standard level of detail. Not only does this improve implementation efficiency over time, it also helps build an internal pool of qualified resources to sustain the digital transformation.

7. Program Management

   Use of integrated program management to implement the digital transformation leads to a higher realization of the benefits of the key enablers and address the key challenges identified above. Individual plant I&C modernization projects (or groups of them in a phased approach) can be approved and implemented following the current, generally accepted framework in place at nuclear utilities. Integrated project management ensures that each project is informed by and coordinated with others in the areas of technical attributes, scheduling, resource management, aggregate licensing impacts, etc. Most importantly, each project is developed in the context of and driven to fully support the SE-enabled endpoint vision.

3.3 Data Systems

3.3.1 Data Capture and Analytics

Current techniques to gather, analyze, and act on operating nuclear plant information to diagnose equipment issues and correct them are largely manual and workload intensive. Current plant processes capture this data in multiple, disparate ways. These include manual logging of physical indicating devices (direct reading physical devices and analog instrumentation), scattered electronic data capture from individual plant I&C systems which have that capability, electronic data captured by activities such as periodic vibration monitoring, etc. Aggregation and analysis of this data is challenging and, in most cases, does not provide real time (or near real time) results that can be leveraged to reduce labor intensive O&M activities or eliminate calendar based surveillances/maintenance that is not warranted based upon actual component operational performance.

Implementation of data systems within the larger digital transformation system architecture depicted in Figure 2 above transforms data gathering and analytics. A real time, closely coupled, expansive dataset is made available for analysis to produce results that can directly reduce labor intensive O&M activities or eliminate calendar-based surveillances/maintenance.

The following are key data capture and analytics enablers that support TCO reduction.

- Vast quantities of digital, time stamped plant data from the safety and non-safety I&C platforms can be made available and used to diagnose process and component health.
- The capability to add non-process control related sensors directly to the data systems infrastructure to fill gaps in the data provided by I&C systems to enhance analytic capabilities when needed.
- The capability for long term trending and analysis of this expanding and tightly coupled dataset with ever improving automated tools to perform the analysis
- Performing this analysis in a non-I&C environment. This allows monitoring and diagnosis to be performed in a remote online monitoring facility (OLM) and even subcontracted as a fee for service. While this information must still be protected from a business investment protection point of view, more stringent NRC cyber security requirements need not be applied.

The following are key challenges associated with deploying data capture and analytics technology.

- A software data architecture needs to be created deliberately and systematically early in the digital transformation to ensure that data is captured, retrieved, and analyzed in a structured and efficient manner. Unfocused or haphazard digital data formatting, collection, storage, and retrieval mechanisms are significant impediments to enabling sophisticated data analytics capability.
- Analytics capabilities within the nuclear industry have been limited because of general technological obsolescence. Focused research on analytical tools for nuclear plant systems and components is needed to enable these long term O&M cost reductions. Properly leveraging rapidly evolving analytical tools being developed and validated in non-nuclear process control industries provides an avenue to realize the potential savings in this area with minimal nuclear industry specific investments. Validation of these tools to enable burden reduction in license obligations such as Technical Specifications surveillances will require investment by the industry.

3.3.2 Work Process Optimization and Enhanced Decision-making

Current nuclear plant administrative work processes that support activities such as configuration control, configuration management, work scheduling, work process control (both sustaining and engineering change activities), and work execution are inefficient, labor intensive, and involve the generation and retention of large volumes of paperwork. Craft personnel performing work in the plant often have little access to real-time plant data or advanced technology that can reduce both workload and human error. Operational decision-making would benefit from more timely and complete information on plant operational status, maintenance work status, and emergent plant issues.

Key data system work process optimization enablers that support TCO reduction include:

- Automatic generation of pre-developed, electronic work packages based upon identification of equipment issues by advanced data analytics features. Automatic scheduling to implement these work packages enables efficient utilization of maintenance resources.
- Use of mobile technologies (e.g., tablets, headsets with cameras, data presentation, and voice recognition capability) to enhance correct and timely execution of maintenance.
- Use of advanced virtual collaboration technologies so that remote plant support organizations (centralized utility functions or vendors) can assist plant workers on a real-time basis.

- Enhanced outage performance enabled by live work management and tracking by a digitally enabled outage control center.
- Automatic archiving of completed electronic work packages for configuration control and record retention.

Key enhanced decision-making capabilities enabled by digital transformation data systems include:

- Availability of view only, near real-time facsimiles all I&C operating displays across the data network infrastructure. These can be used for improved understanding of plant operating status across the enterprise. Properly controlled data system user stations can also be configured as cyber secure nodes and communicate through virtual private networks to enable their utilization to support remote Emergency Response Facility functions.
- Creation of a real time management decision support center that would have full access to all data network capabilities. This, plus development of multi-discipline performance dashboards at the unit, site, or fleet level would inform and improve decision-making by senior management.

Key challenges associated with deploying this technology and methods to address them include:

- Networks need to be selected and installed in ways that provide necessary coverage but do not result in compatibility issues that could impact installed plant electronic equipment. Mobile devices need to be selected and rules established for their use to address the same concern. This can be mitigated to a significant degree over time as the full scope of the digital transformation system architecture is installed, since its components would be designed to be compatible with each other and to minimize interference with other installed plant systems.

  Wireless frequencies, bandwidth use, and power levels need to be allocated to particular functionality to prevent interference between them. Use of personal wireless devices (many of which transmit at multiple frequencies and power levels) also need to be managed. Establishing and adhering to a site wireless communication policy will also help mitigate both identified wireless issues.

  A specific, identified use case for each type of mobile technology must be developed and authorized before implementation. Discipline is needed to prevent an uncontrolled proliferation of diverse electronic devices and associated costs of procuring and maintaining them. These items need a lifecycle support strategy of their own.

3.4 Communications Systems

At many nuclear stations, systems that perform audio communication functions use technology that is decades old with very limited functionality. As digital technology now dominates the transmission of data system information and the transmission of voice information between people, it is natural to include communication systems within the digital transformation system architecture.

Key digital communication system technology enablers that reduce TCO include:

- Shared but segregated physical communications backbones (both between separate audio systems and between audio, data, and I&C systems).
- The ability to cross-connect separate audio communication subsystems to create a larger system coverage and capability envelope while maintaining individual subsystem functionality should other subsystems fail.
- Improved functionality that allows direct, instantaneous, digital wireless audio communication between the control room and remote operations and maintenance personnel (including pre-

defined or ad-hoc team members in separate locations) without use of the site public address system.

- Improved public address system access (through cross connects to wired and wireless telephone systems) and capability (through implementation of pre-recorded site announcements that can be initiated from any source within the digital transformation system architecture). This would relieve control room personnel from making many public address announcements and allowing them to focus on control room actions during plant operational events.
- Improved capability to automatically alert personnel individually (e.g., a cyber security expert) or teams (e.g., emergency response on-call personnel) by using either pre-created recorded messages (telephone) or data (text messages) triggered automatically from any source within the digital transformation system architecture.
- Improved/innovative emergency management communications capabilities (e.g. potentially eliminating sirens for public general emergency notifications and leveraging the national Wireless Emergency Alert System for notifying the public in specific geographic areas surrounding a nuclear power plant in collaboration with federal, state, and local authorities).

Key technical challenges associated with deploying this technology are limited to wireless communication electromagnetic compatibility and frequency management concerns similar to using mobile technology for data systems. Organizational challenges with communications systems revolve around how to best optimize communication systems to meet regulatory requirements for communication and identification of site operating model communication use cases so the systems can be configured to support them.

4. Key Organizational Enablers of Success

The following are key organizational enablers of success in achieving the endpoint operating model and associated digital transformation strategy.

- Appropriate corporate management ownership and approval of the target endpoint vision operating model and related digital transformation.
- Proactive and sustained management support will be provided to drive the digital transformation for an envisioned seven- to ten-year implementation period. Incomplete implementation of the digital transformation can create an interim state which can exacerbate TCO challenges if transition to the endpoint is delayed.
- After proper evaluation, commercial vendor designs and implementation techniques will be readily adopted across the scope of the digital transformation to the maximum extent practicable.
- Schedules for project implementation under the digital transformation strategy will be developed, approved and adhered to. Projects approved for implementation under this strategy will not be rescheduled or re-prioritized without approval of the strategy sponsor. It is an industry lesson learned that constant rescheduling and re-prioritizing of these efforts results in significant delays, cost increases, and reduced digital system operating lifetimes between required technology refreshes.
- A sustained technology lifecycle investment protection plan will be put in place. This is an essential component of the digital transformation strategy. Without it, associated electronic systems will themselves become obsolete and unsupportable at a rate driven by digital technology advances. Near term gains realized by implementing the digital transformation will be lost on an accelerating basis as time passes.

