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Light Water Reactor Sustainability Program

Pilot Business Case Analysis for Digital Infrastructure

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U.S. Department of Energy

Office of Nuclear Energy

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EXECUTIVE SUMMARY

The Inflation Reduction Act Has Provided an Opening to Dramatically Change and Improve the Economics of Nuclear Power

Until recently, the commercial nuclear sector has faced unprecedented financial challenges driven by low natural gas prices and subsidized renewables, in a marketplace that did not reward carbon-free baseload capacity. The industry is also plagued by labor shortages, increasingly obsolete labor-centric operating models and antiquated analog technology that threaten the viability of the long-term operations of domestic nuclear facilities.

In this context, the economic survival of nuclear power plants requires an efficient and technology-centric operating model that harvests the native efficiencies of advanced technology. Such transformations have been made in many other industries – notably, oil and gas. The passage by Congress of the Inflation Reduction Act (IRA) in 2022 provides nuclear operators with unprecedented economic incentives to pursue these upgrades. To realize the benefits of these incentives and achieve the necessary transformations in the nuclear operating model, the nuclear industry must overcome both the continuing unease about licensing pathways and uncertainty related to implementation costs.

Licensing Concerns for Safety-Related Instrumentation and Control Upgrades Have Eased

Historical licensing barriers have largely precluded the modernization of nuclear plant first-echelon safety-related 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 process reflected in Digital Instrumentation and Controls Interim Staff Guidance #06 (DI&C-ISG-06), Revision 2, *Licensing Process* [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 risks associated with being the first adopter of the DI&C-ISG-06, Revision 2 process for a major critical safety system. Constellation Energy Generation (CEG) and the Idaho National Laboratory (INL) Light Water Reactor Sustainability (LWRS) Program have been collaborating to address this issue head-on. This collaboration produced the following two research reports:

- INL/EXT-20-61079, *Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade* [2], and
- INL/EXT-20-5937, *Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations"* – as Applied to the Limerick Generating Station (LGS). [3].

These documents were leveraged by CEG to develop a bid specification to engage vendors and to support a business case justification to approve a safety-related I&C upgrade project for the LGS for implementation. CEG has since approved the project, is advancing the design, and has submitted a license amendment request to the NRC for approval. Two documents that document CEG project activities and lessons learned have been produced, including:

- INL/EXT-20-59809, *Safety-Related Instrumentation and Control Pilot Upgrade: Initial Scoping Phase Implementation Report and Lessons Learned* [4]
- INL/RPT-23-72105, *Safety-Related Instrumentation and Control Upgrade: Conceptual – Detailed Design Phase Report and Lessons Learned* [5]

INL researchers continue to be involved in the LGS project in the human factors engineering (HFE) area.

Digital Infrastructure Pilot Business Case Objective One: Addressing Concerns with Implementation Costs by Demonstrating Long-Term Value of Digital I&C Modernization

The first major objective of this report and the wider LWRS research is to relieve the concern associated with prohibitively high implementation costs of plant I&C upgrades. This is addressed through demonstrating the long-term net economic value of digital upgrades with an in-depth exposition of the business case for, and detailed process associated with digital I&C modernizations.

To fulfill this first objective, the report describes the application of the I&C Business Case Analysis (BCA) methodology on an expanded set of safety-related and non-safety I&C digital upgrades envisioned for implementation at a Merchant Non-Fleet Two-Unit PWR nuclear plant, Comanche Peak - also referred to as the "Reference Plant." The purpose of a BCA is to show such upgrades can be economically justified. LWRS pilot research in this area is intended to enable this modernization effort and provide a roadmap for others to follow. The plant "Owner," Comanche Peak Power Company, LLC, is pursuing a digital upgrade of 22 current safety and non-safety related I&C subsystems by migrating their function or interfacing equipment that performs their function into either a safety-related digital platform or a non-safety distributed control system (DCS) platform. This two-platform solution is being pursued in order to consolidate respective safety-related and non-safety related functions as presented in LWRS research report INL/EXT-21-64580, *Digital Infrastructure Migration Framework* [6].

This BCA methodology systematically establishes a forecast of expected lifecycle costs for existing safety-related and non-safety I&C subsystems identified for upgrade by:

- Definitively bounding the scope of current I&C subsystems envisioned for upgrade.
- Collecting historical labor and material usage data that bound cost contributors related to the subsystems to be upgraded.
- Analyzing the data to establish lifecycle cost forecasts for the current subsystems.
- Estimating the opportunity cost of lost generation revenue from equipment reliability events due to failure of current I&C components for long-term operations. A crucial benefit of system modernization and digitalization is the prevention of unplanned forced outages resulting from the failure of aging and obsolete safety and non-safety equipment which leads to lost generation revenue. This is an important addition to the BCA developed and used for the LGS safety-related I&C upgrades [3].

In collaboration with operations, engineers familiar with the attributes of the replacement I&C digital platforms to be used in the upgrade and how they are envisioned to be applied, cost savings categories and expected savings in those categories are then identified and applied using the analysis tools developed for this purpose. The result is an estimated Present Value (PV) of savings enabled by the upgrade. The benefits of these cost savings are both direct, e.g., surveillance labor costs, as well as indirect cost avoidance items, e.g., inventory carrying costs.

When utility-provided I&C digital upgrade cost estimates are included, the resultant BCA provides a Net Present Value (NPV) for the upgrade project and Internal Rate of Return (IRR). The detailed BCA for applying the two-platform I&C solution from Reference [6] provides a compelling case for these digital I&C upgrades. Table ES-1 summarizes the results of this BCA for the baseline case for 30 years and 50 years of continued operations.

Table ES-1. Net Present Value of I&C Digital Modernizations for 30 years and 50 years

Scenario Title	Payback Period	NPV	IRR
Baseline (30 Years of Continued Operation)	17.8 years	$74M	8.1%
Baseline (50 Years of Continued Operations)	17.8 years	$685M	11.8%

Digital Infrastructure Pilot Business Case Objective Two: Laying the Foundations for Larger Digital Transformations Via Integrated Operations for Nuclear (ION) Research

The second major objective of this report is to lay the foundation to expand the use of the BCA methodology and associated tools developed as described in Reference [3] to a larger scope of digital upgrades beyond I&C, in order to affect a larger digital transformation of a nuclear plant described in Reference [6]. This effort is guided by the Integrated Operations for Nuclear (ION) research as summarized in the following two LWRS research reports:

- INL/EXT-21-64134, *Process for Significant Nuclear Work Function Innovation Based on Integrated Operations Concepts* [7], and
- INL/RPT-22-68671, *Integrated Operations for Nuclear Business Operation Model Analysis and Industry Validation* [8].

The intent of this effort is to optimize the application of digital technology across the larger business enterprise and to lower the total ownership cost (TOC). The overall goal of ION research is to enable long-term nuclear plant economic viability of the existing U.S. nuclear fleet. The potential leveraging of work reduction opportunities (WROs) as presented in references [7] and [8] for the Reference Plant is summarized in this report. Details of the application of general ION-identified WROs at the Reference Plant along with any other specific WROs identified by analysis of Reference Plant work processes is planned as part of future LWRS research in collaboration with the Reference Plant Owner. These are discussed in detail in Section 11 and summarized in Table ES-2 below. The values presented in the table below are representative of costs associated with a generic, two-unit PWR, known in this report as the “Representative Plant,” for a project life of 20 years.

Table ES-2. Net Present Values for Priority WROs as Applied to Reference Plant

WRO Category	WRO(s)	Net Present Value (NPV) (20 years)	Probability of Positive NPV
Mobile Worker Technology	Automated Troubleshooting	$17.3M	100%
	Remote Plant Support/Remote Assistance		
Condition Based Monitoring	Implement Condition-Based Maintenance	$37.9M	95%
Advanced Training Technology	Operations Training Modernization	$5.9M	87%
	Technical Training Modernization		
	General Training Modernization		
	Training Records Modernization		
Software Application Assisted Business Processes	Automated Planning and Scheduling	$5.9M	75%
TOTAL		**$67M**	**88%**

Section 1.1 provides a brief synopsis of the LWRS Plant Modernization Pathway and the foundational concepts of IONs and Digital Infrastructure (DI) that underpin this effort. This is provided for the benefit of those who are unfamiliar with these concepts and as a simplified refresher for those who may benefit from it being specifically summarized within the context of this work.

Points to Note About Pilot Business Case Research and Presentation of Results

The BCA-specific results for the referenced Owner's units are considered proprietary to the Owner and are provided to the Owner separately from this genericized research product. The proprietary results are being used by the Owner to support the approval of conceptual design efforts for digital upgrades at the Reference Plant. For this research report, financial data have been altered to protect the Owner's proprietary information. As presented herein, BCA results are intended to be illustrative and representative in scale of benefits and are not intended to provide material data utilized in the Owner's internal project cost-benefit analysis.

The ultimate purpose of this public, non-proprietary report is to communicate the process and related business case tool to enable similar BCA for digital upgrades throughout the industry. It is expected that this methodology can be abstracted and used for nearly any digital upgrade.

This research also includes Appendix B: Business Case Analysis Presentation. This was created (in Microsoft PowerPoint) to present the benefits of the envisioned digital safety and non-safety I&C subsystem upgrades to further enable the generation of a compelling case for upgrades to both Reference Plant and Owner management. This has been anonymized and the results genericized such that the presentation contains no proprietary information.

The BCA methodology was produced by ScottMadden, Inc., in collaboration with LWRS researchers. Key support for applying this methodology was also provided by subject matter experts (SMEs) from the Reference Plant. The LWRS Program appreciates the research support provided by the Owner. This document makes no Owner commitments.

CONTENTS

FIGURES

TABLES

ACRONYMS AND DEFINITIONS

ACO	Avoided Cost of Obsolescence
AI	Artificial Intelligence
AMSAC	ATWS Mitigation System Actuation Circuitry
ATWS	Anticipated Transient Without Scram
BCA	Business Case Analysis/Analyses
BCAM	Business Case Analysis Model
BOP	Balance of Plant
CAGR	Compound Annual Growth Rate
CAP	Corrective Action Program
CEG	Constellation Energy Generation
CM	Corrective Maintenance
CFR	Code of Federal Regulations
CoC	Cost of Capital
CR	Corrective Action
DA&A	Data Architecture and Analytics
DCS	Distributed Control System
DADS	Digital Rod Position Indication Advanced Display System
DAS	Diverse Actuation System
DI	Digital Infrastructure
DI&C-ISG-06	NRC Digital Instrumentation and Controls Interim Staff Guidance #06
DRPI	Digital Rod Position Indication
DCS	Distributed Control System
DDS	Detector Drive System
EN	Engineering
ENFMS	Excore Neutron Flux Monitoring System
EOF	Emergency Operations Facility
EP	Emergency Preparedness
EPRI	Electric Power Research Institute
FCF	Future Cash Flows
FMC	Flux Mapping Console
FTE	Full Time Employee
HFE	Human Factors Engineering
HSI	Human-System Interfaces
HTI	Human-Technology Integration
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Controls
INL	Idaho National Laboratory
I/O	Input/Output

IO	Integrated Operations
ION	Integrated Operations for Nuclear
INPO	Institute of Nuclear Power Operations
IRA	Inflation Reduction Act
IRR	Internal Rate of Return
IT	Information Technology
ID	Identifier
LAR	License Amendment Request
LEFM	Leading Edge Flow Meter
LGS	Limerick Generating Station
LLC	Limited Liability Company
LWRS	Light Water Reactor Sustainability (Program)
MA	Maintenance
MIDS	Movable Incore Detector System
MCR	Main Control Room
MS	Microsoft
MSPI	Mitigating System Performance Index
NI	Nuclear Instrumentation
NIS	Nuclear Instrumentation System
NPV	Net Present Value
NR	Non-Routine (Maintenance)
NRC	Nuclear Regulatory Commission (United States)
NSSS	Nuclear Steam Supply System
O&M	Operating and Maintenance
OLM	Online Monitoring
OP	Operations
PAMS	Post Accident Monitoring System
PM	Plant Modernization or Preventive Maintenance (context specific)
PPS	Plant Protection System
PTPG	People, Technology, Process, Governance
PV	Present Value
PWR	Pressurized Water Reactor
RCS	Rod Control System
Reference Plant	A specific two-unit nuclear station use as a baseline for the specific Pilot DI Business Case Analysis that is the subject of this research document
Representative Plant	A generic, two-unit nuclear station use as a baseline to for BCA to determine estimated cost savings when applying ION WROs
RG	Regulatory Guide (issued by the NRC)
RO	Reactor Operator
ROC	Return on Capital

RP	Radiation Protection
RPI	Rod Position Indication
RVLM	Reactor Vessel Level Monitoring
SG	Steam Generator
SME	Subject Matter Expert
SSPS	Solid State Protection System
SSRCS	Solid State Rod Control System
SSSS	Solid State Safeguards Sequencer
SV	Surveillance (Test)
TOC	Total Ownership Cost
WMS	Work Management System
WO	Work Order
WRO	Work Reduction Opportunity

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PILOT BUSINESS CASE ANALYSIS FOR DIGITAL INFRASTRUCTURE

1. INTRODUCTION

1.1 Digital Infrastructure in Context of Integrated Operations for Nuclear (ION)

The Plant Modernization (PM) Pathway of Light Water Reactor Sustainability (LWRS) Program is focused on deliberately applying digital technology to enhance the ability of existing nuclear plants in the United States to operate for a total lifetime of 80-100 years. These plants are currently managed using a labor-centric operations model that is increasingly inefficient and costly to operate and sustain when compared to modern generation plant operations such as a natural gas combined cycle plant or other comparable heavy industry such as petrochemical facilities.

The IONs concept, developed by the LWRS PM Pathway, provides a comprehensive, business case-driven strategy to support Plant Modernization for the U. S. nuclear fleet. Its primary objective is to transition the existing labor-centric operating model into a more technology-centric approach. ION business transformation aims to maintain or improve plant safety and operating capacity factor while reducing TOC for the remainder of plant life. These objectives are shown at the top of Figure 1-1 below.

Plant Modernization Research Objectives and Goals				
Objectives	Extend the life and improve the performance of the existing fleet through modernized technologies and improved processes for plant operation and power generation. Develop modernization solutions that improve reliability and economic performance while addressing US nuclear industry's aging and obsolescence challenges. Deliver a sustainable business model that enables US nuclear industry to remain competitive.			
Research Areas	Digital Infrastructure	Data Architecture & Analytics	Human & Technology Integration	Integrated Operations for Nuclear
Outcomes	A multi-layered, sustainable digital foundation to enable plant modernization	Advanced monitoring and data processing to replace labor-intensive support tasks	Tools and methodologies that maximize efficiency while ensuring safety and reliability are maintained	Light water reactor fleet electric market competitiveness

Figure 1-1. LWRS PM Pathway Objectives and Goals

A complementary digital technology strategy is necessary to provide the foundation to host applications that are used both to directly operate the facility (instrumentation and control (I&C) systems) and to perform the other necessary tasks to most efficiently run the business of a nuclear plant. This is shown as the far left under Digital Infrastructure (DI) with associated outcomes. This technology strategy is captured in INL/EXT-21-64580, *Digital Infrastructure Migration Framework* [6]. A simplified depiction of the proposed DI is provided in Figure 1-2 below.

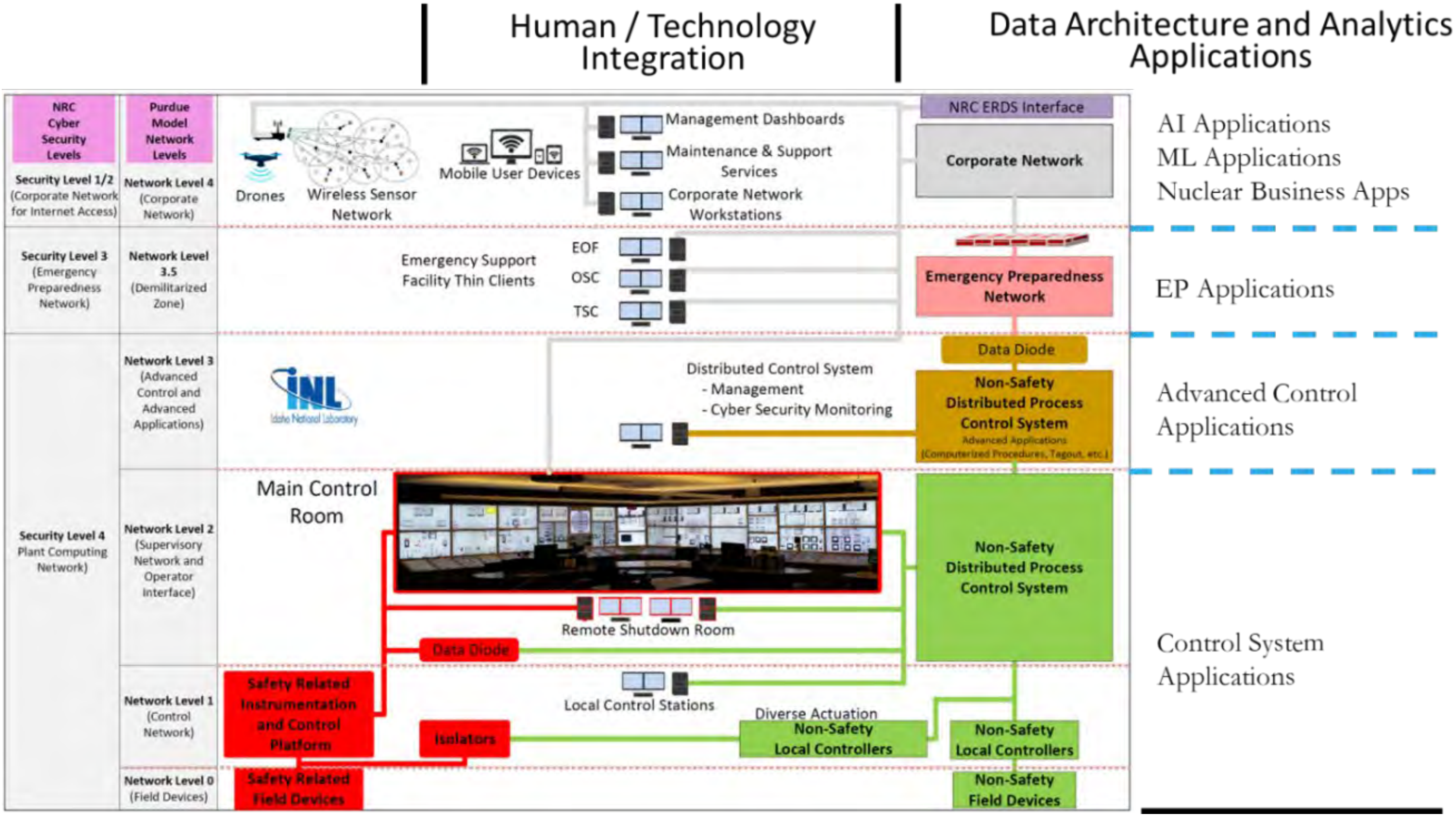

Figure 1-2. Simplified Digital Infrastructure Diagram

Determination of both the DI capabilities needed and the Data Architecture and Analytics (DA&A) applications to be hosted on the DI (as shown on the right of Figure 1-2) achieve this technology-centric concept of operations is accomplished by performing business case analyses. This document focuses on how these business case analyses are used to justify the development of the DI along with DA&A applications to achieve PM Pathway objectives.

There are two parallel and related business case methodologies that are being explored. The first addresses I&C upgrades. Prior to INL business case research, it was assumed by many in the nuclear industry that I&C upgrades could not be economically justified by themselves, resulting in a negative net-present-value (NPV) outcome. These upgrades were seen as a necessary "tax" that would have to be paid to address the obsolescence problem plaguing existing I&C systems which often have exceeded their design lifetime. These I&C upgrades would keep the plant operating, but other cost reduction activities would have to be pursued that would not only pay for themselves, but also pay for the I&C upgrades. However, earlier INL research has demonstrated that for plants that intend to operate for at least another 10-15 years, digital upgrades of safety-related I&C systems can indeed be economically justified [3].

The second parallel business case methodology has been focused on identifying workload drivers within the existing concept of operations for a nuclear plant and identifying work reduction opportunities (WROs). The objective of this effort is to (1) eliminate non-value added activities that have outlived their usefulness and (2) identify where technology could be applied to the performance of these labor-centric efforts to reduce workload in a way that produces a positive NPV. Two specific INL research documents that identify WROs and estimate their costs to implement along with forecasted operating and maintenance (O&M) savings are provided in [7] and [8] respectively.

This document captures efforts to date to apply these two methodologies to Comanche Peak (also referred to as "Reference Plant" in this document) owned by Comanche Peak Power Company, LLC (also referred to as "Owner" in this document). The LWRS Program appreciates the Owner's participation in this research. This document makes no commitments for the Owner.

1.2 Concept of Operations

Applying digital technology by itself to the existing plant concept of operations can provide some opportunities to reduce O&M costs. In order to achieve the envisioned transformation of the business of running a nuclear plant from the existing labor-centric operating model to one that is increasingly technology-centric, a corresponding transformational change of the plant concept of operations is required. The following subsections provide a general discussion of both the current state concept of operations and a transition to the envisioned new state to provide the context for the DI business case efforts presented in this report.

1.2.1 Generic Current State Plant Concept of Operations

A simplified depiction of a generic, current state plant concept of operations for existing nuclear plants is provided in Figure 1-3. While this discussion is referenced around a plant view, for a utility with a fleet of nuclear units, variations of the same model would apply to them all individually or to the whole fleet.

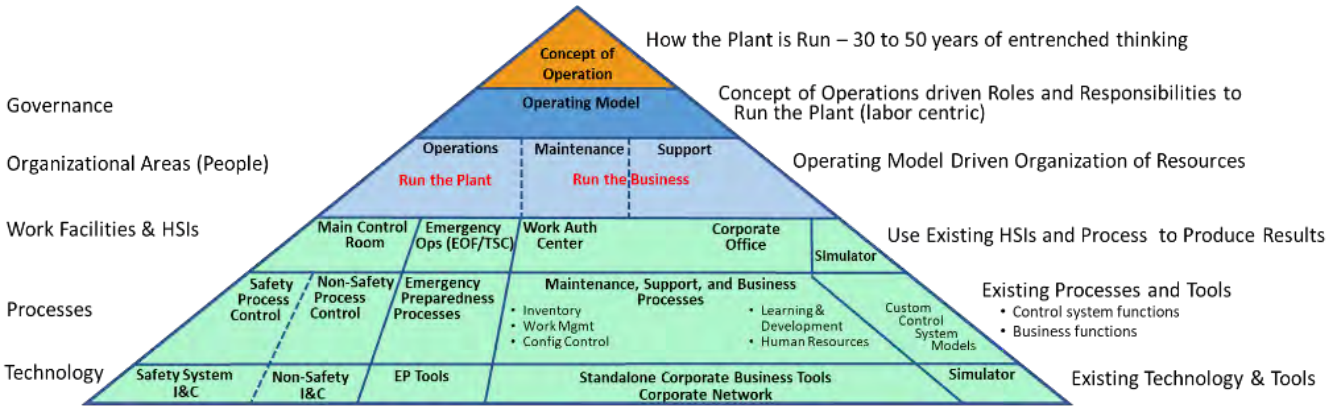

Figure 1-3. Current State Concept of Operations Diagram

The top two layers of the pyramid shown in Figure 1-3 depict the existing overall concept of operations and the governing operating model associated with it. The current concept of operations is focused on maintaining safety margins and maintaining or improving plant capacity factors. This has resulted in high levels of operational performance and capacity factors of over 93% for the U.S. commercial nuclear fleet. Efforts to establish and maintain this continued level of safety and operational performance, however, have largely been focused on the implementation and enhancement of labor-centric processes such as:

- 10 CFR 50.65,"Monitoring the Effectiveness of Maintenance at Nuclear Power Plants" (also known as the "Maintenance Rule")
- The Institute of Plant Operators (INPO) AP-913 "Equipment Reliability Process"
- The Mitigating System Performance Index (MSPI) and associated system health reports
- The Corrective Action (CR) Program
- Many other processes are associated with running the business of a nuclear plant.

This paper does not in any way intend to cast dispersions on this operating model. It has served the industry well for years and has resulted in the safe operation of the commercial nuclear fleet in the United States, while achieving the highest availability factors in the world. The challenge is that the O&M costs to sustain such a model with antiquated technology are increasing, which is significantly impacting the competitive position of U.S. nuclear power production. Critical existing technologies (such as safety-related I&C systems) are at or beyond their forecast useful life and are not sustainable.

The labor-centric nature of this model is driven by several factors, including the existing technologies, processes, and work facilities/human-system interfaces (HSIs) available at the plant. These elements are represented as the bottom three levels in Figure 1-3. A summary of current technologies employed is shown below:

- Safety-related I&C systems: Many of these systems are either analog or, in some cases, first-generation digital systems (e.g., Westinghouse 7300 systems). The cost for replacement parts is increasing and finding such parts is becoming more difficult over time. The skill of craft to maintain these obsolete systems is also waning.
- Non-safety I&C systems: These systems comprise a mix of direct-acting manual controls, analog control systems, electro-hydraulic/mechanical, pneumatic, and point solution digital systems. Some limited distributed control systems have been installed to upgrade certain technologies.
- Emergency Preparedness tools: These tools exhibit varying technology levels, ranging from telephone communications to point solutions or networked digital systems.

- Corporate Business tools: These tools vary from manual paper processes and the use of standalone software packages to networked databases and tools.

This current concept of operations and the associated, technology driven, labor-centric operating model are the root of the operating philosophy of many existing plants. The three fundamental organizational areas (operations, maintenance, and support) where people are assigned to implement the concept of operations and operating model are shown at the third level from the top in Figure 1-3. For the purposes of this report, these three organizational areas are defined more specifically and grouped differently. This is to align the current operating model described in this section with the new-state operating model described in Section 1.2.2 and associated business case efforts,

"Operations" as shown in the third layer from the top of Figure 1-3 supports activities that directly relate to operating the plant to produce power and to support emergency preparedness functions. This is the organizational area necessary to "run the plant" as shown in **red** above. The "maintenance" and "support" organizational areas as shown in Figure 1-3 are grouped as the necessary organizational areas to "run the business" of a nuclear plant. This is also shown in **red** above. This does not diminish their importance. To illustrate, the "run the plant" operations area must be available continuously (plant operators) or on call (to support emergency preparedness functions) to permit plant operation. Maintenance and support personnel largely work business hours except during workups and to perform outage maintenance. However, if the "run the business" function is not performed, the plant will soon be unable to operate because of equipment failures or failure to meet regulatory commitments.

It is important to mention that the Nuclear Energy Institute's "Delivering the Nuclear Promise" initiative has made significant progress in enhancing process efficiency and eliminating non-value-added activities. It was not within the charter of this initiative to propose a fundamental migration from a labor-centric to a technology-centric operating model.

1.2.2 Digitally Enabled ION New State Concept of Operations

Figure 1-4 provides a depiction of a digitally enabled new state concept of operations that is intended to enable the replacement of the current labor-centric model with one that is technology-centric.

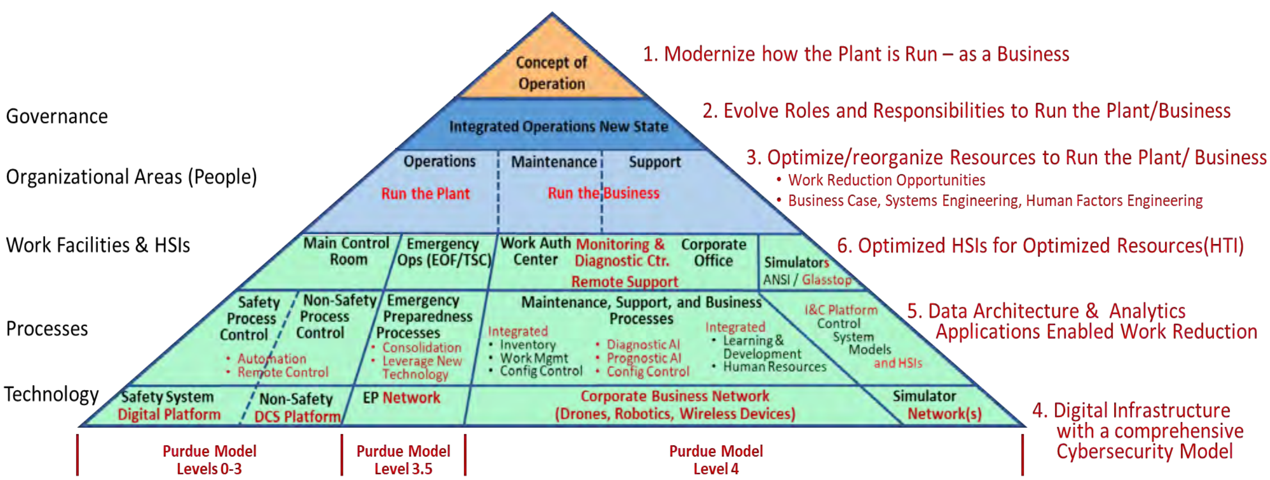

Figure 1-4. ION Enabled New State Concept of Operations Diagram

As can be seen, Figure 1-4 does not fundamentally alter the "what" when it comes to providing the basic outcomes of the existing concept of operations model shown in Figure 1-4. The need to "run the plant" and "run the business" are still necessary. What is proposed is changing "how" these outcomes are achieved by applying comprehensive DI associated DA&A applications across the enterprise. This technology-centric concept of operations is proposed to lower TOC while addressing obsolescence and cybersecurity concerns associated with digital systems.

ION documentation refers to people, technology, processes, and governance (PTPG) that support any concept of operation construct. These items appear to the left of both Figure 1-3 and Figure 1-4. Coupling the ION concept with the application of DI and DA&A applications proposes to reallocate current labor, rely on technology and automation to streamline selected work activities and source certain tasks to vendors who can more efficiently support the industry for other tasks (e.g., engineering, fuels).

1.2.2.1 Work Reduction Opportunity Identification

The approach used to achieve this is outlined in the description of the six items shown to the right of Figure 1-4, as detailed below.

