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Light Water Reactor Sustainability Program

Safety-Related Instrumentation & Control Pilot Upgrade

Initial Scoping Phase Implementation Report and Lessons Learned

September 2020

U.S. Department of Energy

Office of Nuclear Energy

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Light Water Reactor Sustainability Program

Paul J. Hunton, Sr, Research Scientist, Principal Investigator
Robert T. England, Research Engineer

Exelon Generation
Gerald Segner
Mark Samselski
George Bonanni

MPR Associates, Inc.
Paul Heaney
David Herrell
William Jessup

ScottMadden Inc.
Mike Kerrigan
Sean Lawrie

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Executive Summary

The commercial nuclear sector faces unprecedented financial challenges driven by low natural gas prices and subsidized renewables in a market that does not reward carbon-free baseload capacity. These circumstances, along with increasingly antiquated labor-centric operating models and analog technology, have forced the early closure of multiple nuclear facilities and placed a much larger population of nuclear stations at-risk. To enable nuclear plant economic survival in current and forecasted market conditions, an efficient and technology-centric operating model that harvests the native efficiencies of advanced technology is required. This is analogous to transformations that have occurred in other industries.

Historically, regulatory barriers have largely precluded the modernization of nuclear plant first-echelon safety-related (SR) Instrumentation and Control (I&C) systems to support this transformation. These barriers have now been largely addressed through collaboration between industry leaders and the Nuclear Regulatory Commission (NRC). These advances enable the modernization of key safety systems through the streamlined License Amendment Request (LAR) Alternate Review (AR) process reflected in Digital Instrumentation and Controls Interim Staff Guidance #06 (DI&C-ISG-06), Revision 2, *Licensing Process* [Reference 1]. While regulatory advances have improved the environment for modernizing safety systems, the industry has remained reluctant to perform such I&C upgrades because of perceived regulatory and financial risks associated with being the first adopter of the DI&C-ISG-06, Revision 2, AR process for highly critical reactor protection systems.

This Light Water Reactor Sustainability (LWRS) Program research seeks to assist in breaking this impasse through the support of a SR I&C Pilot Upgrade Project. Exelon's Limerick Generating Station (LGS), a Boiling Water Reactor (BWR), has been selected as the target for this Project. This research report (1) describes the process followed and products developed during the SR I&C Pilot Project Initial Scoping Phase and (2) captures lessons learned.

Exelon Generation and LWRS collaborated to develop a Digital Transformation Strategy as part of a larger Advanced Concept of Operations. The proposed SR I&C Pilot Upgrade provides a foundation stone for this Digital Transformation that will improve plant safety, reliability, and operational performance while lowering plant Total Cost of Ownership (TCO). Initial Scoping Phase activities for this Pilot Project have been performed in accordance with industry processes that have been adapted to better support digital upgrades. These processes include IP-ENG-001, *Standard Design Process* (SDP) [Reference 2], NISP-EN-04, *Standard Digital Engineering Process* (SDEP) [Reference 3], and Electric Power Research Institute (EPRI) Report 3002011816, *Digital Engineering Guide* (DEG) [Reference 4]. Completing the Initial Scoping Phase Engineering and Operations, Licensing, and Project Management Activities was necessary to bound the scope, schedule, and estimated cost of the Project sufficiently to enable utility management to authorize moving into the Conceptual Design Phase. A significant finding of the Business Case Analysis (BCA) methodology developed and applied as part of this effort was that the growth rate of material costs for sustaining the operation of obsolete SR I&C equipment is accelerating. This directly contributed to the Project Economic Analysis that justifies the Project.

Project Initial Scoping Phase lessons learned have also been captured to assist the larger industry in understanding the Digital Transformation Strategy and SR I&C Pilot Project Initial Scoping Phase efforts. This is in keeping with the public/private partnership that has been established between the Department of Energy (DOE) and Exelon for this effort with engagement from the NRC. By addressing first-of-a-kind (FOAK) risks and capturing lessons learned, the SR I&C Pilot Upgrade Project addresses technical, regulatory, and business risks to enable subsequent implementers of similar upgrades.

The LWRS Program appreciates the research support provided by Exelon Generation, MPR Associates, Inc., and ScottMadden, Inc. This research report makes no commitments for Exelon Generation.

CONTENTS

FIGURES

ACRONYMS

10 CFR 50	Title 10 of the Code of Federal Regulations, Part 50, Energy
AR	Alternate Review
ATWS	Anticipated Transient Without Scram
BCA	Business Case Analysis
BWR	Boiling Water Reactor
CAGR	Compound Annual Growth Rate
CS	Core Spray
CFR	Code of Federal Regulations
D3	Diversity and Defense-in-Depth
DI&C-ISG-04	Digital Instrumentation and Controls Interim Staff Guidance #04
DI&C-ISG-06	Digital Instrumentation and Controls Interim Staff Guidance #06
DAS	Diverse Actuation System (function in a DCS)
DCS	Distributed Control System
DEG	Digital Engineering Guide (EPRI Report 3002011816)
DOE	Department of Energy
ECCS	Emergency Core Cooling Systems[1]
EPRI	Electric Power Research Institute
FOAK	First-of-a-kind
HFE	Human Factors Engineering
HPCI	High Pressure Coolant Injection
HSI	Human System Interface
I&C	Instrumentation and Control
INL	Idaho National Laboratory
LAR	License Amendment Request
LGS	Limerick Generating Station Units 1 and 2
LWR	Light Water Reactor
LWRS	Light Water Reactor Sustainability (Program)
MCR	Main Control Room
MPR	MPR Associates, Inc.
N4S	Nuclear Steam Supply Shutoff System
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission (United States)
NSR	Non-Safety Related
O&M	Operating and Maintenance

[1] Comprised of separate functions for Core Spray, High Pressure Coolant Injection, the Low Pressure Coolant Injection mode of Residual Heat Removal, and Automatic Depressurization System. The Reactor Core Isolation Cooling System (RCIC) also provides emergency core cooling capability. RCIC is identified as a separate system in plant design documentation. It is grouped with ECCS in this research document for convenience and incorporated into the Plant Protection System.

PMI	Planned Maintenance Item
PPS	Plant Protection System
RCIC	Reactor Core Isolation Cooling
RHR	Residual Heat Removal
RRCS	Redundant Reactivity Control System
RPS	Reactor Protection System
SDP	Standard Design Process (IP-ENG-001)
SDEP	Standard Digital Engineering Process (NISP-EN-04)
SE	Safety Evaluation (Report)
SMA	ScottMadden, Inc.
SME	Subject Matter Expert
SR	Safety-Related
SyRS	System Requirements Specification
TCO	Total Cost of Ownership
TS	Technical Specification(s)

SAFETY-RELATED INSTRUMENTATION & CONTROL PILOT UPGRADE INITIAL SCOPING PHASE IMPLEMENTATION REPORT

1. Industry Need and Upgrade Strategy

1.1 Problem Statement

Currently installed Light Water Reactor (LWR) first-echelon Instrumentation and Control (I&C) safety systems have performed their functions admirably. However, most of these systems are of the original plant vintage and are therefore increasingly less supportable and more maintenance intensive. Parts are increasingly difficult and costly to obtain, and the expertise to maintain these older pneumatic, analog, and in some cases first-generation digital systems is waning.

Costs associated with sustaining efforts for older systems are rising rapidly. Unless this situation is addressed, it will be increasingly difficult to technologically sustain or economically justify the continued operation of existing LWRs for their current license durations and for subsequent extended license renewal periods. Making additional investments on these obsolete systems to keep them functioning or implementing like-for-like digital replacements that perform the same function as the original systems provides no opportunity for employing advanced digital technology capabilities to lower plant costs or improve plant performance.

Considering previous industry experience in modernizing safety I&C systems, nuclear utilities are reluctant to pursue these upgrades due to uncertainty in both licensing and cost. The Oconee Nuclear Station safety-related (SR) I&C system upgrade heavily influences the industry's reluctance. Although ultimately completed, the Oconee upgrade experienced significant schedule and cost overruns and resulted in widespread industry skepticism concerning the regulatory approval process and the predictability of schedule and costs for such upgrades. Two decades later, the chilling effect of this example and the conditions that contributed to it still impede nuclear plant modernization.

To meet the industry need and to overcome industry reluctance in performing first-echelon I&C SR systems, the Light Water Reactor Sustainability (LWRS) Program, in close coordination with Exelon Generation, embarked on a SR I&C Pilot Upgrade Project to demonstrate the viability of executing such an effort. At same time, the Pilot upgrade effort endeavors to create a process and product roadmap for other utilities to follow.

1.2 Safety-Related Pilot Upgrade Strategy and Basic Scope

1.2.1 Plantwide Concept of Operations

Up to now, there has been no roadmap for performing a large-scale Digital Transformation of currently operating nuclear plants to extend their technical longevity, while at the same time reducing their operating and maintenance (O&M) costs. The LWRS Plant Modernization Pathway, with input from Exelon Generation, has developed a design concept for first-echelon Boiling Water Reactor (BWR) safety system I&C upgrades as a key enabler for a larger Concept of Operations that moves an existing plant from a labor-centric analog domain to a technology-centric digital domain. This is illustrated in Figure 1 on the following page.

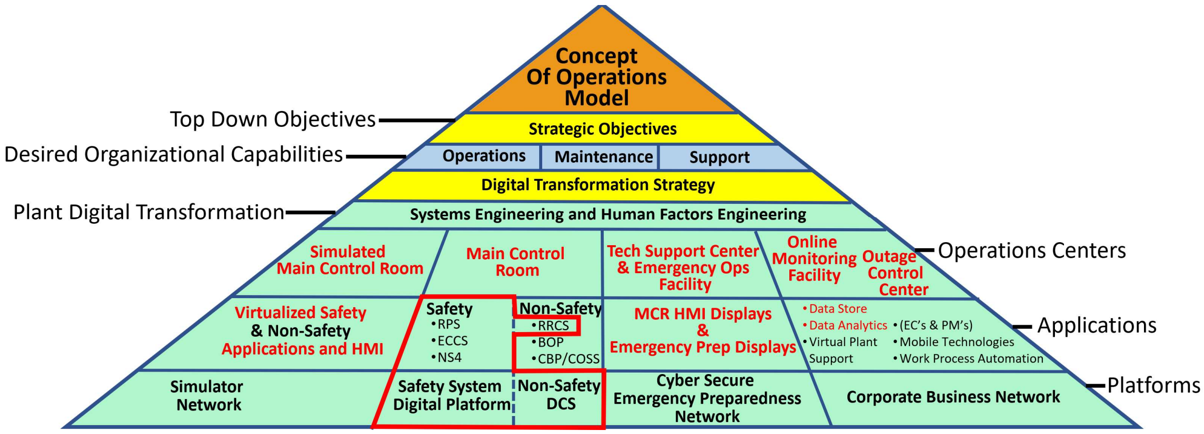

Figure 1 – Advanced Concept of Operations Model.

(Safety-Related I&C Pilot Scope outlined in red)

The Advanced Concept of Operations Model shown in Figure 1 establishes requirements and constraints for all plant and work function modernization efforts ensuring strategic business objectives are achieved. Nuclear power plant budgets are created using a market-based electricity price point to derive total operating, maintenance, and support costs to support this price (top-down). Work is also analyzed for opportunities to aggressively focus workload on essential functions that can be resourced within available budgets (bottom-up). Work functions are then configured into the operating model. Process innovations and technologies are then applied as an integrated set by using Systems Engineering and Human Factors Engineering (HFE). This promotes a business-driven Digital Transformation Strategy that reformulates the traditional labor-centric model to one that is technology-centric. This transformation lends itself to fewer on-site staff that are focused on daily operations, increasing plant safety, reliability, and situational awareness. The transformation strategy, along with process changes, supports employing centralized maintenance and support functions or outsourcing these functions to on-demand service models.