5. Action Plan Approach

There are two key elements to the Action Plan approach; first, a robust research plan for conducting projects that enable plant modernization, and second, nuclear industry collaborations that provide the knowledge base to ensure that projects are based on true industry requirements. Each is described below.

5.1 Plant Modernization Pathway Research Plan

The Plant Modernization Pathway maintains a Technical Program Plan [2] that is updated on an annual basis. This plan has been formulated to address the range in technology and methodology development that is needed to support the nuclear operating model transformation. It describes the broad objectives of the Pathway and provides detailed descriptions of the research projects, including the past, current, and projected deliverables of these projects.

Selected projects that are key enablers of this digital transformation are described in this Action Plan as contributors to the major areas of development of nuclear plant modernization: I&C modernization, control room modernization, plant monitoring and work process automation, and nuclear plant operating model transformation. For full descriptions of these projects, refer to the Plant Modernization Pathway Technical Program Plan.

5.2 Collaborations

In pursuing a digital transformation strategy, the Plant Modernization Pathway has established a number of key nuclear industry collaborations that include nuclear utilities, industry support groups, suppliers, other research organizations, universities, and consultants/contractors. These collaborations are based on mutual interests in the development of advanced technologies and process methodologies for nuclear plant modernization. The collective knowledge and expertise of these collaborators is a significant factor in the success of the research. The participation of some of the nation's leading utilities underscores the confidence the industry places in this DOE research program. While no one company is currently pursuing all aspects of modernization, together they represent the full range of development areas for comprehensive nuclear plant modernization. These collaborations provide the opportunity to understand both the requirements for these individual development areas as well as the interrelationships among them that must be supported by the digital transformation system infrastructure.

These collaborations also provide the opportunity to understand the investment business case in each area and the overall business case in pursuing total plant modernization. Enabled by this understanding, the Pathway is able to develop the transformative concepts, technologies, and methodologies that are responsive to the needs of the operating plants in terms of being affordable and implementable.

Another important aspect of the collaborations to promote commercialization of these developments, where appropriate, such that they result in validated products for use by these utilities. Since the nuclear utilities typically would not take research results and prototypes to fully validated products, they rely on

5.2.1 Nuclear Utilities

The Pathway forms collaborations with nuclear operating companies that have interest in certain technical areas, often driven by performance or cost issues that they are experiencing. Projects are developed to address mutually beneficial outcomes. The Pathway defines the R&D objectives of the project while the utility has opportunity to define the requirements from a nuclear station operational standpoint. The Pathway thereby develops technology that reflect the true operational requirements for use by the operating LWR fleet as a whole, while the utility has opportunity to be an early adopter of a technology that is suited to their needs.

Current collaborating nuclear utilities include Arizona Public Service, Dominion Energy, Exelon Generation, Xcel Energy, Nebraska Public Power District, Luminant, Talen Energy, Energy Northwest, and Utilities Service Alliance.

5.2.2 Major Industry Support Groups

The Plant Modernization Pathway has worked with the Electric Power Research Institute (EPRI) since the inception of the LWRS Program through a memorandum of understanding. There have been many collaborative and cooperative R&D efforts over the years. Currently, the Pathway is collaborating with EPRI in their similarly named Plant Modernization Program in a number of research areas of mutual interest. This collaboration is described in more detail in Section 5.3.

The Pathway participates in the Nuclear Energy Institute (NEI) Digital I&C Working Group to contribute technological solutions for the resolution of certain digital I&C regulatory barriers to plant modernization. NEI is engaged with the NRC on their Integrated Action Plan (IAP) to address a number of areas where regulatory burden is impeding the modernization of I&C systems. The two organizations are exploring solutions in a series of agreed-upon regulatory topics. Two of these topics have recently been resolved in a mutually satisfactory manner; 1) clarification on the use of 10 CFR 50.59 to implement I&C upgrades of lower safety significance, and 2) a more streamlined license amendment process for I&C modifications. Ongoing work is focused on alternate approaches in assessing software common cause failure susceptibility, use of a Safety Integrity Level (SIL) approach to qualifying digital devices for safety related use, and improving the digital I&C regulatory structure. The Pathway will continue to support these efforts with research results and experience reports as needed.

The Pathway cooperates with the Institute of Nuclear Power Operations (INPO) in addressing nuclear plant conduct of operations issues and the related performance objectives and criteria. In previous years, the Pathway has conducted briefings for INPO on the state of digital technology related to the implications for the nuclear plant conduct of operations. INPO representatives have participated in many of the Pathway meetings, workshops, and utility technology demonstrations to better understand emerging digital technologies of interest to utilities and the impact they might have on current plant processes and performance expectations. Currently, the Pathway is participating in meetings at INPO with a collaborating utility in the discussing the transformation of their nuclear plant operating model with respect to INPO nuclear plant performance criteria.

The Pathway participates in the activities of the Nuclear Information Technology Strategic Leadership (NITSL) organization that promotes common solutions in nuclear information technology across the LWR operating fleet. NITSL is working in a variety on information infrastructure topics that match up well with the research activities of the Pathway. The Pathway is ensuring that maximum technology and learnings are made available to the utilities through their involvement in NITSL.

5.2.3 Suppliers

The Pathway engages suppliers in two ways. First, suppliers often seek out the Pathway to participate in research activities that they believe will enhance and add value to their product offerings, understanding that the Pathway is focused on strategic technology developments that ensure the long-term sustainability of the operating nuclear units. These suppliers often have products that are suitable as base technologies for more advanced developments, going beyond the current product capabilities. This highly beneficial to the Pathway in that research funds do not have to be spent on devising these base technologies when the research objective is to create a higher-value technology. This is also beneficial to the suppliers and they are often willing to participate on a cost-share (in-kind contribution) basis.

Second, the suppliers are the usual paths for commercialization of the research products of the Pathway, thus providing viable products to the nuclear utilities based on the research results. While some resulting concepts and methodologies can be directly implemented by the nuclear utilities, and in a few cases the laboratory commercializes a technology, the dominant path to availability of qualified products for use in a nuclear plant is through supplier commercialization. This is the vital connection that takes the research products to the point of actual deployment in a nuclear plant with qualified, reliable products suitable for use in the rigorous requirements of the nuclear safety culture.

Current collaborating suppliers include Westinghouse Electric Company, Rolls Royce, ……

5.2.4 Other Research Organizations

To avoid duplicative research activities wasteful of resources, the Pathway collaborates with other research organizations in their related research activities when there is mutual advantage in coordinating these activities and sharing results. These include other DOE laboratories as well as independent laboratories. This makes available to the Pathway a broad range of experts and body of knowledge in the key technical areas related to nuclear plant modernization. In many cases, it also provides for peer review of the results of the Pathway research, thus adding to the credibility of the research findings and products.

Current collaborating research organizations are Oak Ridge National Laboratory, Argonne National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratory, Institute of Energy Technology (IFE) sponsoring the Halden Reactor Project,

5.2.5 Universities

Similar to other research organizations, the Pathway collaborates with universities in basic technology development as their academic-oriented research is typically focused. This provides access to leading edge developments in these technical areas conducted by both the university staff and their students. University research is often more basic in the sense that it involves the application of scientific principles. This is sometimes a very helpful supplement to the research of the Pathway in grounding the technology developments in science and mathematics, with examples ranging from first principles physics models for component degradation diagnostics to behavioral and human reliability science as the basis for control room designs.

Current collaborating universities include University of Tennessee, Virginia Commonwealth University, University of Idaho, University of Pittsburgh.

5.2.6 Consultants

The Pathway engages a variety of consultants with specialized knowledge and expertise in various aspects of research project objectives. Often these companies have unique and practical experience to lend to the Pathway research activities or have specialized facilities that enable research work to proceed on a more efficient basis. These consultants also offer very practical knowledge based on their professional practices and this helps keep the Pathway research activities grounded in the realities of both operational and business considerations.