1. Modernize how the plant is run – as a business

   The plant concept of operation is modernized through the judicious application of digital technology. Technology is not installed for its own sake, but as justified by business case analyses to provide maximum operational (safety/capacity factor) and financial benefit. Equipment obsolescence issues impacting current operation (running the plant) are addressed. The modernization effort also is designed to allow the harvesting intellectual property when dealing with digital obsolescence to minimize TOC for remaining plant life.

2. Evolve roles and responsibilities to run the plant/business

   Labor-intensive work activities are accomplished by identifying WRO opportunities enabled by technology. These WROs are identified by evaluating the major resource drivers that drive O&M costs at the plant. Expected direct workload O&M savings are identified by identifying the method by which technology can be applied to perform the activity to reduce, consolidate, or eliminate the need for human labor. Costs to implement this technology upgrade are also estimated.

3. Optimize/reorganize resources to run the plant/business

   The results of items 1 and 2 for one or more WROs are aggregated and evaluated. Roles and responsibilities of the remaining staff are re-allocated to maximize harvestable labor savings through staff attrition. For example, the remaining staff would be trained to perform several specific specialized tasks which together justify full-time utilization of that staff resource instead of having several specially trained workers that are not utilized full time but must be retained because of their specialized skills. A practical example of this concept is workload from radiation protection or chemistry technicians can be consolidated and assumed by multi-skilled technicians or potentially non-licensed operators. Work may also be centralized at remote locations or outsourced as enabled by technology to achieve cost efficiencies. The number of auxiliary operators in the plant may also be reduced through remote control/automation capabilities provided by modern digital I&C systems. Through this optimization/reorganization effort, Aggregate O&M cost savings are realized.

1.2.2.2 Work Reduction Opportunity Realization

4. Deploy a DI with a comprehensive cybersecurity model (item number corresponds to Figure 1-4)

   It is expected that utilities will leverage the DI concept depicted in Figure 1-2 to coordinate their digital modernization efforts as presented in [6]. This is a reasonable expectation driven by:

   a. Utilities that have made and continue to make investments in digital technologies. These investments fall within the boundaries of the DI depicted in Figure 1-2. The challenge is to leverage and coordinate these investments as one cohesive set which maximizes dataflows and capabilities while reducing workload.

b. Business case analyses performed to date as captured in [3] for LGS pilot safety-related I&C platform upgrade (which also expands the non-safety distributed process control system at that site),
c. ION identified WRO opportunities identified in [8] that enabled the DI hosting software applications and HSIs.
d. Expanded application of "b" and "c" efforts directly above on the Reference Plant as presented in this report.
e. The need to coordinate cybersecurity efforts across the DI in the most efficient way possible while addressing regulatory requirements and protecting the business of running a nuclear plant.

Key aspects of this DI solution are shown in the bottom technology layer of Figure 1-4 in **red**. These include (but are not limited to):

- Deployment of a two-platform (safety-related and non-safety) digital I&C upgrade solution. This standardizes design efforts and enables the development of long-term obsolescence strategies.
- Consolidation of emergency preparedness (EP) capabilities on a portion of the DI that meets cybersecurity rules, allows for consolidation of these functions, and enables capabilities such as the remote location of the emergency operations facility (EOF) for a single unit and remote and consolidation of EOF facilities for a utility nuclear fleet at a consolidated location.
- Expansion of the existing corporate business network at a plant to:
    - Enable wireless devices (e.g., sensors, robotics, drones, advanced portable HSIs, etc.) to directly gather data digitally
    - Enable aggregation of all digital data in the DI for analysis using DA&A applications hosted on the business network (see #5 directly below)
- Enable advanced main control room simulator features. If properly coordinated, I&C upgrades can be directly leveraged in the simulator. This also facilitates the creation of a glasstop simulator that can be used not only for training but also as an I&C/HSI design tool and a tool to verify and validate HSI designs.

The DI Purdue Industrial Control System Model levels shown on the left in Figure 1-2 are depicted under the bottom technology layer of Figure 1-4 in **red** to show the direct connectivity between the concepts presented in the two figures.

It is expected that for utilities that have already been pursuing significant digital upgrades, that these will be aggregated over time to enable the DI construct. Enveloping these efforts in one overarching DI provides for economy of scale, standardization of design, and development of an overarching cybersecurity defensive architecture. How cybersecurity fits into the DI as architected is depicted on the far left of Figure 1-2. This is explained in detail in Section 2.3 of [6].

5. Data Architecture and Data Analytics applications enable work reductions (item number corresponds to Figure 1-4)

   Enabled by the DI, specific DA&A applications are identified to provide the necessary functionality (perform processes) at the proper level of the DI to optimally provide the functions needed to realize WROs. Example DA&A application capabilities are identified in **red** in the process layer of Figure 1-4. Specific strategies to enable ION identified WROs are the subject of a related research effort which will be completed in the near future.

6. Optimize HSIs for the optimized workforce that remains through human-technology integration (HTI) (item number corresponds to Figure 1-4)

   In order for the people who will be using the DA&A applications hosted on the DI to accomplish their tasks as efficiently and error-free as possible, a properly developed set of HSIs need to be developed. HTI, is a research area under the LWRS Program Plant PM Pathway that uses HFE methods and tools to ensure the safe and reliable use of advanced technologies. HTI also focuses on applying technology in a way that makes a business impact, thereby reducing cost through reduced staffing needs, improved processes and decision-making, or reduced human error risk. This effort is reflected in updates to the work facilities and HSI layer Figure 1-4. This also enables new HTI capabilities such as a centralized monitoring and diagnostic center and remote support centers which are shown in **red** in Figure 1-4.

The overall intent of this effort is to first transition from the current state to a target generation 1 (Gen 1) state as depicted in Figure 1-5 below.

Figure 1-5. Transition from Current State to an ION Generation 1 State

ION Generation I refers to WRO's that are at a sufficient technology maturity level and would support plant transformation within 3–5 years. The ideal state concept drives which technologies are selected based upon based upon meeting plant needs for the near term while also planning to address obsolescence in the long term. Transition states may be necessary depending upon the scope of individual changes and the need to implement them over time (e.g., over more than one outage).

As technology develops over time, it is expected that continuous improvements will be made. This will occur in a periodic cycle as future needs are identified, and business case analyses demonstrate net-positive NPV opportunities to deploy them. This iterative process is shown in Figure 1-6.

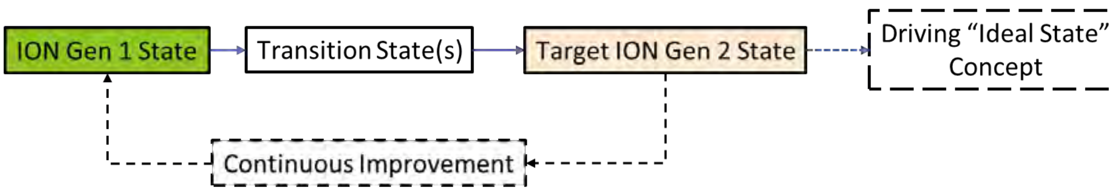

Figure 1-6. Iteration to an ION Generation 2 State

In Figure 1-6, the starting point is the Gen 1 state where improvements are applied to achieve a Gen 2 state. Subsequent target ION states can be pursued for the remaining plant life as business case evaluations of digital upgrades continue to show a positive NPV.

1.3 Specific Digital Infrastructure Business Case Approaches

For this research as performed at the Reference Plant, the generic process for applying the new state concept of operations was leveraged in two separate, but related ways to address the full scope of the envisioned upgrades for this business case. Each of these is described in the subsections below.

1.3.1 Safety-Related and Non-Safety Related Instrumentation and Control System Upgrades

First-echelon safety systems as well as non-safety I&C systems currently installed in operating nuclear power plants have historically performed their intended function admirably. However, almost all safety I&C systems are of the original plant vintage and based on decades-old technology. These systems are increasingly less supportable and more maintenance-intensive than modern digital alternatives. Parts for current systems are increasingly difficult and costly to obtain. Expertise to maintain these older analog (and in some cases, first-generation digital) systems is waning, whilst costs associated with operating and maintaining older systems are rising rapidly. This situation has been documented in the research business case analysis performed for safety-related digital upgrades at Constellation Energy Generation's Limerick

Generating Station [3]. This research shows that continuing to leverage existing safety-related I&C systems that are operating beyond their expected useful lifetime has a negative NPV if it a utility plans to operate these plants beyond the timeframe of their original operating licenses (particularly for subsequent license renewals).

Many original vintage non-safety I&C systems are also operating at or beyond their expected useful lifetimes. Where non-safety digital I&C upgrades have been performed, many have been accomplished as point solutions which provide like-for-like functionality. Making additional investments that provide like-for-like, point solution digital replacements that perform the same function as the original systems provides little opportunity for employing advanced digital technology capabilities to achieve the new state concept of operations presented in Section 1.2.2 to lower TOC. New non-safety DCS digital platforms eliminate nearly all I&C calibrations and provide self-diagnostic capabilities that in most cases eliminate troubleshooting. They can be designed to be redundant to eliminate downtime and permit the repair of many single-point failures. This redundancy can also be leveraged to permit periodic digital platform technology upgrades independent of plant outage periods. These platform solutions are scalable and promote design and parts standardization. Standardized platform design reduces I&C engineering costs as well as training costs. This is because the same core platform and associated HSI can be leveraged over and over as functionality is transferred from diverse legacy I&C technology. This also reduces direct operations and maintenance costs associated with inventory to support a myriad of standalone I&C systems. Proper platform selection takes into account lifecycle support activities to address digital obsolescence. Beyond recognizing the direct financial costs of continuing to extend the current concept of operations by further extending the life of existing I&C systems and performing like-for-like replacements, it is increasingly difficult to attract and retain qualified personnel to service and maintain this equipment when other industries are employing state-of-the-art I&C systems and deploying them using an enterprise-wide systems engineering approach.

The conclusion reached following this line of thinking is that I&C digital upgrades are necessary to extend the operational lifetime of existing plants. This directly supports the "run the plant" aspect of the new state concept of operations. This extended operational lifetime needs to be of a duration long enough to enable a direct return on the investment made while at the same time enabling other advanced capabilities by incorporating these I&C upgrades within a larger DI that can analyze and transmit I&C system data in a way that also optimizes running the business.

This way of thinking drives a predominantly "bottom-up" approach to the business case performed for safety-related and non-safety I&C upgrades to address the I&C portion bottom-left portion of Figure 1-4. This has been excerpted and expanded in Figure 1-7.

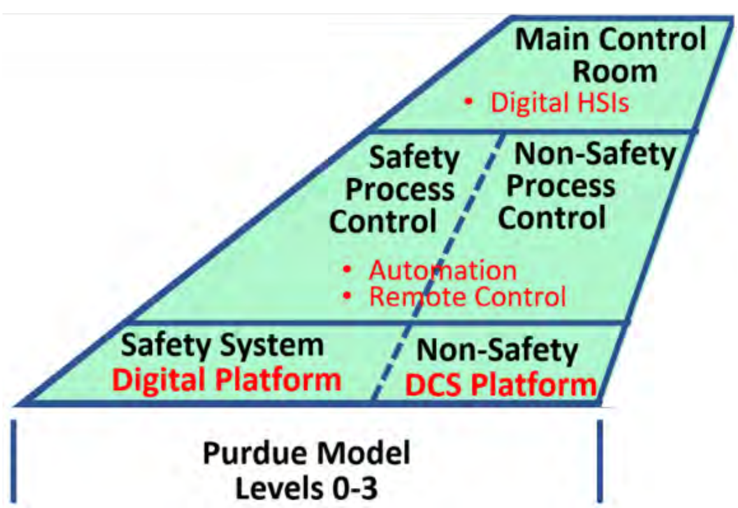

Figure 1-7. Bottom-up Approach to I&C Modernization Business Case Analysis

This "bottom-up" approach:

- Establishes labor and material costs for the current systems within the defined I&C upgrade scope
- Identifies expected labor and material benefits enabled by the upgrade design concept
- Validates the expected benefits with Subject Matter Experts (SMEs)
- Demonstrates a methodology utilized to perform a detailed financial analysis, including the following:
  - Estimation of annual benefits related to organizational workload reductions for both online and outage work
  - 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 Reference Plant
  - Valuation of the modernization because of non-occurrence of reliability events
- Illustrates the scale of benefits that can be expected from a modernization of safety and non-safety related I&C systems at a two-unit Pressurized Water Reactor (PWR) nuclear power plant
- Offers example worksheets and templates to support a business case analysis of similar efforts by other utilities
- Provides lessons learned and opportunities for utilities that might subsequently implement a similar digital modernization effort
- Links how Digital I&C upgrades enable the IONs operating model.

Sections 2 through 10 of this research product evaluate labor and material benefits and conduct a financial analysis as part of the development of the overall business case for digital modernizations for utilities considering a digital modernization of I&C safety and non-safety systems using two separate platforms.

The PWR safety-related and non-safety related I&C nuclear power plant upgrade business case presented in this report follows the methodology developed and used in the *Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations* – as Applied to the Limerick Generating Station. INL/EXT-20-59371 [3]. As noted in that report and as depicted on the DI in Figure 1-2, there is one-way data connectivity out of safety-related I&C platform to the non-safety DCS. The non-safety DCS can provide this data to higher levels of the DI (the EP Network and the Corporate Business Network) for data processing, analysis, and presentation. I&C system health and diagnostic information can also be communicated up the DI in this manner to enable support of these systems (either locally or remote).

1.3.2 Identifying and Planning to Address ION Work Reduction Opportunities

The identification of ION WROs has followed a top-down approach to date. This is depicted on the right side of Figure 1-4. This has been excerpted and expanded in Figure 1-8.

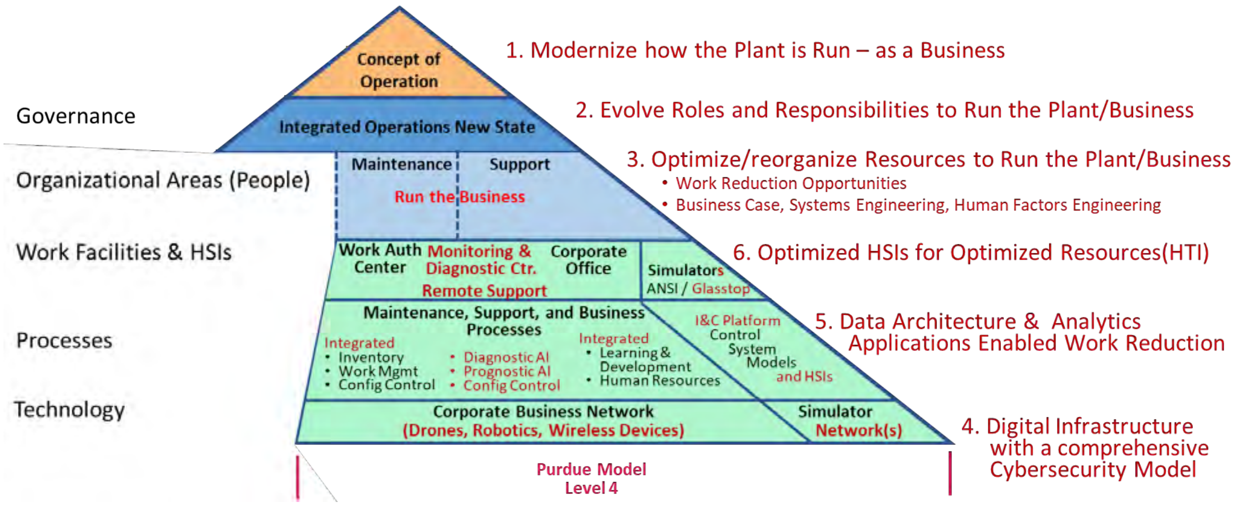

Figure 1-8. Top-down Approach to I&C Modernization Business Case Analysis

This top-down approach is the primary means by which ION WROs are identified. These WROs are identified by more directly following the process presented in Section 1.2.2.1. Once the WROs were identified, a preliminary bottom-up evaluation of costs to implement the WRO along with potential O&M cost savings was carried out. This evaluation included a preliminary validation of initial assumptions with other utilities as well as EPRI. Specific implementation techniques were not fully identified.

Section 11 of this report describes DA&A applications hosted on the higher levels of the DI (primarily Purdue Model Level 4 as shown in Figure 1-2 and abstracted at the bottom of Figure 1-8) can support the realization of WROs identified as part of ION research. It demonstrates the cost savings and net economic benefits that can be potentially realized through plant modernizations of a larger scope than has been shown in Figure 1-7.

1.4 Project Development Approach

1.4.1 Digital Instrumentation and Control Upgrades

A cross-functional team ("Project Team") was assembled to develop the proposed digital safety and non-safety related I&C System Modernization ("Project") for the Reference Plant. The Project Team included representatives from LWRS, ScottMadden Inc., and the Owner. LWRS representation consisted of a principal investigator, a research engineer, contracted conceptual and design engineering, and contracted management consulting to support the BCA. Owner representation consisted of central engineering and project management resources as well as current and former plant systems and I&C engineering. The Owner also made available SMEs from operations, maintenance, engineering, emergency preparedness work management, training, supply chain, and warehousing, as well as representatives from licensing, and training.

At the outset of work, the Project Team drafted a development plan for the Project to coordinate various overlapping and interdependent activities illustrated in Figure 1-9 below.

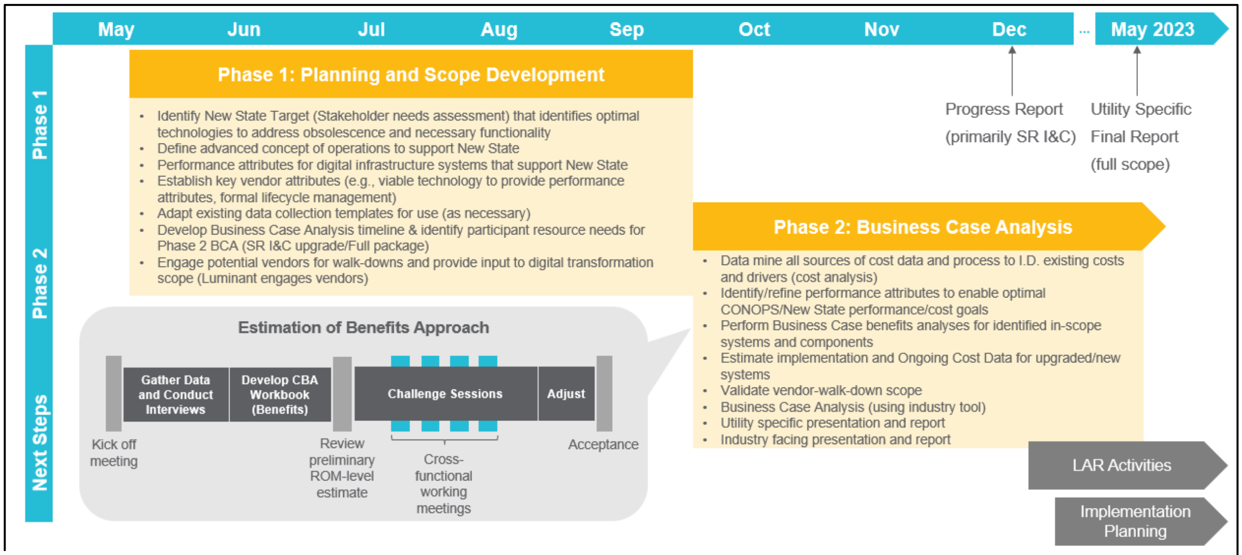

Figure 1-9. High-level Project Development Plan

The high-level plan is broken down into stages:

1. Phase 1: Planning and Initial Scope Development
2. Phase 2: Business Case Analysis
3. Phase 3: (performed solely by the Owner)
   a) Development of the Project Authorization Package which includes items such as:
      i. Project Plan
      ii. Risk Management Plan and Risk Register
      iii. Project Procurement Plan and Vendor Down select
      iv. Project Economic Analysis (leveraging the BCA from #2 above)
      v. Project Schedule, Budget, and Total Project Cost Range
   b) License Amendment Request (LAR) Activities including items such as but not limited to:
      i. Evaluation of Impacted Licensing Commitments
      ii. LAR Strategy (e.g. whether or not to follow the DI&C-ISG-06 Alternate Approach)
      iii. Planning for LAR presubmittal.

The three stages are interdependent and overlap with each other in timing. The focus of this research involves activities highlighted in Phases 1 and 2. This plan is described in more detail in INL/RPT-22-70165, *Initial Scoping Efforts for a Plant-Wide Digital Infrastructure Modernization Business Case Study* [9].

1.4.2 ION Identified Work Reduction Opportunities

During initial scoping efforts to develop a business case for plant-wide digital modernization, the project team carried out workshops with Reference Plant Owner personnel and individuals within the LWRS team. Early workshops were primarily designed to understand the scope of digital I&C upgrades in more detail. In the course of these workshops, it was determined that numerous other WROs existed that the plant may benefit from beyond those directly enabled by I&C digital modernization. As a result, subsequent workshops were carried out to identify potential WROs that would utilize the DI layers above Purdue Model Level 3 as shown in Figure 1-2 and Figure 1-4. These subsequent workshops were informed by ION-related WROs taken from [7] for the Representative Plant.

1.5 Scope of Research

1.5.1 Instrumentation and Control Subsystems

The research scope of this phase of the digital I&C upgrade strategy for the PWR Reference Plant includes digital modernizations of the subsystems grouped below.

- Safety-related subsystems:
  - Post Accident Monitoring System (PAMS)
  - Plant Protection System
  - Nuclear Instrumentation
  - Solid State Safeguard Sequencer
  - Reactor Vessel Level
  - Hydrogen Monitoring
  - Hot Shutdown Panel.

These safety-related subsystem functions are planned to either be directly hosted on the new safety-related digital I&C platform or interfaced to this platform as shown in **red** in Figure 1-2.

- Non-safety subsystems:
  - BOP Controls
  - NSSS Process Control
  - AMSAC (Anticipated Transient Without SCRAM [ATWS] Mitigation System Actuation Circuity)
  - Turbine Controls Interface
  - Containments Atmospheric Monitoring
  - Meteorological Monitoring Interface
  - Rod Control Systems
  - Rod Position Indication
  - Flux Mapping System
  - Annunciator System
  - Plant Computer Interface
  - Leading Edge Flow Meter (LEFM) Interface
  - Feedwater Heater Drain Controls.

These non-safety subsystem functions are planned to either be directly hosted on the new non-safety DCS platform or interfaced to this platform as shown in **green** in Figure 1-2.

This research report captures the process and related business case tool to enable such a BCA. Specific features identified in the design concept leveraged to support this BCA are identified in Section 2.2.

1.5.2 ION Identified Work Reduction Opportunities

As introduced in Section 1.4.2, the workshops performed by the Project Team, identified several ION-related WROs beyond digital I&C upgrades from [7] that could enable future cost savings at the Reference Plant. The result of these workshops determined that the following WRO categories should be the primary focus of the research effort captured in this report:

- Software Application Assisted Business Processes[1]
- Mobile Worker Technology
- Condition-Based Monitoring
- Advanced Training/Advanced Training Technology

The outcome of these workshops is presented in more detail in Section 11 along with an economic analysis of these WROs in the broader context of their application, based on previous INL research initiatives. Other WROs as identified in references [7] and [8] were also discussed at these workshops. It is expected that other WROs will be pursued in future LWRS research and Owner implementation activities as described in Section 1.6.2.

1.6 Expected Project Outcomes

1.6.1 Instrumentation and Control Subsystems

I&C specific BCA results for the Reference Plant performed as part of this research provide specific data used to support Owner project management activities and ultimately support Owner management decision-making regarding Project authorization.

This non-proprietary document communicates the process and related business case tool to enable similar BCA for digital upgrades throughout the industry. It is expected that this methodology can be abstracted and used for nearly any I&C upgrade. It also provides order-of-magnitude results for the Reference Plant effort as an informed datapoint for such upgrades.

1.6.2 ION Identified Work Reduction Opportunity Realization Strategy

INL is separately developing an ION WRO Realization Strategy. This strategy is based upon industry-wide efforts to identify WROs along with specific concepts communicated to INL by the Reference Plant Owner as part of efforts to date. This strategy will be published separately in the near future. INL plans to specifically collaborate with the Reference Plant Owner and other utilities that choose to participate to bound specific implementation methods for WROs.

In order to further develop this realization strategy, it is necessary to engage with vendors to understand the capabilities, use cases, and capital costs of specific, relevant technologies and subsystems involved in the ION-related WROs introduced in Section 1.5.2 and discussed in more detail in Section 11. These WROs can then be more effectively bounded and developed into more detailed and discrete business cases including estimates of expected benefits and overall economic viability.

An initial estimate of the Full Time Equivalents (FTE) reductions and O&M savings for WROs identified in Section 1.5.2 is presented in Table 11-2.

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[1] This category of WROs is known in previous reports as "Process Re-Engineering and Automation." This change was made to prevent conflating automation implemented in physical process control systems (I&C digital systems) with software applications in non-control digital systems that automatically produce information outputs when provided with sufficient data inputs.

2. PROPOSED DIGITAL MODERNIZATION OF SAFETY AND NON-SAFETY RELATED I&C SYSTEMS

2.1 Safety and Non-Safety Related Subsystems Targeted for Modernization at the Reference Plant

Development of a BCA for a subsystem replacement first requires a comprehensive understanding of the subsystems to be replaced as a foundation. The architecture and key features of the proposed digital modernization that enable cost savings and cost avoidance also need to be understood. This information allows the identification of the expected benefits of the proposed digital modernization. Table 2-1 identifies the I&C subsystems to be replaced at the Reference Plant. This establishes the basis for the BCA.

Table 2-1. Existing I&C Subsystems List Identified for Modernization at the Reference Plant

#	Existing I&C Subsystem	Safety/Non-Safety	Current Platform
1	Plant Protection System	Safety	7300
2	Nuclear Instrumentation – Safety/Control	Safety	NIS
3	Nuclear Instrumentation – RG1.97	Safety	ENFMS
4	Solid State Safeguards Sequencer	Safety	SSSS
5	PAMS Variables	Safety	Analog Meters
6	Reactor Vessel Level	Safety	Vendor Multibus (HJTC)
7	Hydrogen Monitoring	Safety	Analog Meters
8	Hot Shutdown Panel	Both	Analog
9	BOP Controls	Both	Analog Meters
10	BOP Controls	Both	7300
11	NSSS Process Control	Non-Safety	7300
12	AMSAC	Non-Safety	Vendor Multibus
13	Turbine Controls Interface	Non-Safety	Analog
14	Containment Atmospheric Monitoring	Non-Safety	Digital
15	Meteorological Monitoring Interface	Non-Safety	Digital
16	Rod Control Systems	Non-Safety	SSRCS
17	Rod Position Indication	Non-Safety	Vendor DRPI
18	Flux Mapping System	Non-Safety	Vendor MIDS
19	Annunciator System	Non-Safety	Beta Products, Inc.
20	Plant Computer Interface	Non-Safety	Windows PMS
21	LEFM Interface	Non-Safety	Digital
22	Feedwater Heater Drain Controls	Non-Safety	7300

These subsystems are targeted for incorporation or interface into either a safety-related digital platform or a non-safety DCS according to their designation in Table 2-1.

2.2 Modernization Upgrades to Safety-Related Subsystems at the Reference Plant

Areas of expected cost reductions enabled by the digital upgrade design concept for I&C are described below.

2.2.1 Upgrades to Existing Plant Protection System and Safety-Related Balance of Plant Control

The functions of Plant Protection System's analog 7300 cabinets 1-4, 7300 safety-related BOP control systems, and 7300 N-16 nuclear instrumentation cards will be hosted on a new, safety-related digital platform. The safety-related system will be installed in the existing cabinets and retain the existing interfaces with the field wiring and the SSPS. The upgrade only digitalizes the cabinet to Safety-related I&C digital platform while the field wiring and sensors will stay in place. This addresses item 1, as well as items 8, 9, and 10 for safety-related I&C in Table 2-1.

2.2.2 Upgrades to Nuclear Instrumentation – Safety/Control and RG-1.97

The existing Nuclear Instrumentation (NI) Protection Equipment used for safety/control will be replaced with updated, analog Protection Equipment as shown in Figure 2-1. The existing NI Wide-Range equipment will be retired. This addresses item 2 in Table 2-1.

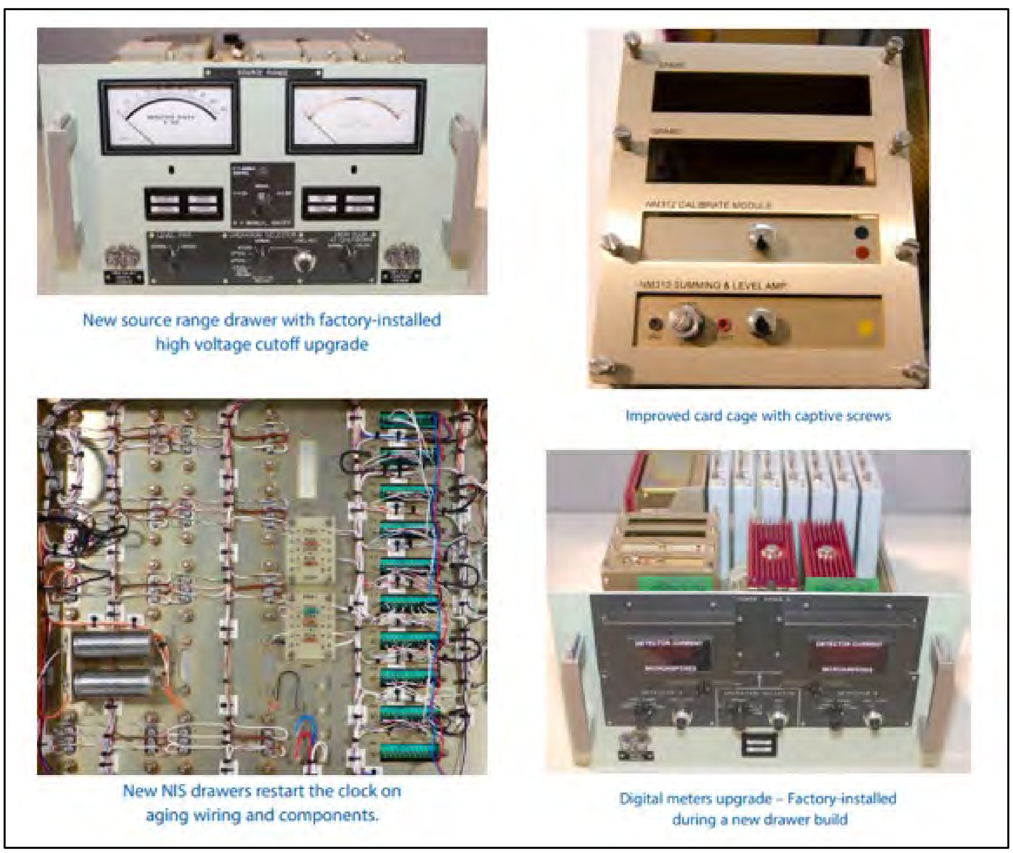

Figure 2-1. Upgraded Nuclear Instrumentation Protection Equipment Examples

The wide-range RG-1.97 nuclear instrumentation excore detector and its associated electronics are qualified for harsh containment conditions and are recommended for elimination based upon industry precedent at another site. Costs associated with maintaining this system are eliminated. This addresses item 3 in Table 2-1.

