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Safety-Related Instrumentation & Control Pilot Upgrade: Initial Scoping Phase Implementation and Lessons Learned

In May 2016, the United States Nuclear Regulatory Commission (NRC) staff provided a digital Instrumentation and Control (I&C) regulatory infrastructure integrated action plan to the Commission for approval. One of the objectives of that plan is to establish a clear regulatory structure with reduced regulatory uncertainty to enable the expanded safe use of digital I&C in commercial nuclear reactors while continuing to ensure safety and security. To achieve this end, the NRC, with collaboration from industry, developed a streamlined License Amendment Request Alternate Review (AR) process for Safety-Related (SR) digital I&C upgrades. In spite of this effort, the industry has remained reluctant to perform such I&C upgrades because of perceived regulatory and financial risks associated with being the first or an early adopter of the AR process for SR I&C upgrades.

The Department of Energy Light Water Reactor Sustainability Program at the Idaho National Laboratory performed Initial Scoping Phase research to help break this impasse by supporting a SR I&C Pilot Upgrade, working with MPR Associates, ScottMadden Inc., and Exelon Generation. Exelon's Limerick Generating Station (LGS) was selected as the target for this research. This paper summarizes the Initial Scoping Phase Engineering and Operations, Licensing, and Project Management Activities necessary to bound the scope, schedule, and estimated cost of the Project sufficiently to enable utility management authorization of Conceptual Design Phase activities. These efforts and associated products are intended to provide a template to support larger industry efforts to perform similar upgrades as a foundation stone for a Digital Transformation that will improve plant safety, reliability, and operational performance while lowering plant total cost of ownership.

As a result of the combined effort of Exelon Generation and research participants, Conceptual Design Phase activities for the subject upgrade at LGS were approved by Exelon. The Department of Energy also awarded a $50 million cost share award to Exelon in order to pave the way for SR I&C modernization and associated control room upgrades across the U.S. nuclear fleet. Additional research reports are planned for the Conceptual Design Phase, Detailed Design Phase, and the Implementation Phase of the LGS Project to document the process followed and promulgate lessons learned to industry.

Keywords: digital, instrumentation, controls, upgrade, transformation

I. INTRODUCTION

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

Costs to sustain older systems are rising rapidly. Unless this situation is addressed, it will be difficult to technologically sustain or economically justify continued operation of existing light water reactors for their current license durations and for subsequent license renewal periods. Making additional investments on 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 applying advanced digital technology capabilities to lower plant costs, reduce technical specification surveillances, or improve plant performance.

To meet industry needs and to overcome industry reluctance in performing first-echelon I&C safety-related (SR) system upgrades, 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 the same time, the Pilot upgrade effort endeavors to create a process and product roadmap for other utilities to follow.

I.A SCOPE DEFINITION AND PLANT 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 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. With adjustments, this is also applicable to a Pressurized Water Reactor. The transformational approach is illustrated in Figure 1 below.