Current collaborating consultants include ScottMadden Management Consultants, Nuclear Automation Engineering, Remer Engineering, Knowledge Relay, Benchmark Electronics.

5.2.7 NRC Engagement

The Pathway regularly engages with the NRC to promote communications on emerging technologies and to understand any regulatory implications for the developments, increasing the likelihood that the technology and process improvements can be readily implemented by utilities. The Pathway has held two technical exchange meetings with the NRC over the past year to advise them on these emerging digital technologies thought to be of value and interest to the nuclear utilities. As mentioned in Section 5.2.2, the Pathway participates in the NEI Digital Working Group, which is working with the NRC on resolving certain regulatory issues with respect to I&C modernization. Further, the Pathway is collaborating with Exelon Generation on a potential upgrade of safety related systems, and through this collaboration the Pathway has participated in direct discussions with senior NRC executives on how the LWRS Program and specifically the Plant Modernization Pathway can contribute to the success of this objective through its research activities.

5.3 EPRI Plant Modernization Program

The Plant Modernization Pathway is involved in a significant collaboration with EPRI in their similarly named Plant Modernization Program which began in 2018. In this collaboration, the Pathway represents DOE on a committee made up of EPRI-member nuclear utilities, research organizations, and industry support organizations. As stated in their program plan, this Program will determine if a technical foundation can be established through which operating and new nuclear plants can fully modernize and adopt process improvements and advanced technology to potentially reduce operating costs [8]. The Vision of the Program is:

Preserve nuclear power as a carbon-free, safe, and reliable energy resource.

The Mission of the Program is:

Achieve nuclear power plant economic viability through collaboration, transformative technology and innovation to optimize operations and maintenance while ensuring safety and reliability.

The EPRI Plant Modernization Committee provides utility and industry input and advice on the program strategy, tasks, and progress. This committee consist of utility leads/experts in the various modernization areas and representatives of the Owners Groups, U.S. Department of Energy, Nuclear Energy Institute, the Nuclear Information Technology Strategic Leadership Group, and others. EPRI also engages other stakeholders such as Owners Groups, commercial vendors, and international organizations such as the CANDU Owners' Group (COG).

The Program is being conducted in three phases: 1) Phase I – Feasibility, 2) Phase II – Methods, and 3) Phase III – Deployment. The technical areas of development:

- Automated Work Planning
- Condition-Based Maintenance Monitoring
- Risk-Informed Engineering
- Digital Upgrades
- Wireless Connectivity
- Automated Radiation Monitoring
- Automated Chemistry Monitoring
- Structural Health Monitoring
- Big Data Analysis
- Physical Security
- Emergency Planning
- Common Information Model.

This research involves the use of demonstration projects to provide data and serve as test beds for investigating modernization concerns through inspections, testing, demonstrations of new technologies, and analyses.

The Plant Modernization Pathway and the EPRI Plant Modernization Program conduct monthly phone calls to coordinate research activities, share information, and to advise each other of the status and results of the ongoing projects. Periodic planning meetings are held to conduct in depth discussions of utility technology requirements and the opportunities for coordinated research between the two research programs.

Current areas of collaboration include digital I&C human factors engineering for control room modernization, online monitoring, work process automation, digital architecture, risk-informed methodologies, outage risk management improvement, and nuclear plant physical security. New projects in the coming year will be evaluated for additional collaboration opportunities.

6. Nuclear Power Plant Modernization Action Plan

The Action Plan for nuclear power plant modernization addresses four major areas of opportunity to improve plant performance and work efficiency while resolving concerns with component reliability and obsolescence. These areas are:

- I&C Modernization
- Control Room Modernization
- Plant Monitoring and Work Process Automation
- Nuclear Plant Operating Model Transformation.

Each of these areas is addressed in the following sections, describing the specific research developments and resulting products that will contribute to nuclear plant modernization and operating model transformation to achieve technical and economic viability for extended operating life.

6.1 I&C Modernization

Nuclear plant I&C systems today are largely based on legacy analog technologies that have been abandoned by other industry sectors in favor of modern digital technologies that offer improved I&C functionality and lower operating costs. Given the size and complexity of nuclear plants, one difficulty the operating plants have in pursuing a similar I&C modernization strategy is the sheer volume of discrete control and indication devices throughout the plant. Another is that the design and licensing bases of the plants reflects these legacy technologies and a sizable portion of the plant's operating and maintenance infrastructure (drawings, specifications, procedures, and training modules) are impacted by digital upgrades. Finally, there is a degree of familiarity and comfort with the legacy technology that makes it difficult to move to a different technology base. In spite of these obstacles, the operating plants have achieved a high degree of reliability with these analog systems through cost-intensive maintenance efforts. However, there are growing concerns with technology obsolescence as the supplier base for these declining technologies continues to shrink. Moreover, expensive maintenance practices are no longer tenable as these operating nuclear plants have to be cost competitive in today's energy markets.

The objective of this action plan in the I&C modernization area is to conduct research that provides essential knowledge and technologies that enable nuclear utilities to move forward with much-needed upgrades to both resolve the I&C obsolescence problems as well as provide the foundation for significant cost reduction across the plant. These two aspects of I&C modernization establish the basis for an investment business case and the confidence to undertake digital technology upgrades of this magnitude.

6.1.1 Safety Related I&C Systems

Safety related I&C systems should be the highest priority for digital upgrades due to expected gains in reliability, continuous system health monitoring, and reduced wear and tear on critical components as a result of the continuous invasive testing. Operational readiness, particularly for passive reactor protection systems, would likewise have a higher degree of assurance with self-monitoring digital I&C technology rather than relying on the periodic surveillance tests required for analog technology.

However, in practice, the modernization of safety related I&C systems has been the most difficult hurdle to cross in modernization of nuclear plants. Only a few industry upgrades that involve NRC license amendments (for highly-safety significant I&C systems) have been pursued, due to the history of regulatory, cost, and schedule risk. The early instances of these types of safety significant I&C modifications have had a chilling effect on additional upgrades.

To address this, the industry has worked with the NRC to address and resolve these barriers (see Section 5.2.2) and there is optimism today that these types of I&C upgrades can be successfully completed. Recent achievements as well as continuing efforts include:

- Safety-related systems of lower safety significance can now be addressed through the 10 CFR 50.59 process and thereby such upgrades can be implemented without requiring an NRC license amendment. Through the coordination of the NEI Digital I&C Working Group, the industry worked with the NRC to clarify requirements for these types of digital upgrades through the issue of RIS 2002-22 Supplement 1, which, among other provisions, provided for a qualitative assessment of susceptibility to digital common cause failure. The industry is now successfully using this regulatory guidance to pursue these types of modifications and significant modernization of this class of systems is expected in the coming years.
- The industry has also worked with the NRC through NEI to address the safety related I&C license amendment process, with a revision to the existing regulatory guidance of ISG-06 providing an alternate review process for digital I&C license amendment requests. The alternate review process provides a less-burdensome process with earlier confidence that the amendment will be approved, both of which significantly lower technical, schedule, and cost risks.
- The Electric Power Research Institute is also working on a basis for using the Safety Integrity Level (SIL) concept that is described in IEC 61508 as a more efficient means of commercial grade acceptance of digital devices for use in safety related applications. The NRC is now working with the industry through NEI to potentially develop regulatory guidance in this area.
- The NEI Digital I&C Working Group is continuing to work with the NRC to provide additional options for addressing software common cause failure in digital systems, by revising NRC NUREG-0800, Branch Technical Position 7-19. This has potential to provide for alternate and less burdensome assessment of software common cause failure.

Apart from these promising developments, it is yet to be demonstrated is that a highly-safety significant I&C system modification can be successfully licensed and implemented by a utility without significant schedule and cost overruns. Such a demonstration would likely lead to widespread modernization of these systems across the US operating fleet. Thus, the Action Plan for safety related I&C systems is rightly focused on such a demonstration.

Beginning in FY 2016, the Plant Modernization Pathway conducted a project with Nuclear Automation Engineering, LLC, in the development of a comprehensive reference I&C architecture that addresses all aspects of nuclear plant modernization – safety related systems (including protection systems), non-safety related systems (including all balance-of-plant systems), diverse actuation systems, and control room modernization. This reference specification for a digital modernization is known as the Compact Digital Modernization (CDM) and is depicted in Figure 5.