A tenet directing the larger Digital Transformation Strategy in general and the SR I&C Pilot Upgrade Project in particular is that the replacement of current equipment is not to simply to provide like-for-like functionality when compared to the existing equipment. Instead, digital upgrades are undertaken to fully leverage the capabilities of the technology as part of a holistic effort to establish a “New State” that reduces the Total Cost of Ownership (TCO) for facilities that deploy them for the balance of the plant operating period.

1.2.2 Basic Safety-Related Instrumentation and Control Pilot Project Scope

The basic scope of the BWR SR I&C Pilot Upgrade Project within the larger Digital Transformation Strategy is outlined in red in Figure 1 and includes:

- A common, SR, Plant Protection System (PPS) platform that will implement the functions of the following BWR systems as applications:
    - Reactor Protection System (RPS)
    - Nuclear Steam Supply Shutoff System (N4S) – also referred to as the Primary Containment Isolation System in other BWRs
    - Emergency Core Cooling Systems (ECCS)
- A Non-Safety Related (NSR) platform to host the existing SR Redundant Reactivity Control System (RRCS) function. In accordance with 10 CFR 50.62, *Requirements for reduction of risk from anticipated transients without scram (ATWS) events for light-water-cooled nuclear power plants* [Reference 5], the RRCS must remain fully independent of the PPS (transmitters may be shared) but does not have to be constructed of SR components. Consequently, the RRCS will be

upgraded using a NSR distributed control system (DCS). This DCS is expected to host most of the NSR functions in the unit. This includes a segment of DCS to receive data from the PPS and perform the channel check function, alerting the operator to significant disagreement in PPS and RRCS inputs.

This basic scope was established at the inception of the Pilot. At that time, a tenet was established that both the PPS and the NSR DCS are to be expandable. The PPS and NSR DCS are intended to become the "target platforms" onto which the functions of other obsolete I&C systems are migrated. Over time, the number of diverse I&C systems will be substantially reduced. By digitizing I&C plant information and passing it unidirectionally to other data networks, remote monitoring and data analytics capabilities are enabled to further reduce facility TCO. Coordinating I&C technology upgrades with training simulator upgrades also reduces facility TCO. These opportunities are reflected in the red text items in Figure 1.

1.2.3 Design Tenets as Applied to the Project Scope

Design Tenets of the SR I&C Pilot Upgrade Project upgrade strategy to support the Advanced Concept of Operations and the long-term economic viability of the industry include:

- Minimizing I&C upgrade development and implementation costs as well as technical and licensing risk by applying "state-of-the-industry" process control technology to the maximum extent practicable. The need to address economic viability is acute. Near-term economic needs necessitate that available systems be used to address current I&C obsolescence. Developing new system platforms is time consuming, costly, and not necessary to improve economic viability. Use of proven technology platforms also reduces project risk, in that the platform is proven in use and demonstrated to be reliable.

  Digital platforms exist that have been generically approved for first-echelon safety system use by the NRC. Such a platform will be utilized for this Pilot. This is required to use the streamlined AR process defined in DI&C-ISG-06, Revision 2, "Licensing Process."

  Many vendors have well developed NSR DCS platforms that include advanced features and capabilities. Many US nuclear plants have successfully deployed such platforms for NSR functions (e.g. main turbine controls and feedwater level controls) and demonstrated their capabilities.

- Leveraging the enhanced reliability of digital technology. Using a proven platform significantly reduces the potential for design errors in the platform software. Properly designed and tested application code has a limited potential to fail. This, coupled with increased component reliability and component count reduction when transitioning from analog to digital, will significantly improve system and plant reliability and availability.

- Leveraging the capability of new I&C systems to digitally capture and correlate plant data for those systems serviced by the new digital I&C platforms. Augmenting the existing functionality provides data and control capability previously unavailable to operators in the Main Control Room (MCR). This can aid in eliminating remote stations. Trending, diagnostic, and prognostic features enabled by the availability of this data can be used to improve plant performance and reduce time-based maintenance activites.

- Minimizing plant acquisition and lifecycle costs for modernization by elimination of diverse, legacy I&C systems. This is accomplished by:

  - Consolidating the functions of the identified safety I&C systems on the PPS. The PPS platform is expected to be expandable to be capable of hosting most of the SR functions in the unit, within the hardware capabilities of the utility selected vendor product. The Project required that the selected platform have a Safety Evaluation Report (SE Report) from the NRC.

By using application code to perform logic functions and through the elimination of redundant equipment in the disparate systems to be combined into the PPS, component count can be reduced dramatically. For this Pilot, the total component count for the envisioned design concept created during the Initial Scoping Phase is ~75% less than the number needed for the legacy systems. This will also reduce surveillance and calibration costs for maintaining the equipment as well as acquisition, installation, and lifecycle support costs (including supply chain costs) for obtaining replacement parts and keeping them in inventory.

- o Consolidating RRCS ATWS and any necessary PPS DAS functionality on a diverse NSR DCS. The Project presupposed that a D3 analysis of the implementation of the NRC prequalified platform for PPS based on NUREG/CR 6303, *Method for Performing Diversity and Defense-in-Depth Analyses of Reactor Protection Systems* [Reference 6] and *Branch Technical Position Guidance for Evaluation of Diversity and Defense-in-Depth in Digital Computer-Based Instrumentation and Control Systems*, BTP-7-19 Revision 7 [Reference 7] will determine that DAS functionality is required to address the potential for a common cause failure of the SR platform. Even if additional DAS functions are not required for the PPS functionality, the ATWS functionality is required by 10 CFR 50.62. By consolidating ATWS and DAS functionality on the single envisioned NSR DCS, there is no need for a separate system to host DAS functionality. Consolidating NSR I&C functionality, including DAS functionality on a DCS has same effect of reducing equipment count and equipment diversity.
- o Providing a standard, shared, SR Human System Interface (HSI) architecture that provides for a flexible solution for the MCR that supports both the interim states and the envisioned hybrid New State for the MCR. A minimal number of manual switches and hardwired indications for the PPS remain in the MCR. The remaining manual hardwired PPS switches and indications are retained as diverse backups for the PPS itself. The remaining hardwired switches act directly to execute such functions as a reactor scram by deenergizing the primary scram solenoid pilot valves and energizing the backup scram valves. All other operator interactions use soft controls on the video displays. Through the implementation of HFE, the potential for human performance errors can also be reduced. The HSI architecture design concept developed during the Initial Scoping Phase leverages a commercially available design example that is expected to meet the cyber security requirements of 10 CFR 73.54, *Protection of digital computer and communication systems and networks* [Reference 8] and the communications precepts of *Digital Instrumentation and Controls Interim Staff Guidance #04 (DI&C-ISG-04), Revision 1, Highly Integrated Control Rooms – Communications Issues (HICRc)* [Reference 9].

- Standardizing designs. By using standard platform building blocks, the number of disparate parts in the new platforms are reduced. Further migration of other legacy functions to the SR platform and NSR DCS not addressed by this upgrade will be able to use these standard building blocks and associated development tools, standardizing design processes while supporting further supply chain consolidation benefits. An example of a standard design benefit is the consolidation of cyber security activities. All system functions of obsolete digital systems migrated to the NSR DCS will be enveloped by the one cyber security defensive strategy built into that platform as opposed to maintaining the disparate cyber security efforts currently applied to each individual legacy system.
- Reducing direct O&M costs associated with sustaining the replacement I&C systems for up to an 80-year plant life. Several digital platforms approved for SR use by the NRC include advanced fault detection and self-diagnostics features to minimize O&M costs when compared to current analog systems. The NRC has approved the use of such features to eliminate Technical Specification (TS) surveillance requirements [Reference 10] for SR digital equipment in new plant designs (i.e. Westinghouse AP1000®). These features, coupled with proper system design,

identify failures down to the affected field replaceable unit, which can then be replaced while the plant remains online, again improving system and plant reliability and availability. All modern digital NSR platforms have such capabilities. By design, both digital platforms eliminate analog equipment calibrations for the equipment they replace.

- Managing technology obsolescence. Digital equipment also is susceptible to technology obsolescence. Equipment vendors are well aware of this limitation and have taken steps to address it. Most SR vendors and all major NSR DCS vendors have well developed obsolescence management strategies that support backwards compatibility of aging equipment to new equipment. The NSR DCS vendors design their new equipment, software, and design tools in such a way as to support migrating of the intellectual property (software applications) from obsolete to new equipment. This is further described in INL/EXT-19-55799, *Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries* [Reference 11]. This significantly reduces the installation and testing costs of performing a "technology refresh" of the platform when compared to the legacy practice of performing complete system replacements, including re-design, re-implementation, re-coding, re-verifying, and re-validating the application software. SR platform vendors have similarly identified techniques to manage digital obsolescence to reduce lifecycle costs.
- Enabling a "design once, build many" approach. The SR I&C Pilot Upgrade Project is being pursued as a public/private partnership between the participating utility and the DOE to address first-of-a-kind (FOAK) engineering, licensing, and costs risks associated with performing a first-echelon SR I&C upgrade. The Pilot Project will demonstrate the use of the DI&C-ISG-06, Revision 2, AR process by selecting a vendor platform that has received a SE Report from the NRC. The Engineering, Licensing, and Project Management deliverables produced by the Pilot will be made available to the larger nuclear industry to the maximum extent possible so that they can be leveraged to economically perform similar upgrade projects across the industry as a foundation for a larger Digital Transformation.

1.2.4 Pilot Project Execution Approach

The SR I&C Pilot Upgrade Project will also demonstrate the use of the latest industry guidance in the implement I&C upgrades. First-echelon SR I&C upgrade efforts led by Exelon are employing the SDP, SDEP, and the EPRI DEG. By using these industry standard processes, the concepts and methods used become fully transportable to all nuclear plant owner-operators.

Figure 2 on the following page, taken from Section 4 of EPRI DEG, visually represents the overall upgrade process. Phases for the Project directly follow this template and include:

- **Phase 0:** Initial Scoping
- **Phase 1:** Conceptual Design
- **Phase 2:** Detailed Design
- **Phase 3:** Implementation (which includes Installation Planning, Install/Test, and Closeout)

Project activities depicted in Figure 2 are performed as described in the EPRI DEG. This research report describes the activities taken and lessons learned associated with performing Phase 0 – Initial Scoping. Subsequent research reports will describe the activities and lessons learned for the remaining phases.