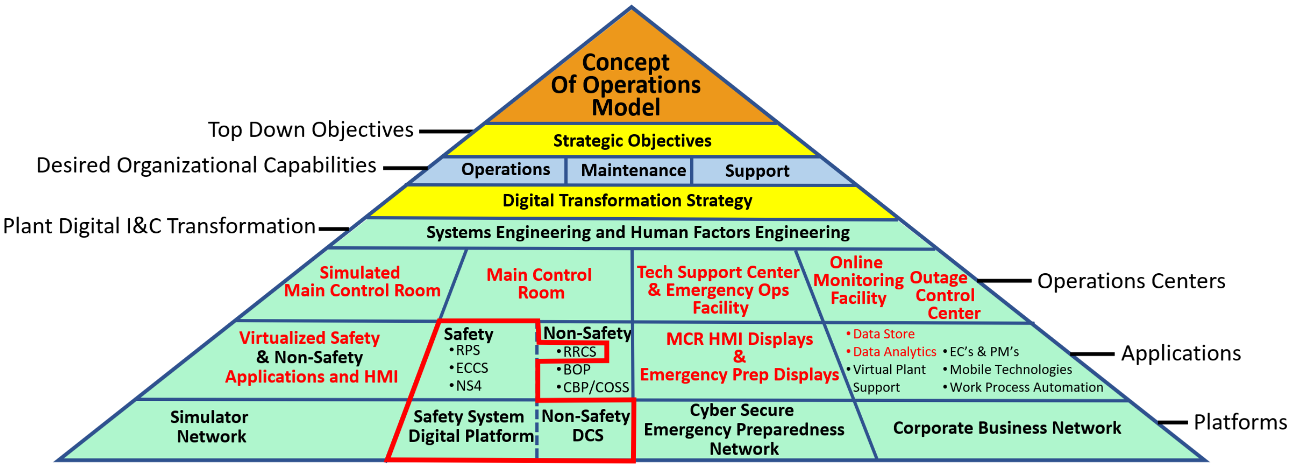

Figure 1. Advanced Concept of Operations Model. (SR I&C Pilot Scope outlined in red)

The Advanced Concept of Operations Model 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 realize 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. This promotes a business-driven Digital Transformation Strategy that reformulates the traditional labor-centric model for plant operation to a technology-centric plant operational model. This transformation lends itself to fewer onsite staff that are focused on daily operations, while 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. This composite LWRS research effort is enveloped under the umbrella of Integrated Operations for Nuclear (ION) at Idaho National Laboratory.

In Figure 1, the scope of the BWR SR I&C Pilot Upgrade Project is outlined in red within the larger Advanced Concept of Operations Model. The pilot project includes:

1. A common, SR, Plant Protection System (PPS) platform that will implement the functions of the following BWR systems as applications:
    a. Reactor Protection System (RPS)
    b. Emergency Core Cooling Systems (ECCS)
    c. Nuclear Steam Supply Shutoff System (N4S) – also referred to as the Primary Containment Isolation System in other BWRs. The Leak Detection System is also absorbed into the N4S.
2. A non-safety related (NSR) platform will be installed to host the existing SR Redundant Reactivity Control System (RRCS) functions. 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," the RRCS must remain independent of the PPS 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 eventually host most of the unit NSR I&C functions. The NSR DCS is also expected to host any necessary diverse actuation system (DAS) functionality, should a defense-in-depth and diversity (D3) analysis of the PPS identify the need for such diverse functionality. 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 the same effect of reducing equipment count and overall equipment diversity, thus reducing costs including training requirements, the number of procedures, and spares inventory.

This basic scope was established at Pilot inception. Once design concept development began, it became apparent that a more detailed scope boundary was needed. Typical BWR design documentation assigns I&C equipment to the fluid, mechanical, and electrical systems to which they are attached. This equipment is then shown as interfacing to the RPS, N4S, ECCS, or RRCS. To accomplish a complete digital upgrade to address SR I&C obsolescence, the Pilot Project scope was expanded to address these additional I&C items. This includes logic devices that are replaced by this project and field sensors and field actuators that are not changed by this project. Field sensors and actuators must also be also considered in the design. This resulted in the incorporation of electronic devices from a total of 20 plant systems.

I.B Design Tenets

Ten basic design tenets for the SR I&C Pilot Upgrade Project were established to support the Advanced Concept of Operations and promote long-term industry economic viability:

1. Replacement equipment is to provide more than like-for-like functionality when compared to the existing equipment. Instead, digital upgrades leverage technology capabilities as part of a holistic effort to establish a "New State" that reduces the total cost of ownership (TCO) and is receptive to expansion, the incorporation of new technologies, and new software

applications without redesign.

2. The PPS and the NSR DCS are to be expandable "target platforms" onto which the functions of obsolete I&C systems are migrated. Over time, I&C system diversity will be reduced, reducing TCO. These two target platforms (PPS in red and the NSR DCS in green) form the foundation of a holistic, enterprise-wide Digital Infrastructure shown in Figure 2.