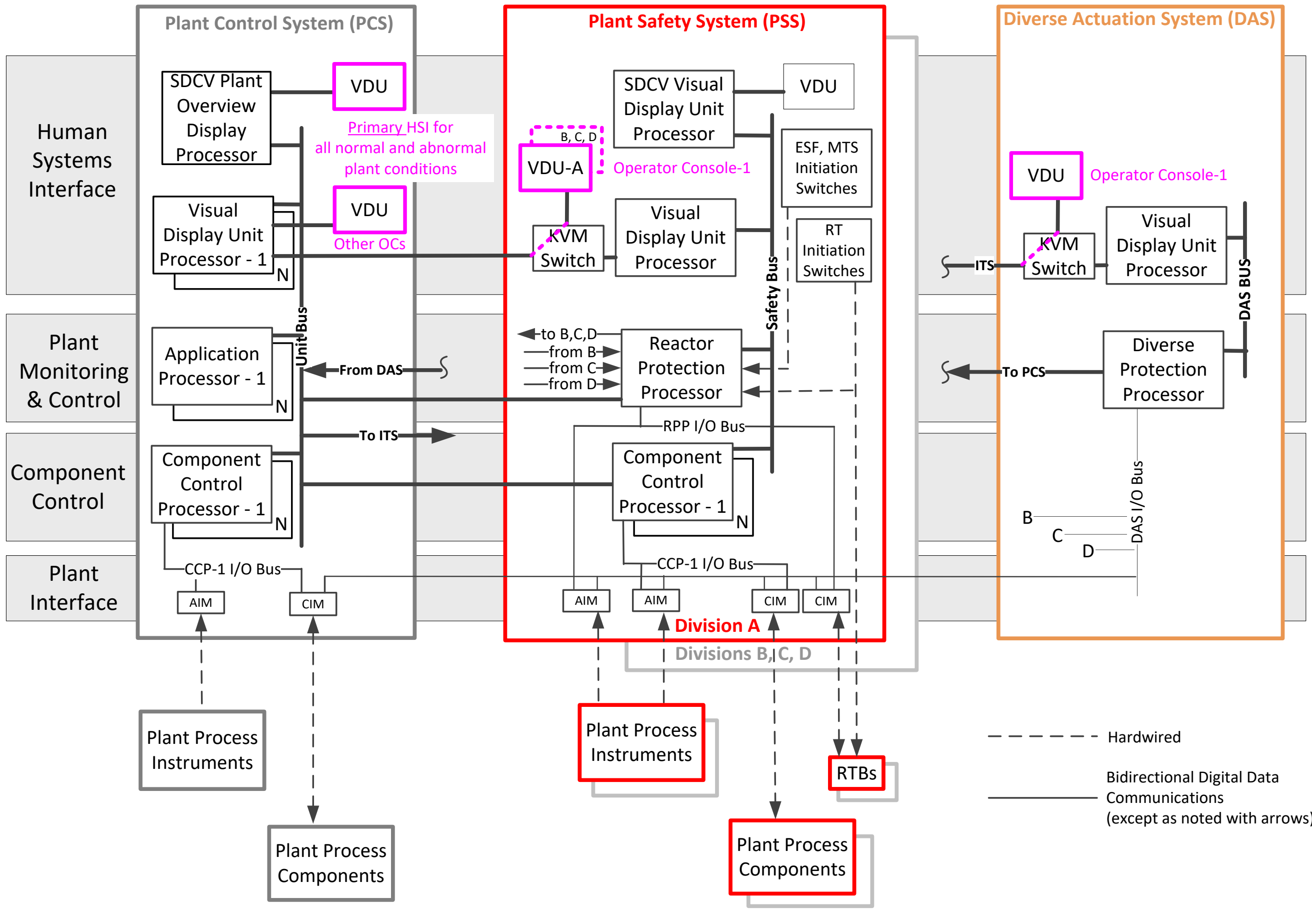

Figure 5. The CDM Reference Architecture for Nuclear Plant I&C Modernization

An objective of this Action Plan is to leverage this reference architecture to support a pilot a major safety related I&C system upgrade by applying its vendor independent design principles, attributes, and system requirements to result in a design of superior I&C functionality the enabling of operational benefits sufficient to justify the project. Building on this and previous work by the Pathway in pro forma business cases for I&C and control room modernization, the Pathway is working with Exelon Generation to formulate a design requirements document and business case for upgrading the reactor protection system for Limerick Nuclear Station. This collaboration addresses:

- Development of a vendor-independent design requirements document for a boiling water reactor plant reactor trip and plant protection system, suitable for obtaining vendor proposals for this I&C upgrade. This design requirements document will be based on the design principles, attributes, and system requirements of the CDM, as applicable, in order to achieve maximum I&C functionality as well as O&M cost reducing features to support a business case for the investment.
- Development of a detailed business case analysis to support a utility commitment to perform this safety related digital I&C upgrade both as a standalone project and as part of the implementation of an advanced concept of operations program at the target station. This activity will provide an economic analysis of the benefits of performing the upgrade and the costs (provided by the implementing utility) to support approval of the detailed design effort by the implementing utility. The business case will look at applicable savings categories and

quantify the expected cost offsets in the current operating model. The business case will also look at the system cost, installation cost, and ongoing support cost to determine the expected return on investment.

- Development of an implementation report on the safety system digital I&C upgrade that describes the process and lessons learned so that other utilities can leverage the experience for similar activities.

In a related area of research for safety related I&C modernization, the Pathway is identifying new methods for qualifying safety-related I&C for use in regulatory-approved applications, based on NRC regulatory guidance found in NRC BTP 7-19. The current work is a method for exhaustive (100%) testing of a simple digital component such as a digital transmitter. Based on initial testing results in August of FY 2019, this work will potentially result in a new methodology to determine a low likelihood of susceptibility to software common cause failure, which is now recognized by the NRC as a component of qualitative analysis of software reliability. Additional testing will be conducted during the first quarter of FY 2020 to further confirm the efficacy of this qualification method. Consultation on pursuit of this methodology throughout FY 2020 will be provided through the Industry and Regulatory Engagement function of the Pathway.

Table 1. Safety Related I&C Systems Modernization Action Steps

No.	Action Step	Collaborators	Completion
1.1	Develop Vendor-Independent Design Requirements for a BWR Safety System Upgrade.	Exelon, EPRI, MPR, ScottMadden	05-31-2020
1.2	Develop a Business Case Analysis for the Pilot Digital Safety Related Instrumentation & Control System Upgrade	Exelon, EPRI, MPR, ScottMadden	08-31-2020
1.3	Develop Implementation Report for Pilot Safety Related I&C Upgrade	Exelon, EPRI, MPR, ScottMadden	09-30-2020
1.4	Industry Consultation on Application of Bounded Exhaustive Testing as a Potential Methodology for Safety Related I&C Qualification	VCU, NIST, NEI	09-30-2020

6.1.2 Non-Safety Related I&C Systems

Non-safety related I&C systems are by far the largest portion of the plant I&C systems and are generally speaking the systems that are used on a daily basis for normal plant operations and various ancillary functions. By contrast, many of the safety related systems serve as protection or stand-by safety functions and are not frequently manipulated by the operators.

The industry has far more experience in upgrading non-safety related I&C systems to digital systems, with a number of conversions of the main plant production control functions (reactor power through turbine control) converted to microprocessor-based systems referred to as distributed control systems (DCS). The boundaries of these conversions are typically defined by the legacy integrated analog control systems of the original plant design. They usually do not include the thousands of single loop control and indication circuits that are used in the plant and compose the majority of devices on the main control room operating panels.

As introduced in Section 6.1.1 as a reference I&C architecture, the scope of the CDM is the entire plant I&C system and consolidates all of the I&C into two platforms – one for safety functions and the other for non-safety. Regarding the non-safety platform, the CDM informs the industry of a highly-integrated architecture for all non-safety I&C functions and enables the consolidation of all of the balance-of-plant and single loop control and indication functions to be part of this integrated architecture, significantly reducing support costs.

The development of the CDM occurred over several years and was completed in FY 2019. However, adoption of some of the key concepts of the CDM is just beginning. A significant step was taken when this reference specification was used by Dominion Energy FY 2019 as a basis for their procurement specification for a large scale I&C modernization effort. Other nuclear utilities have expressed interest in it for the same purpose. While there is no additional Pathway deliverable for the CDM in FY 2020, the Pathway will continue to provide consultation to the industry on the application of the CDM through its Industry and Regulatory Engagement function.