2.2.3 Upgrades to Existing Solid State Safeguards Sequencer

The current analog components will be replaced with the digital software-based safety-related I&C digital platform safeguards sequencer system. It is assumed that the upgrade eliminates all maintenance associated with the old hardware. This addresses item 4 in Table 2-1.

2.2.4 Upgrades to Existing PAMS Variables

The analog PAMS indicators in the control room will be removed during this upgrade and replaced with digital HSIs on the safety-related I&C digital platform, via a PAMS Operator Module (see Figure 2-2 for an example). As a result of the upgrade, PAMS signals will be read by the safety-related I&C digital platform and sent via datalink. If connecting to sensors at the source, only prime standard alignment calibrations will remain; all other calibrations associated with the analog equipment will be eliminated. The hydrogen monitoring will be integrated into the PAMS display. This addresses item 5 in Table 2-1.

Figure 2-2. Example Safety-related Human-System Interface Installation

Regarding safety-related control room HSIs, further evaluation is needed to determine the degree to which the future state is software-based.

2.2.5 Upgrades to Existing Reactor Vessel Level

The Reactor Vessel Level Monitoring (RVLM) signal processing system is on an obsolete digital platform and will be replaced with a new digital system as shown in Figure 2-3. New equipment will be installed into existing cabinets, while the existing probe can be reused or replaced. The upgraded signal processing electronics will be integrated into the Post Accident Monitoring System (PAMS) functionality which is being integrated into the safety-related digital I&C platform as described in Section 2.2.4. The heater power supply should be replaced as part of the signal processing upgrade. This addresses item 6 in Table 2-1.

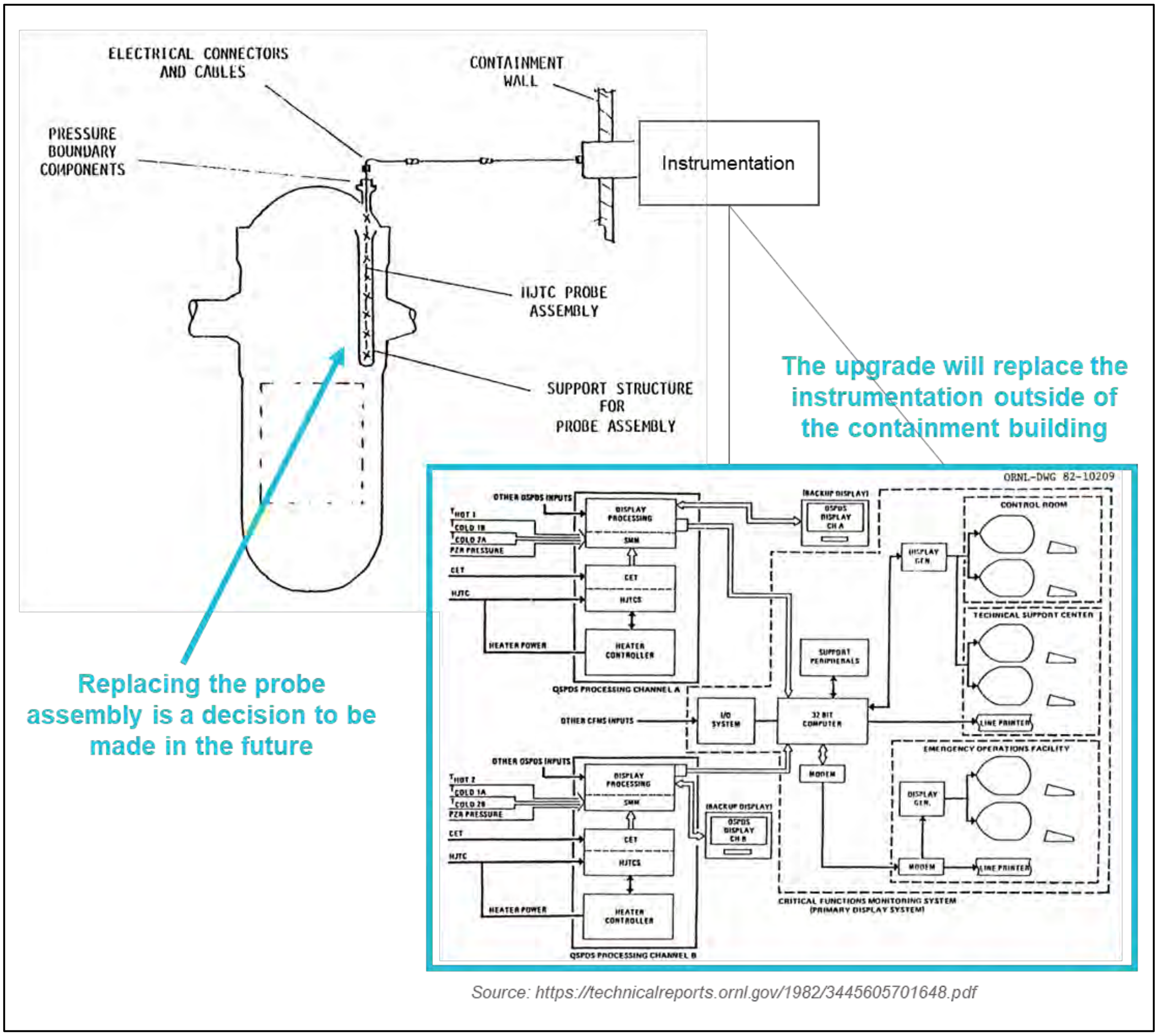

Figure 2-3. Example RVLM System

2.2.6 Upgrades to Existing Hydrogen Monitoring

The upgrade will replace the signal processing electronics portion of the Hydrogen Monitoring System and interface into the existing sampler (inside containment). This is shown in Figure 2-4. The new signal processing portion will be interfaced with PAMS for display. The new system will be installed as an associated circuit which will be powered from the safety cabinet but will not necessarily have the capability to perform a safety-related function. This addresses item 7 in Table 2-1.

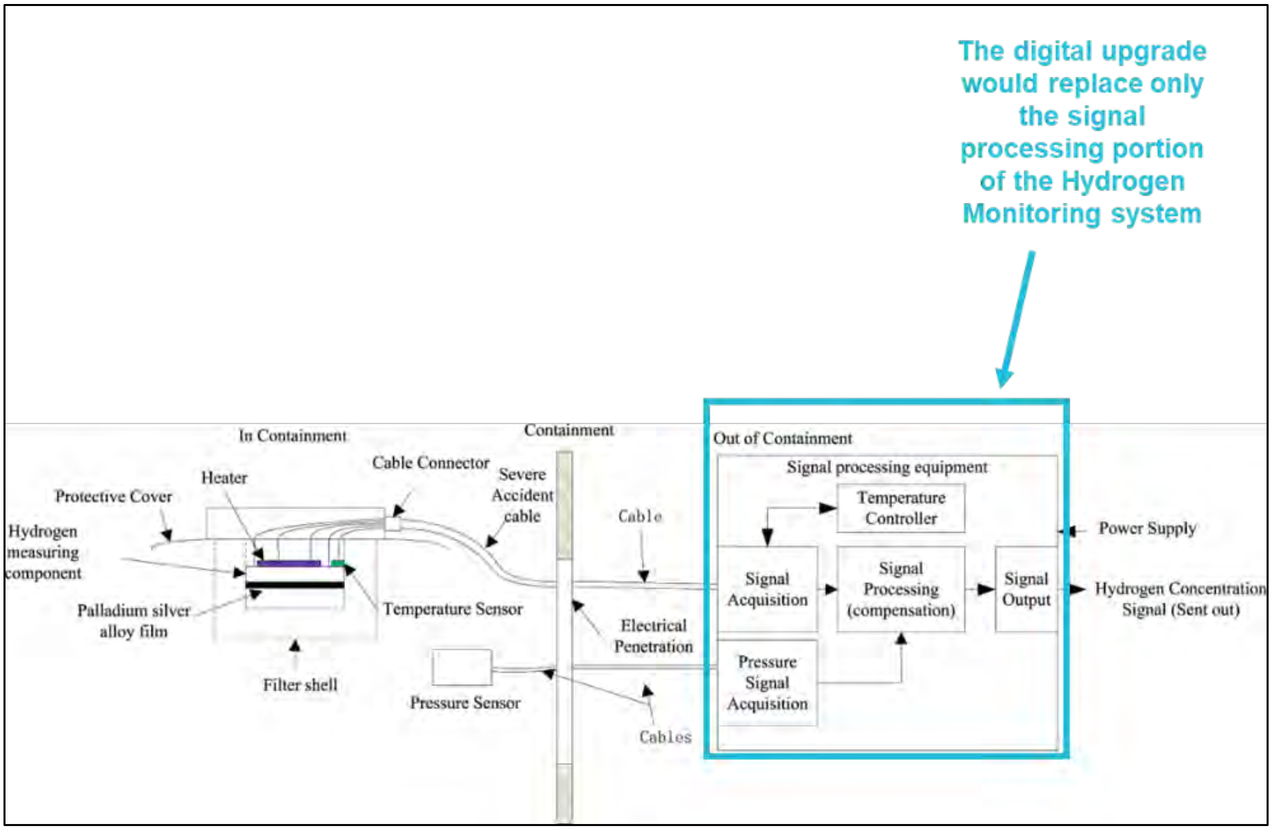

Figure 2-4. Example Hydrogen Monitoring System Configuration

2.3 Modernization Upgrades to Non-Safety Related Subsystems Targeted at the Reference Plant

Areas of expected cost reductions enabled by the digital upgrade design concept for non-safety related subsystems are described below.

2.3.1 Upgrades to Existing Non-Safety NSSS, BOP Controls, and Non-Safety Hot Shutdown Panel Functionality

The current non-safety 7300 NSSS and BOP control systems automatically regulate the reactor and other key components in response to load changes or other plant disturbances. The systems control important plant parameters to provide margin to plant safety limits and determine the plant’s transient performance for operability design basis events. The various NSSS and BOP control functions are listed below and are planned to be implemented with digital non-safety DCS.

NSSS Control Functions:

- Steam Generator Level/Feedwater Control
- Pressurizer Pressure and Level Control
- Steam Dump Control
- Reactor Temperature and Rod Speed Control, Rod Insertion Limit
- Chemical Volume Control
- Low Pressure Letdown Control
- Boron Recovery

BOP Control Functions:

- Auxiliary Steam
- Circulating Water
- Component Cooling Water
- Compressed Air
- Condensate
- Demineralized & Reactor Makeup Water
- Extraction Steam
- Heater Drains
- Main Steam Reheat & SD
- Plant Gas Supply
- Potable & Sanitary Water
- SG Blowdown Cleanup
- SG Feedwater
- Spent Fuel Pool Cooing & Cleanup
- Station Service Water
- Turbine Oil
- Turbine Plant Cooling Water
- Miscellaneous Ventilation area functions.

For non-safety I&C, all current 7300 system electronic hardware is being replaced by non-safety DCS.

Non-safety physical indications are removed and replaced with touch screen displays as illustrated in Figure 2-5.

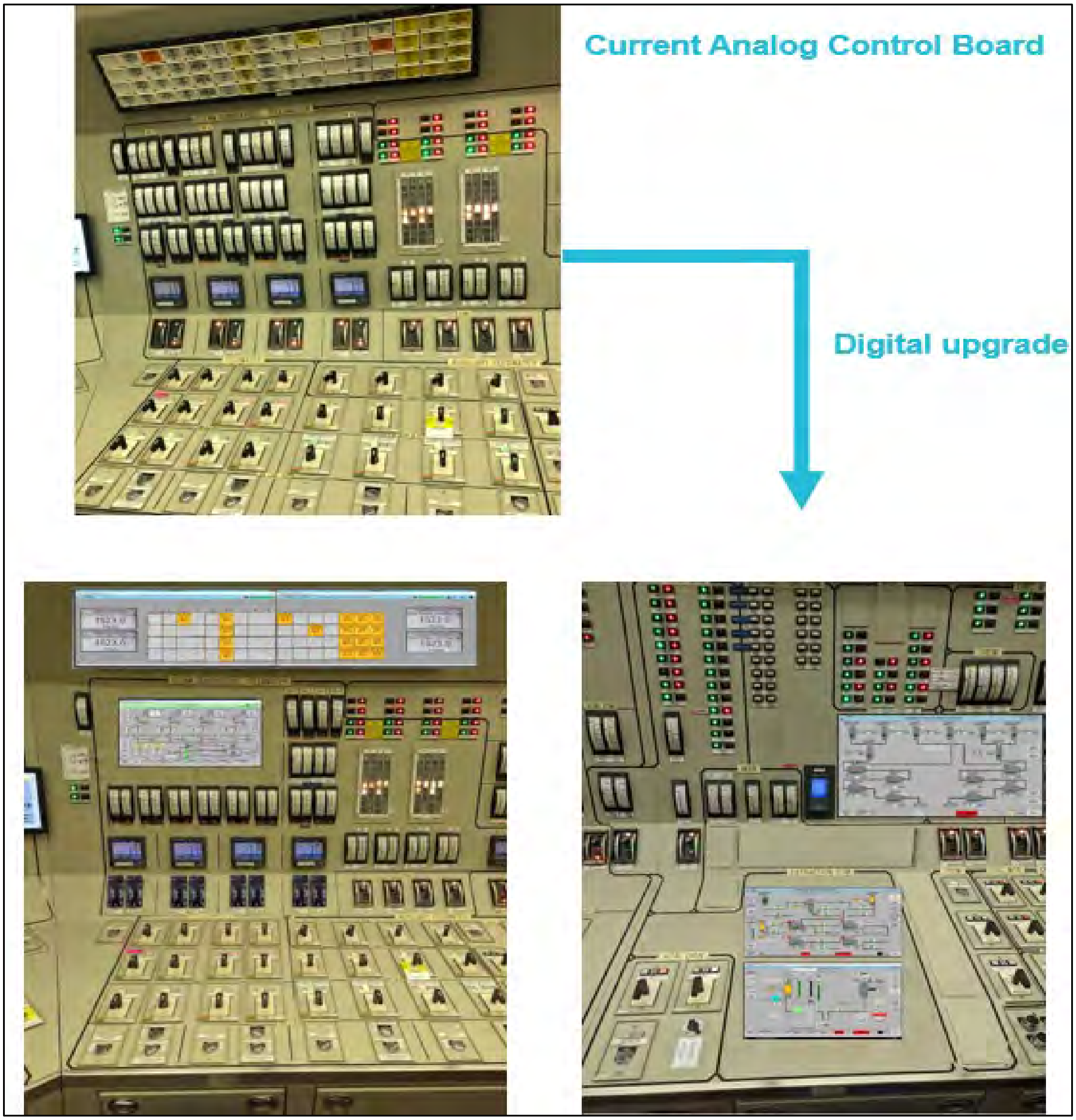

Figure 2-5. Example of Non-Safety Control Board Updates

The current plan for the Reference Plant prior to a detailed conceptual design is that indications that are not related to PAMS will be upgraded to a digital format. Controls that feed directly into logic will be included in the replacement or items that have set operator actions or difficult or complex will be considered for automation (i.e. boration). Switches that directly drive field devices such as motor control centers, pumps, or valves will not be replaced on a wholesale case. A case-by-case basis will be evaluated. This addresses items 8, 9, 10 for non-safety I&C and item 11 in Table 2-1.

2.3.2 Upgrades to Existing AMSAC

The proposed modernization will consist of the Diverse Actuation System (DAS) replacing the current AMSAC digital system as shown in Figure 2-6 with a non-safety DCS redundant controller pair that is powered by redundant power supplies. This addresses item 12 in Table 2-1.

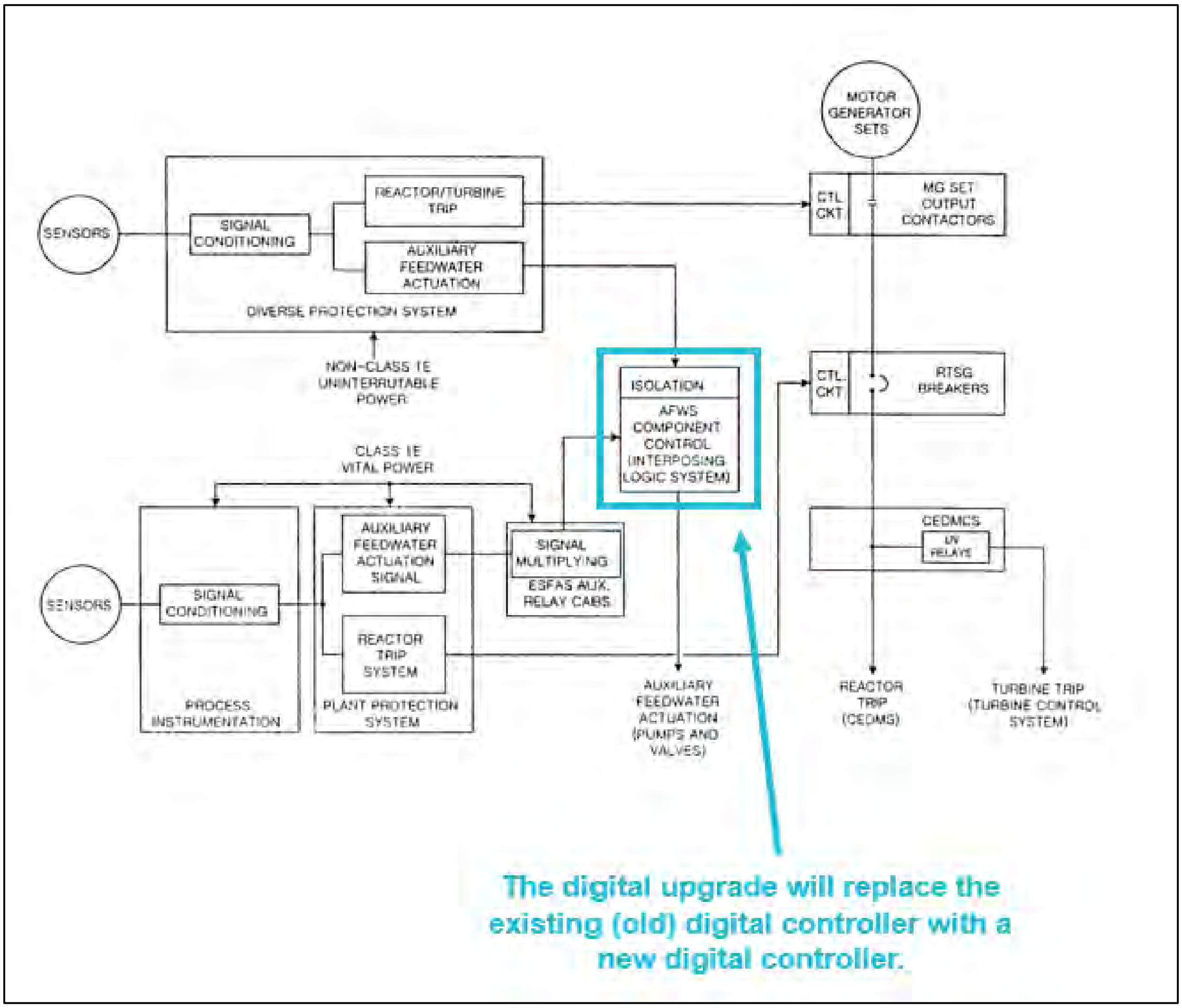

Figure 2-6. AMSAC Basic Diagram with identified upgrade

2.3.3 Upgrades to Existing Systems Interfaces: Turbine Controls Interface, Lead Edge Flow Meter (LEFM) Interface, and Meteorological Monitoring Interface

The Turbine Control and Protection System Interface was recently replaced at the Reference Plant. All three interfaces will remain separate but have datalinks into the non-safety DCS and will be connected to the new digital controls. The systems were evaluated for potential cost savings but it was determined that none were likely to result from the upgrade. The cost to accomplish these interfaces was included in the overall cost to migrate the non-safety NSSS and BOP functionality to the non-safety digital DCS. This addresses items 13, 15, and 21 in Table 2-1.

2.3.4 Upgrades to Existing Containment Atmospheric Monitoring

The sensors in the containment building will connect to the non-safety DCS platform. The current analog indicators for the containment atmospheric monitoring system will be converted to digital and displayed on the non-safety DCS platform in the main control room. This addresses item 14 in Table 2-1.

2.3.5 Upgrades to Existing Rod Controls System

The existing rod control system (RCS) will be replaced with the Advanced Rod Control Hybrid (not a full digital replacement), leveraging the features and functions of a digital RCS, while maintaining the same cabinets, system architecture, and power electronics. The Logic Cabinet will be upgraded to a non-safety DCS logic controller panel to coordinate rod control operations. This is depicted in Figure 2-7. The Power Cabinet will be upgraded with replacement components to enhance the operation of regulating the power to the control rod drive mechanism coils. Field wiring and terminations will not be replaced as part of the modernization.

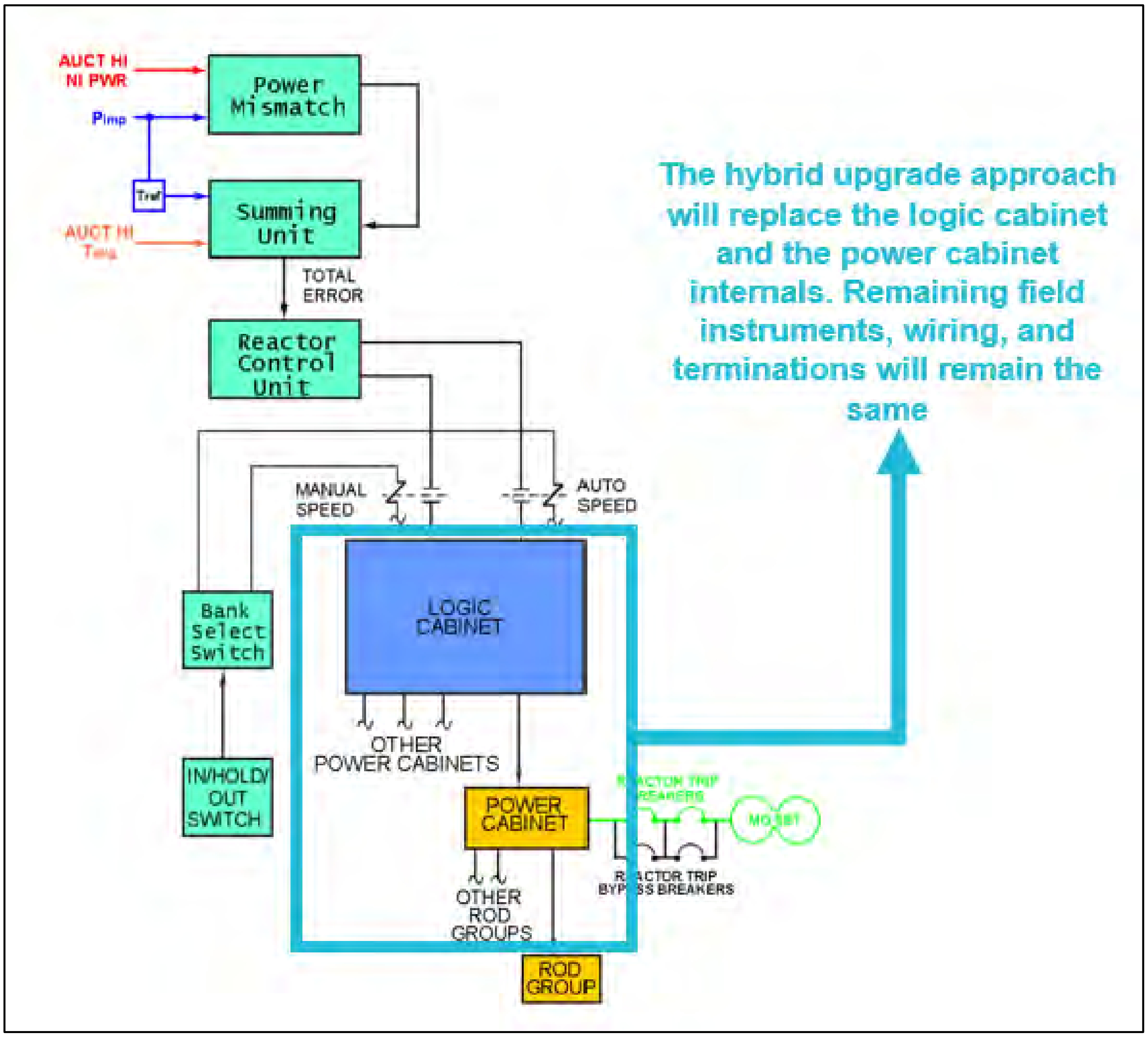

Figure 2-7. Example Rod Control System Diagram

There remain several decisions to be made for the configuration of the control room, such as whether the physical controls for the control rod drive would remain physical or whether it would be digitized through the use of buttons on graphical displays. This addresses item 16 in Table 2-1.

2.3.6 Upgrades to Existing Rod Position Indication

The Reference Plant upgraded its Rod Position Indication (RPI) cables in 2006 and the RPI data cabinet electronics for Unit 1. However, Unit 2 is not upgraded.

The RPI upgrades will occur in two phases. In Phase 1, the indication display in the control room will be updated to the DADS displays system. The DADS indications are then linked to the non-safety DCS to house rod positions and maintain rod position historical information. During Phase 2, the Next Generation RPI will be installed as depicted in Figure 2-8. At this point, all setup required for rod drop testing – for example, containment – will be eliminated. This addresses item 17 in Table 2-1.

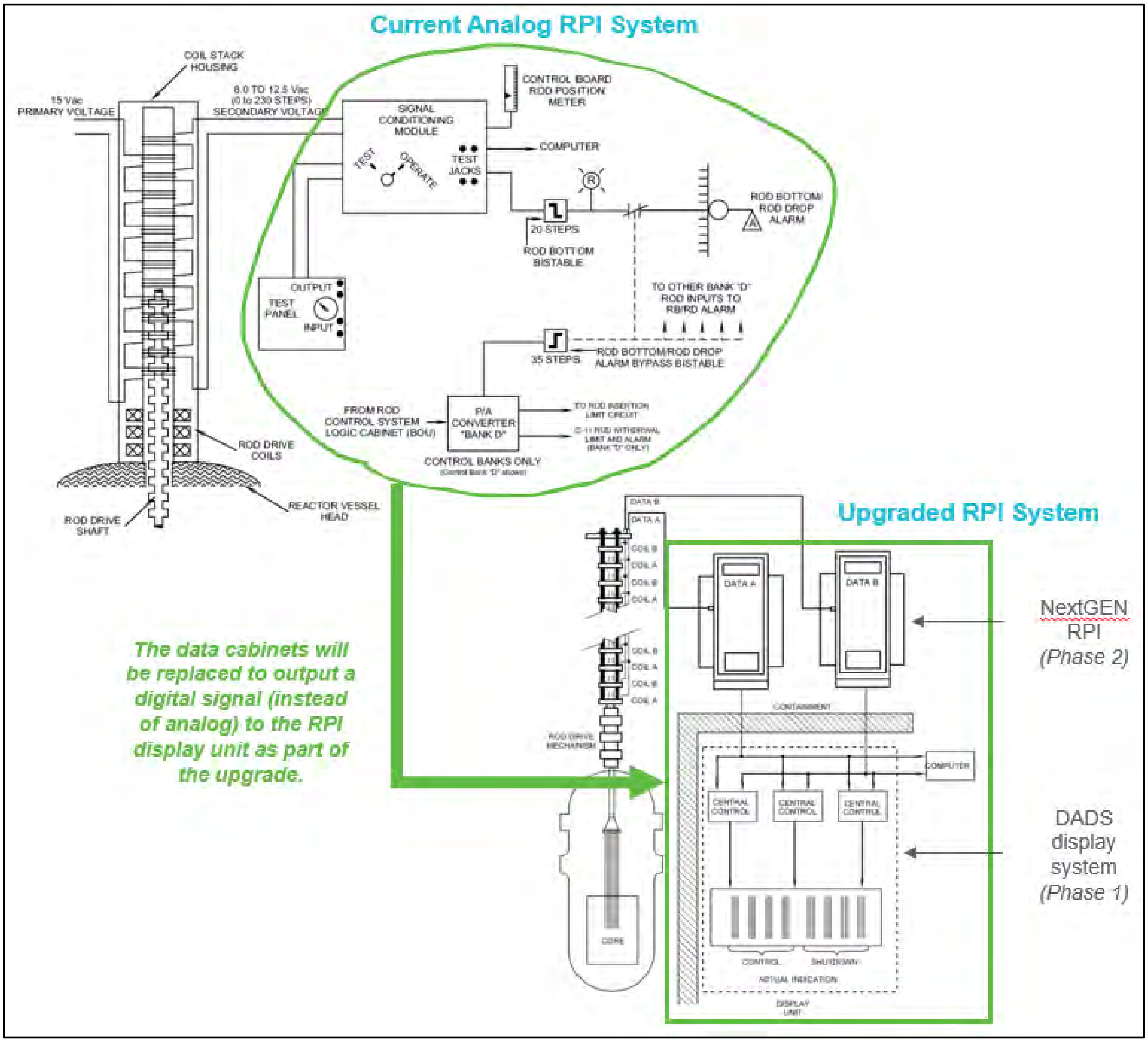

Figure 2-8. Upgraded Rod Position Indication System

2.3.7 Upgrades to Existing Flux Mapping System

The scope of the upgrade includes new electronics for the Flux Mapping Console (FMC) and Detector Drive System (DDS) which utilizes existing cabinets, field writing and terminations as shown in Figure 2-9. The current FMC will be replaced with the LabVIEW real-time monitoring and the control system. The drive units and transfer devices will be replaced within the DDS. These upgrades do not include updates to other Flux Mapping System instrumentation. This addresses item 18 in Table 2-1.