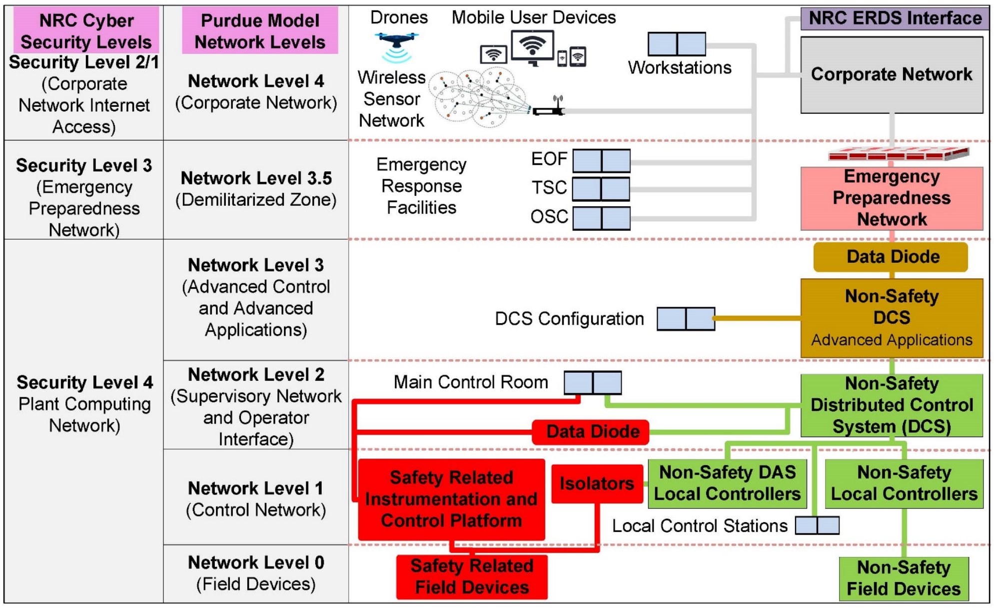

Figure 2. Simplified Digital Infrastructure diagram.

Digitization and unidirectional I&C plant information transfer by the target platforms to higher levels of the Digital Infrastructure is shown in Figure 2 enables remote monitoring and data analytics capabilities to further reduce facility TCO. These capabilities are identified as red text items in Figure 1. More information with regards to the Digital Infrastructure concept and its implementation, use, and lifecycle support strategy can be found in a related research report.[1]

3. The standard design from input/output devices through the human-system interface for the target I&C platforms minimizes the number of disparate parts and implementation methods. This also includes standardization of

Human Factors Engineering efforts and cybersecurity, which lowers TCO.

4. I&C upgrade development and implementation costs as well as technical and licensing risks are reduced by applying “state-of-the-industry” technology. This includes using a generic digital platform for PPS that has been approved for first-echelon safety system use by the Nuclear Regulatory Commission (NRC), enabling use of the streamlined Alternate Review (AR) process defined in Digital Instrumentation and Controls Interim Staff Guidance #06 (DI&C-ISG-06), Revision 2.[2]
5. The use of proven technology reduces project cost risk. Developing new system platforms is time consuming, costly, and unnecessary to improve economic viability.
6. The enhanced reliability of digital technology is leveraged. Using proven platforms reduces the potential for platform software design errors. Properly designed and tested application code has a limited potential to fail. This, coupled with increased component reliability and component count reduction when going from analog to digital, improves system and plant reliability and availability.
7. Capabilities of new I&C systems to capture and correlate plant data for systems serviced by the new digital I&C platforms are leveraged. Augmenting existing functionality provides data and control capabilities previously unavailable to Main Control Room operators. This aids in eliminating remote stations in the future and reduces dependence on data retrieved by equipment operators. Trending, diagnostic, and prognostic features enabled by the availability of this data are used throughout the Digital Infrastructure shown in Figure 2 to improve plant performance and reduce time-based maintenance activities.