One of the daunting challenges of digital modernization of operating LWRs is the digital conversion or even elimination of the analog field circuits in the plant I&C systems, including the field logic devices (relays, timers, etc.) and associated cables. Developing the digital system software equivalents of these analog circuit is labor-intensive and susceptible to error. An automated or semi-automated means of converting analog circuit design information (as shown on electronic design drawings) to equivalent digital system function block logic would be a significant enabler of full digital modernization for nuclear plants.

Development of this type of capability has been proposed in a related DOE research program known as Consolidated Innovative Nuclear Research. In addition, there are certain techniques that can be applied in computer-aided design systems for electronic drawings that would make this process considerably more efficient. Again, there is no specific development in the LWRS Program during FY 2020, but consultation for the industry on approaches for digitization of these balance-of-plant I&C systems will be provided through the Industry and Regulatory Engagement function.

Table 2. Non-Safety Related I&C Systems Modernization Action Steps

No.	Action Step	Collaborators	Completion
1.5	Industry Consultation on Application of the CDM to I&C Modernization to Achieve Maximum O&M Cost Reduction Benefits.	Dominion Energy	09-30-2020
1.6	Industry Consultation on Methods for Conversion of Analog I&C logic to Software-based Logic on Digital I&C Platforms.	Dominion Energy	09-30-2020

6.2 Control Room Modernization

Control room modernization is an opportunity to both improve operator performance and to reduce operating cost. Nuclear utilities have been reluctant to undertake significant modifications to their control rooms due to a number of factors, including not wanting to change their current licensing basis, concerns on loss of operator familiarity, wanting to preserve their investment in operations and maintenance procedures, and the difficulty of achieving these modifications during refueling outages. However, control rooms are subject to the same obsolescence and reliability concerns as the I&C systems because these systems are represented as hundreds of devices on the main control boards. There is also opportunity to reduce control room staffing requirements in a fully modernized control room.

The Plant Modernization Pathway is conducting research in multiple areas of interest by nuclear utilities to address the needs for control room modernization. First, is the application of digital technologies for improved human factors in hybrid control rooms. Hybrid control rooms are simply control rooms with a mixture of analog and digital technology. Second, the CDM reference I&C architecture provides a migration path to a fully integrated control room, which is defined as all digital HMI with perhaps the exception of a few analog switches for diverse operation. This enables the maximum control room efficiency and operator performance gains. It is possible to employ an evolutionary strategy of using a hybrid control room as a path to a fully integrated control room. Third, the Pathway is developing new technologies that can be applied in either of these control room concepts to reduce both operator workload and error potential.

6.2.1 Hybrid Control Rooms

The scope of hybrid control room research is to develop and demonstrate concepts for integration of advanced technologies in the main control room, which includes control system information, information from the field, and decisions support including computerized operator support systems (COSS) and online monitoring information. This integrated concept will increase efficiency of routine operations, ultimately reducing costs and promote the long-term sustainability of the LWR fleet by assisting nuclear utilities in addressing reliability and obsolescence issues of legacy analog control rooms and demonstrating how strategically integrating advanced technologies will achieve those results.

This research will develop new display and information technologies for control room operator use to improve control room operator response as depicted in Figure 6. The transition from analog to digital systems through control room modernization efforts enables the development of new technologies and information that can be used to guide control room operator performance by integrating new data sources and providing decision support and operator aids. Digital technology also provides the opportunity to reduce costs cost by automating or streamlining manual processes.

This research will leverage previous work on alarm management and advanced task-based displays and data analytics for individual systems to develop an integrated plant overview display which includes task-based plant status, online monitoring and decision support information to support streamlined plant operation. This will enable the operator to perform routine tasks more efficiently and safely.

Figure 6. Concept Design for an Advanced Hybrid Control Room

This work will be conducted with input from partnering nuclear utilities and vendors to ensure that research results are based on realistic industry needs while also going beyond existing modernization approaches which focus on obsolescence management but do not fully leverage digital technologies to enhance operator performance and efficiency.

Current efforts are in collaboration with Arizona Public Service's Palo Verde Generating Station, which is conducting a major non-safety related I&C upgrade with the implementation of a DCS. The Pathway has worked with Palo Verde over the past several years to exploit the DCS features for improved operator interface technology in the main control room, as well as a local control room in the plant for radwaste operations. This research has provided opportunity for significant improvements in the use of large displays embedded in the control boards, along with improved operator controls in the form of task-based displays, which are changeable, customized control displays for specific operational tasks.

This research will leverage previous work on alarm management and advanced task-based displays and data analytics for individual systems to develop an integrated plant overview display which includes task-based plant status, online monitoring and decision support information to support streamlined plant operation. This will enable the operator to perform routine tasks more efficiently and safely.

Table 3. Control Room Modernization Action Steps

No.	Action Step	Collaborators	Completion
2.1	Develop advanced technology concepts for hybrid control rooms that integrate task-based displays, advanced alarms, computerized operator support systems augmented with data analytics and online-monitoring capabilities.	Arizona Public Service	03-31-2020
2.2	Demonstrate and evaluate integrated technology concepts in a full-scale study with operators to provide evidence-based insights into how to support reduced costs with the integrated operations concept.	Arizona Public Service	05-31-2020

6.2.2 Fully Integrated Control Room

In assessing proposed modernization solutions for cost reductions and performance improvements, the Pathway has developed a concept for a fully integrated control room as part of the CDM. This research complements the hybrid control room concept as the basis for collaborating with nuclear utilities in assessing the best options for a digital control room in their respective nuclear plants.

Dominion Energy has expressed interest in a concept design for a fully digital control room that improves operational performance, reduces human error, and potentially enables reductions in operations shift staffing. To pursue this, a prototype of the control room concept will be installed on the reconfigurable simulator in DOE Human Systems Simulation Laboratory (HSSL). The Pathway will collaborate with Dominion in human factors studies using the prototype with Dominion control room operators to optimize the control room concept. The Pathway will conduct a series of human factors engineering activities leading to a conceptual design of a digital control room. Dominion will provide operating crews for the HSSL human factors studies to validate the control room conceptual design.

Figure 7. Concept Design for a Fully Integrated Control Room

Once the conceptual design is complete, Dominion intends to have a subcontractor build the digital I&C systems for Dominion’s control rooms according to a requirements specification as described in Section 6.1.2. Working with the subcontractor, the Pathway will install a prototype of the new digital control room in HSSL for operator testing. The prototype will be a fully functioning physical mock-up of the advanced digital control room anticipated to be installed by Dominion in the Surry and North Anna control rooms.

This research will use a systems engineering theoretical framework, human systems integration, and macro ergonomic concepts to develop a methodology that will synthesize 1) human factors engineering (HFE) R&D, 2) instrumentation and control (I&C) systems engineering R&D, 3) R&D to develop the business case for digital upgrades, 4) organizational change and operations process improvement activities, and 5) regulatory considerations to enable the transformation of the U.S. commercial nuclear industry. The Pathway will then collaborate with Dominion to produce a control room requirements specification based on the findings of this research.

Table 4. Fully Integrated Control Room Action Steps

No.	Action Step	Collaborators	Completion
2.3	The Development of a Methodology to Assess Proposed Modernization Solutions to Reduce Costs and Improved Performance.	Dominion Energy	04-03-2020
2.4	An Evaluation of Nuclear Power Plant Utility Modernization Approaches and Solutions	Dominion Energy	09-18-2020

6.2.3 Control Room Technology for Improved Operator Performance

The Plant Modernization Pathway is developing advanced control room technologies based on human factors engineering to improve operator performance and to enable cost reductions in operating the plant. These new technologies are enabled by and are built on the digital I&C systems that are implemented to address the obsolescence issues with the legacy analog systems they replace. In this way, these new technologies represent additional return on investment through their added capabilities.

One such development will be a COSS for the boric acid concentrator and liquid radwaste systems at Arizona Public Service's Palo Verde Generating Station. A COSS is an operator advisory system that monitors system performance parameters, detects off-normal conditions at a very low threshold, diagnoses the condition, and then provides guidance to the operators in addressing the condition and returning the system to normal conditions. Applying to these systems will provide an opportunity to gain valuable experience and concept validation on non-safety related systems. If successful, this will raise the technology readiness level to a level for future consideration of use in the main control room (along with other considerations).