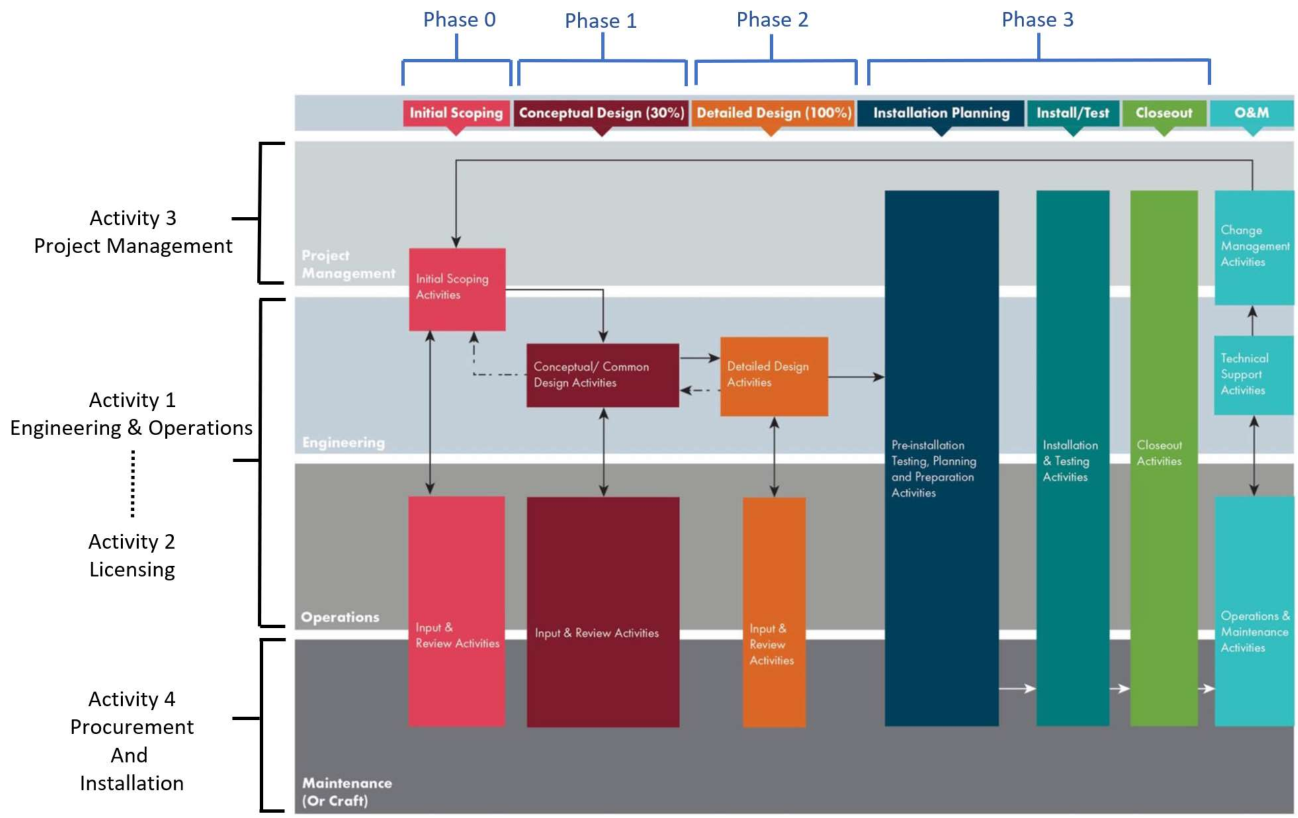

Figure 2 – Plant Protection System and RRCS Design Change Swimlane Diagram.

Project activities are grouped differently (as shown on the left of Figure 2) in this document for several reasons described below. Project Phase activities are broken into four main categories. These include:

- **Activity 1 – Engineering & Operations**: These two areas are very closely intertwined in this effort. Engineering services provided by vendors and subcontractors are also included in activity 1.
- **Activity 2 – Licensing**: While included with Engineering in the EPRI DEG, Licensing is broken out separately here as activity 2 to more clearly define Licensing deliverables and how these deliverables support using the DI&C-ISG-06, Revision 2, AR process.
- **Activity 3 – Project Management**: This activity guides all the others and is broken out separately as provided in the DEG. This also clearly defines key project management authorization milestones.
- **Activity 4 – Procurement and Installation**: This includes specific efforts associated with hardware and software procurement and installation. For the Initial Scoping Phase, this activity is combined with the Project Management activity.

This report describes efforts to complete the activities above for the Initial Scoping (Phase 0) and associated lessons learned.

1.2.5 Pilot Project Licensing Approach

A prerequisite to implementing a first-echelon, SR I&C upgrade is to submit a LAR to the NRC for approval. The process for LAR submission and approval provided in DI&C-ISG-06, Revision 2 for the AR process is depicted in Figure 3 on the following page.

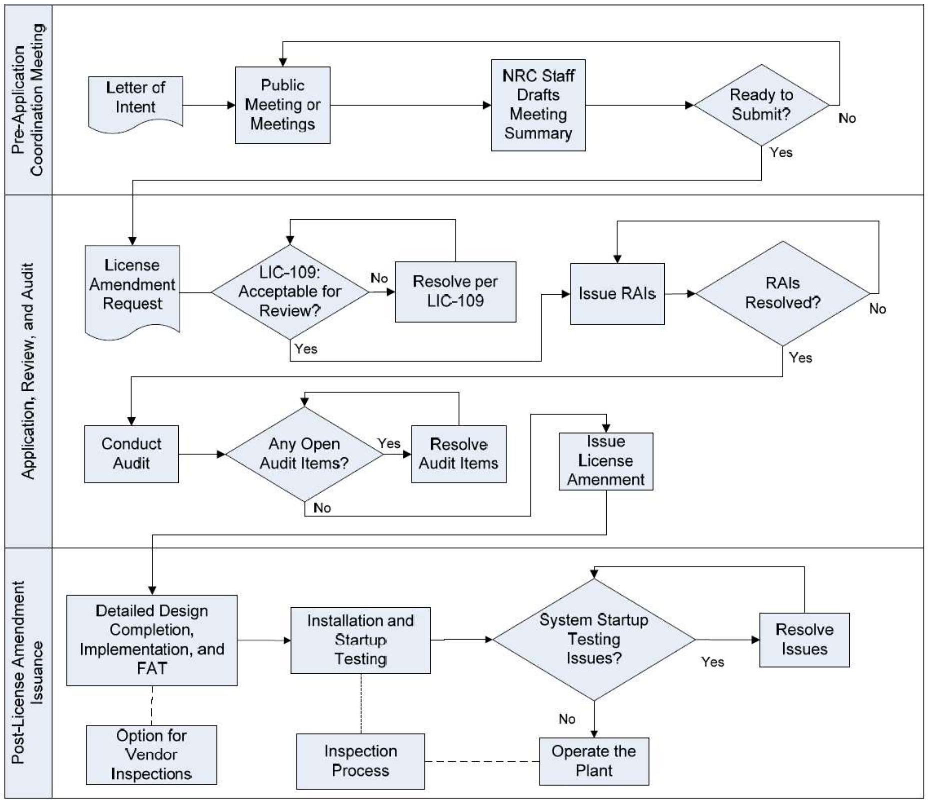

Figure 3 – Alternate Review Process From DI&C-ISG-06, Revision 2.

The LAR must describe how use of the selected platform for the proposed design will meet design and licensing basis requirements. For this Pilot Project, a LAR for the SR PPS upgrade will be required. No LAR is expected for the RRCS Upgrade; however, the final design of the RRCS may impact existing TS wording, and these impacts may need to be included in the LAR. The RRCS upgrade will be performed pursuant with 10 CFR 50.69, *Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors* [Reference 12] and 10 CFR 50.62, *Requirements for reduction of risk from anticipated transients without scram (ATWS) events for light-water-cooled nuclear power plants* [Reference 5]. For the Phase 0 – Initial Scoping, sufficient design concept and licensing strategy development is necessary to establish implementing utility confidence to authorize proceeding to Phase 1 – Conceptual Design and to subsequently submit a Letter of Intent to proceed as the formal entry to the AR process shown in Figure 3 above.

The I&C Pilot Initial Scoping Phase Licensing research included developing a design concept in a structure that addresses the digital aspects identified in DI&C-ISG-06 for input into the AR process. This product is further described in Sections 2.2.3 and 2.4.1 below. Initial Scoping Phase Licensing activities, in addition to supporting authorization to proceed with Phase 1 – Conceptual Design, are intended to provide Exelon with sufficient information to submit a Letter of Intent to proceed with the upgrade as depicted in Figure 3 above, once Conceptual Design Phase activities are authorized.

2. Pilot Initial Scoping Phase: Activities and Deliverables

With the basic Project scope and the governing Design Tenets established, authorization was obtained to begin the Project Initial Scoping Phase. A Project Manager was assigned by Exelon. Engineering and Operations activities commenced, including related LWRS research efforts. Engineering and Operations Initial Scoping Phase activities and resulting deliverables were worked in parallel with Licensing and Project Management activities, as described in the subsections below.

Resulting Engineering products and Project Management products were produced that meet the intent of Section 4.1 of the EPRI DEG. Licensing products not included in the EPRI DEG Process were also produced. These regulatory-oriented products support implementing utilities by providing an avenue to develop technical information associated with the envisioned upgrades in a way that maps to the DI&C-ISG-06, Revision 2, AR process.

2.1 Engineering and Operations Activities

2.1.1 Assembling the Research / Design Teams

In order to conform the SR I&C Pilot Upgrade to the New State identified in the Plantwide Concept of Operations (Section 1.2.1) and to apply the Design Tenets established at the inception of this Project (Section 1.2.3), an experienced and diverse Research Team/Design Team was assembled. While the Research Team and the Design Team consisted of the same personnel, a subtle but important distinction between their roles needs to be made.

- The Research Team, led and funded primarily by the Department of Energy through the Light Water Reactor Sustainability (LWRS) Program at the Idaho National Laboratory (INL), created FOAK research products tailored toward a New State vision for I&C Digital Transformation to be leveraged by industry. These LWRS SR I&C Pilot Upgrade Project research products, while supported in their creation by Exelon and tailored to the Limerick Generating Station (LGS) baseline units, make no design commitments for Exelon.
- The Design Team, led and funded by Exelon with LWRS support as described above, is leveraging the research products produced by the Research Team, for specific LGS upgrade efforts as part of the SR I&C Pilot Upgrade Project. The Design Team will adapt research products to meet Exelon specific engineering and project management objectives, implementation timelines, and to conform to Exelon selected vendor product capabilities.

This is in keeping with the public/private partnership established for this effort as described in Section 1.2.3 above.

The Research/Design Teams include Subject Matter Experts (SMEs) on the existing systems being replaced including:

- System Engineering: Personnel who are responsible for maintaining the day-to-day operation of the systems targeted for replacement and to identify and address any issues impacting existing system health.
- Design Engineering: Personnel who possess design authority for the systems to be replaced and are responsible for Engineering activities associated with design changes.
- Operations: Personnel who run the plant who are intimately aware of operational issues and challenges associated with the existing systems and can provide insights with regard to potential improvements. This also includes knowledge of the "mental model" of how the current systems operate within the MCR and plant environments and how this mental model will be impacted by the envisioned replacement systems.
- Maintenance: Personnel familiar with the existing systems and familiar with the maintenance activities required to keep the systems operating reliably.
- Simulator Training: Simulator instructors are well versed when it comes to operational issues and challenges associated with existing systems due to the nature of their work (running challenging drills to certify and maintain operator capabilities). They are also familiar with the operations mental model of how the current systems operate within the MCR. They also can provide insights with regard to potential improvements.

- Licensing: Licensing personnel who are familiar with the licensing basis for the existing plant systems scoped in the upgrade to ensure that current regulator commitments are met by the upgrade or, when changes to commitments are needed, that they are clearly identified for licensing action as required.

The Research/Design Teams also requires SMEs familiar with the attributes of new technology and new processes envisioned for application in the Pilot upgrade, including experienced nuclear industry personnel in the areas of:

- State-of-the-industry SR I&C system design and implementation. This includes knowledge of SR digital I&C platforms that have received a SE Report from the NRC and of the latest NRC regulatory guidance for obtaining NRC approval for their implementation.
- State-of-the-industry NSR system I&C design and implementation. This includes experience including design development, configuration, testing, and installation of modern DCS platforms in nuclear plants to meet NRC requirements.
- Design and implementation of digital technology in MCRs ranging from small modifications to the HSI up to and including completely new control room designs using digital technology.

Finally, business analysts were also included in the Research/Design Teams. Their function is to act as a liaison between the rest of the Research/Design Teams and organizations that incur and track the lifecycle costs of the current systems within the upgrade scope. A technical expert was embedded with the business analysts to support their analyses with systems understanding. Through engagement with these parties, business analysts were able to apply expected design upgrade features identified by other members of the Research/Design Teams to current system lifecycle cost drivers. This allowed for the identification of potential labor and material savings enabled by the replacement systems. LWRS-led business analyst efforts and products are captured under Exelon Project Management activities (Section 2.5) and Project Management deliverables (Section 2.6) below, because their work products directly support project management decision making.

Organizations participating in the Research/Design Teams in the Initial Scoping Phase included Exelon Generation, direct support from LWRS Program at INL, and LWRS-contracted support organizations, including MPR Associates (MPR), Inc. and business analysts from ScottMadden, Inc (SMA).