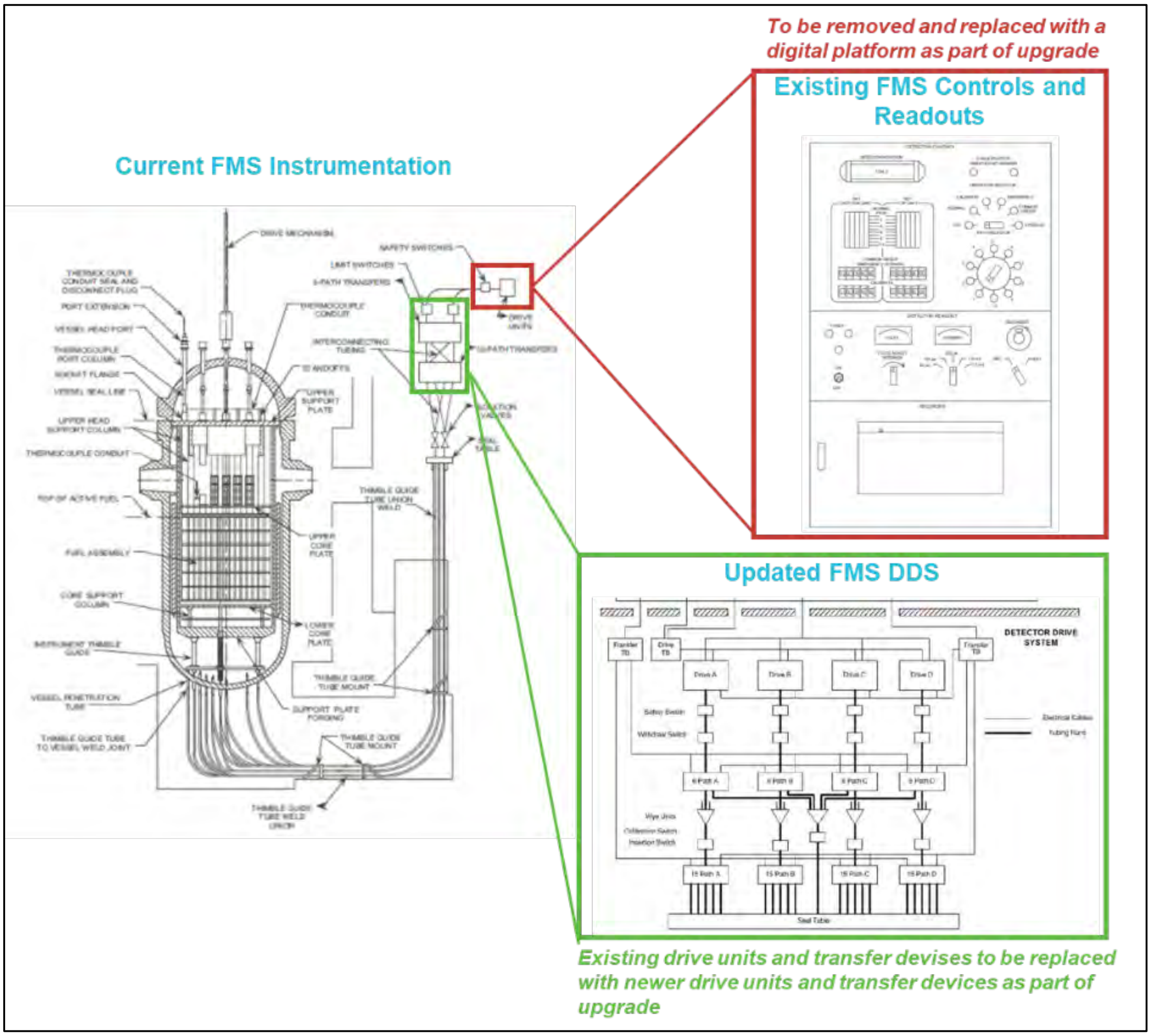

Figure 2-9. FMS Upgrades

2.3.8 Upgrades to Existing Annunciator System

The components of the existing main control room annunciators, including the Beta Hathaway alarm boxes, will be replaced with one consolidated and integrated alarm system in the non-safety DCS. This is notionally depicted in Figure 2-10. All the sensors and detectors that feed data to the main control room annunciators will remain in place unless they are impacted by the upgrade of another I&C system. This addresses item 19 in Table 2-1.

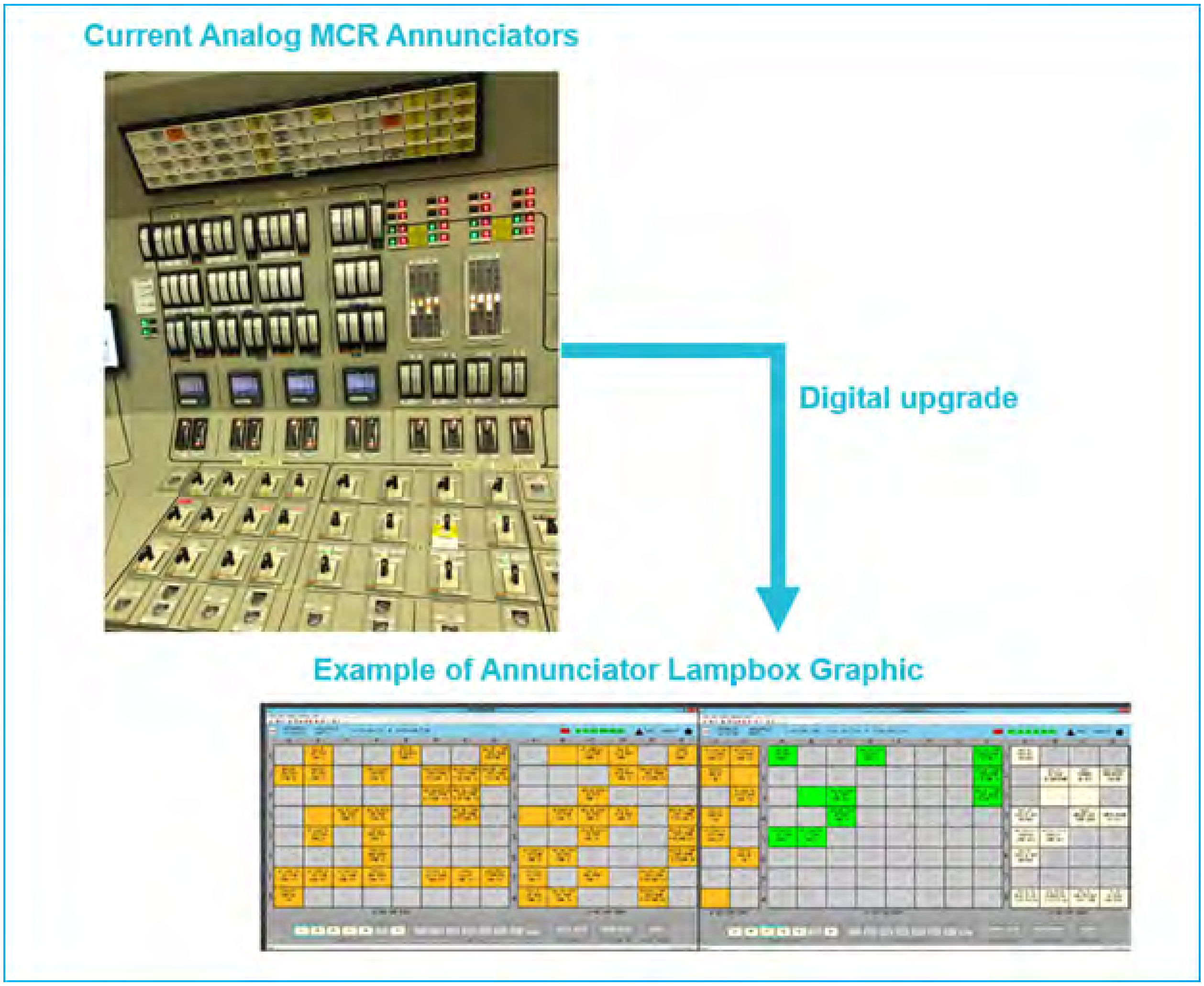

Figure 2-10. Annunciator System Upgrades

2.3.9 Upgrades to Existing Plant Computer Interface

The existing plant computer system will be updated with a datalink to the non-safety DCS to integrate additional points. By the end of implementation, the non-safety DCS will be used for all plant computer points and controls implemented in earlier phases; thus, the plant computer will be eliminated by the end of the upgrade. This is notionally depicted in Figure 2-11. As part of the upgrade, hardwired signals that interface to the plant computer will be removed and sent via the non-safety DCS data network and converted to graphic displays. This addresses item 20 in Table 2-1.

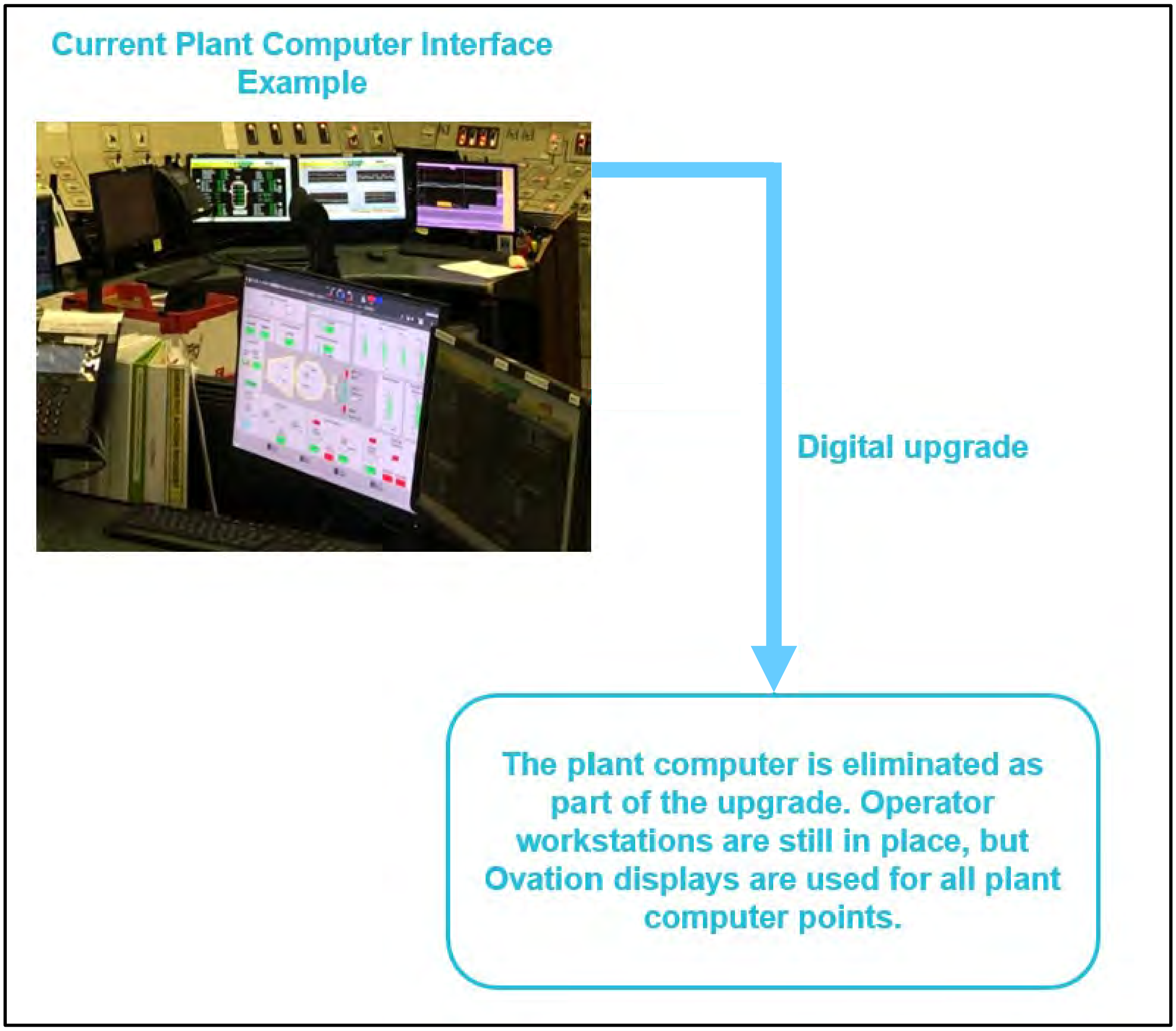

Figure 2-11. Plant Computer Interface Upgrades

2.3.10 Upgrades to Feedwater Heater Drain Controls

New level control instruments are required for each heater; a digital positioner will replace the existing pneumatic positioner on the normal and alternate control valves. In addition, new sensors will be brought in for level and pressure signals. Manual auto stations, selector switches, level indicators, and annunciator panels will be removed and replaced with soft controls and display graphics in the main control room. Redundant non-safety DCS controllers will also be installed in the current BOP cabinets. This addresses item 22 in Table 2-1.

2.4 Description of Expected Benefits of Proposed Digital Modernization of Target Safety-Related I&C Subsystems

This design concept includes features that enable improved Reference Plant performance, improved data retention and analysis, and improved HSIs. These features enable a larger, plantwide digital transformation end state that minimizes the plant TOC. Areas of expected cost reductions enabled by the digital upgrade design concept are described below.

2.4.1 Labor Benefits

2.4.1.1 Surveillance and Test Workload Reductions

Logic System Function Tests

I&C systems rely heavily on logic strings to determine whether various automatic actions need to occur in response to one or more abnormal inputs. Logic system functional tests are used to assess whether a logic string responds appropriately to a simulated or actual input to ensure that no portion of the logic string is faulted. Modern digital platforms include self-diagnostic features which can detect system failures in real-time to ensure that I&C systems remain capable of performing their specified functions. Faults are annunciated so that plant O&M personnel can take the appropriate action. This eliminates the need to perform time-based surveillances of the same equipment and eliminates the potential that a hidden failure exists until the next instance of time-based surveillance.

Currently, logic system function tests are performed quarterly, whereas a digital system is constantly monitoring the logic functionality, eliminating the need for time-based manual testing. The benefits analysis eliminated 100% of the workload associated with these tests.

Functional Tests

Functional tests verify that all elements of a control loop respond appropriately to simulated or actual input to the loop. Modern digital platforms include self-diagnostic features which are capable of detecting system failures in real-time to ensure that I&C systems remain capable of performing their specified functions. Faults are annunciated so that plant O&M personnel can take the appropriate action. This eliminates the need to perform time-based surveillances of the same equipment and it eliminates the potential that a hidden failure exists until the next instance of time-based surveillance.

Although functional tests were not eliminated entirely in the benefits analysis, a significant reduction of field maintenance and operations labor is expected as the need to install temporary modifications to perform the test is eliminated.

Channel Checks

Channel checks are performed to ensure that redundant analog instrument channels are reading values that are within an acceptable range of one another. The broader I&C modernization efforts at the Reference Plant make use of safety-related and non-safety related digital platforms and other digital networks. The data obtained by the safety-related platform will be transferred unidirectionally to the non-safety related platform. Software in the non-safety related or other appropriate digital platforms compares the data from redundant transmitters, checking that all readings are within an acceptable range defined for each transmitter. This function is carried out automatically, eliminating the need for manual channel checks and the surveillance requirements that drive their performance.

Calibration Tests

All calibrations for legacy analog trip units are eliminated by the replacement digital systems through the nature of the new system design and/or the application of self-diagnostic features of the new system.

Analog sensing instrument performance is typically maintained by periodic, time-based calibration. Calibration is still required for most sensing instruments due to their tendency to drift. The use of Online Monitoring (OLM) techniques has the potential to eliminate the need for time-based calibration activities for the analog sensing units through the implementation of condition-based maintenance. Condition-based maintenance would only be performed when monitored conditions are determined to be out of the prescribed bounds for that sensing instrument. In the future, OLM is expected to be implemented by the new digital platform transmitting sensor data to application software in a non-safety system to determine whether the equipment has encountered an anomaly or fault that requires recalibration. This, in turn, would allow the extension of existing surveillance test frequencies for calibration.

The benefits analysis did not credit the extension of sensing instrument calibration since this type of OLM has not been adequately demonstrated in a nuclear environment. The PPS platform will have the capability of transmitting data to non-safety digital systems to enable future OLM capabilities to reduce sensor calibration activities as these techniques mature.

Response Time Tests

Response time tests are used to ensure that a control loop responds in an appropriate amount of time to a simulated or actual input signal. Digital processing equipment does not suffer the effects of drift that must be accounted for with analog I&C equipment. Therefore, following initial factory acceptance testing whereby the control loop timing is verified, it is not expected that further response time testing will be required. Further, degradation of internal electronics which could impact system response time will be detected using self-diagnostic capabilities inherent in the digital platform. Response time tests for equipment external to the PPS is still required.

Response time tests were not completely eliminated in the benefits analysis. Credit was taken for the expected workload reductions associated with manipulating analog devices during the test.

Shift Surveillances

The benefits analysis also takes full credit for eliminating shift surveillances (i.e., collection of field data, verification, and analysis) by Operations personnel. All such activities are eliminated by digitizing the field data and passing it to the non-safety related platform for recording and analysis.

2.4.1.2 Preventive and Corrective Maintenance Workload Reductions

I/O Cards

Existing Input Output (I/O) equipment is replaced in its entirety by modernized I/O equipment that is less susceptible to failure. This reduction in failure risk is expected to convey to a similar reduction in Preventive Maintenance (PM) scope for this type of equipment.

Trip Units

Analog trip units will be eliminated in their entirety to support the implementation of the modernized digital platform. The existing functions performed by the analog trip units will be performed through the use of modernized I/O equipment and application software. Application software does not require the performance of PM. Additionally, modernized I/O equipment will require a reduced scope of PM compared to existing analog trip units.

Relays

Legacy relays (e.g., Agastat) used in existing I&C architectures will be eliminated and replaced with application software running on modern digital platforms. Any switching functions used in the modernized platform will make use of solid-state electronics. Planned maintenance activities do not need to be performed on application software. Additionally, solid-state electronics have fewer potential failure modes when compared to existing electromechanical relays currently in use at the Reference Plant, thus necessitating fewer planned maintenance activities. Together, these design attributes have the effect of lowering the PM costs currently attributed to existing relays.

Contacts and Coils

Contacts and coils used in existing I&C architectures will be eliminated and replaced with solid-state electronics and application software. Solid-state electronics have no moving parts. This lowers the number of failure modes when compared to electromechanical devices, permitting a reduced scope of PM compared to the current scope associated with electromechanical equipment. Contactors that are expected to remain as part of the new system will be replaced by modernized equipment with inherently increased reliability. Application software is expected to replace some logic-based functions which were previously performed using relay contacts. Application software does not require the performance of PM.

Power Supply

Implementation of a modernized platform will include the use of redundant power distribution units. Use of modernized equipment, combined with a robust lifecycle support strategy, will reduce the obsolescence and overall material costs associated with this equipment.

Self-Diagnostics and Redundancy

Both the safety-related and non-safety DCS digital platforms are expected to perform self-diagnostic functions that will identify failures in system devices down to the line-replaceable unit. This will greatly reduce the need for troubleshooting platform faults. Design redundancy in both platforms can eliminate many existing single-point failure mechanisms and permit the replacement of many failed line-replaceable units without impacting plant operation.

Field Instrumentation

Labor associated with planned and unplanned maintenance of field instrumentation will be reduced in two ways as part of digital platform implementation: first, elimination (e.g., abandon in place) of redundant transmitters for sensed variables such as reactor water level and reactor pressure, and; secondly, implementation of OLM by leveraging non-safety related application software. The digital platform enables the use of a smaller set of redundant sensing instruments to perform multiple functions. This enables the elimination of separate, redundant sensing elements that separately support PAMS, PPS and NSSS, and inherently reduces the total number of PM activities required for sensing instrumentation. In the future, OLM will permit the use of condition-based maintenance whereby calibration is only performed when necessary, as opposed to time-based maintenance strategies.

2.4.1.3 Incident Reports and Corrective Actions Workload Reductions

Existing I&C architectures rely on electromechanical devices and vintage digital components to monitor and react to signals received from field instrumentation. These devices are inherently less reliable than modern digital platforms. In legacy systems, these shortcomings are overcome, in part, by designing systems with redundant channels and voting logic schemes. Combined, these characteristics of legacy I&C architectures yield several consequential failure modes. Failures associated with this type of equipment require reporting and event investigation in accordance with the Reference Plant’s corrective action program (CAP). Failure modes and rates associated with modern digital platforms and associated equipment are expected to be much lower. The benefits analysis eliminated the effort expended on corrective action item reporting and investigating by engineering, operations, maintenance, leadership, and personnel caused when incidents of failure occur of legacy I&C components.

2.4.2 Materials Benefits

2.4.2.1 Annual Material Expenditure Reductions

For reasons already outlined in Section 2.4.1.2, it is expected the Reference Plant will experience lower material costs proportionate with reductions in preventive and corrective maintenance workload. These activities generally require some level of parts (materials) replacement which will no longer be required for eliminated components. It is expected that a ~82% reduction of components will be achieved through the implementation of the digitalization and modernization of safety and non-safety subsystems.

2.4.2.2 Carrying Cost of Inventory Reductions

With a simplified architecture and solid-state components, the Owner will no longer be required to maintain a significant quantity of spare parts and components in inventory to respond to planned and unplanned maintenance activities. The elimination of inventory will provide the opportunity for the Owner to reduce inventory carrying costs.

2.4.2.3 Avoided Cost Attributable to Obsolescence

In addition, prices for the replacement of specialized components of the current legacy safety systems are increasing. As many of these components are obsolete, they have experienced a deterioration in reliability while, at the same time, prices for refurbished components have increased at an accelerating rate over the past 10-15 years (refer to Section 6.1.3). Replacement with a modernized digital system coupled with obsolescence management as part of a lifecycle support strategy will address the exponential growth of legacy system material costs.

2.4.3 Avoidance of Lost Generation Revenue from Forced Unplanned Outages

Failures of existing analog safety and non-safety systems have led and will continue to lead to forced unplanned outages of the Reference Plant. Units are not able to come back online until the fault is repaired or the necessary replacement parts are procured and installed. The cost of plant shutdowns is measured in the opportunity cost of lost revenue during the period the plant is offline. Digitalized safety and non-safety systems are orders of magnitude less prone to failures which lead to system shutdowns. Digitalization upgrades bring direct benefits because they prevent failures of both safety and non-safety systems which lead to unplanned forced outages and lost revenue opportunities.

3. BUSINESS CASE ANALYSIS METHODOLOGY

The BCA methodology was drafted to systematically evaluate and forecast expected lifecycle costs for the related I&C subsystems targeted for modernization. This is depicted in Figure 3-1.

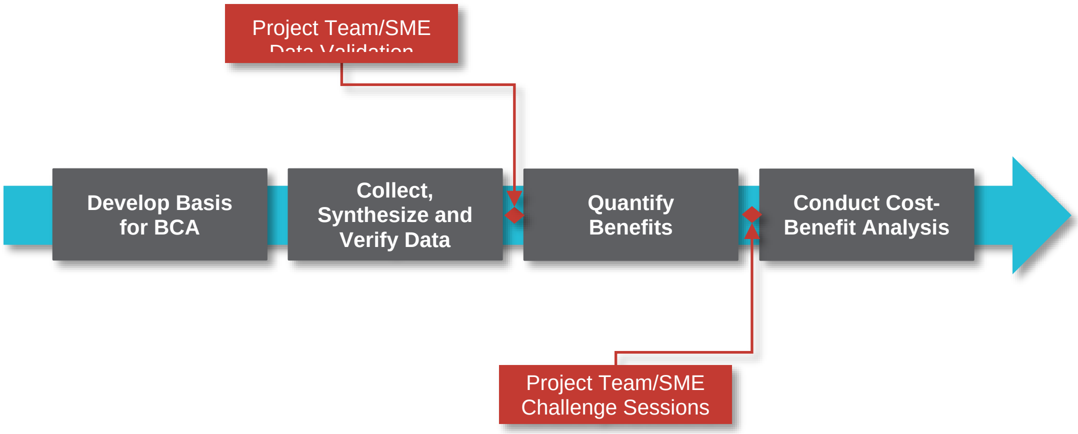

Figure 3-1. Business Case Analysis Methodology

The methodology provided an approach for the Project Team to build the business case for the modernization by:

1. Developing a basis for and bounding the scope of the BCA
   - Definitively bound the scope of current I&C subsystems envisioned for modernization
   - Propose improvements and describe key features of modernization that may offer potential for financial benefits
   - Conduct initial interviews with SMEs to hypothesize potential reductions in labor and material costs enabled by identified improvements/key features
   - Catalog expected benefits of the proposed digital modernization
   - Prepare preliminary engineering studies and deliverables to support data collection activities -see INL report INL/RPT-22-70165 [9].
2. Collecting and synthesizing historical data and determining costs associated with current safety and non-safety related I&C subsystems
   - Mine data sources that bound cost contributors related to the subsystems to be upgraded (Contributors include historical material costs and trends, direct labor costs to maintain and support the subsystems, including surveillances, and indirect costs)
   - Filter, assemble, and categorize cost data into workbooks
   - Apply enablers of quantifiable Project benefits to the cost data to support validation
   - Present and validate cost data with SMEs to further identify existing subsystem costs.
3. Quantifying benefits associated with proposed modernization of safety and non-safety related I&C subsystems

   In collaboration with engineers familiar with the attributes of the digital equipment to be used in the upgrade and its envisioned application; cost savings categories and expected savings in those categories are then identified and applied using the analysis tools developed for this purpose. This effort included:

   - Consolidating enabled workload reductions across existing subsystems to exploit features and economies of scale of the new digital systems and quantify harvestable labor benefits
   - Analyzing existing subsystem historical data of purchased materials and expenditures to forecast avoided lifecycle costs enabled by the new digital systems
   - Presenting and challenging benefit estimates with SMEs and management representatives to refine those estimates based on expert judgment and achieving cross-functional consensus

- Estimating the value of opportunity cost savings / increased revenue through the elimination of failures and forced outages.

The result is a Present Value (PV) of benefits and savings enabled by the upgrade. This includes both direct cost savings (e.g., surveillance labor costs), cost avoidance items (e.g., inventory carrying costs) and opportunity cost savings (i.e. increased revenue through elimination of forced outages).

1. Conducting financial cost-benefit analysis of BCA results
   - Comparing costs to implement and operate the proposed modernized I&C systems to avoided costs (i.e., benefits) of maintaining the current subsystem
   - Present Project metrics of NPV, Internal Rate of Return (IRR) and payback period to Owner's leadership.

The BCA results, which are limited to the development of a detailed cost-benefit analysis, are considered proprietary to the Owner and are provided in a limited distribution version of this research product. For this public version, financial data have been altered to protect the Owner's proprietary information. As presented, the financial data included herein is intended to be illustrative and representative in scale of benefits and is not intended to provide material data utilized in the Owner's financial analysis. The ultimate purpose of this public, non-proprietary version is to communicate the process and related business case tool to enable similar BCAs for digital upgrades throughout the industry. It is expected that this methodology can be abstracted and used for nearly any digital upgrade.

4. DEVELOPMENT OF BASIS FOR BUSINESS CASE ANALYSIS

In order to effectively prepare a BCA, the scope of the modernization must first be bound to a basis. While initiating the Project, discussions were focused on reviewing and applying the Digitally Enabled ION New State Concept of Operations described in Section 1.2.2 and determining how it could best be applied at the Reference Plant as an integrated digital replacement for current safety and non-safety related subsystems.

These initial discussions resulted in a preliminary list of targeted safety and non-safety related subsystems that baselined the Project Team in continued discussions of the benefits that could be achieved with such a solution. These initial discussions were progressively elaborated during the development of the Project in order to bound the scope of the modernization, define key features that would enable benefits, and then catalog those potential benefits.

4.1 Define Target Safety and Non-Safety Related Subsystems

Subsystems targeted for modernization need to be defined at appropriate levels of detail for the Project benefits to be estimated. Defining the extent of the modernization defines the limits of the BCA and serves to direct data acquisition and mining efforts. A list of the existing safety and non-safety related subsystems proposed for modernization at the Reference Plant is provided in Section 2.1 above.

4.2 Define Architecture and Key Features of Proposed Modernization

Project benefits are primarily based on understanding the associated avoided operational and maintenance costs. The architecture and key features of the proposed modernization need to be defined to the extent that detailed engineering studies can be conducted to identify the equipment and components that are functionally replaced or removed by the implementation of the proposed modernized systems. A full description of the architecture and key features of the proposed digital modernization is provided in Sections 2.2 through 2.4 above.

4.3 Catalog Expected Benefits

A catalog of expected benefits is necessary to plan and direct BCA activities. The expected benefits serve as a hypothesis for the Project Team to verify through data acquisition and analysis. Understanding the expected benefits guides the design of a construct for the analysis which then informs the data that needs to be collected. A full description of the expected benefits of the proposed digital modernization is provided in Section 2.4 above.