Figure 8. Computerized Operator Support System Depicted in a Control Board

In FY 2019, the Pathway researchers worked with staff from IFE Halden to develop a state-based alarm system using machine learning. Building on this, IFE Halden and the Pathway will conduct R&D to compare the state-based alarm system developed using machine learning to a state-based alarm system developed by human subject matter experts. This comparison is a straightforward approach to performing the necessary step of validating the effectiveness of using machine learning to develop a state-based alarm system. Differences in performance will be identified and provided as feedback to the developers of the machine learning approach to modify and improve the effectiveness of this technique.

Table 5. Control Room Technology Action Steps

No.	Action Step	Collaborators	Completion
2.5	Develop a COSS for Boric Acid Concentrator and Liquid Radwaste System.	Arizona Public Service	09-30-2020
2.6	The Comparison of a State-Based Alarm System Developed Using Machine Learning to a State-Based Alarm System Developed by Human Subject Matter Experts	IFE Halden	09-04-2020

6.3 Plant Monitoring and Work Process Automation

A key tenet of plant modernization and economic viability for the operating LWR fleet is reducing the high labor requirements for maintaining the nuclear plants as driven by the current plant technology. These high labor costs are no longer affordable in today's energy markets, and other industry sectors have long since employed digital technologies to displace labor-intensive field maintenance activities.

There are two major areas of development that have potential for substantial cost reductions while actually improving work results.

1. Plant monitoring is replacing worker-based testing and surveillances with online monitoring technologies that collect the needed data, send it to monitoring and diagnostic centers, detect off-normal conditions, and then conduct analysis to determine cause and urgency of addressing the problem. This enables an emerging concept known as condition-based maintenance (rather than time-based maintenance), avoiding the cost of conducting field tests on a sampling basis and the cost of component degradation due to the testing itself. Human involvement in condition-based maintenance is greatly reduced.
2. For activities where worker involvement and judgment are still needed, work processes can be semi-automated, and the workers equipped with mobile technologies to greatly reduce the time and effort to conduct these activities. Higher work quality is also obtainable due to the capabilities and human error prevention features that are embedded in these technologies.

The objective of the Plant Modernization Pathway in this area is to develop more advanced technologies to complement the commercial monitoring and work process technologies that are now available. This involves extending these technology types into areas currently not possible, combining them with advanced analytic and risk assessment tools, and in some cases defining entirely new types of technologies to address plant maintenance and support requirements in an even more effective way.

6.3.1 Technology-Enabled Risk-Informed Maintenance Strategy (TERMS)

The primary objective of this proposed research project is to integrate advancements in online asset monitoring and data analytic techniques with advanced risk assessment methodologies to reduce maintenance costs and enhance the reliability of commercial nuclear power plants. The outcomes of the research project will result in technologies being available to the nuclear industry that will dramatically reduce the cost associated with asset maintenance.

Integration of asset specific risk models with plant asset condition monitoring on a continuous basis will enable the ability to predict the asset health and risk simultaneously. This research will also develop a risk-informed approach to extend technical specification surveillance intervals for digital equipment equipped by developing an accepted approach to credit self-diagnostics and online monitoring calibration.

The research will include identification of high-value asset and digital equipment data sources (existing), identification and installation of additional sensors to gather new data points, development of diagnostic and prognostic models, development of risk methodologies to extend maintenance interval and technical specification surveillance intervals, and development of user-friendly dashboard for informed decision-making. To support the research, a cost benefit analysis will be performed to develop a value proposition to support implementation of predictive maintenance strategy at scale. In addition, a hybrid approach is proposed to support development of a digital twin of a plant system strategy at scale.

Table 6. Technology-Enabled Risk-Informed Maintenance Strategy Action Steps

No.	Action Step	Collaborators	Completion
3.1	Develop Technical Evidences to Scale the Risk-Informed Predictive Maintenance Strategy for a Plants System Across Nuclear Power Plants	Rolls Royce, PSEG	05-25-2020
3.2	Develop Technical Evidences Demonstrating Value Proposition for Predictive Maintenance Strategy	Rolls Royce, PSEG	07-27-2020
3.3	Develop an Initial Hybrid Model of a Plant System, Integrating Physics-Based Approach with Data-Driven Approach to Support Predictive Maintenance Strategy by Inferential Assessment.	Rolls Royce, PSEG	08-31-2020
3.4	Develop a Risk-Informed Approach to Support Extension of Technical Specifications Surveillance Interval of a Digital Equipment with Self-Diagnostic/Online Monitoring Capability	Rolls Royce, PSEG	09-14-2020

6.3.2 Advanced Remote Monitoring for Operations Readiness (ARMOR)

At a nuclear power plant, Operations is the organization that is the NRC license holder for the facility and is accountable for the overall safety of the plant. Operations staff are assigned multiple roles in this regard, including monitoring the plant from the control room and the field, configuring and controlling the plant in modes of operation, performing surveillances (monitoring and test runs) and non-surveillance rounds (leaks, fire watch, etc.), tagging out/in equipment, and issuing clearance orders. Operations is required to be involved in almost all activities of the plant and is often the cause of work delays due to the inability of Operations to meet the concurrent demand for their involvement. In other words, Operations is typically a bottleneck in the execution of the day-to-day work activities in a nuclear plant.

The research objective for this area is to automate Operations activities to achieve two objectives: 1) reduce labor-intensive surveillances at nuclear power plants to allow operations to focus more on optimal plant performance, and 2) detect and identify process anomalies through enhanced monitoring to reduce the probability of an unexpected plant outage,. The expected results of these objectives will be a reduction in the labor requirement for gathering data, a reduction in unexpected plant outages, and an improvement in plant thermal efficiency.

The scope of this research includes capabilities to:

1. Automate collection of data that are now being manually collected by Operations. Examples of such data are the surveillance test results of equipment and measurement of equipment performance to determine the ability of the equipment to perform its safety function when needed. This scope of automation is use of currently available process data and by adding new sensors when the process data is deemed insufficient.
2. Manage/use data for additional Operations insight. Currently, Operations is usually only aware of plant issues after they occur, such as degraded thermal performance in the form of missing megawatts. A more proactive than reactive approach to operations is to be developed. The aim of this effort is to research the proactive approach to enable machine leaning (supervised and non-supervised) early detection (in terms of hours, days, weeks, or even months) that an equipment requires attention. Operations can then direct maintenance, engineering, or projects to investigate

the issue and perform detailed diagnostics before component failure. An example of the type of early detection capability being pursued is one that could have prevented a dry well cooling fan failure which occurred at Nebraska Public Power District's Cooper Nuclear Station in 2018, resulting in a six-day outage.

This research is being performed in collaboration with Utilities Service Alliance in a multi-year R&D project, with the specific FY 2020 task being conducted with Nebraska Public Power District in the area of use of acoustic sensors for contactless condition monitoring.

Table 7. Advanced Remote Monitoring for Operations Readiness Action Steps

No.	Action Step	Collaborators	Completion
3.5	Research a Technology to Use Acoustic Sensors to Perform Contactless Condition Monitoring.	Nebraska Public Power District	09-30-2020

6.3.3 Work Process Automation

As nuclear power plants deploy different types of mobile work management solutions, several high cost processes remain part of the work process. Some of these processes can be automated by current technologies (such as drones, image recognition, data mining, wireless identification, artificial intelligence, and virtual environments), but gaps exist to be able to effectively and safely deploy them in nuclear power plants. This research is targeted towards closing these gaps through innovative solutions to enable the use of technologies to replace labor-intensive activities. The project will focus on automation technologies that have high impact for reducing work process costs in the operating nuclear plants.

The focus for the FY 2020 research is on drones, which is a technology that has high potential for cost savings due to its wide variety of applications. Such applications include:

- conduct periodic inspections and surveys
- conduct plant work activities by being outfitted with tooling, sensors, and other capabilities
- perform operator rounds and operator field actions
- transport resources (such as materials tools and equipment or documents) to and from a work site
- enable remote verification of work progress and completion
- detect and inspect for certain abnormalities and conditions, such as conducting a fire watch
- complement human activities to accelerate work tasks and compensate for lack of certain human skills and abilities
- perform actions in human-restricted areas that would otherwise be done in outage only. For example, drones can be flown autonomously to replace certain inspections, particularly in high radiation areas of the plant, activities that are at an elevation (require scaffolding) or hard to reach, and for cyclic activities (such as operator rounds).