2.1.2 Applying the Systems Engineering Vee Model to Guide Activities

The Initial Scoping Phase Engineering and Operations activity bounds the scope of the SR I&C Pilot Upgrade Project and establishes an initial design concept. These in turn support the development of Licensing and Project Management deliverables that are required for management to understand project costs, schedules, and risks and to determine whether approval to proceed to Phase 1 – Conceptual Design should be authorized. This also enables early vendor selection, which is critical in digital upgrade projects to enable early collaborative design efforts between the implementing utility and vendor to control project costs.

Guidance with regard to Initial Scoping Phase Engineering and Operations Activities is contained within the EPRI DEG, Section 4.1 and is best described by examining the Systems Engineering Vee Model presented in Section 4 of the EPRI DEG. The Systems Engineering Vee Model is shown in Figure 4 on the following page. Additional V-Models exist within the process, such as the Hardware and Software V-Models.

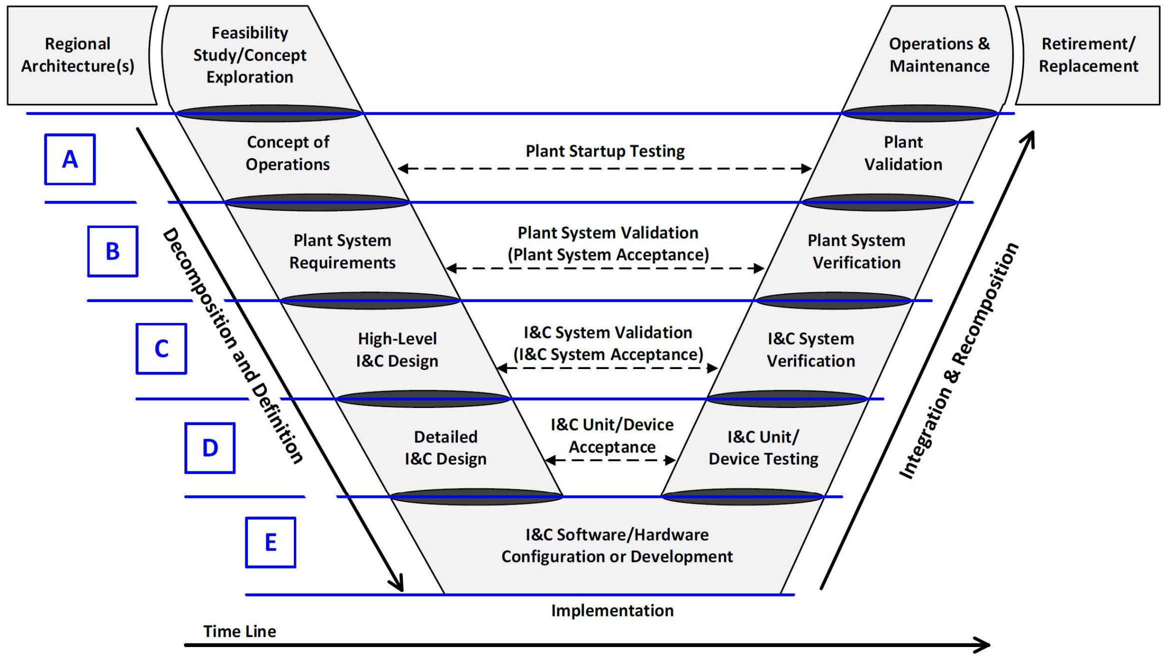

Figure 4 – Systems Engineering Vee Model from the EPRI Digital Engineering Guide.

In the Initial Scoping Phase, each item on the left side of the Vee Model (A through E) is evaluated as part of the "Feasibility Study/Concept Exploration" effort. This effort does not start from a clean sheet. This effort is bounded by the following topics:

- Definition of the problems to be resolved
- Information about the structures, systems, and components at the identified level(s) of change
- Stakeholder needs at the identified levels of the change
- Available technology and strategic alternatives to meet needs within the Concept of Operations and I&C Strategy
- Making necessary tradeoffs (decisions) between alternatives at the identified level(s).

The following subsections present in more detail how each item on the left side of the EPRI DEG Vee Model (A through E) in Figure 4 was addressed by the Engineering and Operations activities in Initial Scoping Phase. Where each item on the left side of the Vee Model (A through E) is addressed is identified (e.g. **{VM-A, VM-B,** etc.**}**). Tangible products created by these efforts are described in Section 2.2.

2.1.2.1 Apply Concept of Operations Model / Instrumentation & Control Strategy / Design Tenets

{VM-A} Section 1.1 above identifies the problems that this Project intends to address. The Plantwide Concept of Operations Model for a larger plant Digital Transformation is outlined in Section 1.2.1. Figure 1 shows how the SR I&C Pilot Upgrade Project fits into the Plantwide Concept of Operations model. This is further explained in Section 1.2.2. Design Tenets established at Project inception to achieve Concept of Operations objectives are identified in Section 1.2.3.

Developing a design concept for first-echelon BWR SR system I&C upgrades, based on the foundation described directly above, is a key enabler for the envisioned Digital Transformation New State. This holistic approach positively impacts business and operational needs that are beyond the scope of the systems being upgraded as part of the SR I&C Pilot themselves. As a representative example, consider online performance monitoring. Digital systems are inherently capable of collecting and disseminating large volumes of process and plant performance data. Including electronic data gathering in the system upgrade requirements eliminates the manual recording of data for legacy systems within the upgrade scope. The digital equipment also significantly increases the amount of outbound information that is available from the SR systems for remote monitoring and data analytics, which enables condition-based maintenance.

2.1.2.2 Project Scoping and Stakeholder Engagement

Initial Project Scoping

{VM-B} Plant process systems (reactor, fluid, and mechanical systems) are not within the scope of this Project. The intent is to conform the SR I&C upgrades within the analyzed plant design; maintain safety limits for reactor power, reactivity, radiation, pressure, flow, temperature, level, and time response; and ensure the replacement systems operate within the existing power budget, available space, and heating, ventilation, and air conditioning system capabilities. The MCR will be upgraded by this Project. The Project eliminates most indicating stations in the electronic (auxiliary) equipment room where the PPS will be installed.

{VM-C} This basic scope was established at the inception of the Pilot Project, as described in Section 1.2.2.

Implementing utility stakeholders have identified the existing systems within the Project scope as obsolete. It is increasingly difficult and expensive to procure refurbished or replacement equipment. Skill sets needed to support the current systems are also waning. O&M costs to perform preventive and corrective maintenance as well as surveillance and test tasks are excessive. The current systems also require personnel outside the MCR to obtain and report information to the MCR during certain plant operational sequences.

In addition to performing the functions of the current systems, the new PPS and the RRCS application to be placed on the DCS are to provide advanced features that that lower plant TCO. Key Design Tenets to achieve this end through Project implementation are identified in Section 1.2.3. These are decomposed into quantifiable and qualitative benefits in the research Business Case Analysis (BCA), as described in Section 2.6.4 below, to support the Project Management activity.

Project Scoping Refinement and Continued Stakeholder Engagement

{VM-C/D} Once design concept work had begun for the Project, it became immediately apparent from interactions with stakeholders and by reviewing the current system design documentation that a much more detailed scope boundary beyond that described in Section 1.2.2 was needed. Typical BWR design processes assign the electronic control (i.e., actuation) and monitoring equipment to the fluid, mechanical, and electrical systems to which they are physically attached. This was observed in the LGS design documentation and plant database documentation. This equipment is then shown as interfacing to the RPS, N4S, ECCS, or RRCS. To affect a complete digital upgrade to address potential obsolescence and lifecycle cost issues, the SR I&C Pilot Upgrade Project scope was expanded to include these additional electronic items. Furthermore, system walkdowns identified that additional electronic devices in the RPS, N4S, ECCS, and the RRCS cabinets are present in those cabinets that are not assigned to these systems but use similar and equally obsolete technology. These additional device functions were also included in the Project scope. As a result, the Project scope expanded from the electronic devices directly associated with RPS, N4S, ECCS, and the RRCS in plant documentation to also affect electronic devices from a total of 20 discrete plant systems, as shown in

Table *1* on the following page. This scope growth also greatly increased the set of lifecycle cost information that needed to be collected for the BCA developed to support the Project Management Activity.

Table 1: In-Scope System List.

Plant System Code	Existing Primary System	Existing Subsystem I&C Electronics	Target Replacement Platform
001	N4S	Main Steam	PPS
025	N4S	Temperature Monitoring	PPS
026	N4S	Radiation and Meteorological Monitoring System	PPS
036	RRCS	RRCS	NSR DCS
041	ECCS	Main Steam/ADS	PPS
042	Common	Nuclear Boiler Instrumentation	PPS
044	N4S	Reactor Water Cleanup	PPS
046	RPS	Control Rod Drive	PPS
048	RRCS	Standby Liquid Control	NSR DCS
049	ECCS	RCIC	PPS
050	ECCS	ADS	PPS
051	ECCS	RHR	PPS
052	ECCS	Core Spray	PPS
055	ECCS	HPCI	PPS
056	ECCS	HPCI	PPS
059	N4S	PCIG & TIP Power Supply	PPS
071	RPS	RPS	PPS
072	N4S	N4S	PPS
076	N4S	HVAC	PPS
092	ECCS	Emergency Diesel Generators	PPS

2.1.2.3 Development of the Design Concept and Identifying Engineering Deliverables

{VM-C/D/E}

For any project, the earlier a clear design concept and a set of basic tenets can be identified and documented in the project Initial Scoping Phase, the more likely that project is to be clearly understood, be approved for further development, and ultimately deliver on the benefits presented to justify its implementation. For digital I&C upgrade projects, this is particularly the case. This is because digital I&C upgrades:

- Typically introduce a significant change from the legacy technology employed (either pneumatic, electro-hydraulic, or analog systems [1960s and 1970s] or early digital technology systems [1980s]) to current, state-of-the-industry digital technology.
- Offer the potential to not only provide like-for-like functionality, but also provide for significant operational improvement, This is accomplished by providing additional information and control capabilities not currently in the MCR, as well as by providing self-diagnostic features that can significantly reduce both workload and operator error when compared to the existing systems. Such changes can provide significant opportunities to lower direct I&C system TCO if properly implemented.
- Offer the potential for larger data integration to further reduce plant TCO. To achieve this end, the direct Pilot Project scope functionality, outlined in red in the Advanced Concept of

Operations Model (shown in Figure 1), is augmented by design features beyond this direct scope as identified in red text in the same Figure. The intention is to produce results that reduce TCO in a way that magnifies the benefits that could be achieved beyond that provided by like-for-like replacements.

- Present unique risks associated with the new technology that can threaten the delivery of promised benefits if the project objectives are not clearly established, the project scope is not clearly defined, the technology being employed is not clearly understood, requirements are not clearly documented and testable, and a long-term lifecycle support strategy is not adopted to address digital obsolescence.

These ideas are discussed further in Section 1 of Attachment B to the EPRI DEG under the heading "Digital is Different." Achieving the envisioned benefits of the Pilot Project digital upgrades as part of a Digital Transformation requires a positive change that is at the same time disruptive to traditional nuclear industry thinking. To help manage this disruption and provide the maximum benefit while avoiding risks, digital projects typically require a more detailed design concept development in the project Initial Scoping Phase than traditional fluid, mechanical, or electrical system upgrades. This, combined with the fact that this Pilot is a FOAK effort to exercise new licensing guidance developed by the NRC, resulted in the Pilot Project Initial Scoping Phase taking nearly one year and several million dollars to complete. It is expected that Engineering, Licensing, and Project Management products developed by this FOAK Pilot Project Initial Scoping Phase effort can be leveraged by industry to reduce Initial Scoping Phase and overall project costs for similar upgrades.

Once necessary Project Management activities were completed as described in Section 2.6, Initial Scoping Phase Engineering activities commenced. These are summarized below:

- Project kickoff

  Members of the Research/Design Teams, as described in Section 2.1.1, were assembled. Initial Strategy, Scope, and Design Tenets were reviewed and refined. This was an iterative process that continued throughout the Project Initial Scoping Phase, with results described above.