8. Design attributes and advanced fault detection and self-diagnostic features of new digital platforms reduce calibration and surveillance costs when compared to analog systems. These labor savings are enabled for the balance of plant operational life.
9. Technology obsolescence is managed from Pilot Project inception. Design decisions and vendor contracting are accomplished in a way that manages obsolescence and promotes the migration of intellectual property (e.g., control algorithms, graphics displays, system configurations) when necessary equipment hardware and operating system "technology refresh" activities occur.
10. The Pilot Upgrade Project addresses first-of-a kind engineering, licensing, and cost risk reduction activities. The non-proprietary deliverables produced by the Pilot have been and will continue to be made available to the nuclear industry so that they can be leveraged to economically perform similar upgrade projects across the industry as a foundation for a larger Digital Transformation.

I.C Pilot Project Execution and Licensing Approach

The SR I&C Pilot Upgrade Project is also using the latest industry guidance, including the Nuclear Industry Standard Design Process,[3] the Standard Digital Engineering Process,[4] and the Electric Power Research Institute (EPRI) Digital Engineering Guide (DEG).[5] By using these industry standard processes, the concepts and methods used become fully transportable to all nuclear plant owner-operators.

Phases for the Pilot Project directly follow the EPRI DEG and include:

1. Phase 0: Initial Scoping
2. Phase 1: Conceptual Design

3. Phase 2: Detailed Design
4. Phase 3: Implementation (which includes Installation Planning, Install/Test, and Closeout)

Project activities are grouped differently for this effort when compared to the EPRI DEG[5] for several reasons described below. Project Phase activities are broken into four main categories as follows:

1. Activity 1 — Engineering and Operations: These two areas are very closely intertwined in this effort. Engineering services provided by vendors and subcontractors are also included in Activity 1.
2. Activity 2 — Licensing: While included with Engineering in the EPRI DEG[5], 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.[2] Licensing and engineering activities must be coordinated, and insights from both must be considered in the design.
3. Activity 3 — Project Management: This activity guides all others and is broken out separately as provided in the EPRI DEG. This also clearly defines key project management authorization milestones.
4. Activity 4 — Procurement and Installation: This includes activities for both hardware and software. For the Initial Scoping Phase, this is combined with the Project Management activity. The installation scope is also coordinated with Engineering activities.

The relationship between Project Phases and Project Activities is depicted pictorially in Figure 3 below as adapted from the EPRI DEG.