Drones are mainly designed for outdoor applications; however, nuclear power plants are mostly an in-door environment. In-door deployment requires more precise control of the drone's position which can't be achieved by GPS-based solutions (used outdoors and result in few feet of position accuracy). Other, non-GPS, solutions exist but are expensive and therefore hinders the use of drones in an NPP. This research addresses this gap by creating an affordable method for drones to navigate in-doors with a targeted precision in the order of an inch or less. Other research objectives of this effort involve developing automated plant support activities and using image recognition to replace human visual checks and data collection (e.g. automated gauge logging).

Partnering with universities and other research institutes, another area of research for work process automation addresses the challenges associated with monitoring secondary system piping. This effort will develop and demonstrate an I&C infrastructure that integrates with business side IT infrastructure. This research seeks to drive down cost of O&M through advanced remote monitoring methods. An additional benefit of this project is analysis and recommendations for science-based methods for structural health monitoring of secondary systems in nuclear power plants that can be used to enhance materials management programs and thereby contribute to the sustainability to the existing commercial light water reactor fleet. This research effort will leverage ongoing research collaboration with University of Pittsburgh and EPRI on high resolution fiber optic sensors. This research is:

- finalizing a solution to improve detection of corrosion/erosion -induced defects in complex piping geometries such as elbows, tees, and bends.
- addressing the technology gap in the area of piping erosion and corrosion/erosion monitoring by adding new sensor modality capable of dealing with geometries inaccessible with ultrasonic guided waves UGW and significantly increase the coverage for online monitoring systems.

Finally, another area of work process automation research is addressing the challenge of effectively monitoring concrete structures, demonstrating an advance structural health monitoring framework using advanced data analytics and machine learning techniques. Nuclear utilities will be able to leverage this framework to replace/augment their current inspection-based aging management plan with online monitoring (reducing maintenance costs) and provide technical evidence on concrete structural integrity to support the subsequent license renewal process. The FY 2020 research will demonstrate the effect that reinforcement steel (rebar) in concrete structures has on vibroacoustic modulation (VAM) technique in assessing the extent of alkali-silica reaction (ASR) degradation.

Table 8. Work Process Automation Action Steps

No.	Action Step	Collaborators	Completion
3.6	Develop and Pilot the Drone Self-Navigation Technology to Support Operations and Maintenance Activities at a Nuclear Power Plant Site and Survey Specific and General Use Cases for the Technology.	Xcel Energy, University of Idaho	09-30-2020
3.7	Concept of Multi-Modal Piping Monitoring System Using Advanced Fusion and Data Analytics Algorithms for Detection and Quantification of Degradation in Secondary Circuit Piping.	EPRI, University of Pittsburgh, Vanderbilt University, Southwest Research Institute	09-30-2020
3.8	Develop Multi-Modal Online Diagnostic Reinforced Concrete Monitoring System, Implementation Strategy, and a Transition Plan	EPRI, India-US bilateral Civil Nuclear Energy Working Group, Vanderbilt University, Oak Ridge National Laboratory	09-30-2020

6.4 Nuclear Plant Operating Model Transformation

Over decades of operation, the U.S. nuclear power plants evolved an operating model that brought continuous improvement in technical results and nuclear safety. A great degree of consistency among stations was the result of freely sharing good practices and operating experience among these stations, as well as through their involvement with the major industry support groups of EPRI, INPO, NEI, and the owner's groups. This led the industry to new levels of nuclear safety, production reliability, financial success, and public confidence in nuclear energy. Capacity factors improved to the highest levels of any electric energy source.

However, to achieve this, the industry continually added cost to their business model in the form of additional work activities in this pursuit of ever-improving equipment and human performance, along with extensive plant modifications to address certain safety and reliability issues. Essentially all nuclear industry key performance indicators improved to historic high levels. Until the mid-2000's, the rising O&M costs were masked by the increasing capacity factors because the market value of the additional plant electric output was higher than the increased costs.

Then, two factors impacted the financial position of the operating nuclear plants. First, capacity factors leveled off in the mid-to-upper 90% range due to refueling outage production losses and forced generation losses approaching their minimum practical levels. Second, with the emergence of shale-based gas generation and the expansion of subsidized renewal generation, a significant portion of the operating fleet found themselves in a non-competitive position with respect to the electric market. This was exacerbated with the transition of some of these plants into unregulated merchant electricity markets rather than continuing in state regulated markets that provided a fair return on the investment basis of the plant. The clear message was that the U.S. operating fleet had to reduce cost to continue to operate.

The objective of the Plant Modernization Pathway research is to transform the operating model of a nuclear plant to one that is technically and economically sustainable for the long-term, overcoming these negative factors impacting the viability of the U.S nuclear fleet. This will be based on the application of advanced digital technologies that enable new business structures and relationships. To this end, the Pathway is working with Xcel Energy to define a new operating model in their nuclear fleet initiative to ensure that nuclear generation is a competitive component in their company's future carbon-free generation mix.

6.4.1 Advanced Concept of Operations

Working with Xcel Energy Nuclear Generation in their XE1 Program, this research is focused on developing a business-driven approach to transforming the operating model of a commercial nuclear plant from one that is labor-centric to one that is technology-centric, as has been achieved in many other industry sectors. A top-down/bottom-up process is being developed and used as the means to define this transformed operating model. A market-based price point (typically bus-bar cost in $/MWH) for electric generation is set by the utility based on their market realities, and is then used to back calculate the maximum total O&M budget for the nuclear fleet that will support this market price. This budget, in turn, is allocated over the nuclear fleet organization in a top-down fashion as the starting point of an iterative process to reconcile the acceptable cost of operation.

A bottom-up process, termed work function analysis (WFA), is then used to of apply technology and process innovations in a business-driven approach. This continues until the essential work functions can be accomplished within the constraints of the top-down budget allocations. From these streamlined and significantly automated work functions, a new organization reflecting the transformed operating model is formulated.

The scope of this research in FY 2020 will be to develop the analysis and planning framework for identifying and implementing the transformative concepts in nuclear operations. It will be published in a form that Xcel and other nuclear operating utilities can use to analyze their operating nuclear plants to improve operating performance and reduce operating costs for extended operational life. The research results will support transforming the nuclear plant operating model to one that enables long-term sustainable, economically competitive operations.

The scope of this research included the development of an advanced analysis and planning tool set, these tools would enable addressing work function analysis, technology application, and business case development. The tool set will be prepopulated with generic nuclear plant operating data as a starting point for the analysis, with the data customizable to that of a specific nuclear plant. The tool set will be published in a form that individual nuclear utilities can incorporate into their own efforts to improve the plant performance and reduce the operating costs of their nuclear plants.

In addition, outreach activities will be conducted through Industry and Regulatory Engagement function of the Pathway to assist other early-adopter nuclear utilities (and their suppliers) in using the deliverables of this research activity in their efforts to make their nuclear plant operating models sustainable in view of both technical obsolescence and electric market price constraints.

Table 9. Advanced Concept of Operations Action Steps

No.	Action Step	Collaborators	Completion
4.1	Develop an Analysis and Planning Framework for Nuclear Plant Transformation	Xcel Energy, Remer Engineering, IFE Halden, ScottMadden Management Consultants	08-31-2020
4.2	Develop an Analysis and Planning Tool Set for Nuclear Plant Transformation	Xcel Energy, Remer Engineering, IFE Halden, ScottMadden Management Consultants	09-30-2020
4.3	Engage Other Early-Adopter Nuclear Utilities and Suppliers in the Transfer of Learnings and Technology from the Collaboration Projects with Utility Partners in Plant Modernization and Advanced Concept of Operations.	Xcel Energy, Remer Engineering,	09-08-2020

6.4.2 Digital Architecture for an Automated Plant

The data of a nuclear power plant are stored in databases such as plant computer, work management system, scheduling, systems engineering, operator logs, and condition reporting. These databases have different structures and tools and are therefore used independently. The integration of dynamic and static data from these databases is performed manually and on as needed basis. The objective of research is to create a data warehouse to automate the data integration and create a streamlined process to combine the data from all plant data sources. A further objective of this research is to facilitate this concept of a data warehouse by identifying and addressing the challenges associated with integration of data sources including readiness of data for integration, coupling issues of data, and creating a data integration model and ontology. This results in direct and indirect cost saving because it reduces the amount of data search activities, thereby increasing plant work efficiency, and enables the use of machine decision making for streamlined and improved plant activities. This also reveals and enables better visualization of plant information across the nuclear plant organization, provides new technical and business insights from the data, reduces the need for training on various tools for plant staff, and enables a more holistic staff perception of plant activities.