4.4 Conduct Initial Interviews with SMEs

A series of interviews were conducted with Reference Plant SMEs where the SMEs were presented with the Project scope and an overview of the expected benefits. These interviews served multiple purposes:

1. Review the Project scope and objectives with SMEs and inform them of their supporting role in the development of the BCA.
2. Review expected benefits and determine if additional categories should be investigated.
3. Exchange ideas on how labor and material benefits are evaluated and highlight the sources of data.
4. Determine if additional SMEs should be interviewed or included in the review and validation of data.
5. Input into how the future design of the control room and operating platforms would be beneficial for the day-to-day operations of the plant
6. Input into operations procedures that could benefit from electronic operator-assisted work protocols and procedures.

4.5 Prepare Preliminary Engineering Studies

In order to efficiently process the very large amounts of historical plant data associated with 22 Reference Plant subsystems, the Project Team conducted engineering studies of the plant design to ultimately develop the following lists to support data collection, segregation, and synthesis:

1. In-Scope Subsystem List: As explained above, the initial scoping phase of the project led to 22 of the approximately 120 Reference Plant systems on record in the Work Management System (WMS) being included in the project for analysis. The In-Scope Subsystem List (Table 2-1) was used to direct and limit data-mining activities. How this list was used to collect and categorize data sourced from the WMS is further described in Section 5 below.
2. In-Scope Equipment List: The product of this effort was ultimately a list of all equipment that would be replaced or eliminated by the proposed modernization effort. How this list was used to mine, filter, and synthesize data sourced from the Reference Plant's WMS is further described in Section 5 below.

5. COLLECTION, SYNTHESIS, VERIFICATION AND VALIDATION OF DATA RELATED TO TARGET SAFETY-RELATED AND NON-SAFETY I&C SUBSYSTEMS

To perform a BCA for any system upgrade, the costs associated with continued operation and maintenance of the current systems through the remaining operational lifetime of the unit must be established. To accomplish this, collection, synthesis, and verification of historical cost data was performed to allow identification of trends and forecast of costs for the systems. The basis of the upgrades for the subsystems listed in Section 2.1 represents a good starting point for a general understanding of the overall upgrade. The subsections below provide an overview of the methods employed to develop and present the labor workload associated with those existing subsystems.

To establish the full breadth of costs to maintain the current safety and non-safety subsystems and associated electronic equipment, data mining labor categories and associated research subject unit data were identified. Labor data was then gathered and synthesized to create worksheets within a Microsoft Excel workbook that served as a foundation for the BCA. Material data was similarly gathered and synthesized. Verification and validation of labor and material data by SMEs was performed in areas where savings were expected. Activities associated with this effort are described below. Additional information regarding the systematic approach, as well as sample job aids used to perform the activities described above are available in Appendix A: Systematic Presentation of Business Case Analysis Process.

5.1 Collection, Synthesis, Verification, and Validation of Material Expenditures and Value of Inventory

5.1.1 Data Mining of Material Purchase and Inventory Data from the Reference Plant WMS

To develop an estimate of materials and equipment expenditures related to the target safety and non-safety related subsystems being replaced, the Project Team reviewed both the WMS work order data and the purchase and consumption data from 2015-2022 for each of the 22 subsystems subject to modernization and digitalization. Custom work order (WO) reports were generated with the support of the Reference Plant for each in-scope subsystem.

Each subsystem WO report generated a list of equipment with associated item numbers which could be cross-checked against historical procurement and cost data. The data were filtered against the in-scope equipment list to create a table of equipment for each existing subsystem that was purchased and/or consumed that is in the project scope.

For each catalog item identified in the table of equipment described directly above, the Project Team utilized historical purchase data in the Reference Plant procurement system to document the change in purchase price and the average expenditure over the period in question.

The Reference Plant made a change in their WMS which prevented the Project Team from gathering purchase history prior to 2015 for the in-scope I&C subsystems.

5.1.2 Synthesizing and Presentation of Material Expenditures and Value of Inventory

The results of mining the WMS were synthesized and presented in an MS Excel worksheet for each of the primary targeted safety and non-safety related subsystems in the BCA Workbook. The historical purchase data was used to estimate a weighted average Compound Annual Growth Rate (CAGR) for the price of subsystem components. This value was used to adjust historical purchase prices to current values and determine the value of inventory for each component.

The Project Team identified potential equipment items that would be eliminated with the upgrade and confirmed these items with the vendor. The annual purchase of materials, percent of material purchases avoided, and material price escalation rate were compiled into a separate MS Excel worksheet to quantify the annual costs avoided over the next 30 years for each material as a result of the I&C upgrades. Additional information regarding the systematic approach used to perform the activities described above is available in Appendix A: Systematic Presentation of Business Case Analysis Process appended to this research product.

5.1.3 Capital Carrying Cost

Historical components pricing data and current inventory levels were analyzed to determine the current value of inventory held by the corporation for the Reference Plant. Historical escalation rates were used to estimate the future value of inventory. Other carrying costs, including annual depreciation, supply chain and warehousing factors, property taxes, insurance, and one-time write-down costs were examined and determined by the Project Team to be unrealized by the project.

5.1.4 Verification and Validation of Material Expenditures and Carrying Costs of Inventory

The Project Team verified data related to material purchases in inventory levels as part of a data verification and validation workshop with SMEs from Procurement, Warehousing, Maintenance, and System Engineering. The objectives of the workshop were to:

1. Review the methods used by Engineering and Business Analysts to mine, filter, and synthesize data in the BCA Excel Workbook and confirm that the approach is rational.
2. Validate that the purchase data, unit costs, and inventory levels presented are reflective of their experience as SMEs and adjust or correct where warranted.
3. Verify that the consolidated results presented are aligned with their overall expectations as SMEs and adjust or correct where warranted.

5.1.5 Backlog and Training Content Reduction

Although backlog reduction was not reviewed in this analysis, prior analyses have shown backlog reduction from this type of upgrade. On the other hand, appreciable training reduction would not be realized in either operations or maintenance training regimens.

5.2 Collection, Synthesis, Verification, and Validation of Operations and Maintenance Labor Workload

5.2.1 Data Mining of Raw Labor Data Sourced from Reference Plant Work Management System

Direct O&M labor workload tied to existing in-scope safety and non-safety related subsystems (Table 2-1) and associated in-scope equipment identified by engineering in the lists described in Section 4.5 were largely collected from examination of historical records of WOs sourced from the Reference Plant's WMS. Custom WMS reports were developed for each in-scope subsystem with the support of the Reference Plant's IT department. Each report provided a set of all recorded WO tasks for a particular subsystem over the history of the Reference Plant. Each task identified the resources required and the estimated hours to complete.

The Project Team analyzed over 96,000 line items of 2015-2022 historical work management data collected from the WMS to determine the current annual workload for all 22 in-scope subsystems. The dataset contained a complete list of Preventative Maintenance (PM), Surveillance (SV), and Non-Routine (NR) maintenance WOs at the Reference Plant and detailed information pertaining to the work completed on-site. The raw data provided by the WMS for each work type was consistent except for scheduled/required frequencies. The raw data did not include frequencies for NR WOs as they are not planned or scheduled. Relevant information from the raw data was filtered into subsystem-specific Microsoft Excel workbooks and finally segregated into the categories of activities as described below:

5.2.1.1 Preventative Maintenance

PM WOs are preventative, predictive, or seasonal maintenance activities performed on a routine basis as part of the Reference Plant's equipment reliability program. The description, number of locations, work group, average WO hours, and labor hours for PM work types were derived from the raw data. Additional calculations were necessary to determine the total annual hours and frequencies. The PM frequencies were annualized by dividing the number of days in the year by the lower (more conservative) scheduled or required maintenance value for each work order. The total annual hours were calculated by multiplying the labor hours used by the planned PM frequency and the number of locations for each work order.

5.2.1.2 Surveillance

Functional tests of installed equipment and/or systems to satisfy technical safety requirements. The description, number of locations, work group, average WO hours, and labor hours for SV work types were derived from the raw data. Additional calculations were necessary to determine the total annual hours and frequencies. The SV frequencies were annualized by dividing the number of days in the year by the lower (more conservative) scheduled or required maintenance value for each work order. The total annual hours were calculated by multiplying the used labor hours by the planned SV frequency and the number of locations for each work order.

An example of the data included in refined PM and SV Excel worksheets can be seen in Table 5-1.

Table 5-1. Example of PV Refined Dataset

		PLANNED				ACTUAL		USED			
Description	Locations	PM Frequency	Online or Outage	Work Group	Avg WO Hours	Work Group	Avg Total WO Labor	Work Group	Labor Hours	Total Annual Hours	Eliminated?
7300 P/S FUNCTION CHECK	6	0.67	Outage	MT1	3.5	MT1	5.4	MT1	5.4	21.6	
7300 POWER SUPPLY CAP REPLACE	6	0.11	Outage	MT1	14.7	MT1	27.9	MT1	27.9	18.6	Y
CAL TIME DELAY RELAYS	2	0.33	N/A	PEMR	13.2	PEMR	11.0	PEMR	11.0	7.3	Y
ICI-4092 CCAL LEFM	1	0.67	Online	IC	16.0	MT1	20.2	MT1	20.2	13.4	Y

5.2.1.3 Non-Repetitive Maintenance

The repair of failed or malfunctioning equipment, systems, or facilities to restore the intended function or design condition. The raw data files sourced from the WMS for each subsystem were mined for WOs that were tagged as NR WOs in the WMS System. The data were then filtered to omit data not included in the table of equipment for each existing subsystem that was purchased and/or consumed that is in the project scope as described in Section 5.1.1 above. The description, work group, and total hours (actual) for NR work types were derived from the raw data. The total hours (planned) were pulled separately from the WMS and included in the refined NR spreadsheets. The labor hours (used) referenced the total hours (actual) or total hours (planned) if the actual hours used were not recorded in the raw data.

An example of the data included in refined NR Excel worksheets can be seen in Table 5-2.

Table 5-2. Example of NR Refined Dataset

	PLANNED		ACTUAL		USED		
Description	Work Group	Total Hours	Work Group	Total Hours	Work Group	Labor Hours	Completion date
CR-2011-013064 1-PI-524A is failing	PT	8	PT	0	PT	8	12/14/2011
CR-2012-000147 Blown Fuse on 2-HS-2371	PT	0	PT	3	PT	3	1/5/2012
Rework Indicating light	PT	2	PT	2	PT	2	1/10/2012
CR-2012-004666 2-FI-4391 Fluctuating	PT	8	PT	0	PT	8	5/20/2012

5.2.1.4 Calibration Support

The WMS at the Reference Plant did not contain calibration support as a work order type, however, calibrations accounted for a significant amount of labor. To develop an estimate of expected calibration support workload reductions attributable to the digital I&C upgrade, the Project Team manually counted work order descriptions that included calibrations between 2015-2022 and summed the annual totals for 2015-2022. These sums were then averaged to calculate an estimated calibration support workload. A conservative assumption of one hour per calibration support work order was used for the analysis.

5.2.1.5 Support Hours

Support activities for maintenance of I&C were not included as separate work types in the WMS. Support activities such as pre-job briefing/prepping, scheduling, preparing work packages, coordination, WO closeout, and record maintenance also amount to substantial labor workloads. The Project Team compiled data from support activities and found that on average one WO required support from nine individuals, totaling approximately seven hours per WO.

5.2.2 Synthesis and Presentation of Preventative Maintenance (PM) Workload

Estimates for workload reductions for each in-scope subsystem were based on the work order tasks that are projected to be eliminated with the digital upgrades. The Project Team identified the types of PM tasks that would be reduced or no longer necessary with an I&C upgrade following discussions with vendors as well as SMEs. The percentage of workload reduction, or efficiency, was calculated by dividing the number of hours eliminated by the total annual hours. The efficiency for each activity was then multiplied by the duration of activity per unit to determine the total estimated savings in personnel hours after the I&C modernization. Analysis of total workload reductions was used to determine the potential reductions of FTEs at the Reference Plant.

While there were 22 in-scope subsystems at the Reference Plant, there were several excluded from the PM analysis, resulting in 14 total subsystems with PM WOs. To develop an estimate of expected FTE reductions attributable to existing subsystems impacted by the proposed modernization, PM workload data was consolidated by subsystem into 14 MS Excel worksheets. The Project Team modeled the tasks and resources required and established the expected PM workload utilizing the historical labor data. Additional workload to support PM WOs, such as craft supervision, planning, scheduling, work management, and subsystem engineering support that are not included in the WMS WO data were identified as part of the data verification and validation process described in Section 5.2.5 below.

5.2.3 Synthesis and Presentation of Surveillance and Test (SV) Workload

Estimates for workload reductions for each in-scope subsystem were based on the work order tasks that are projected to be eliminated with the digital upgrades. The Project Team identified the types of SV tasks that would be reduced or no longer necessary with an I&C upgrade following discussions with vendors as well as SMEs. The percentage of workload reduction, or efficiency, was calculated by dividing the number of hours eliminated by the total annual hours. The efficiency for each activity was then multiplied by the duration of activity per unit to determine the total estimated savings in personnel hours after the I&C modernization. Analysis of total workload reductions was used to determine the potential reductions of FTEs at the Reference Plant.

While there were 22 in-scope subsystems at the Reference Plant, there were several subsystems excluded from the SV analysis, resulting in 13 total subsystems with SV WOs. To develop an estimate of expected FTE reductions attributable to existing subsystems impacted by the proposed modernization, SV workload data was consolidated by subsystem into 17 MS Excel worksheets. The Project Team modeled tasks and resources required and established the expected SV workload utilizing the historical labor data.

Additional workload to support SV WOs, such as craft supervision, planning, scheduling, work management, and system engineering support not included in the WMS WO data, were identified as part of the data verification and validation process described in Section 5.2.5 below.

5.2.4 Synthesis and Presentation of Non-Routine (NR) Workload

To develop an estimate of expected FTE reductions attributable to existing subsystems impacted by the proposed modernization, NR workload data was consolidated by subsystem into 17 MS Excel worksheets. Unlike planned maintenance WOs (i.e., SV and PM WOs), unplanned NR WOs do not lend themselves to forecasting at the task level. Instead, the historical trend of annual workload for each resource type, sometimes described as a “run-rate,” was used as the basis to trend workload into future years. Additional workload to support field labor activities, such as craft supervision, planning, scheduling, and system engineering not included in the WMS WO data were estimated by factoring the number of tasks and SV WOs associated with in-scope equipment. The NR labor reduction benefits were a function of the number of hours needed to complete activities, the work order tasks expected to be eliminated with the upgrade, and the percentage of site savings that are applicable, efficient, and harvestable.

Following discussions with the vendors as well as SME’s, the Project Team identified the types of NR tasks that would be reduced or no longer necessary with an I&C upgrade. The Project Team calculated the estimated NR savings in personnel hours annually using the percent reduction of NR activities.

5.2.5 Verification and Validation of Operations and Maintenance Workload

A series of workshops were conducted with SMEs to verify the estimated workload reductions synthesized from the engineering studies lists and mined data. These workshops also engaged the SMEs to validate the key features and enablers of quantifiable project benefits (Section 2.1 to 2.3) and the description of expected benefits (Section 2.4) was applied to the data by Engineering personnel to identify specific areas of potential workload reductions. SMEs included representatives from I&C Maintenance Craft, I&C Maintenance Supervision, Maintenance Preparation (Scheduling and Planning), Work Management, Outage Management, Operations, and System Engineering. Where needed, follow-up interviews were conducted with additional SMEs identified to confirm open items generated in the workshops.

The objectives of these sessions were to:

1. Provide SMEs with an overview of how the data was collected by Engineering and Business Analysts and compiled in the BCA Workbook to confirm the approach is reasonable
2. Validate that the detailed data presented is reflective of their experience as SMEs and adjust or correct where warranted
3. Provide an opportunity to make necessary adjustments to the data based on SME experience (i.e., there might be wide discrepancies in the resources and time required on various WOs that need to be reconciled)
4. Identify additional support tasks not identified on the WOs (i.e., WOs will identify field labor to perform tasks as part of a WO, but they generally do not identify time spent scheduling, coordinating, and supervising the work, which are tasks added in manually by the Project Team based on SME input)
5. Verify that the workload described in the data can be eliminated as identified by Engineering and captured in the BCA Excel Workbook based on the scope and description of benefits of the proposed modernization of safety-related systems; where the workload is only partially eliminated, SMEs were asked to assign a percentage value for the reduction

6. Verify that the consolidated results indicating total workload reduction are within the bounds of available resources assigned to the Reference Plant.

5.2.6 Variability in Operations and Maintenance Workload Reductions

A certain amount of variability and uncertainty exists in determining the workload reductions from the I&C modernizations included in the BCA for future plants. The sources of this variability are threefold.

First, as mentioned, for certain subsystems workload eliminations were considered partial and estimates were given as to the percentage value of workload reduction. Secondly, aggressive modernization could lead to the elimination of more subsystem components. Thirdly, predicting future non-routine maintenance is driven by the history of past maintenance. Future maintenance could be more or less. Additionally, older power plants could require more maintenance than what is in the BCA. The Reference Plant included in the analysis is newer than the U.S. Domestic Light Water Reactor fleet average.

5.3 Other Labor Categories Examined

5.3.1 Engineering

The Project Team conducted interviews with Operations and System Engineers to estimate the level of support that would no longer be necessary with modern digital systems. System Engineers currently spend a significant portion of their time troubleshooting faults and failed system components. They also spend significant time supporting procurement in the sourcing of parts and components, particularly those that are experiencing obsolescence challenges. Improved reliability of modern digital components and the capability of digital systems to self-diagnose failures and their cause down to the line-replaceable unit would eliminate much of these efforts. System engineering workload reductions were estimated to achieve cumulative labor efficiency savings of approximately 300 hours per year across the entire engineering function of the Reference Plant.

5.3.2 Training

Through interviews with Operations, Maintenance, and Training program managers, and an examination of training content and delivery, it was determined that no appreciable reductions would be realized in either operations or maintenance training regimens. The assessment of the Operator Training Program indicated that, while some training materials would be modified, the overall content and frequency of training would not be reduced. Training for the legacy systems would be replaced with training on the new systems. The assessment of the Maintenance Training Program indicated that the program is based on the development of craft qualifications, and that the proposed scope would not impact qualifications required to perform day-to-day activities across the Reference Plant.

5.3.3 Contract Labor

It was established through discussions with the Reference Plant personnel that some maintenance I&C WOs that are completed on in-scope subsystems at the plant are assigned to contractors. To determine the benefits associated with contract labor, the estimated annual labor hours for PM, SV, and NR tasks across all I&C subsystems were compiled in a separate Excel Workbook. After accounting for the percent reduction of labor for each I&C subsystem that would occur from the digital upgrades, the annual external contractor hours were harvested to estimate the savings in FTEs.

5.3.4 Supply Chain

It was established through discussions with the Supply Chain and warehouse personnel that there would be between 1.5 to 2.0 hours of workload reduction per corrective maintenance I&C WO for the in-scope subsystems would be reduced. These hours were rolled up into the labor efficiency hour summary for the I&C modernization.

5.4 Incident Reporting

It was established through interviews and discussions with Operations, Maintenance, Performance Improvement, and Engineering personnel that each root cause or corrective action item that occurs during an adverse operational event generates at least 650 annual hours of workload across over 20 Reference Plant positions. These workload hours are estimated to be saved if the operational performance of the new I&C components are more reliable than the current components. These workload savings were documented as workload efficiency as a result of this I&C modernization.

6. QUANTIFYING BENEFITS OF THE PROPOSED DIGITAL SAFETY AND NON-SAFETY RELATED I&C SUBSYSTEMS

6.1 Quantification of Materials Benefits

6.1.1 Estimating Annual Material Expenditure

Using the materials data collected and synthesized for each item number, the Project Team employed an 8-year average expenditure to estimate annual material expenditures for each targeted subsystem (refer to Section 5.1.1). It was often the case that catalog items were common to multiple subsystems. In such cases, catalog item costs were allocated by the Project Team on a percentage basis to each target subsystem.

6.1.2 Establishing Escalation Rate of Total Material Expenditures

Understanding the escalation rate of material expenditures is necessary to trend expected benefits in future years. Anecdotal evidence produced during initial interviews made it apparent that material costs to support some of the targeted safety-related subsystems have been escalating at higher rates than what would be expected for a I&C system. Rather than apply an industry standard material escalation rate to trend material costs in future years, an analysis was conducted to establish a definitive escalation rate for material expenditures of high impact I&C equipment, power supplies and circuit cards, for each of the targeted safety and non-safety related subsystems.

Catalog items were sampled from each target subsystem and analyzed to establish material expenditure growth rates over the period. The selection criteria for samples were based on the frequency of purchase and component total expenditure so that approximately 80% of total expenditures for each targeted subsystem were represented in the sample set.

The analysis of sample subsystem price escalation found average CAGRs over the period of 13%. Accounting for the impact of increased failure rates as components age, the project's analysis determined that a forward-looking CAGR was likely to average 18% across all 22 subsystems. However, other analyses have found higher escalation rates for similar subsystem components with CAGR's of approximately 25%.

The resulting CAGRs were used to project expected material expenditures for each targeted subsystem in future years and to demonstrate the Avoided Cost of Obsolescence (ACO) described in the next section.

6.1.3 Estimating Avoided Material Cost Attributable to Obsolescence

Based on early interviews with Reference Plant staff, the Project Team investigated reports of high escalation of component prices in recent years. An analysis of material costs for multiple in-scope replacements in this Project revealed that costs to maintain the subsystem are escalating at a CAGR of 13 to 18%. These estimated CAGRs are higher than the average expected inflation of the economy at 3 -5%. For the purposes of this report, we used a midpoint material CAGR of 15% however, this rate does not necessarily represent the CAGR used for the actual Reference Plant's BCAM.

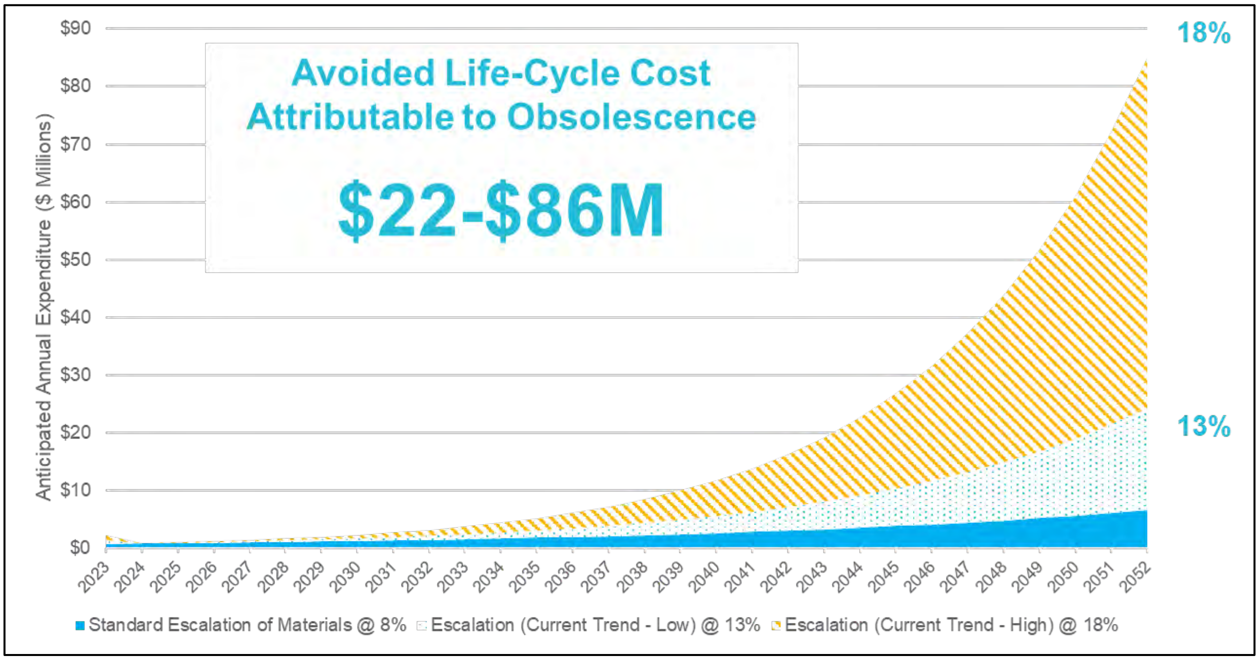

Figure 6-1. Avoided Cost of Obsolescence Analysis

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 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
- A limited supplier base has shifted market power to the shrinking number of vendors that still supply/service this equipment.

Given that the obsolescence of components is the driving force behind rapidly increasing subsystem costs, replacement of the 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.

This research product defines the ACO as the difference between the PV of future material expenditures at observed escalation rates (e.g., 13–18% CAGR) and the PV of future material expenditures at expected escalation rates (e.g., 8% CAGR).

6.1.4 One-Time Write-Off of Obsolete Inventory and Equipment

In cases where implementation of a project will strand obsolete parts and equipment, these items should be assessed to determine if they can be sold and/or written off the books. This analysis was conducted and credited as part of the Project cost estimate by the Owner. A value for stranded inventory was not included in the baseline scenario for this project.

An analyst conducting a subsequent BCA should consult with the Owner's finance team to determine a more accurate treatment of these one-time benefits. In some cases, this benefit is written as part of the capital project as an offset of costs, and care should be taken not to double-count this on both sides of the BCA.

6.1.5 Estimating Current Value of Inventory

The current value of inventory was estimated utilizing historical purchase data of catalog items. The most recent purchasing unit cost for each unit ID identified was mined from the Reference Plant procurement system. In many cases, the most recent purchase was several years in the past and needed to be adjusted to reflect current pricing; however, there were not enough instances of purchases to reliably establish rates of increases in cost over time.

In a similar fashion to establish CAGR for total material expenditures above, a sample set of catalog items was selected from each target subsystem and analyzed to establish unit pricing trends over the period. This in-depth analysis revealed that unit costs for specialized components were increasing at CAGRs higher than expected. From this analysis, a weighted average of unit price CAGR was established for each targeted subsystem. This CAGR was applied to historical unit prices to estimate the current value. The current value of inventory was then calculated by taking the sum-product of adjusted unit prices and quantity in inventory. In cases where components were shared by multiple subsystems, the value of inventory was allocated by the Project Team on a percentage basis to each target subsystem.

6.1.6 Estimating Carrying Cost of Inventory

The carrying cost of inventory can be described as the burden of holding capital in inventory that may otherwise be invested elsewhere. The carrying cost of inventory was estimated as the sum of the components listed below:

- *Capital Carrying Cost:* Capital carrying cost represents the opportunity cost of maintaining assets in inventory that might otherwise be invested elsewhere. It is calculated as the *Value of Inventory* multiplied by the Owner's Cost of Capital (CoC).
- *Supply Chain and Warehousing Charges:* Supply chain and warehousing charges (if applicable) are the estimated costs for procurement and warehousing services borne by the Reference Plant.
- *Annual Depreciation:* Annual depreciation (if applicable) is the annual write-down of the value of inventory in stores. Applicability of this depends on Owner's treatment of assets in inventory.
- *Property Taxes:* Property taxes (if applicable) are costs borne by the Owner based on the value of inventory and regulations by the local taxing authority.
- *Insurance*: Insurance (if applicable) is costs borne by the Owner to insure the value of assets in inventory from loss and/or damage.

It was estimated that annual inventory carrying costs were 25% of the value of inventory. Therefore, the annual additional inventory benefit from avoided material costs was 25% of the value of the total material reductions as a result of modernizations.

6.1.7 Avoided Material Cost Summary

A summary table of avoided material costs based upon baseline assumptions is provided in Table 6-1.

Table 6-1. Avoided Material Costs: With Baseline Assumptions

#	Existing I&C Subsystem	System Type	Annual Purchases of Material	Purchases Avoided Due to Modernization
1	Plant Protection System	Safety	\$156.21k	\$153.08k
2	Nuclear Instrumentation – Safety/Control and RG1.97[2]	Safety	\$43.18k	\$13.39k
4	Solid State Safeguards Sequencer	Safety	\$21.31k	\$7.25k
5	PAMS Variables	Safety	\$82.47k	\$70.51k
6	*Reactor Vessel Level*[3]	*Safety*	*N/A*	*N/A*
7	*Hydrogen Monitoring*[4]	*Safety*	*N/A*	*N/A*
9	BOP Controls - Safety, Hot Shutdown Panel	Safety	\$3.44k	\$0k
10	BOP Controls - Safety	Safety	\$13.57k	\$10.45k
11	BOP Controls - Non-Safety	Non-Safety	\$13.57k	\$10.45k
12	NSSS Process Control	Non-Safety	\$39.35k	\$27.54k
13	AMSAC	Non-Safety	\$.68k	\$0
14	*Turbine Controls Interface*[5]	*Non-Safety*	*N/A*	*N/A*
15	Containment Atmospheric Monitoring	Non-Safety	\$11.14k	\$7.13k
16	*Meteorological Monitoring Interface*[6]	*Non-Safety*	*N/A*	*N/A*
17	Rod Control Systems	Non-Safety	\$11.10k	\$9.55k
18	Rod Position Indication	Non-Safety	\$5.17k	\$4.86k
19	Flux Mapping System	Non-Safety	\$104.24k	\$72.97k
20	Annunciator System	Non-Safety	\$16.39k	\$4.75k
21	Plant Computer Interface	Non-Safety	\$8.21k	\$8.21k
22	*LEFM Interface*[7]	*Non-Safety*	*N/A*	*N/A*
23	Feedwater Heater Drain Controls	Non-Safety	\$319.40k	\$300.23k
	TOTAL		**\$849k**	**\$700k**

6.2 Quantification of Labor Benefits

6.2.1 Summary Labor Reductions from Modernization Efforts

Various PM, NR, and SV work types were reduced or eliminated because of the Reference Plant's digital I&C modernization efforts, as shown in below. The percentage reductions represent the time saved

[2] Nuclear Instrumentation – RG1.97 and Nuclear Instrumentation – Safety/Control were combined into a single category for the analysis of avoided material costs

[3] Reactor Vessel Level's avoided costs are included in #5 PAMS

[4] Hydrogen Monitoring's avoided costs are included in #5 PAMS

[5] It was determined that the modernization of Turbine Controls does not result in cost-saving benefits

[6] It was determined that the modernization of the Meteorological Monitoring Interface does not result in cost-saving benefits

[7] It was determined that the modernization of the Leading Edge Flow Meter Interfaces does not result in cost-saving benefits

annually on tasks for specific safety and non-safety subsystems. The methodology to determine the percentage reductions for each work type was previously described in Sections 5.2.2 through 5.2.4. The resulting percentages in reductions were then used to estimate the total savings in personnel hours. Table 6-2 only depicts the reductions attributed to maintenance activities at the Reference Plant.