- Identification of Engineering deliverables and division of responsibility

  Based upon the availability of Research/Design Team resources and the desire to create a more general SR I&C upgrade design concept and business case methodology, it was decided to divide the development of Engineering Deliverables into (1) research products that would then be (2) leveraged by Exelon to develop specific products for their target Limerick Generating Station.

  - Research Engineering deliverables to establish a design concept (LWRS led with Exelon collaboration) include:
    - A Research Decision Matrix (see Section 2.2.1)
    - Functional Requirements Baselines [2] (see Section 2.2.2)
      - For the SR PPS that will host the RPS, NSR, and ECCS functions as applications
      - For the NSR DCS that will host the RRCS ATWS function and any other diverse PPS functions, as dictated by a future D3 analysis of PPS.
      - A LAR Framework Document that serves both an engineering purpose (see Section 2.2.3) and a licensing purpose (see Section 2.4.1).

    Engineering design concept information from the functional requirements baselines and the LAR Framework Document were used to identify features expected to produce financial benefits in BCA, which are captured in the Project Management activity (see Section 2.6.4)

  - Utility Engineering deliverables to enable vendor down-select and authorization to proceed to the Conceptual Design Phase (Exelon developed) include:
    - A performance specification to support the vendor down-select process (see Section 2.2.4)
- Identification and obtaining of necessary data to produce the Engineering deliverables identified above
  - Site activities
    - Gathering design documentation
    - SME engagement through multiple workshops and direct personal communications with:
      - Engineering
      - Operations
      - Simulator Training
      - Licensing
      - Maintenance
      - Supply Chain
    - Plant walkdowns
  - Weekly teleconferences to address engineering and project management issues
- Production, review, comment incorporation, and release of Engineering products for use.

Details with regard to Engineering Initial Scoping Phase deliverables are provided in Section 2.2 below. While many attributes captured in these deliverables are at a “high-level I&C design” level **{VM-C}**, certain design properties and configuration details contained in these deliverables go to the level of “Detailed I&C Design” **{VM-D}** and “I&C Software/Hardware Configuration” **{VM-E}**. This is driven by the fact that:

- Many input requirements to the identified Engineering deliverables go to this level of detail
- It is expected that fully engineered platforms will be used and configured to meet these requirements
- That certain fundamental configuration changes (e.g. the changing of the voting logic for PPS protective functions) needed to be presented so that the Project scope and associated licensing risks may be better understood to reduce uncertainty when seeking approval to proceed to the Conceptual Design Phase.

2.2 Engineering Deliverables

2.2.1 Research Decision Matrix

When developing a design concept to replace nuclear plant I&C systems, the Research Team must consider all the existing design bases, requirements, constraints, and regulatory commitments as the design iterates. This team must also consider and balance other items such as (but not limited to): the technical, programmatic, and economic objectives driving the I&C upgrade; the as-built condition of the units being upgraded; upgrade physical boundaries and interfaces; perceived technical and regulatory risks; technologies available to support the upgrade; and methods to integrate the upgrade with the rest of the target unit. Decisions must be made based upon the team’s knowledge and experience to provide direction.

Decisions of this nature are necessarily utility and unit specific. With Exelon Generation’s support and participation, LGS was chosen as the basis facility for collaborative LWRS research in support of the

Project Initial Scoping Phase feasibility study and concept exploration effort. LGS-specific functionality provided the basis around which the first-echelon SR I&C upgrade research would be conducted. The Research Decision Matrix provided in Appendix D of INL/LTD-20-58490, *Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade* [Reference 13], captures a snapshot of decisions that the Research Team made in order to produce the vendor-independent functional requirement baselines (described in Section 2.2.2 below) and the LAR Framework Document (described in Sections 2.2.3 and 2.4.1 below). Research decisions items captured in the Research Decision Matrix were discussed during meetings with the resulting dispositions documented to support the direction to be pursued by the research.

The Research Decision Matrix is, of necessity, a snapshot of a working document. Some research decisions documented in the matrix are likely to be changed as a design progresses, as more information is gathered, or as needs dictate. Additional decisions will also need to be made and documented throughout the entire effort to bring the identified upgrades to completion.

Utilities leveraging the results of the research products captured in Reference 13 need to be aware of the research decisions made by the Research Team because these decisions directly impact the vendor-independent functional requirement design baselines and the LAR Framework Document produced by this same research. Utilities will need to critically evaluate whether or not the decisions made by the Research Team meet particular utility objectives and their particular unit's needs. Utilities will need to tailor the decisions captured in the Research Decision Matrix and augment the list with new decisions as their situation dictates. Modifications to the matrix will drive the need to assess the functional requirement baselines, the LAR Framework Document, and the BCA for impacts.

Research decisions captured in this matrix are intended to be tracked going forward to design/regulatory artifacts, which document the basis for each decision. Several research decisions and resolutions captured in the matrix identify sections in the LAR Framework Document where the decisions are addressed in the design concept. Going forward, an implementing utility should provide this traceability in a more formal manner.

2.2.2 Functional Requirements Baselines

MPR was subcontracted by the LWRS Program to lead the authoring of two vendor-independent functional requirements baseline documents, including:

- A SR PPS platform and application functional requirements baseline (Appendix A to Reference 13)
- A NSR DCS platform requirements and application requirements baseline for the RRCS (Appendix B to Reference 13).

With the cooperation of Exelon Generation, the LGS was selected as a basis for the creation of these two baseline documents as bounded by the expanded Project scope described in Section 2.1.2.2 under the heading "Project Scoping Refinement and Continued Stakeholder Engagement." MPR coordinated extensively with personnel from the Exelon LGS and LWRS in the creation of the functional requirements baselines.

These research products are intended to support first-echelon BWR SR upgrades not only at LGS, but also to serve as a basis for similar industry upgrades.

The "requirements" in the functional requirements baselines are, in fact, only research baselines. Information in the requirements baseline documents represents a bottom-up view of the upgrade design concept driven from existing LGS licensing and design requirements, envisioned new platform properties, and decisions captured in the Research Decision Matrix. Appendices A and B to Reference 13 are intended to provide specific information regarding desired attributes of the envisioned New State when the scoped systems are replaced with new digital technology. The requirements baselines have been developed as tools for the nuclear industry to engage vendors in a collaborative effort to adapt and conform the baselines with the needs of a particular unit and to the capabilities of the selected vendor's product line.

LGS was selected as the reference facility for this effort to provide a firm foundation for the requirements baselines. Accordingly, the research information contained therein is tailored to the LGS plant design and reflects design concept decisions made by research participants to achieve objectives associated with LGS Digital Transformation plans. From an industry perspective, these requirements baselines contain design concepts based on an actual reference plant. These baselines, along with the LAR Framework Document described in Section 2.2.3, can be adapted and leveraged by utilities and their selected vendor(s). The intent is for these baselines to be used to aid in the Project Initial Scoping Phase and follow-on project phases for similar upgrades.

Exelon is leveraging the requirements baselines as part of an effort to perform first-echelon SR I&C upgrades at LGS. Section 2.2.4 presents how Exelon used the functional requirements baseline information to create a performance specification used to solicit vendor requests for proposals.

2.2.3 License Amendment Framework Document

MPR was subcontracted by the LWRS Program to lead the authoring of the vendor-independent LAR Framework Document. MPR worked with personnel from the Exelon LGS and LWRS to generate much of the technical content contained in the LAR Framework Document that is presented in Appendix C of Reference 13.

A complete LAR must be submitted to the NRC and approved to enable the implementation of first-echelon safety system upgrades in the target unit or units. This research product provides a vendor-independent LAR Framework Document created in a format consistent with the AR process defined in DI&C-ISG-06, Revision 2. Non-digital plant-specific details, formatting, and many other aspects of a complete LAR, as defined in guidance provided in Nuclear Energy Institute 06-02, *License Amendment Request Guidelines* (NEI 06-02) [Reference 14], are not incorporated in the LAR Framework Document. The LAR Framework Document focuses on the LAR aspects that are different for digital content, leaving the established LAR details in Reference 14 to the utility to add and generate a complete LAR. The decision to focus only on the digital aspects in this research ensures that the digital detail is not obscured by the content required in the complete LAR.

At this point in the Initial Scoping Phase design concept development, the LAR Framework Document supports two separate but related purposes. First and foremost, the LAR Framework Document provides a mechanism for the Research Team to capture and communicate a comprehensive description of the systems being replaced, their interface to the plant, and functions implemented, along with a technical description of the replacement systems and their overall function in one place. The LAR provides a comprehensive description of the changes in functionality as well as a suggested revision to reflect removal of surveillance testing and calibration associated with installation of the PPS. This design concept in the LAR Framework Document is consistent with the plantwide Concept of Operations captured in Section 1.2.1 above. Secondly, the LAR Framework Document provides a foundation on which to generate a LAR consistent with NRC expectations for a digital system.

To address the first purpose, this upgrade effort does far more than provide like-for-like functional replacements of the current systems. The new systems leverage current state-of-the-industry digital technology not only to implement the functions of the original systems but also to leverage that technology to deliver on the Design Tenets listed in Section 1.2.3 above. In the aggregate, the implementation of these tenets is intended to support the overarching objective of economical and sustainable nuclear plant operation, including a path to address digital equipment obsolescence through lifecycle management. While informed by and consistent with the bottom-up view of the proposed replacement systems provided by the functional requirements baselines developed, as described in Section 2.2.2, the LAR Framework Document provides a top-down technical view of overall system architecture and features, which cannot be easily gleaned from the functional requirements by themselves. Eventually, design documentation will be created by the implementing utility and their vendor in later Project phases that will govern the design, as described in the actual, complete LAR document created by the utility. But for the Initial Scoping Phase, the LAR Framework Document focuses on, captures, and communicates this technical information.

The second purpose of the vendor-independent LAR Framework Document is to provide a mechanism for the NRC staff to obtain an early and complete understanding of envisioned safety system digital replacement design concept attributes in a format that allows for an early evaluation of their safety, and thus their licensability. By providing the draft technical information, as described above, as early as possible in the design process in a format consistent with that identified in DI&C-ISG-06, Revision 2 for the AR process, the NRC staff can provide early feedback on both the technical content and the format in which an implementing utility may communicate that information. The intent of early communication with the NRC is to reduce implementing utility licensing risk. More on the licensing purpose of the LAR Framework Document is provided in Section 2.4.1 below.

The technical information in the LAR Framework Document, along with the functional requirements baselines described in Section 2.2.2, are intended to be adapted and leveraged by utilities to meet their specific needs. The intent is for these to be used to aid in the Project Initial Scoping Phase and follow-on project phases for similar upgrades.

The vendor-independent LAR Framework Document provided in Appendix C of Reference 13 is written at a level of detail to satisfy the DI&C-ISG-06, Revision 2 AR process. Given the expectations of this guidance and the scope of the envisioned SR upgrade, the LAR Framework Document is lengthy (approximately 250 pages). Section 3.6 of Reference 13 provides an overview of the SR technical information contained in the LAR Framework Document. This overview is provided as an aid to promote a more general understanding of the top-down design technical information contained in Appendix C of Reference 13.

2.2.4 Performance Specification for Vendor Request for Proposals / Vendor Selection

Exelon, as a member of the Research Team, participated in the development of the functional requirements baseline research documents described in Section 2.2.2. While these research products were developed using LGS as a foundation, their research intent is to support a more generically applicable and detailed New State vison for SR I&C upgrades across the industry.

While the functional requirement baseline documents are informed by design requirements for the subject Exelon facility, they were not tailored to best apply to the specific Project requirements for Exelon. In order to tailor the functional requirements baseline information to the LGS New State vision, the information provided by them was reformulated by Exelon Design Team members into a LGS-specific performance specification.