In FY 2020, this research will be conducted in collaboration with Nebraska Public Power District – Cooper Nuclear Station, Xcel Energy, NITSL, and Arizona Public Service. Specifically, the effort will be to increase the fidelity of the developed data integration model and ontology for nuclear power plants and pursue making the model an open standard project. The fidelity of the model will be increased by:

1. Continuing research into individual data sources structuring
2. Leveraging other effort by the industry and other research efforts within and outside INL
3. Customizing the model to become an open standard for vendors to directly contribute to it and use it.

Table 10. Digital Architecture for an Automated Plant Action Steps

No.	Action Step	Collaborators	Completion
4.4	Develop a Data Integration Model and Ontology That Could Be Used in a Data Warehouse to Automate Data Integration and Create a Streamlined Process to Combine the Data from All Plant Data Sources Into a Data Warehouse	Nebraska Public Power District, Xcel Energy, Arizona Public Service, Curtiss Wright, and Knowledge Relay	09-30-2020

7. Summary of Nuclear Power Plant Modernization Action Plan Action Steps

Table 11 is a summary of the action steps from all areas of the Nuclear Power Plant Modernization Action Plan, providing new digital technologies and process methodologies for modernizing nuclear plants and transforming the operating model.

Table 11. Summary of the Nuclear Power Plant Modernization Action Plan Action Steps

No.	Action Step	Collaborators	Completion
I&C Modernization			
1.1	Develop Vendor independent Design Requirements for a BWR Safety System Upgrade.	Exelon, EPRI, MPR, ScottMadden	05-31-2020
1.2	Develop a Business Case Analysis for the Pilot Digital Safety Related Instrumentation & Control System Upgrade	Exelon, EPRI, MPR, ScottMadden	08-31-2020
1.3	Develop Implementation Report for Pilot Safety Related I&C Upgrade	Exelon, EPRI, MPR, ScottMadden	09-30-2020
1.4	Industry Consultation on Application of Bounded Exhaustive Testing as a Potential Methodology for Safety Related I&C Qualification	VCU, NIST, NEI	09-30-2020
1.5	Industry Consultation on Application of the CDM to I&C Modernization to Achieve Maximum O&M Cost Reduction Benefits.	Dominion Energy	09-30-2020
1.6	Industry Consultation on Methods for Conversion of Analog I&C logic to Software-based Logic on Digital I&C Platforms.	Dominion Energy	09-30-2020
Control Room Modernization			

No.	Action Step	Collaborators	Completion
2.1	Develop advanced technology concepts for hybrid control rooms that integrate task-based displays, advanced alarms, computerized operator support systems augmented with data analytics and online-monitoring capabilities.	Arizona Public Service	03-31-2020
2.2	Demonstrate and evaluate integrated technology concepts in a full-scale study with operators to provide evidence-based insights into how to support reduced costs with the integrated operations concept.	Arizona Public Service	05-31-2020
2.3	The Development of a Methodology to Assess Proposed Modernization Solutions to Reduce Costs and Improved Performance.	Dominion Energy	04-03-2020
2.4	An Evaluation of Nuclear Power Plant Utility Modernization Approaches and Solutions	Dominion Energy	09-18-2020
2.5	Develop a COSS for Boric Acid Concentrator and Liquid Radwaste System.	Arizona Public Service	09-30-2020
2.6	The Comparison of a State-Based Alarm System Developed Using Machine Learning to a State-Based Alarm System Developed by Human Subject Matter Experts	IFE Halden	09-04-2020
Plant Monitoring and Work Process Automation			
3.1	Develop Technical Evidences to Scale the Risk-Informed Predictive Maintenance Strategy for a Plants System Across Nuclear Power Plants	Rolls Royce, PSEG	05-25-2020
3.2	Develop Technical Evidences Demonstrating Value Proposition for Predictive Maintenance Strategy	Rolls Royce, PSEG	07-27-2020
3.3	Develop an Initial Hybrid Model of a Plant System, Integrating Physics-Based Approach with Data-Driven Approach to Support Predictive Maintenance Strategy by Inferential Assessment.	Rolls Royce, PSEG	08-31-2020
3.4	Develop a Risk-Informed Approach to Support Extension of Technical Specifications Surveillance Interval of a Digital Equipment with Self-Diagnostic/Online Monitoring Capability	Rolls Royce, PSEG	09-14-2020
3.5	Research a Technology to Use Acoustic Sensors to Perform Contactless Condition Monitoring.	Nebraska Public Power District	09-30-2020

No.	Action Step	Collaborators	Completion
3.6	Develop and Pilot the Drone Self-Navigation Technology to Support Operations and Maintenance Activities at a Nuclear Power Plant Site and Survey Specific and General Use Cases for the Technology.	Xcel Energy, University of Idaho	09-30-2020
3.7	Concept of Multi-Modal Piping Monitoring System Using Advanced Fusion and Data Analytics Algorithms for Detection and Quantification of Degradation in Secondary Circuit Piping.	EPRI, University of Pittsburgh, Vanderbilt University, Southwest Research Institute	09-30-2020
3.8	Develop Multi-Modal Online Diagnostic Reinforced Concrete Monitoring System, Implementation Strategy, and a Transition Plan	EPRI, India-US bilateral Civil Nuclear Energy Working Group, Vanderbilt University, Oak Ridge National Laboratory	09-30-2020
Nuclear Plant Operating Model Transformation			
4.1	Develop an Analysis and Planning Framework for Nuclear Plant Transformation	Xcel Energy, Remer Engineering, IFE Halden, ScottMadden Management Consultants	08-31-2020
4.2	Develop an Analysis and Planning Tool Set for Nuclear Plant Transformation	Xcel Energy, Remer Engineering, IFE Halden, ScottMadden Management Consultants	09-30-2020
4.3	Engage Other Early-Adopter Nuclear Utilities and Suppliers in the Transfer of Learnings and Technology from the Collaboration Projects with Utility Partners in Plant Modernization and Advanced Concept of Operations.	Xcel Energy, Remer Engineering,	09-08-2020
4.4	Develop a Data Integration Model and Ontology That Could Be Used in a Data Warehouse to Automate Data Integration and Create a Streamlined Process to Combine the Data from All Plant Data Sources Into a Data Warehouse	EPRI. Nebraska Public Power District, Xcel Energy, Arizona Public Service, and NITSL	09-30-2020

8. Summary

The Plant Modernization Pathway is conducting a robust research program to enable performance improvement and economic sustainability for the U.S. nuclear operating fleet, as represented in this Nuclear Power Plant Modernization Strategy and Action Plan. This Strategy and Action Plan is built on years of technology development by the Pathway in each of the technical areas that is addresses. It is the product of a highly capable research staff that understand the challenges the operating nuclear plants are facing and that has the needed experience, knowledge, and research skills to devise innovative solutions for these challenges.

The Pathway has a large number of collaborators who share these objectives, including nuclear utilities, industry support groups, suppliers, other research organizations, universities, and consultants/contractors. The collective knowledge and expertise of these collaborators is a significant factor in the success of the research. The participation of some of the nation's leading utilities underscores the confidence the industry places in this DOE research program. Moreover, the Pathway works with leading nuclear industry suppliers to promote commercialization of these research developments so that, where appropriate, they result in validated products for use by these nuclear utilities.

In addition, the Pathway regularly engages with the NRC to promote communications on emerging technologies and to understand any regulatory implications for the developments, thereby ensuring that these technology and process improvements can readily be implemented by utilities.

The Action Plan consists of 24 major developments during FY 2020, which represent beneficial developments in four major areas of nuclear plant modernization: 1) I&C Modernization, 2) Control Room Modernization, 3) Plant Monitoring and Work Process Automation, and 4) Nuclear Plant Operating Model Transformation. These areas together comprehensively address the opportunities for performance improvement and cost reduction needed to ensure the long-term sustainability of the U.S. nuclear operating fleet.

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