Table 6-2. Percent of Maintenance Labor Reductions: Baseline

Work Type	System Type	I&C Subsystem	% Reduction
PM	Safety	Plant Protection System	71%
SV	Safety	Plant Protection System	50%
NR	Safety	Plant Protection System	50%
PM	Safety	Nuclear Instrumentation – Safety/Control and RG1.97	52%
SV	Safety	Nuclear Instrumentation – Safety/Control and RG1.97	7%
NR	Safety	Nuclear Instrumentation – Safety/Control and RG1.97	50%
PM	Safety	Solid State Safeguards Sequencer	20%
NR	Safety	Solid State Safeguards Sequencer	50%
SV	Safety	PAMS Variables	31%
NR	Safety	PAMS Variables	50%
SV	Safety	Reactor Vessel Level Control	100%
NR	Safety	Reactor Vessel Level Control	50%
PM	Safety	Hydrogen Monitoring	63%
NR	Safety	Hydrogen Monitoring	50%
N/A	Safety	*Hot Shutdown Panel*[8]	*N/A*
PM	Safety	BOP Controls	100%
NR	Safety	BOP Controls	50%
SV	Non-Safety	BOP Controls	81%
NR	Non-Safety	BOP Controls	50%
PM	Non-Safety	NSSS Process Control	35%
SV	Non-Safety	NSSS Process Control	100%
NR	Non-Safety	NSSS Process Control	50%
PM	Non-Safety	AMSAC	60%

[8] The labor benefits related to the modernization of the Hot Shutdown Panel are incorporated into those of BOP Controls, Safety

Work Type	System Type	I&C Subsystem	% Reduction
NR	Non-Safety	AMSAC	50%
N/A	*Non-Safety*	*Turbine Controls Interface*[9]	*N/A*
PM	Non-Safety	Containment Atmospheric Monitoring	37%
NR	Non-Safety	Containment Atmospheric Monitoring	50%
N/A	*Non-Safety*	*Meteorological Monitoring Interface*[10]	*N/A*
PM	Non-Safety	Rod Control	3%
NR	Non-Safety	Rod Control	50%
PM	Non-Safety	Rod Position Indication	29%
NR	Non-Safety	Rod Position Indication	50%
PM	Non-Safety	Flux Mapping	100%
SV	Non-Safety	Flux Mapping	100%
NR	Non-Safety	Flux Mapping	50%
PM	Non-Safety	Annunciator System	100%
NR	Non-Safety	Annunciator System	75%
PM	Non-Safety	Plant Computer Interface	100%
NR	Non-Safety	Plant Computer Interface	100%
N/A	*Non-Safety*	*LEFM Interface*[11]	*N/A*
PM	Non-Safety	Feedwater Heater Drain Controls	15%
SV	Non-Safety	Feedwater Heater Drain Controls	21%
NR	Non-Safety	Feedwater Heater Drain Controls	100%
NR	N/A	NR Support Hours (pre-job briefs at.25 hours per WO)	100%

[9] The labor benefits related to the modernization of the Turbine Controls Interface are incorporated into those of the Feedwater Drain Controls

[10] The labor benefits related to the modernization of the Meteorological Monitoring Interface are incorporated into those of the Feedwater Drain Controls

[11] The labor benefits related to the modernization of the Leading Edge Flow Meter (LEFM) Interface are incorporated into those of the Feedwater Drain Controls

Table 6-3. Total Workforce Savings

Modernization Effort	Total Harvestable Site Savings (Person Hrs.)	Total Harvestable Site Savings (FTEs)
Safety	3,393	2.2
Non-Safety	7,511	4.8
TOTAL	**10,904**	**7.0**

6.2.2 Quantification of Labor Benefits

Once labor data collection activities were completed and workload reductions attributable to in-scope equipment were validated, a summary of this data was assembled onto a single table in order to support the quantification of labor benefit. The summary data was provided by resource type and segregated into the following categories and subcategories.

- Labor Benefits
  - Target System
    - Preventive Maintenance
    - Surveillance
    - Non-Routine Maintenance
    - Calibration
    - Other Support.

Presenting the workload reductions in this way in the BCA Excel Workbook allowed the Project Team to demonstrate how these reductions can be actualized as budget reductions at the Reference Plant. Benefits that can be translated to staffing adjustments are regarded as harvestable labor benefits. For the purposes of estimating staffing adjustments, the Project Team considered online workload reductions as harvestable. Outage workload adjustments, which are supported by external labor sourced from contracts or other plants, were not considered harvestable by the Reference Plant, but rather redeemable as reductions of temporary support, contracted or otherwise, transferred from other plants.

6.2.3 Treatment of Harvestable Online Workload Reductions

Harvestability is defined as the actual reduction in required workload in units of FTEs notwithstanding regulatory staffing requirements. More specifically, estimated workload reductions must be at least equal to or greater than one FTE in resource-hours for a particular resource function to be counted as harvestable. To determine harvestability, the Project Team summed up the total online workload reductions by resource types and determined if the workload reduction was great enough to affect an organization in terms of the number of FTEs. The following examples illustrate how the concept of harvestability can be applied.

Example 1.
A benefits analysis has been completed on a plant initiative to outsource the operation of a water dosing system to an external contractor. The Project indicates that the plant may expect an annual reduction of 250 hours of mechanical maintenance labor and 1,050 hours in chemistry labor. The FTE equivalent is 1,400 hours for a mechanical craft person and 1,600 hours for a chemistry technician. This workload reduction is therefore not harvestable as the workload reductions do not meet the threshold of one FTE for either resource type.

In some cases, like-for-like resources from different work groups can be combined to achieve harvestability.

Example 2.
A plant is considering implementing a new computer-based WMS featuring paperless WOs. A benefits analysis has been completed that indicates workload related to clerical support in various work groups will be reduced as follows:

Mechanical Maintenance – 600 hours

Electrical Maintenance – 1,350 hours

Instrument Maintenance – 1,550 hours

Maintenance Planning – 900 hours

Total Clerical Workload Reduction – 4,400 hours

The FTE equivalent of a clerical worker is 1,800 hours. Individually, the workload reductions listed above are not harvestable from any one work group. The Project Team then discussed the Project with department leads and determined that clerical resources could be shared between work groups in a way to support the harvestability of two FTEs.

Regulatory staffing requirements can present an obstacle but can be overcome in certain situations:

Example 3.

A modernization of plant operations is being proposed for a plant which is expected to reduce the workload of equipment operators by the equivalent of three FTEs. The plant's Operations staffing currently is at the minimum allowed per shift under its current operating license. However, the workload reductions allow plant Operations to take on some field tasks currently performed by chemistry. After analysis of the chemistry workload that could be transferred to operations, the Project Team recognized that at least two FTEs could be harvested from chemistry as a result of the modernization.

6.2.4 Treatment of Unharvestable Workload Reductions

The Project Team evaluated if unharvested workload reductions could be credited toward other budget reductions or qualitative performance improvements.

1. For resources that were determined to be eligible to receive compensation for overtime, unharvested workload reductions were credited as reductions in overtime and quantified as a benefit for the purposes of the BCA.
2. Any remaining unharvested labor benefits were recorded as available for other uses but were not quantified as monetary benefits for the purposes of the BCA. These benefits are identified and made available for management discretion, possibly to achieve other strategic objectives. Examples of strategic objectives where unharvested workload reductions might be utilized:
    - Reduction of backlog (i.e., maintenance, training)
    - Improved situational awareness (operations)
    - Participation in performance improvement efforts
    - Potential to combine savings with other initiatives.

6.3 Estimating the Impact on Generation Revenue of Avoiding Forced Unplanned Outages

6.3.1 Estimating the Number of Hours of Generation Lost to Unplanned Forced Outages Caused by Failures of Relevant Subsystems

The Project Team conducted a meeting with managers and engineers from the Reference Plant to understand the plant's experience with unplanned forced outages. The meeting had three objectives:

1. Obtain accurate data on the historical record of unplanned forced outages at the Reference Plant;
2. Ascertain the extent to which these hours were caused by the safety and non-safety subsystems that planned modernizations were to replace;
3. In the context of the historical record of unplanned forced outages at the Reference Plant, understand the likely trajectory of future forced outages at the plant given the probable decreasing reliability with aging equipment.

6.3.1.1 Historical Data on Unplanned Forced Outages

Reference Plant personnel determined that the plant experienced approximately three unplanned forced outages of one of their two units every nine years in 30 years of operation. Twice as many of these outages occurred during winter as in summer. Each outage lasted on average 14 days, which included three days to power down the plant so that the required maintenance could be carried out and three days to return to operability once repairs had been completed. At a minimum, four days were required to obtain or procure the necessary replacement parts and to complete the maintenance work. The average length of time this took was eight days.

6.3.1.2 Forced Outages as Consequence of Safety and Non-Safety Subsystems

The Reference Plant personnel did not ascertain with firm accuracy which safety subsystems and their related components failed to cause forced outages in each case. However, based on the review of the subsystems included in the project's modernization efforts, Reference Plant personnel estimated that the large majority of failures would have been prevented with the planned modernizations. Further studies will be required for individual plants to determine the failure rates of subsystems at each plant that undertakes a similar modernization effort.

6.3.1.3 Predicting the Frequency of Future Outages

Evidence from the record of subsystem failures and forced outages in the Reference Plant thus far suggests that without modernization efforts the Reference Plant will experience increasing numbers of hours lost to forced outages. Detailed data will be beneficial to provide more accurate forecasts of subsystem failures in the future.

6.3.2 Estimating and Modelling the Value of Lost Generation

Given some of the data limitations described above, the Project took a conservative approach to estimating the value of subsystem modernizations in avoiding unplanned forced outages - "reliability events" - and preventing loss of generation revenue.

For the baseline analysis, the frequency of reliability events was maintenance at three events per nine years, with a summer-winter-summer schedule of events. The winter value of electricity was set at $30/MWh and the summer value at $300/MWh. The baseline duration was established at 10 days per event. Neither the value of electricity, nor the duration or frequency of reliability events was escalated over the lifetime of the project. Other analyses modelled situations where future reliability events were more frequent. The results of these models can be seen in Section 10.

6.3.3 Summary of the Value of Lost Generation Revenue Avoidance through Modernization

Applying the assumptions developed above, modernization provides the following reliability values:

- The value of lost revenue avoidance through subsystem modernizations and digitalization, per winter event equals ~ $8.7M.
- The value of lost revenue avoidance through subsystem modernizations and digitalization, per summer event equals ~ $87M.
- The annual value of lost revenue avoidance through subsystem modernizations and digitalization equals ~$11.6M.

6.4 Challenge Sessions

A series of workshops were conducted with Owner's SMEs and sponsor representatives to review the results of the benefits analysis. SMEs included representatives from I&C Maintenance Craft, I&C Maintenance Supervision, Maintenance Preparation (Scheduling and Planning), Work Management, Outage Management, Operations, and System Engineering. Sponsor representatives included Reference Plant and corporate leadership and capital project and finance management. The objectives of these sessions were to:

1. Provide SMEs and Owner's leadership with an overview of how data was collected, and benefits were calculated
2. Review key assumptions made and incorporate feedback into the analysis and resulting financial model
3. Verify that the quantified benefits were reasonable in nature and were the logical outcome of the analysis conducted.

At the end of these challenge sessions, participants indicated their understanding of the process followed and the rationality of the results obtained by that process as presented. Participants also highlighted those areas where the potential for variability in project costs and benefits existed, and what the lower and upper bounds of these variability would likely be. This analysis was incorporated into the scenario modelling, explained further in Section 9.

7. QUANTIFICATION OF CAPITAL COSTS AND ONGOING COSTS

The estimates of one-time installation and ongoing licensing costs associated with the installation and operation of the proposed modernized systems were provided by the Owner to the Project Team. The estimates were based on parametrics and scaling of costs from similar modernization efforts conducted on other similar systems.

The cost estimates provided were based on the scope and benefits described in this research product and have not been validated against a selected solution. Costs presented are indicative of expected Project costs by the Owner and are considered within an order-of-magnitude of true costs.

7.1 Capital Costs

Total capital costs are estimated at $250M over 8 years for two units. These estimates reflect the upper bound of the range presented for capital costs and which are reflected in the subsequent financial results presented in Section 9. Using the upper bound for the baseline reflects the fact that the Owner's activity is a first-of-a-kind activity with impacts on expected Project costs.

It is expected that future safety and non-safety related I&C modernizations of a similar scope at a PWR will leverage the work products of this pilot as a roadmap, eliminating these first-of-a-kind costs. This elimination is reflected in the lower end of the range of $150M presented for capital costs and subsequent financial metrics in the lowest reliability scenario presented in Section 10.

7.2 Ongoing Software Licensing Costs

Based on vendor input the ongoing software licensing cost was estimated to be $100,000 annually.

8. FINANCIAL ANALYSIS AND VALUATION OF BCA

Based on the methodology and insights described in previous sections, financial models were applied to provide the Owner with key metrics to evaluate the viability of the Project. The inputs to these models were the results of the analysis described in prior sections of this document. The outputs included industry-standard financial analytics, including the Project's NPV, IRR, and payback period.

8.1 Project Team Financial Model

A financial model was developed to incorporate one-time project costs associated with the Project as well as ongoing, incremental annual O&M costs over the Reference Plant's anticipated license period. The financial model utilized a discounted cash flow methodology. The model incorporated three central elements to determine financial metric outputs:

- One-time Project costs
- Recurring annual costs and benefits (and associated escalation rates)
- NPV of Project.

A description of each of these elements and how each was implemented in the Project Team's model is described in the following subsections.

8.1.1 One-Time Project Costs

The estimate of one-time installation and ongoing O&M costs associated with installing and operating the proposed modernized system was provided by the Owner to the Project Team. The estimates were based on parametrics and scaling of costs from similar modernization efforts conducted on non-safety related systems. The Owner also considered additional costs associated with licensing and engineering the Project to meet regulatory requirements. Future iterations of the BCA are expected to occur with conceptual design phase input from the Owner and their selected vendor.

8.1.2 Recurring Annual Costs and Benefits

Recurring annual costs and benefits represent expected changes to the Reference Plant's O&M expenses (including carrying cost of inventory[12]) resulting from project implementation. These costs and benefits were estimated by the Project Team (as illustrated in prior sections) and are expressed in current-year dollars.

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[12] For the purposes of this research product, expected recurring O&M costs associated with the modernized safety and non-safety related systems were provided by the Owner to facilitate the financial analysis. The Project Team did not participate in the development or analysis of the recurring O&M cost estimate.

8.1.3 Net Present Value of Project

8.1.3.1 Determining Future Cash Flows

As illustrated in prior sections of this research product, the Project Team analyzed Reference Plant data to determine the expected annual cost reductions for the current year and cast these benefits into future years utilizing escalation rates determined by the Project Team.

In a similar manner, FCFs can be forecast for other recurring benefits and costs, including outage contract labor, overtime savings, and carrying cost of inventory for each of the subsystems analyzed.

8.1.3.2 Determining Present Value of Future Cash Flows

Once expected cash flows from both one-time and recurring project costs and benefits have been tabulated in the financial model for each of the cost and benefit value streams, the PV (i.e., the value of the future cash flow in present dollars) for each of the value streams can be determined by discounting the FCF by a discount rate. In this case, the discount rate is equal to Owner's CoC. The CoC represents the lost opportunity for the Owner to place capital in alternative investments instead of this Project.

8.1.3.3 Determining Net Present Value

To calculate the NPV of the Project, the Project Team summed the PV calculated for each cash flow stream:

The resulting value can either be positive or negative, and the resulting implications of each of these values are explained in Table 8-1 below.

Table 8-1. Net Present Value Outcomes and Implications

If the NPV is …	Then the business case…
Positive (i.e., greater than or equal to zero)	Is favorable for the project investment. This implies that the project is expected to return more free cash to the utility as an investment, generating the Owner's CoC.
Negative (i.e., less than zero)	Is not favorable for the project investment. This implies that the project will return less free cash to the utility as an investment, generating the Owner's CoC.

8.1.4 Internal Rate of Return

The IRR of a project is the Return on Capital (ROC) required for the NPV of the upgrade to be zero. It inverts the concept of an NPV calculation and instead calculates a project's ROC. This analysis enables the model to determine if the Project meets the utility's ROC requirements. How to consider an IRR analysis is outlined in the Table 8-2 below:

Table 8-2. Internal Rate of Return Outcomes and Implications

If the IRR is …	Then the business case…
Positive (i.e., greater than or equal to cost of capital)	Is favorable for the project investment. This implies that the return of the project is greater than the utility's ROC.
Negative (i.e., less than zero)	Is not favorable for the project investment. This implies that the return of the project is less than the utility's ROC.

8.1.5 Payback Analysis

To calculate the Project payback period, the Project Team started with the FCF at the initial investment period (year 0). This value was negative due to upfront Project costs. Then, the Project Team cumulatively summed the FCFs for each following year. The payback period is calculated as the amount of time required for the cumulative sum of the FCFs to exceed zero.

This is sometimes referred to as a "break-even" analysis. Generally, a project can have multiple years of negative FCFs before having years of positive FCFs. It does not account for any ROC rate and does not discount FCFs to their PV. As a result, FCFs after year 0 are inflated in a payback analysis compared to those in an NPV analysis. The representative payback analysis for this Project can be seen below in Figure 8-1.

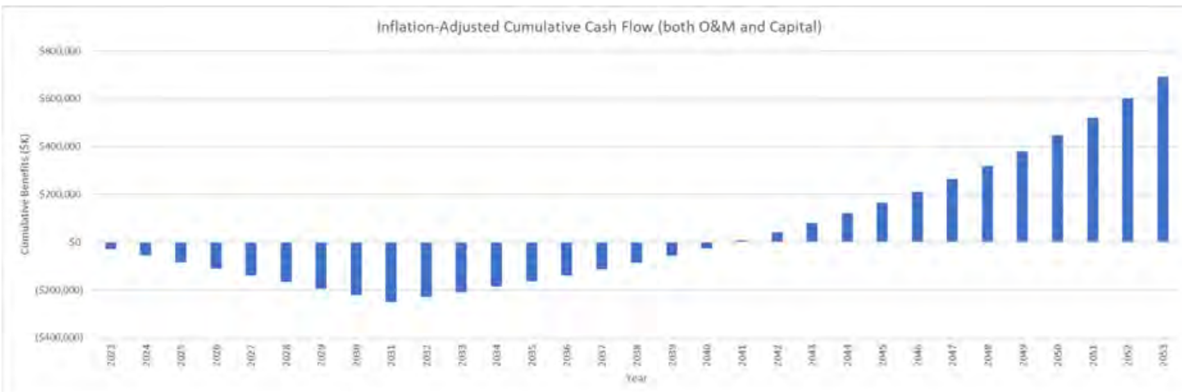

Figure 8-1. Illustration of Cumulative Cash Flow Chart

8.2 Validation of Electric Power Research Institute Business Case Analysis Model

EPRI developed the Business Case Analysis Model (BCAM) financial model tool to evaluate the business cases of potential upgrades to power plants. The Project Team has previously worked with EPRI in the development of the model for other business cases. The BCAM model went through numerous changes and improvements when used to support this research. The Project Team was pleased to report that it was a useful tool for carrying out financial analysis of this modernization and can be effectively utilized for other similar business cases.

9. SUMMARY OF RESULTS FROM BUSINESS CASE ANALYSIS (BCA)

NOTE: The table provided in this section is intended to be illustrative and representative of an order of magnitude in scale of benefits identified by the research Project Team and are not intended to present material data utilized in the Owner's cost-benefit analysis.

The summary results of the benefits analysis of the modernization of 22 safety and non-safety subsystems yielded the potential for substantial annual cost savings as well as other indirect benefits of value to the Reference Plant. The overall results of the financial models employed yielded a positive business case for the Owner.

The summary results presented in this section represent those of the BCA's baseline; that is, the scenario which incorporates assumptions about the key variables/inputs to the BCA model that the Owner considered the most probable or plausible. Section 10 provides results from a detailed sensitivity analysis where further possible scenarios are presented using different assumptions about key variables.

Table 9-1. Summary of Variables Used in Scenario Modelling

#	Scenario Title	Variables								
		Reliability Challenges Events	**Inflation**	**Material CAGR**	**Cost to Implement**	**On-going cost**	**Labor Benefits occur by year**	**Annual Material Spend Reduced**	**Salvage Value of Stranded Inventory**	**WACC**
1	**Baseline (most probable)**	**3 events every 9 years (occurs in the Winter/Summer/ Winter)**	**3.0%**	**15%**	**$250M**	**$100k per year**	**7 FTE reduction in Year 9**	**$700K**	**0%**	**6.0%**
2	Lowest Reliability	3 events every 6 years (occurs in the summer/winter)	4.0%	25.0%	$150M*	$100k per year	12 FTE reduction in Year 9	$800K	10%	6.0%
3	Reliability Challenges	3 events every 6 years (occurs in the summer/winter)	3.0%	15%	$250M	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
4	Reduced Cost to Implement	3 events every 9 years (occurs in the Winter/ summer/inter)	3.0%	15%	$150M*	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
5	No Reliability Challenges	None	3.0%	15%	$250M	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
6	More Tightly Targeted I&C Modernization	Nearly 6 (5.8) lost days of generation during the winter per year**	3.0%	15%	$100M	$50k per year	2 FTE reduction in Year 5	$100K	0%	6.0%

9.1 Direct Annual Benefits

Utilizing the approach and methodologies outlined in this research product, more than $4 million of direct annual benefits were identified as attributable to the modernization.

- Harvestable FTEs: An analysis of online workload reduction in SV, PM, and NR activities resulted in **seven harvestable FTEs.**
- Material Expenditures: An analysis of the material required to maintain and support current subsystems revealed the potential for approximately **$700,000 in annual benefits.**
- Overtime Labor: An analysis of unharvestable workload reductions (i.e., workload reductions not sufficient in quantity to yield an FTE resource) of resources eligible for overtime yielded the potential for up to **$98,000 in annual savings.**
- Revenue Opportunity Cost Savings: An analysis of the likely number of hours of output saved from the digitalization modernizations yielded additional annual revenue of **$11.6M.**

9.2 Indirect Benefits

Utilizing the approach and methodologies outlined in this product, additional indirect benefits and avoided costs were identified and considered in the overall business case.

- Workload Efficiencies: Up to 4,700 hours of additional workload efficiencies that can be utilized by the Reference Plant toward internal strategic objectives.
- Outage Support Efficiencies: Identified reduction to support fewer outage contract I&C resources (e.g., security, onsite training, briefs, etc.) as identified above.
- Avoided Cost of Obsolescence: Material costs for obsolete subsystem components are increasing at exponential rates. The Project Team's analysis of these components revealed a PV of approximately $30 million in avoided costs over 30 years.
- Carrying Cost of Inventory: An analysis of current inventory of materials and spare components resulted in a PV of $10 million in Owner's avoided capital carrying costs.

9.3 Business Case Analysis – Baseline Aggregate Results

- NPV: $74 million (positive business case over the lifecycle of the Reference Plant)
- Payback Period: 18 years
- Internal Rate of Return: 8.1%

10. SENSITIVITY ANALYSIS

Five additional scenarios were developed to estimate the expected benefits attributable to the proposed I&C modernization. The baseline scenario is a conservative, representative case built from a set of assumptions and was used as a comparison to the remaining five scenarios.

A summary of each scenario can be seen in Table 10-1.

NOTE: The table provided in this section is intended to be illustrative and representative of an order of magnitude in scale of benefits identified by the research Project Team and are not intended to present material data utilized in the Owner's cost-benefit analysis.

Table 10-1.Summary of Final Results

		Key Outputs			
#	**Scenario Title**	**Payback Period (Years)**	**NPV ($)**	**IRR (%)**	**Key Changes to Baseline**
1	**Baseline**	**17.8**	**$74M**	**8.1%**	**N/A**
1A	**Baseline (50 Years)**	**17.8**	**$685M**	**11.8%**	**N/A**
2	Lowest Reliability	11.1	$1.1B	21.6%	3 reliability challenge events in 6 years; Inflation 4%; Material CAGR 25%; Cost to Implement $150M; 12 FTE reduction in Year 9
3	Reliability Challenges	14.2	$231M	11.6%	3 reliability challenge events every 6 years
4	Reduced Cost to Implement	14.5	$153M	11.8%	Cost to Implement reduced from $250M to $150M
5	No Reliability Events	25.3	($75M)	3.4%	No reliability challenge event during the next 30 years of operation
6	More Tightly Targeted I&C Modernization	17.8	$0[13]	6.0%	Costs/Benefits of more tightly targeted I&C modernizations were not included in the financial analysis

[13] To break even in this scenario, 6 days of winter generation revenue must be lost per year

10.1 Lowest Considered Reliability Scenario

Under this lowest considered reliability scenario, lower implementation costs, a higher growth rate in material costs, greater realized labor benefits, and higher projected losses from reliability events mean the project has a predicted NPV of $1.1B, compared to the baseline of $74M.

The *lowest considered reliability scenario* simulates the following differences in assumptions compared to the baseline:

- Lower capital costs of $150m versus baseline of $250m
- Higher annual material reductions of $800k vs. $700k for the baseline
- Material CAGR of 25% versus 15% for the baseline
- Overall inflation of 4% versus 3% for the baseline
- 12 FTEs reduced in Year 9 versus 7 FTE for the baseline.

Finally, the lowest considered reliability scenario models a higher number of reliability events of one per two years with an equal number of Winter and Summer reliability events.

The following assumptions remained the same as the baseline scenario:

- Annual on-going cost of $100K
- Cost of capital of 6%.

This scenario was determined to be not realistic because of the high number of reliability events modeled.

10.2 Reliability Challenges Scenario

The *reliability challenges scenario* projects higher losses from reliability events that occur once every two years, with an equal number of Winter and Summer reliability events. The following assumptions remained the same as the baseline scenario:

- Annual on-going cost of $100K
- Cost of capital of 6%
- Inflation of 3%
- Material CAGR of 15%
- Implementation costs of $250 million
- Realized labor reduction of 7 FTEs by Year 9.

10.3 Reduced Cost to Implement Scenario

The *reduced cost-to-implement scenario* projects that the costs of implementation are lowered to $150 million from the baseline scenario due to contract negotiations or through obtaining a public grant. The following assumptions remained the same as the baseline scenario:

- Annual on-going cost of $100K
- Cost of capital of 6%
- Inflation of 3%
- Material CAGR of 15%

- Realized labor reduction of 7 FTEs by Year 9.

10.4 No Reliability Events Scenario

The *no reliability events* scenario assumes no reliability challenge events over the next 30 years, while the following variables remain the same as in the baseline scenario.

- Annual on-going cost of $100K
- Cost of capital of 6%
- Inflation of 3%
- Material CAGR of 15%
- Implementation costs of $250 million
- Realized labor reduction of 7 FTE's by Year 9.

10.5 More Tightly Targeted I&C Modernization Scenario

The more tightly coupled I&C modernization scenario excludes 11 I&C subsystems from the financial analysis with technical specifications and unfavorable performance that would already be upgraded by the Reference Plant. The subsystems not included are listed below:

- #1 Plant Protection System
- #2 Nuclear Instrumentation- Safety/Control
- #3 Nuclear Instrumentation
- #4 Solid State Safeguards
- #5 PAMS Variable
- #6 Reactor Vessel Level
- #7 Hydrogen Monitoring
- #8 Hot Shutdown Panel
- #12 AMSAC
- #18 Flux Mapping System
- #19 Annunciator System.

The costs and benefits from these specific subsystem scope upgrades are not included in the analysis. As a result, capital costs were $100 million, the annual ongoing cost was reduced to $40K, the net benefits in materials reduced from the baseline to $72K, and the inventory holding cost benefits were reduced to $18K. In addition, the time period for implementation decreased from eight years to four years. In order to break-even, six days per year of lost winter generation revenue are required.

The following variables are the same as the baseline scenario:

- Annual on-going cost of $100K
- Cost of capital of 6%
- Inflation of 3%
- Material CAGR of 15%.

11. DIGITAL INFRASTRUCTURE ENABLED WORK REDUCTION OPPORTUNITIES AND RELATED COST SAVINGS

11.1 Summary of Integrated Operations for Nuclear Business Case Efforts

As introduced in Section 1.2, the ION framework seeks to apply a comprehensive, business case-based strategy to facilitate Plant Modernization for the U.S. nuclear fleet. Ultimately, the strategy envisages a transition from the existing labor-centric operating model towards a technology-centered one. The ION framework's origins are in the Integrated Operations (IO) approach used by other industries – primarily oil and gas – which is adapted for use by the nuclear industry. ION seeks to harness the power of information and communication technology to integrate people, disciplines, organizations, and work processes to recover economic competitiveness while maintaining safety and production goals.

The bottom-up component of this approach has been applied to digital I&C upgrades - as explained in Section 1.3.1 - because the functions of existing subsystems being upgraded are well known, as are the properties of the replacement digital systems. This allows for bounding work reduction opportunities for the new systems by leveraging features such as elimination of calibrations and self-diagnostics. To date, two business cases that incorporate ION-identified WROs in the WRO category of Digital I&C – have been developed: LGS as captured in [3], and the Reference Plant as captured in Sections 2 through 10 of this document.