A performance specification defines the functional requirements for the system, the environment in which the system operates, and interface characteristics. The performance specification does not describe how a requirement is to be achieved. Exelon believed that this would allow the vendors an opportunity to provide their best design and cost-effective solution, since the Research Team members outside of Exelon were not intimately aware of vendor products being offered because of vendor proprietary information constraints.

The performance specification provided a high-level system hierarchy and all the criteria that prospective vendors would be graded against, in accordance with the EPRI DEG, Section 5.1.1. The performance specification used most of the requirements developed in the functional requirement baseline documents. The performance specification was further vetted and revised to address comments from potential vendors and Exelon stakeholders to ensure that the solution being solicited was correct for the subject station. The performance specification conveys a clear understanding of what the system is supposed to do and what remains to be designed.

The requirements contained in the performance specification will be used by the selected vendor as a starting point for the System Requirements Specification (SyRS). The tables of information were controlled using Microsoft Office products to support the migration to a requirements management system. The SyRS is a deliverable from the vendor with support from Exelon following contract award.

Use of the performance specification provides the foundation of documenting required operational capabilities into an integrated system design through the concurrent consideration of all lifecycle needs. The specification provided a robust, systems engineering approach that balances total system performance and total ownership costs. Leveraging the functional requirements baseline research documents described in Section 2.2.2 and utilizing the systems engineering process allowed Exelon Design Team members to describe the solution required to meet LGS needs and allow the potential vendors to arrive at their most elegant solution. This provided flexibility to the vendors. Ultimately, the vendors have the freedom to achieve the goals as long as they meet the performance objectives.

2.3 Licensing Activities

In the Initial Scoping Phase, Exelon Licensing activities included the following:

- Participation on the Research/Design Team meetings and review of documentation.
- Meetings with DOE with the NRC in attendance to keep the NRC abreast of Pilot Project activities.
- Support of LAR Framework Document development (see Section 2.2.3 and 2.4.1) as an input to Exelon's future effort to develop a LAR. The Licensee will use the LAR Framework Document in conjunction with its own licensing process and procedures to develop the final LAR submitted to the NRC.
- Development of strategy and timeline to begin formal a LAR process using DI&C-ISG-06, Revision 2, AR process.
- Development of a Letter of Intent for submittal to the NRC for the SR I&C Pilot Upgrade at LGS.

Licensing deliverables produced during the Initial Scoping Phase are described in Section 2.4 below.

2.4 Licensing Deliverables

2.4.1 License Amendment Framework Document

LAR Framework Document described in Section 2.2.3 was written in a format consistent with addressing the digital aspects of an I&C upgrade in accordance with the DI&C-ISG-06, Revision 2, AR process. The decision to focus only on the digital aspects in the LAR Framework Document ensures that the digital detail is not obscured by the content required in the complete LAR.

The content of the LAR Framework Document will need to be augmented with the other LAR text in accordance with NEI 06-02 [Reference 14], as well as tailored to the individual site and a utility's specific needs and objectives when pursuing similar upgrades. The LAR Framework Document also provides the NRC an understanding of envisioned design concept attributes in a format that allows for an early evaluation of their licensability.

The LAR Framework Document is a research product that will never be formally submitted to the NRC, although the NRC may choose to read it.

The LAR Framework Document is intended to streamline the future generation of a complete, utility-developed, vendor and unit-specific LAR. A complete LAR must be submitted to the NRC and approved to enable the implementation of first-echelon safety system upgrades in the target unit or units. Plant-specific details, utility-specific formatting, unit-specific TS changes, and other aspects of a complete LAR, as defined in guidance provided in Nuclear Energy Institute 06-02*, License Amendment Request Guidelines* (NEI 06-02) [Reference 14], are not incorporated in the LAR Framework Document.

The Exelon Licensing organization was involved in the Initial Scoping Phase to ensure that the design concepts captured in Engineering deliverables (Section 2.2) can be successfully implemented from a TS and Licensing perspective. The TS will need to address potential interim configurations during the installation of the modification.

2.4.2 Licensing Activity Timeline

Assuming one refueling outage per unit will be sufficient to install the I&C SR Pilot Upgrade scope defined in Section 2.1.2.2, the overall timeline for the LAR submittal is expected to take a year and a half plus a three month contingency starting from the date when Exelon approves the Concept Design – Phase 1 Authorization to Proceed. This timeline includes NRC pre-submittal meetings, the development of the LAR, and the final internal Exelon validation and concurrence reviews prior to submittal.

2.4.3 Development of Letter of Intent for Submittal after Concept Design – Phase 1 Authorization to Proceed

The Letter of Intent is being developed. The letter will be submitted to the NRC per the DI&C-ISG-06, Revision 2, AR process after Exelon approves the Concept Design – Phase 1 Authorization to Proceed.

The Letter of Intent will include a brief description of the LGS Project. The letter will express the intent to request a fee exemption per 10 CFR 170.11, *Fees for Facilities, Materials, Import and Export Licenses, and other Regulatory Services under the Atomic Energy Act of 1954, as Amended, Exemptions* [Reference 15] in a follow-up submittal. The letter also will include a forecasted date for the submittal of the LAR, a request for a NRC one year review and approval timeframe, and a description of the future designated refueling outages for the installation at each of the two LGS units.

Exelon will request that the NRC review fees associated with the NRC evaluation of the planned LAR be waived in accordance with 10 CFR 170.11(b), on the basis that the fee waiver is authorized by law and is otherwise in the public interest.

2.5 Project Management, Procurement, and Installation Activities

Project Management and Procurement activities for the Initial Scoping Phase are also identified in the EPRI DEG as necessary and are depicted in Figure 2. In the Pilot Initial Scoping Phase, Exelon Project Management, Procurement, and Installation activities included the following:

- A Project Manager was assigned to oversee all Project Initial Scoping Phase activities and support the development of initial SR I&C Upgrade Pilot scope, costs, and schedule.
- The Project Team was identified. Needed organization engagements and resource qualifications were identified. Exelon resource assignments were solicited and obtained at key leadership and Project initial authorization meetings. Exelon provided Research/Design Team SMEs on the existing systems being replaced at LGS, including those identified in Section 2.1.1. Additionally, contracts and business management professionals were assigned to support vendor engagement and the development of necessary Project documentation to enable the approval of the Concept Design – Phase 1 Authorization to Proceed.
- Close coordination with the Principal Investigator for the SR I&C Pilot Upgrade at LWRS was established as part of the public/private partnership discussed in Section 1.2.3.
- Initial Scoping Phase funding from Exelon management was solicited and approved.

- A kickoff meeting was conducted as required by procedure to ensure that all key stakeholders and Project Team members at Exelon and LWRS were aligned to the Project objectives, understood assigned roles and responsibilities, and reviewed and understood the overall Project Plan.
- Necessary Engineering and Operations activities (Sections 2.1) and Licensing activities (Section 2.3) were identified, initiated, and tracked to ensure that associated deliverables (Section 2.2 and Section 2.4, respectively) were developed in a timely manner, within budget, and with sufficient quality to enable approval of the Concept Design – Phase 1 Authorization to Proceed.
- Development and approval of the Project Plan.
- Development of the Risk Management Plan and Risk Register.
- Development of Project Procurement Plan and Vendor Down-Selection in accordance with Section 5.1.1 of the EPRI DEG.

Specific SR I&C Pilot Upgrade Project Initial Scoping Phase Project Management and Procurement deliverables are presented in Section 2.6 below.

2.6 Project Management, Procurement, and Installation Deliverables

Required Project Management deliverables at Exelon are specified by Exelon Procedure EC-AA-1005, *Project Implementation* [Reference 16]. Key Project Management deliverables for the Initial Scoping Phase are discussed below. Exelon accomplished all Project Management and Procurement related activities in the Project Initial Scoping Phase with the exception of development of the research BCA as described in Section 2.6.4. Exelon fully supported and collaborated with the Research Team on the development of the BCA.

2.6.1 Project Plan

A Project Plan was developed by the Exelon Project Manager, commensurate with the level of Project complexity, to ensure all Project objectives and deliverables required to execute the Project are defined and in place. The Project Plan also forms the basis for the Project Controls organization to monitor Project activities through all phases. This Project Plan will be updated and maintained for the remainder of the Project.

2.6.2 Risk Management Plan and Risk Register

A Risk Management Plan was also developed by the Exelon Project Manager to identify potential risks, identify methods to address those risks (e.g. accept, mitigate, transfer) as appropriate, and estimate Project impacts if potential risks are realized.

A Risk Register was developed as part of the Risk Management Plan with the Exelon Project Team and stakeholder input to monitor and control the risk profile of the Project. Individual risks are monitored and tracked throughout the Project, along with actions taken to address realized risks or planned to address potential future risks. Estimated monetary value of risks above economic thresholds are budgeted for as contingency. The Risk Management Plan and Risk Register will be updated and maintained for the remainder of the Project as needs dictate.

2.6.3 Project Procurement Plan and Vendor Down-Selection

A Project Procurement Plan was also developed by the Exelon Project Manager in accordance with Section 5.1.1, "Develop or Apply a Procurement Strategy," of the EPRI DEG [Reference 4], and Exelon procedure EC-AA-1005 [Reference 16]. For the SR I&C Pilot Upgrade, the type of procurement will consist of both "system" and "services," as identified in the EPRI DEG.

Vendor selection, an element of the Project Procurement Plan, was performed using objective evaluation criterion as specified in the EPRI DEG to review requested PPS Request for Proposal submittals, characterize the vendor suitability technically and financially, and document the results. Results were communicated to internal stakeholders to ensure that the down-select results were challenged and that the best fit selection was aligned upon prior to the contract award.

The level of effort expended and technical detail developed in the Initiation Phase for the vendor down-select process was front-loaded as much as possible. This goes beyond the level of effort identified in EPRI DEG, Section 5.1.1, “Develop or Apply a Procurement Strategy.” This Project intends to engage the vendor as early as possible to establish a collaborative relationship between the utility and the vendor. This collaboration is expected to evaluate and refine information communicated in the initial performance specification described in Section 2.2.4 and develop more detailed requirements, specifications, and system configuration instructions. Through such a collaborative and iterative Conceptual Design Phase and Detailed Design Phase effort, Project costs will be more closely controlled, final products will provide the maximum benefit, and lifecycle support strategies will be refined to lower TCO.

2.6.4 Research Business Case Analysis

As part of the Initial Scoping Phase, SMA was subcontracted by the LWRS Program to lead the authoring of INL/EXT-20-59371, *Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations* [Reference 17]. SMA analysts worked with personnel from the Exelon LGS, MPR, and LWRS to produce Reference 17.

This research product illustrates a methodology for utilities considering a digital modernization of I&C systems to evaluate cross-functional labor and material benefits and conduct a financial analysis as part of the development of the overall business case for digital modernizations. The objectives of this research product include:

- Providing a bottom-up approach to:
  - Establish labor and material costs for the current systems within the defined I&C upgrade scope
  - Identify expected labor and material benefits enabled by the upgrade design concept
  - Validate the expected benefits with SMEs
- Demonstrating the methodology used to perform a detailed financial analysis, including the following:
  - Estimation of annual benefits related to organizational workload reductions for both online and outage work. This included both quantitative benefits (which were included in the BCA result) and qualitative benefits (which were identified as areas of additional potential savings but where not included in the BCA result).
  - Estimation of annual benefits related to materials and inventory expenditures
  - Valuation of avoided lifecycle costs associated with escalation of material expenditures
  - Valuation of the modernization over the lifecycle of the Station
- Illustrating the scale of benefits that can be expected from a modernization of SR I&C systems at a two unit BWR nuclear power station
- Providing example worksheets and templates to support a BCA of similar efforts by other utilities
- Providing lessons learned and opportunities for utilities that might subsequently implement a similar digital modernization effort. These are specifically identified in Appendix A to Reference 17.

This methodology, when specifically applied to the LGS for Exelon as part of the Initial Scoping Phase of the SR I&C Pilot Upgrade, produced results that were used as an input to the Project Economic Analysis developed by Exelon, as described in Section 2.6.5 below. The proprietary version of Reference 17 created for this purpose is captured in INL/LTD-20-59707 *Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations"* - as Applied to the Limerick Generating Station, [Reference 18].