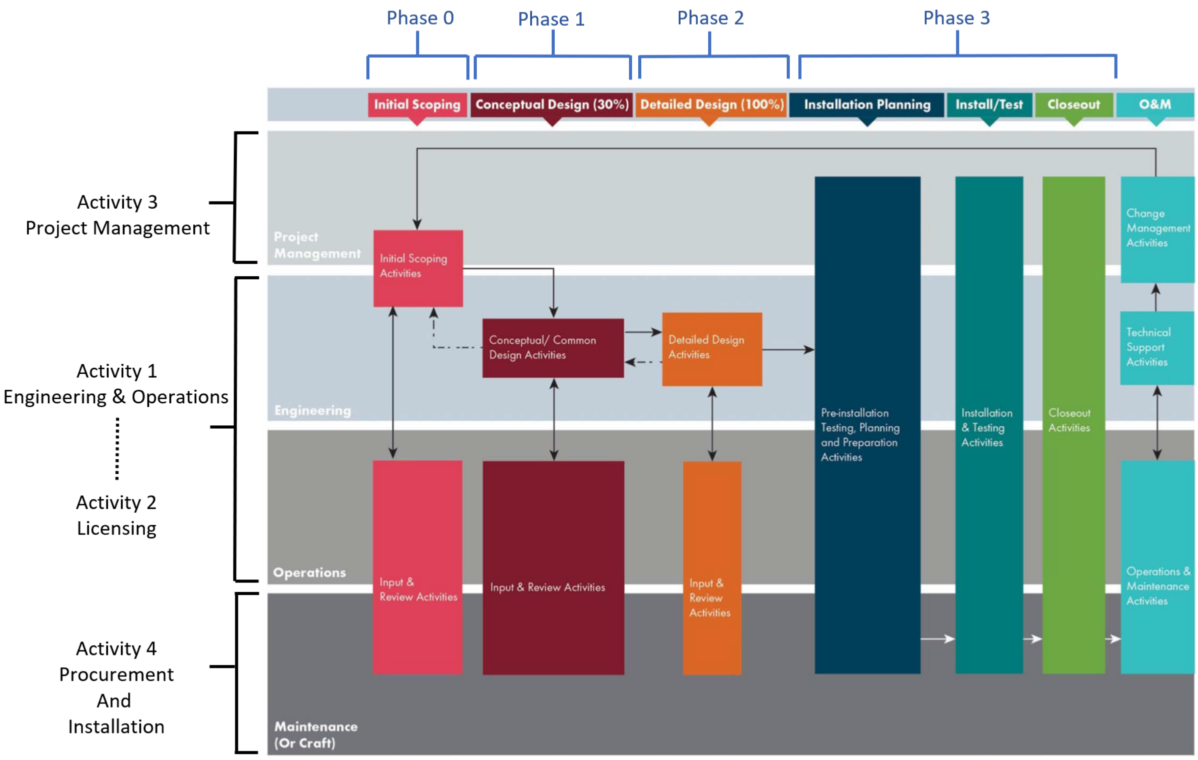

Figure 3. PPS and RRCS design change swimlane diagram.

The remainder of this paper summarizes efforts to execute the activities described above for the Initial Scoping (Phase 0) and presents associated lessons learned.

II. INITIAL SCOPING PHASE ACTIVITIES AND DELIVERABLES

II.A Activities

An experienced and diverse Research and Design Team was assembled to conform the SR I&C Pilot Upgrade to the Plantwide Concept of Operations and to apply the design tenets described above. While the Research Team and the Design Team consisted of the same personnel, a subtle but important distinction between their roles, and the products they produced, needs to be made.

1. The Research Team, led and funded primarily by the Department of Energy through the LWRS Program at Idaho National Laboratory, created first-of-a-

kind 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 make no commitments for Exelon. The research products were supported by Exelon and tailored to the Limerick Generating Station (LGS) as research baseline units.

2. The Design Team, led and funded by Exelon with LWRS support as described above, leveraged 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 adapted research products to meet Exelon specific engineering and project management objectives and implementation timelines and to conform to Exelon selected vendor product capabilities. It is expected that other utilities will use Research Team products in a similar manner.

The Research and Design Teams included Subject Matter Experts (SMEs) on the existing systems being replaced including plant system engineers, design engineering, operations, maintenance, simulator training, and licensing personnel. The teams also included SMEs familiar with the attributes of new technology and new processes envisioned for application in the Pilot upgrade.

Business analysts were also included in the Research/Design Teams. Their function was 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 Project Management Activities and Deliverables (Section II.C below), because their work products directly support project management decision making.

II.B Engineering and Licensing Deliverables

II.B.1 Research Decision Matrix

The Research Team considered existing LGS design bases, requirements, constraints, and licensing bases during Initial Scoping Phase design concept iteration. This team also balanced other items such as the technical, programmatic, and economic objectives driving the upgrades; as-built condition of the units being upgraded; upgrades to 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 were made based upon the team's knowledge and experience.

Decisions of this nature are necessarily utility and unit specific. The LGS-specific Research Decision Matrix provided in Appendix D of INL/EXT-20-61079, "Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade,"[6] captures a snapshot of decisions that the Research Team made in order to produce the vendor-independent functional requirement baselines (described in Section II.B.2 below) and the License Amendment Request (LAR) Framework Document (described in Section II.B.3 below). Research decision 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 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 other research products described in this subsection 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. Other utilities could face similar issues and concerns as captured in the matrix but should come to their own conclusions and decisions, based on the unique requirements of each nuclear generating station.