The top-down component of the overall ION framework, as presented in Sections 1.2.2.1 and 1.3.2, evaluates the capabilities required for achieving a given modernization goal and then identifies the work functions and associated WROs necessary to support these capabilities and achieve the overall goal. The starting point of this process is determining the total O&M budget available and allocating it to the nuclear organization. The maximum total O&M budget is derived by setting a market-based price point for nuclear generation.

The report "Process for Significant Nuclear Work Function Innovation Based on Integrated Operations Concepts" [7] captures WROs utilizing this top-down method. Reference 7 describes the ION model, identifies 37 WROs derived from applying it, and demonstrates a high level approach to implement these WROs to drive operation cost reductions. The report categorizes the WROs into 10 discrete categories of critical work, representing the areas where the bulk of the O&M work is performed. Although it is recognized that these categories are in the process of being revised, we maintain this categorization for the current report with some terminological adjustments. WROs are also analyzed into three cost savings categories: Materials, Contract Services, and Direct Labor.

In collaboration with several U.S. utilities, informal assessments of ongoing projects, and reference to third-party research produced by the Nuclear Energy Institute, Lazard, and EPRI, the report estimated capital and ongoing costs associated with the realization of the identified WROs are presented. The potential cost savings from workforce reductions (FTE eliminations) were also estimated and discussed. In general, this research provided an important jumping off point for more focused and detailed economic analysis of the costs, challenges and benefits of realizing future WROs.

Table 11-1. WROs Identified in INL/EXT-21-64134 [7]

WRO Category	WRO	#
Condition-Based Monitoring	Chemistry Monitoring Reductions	CB-01
	Implement Condition-Based Maintenance	CB-02
Advanced Analytics/Assurance	Reactor Core Design and Fuel Optimization	AA-02
	Maintenance Testing and Surveillance Reduction	DG-01

WRO Category	WRO	#
Digital I&C/Control Room Modernization	Digital Control Room/Operational Efficiency	DG-02
	Analog I&C Work Elimination	DG-03
	Obsolescence/Spare Parts Cost Reduction	DG-04
Software Application Assisted Business Processes (1)[14]	Workflow Enabled Clearance and Tagging, Lock Out Tag Out	PA-01
	Tool Calibration Consolidation	PA-02
	M&TE Controls – Tool Tracking	PA-03
	AI Auto-Assist Condition Reporting Analysis	PA-04
	Autonomous or Assisted Inspections (Drones and Robots)	PA-05
	RP Surveys and Job Coverage	PA-06
	ALARA Planning	PA-07
	Decontamination Robotics	PA-08
	IPAWS EP - Alert Notification	PA-09
	Crew Scheduling	PA-10
Software Application Assisted Business Processes (2)[15]	Automated Planning and Scheduling	PR-01
	Computer-Based Procedures – Digitization and Workflow	PR-02
	Campaign Maintenance	PR-04
	Records Management	PR-05
	Enhanced Contracts Craft Hiring	PR-07
Mobile Worker Technology	Automated Troubleshooting	MW-01
	Remote Plant Support	MW-02
	Fieldwork Task Consolidation	MW-04
	Automated or Self-Personnel Dose Coverage	MW-05
	Field Work Preparation and Coordination	MW-06
Advanced Training Technology	Operations Training Modernization	AT-01
	Technical Training Modernization	AT-02
	General Training Modernization	AT-03
	Training Records Automation	AT-04
Remote Collaboration	Remote Rad Monitoring	RC-01
	Engineering Outsourcing	RC-04
Work/Requirement Reduction	Rad Effluent Monitoring (Environmental)	WR-02
	Licensing Work Reduction	WR-04
	Reduction in Managerial Overhead	WR-07
Security	Security Technology Work Reduction Opportunities	SE-01

11.2 Potential Application of Future ION WROs to the Reference Plant

Section 11.1 explained the approach to identifying WROs that can be implemented as part of ION transformation for a generic, two-unit nuclear plant. In this section, the potential specific application of this WRO research into the real-world example of the Reference Plant is introduced. As explained in Section 1.4 and 1.5, the Project Team carried out workshops with the Reference Plant Owner to determine which ION WROs were considered to have the most potential for future modernization initiatives. This

[14] Referred to as Automation in previous reports.

[15] Referred to as Process Re-Engineering and Automation in previous reports

section describes these WROs, and introduces how the Reference Plant may benefit from these initiatives. The estimated economic costs and benefits of these WRO are shown in Table 11-2.

11.2.1 Software Application Assisted Business Processes

Software Application Assisted Business Processes were an important category in which future WROs were identified for the Reference Plant, particularly opportunities in the area of Automated Planning and Scheduling. This involves the implementation of business process automation tools to assist the work planning process and automate the creation of previously manual work packages. Historical plant data, plant operating experience, and changing plant conditions can be used to auto-generate work requests, create work orders, and schedule online or outage work. Automated systems can replace manual searching and compiling plant data formerly used to create and schedule work packages. Such automation allows for the elimination of T-Week processes for engineering, maintenance, supply chain, operations, and work management.

11.2.2 Mobile Worker Technology

Mobile Worker Technology was identified as a potentially fruitful category for finding future WROs, including in the areas of Fieldwork Task Consolidation, Fieldwork Preparation, Automated Troubleshooting, Remote Plant Support, and Automated or Self-Personnel Dose Coverage. The category of Mobile Worker Technology improves worker efficiency and reduces labor resources by automating eligible time-consuming manual tasks. Fieldwork Task Consolidation applies mobile technologies to assist in the completion of specialized, physical tasks for the generalized plant worker through the application of detailed procedures. This work reduction opportunity would allow for better allocation of workers' time while efficiently preparing and coordinating fieldwork.

Similar to Condition-Based Monitoring, Automated Troubleshooting is the computerized monitoring and on-board diagnosis of power plant component failure modes. This is accomplished by installing digital technology designed to monitor an individual component's mechanical or electrical parameters like vibration or motor current. Remote Plant Support (or Remote Assistance) utilizes digital video, voice, and collaborative devices to free support staff from being required to be present at the site at all times. It also frees the O&M staff from performing critical work during normal work hours as experts may be available in different time zones or able to assist from home without driving to the facility. With remote support enhanced, support staff can become more specialized, located in faraway places, avoid dose, mispositions, and safety incidents, and more easily conform to the plant's ideal schedule. Finally, the application of Automated or Self-Personnel Dose Coverage, which streamlines the responsibilities of a Radiation Protection technician and reduces their radiation exposure was another Mobile Worker Technology-related WRO identified during the workshops. Instead of working on-site, the Radiation Protection technician would complete remote monitoring through advanced technologies such as cameras and local instruments.

11.2.3 Condition-Based Monitoring

Condition-based monitoring was identified as an important WRO for the Reference Plant and can be achieved by transforming periodic, manual assessments, and surveillance of components to a more centralized online condition monitoring. This transformation would allow real-time assessment and improved monitoring and management of systems and components while gathering and analyzing a substantial amount of data automatically. Condition-based monitoring allows for condition-based maintenance which is superior to the predictive maintenance typically deployed in plants. While predictive maintenance takes up many technician man-hours to maintain, condition-based maintenance auto-generates reporting of failures and internal parameters which allows for maintenance activities to be carried out as needed.

11.2.4 Advanced Training/Advanced Training Technology

A final category in which the workshops identified potential WROs is the area of Advanced Training/Advanced Training Technology. This category focuses on delivering digitally produced training material in a variety of ways to the worker including videos of actual job task demonstrations, and multimedia experience utilizing video, graphics, text, documents, procedure steps, and perspective camera shots. The opportunities discussed here are in alignment with the recommendations for improvement in the recent initiative from the Institute of Nuclear Power Operations, *Guidelines for Advancing Teaching and Learning in the Nuclear Power Industry* [10]. Teaching and Learning Enablers from [10] are shown in Figure 11-1.

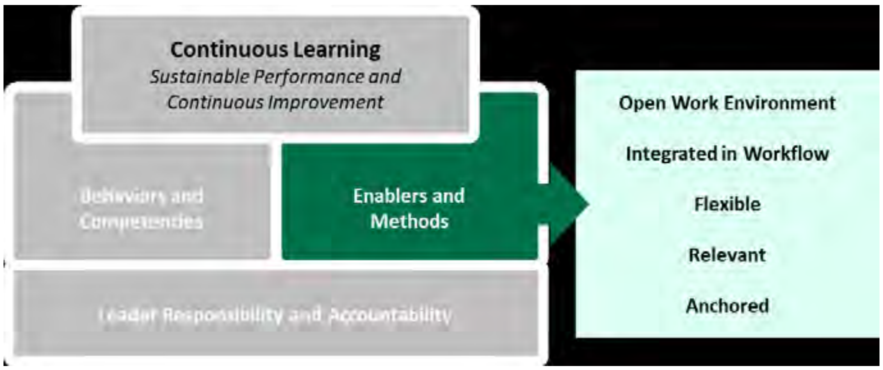

Figure 11-1.Teaching and Learning Enablers and Methods from [10]

Operations Training Modernization is a critical training area within the nuclear industry as operators must demonstrate ongoing proficiency and competency gaps will not be tolerated. Traditionally, operations personnel must attend regular classroom-style learning and use of a replica control room. There is considerable scope for modernization and cost savings through digitalization. The benefit of digitized training is that it can be taken anywhere and at any time with little need for the classroom experience. Students can take tests online and submit groups of courses for qualifications without any in-person instruction while operators learn about plant systems, procedures, protocols, and responses. Operators can also take advantage of a digitized control room to learn scenarios and keep up with the latest plant modifications.

There are considerable opportunities for modernization in Technical and General Training through the use of video and digital-based training to deliver “just-in-time” training delivery which is especially practical when integrated into mobile devices to be taken just before a specific job is carried out. Orientation training is another area where replacing the classroom model with video and digital-based training may achieve cost savings and efficiencies.

Training Records Automation is the final training related-WRO and involves the digitalizing and automating of legacy training systems, allowing for savings in the administration of training programs.

11.3 Estimated NPVs for Application of Select WROs at the Reference Plant

The report “Integrated Operations for Nuclear Business Operation Model Analysis and Industry Validation.” INL/RPT-22-68671 Revision 1 [8] provided more detailed and specific estimates of values associated with technology costs and savings of FTEs from WROs identified in the earlier [7]. Whereas the initial report modelled WRO costs and savings using nominal values which represented a single possibility among a multitude of possibilities, [8] built a probabilistic model with several input possibilities derived from multiple U.S. utility research participants. Utilities and nuclear operators actively implementing projects with similar features to those of the ION framework were sought out for inclusion in the research.

Reference [8] focused on only a selection of ION WROs for more in-depth treatment from the WROs or WRO categories identified in the earlier research [7] for a generic, representative, two-unit plant. These were selected based on a range of criteria identified by multiple industry sources as part of ION research including the expected NPV from modernizations, whether the upgrades were deemed to be essential by plant operators, and access to data from which to carry out analysis.

Section 11.2 provides details about the selection and associated attributes of WROs identified by the Reference Plant Project Team as high potential or priority, as first introduced in Section 1.5.2. Savings associated with applying the WROs identified in Section 11.2 as taken from Reference [8] are presented in Table 11-2. These have already been presented to the Reference Plant Owner and were accepted as a value-add.

Table 11-2. Summary of Estimate of Costs and Benefits of WROs Identified By Reference Plant Owner as High Potential or Priority

WRO Category	WRO(s)	# from Table 11-1	Capital Costs	FTE Savings	O&M Savings	NPV Mean	Probability of Positive NPV
Mobile Worker Technology	Automated Troubleshooting	MW-01	$13-17M	29-33 FTEs	$4.7-5.4M	$17.3M	100%
	Remote Plant Support/Remote Assistance	MW-02					
Condition Based Monitoring	Implement Condition-Based Maintenance	CB-02	$8-12M	20-39 FTEs	$3.3-6.4M	$37.9M	95%
Advanced Training Technology	Operations Training Modernization	AT-01	$23-34M	16-24 FTEs	$2.6-3.9M	$5.9M	87%
	Technical Training Modernization	AT-02					
	General Training Modernization	AT-03					
	Training Records Modernization	AT-04					
Software Application Assisted Business Processes	Automated Planning and Scheduling	PR-01	$9-17M	7-16 FTEs	$1.1-2.6M	$5.9M	75%
		TOTAL	**$53-80M**	**72-112 FTEs**	**$11.7-18.3M**	**$67M**	**88%**

12. FUTURE RESEARCH RECOMMENDATIONS

This section contains discussions on select, representative items that may be explored in future research. This is not an exhaustive list but is meant to stimulate the identification of additional items by key stakeholders in this area.

12.1 Further Instrumentation and Control System Upgrades

The current scope of the modernization efforts upgraded 22 I&C subsystems that focused on a cost-benefit analysis of replacing materials as well as maintenance and planning labor associated with the workload of maintaining old subsystems that will be eliminated through I&C upgrades. In the future, additional I&C system functionality should be migrated to the digital safety-related and non-safety DCS as they become obsolete and as business case analyses justify. For example, at the Reference Plant, the recently upgraded turbine control system should be operated through the planned interface to the non-safety DCS. If the turbine control system becomes obsolete either due to age or lack of vendor support, its functionality may be best incorporated into the non-safety DCS. This would have the benefit of continuing to minimize standalone I&C systems and envelope the turbine control system function into the lifecycle support strategy of the non-safety DCS. Such standardization tends to minimize the diversity of I&C equipment, training, support workload, and equipment inventory. This tends to lower costs and provide higher reliability in the long run. In addition, operational efficiencies and human performance improvements may be realized with expanded I&C system upgrades.

12.2 ION Realization of Work Reduction Opportunities

INL is separately planning to develop an ION WRO Realization Strategy based upon industry-wide efforts to identify WROs along with specific concepts communicated to INL by the pilot Reference Plant Owner as part of efforts to date. This strategy will be published separately in the near future.

INL plans to specifically collaborate with the Reference Plant Owner and other utilities that choose to participate to bound specific ION-identified WROs for implementation as part of this future effort. It is expected that these WROs will include those identified and discussed in Section 11.2 above and may include additional WROs identified in Section 11.1 above. Additional WROs identified by LWRS ION research may also be considered for realization as part of this effort.

12.3 Operations-Assisted Procedures

An area of particular Reference Plant interest for future research that offers potential WROs is operations-assisted procedures. Whereas the digitalization of maintenance procedures was considered but ultimately rejected as a WRO by the Plant Reference Owner because of challenges of implementation, computerization of operations procedures is an area that offers strong potential net benefits. The digitalization of certain operations procedures has the potential to increase operator efficiencies through the streamlining of record keeping, reductions in operator shift operator rounds, and increasing response times for actions such as RCS leakage calculations, calorimetric calibrations, and pump operability testing. It also has considerable potential to make human performance improvements through reductions in routine data collection errors. Future research in this area should focus on scoping the readiness, availability and cost of the relevant technology, as well as developing a detailed, bottom-up design of how digitalized operations procedures can be integrated into a plant's operations.

13. SUBSEQUENT UTILITY IMPLEMENTERS

It is envisioned that subsequent utility implementers interested in performing a BCA for a comparable modernization with cross-functional impacts as part of a larger digital transformation will follow a similar approach and utilize the methodologies and tools provided as part of this research product. Appendix A: A Systematic Presentation of the Business Case Analysis, is intended to provide a starting point for these efforts. In such cases, it is important that a qualified analyst familiar with financial modeling of complex projects be selected to lead the Project Team through the methodology. Engineers knowledgeable of the current design and the envisioned replacement systems are also necessary to bound the scope and identify potential areas of material and labor cost savings as a starting point.

It is also necessary to work with SMEs to correct/validate these savings. While a significant level of detail is provided based on the work performed for this Project in this research product, the subsequent analyst should seek to modify or improve upon the techniques presented based on the availability and integrity of the base data available in the bottom-up approach.

14. REFERENCES

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15. APPENDIX A: SYSTEMATIC PRESENTATION OF BUSINESS CASE ANALYSIS PROCESS

15.1 Demonstration of Collection, Synthesis, Verification, and Validation of Material Expenditures

15.1.1 Example of Data Mining of Material Purchase and Inventory Data from Reference Plant WMS

As described in Section 5.1.1 of the main body of the report, WO reports were generated with a list of equipment for each subsystem determined as in-scope for modernization. Table 15-1 provides a sample of this WO raw data associated with material expenditures for components of the AMSAC subsystem.

Table 15-1. WMS with Historical Cost Data for AMSAC Subsystem Materials

WO#	DESCRIPTION	LOCATION	LOCATION DESCRIPTION	SYS	SITEID	UNIT	ASSETNUM	STATUS	ACTUAL FINISH DATE	WORK TYPE	WORK CAT	WORK GROUP	PWT	JPNUM	PMNUM	BASIS	SCHED FREQ	REQD FREQ	LAST COMP	SCHED CODE	ITEM	ITEM DESCRIPTION	ITEM STATUS	REPAIRABLE?	QTY USED	CURRENT BALANCE	MIN BAL	MAX BAL	ISSUES YTD	ISSUES LAST YR	ISSUES 2 YRS	ISSUES 3 YRS	AVG COST	LAST COST
5966540	INC-4909 CCAL AMSAC	TBX-ESELAM	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 1-AM-01	ES	CP	1	216425	COMP	05/04/2022	PM	PM	IC	N	270274	312975	TU	550	550	05/04/2022	1RF22	339728	FILTER;BLOWER	ACTIVE	NO	1	11	0	2	1	1	6	-1	$18.55	$19.58
5966540	INC-4909 CCAL AMSAC	TBX-ESELAM	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 1-AM-01	ES	CP	1	216425	COMP	05/04/2022	PM	PM	IC	N	270274	312975	TU	550	550	05/04/2022	1RF22	361781	BATTERY,NONRECHARGEABLE; HIGH PERFORMANCE; 3.9 V;10 MA;1.6 AH;DIA 13.7 X LG 49.2 MM;LITHIUM	ACTIVE	NO	3	6	5	12	6	3	12	1	$88.64	$97.00
5894202	INC-4909 CCAL AMSAC	TCX-ESELAM	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 2-AM-01	ES	CP	2	239726	COMP	10/10/2021	PM	PM	IC	N	270134	306229	TU	550	550	10/10/2021	2RF19	339728	FILTER;BLOWER	ACTIVE	NO	1	11	0	2	1	1	6	-1	$18.55	$19.58
5894202	INC-4909 CCAL AMSAC	TCX-ESELAM	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 2-AM-01	ES	CP	2	239726	COMP	10/10/2021	PM	PM	IC	N	270134	306229	TU	550	550	10/10/2021	2RF19	361781	BATTERY,NONRECHARGEABLE; HIGH PERFORMANCE; 3.9 V;10 MA;1.6 AH;DIA 13.7 X LG 49.2 MM;LITHIUM	ACTIVE	NO	3	6	5	12	6	3	12	1	$88.64	$97.00
5762082	INC-4909 CCAL AMSAC	TBX-ESELAM	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 1-AM-01	ES	CP	1	216425	CLOSE	10/17/2020	PM	PM	MT1	N	270274	312975	TU	550	550	05/04/2022	1RF21	339728	FILTER;BLOWER	ACTIVE	NO	1	11	0	2	1	1	6	-1	$18.55	$19.58

The raw data is analyzed to understand the total annual expenditures on the subsystem, the percentage of these expenditures that are associated with items that the proposed modernization is expected to eliminate, and the year-on-year change in prices for these subsystem components over the period. To isolate only those items impacted by the modernization, relevant item numbers in *Column W* are filtered for analysis.

15.1.2 Example of Synthesis of Material Expenditures

As the example provided in Table 15-2 demonstrates, the raw data from Table 15-1 was analyzed to show both average annual expenditures related to the procurement of replacement parts for subsystem components and CAGRs for these components over the period under analysis.

Table 15-2. Calculation of CAGRs for AMSAC Subsystem Materials

Item #	Item Description	Status	Repairable?	Last Unit Price	Last Price Date	Average Unit Price	Earliest Price Year	Price Increase per Year	Price in Earliest Year	CAGR	Current Unit Price	Qty Inventory	Current Value of Inventory	Quantity used since 2015	Average Annual Expenditure
361781	BATTERY,NONRECHARGEABLE:HIGH PERFORMANCE;3.9 V;10 MA;1.6 AH;DIA 13.7 X LG 49.2 MM;LITHIUM	ACTIVE	NO	$97.00	2022	$88.64	2022	$16.72	$80.28	20.8%	$113.72	6	$682.30	35	$497.51
394489	SCREW, MACHINE, TRUSS HD, SLOTTED, CS, ANSI B18.6.3, ELECTRO GALV B633 FE/ZN 5, 10-32 UNF X 3/4 IN	ACTIVE	NO	$9.87	2019	$9.50	2019	$0.74	$9.13	8.1%	$12.82	332	$4,256.11	20	$32.05
471557	SCREW, PAN HD, 6-32 X 1/2"	ACTIVE	NO	$15.86	2019	$15.27	2019	$1.17	$14.68	8.0%	$20.55	12	$246.65	2	$5.14
467993	FAN,ELECTRICAL:AC AXIAL;115 VAC;HT 119 X WD 119 X THK 38 MM;106 CFM;18 TO 20 W;FLANGE MOUNT;METAL	ACTIVE	NO	$45.78	2019	$45.78	2019	$0.00	$45.78	0.0%	$45.78	3	$137.35	2	$11.45
339728	FILTER:BLOWER	ACTIVE	NO	$19.58	2022	$18.55	2022	$2.06	$17.52	11.8%	$21.65	11	$238.10	10	$27.06
									AVERAGE	**9.7%**				TOTAL	$573.20
														TOTAL + 20%	**$687.84**

15.1.3 Material Expenditure Data for All Subsystems

Table 15-3 aggregates the analysis of procurement expenditures and cost escalations for all in-scope subsystems as demonstrated in Table 15-2. It also summarizes the estimated percentage of material eliminated as part of the modernization. This information is used to inform the financial modeling carried out in the BCAM and is described in further detail in Section 15.3.

Table 15-3. Summary of Material Expenditures and CAGRs for All Subsystems

I&C System	Estimated Materials Spend							
	Estimated Average Annual Materials Spend ($)	Estimated Recent Maximum of Annual Materials Spend ($)	Estimated % Eliminated Materials	Estimated Average Annual Materials Spend Eliminated ($)	Estimated Recent Maximum of Annual Materials Spend Eliminated ($)	Year of Estimated Recent Maximum Materials Spend	Average CAGR of Equipment Unit Cost	Highest CAGR of Equipment Unit Cost
Nuclear Instrumentation	$43,183	$91,283	10%	$4,318	$9,128	2022	14.10%	123.60%
Process Protection System	$156,209	$156,209	98%	$153,085	$153,085	2022	3.40%	14.00%
PAMS Variables	$82,469	$88,243	83%	$68,449	$73,242	2022	1.50%	20.80%
Hydrogen Monitoring	$0	$0	0%	$0	$0	n/a	n/a	n/a
Reactor Vessel Level Monitoring System	$0	$0	0%	$0	$0	n/a	n/a	n/a
Solid State Safeguard Sequencer	$21,310	$31,254	34%	$7,245	$10,627	2020	3.80%	17.80%
Hot Shutdown Panel	$3,437	$3,437	0%	$0	$0	2022	100.80%	221.80%
BOP Controls	$27,147	$35,977	77%	$20,903	$27,702	2019	2.50%	16.90%
Annunciator System	$16,388	$29,045	29%	$4,753	$8,423	2020	9.50%	73.70%
Flux Mapping System	$104,239	$209,200	65%	$67,756	$135,980	2021	3.90%	13.60%
Plant Computer	$8,213	$14,504	100%	$8,213	$14,504	2018	21.80%	140.00%
AMSAC	$681	$681	0%	$0	$0	2022	9.70%	20.80%
Containment Atmospheric Monitoring	$11,137	$25,963	64%	$7,127	$16,616	2019	15.90%	29.20%
NSSS Process Controls	$39,347	$81,827	55%	$21,641	$45,005	2021	9.50%	71.80%
Rod Position Indication	$5,165	$20,403	94%	$4,855	$19,179	2022	2.90%	8.40%
Rod Control System	$11,099	$11,099	86%	$9,545	$9,545	2022	10.60%	46.80%
Sub-Total	**$513,759**	**$767,623**		**$377,891**	**$523,036**			
Feedwater Heater Drain Controls	$319,396	$500,000	100%	$319,396	$500,000	2022	5.40%	49.60%
Total	**$833,155**	**$1,267,623**		**$697,287**	**$1,023,036**			

15.2 Demonstration of Collection, Synthesis, Verification, and Validation of Operations and Maintenance Labor Workload

15.2.1 Data Mining of Raw Data of Reference Plant Work Management System

As explained in Section 5.2, raw work order data was filtered into Excel workbooks by subsystem and then data-mined and segregated by maintenance category. Table 15-4 provides an example of raw data derived from the Reference Plant's WMS after having been filtered for the BOP subsystem.

Each maintenance work order (Column D) corresponds to a component represented by an asset number (Column K). The work type in Column N indicates whether the WO was Preventative Maintenance (PM), surveillance (SV), or non-routine (NR) work type. Scheduled and required frequencies (shown in Columns U and V) were used to calculate PM and SV frequencies for all subsystem work items. Column AB represents the actual hours needed to complete the corresponding work order.

Table 15-4. Example WMS Raw Data for BOP Subsystem

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
SCENARIO	WONUM	WO#	DESCRIPTION	LOCATION	LOCATION DESCRIPTION	SYS	SITEID	UNIT	ASSETNUM	STATUS	ACTUAL FINISH DATE	WORK TYPE	WORK CAT	WORK GROUP	PWT	JPNUM	PMNUM	BASIS	SCHED FREQ	REQD FREQ	LAST COMP	SCHED CODE	TASK ID	LABOR	CRAFT	ACTUAL HOURS
PARENT	22-455257	22-455257	INC-4909 SYSTEM TEST	TCX-ESELAM-01	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 2-AM-01	ES	CP	2	239726	COMP	12/2/2022	PM	PM	IC		264592	309227	TU	84	91	12/2/2022	PWR	0	Arroyos, David	CRFT	4
PARENT	22-455257	22-455257	INC-4909 SYSTEM TEST	TCX-ESELAM-01	ATWS MITIGATION SYSTEM ACTUATION CIRCUITRY CABINET 2-AM-01	ES	CP	2	239726	COMP	12/2/2022	PM	PM	IC		264592	309227	TU	84	91	12/2/2022	PWR	0		CRFT	4
PARENT	22-387917	22-387917	{STB} OPT-447B, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	TCX-ESELSP-01A	SOLID STATE PROTECTION SYSTEM TRAIN A INPUT/LOGIC CABINET 2-SP-01A	ES	CP	2	251745	COMP	11/22/2022	SV	SV	POS		270154	500700	TSM	84	92	11/22/2022	PWR	0	Perry, Jason	CRFT	3
PARENT	22-295661	22-295661	FDA-17-000141 -01 LEFM POST COMMISSIONI NG TESTING BY VENDOR	CPX-FWELRK-50	FEEDWATER LEADING EDGE FLOW MEASURING SYSTEM CABINET X-50	FW	CP	X	262567	COMP	11/18/2022	NR	ODM	SEDE								PWR	0	Pratka, Clint	CRFT	40
PARENT	22-295659	22-295659	FDA-17-000141 -01 LEFM - MT1 CALIBRATION S PER ICI-4092	CPX-FWELRK-50	FEEDWATER LEADING EDGE FLOW MEASURING SYSTEM CABINET X-50	FW	CP	X	262567	COMP	11/18/2022	NR	ODM	IC								PWR	0	Pratka, Clint	CRFT	1
PARENT	5953260	5953260	FDA-17-000141 -01 LEFM TERMINATE EQUIPMENT	CPX-FWELRK-50	FEEDWATER LEADING EDGE FLOW MEASURING SYSTEM CABINET X-50	FW	CP	X	262567	COMP	11/15/2022	NR	ODM	SSPE	N							PWR	0	Yott, Shawn	CRFT	0

15.2.2 Collating Raw Work Order for Further Analysis

Table 15-5. Example WMS Work Order Data Analysis for BOP Subsystem

B	C	D	E	F	G
WO	**Description**	**Type**	**Work Group**	**Total Hours**	**Date**
21-399653	{STB} OPT-447A, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	SV	POS	7	8/23/2021
21-436201	INC-4909 SYSTEM TEST	PM	IC	6	8/23/2021
21-436595	{STB} OPT-448B, TADOT TRAIN B SSPS LOGIC ACTUATION TEST	SV	POS	5	9/8/2021
21-570210	IR-2021-004401 - Troubleshoot EDG 2-01 SSW flow .	NR	PT	4	7/2/2021
21-577897	IR-2021-004485 - Troubleshoot 1-HS-2372	NR	PT	2	7/8/2021
21-597167	INC-4909 SYSTEM TEST	PM	IC	3	1/4/2022
21-671229	IR-2021-005388 - Troubleshoot/Repair	NR	FIN	0	7/22/2022
21-674263	IR-2021-005413 - Troubleshoot/repair open light indication	NR	PT	0	9/4/2021
21-680369	{STB} OPT-448A, TADOT TRAIN B SSPS LOGIC ACTUATION TEST	SV	POS	3	11/8/2021
21-683312	INC-4909 SYSTEM TEST	PM	IC	6	11/8/2021
21-691266	IR-2021-005584 - 2-LV-2371 failed open	NR	PT	6	8/31/2021
21-707022	IR-2021-005784 - troubleshoot/fix	NR	PT	2	9/9/2021
21-707818	{STB} OPT-447B, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	SV	POS	2	11/22/2021
21-816984	IR-2021-007328 - U2 Trn B Seq Optical Isolator U34 T/S	NR	PT	1	10/30/2021
21-836117	{STB} OPT-447A, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	SV	POS	2	2/7/2022
21-836130	INC-4909 SYSTEM TEST	PM	IC	6	2/25/2022
21-859297	DAYLIGHT SAVINGS & SET TIME - Unit 1/ 2 AMSAC	PM	IC	4	11/9/2022
21-875380	{STB} OPT-448B, TADOT TRAIN B SSPS LOGIC ACTUATION TEST	SV	POS	3	2/22/2022
21-942765	IR-2021-008432 - Troubleshoot delayed open indication for 1-HS-2399	NR	FIN	0	5/20/2022
22-114446	{STB} OPT-447B, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	SV	POS	6	5/10/2022

The raw WMS work order data was refined into a new worksheet to collate the total hours of maintenance carried out by work type. is an example of the refined work order data for the BOP subsystem at the Reference Plant. It includes the description of the work order and aggregates total hours by work type.