The most significant finding of the BCA effort was establishing that the material costs for sustaining the operation of obsolete I&C equipment is increasing. Based on early interviews with plant staff, the Project Team investigated reports of high escalation of component prices in recent years. An analysis of material costs for one system in-scope for replacement in this Project revealed that costs to maintain the system are escalating at a compound annual growth rate (CAGR) of more than 20%. This observed rate is higher than the expected rate of 3% to 5%, which is considered typical for the industry.

A comparative analysis of both labor and material trends for this sample system, illustrated in Figure 5 below, demonstrates that, although cost management efforts reduced the annual cost of labor to maintain the system over time, these gains have been offset by growth in the cost of materials.

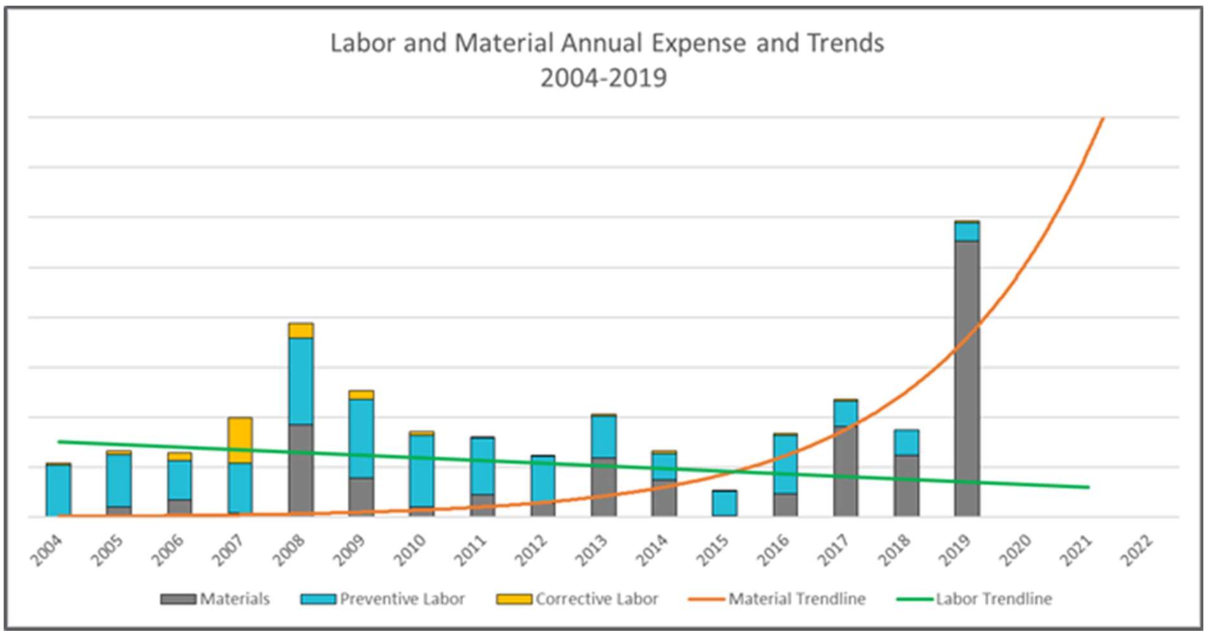

Figure 5 – Sample System Labor and Material Cost Analysis.

A causal analysis produced the following contributing factors to this high growth rate:

- Annual material expenditure increases are driven by both escalating component unit prices and the increasing failure rates of aging analog subcomponents,
- Replacement components are harder to find, resulting in more supply chain and engineering time spent trying to procure the parts, and
- The limited supplier base has shifted market power to the shrinking number of vendors that still supply and service this equipment.

Given that the obsolescence of components is the driving force behind rapidly increasing system costs, the replacement of obsolete components with a modern system would eliminate the current risks posed by this issue. A lifecycle management strategy of the newer system would further mitigate this risk from occurring in the future.

2.6.5 Project Economic Analysis

The Exelon internal Project Economic Analysis is fundamentally based on the LWRS research BCA results described in Section 2.6.4 and current budgetary estimates for the Project. Labor benefits made available by achieving the New State are bounded by plant TS, Fukushima Flex strategies, and Fire Safe Shutdown staffing requirements and adjusted as sensitivities to the base case. All labor and material benefits influence the economic analysis and Net Present Value as a function of time to achieve those benefits based on Project implementation scheduling.

2.6.6 Project Schedule, Budget, and Total Project Cost Range

As an input to the Phase 1 – Conceptual Design Project Authorization Package, a Level 2 Project Schedule was developed by Exelon to bound key deliverables and milestones. Order of magnitude estimates, with a certainty range of +75% to -50% for Initial Scoping Phase Project, were developed. These are used to initially budget the Project and form the financial basis of the Project Authorization Package (Section 2.6.7 directly below).

2.6.7 Project Authorization Package

The Phase 1 Project Authorization package developed for the SR I&C Upgrade Project at LGS presents the financial justification for proceeding with the Project for approval. It is a compilation of:

- The LWRS Initial Scoping Phase Research and DOE Office of Nuclear Energy mission, which provides the Project background,
- The proposed New State and Project Plan that identifies the Project objectives and proposed solution, including the vendor selection process,
- The economic analysis forecasts, which includes the financial upside and risks with proceeding with the Project, and
- The budget estimates for the Project, which frame the initial budget requests for the Conceptual Design Phase.

The authorization package is reviewed with Project stakeholders prior to an authorization committee presentation. The purpose of this presentation is to obtain Exelon management approval of the Concept Design – Phase 1 Authorization to Proceed for this Project.

3. Lessons Learned

As part of the Initial Scoping Phase public/private partnership for the SR I&C Pilot Upgrade Project, lessons learned associated with LWRS research and Exelon Project activities have been captured for communication to industry. These are documented in the subsections below to assist follow-on implementers of first-echelon SR I&C upgrades. The objective in providing these lessons learned is to further support these follow-on upgrades so they can be performed more smoothly, at minimum cost, and with maximum safety, operational, and financial benefit to support continued LWR operation.

3.1 Engineering and Operations Activities

Lessons learned associated with Engineering and Operations activities performed during the Initial Scoping Phase are listed below:

- Having a vision of a New State enabled by a comprehensive plant Digital Transformation and how the new SR PPS and NSR DCS platforms fit into that New State drove engineering design concept decisions. Design concept decisions were made to allow the PPS, DCS, and MCR modifications being considered as part of this Project to fit into that New State. Failing to consider the New State vision would have resulted in the later need to modify the PPS to fit into the New State.

- Utility I&C SME knowledge naturally centers around the operation and support of current systems. This includes an intermingling of knowledge of both "what" the current systems functionally provide and "how" the current systems provide that functionality. It is difficult for such utility SMEs to extract true functional requirements from existing documentation for application on new digital platforms. It is even more difficult to identify new, actionable requirements for the use of advanced features offered by digital vendor products without profound knowledge of the capabilities of those new platforms and how to apply them. New digital platforms are also so configurable that consideration must be given as to what functions the platforms can perform that the utilities do not want them to perform (e.g. requirements that define what the platform shall not do). The result of all this is that the standard nuclear practice of utilities writing requirements and vendors being contracted to meet them can result in functionally suboptimal, custom designed digital system solutions that are extremely expensive to procure and expensive and difficult to maintain and support.
- While considering the lesson learned directly above, the more detailed information that can be incorporated by a utility into the early design concept for a project and communicated to the vendor in the Initial Scoping Phase, the more likely that engagement with that vendor will result in quality design products and lower costs. Early communication of Design Tenets (Section 1.2.3) and Initial Scoping Phase Engineering deliverables (Section 2.2) can clearly communicate needs and expectations and guide vendor selection but should not be seen as communicating formal requirements. This information starts the technical collaboration where utility needs and vendor capabilities are blended to create optimal requirements in the Conceptual Design Phase. This may ultimately result in many items communicated in the Initial Scoping Phase in the form of requirements being modified or dropped from the design as well as the addition of missing requirements.
- The Design Team will need to make decisions throughout the life of a project. The Design Team should maintain a recorded decision matrix from the start as was done for this Project. The decision matrix captures fundamental design concept information, including design decisions. The decision matrix documents what was chosen and why the decision was made. Many design bases are set by the Design Team and are not driven by a previously existing requirement, although the decision may be driven by a previously existing design decision. Review of the content of the decisions matrix should be part of the preparation for any visit with the NRC to discuss the plans forward and the changes to the systems.
- Project scope needs to be bounded as completely as is possible, realizing that the scope will shift as the Design Team delves into the design of the existing system and identifies additional scope that would be useful or appropriate. Lessons learned with regard to Initial Scoping Phase activities for this Project include:
    - I&C upgrade designs must consider interface boundaries carefully to ensure that the upgraded systems can interface with the portions of the plant that are not modified. For the Pilot Upgrade, early development of the initial sections of the License Amendment Request (LAR) Framework Document contained in Reference 13 helped define and document the existing system boundaries and interfaces, as well as define and document the modernized system boundaries and interfaces. While doing an interface assessment, the I&C design should consider the implications of the equipment to which the system interfaces. As an example from this Pilot Project, LGS has multiple sets of redundant transmitters hardwired to the RPS, N4S, and ECCS. When these separate systems functions were combined in the PPS design concept, there is no need for the multiple sets, so the multiple sets of redundant transmitters could be reduced to a single set of redundant transmitters serving all functions within the PPS. The design must also consider interfaces with the human user to minimize the potential for human performance error while using and maintaining the modernized system.

- The process will identify opportunities for design improvements, which should be incorporated into a decisions matrix and into project documents. An example decision made in this way for the Pilot Project was to include within the modernization of the PPS a two-out-of-four logic system, replacing the one-out-of-two taken twice logic in the existing systems. The Pilot Project also considered the Residual Heat Removal (RHR) system, which had several NSR modes of operation that were automated (minimizing the potential for significant events resulting from human performance error) and interlocked with the safety functions (minimizing the potential for attempting to initiate NSR modes in manners that are not within the plant's licensing basis or that disable safety functions inadvertently).
- Early and sustained engagement of Operations, Maintenance, and Simulator Training personnel is critical. The Operations Department is the ultimate customer for digital I&C upgrade projects. The Maintenance staff have to test, troubleshoot, and repair the system. Simulator personnel are well versed in the operational use of the current systems. For the Pilot Project, these individuals provided specific insights during several workshops with regard to operational issues with the current systems they experience and observe during plant operation and simulator training sessions. They proposed methods to address these issues in the new system design and also provided insights with regard to the viability of design concepts proposed by Engineering. This directly contributed to the development of replacement system design attributes. This engagement also established a degree of Project ownership within these organizations, which is instrumental when engaging with management to justify Project continuance.
- Modifications to the TS should be considered early. For the Pilot Project, earlier consideration of the development of the FOAK modifications to the TS would have helped to establish the boundaries for system requirements and design and would have reduced rework in design concept development.
- I&C upgrade design concepts must consider the reduced TS requirements for surveillance tests and calibration, and ensure that any remaining surveillance tests and calibrations are supported in the new hardware and software, especially avoiding the requirement to lift and land wires to perform these activities.
- Previously unrecognized design constraints will be identified during the Concept Initiation Phase (and other project phases). The Design Team must determine how these design constraints will be incorporated into a project. For the Pilot Project, initially unrecognized interactions with the remote shutdown room and panels had to be addressed, and equipment in cabinets that was not initially scoped as part of the systems being modernized were absorbed into the PPS. For the Pilot Project, these decisions, and the rationale for incorporating the decisions into the design, were documented in the decisions matrix.
- As information understood to be existing system level requirements is being extracted, it should be examined. This examination should determine if identified features are indeed requirements or if the identified features are design choices made in the original system's design process. For the Pilot Project, several items that were initially understood to be requirements were determined to be implementations of design choices only and are so identified in the design concept. For the Pilot Project, if a feature could not be clearly established as a design choice only, that feature was conservatively classified as a requirement in the design concept.