II.B.2 Functional Requirements Baselines

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

1. A SR PPS platform and application functional requirements baseline[6]
2. A NSR DCS platform and application requirements baseline for RRCS[6]

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 project scope in order to provide a firm foundation for the two documents. MPR coordinated extensively with personnel from the Exelon LGS and LWRS in the creation of the functional requirements baselines. Exelon leveraged the requirements baselines to create a performance specification used to solicit vendor requests for proposals.

II.B.3 License Amendment Framework Document

MPR was also subcontracted to lead the authoring of a 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 Vendor-Independent LAR Framework Document.[6]

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 DI&C-ISG-06, Revision 2 AR process,[2] which should be maintained for the final, complete LAR. 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,[7] are not incorporated in the LAR Framework Document, although the digital specific guidance of NEI 06-02 was 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 the non-digital portions of NEI 06-02 to the utility to add and thus 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.

For Initial Scoping Phase design concept development, the LAR Framework Document supports three separate but related purposes. First, 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 the removal of surveillance testing and calibration associated with the installation of the PPS. This LAR Framework Document design concept is consistent with the Plantwide Concept of Operations described above. 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 enable the plant to leverage that technology to deliver on the design tenets listed above.

Second, the LAR Framework Document provides a mark-up of the proposed changes to the Technical Specification surveillance tests required. When changing technology from an analog to a digital technology, significant numbers of the surveillance tests are affected, just based on the failure mechanisms eliminated in the digital implementation and the added self-test capabilities provided by the digital platform. The LAR includes the rationale for eliminating many of the surveillance tests required to support the analog system. The failure mechanisms that the surveillance tests were designed to uncover do not exist in the digital implementation.

Third, the LAR Framework Document provides a foundation on which to generate a complete LAR consistent with NRC expectations for a digital system upgrade, consistent with the guidance in NEI 06-02.[7] The LAR Framework Document provides 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 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 for the AR process,[2] the NRC staff can provide early feedback on the technical content. Early communication with the NRC is imperative to reduce implementing utility licensing risk.

The technical information in the LAR Framework Document, along with the functional requirements baselines described in Section II.B.2, are intended to be adapted and leveraged by utilities to meet their specific needs for similar upgrades.

The vendor-independent LAR Framework Document is written at a level of detail to satisfy the DI&C-ISG 06 AR process[2] and NEI 06-02.[7] 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 Ref. 6 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 technical information supporting the top-down design.

II.C Project Management Activities and Deliverables

Project Management and Procurement activities and deliverables for the Initial Scoping Phase are also identified in the EPRI DEG.[5] In the Pilot Initial Scoping Phase, Exelon efforts in this area included:

1. Assignment of a Project Manager and assembly of the Project Team
2. Obtaining funding for and executing Initial Scoping Phase activities
3. Development of a Project Plan, Risk Management Plan, and Risk Register
4. Development of a Project Procurement Plan and completion of a vendor down-selection effort
5. Development of a Project Authorization Package, including a Project Schedule, Project Budget, and a Project Economic Analysis, including an estimate of a Total Project Cost Range

The Engineering and Licensing deliverables described above provided a design concept to support vendor down-selection.

To support the Project Economic Analysis included in the Project Authorization Package, ScottMadden Inc. was subcontracted by the LWRS Program to lead the authoring of INL/EXT-20-59371, "Business Case Analysis (BCA) for Digital Safety-Related Instrumentation & Control System Modernizations."[8] Ref. 8 illustrates a methodology for utilities considering digital modernization of I&C systems to evaluate cross-functional labor and material benefits and conduct a financial analysis as part of the business case development for digital modernizations. The objectives of this research product include:

1. Providing a bottom-up approach to:
    a. Establish labor and material costs for current systems within the defined I&C upgrade scope
    b. Identify expected labor and material benefits enabled by the upgrade design concept
    c. Validate the expected benefits with SMEs
2. Demonstrating the methodology used to perform a detailed financial analysis, including:
    a. Estimation of annual benefits related to organizational workload reductions for both online and outage work, including both quantitative benefits (which were included in the BCA result) and qualitative benefits (which were identified as areas of additional potential savings but were not included in the BCA result)
    b. Estimation of annual benefits related to materials and inventory expenditures
    c. Valuation of avoided lifecycle costs associated with escalation of material expenditures
    d. Valuation of the modernization over the lifecycle of the Station
3. 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 by:
    a. Providing example worksheets and templates to support a BCA performed by other utilities
    b. Providing lessons learned and opportunities for utilities planning a similar digital modernization effort, specifically identified in Appendix A of Ref. 8

The most significant finding of the BCA effort was establishing that the material costs for sustaining the operation of obsolete I&C equipment are 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 of more than 20%. This observed rate is higher than the expected rate of 3–5%, which is considered typical for the industry. A comparative analysis of both labor and material trends for this sample system, illustrated in Figure 4 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.

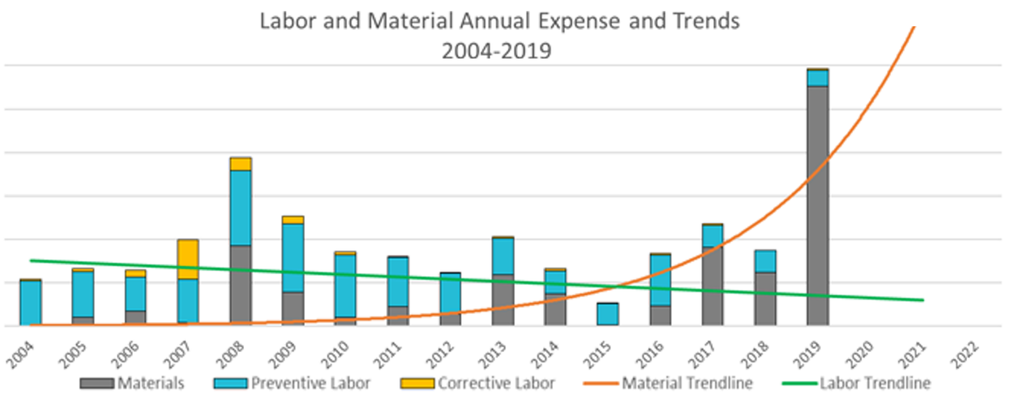

Figure 4. Sample system labor and material cost analysis.

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

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

Given that component obsolescence is driving rapidly increasing system costs, the replacement of obsolete components with a modern system, with a strong, demonstrated vendor commitment to maintaining the platform, eliminates the current risks posed by this issue. A lifecycle management strategy for the new system would further mitigate this risk from occurring in the future.

III. LESSONS LEARNED

Over thirty specific lessons learned are captured in Ref. 9 for the Initial Scoping Phase of the SR I&C Pilot effort executed as a public/private partnership established between the Department of Energy LWRS Program and Exelon. Key items are summarized in the subsections below.

III.A Engineering and Operations

1. Establish a Plantwide New State vision and design the new SR PPS and NSR DCS platforms to fit into that New State. The vision drove engineering design concept decisions. Failure to consider the New State vision will result in future modifications to the PPS to fit into the New State.
2. Utility I&C SME knowledge is centered on the operation and support of current systems. Utility SMEs are not normally asked to extract true functional requirements from existing documents and designs to apply on new digital platforms, including determining which design decisions from the original system become requirements in the replacement system. It is even more difficult to identify new requirements for advanced features offered by new digital vendor products without knowledge of the new platform's capabilities.
3. Ensure correctness and applicability of the implicit assumption that nothing being changed affects the assumptions in Chapter 15 of the unit's Final Safety Analysis Report.

4. The more detailed the information that is incorporated in the Initial Scoping Phase design concept and communicated early to the vendor, the more likely quality design products will be produced at lower costs. Such information can guide vendor selection but this information 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.
5. Project scope needs to be bounded as early and completely as possible, realizing that scope will shift as the Design Team delves into the existing system designs and identifies additional scope that would be useful or appropriate. Poor early scope bounding can negatively affect BCA efforts.
6. 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 Licensing to help inform the design and avoid rework associated with concepts that either cannot be licensed or would be difficult to license with only limited benefits.

III.B Licensing

1. Licensing must maintain active participation in the design and requirements elicitation processes and maintain active participation through the life of a project. Licensing has a unique perspective on what is possible within a unit's regulatory framework and why certain aspects of a system exist. Licensing also will be responsible for defending changes to the current system designs. Licensing must also ensure that changes made to the system remain within the Final Safety Analysis Report Chapter 15 safety analyses or that such changes are supported by new analyses and presented in the LAR.

2. Digital I&C platforms inherently require less manual labor than currently expended to operate and maintain existing analog I&C systems. These labor savings may be equated to reductions in required personnel. Licensing staff should be engaged to ensure that potential reductions in personnel appropriately consider licensing basis requirements.
3. The Design Team and utility Licensing staff should remain involved in LAR development through NRC acceptance and Safety Evaluation Report issuance even if LAR finalization is turned over to the vendor to ensure that the utility remains informed of vendor efforts and design choices.

III.C Project Management and Business Case Analysis

1. Having a plant Project Manager in the Project Initiation Phase drove collaboration on LWRS Research Team and Exelon Design Team efforts, as well as scope, schedule and cost estimate development for the Exelon Project. 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 established Exelon confidence to authorize proceeding to Phase 1 – Conceptual Design.
2. Cost data for systems being replaced must be gleaned from site databases. This can be challenging. For the Pilot Project, a method had to be developed to glean pertinent information from the databases. For this research, the available historical data amounted to hundreds of thousands of records for the set of 20 examined plant systems. Experienced data analysts supported by technical experts were critical in gleaning and evaluating pertinent information from these records to support the BCA. Seven additional detailed points in this area are

provided in Ref. 9.

3. Accurately assessing digital modernization benefits required interactions with plant staff (e.g., I&C craft that perform surveillances likely reduced through analog I&C system elimination). These interactions should be planned early for a BCA to ensure resource availability for verifying estimated benefits. Additionally, early and frequent engagement ensures that stakeholders feel a sense of project ownership. This is critical for efforts involving changes to plant structures, systems, and components and drastic changes to workflows and organizational hierarchies.
4. The BCA requires information regarding the proposed modernized I&C design. This information must be validated by technical SMEs in engineering, licensing, and operations. Because these organizations were on the Research and Design Teams and early design concepts were available in the Initial Scoping Phase, a higher fidelity BCA was performed, where the derived economic benefits from the modernized I&C design were appropriately justified by the design concept.
5. Benefits estimation associated with SR I&C modifications requires review of the plant's Technical Specification surveillance requirements related to those systems and their associated testing programs. Understanding the capabilities of the system to be installed and basing the elimination of technical specification testing against those requirements leads to an understanding of which surveillance requirements can be deleted. 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.

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

IV. RESULTS AND FUTURE PLANS

As a result of the combined effort of Exelon Generation and research participants, Conceptual Design Phase activities for the subject upgrade at LGS were approved by Exelon. The Department of Energy also awarded a $50 million cost share award to Exelon in order to pave the way for SR I&C modernization and associated control room upgrades across the U.S. nuclear fleet.[10] Idaho National Laboratory reports describing and supporting this effort (Refs. 1, 6, 8, and 9) are publicly available for other utilities to leverage in support of similar digital I&C upgrades. Additional LWRS research reports are planned for the Conceptual Design Phase, Detailed Design Phase, and the Implementation Phase of the LGS Project to document the process followed and promulgate lessons learned to industry.

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