* The Design Team, including the Licensing staff and the selected vendor, must plan for discovery, iterations, and refinements through the life of a project. This planning should include cooperative work with the Licensing activities to help inform the design and avoid rework associated with concepts that either cannot be licensed or would be difficult to license (with no appreciable

benefits). Since past experience shows that all requirements are likely not identified until later in a project, projects should plan for change and refinement as they progress. Changes in requirements that have been submitted to the NRC are particularly of interest in this regard.

- The Design Team and utility Licensing should remain involved with the development of the LAR through NRC acceptance and issuance of the SE Report even if LAR finalization is turned over to the vendor. This is to ensure that they remain informed of vendor efforts and any design choices made by the vendor. For the Pilot Upgrade, the LAR is planned to be finalized and completed by Exelon Licensing.
- The Design Team must plan for methods to be used to incorporate any conditions or commitments made through the NRC's SE Report in all lifecycle activities, including an evaluation of any effects of those conditions or commitments in work already completed.

3.2 Licensing Activities

The following summarizes licensing lessons learned while developing the LAR Framework Document as described in Sections 2.2.3 and 2.4.1 and included as Appendix C to Reference 13.

- Licensing must maintain active participation in the initial design and requirements elicitation processes and maintain that active participation through the life of a project. Licensing has a unique perspective on what is possible and why certain aspects of a system exist. Licensing also will be responsible for defending changes to the current system designs made by the upgrades (e.g., elimination of multiple sets of redundant transmitters incorporated in the current system design and licensing basis along with the elimination of TS requirements associated with those eliminated sensors).
- Engaging the entire Design Team in the early development of the initial sections of the LAR Framework Document (for this Pilot Project) and the LAR (generally) ensures that a project defines and documents both the existing system boundaries and interfaces and the modernized system boundaries and interfaces. HFE must be understood by the Licensing staff because these are the first major enhancements to nuclear power plant control rooms in decades (considering the changes made to install Three Mile Island Lessons Learned as major changes).
- Licensing should be part of each discussion with the NRC to ensure that the design remains licensable and to ensure that the Licensing activities are informed by the design decisions and design decisions are informed by Licensing activities.
- Utility Licensing and other members of the Design Team should remain involved with the development of the LAR through NRC acceptance and issuance of the SE Report even if LAR finalization is turned over to the vendor. This is to ensure that the utility staff remain informed of vendor efforts and any design choices made by the vendor. For the Pilot Upgrade, the finalization of the LAR is planned to be completed by Exelon Licensing.
- The Licensing staff, as a member of the Design Team, must plan for methods to be used to ensure the incorporation of any conditions or commitments made through the NRC's SE Report in all lifecycle activities, including an evaluation of any effects of those conditions or commitments in work already completed.
- Implementation of digital I&C platforms will inherently reduce a significant amount of manual labor currently expended to operate and maintain existing analog I&C systems. These labor savings may be equated to harvestable resources (i.e., reductions in required personnel). However, Licensing staff should be engaged (along with other departments) to ensure that assumptions regarding potential reductions in personnel resources appropriately consider licensing basis requirements. For example, digital I&C modernization may permit the reduction of two personnel per shift due to the reduced workload required for normal operations. However,

this reduction must consider minimum staffing requirements driven by a station's Emergency Plan, Security Plan, and other requirements. Reductions in shift staffing below these levels will require consideration of additional licensing actions beyond those associated with a LAR developed in accordance with DI&C-ISG-06, Revision 2.

3.3 Project Management, Procurement, and Installation Activities

Exelon accomplished all Project Management and Procurement related activities in the Project Initial Scoping Phase with the exception of development of the research BCA as described in Section 2.6.4. Exelon fully supported and collaborated with the Research Team on the development of the BCA. Project Management and Procurement activity lessons learned captured below were provided based upon this division of work.

3.3.1 Project Plan

A Project Manager was assigned early during the Project Initiation Phase to assist the technical teams collaborating on the LWRS research as well as to develop the scope, schedule and order of magnitude cost estimate of the Exelon Project. Both efforts occurred in parallel. Typically, a Project Manager is assigned at the inception of Conceptual Design Phase. By appointing a Project Manager and developing a Project Plan in the Initiation Phase, additional rigor not typically applied until the Conceptual Design Phase was brought to bear with the resulting production of more detailed Initiation Phase Engineering, Licensing, and Project Management deliverables. These enhanced deliverables are intended to address first-of-a-kind risks as early as possible and to establish implementing utility confidence to authorize proceeding to Phase 1 – Conceptual Design.

3.3.2 Risk Management Plan and Risk Register

Early development of a Risk Management Plan and associated Risk Register allowed analysis of base scope, decisions, and Initiation Phase planning at a finer level. Application of this rigor enabled development and evaluation of risk mitigation strategies and influenced the cost basis to capture the expected monetary value of Project risk. The Risk Plan and Risk Register are principally tailored to the Conceptual Design phase activities and will further be refined during Conceptual Design to capture and evaluate subsequent Detailed Design and Implementation Phase risks.

3.3.3 Project Procurement Plan and Vendor Down-Selection

Project Management principles were applied to PPS Performance Specification development and vendor down-select efforts. This resulted in a further refinement of vendor evaluation criteria beyond a set that were purely technical in nature. This resulted in more comprehensive vendor responses to Requests for Proposals. The vendor offering the best total PPS Project solution was selected based on these refined criteria, augmenting a vendor selection process based solely on technical merit.

3.3.4 Research Business Case Analysis

As stated in Section 2.6.4, Appendix A to the research BCA (Reference 17) includes specific lessons learned during its development. The following summarizes the 18 lessons learned as captured in the research BCA, along with others noted by other members of the Research/Design Teams as they supported efforts that resulted in Reference 17. These are identified here to support future, similar efforts:

- Section 2.1.2.2 describes the challenges associated with developing the scope of systems to be replaced and, subsequently, equipment considered in the modification. Developing the appropriate scope requires early interactions with plant personnel that maintain a strong understanding of integrated plant system operation. Accordingly, this need must be considered when establishing the core Project Team.

- The Project Team should agree early with regard to how the BCA will be developed and align BCA efforts with the development of the broader project scope. Other aspects and efforts working in parallel with BCA might include system engineering studies, development of a License Amendment Request, stakeholder needs identification and vendor qualification. BCA efforts for the Pilot Project began in parallel with Project scoping and design concept development. Because of the early challenges with establishing the Project scope identified directly above, initial BCA efforts were less efficient. Once the scope was more clearly defined along with sources of economic data, BCA efforts became much more focused and effective.

- The analysis requires the use of several assumptions regarding the proposed design of the modernized I&C architecture. These assumptions are required because performing a BCA in the Initial Scoping Phase inherently precedes Conceptual Design Phase and Detailed Design Phase activities. These assumptions must be validated with technical SMEs in engineering, licensing, and operations. For example, the research BCA in the Pilot Project assumed that several existing process transmitters (e.g., reactor water level transmitters) would be eliminated as part of the proposed modification. This decision was validated through discussions with the broader Design Team to ensure that the benefits derived from this equipment elimination were appropriately justified.
- Accurately assessing the benefits associated with the digital modernization required several interactions with plant staff (e.g., I&C craft responsible for executing many of the surveillances that would be reduced through the elimination of analog I&C systems, supply chain organizations, etc.). These interactions should be planned early in the process of developing a BCA for a similar project to ensure availability of these resources for verifying estimated benefits. Additionally, early and frequent engagement serves the broader purpose of ensuring that all stakeholders feel a sense of ownership relative to a project. This is critical for efforts that involve not only changes to plant structures, systems, and components but drastic changes to workflows and organizational hierarchies.
- Estimation of the benefits associated with a SR I&C modification inherently requires a review of the plant's TS surveillance requirements related to current SR I&C systems and their associated testing programs. This effort benefitted from developing a matrix of TS surveillance requirements against the implementing procedures used to satisfy those surveillance requirements. Implementing procedures often have an identifier used to track the scheduling of procedure performance in the station's work management platform. Developing a matrix of surveillance requirements against implementing procedures and work management tracking mechanisms will assist in mining the data required for a benefits estimation when determining the potential labor and material cost savings associated with surveillance requirement elimination.
- Available cost data for the systems scoped for replacement must be gleaned from site databases that collect such data. This can be a challenging effort. For the Pilot Project, a method had to be developed to filter pertinent information from the utility's electronic databases. For this research, the amount of historical data available amounted to hundreds of thousands of records for each of the 20 plant systems examined. To collect, sort through, and augment the data, the following activities were identified and used:
    - Initial data requests were developed by working backward by (a) documenting the desired result, (b) defining the analysis needed to calculate the result, and (c) identifying the data needed to support the analysis. This aided in data identification and filtering as described directly above.
    - Preliminary deliverables were identified and designed to enable the Research Team to filter the electronic data efficiently.
    - Historical work management labor records need to be critically evaluated to establish whether they can be used to identify future workload reductions. It was discovered during data collection that much of the work order historical records were linked to Planned Maintenance

Items (PMIs) that were retired or out of service. The station had also undergone a cost reduction effort where periodic maintenance on components was evaluated and reclassified to condition-based maintenance. As a result, the Research Team made efforts to filter out records linked to retired or inactive PMIs and calendar-based periodic maintenance items converted to condition-based maintenance as appropriate so as not to include this work in forecasting future workload reductions.

    - Labor resource types identified in the utility's work management electronic database were inconsistent. The Research Team developed a simplified list of resource types to consolidate workload into like resources.
    - Use of SMEs is critical in verifying workload estimates made from the work management electronic database data and identifying support resources not identified in work orders (e.g., Planner, Scheduler, Supervisor, Clerical). Resources need to identified and allocated to support engagement of these SME.
    - The work management electronic database provided a list of catalog items used that were expendable in nature (e.g., grease, hardware, fuses). Such items were not attributable to any system. In fact, they could be used in one of many applications within the station. As such, these expendable catalog items were excluded from the work management data as they were manually reviewed. To determine the cost benefits for miscellaneous, sundry, and consumable items, the Research Team provided a factored estimate and added this estimate back to the materials cost estimate.
    - The station's work management electronic cost tracking database did not provide reliable cost data for components used in the field. The Research Team needed to obtain this purchasing data from the station's purchasing system.

- To value inventory, the Research Team needed to determine the growth rate associated with components for each system. This was done by calculating the weighted average CAGR for a sample set of components. The key finding was that the cost of components making up the legacy systems targeted for replacement are escalating at higher rates than what would be typically expected.

3.3.5 Project Economic Analysis

The Exelon Initiation Phase internal Project Economic Analysis is founded on the LWRS CBA research [References 17 and 18]. This provided more well-rounded and detailed material and labor cost data to evaluate the monetary benefit that digital modernization and pursuing the PPS Project can enable. This permits adjusting those benefits as sensitivities to the base business case assumptions and evaluating the influence on the Project Net Present Value

3.3.6 Project Schedule, Budget, and Total Project Cost Range

The Project Team developed a resource loaded schedule for the Conceptual Design Phase Activity during the late stages of the Project Initiation Phase. The primary goal was to baseline the Project Schedule from a work breakdown structure developed from the SDP [Reference 2], the SDEP [Reference 3], the EPRI DEG [Reference 4], and the DI&C-ISG-06 Revision 2 LAR AR process [Reference 1]. This also provided early insight into resource demands from reviewing resultant resource histograms and influenced the Project staffing plan. This effort was also used to validate that Project cost are bounded, current order of magnitude estimates (+75/-50% budget) and is the process required to certify the Project is within the criteria for budgetary certainty ranges (+/- 20% budget).

3.3.7 Project Authorization Package

As of the writing of this report, the Project Authorization Package is in the Exelon management approval process to authorize proceeding to Phase 1 – Conceptual Design.

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