15.2.3 Calculating Preventative Maintenance (PM) Labor Workload by Subsystem

Table 15-6 is an example of PM summary data for the AMSAC subsystem that aggregates maintenance of components over the time period analyzed. As previously discussed in Section 5.2.1.2, the PM frequencies in *Column D* were a calculated input in the workbook. *Column M* demonstrates whether the maintenance for a given component is eliminated from modernization efforts. Table 15-9 sums up the various PM work group types and generates the amount of annual PM labor hours.

Table 15-6. Example PM Worksheet for AMSAC Subsystem

B	C	D	E	F	G	H	I	J	K	L	M	N
						ACTUAL		USED				
Description	Locations	PM Frequency	Online or Outage	Work Group	Avg Time to Complete	Work Group	Avg WO Hours	Work Group	Labor Hours	Total Annual Hours	Eliminated?	Notes
CCAL and POWER SUPPLY REPLACEMENT	1	0.17	Outage	MT1	36	MT1	46	MT1	46	7.7	Y	
DAYLIGHT SAVINGS & SET TIME - Unit 1/ 2	1	1.09	Online	IC	3.7	IC	4.5	IC	4.5	4.9	Y	
INC-4909 CCAL AMSAC	2	0.67	Outage	MT1	15.8	MT1	47.3	MT1	47.3	62.9	Y	
INC-4909 SYSTEM TEST	2	4.36	Online	IC	5.8	IC	6.4	IC	6.4	55.6		
POWER SUPPLY REPLACEMENT	2	0.17	Outage	MT1	8.5	MT1	44	MT1	44	14.7	Y	
RESET AMSAC TEST ERROR INDICATION	2	0.67	Outage	IC	2	IC	3	IC	3	4		
									TOTAL	149.7	90.2	

15.2.4 Calculating Surveillance and Test (SV) Labor Workload by Subsystem

Table 15-7 is an example of SV summary data for the BOP subsystem that aggregates maintenance of components over the time period analyzed. As previously discussed in Section 5.2.1.2, the SV frequencies in Column D and annual hours in Column L were calculated input in the workbook. Table 15-11 sums up the various SV work group types and generates the amount of annual SV labor hours.

Table 15-7. Example SV Worksheet for BOP Subsystem

		PLANNED				*ACTUAL*		*USED*			
Description	**Locations**	**PM Frequency**	**Online or Outage**	**Work Group**	**Avg WO Hours**	**Work Group**	**Avg Total WO Labor**	**Work Group**	**Labor Hours**	**Total Annual Hours**	**Notes**
{STB} MSE-S1-0664, RCP UV TEST	1	0.67	Outage	PEMR	14	PEMR	13.3	PEMR	13.3	8.8	
{STB} MSE-S2-0664, RCP UV TEST	1	0.67	Outage	PEMR	14	PEMR	13.7	PEMR	13.7	9.1	
{STB} OPT-447A, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	1	4.36	Online	POS	2	POS	5.3	POS	5.3	23	
{STB} OPT-447B, TADOT TRAIN A SSPS LOGIC ACTUATION TEST	1	4.36	Online	POS	8.8	POS	7.9	POS	7.9	34.4	
{STB} OPT-448A, TADOT TRAIN B SSPS LOGIC ACTUATION TEST	1	4.36	Online	POS	4.5	POS	6.2	POS	6.2	27.1	
{STB} OPT-448B, TADOT TRAIN B SSPS LOGIC ACTUATION TEST	1	4.36	Online	POS	7.9	POS	5.4	POS	5.4	23.7	
INC-7917B,CCAL SSSS TRN A	1	0.67	Outage	MT1	12	MT1	12.4	MT1	12.4	8.2	
INC-7918B,CCAL SSSS TRN B	1	0.67	Outage	MT1	4	MT1	11.3	MT1	11.3	7.5	

15.2.5 Calculating Non-Routine (NR) Labor Workload by Subsystem and Component

Table 15-8 provides an example of NR summary data for the AMSAC subsystem that aggregates maintenance of components over the time period analyzed. The used labor hours in *Column I* reference the actual total hours in *Column G* or planned total hours in *Column E* if the actual hours used was not recorded in the raw data. Table 15-10 sums up the various NR work group types and generates the amount of annual NR labor hours.

Table 15-8. Example NR Worksheet for AMSAC Subsystem

B	C	D	E	F	G	H	I	J
		Planned		ACTUAL		USED		
WO	Description	Work Group	Time to Complete	Work Group	Total WO Labor	Work Group	Labor Hours	Notes
4311457	CR-2011-014227 Fan in bottom of cabinet making noise.	PT	4.0	PT	8.0	PT	8.0	
4466238	CR-2012-008803 Maint. LED ON did not come on during test	PT	0.0	PT	6.0	PT	6.0	
4748252	CR-2013-011737 Reset TEST ERROR light	PT	0.0	PT	4.0	PT	4.0	
4881693	CR-2014-007548 Failed semi-automatic test	MT1	8.0	MT1	60.0	MT1	60.0	
4933142	AI-CR-2014-010591-1 Change password	MT1	3.0	MT1	2.0	MT1	2.0	
4933146	AI-CR-2014-010591-1 Change password	MT1	4.0	MT1	4.0	MT1	4.0	
5050783	CR-2015-004134 TBX-ESELAM-01 improper light indication.	MT1	8.0	MT1	6.0	MT1	6.0	
5345416	IR-2016-008844 Troubleshoot AMSAC	MT1	8.0	MT1	75.0	MT1	75.0	
5348661	CR-2016-008844 Replace Test/Maintenance Processor (TMP)	MT1	0.0	#N/A	#N/A	MT1	0.0	
5701148	IR-2019-000452 Troubleshoot and clear AMSAC alarm	MT1	4.0	MT1	24.0	MT1	24.0	

15.2.6 Workload by Subsystem by Workgroup (AMSAC Subsystem)

After calculating the maintenance workload by subsystem component, the maintenance workload by work-group was calculated to determine the categories of labor in which efficiencies and savings were to be found. These were calculated for each maintenance type, as shown in Table 15-9, Table 15-10 and Table 15-11.

Table 15-9. Summary of PM Workload by Work Group

TOTALS	
Work Orders	336
Total PM Labor Hours	10599.85
FIN	0
IC	1228
MT1	9206.86
MT11	0
MT14	0
MT2	33
PEMR	121.99
PISC	0
PMMV	0
PMW	0
POS	0
PT	10
PT11	0
PT12	0
PT15	0
SEDE	0
SSPE	0
ZD	0
ZSS3	0
Annual PM Labor Hours	883.32083

Table 15-10. Summary of NR Workload by Work Group

TOTALS	
Work Orders	10.0
Non-Support NR Labor Hours	189.0
IC	*0.0*
MT1	*171.0*
PT	*18.0*
Support Hours	63.8
Total NR Labor Hours	252.8
Annual NR Labor Hours	23.0

Table 15-11. Summary of SV Workload by Work Group

TOTALS	
Work Orders	335
Total SV Labor Hours	2360.3
FIN	0
IC	36
MT1	58.5
MT11	0
MT14	0
MT2	0
PEMR	365
PISC	0
PMMV	0
PMW	0
POS	1900.8
PT	0
PT11	0
PT12	0
PT15	0
SEDE	0
SSPE	0
ZD	0
ZSS3	0
Annual SV Labor Hour	196.6916667

15.2.7 Total Labor Workload for All Subsystems Included in Business Case

Table 15-12 summarizes the labor workload per work-group for all in-scope I&C subsystems.

Table 15-12. Summary of Labor Workload for All Subsystems (in hours)

B	C	D	E	F	G	H	I	J
I&C System	**Estimated Annual Labor (Hours)**							
	Total (PM, Surveillance, NR)							
	I&C Craft	**I&C Supervisor**	**Clerical**	**Scheduler**	**Planner**	**SRO**	**RO**	**Total**
Nuclear Instrumentation	1,785.6	0.0	1,785.6	0.0	7.0	0.0	493.3	2,389.0
Process Protection System	888.5	0.0	888.5	0.0	0.0	0.0	3.0	984.3
PAMS Variables	2,101.7	0.0	2,101.7	28.7	0.0	0.0	0.7	2,185.3
Hydrogen Monitoring	264.6	0.0	264.6	0.0	0.0	0.0	0.0	273.7
Reactor Vessel Level Monitoring System	163.2	0.0	163.2	0.0	0.0	0.0	0.0	177.7
Solid State Safeguard Sequencer	881.8	0.0	881.8	512.6	88.5	4.9	5.0	1,569.4
Hot Shutdown Panel	25.8	0.0	25.8	564.8	0.2	0.0	5.3	614.1
BOP Controls	1,175.5	0.0	1,175.5	158.4	21.1	0.0	2.6	1,530.4
Annunciator System	474.4	0.7	475.1	0.0	23.4	0.0	0.0	766.5
Flux Mapping System	81.0	1.1	82.1	0.0	2.3	0.0	789.0	893.1
Plant Computer	1,012.2	0.0	1,012.2	0.0	2.0	0.0	16.0	1,214.7
AMSAC	139.0	0.0	139.0	0.0	0.0	0.0	0.0	144.8
Containment Atmospheric Monitoring	1,304.6	0.0	1,304.6	0.0	1.0	0.0	0.4	1,354.1
NSSS Process Controls	443.1	0.0	443.1	0.0	5.3	0.0	13.7	509.7
Rod Position Indication	249.4	502.5	751.9	7.2	0.0	2.0	9.2	811.2
Rod Control System	30.3	0.5	30.8	148.3	39.4	0.5	0.9	235.6
Sub-Total	11,020.7	504.8	11,525.5	1,420.0	190.2	7.4	1,339.1	15,653.6
Feedwater Heater Drain Controls	1,272.1	0.0	1,272.1	20.9	237.8	0.0	0.0	1,672.8
Total	12,292.8	504.8	12,797.6	1,440.9	428.1	7.4	1,339.1	17,326.4

15.2.8 Assumptions for Modeling Support Workload for Maintenance Activities

Table 15-14 displays the labor workloads associated with activities that support maintenance activities. *Columns F and G* are multiplied together to generate *Column H*, the total hours used per activity. Table 15-14 sums the total support hours per role which indicates a summary percentage for each role. This percentage is represented in Table 15-13.

Table 15-13. Support Hours by Role; Summary Percentage

Role	**Total**	**%**
I&C Craft	0.25	4%
I&C Supervisor	0.5	8%
Clerical	0.38	6%
Scheduler	1	15%
Planner	4	60%
SRO	0.25	4%
RO	0.25	4%

Table 15-14. Support Hours for I&C Maintenance

B	C	D	E	F	G	H
Support Activity	**Type**	**Group**	**Role**	**# of People**	**Hours per Person**	**Total Hours**
Pre-Job Brief/Prep	MA	I&C	Craft	1	0.25	0.25
Pre-Job Brief/Prep	MA	I&C	Supervisor	1	0.25	0.25
Pre-Job Brief/Prep	OP	Shift Ops	SRO	1	0.25	0.25
Pre-Job Brief/Prep	OP	Shift Ops	RO	1	0.25	0.25
Scheduling	MA	Maint Prep	Scheduler	1	1	1
Prepare work package & Coordination	MA	Maint Prep	Planner	1	4	4
Print Out Procedures & Work packages	MA	Maint Prep	Clerical	1	0.13	0.13
WO Closeout	MA	I&C	Supervisor	1	0.25	0.25
Maintain Records	MA	Maint Prep	Clerical	1	0.25	0.25
Total per Work Order				**9**	**6.63**	**6.63**

15.2.9 Total Labor Workload for Calibrations Across All Subsystems

As explained in Section 5.2.1.4, calibrations constitute a significant amount of labor for Reference Plant subsystems. Table 15-15 demonstrates the total hours taken up by calibrations associated with work orders of in-scope I&C subsystems.

Table 15-15. Total Workload for Calibrations Across all Subsystems

B	C	D	E	F	G	H	I	J
System	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
AMSAC	0	0	3	0	0	0	27	29
Annunciator	0	9	5	2	4	0	10	1
BOP Control	0	0	0	8	0	2	0	1
CONT MON	0	0	0	0	0	0	0	0
FLUX	8	11	18	8	10	8	8	9
H2	37	24	9	5	10	4	0	0
LEFM	8	5	5	6	3	7	3	1
MET MON	36	39	31	26	21	32	38	41
NSSS	22	17	44	17	23	28	8	13
NI	2	6	2	0	4	4	2	6
PAMS	0	0	0	3	2	0	0	0
PPS	2	1	1	1	2	3	0	7
RVL	3	3	4	2	2	6	4	4
RCS	0	0	2	0	0	2	0	0
RPI	6	6	6	0	2	0	0	0
Solid State	10	7	12	8	6	12	12	4
Sub-Total	**134**	**128**	**142**	**86**	**89**	**108**	**112**	**116**
FWHD	39	53	55	6	17	0	0	0
Total	**173**	**181**	**197**	**92**	**106**	**108**	**112**	**116**

15.3 Business Case Analysis Modelling (BCAM)

15.3.1 Direct Labor Tasks Worksheet Showing Impacts of Modernization on Workload Reductions By Task

Table 15-16 represents example maintenance activities that are predicted to be reduced as a result of I&C modernization efforts. The worksheet organizes maintenance activities by work type in *Column F*. As described in Section 5.2.2, workload efficiency in C*olumn M* was calculated by dividing the estimated hours eliminated by the total annual hours presented in the raw data for each subsystem and work type. The projected labor savings in hours from I&C upgrades is shown in C*olumn P*.

Table 15-16. Predicted Reductions of Maintenance Activities Post Modernization

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Functional Area	**FA & Resource ID**	**WC**	**Resource Name**	**Task Description**	**Modernization Effort Providing Benefit**	**Central or Site?**	**How Many Times Per Year is the Activity Performed? (Units)**	**Duration of Activity per Unit (Person-Hours/Unit)**	**# of Activities Reduced (Units)**	**% of Remaining Tasks Impacted (Applicability)**	**% Time Saved on Remaining Activities (Efficiency)**	**How Many Times is the Activity Performed? (Units)**	**Duration of Activity per Unit (Person-Hours/ Unit)**	**Estimated Savings (person hrs)**	**Use Case (if applicable)**	**Comments / Qualitative Benefits**
Maintenance	MA.1.	Perform Maintenance Activities														
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	PM Activities - AMSAC	Non-Safety	Site	1.0	149.70	-	100%	60%	1.00	59.88	89.82		Eliminated calibrations, power supply replacements
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	NR Activities - AMSAC	Non-Safety	Site	1.0	23.00	-	100%	50%	1.00	11.50	11.50		Assumed 50% reduction of NR labor
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	PM Activities - Annunciator System	Non-Safety	Site	1.0	1.78	-	100%	100%	1.00	0.00	1.78		Eliminated calibration
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	NR Activities - Annunciator System	Non-Safety	Site	1.0	764.60	-	100%	75%	1.00	191.15	573.45		Assumed 75% reduction of NR labor (almost all torubleshoot alarms)
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	PM Activities - BOP Controls (non-safety)	Non-Safety	Site	1.0	916.80	-	100%	81%	1.00	174.19	742.61		All BOP PMs. Eliminated calibrations, power supply replacements
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	NR Activities - BOP Controls (non-safety)	Non-Safety	Site	1.0	225.15	-	100%	50%	1.00	112.58	112.58		Attributed 50% of BOP NR labor for non-safety. Assumed 50% reduction of NR labor
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	PM Activities - Containment Atmospheric Monitoring	Non-Safety	Site	1.0	900.80	-	100%	37%	1.00	567.50	333.30		Eliminated most calibrations
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	SV Activities - Containment Atmospheric Monitoring	Non-Safety	Site	1.0	-	-	100%	0%	1.00	0.00			No SV calibrations show labor hours; used 0
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	NR Activities - Containment Atmospheric Monitoring	Non-Safety	Site	1.0	189.40	-	100%	50%	1.00	94.70	94.70		Assumed 50% reduction of NR labor (lots of troubleshooting, erractic readings, etc.)
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	PM Activities - FW Heater Drain Controls	Non-Safety	Site	1.0	11,140.00	-	100%	15%	1.00	9469.00	1,671.00		Eliminated most calibrations, positioner replacement, etc.
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	SV Activities - FW Heater Drain Controls	Non-Safety	Site	1.0	898.00	-	100%	21%	1.00	709.42	188.58		Eliminated Calibrations
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	NR Activities - FW Heater Drain Controls	Non-Safety	Site	1.0	411.00	-	100%	100%	1.00	0.00	411.00		Eliminated NRs associated with replacement (manometer fluid, controller WOs, etc.)
	MA.1.MAIC	**Perform Maintenance Activities**	Craft - Instrument & Control	PM Activities - Flux Mapping	Non-Safety	Site	1.0	38.66	-	100%	100%	1.00	0.00	38.66		Eliminated calibration and power supply refurb

15.3.2 Direct Labor Categories Worksheet Showing Impacts of Modernization on Workload Reductions by Category

Table 15-17 aggregates the total estimated site savings in *Column E* by functional area and work category. *Column F* indicates whether the site savings are harvestable, while *Column G* shows estimates of the harvestability percentage for the corresponding work category. The methodology for harvestable FTEs is described in Section 6.2.3. *Column H* sums up the total site savings in FTEs.

Table 15-17. Predicted Site Savings and Harvestable FTEs Post Modernization

B	C	D	E	F	G	H	I
Functional Area	**WC ID**	**Work Category**	**Total Estimated Site Savings (person hrs)**	**Are Site Savings Harvestable? (Yes/No)**	**% Harvestable for Site (%)**	**Total Estimated Site Savings (FTEs)**	**Total Estimated Added Site Labor (FTEs)**
Operations	OP.1.	Perform Field Operations	114	No		0.000	0.000
	OP.2.	Conduct Control Room Operations	-			0.000	0.000
	OP.3.	Support Work Management	-			0.000	0.000
	OP.4.	Perform Planning Activities	-			0.000	0.000
	OP.5.	Perform Support Activities	680	No		0.000	0.000
	OP.6.	Participate in Requalification Training	-			0.000	0.000
	OP.7.	Participate in Initial Training	-			0.000	0.000
	OP.8.	Oversee and supervise department personnel	-			0.000	0.000
Maintenance	MA.1.	Perform Maintenance Activities	9,337	Yes	95%	6.003	0.000
	MA.2.	Support Work Management	166	Yes	0%	0.000	0.000
	MA.3.	Perform Planning Activities	665	Yes	0%	0.000	0.000
	MA.4.	Perform Support Activities	663	Yes	0%	0.000	0.000
	MA.5.	Participate in Training	-			0.000	0.000
	MA.6.	Calibrate Maintenance and Test Equipment	-			0.000	0.000
	MA.7.	Oversee Maintenance Program Implementation	-			0.000	0.000
	MA.8.	Perform Site Services/Commercial Maintenance	-			0.000	0.000
	MA.9.	Perform Reactor/Refuel Services	-			0.000	0.000
	MA.10	Perform Turbine Services	-			0.000	0.000
	MA.11	Oversee and supervise department personnel	2,080	Yes	100%	1.000	0.000
Engineering	EN.1.	Perform Engineering activities	-			0.000	0.000
	EN.2.	Monitor and report	-			0.000	0.000
	EN.3.	Perform Support Activities	720	No		0.000	0.000
	EN.4.	Oversee and Manage Engineering Programs	-			0.000	0.000
	EN.5.	Training Activities	-			0.000	0.000
	EN.6.	Perform cyber security activities	-			0.000	0.000
	EN.7.	Oversee and supervise department personnel	-			0.000	0.000
Performance Improvement	PI.1.	Track and Trend Performance	300	No		0.000	0.000
	PI.2.	Perform Support Activities	-			0.000	0.000
	PI.3.	Oversee and supervise department personnel	-			0.000	0.000
Corrective Action Program	CA.1.	Conduct/participate in investigations	240	No		0.000	0.000
	CA.2.	Monitor and manage records	-			0.000	0.000
Procedures	PR.1.	Manage procedure/program documents	-			0.000	0.000
	PR.2.	Oversee and supervise department personnel	-			0.000	0.000
Nuclear Fuels	NF.1.	Core Reload Design	-			0.000	0.000
	NF.2.	Safety Analysis and Non-Reload Safety Analysis	-			0.000	0.000
	NF.3.	Fuel Supply Strategy, Procurement, Budgeting, and Accounti	-			0.000	0.000
	NF.4.	Radiological Engineering	-			0.000	0.000
	NF.5.	Spent Fuel Management and Strategy	-			0.000	0.000
	NF.6.	Oversee and Supervise department personnel	300	No		0.000	0.000
	QC.4.	Receipt inspections and vendor coordination	-			0.000	0.000
Warehouse	WR.1.	Inventory Management	400	No		0.000	0.000
	WR.2.	Supply Chain/Information Management	-			0.000	0.000
Supply Chain	SC.1.	Purchasing and Accounts Payable	-			0.000	0.000
			15665.47			7.003	0.000

15.3.3 Direct Labor Categories Worksheet Summarizing FTE Reductions

Table 15-18 categorizes the harvestable FTE data in Table 15-7 by in-scope safety and non-safety I&C subsystems. *Column M* quantifies the dollar savings from harvestable FTEs.

Table 15-18. Harvestable FTEs for In-Scope Safety and Non-Safety I&C Subsystems

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Modernization Effort	**Total Harvestable Site Savings (person hrs)**	**Total Added Site Labor (person hrs)**	**Total Harvestable Central Savings (person hrs)**	**Total Added Central Labor (person hrs)**	**Total Harvestable Site Savings (FTE)**	**Total Added Site Labor (FTE)**	**Total Harvestable Central Savings (FTE)**	**Total Added Central Labor (FTE)**	**Total Harvestable Savings (FTE)**	**Total Added Labor (FTE)**	**Total Harvestable Savings ($)**	**Total Added Labor ($)**	**Total Harvestable Savings (FTE) CHECK**	**Total Added Labor (FTE) CHECK**
Safety	3,392.90	-	-	-	2.188	-	-	-	2.19	-	$ 409.08k	$ - k	o.k.	o.k.
Non-Safety	7,510.96	-	-	-	4.815	-	-	-	4.81	-	$ 901.40k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
0	-	-	-	-	-	-	-	-	-	-	$ - k	$ - k	o.k.	o.k.
TOTALS	10,903.85	-	-	-	7.00	-	-	-	7.00	-	$ 1,310.48k	$ - k		

15.3.4 BCAM Model: Material Expenditure Data for All Subsystems

Table 15-19 shows material purchase data for in-scope safety and non-safety I&C subsystems. *Column E* displays the estimated percentage of material purchases that will be avoided as a result of the modernization effort. The logic behind the material price escalation rate in *Column F* can be found in Section 6.1.3.

Table 15-19. Avoided Material Purchases Estimated from I&C Subsystem Upgrades

B	C	D	E	F
Material	**Modernization Effort Providing Benefit**	**Annual Purchases of Material**	**Percent of Material Purchases Avoided**	**Material Price Escalation Rate**
FW Heater Drain Controls	Non-Safety	$ 319.40k	94%	15%
Annunciator System	Non-Safety	$ 16.39k	29%	15%
Flux Mapping	Non-Safety	$ 104.24k	70%	15%
Rod Position Indication	Non-Safety	$ 5.17k	94%	15%
Rod Control	Non-Safety	$ 11.10k	86%	15%
Containment Atmospheric Monitoring	Non-Safety	$ 11.14k	64%	15%
AMSAC	Non-Safety	$ .68k	0%	15%
NSSS Process Control	Non-Safety	$ 39.35k	70%	15%
BOP Controls - Non-Safety (50% of BOP Controls Annual Spend for non-safety)	Non-Safety	$ 13.57k	77%	15%
Plant Computer Interface	Non-Safety	$ 8.21k	100%	15%
Process Protection System	Safety	$ 156.21k	98%	15%
Nuclear Instrumentation	Safety	$ 43.18k	31%	15%
Solid State Safeguards Sequencer	Safety	$ 21.31k	34%	15%
PAMS Variables	Safety	$ 82.47k	86%	15%
BOP Controls - Safety (50% of BOP Controls Annual Sp	Safety	$ 13.57k	77%	15%
BOP Controls - Safety (hot shutdown panel)	Safety	$ 3.44k	0%	15%

15.3.5 Cash-Flow Model - Financial Output Worksheet

Table 15-20 summarizes the cash-flows over 30 years using assumptions from the baseline scenario described in Section 9. It shows that the projects begins to see net benefits in Year 9, and capital costs from implementation are equally distributed in each of the first eight years. By Year 30, the project is seeing positive free cash flow as a result of the project of around $90M per year

Table 15-20. Summary of Cash-Flows for Baseline Scenario Over 30 Years

	Year		0	1	9	10	11	12	13	28	29	30
Safety	Costs ($)	**Initial Implementation Costs**	($ 9,248.49k)	($ 9,248.49k)	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k
	Benefits ($)	**Annual Avoided Direct Labor Costs**			$ 533.76k	$ 549.77k	$ 566.27k	$ 583.26k	$ 600.75k	$ 935.95k	$ 964.03k	$ 992.95k
		Annual Avoided Other-Online Costs			$ 64.03k	$ 65.95k	$ 67.93k	$ 69.97k	$ 72.06k	$ 112.27k	$ 115.64k	$ 119.11k
		Periodic Avoided Other-Outage Costs			$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k
		Annual Avoided Other - Material Costs			$ 895.93k	$ 1,030.32k	$ 1,184.87k	$ 1,362.60k	$ 1,566.99k	$ 12,750.69k	$ 14,663.29k	$ 16,862.78k
		Annual Avoided Cost of Inventory Reductions										
	Net Benefits		($ 9,248.49k)	($ 9,248.49k)	$ 1,801.54k	$ 2,000.03k	$ 2,226.15k	$ 2,483.97k	$ 2,778.18k	$ 18,179.66k	$ 20,780.82k	$ 23,768.38k
	Cumulative Net Benefits		($ 9,248.49k)	($ 18,496.98k)	($ 81,434.89k)	($ 79,434.86k)	($ 77,208.71k)	($ 74,724.75k)	($ 71,946.57k)	$ 56,142.40k	$ 76,923.22k	$ 100,691.60k
Non-Safety	Costs ($)	**Initial Implementation Costs**	($ 9,243.53k)	($ 9,243.53k)	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k
		Total Annual Direct Costs			($ 100.0k)	($ 100.0k)	($ 100.0k)	($ 100.0k)	($ 100.0k)	($ 100.0k)	($ 100.0k)	($ 100.0k)
	Benefits ($)	**Annual Avoided Direct Labor Costs**			$ 1,176.12k	$ 1,211.41k	$ 1,247.75k	$ 1,285.18k	$ 1,323.74k	$ 2,062.34k	$ 2,124.21k	$ 2,187.94k
		Annual Avoided Other-Online Costs			$ 15,245.33k	$ 15,702.69k	$ 16,173.77k	$ 16,658.98k	$ 17,158.75k	$ 26,732.77k	$ 27,534.75k	$ 28,360.80k
		Annual Avoided Other - Material Costs			$ 1,567.87k	$ 1,803.05k	$ 2,073.51k	$ 2,384.54k	$ 2,742.22k	$ 22,313.62k	$ 25,660.66k	$ 29,509.76k
		Annual Avoided Cost of Inventory Reductions			$ 307.81k	$ 353.99k	$ 407.08k	$ 468.15k	$ 538.37k	$ 4,380.74k	$ 5,037.85k	$ 5,793.53k
	Net Benefits		($ 18,492.02k)	($ 18,492.02k)	$ 18,197.14k	$ 18,971.13k	$ 19,802.11k	$ 20,696.85k	$ 21,663.07k	$ 55,389.47k	$ 60,257.47k	$ 65,752.02k
	Cumulative Net Benefits		($ 18,492.02k)	($ 36,984.03k)	($ 148,231.02k)	($ 129,259.89k)	($ 109,457.77k)	($ 88,760.93k)	($ 67,097.85k)	$ 464,974.48k	$ 525,231.96k	$ 590,983.98k
		Online Benefits	($ 27,740.51k)	($ 27,740.51k)	$ 19,998.67k	$ 20,971.16k	$ 22,028.26k	$ 23,180.81k	$ 24,441.25k	$ 73,569.12k	$ 81,038.29k	$ 89,520.40k
		Outage Benefits	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k	$ - k
		Net Cash Flow	**($ 27,740.51k)**	**($ 27,740.51k)**	**$ 19,998.67k**	**$ 20,971.16k**	**$ 22,028.26k**	**$ 23,180.81k**	**$ 24,441.25k**	**$ 73,569.12k**	**$ 81,038.29k**	**$ 89,520.40k**
		Cumulative Cash Flow	**($ 27,740.51k)**	**($ 55,481.02k)**	**($ 229,665.91k)**	**($ 208,694.75k)**	**($ 186,666.49k)**	**($ 163,485.67k)**	**($ 139,044.42k)**	**$ 521,116.89k**	**$ 602,155.18k**	**$ 691,675.58k**

16. APPENDIX B: BUSINESS CASE ANALYSIS PRESENTATION

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INL/Owner
Digital Modernization Business Case

Reference Plant Report

June 16, 2023

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Executive Summary

Executive Summary

Objectives

Background:

- Owner, as a leader of the nuclear industry, has recently partnered with Idaho National Laboratory to evaluate a modification of their safety and non-safety systems from analog to digital to modernize their control room and reduce operating and maintenance (O&M) costs.

Project Objective:

- Leverage digital infrastructure (DI) modernization guidance and safety-related instrumentation and control business case research to scope and perform a business case analysis effort for a plant-wide DI implementation at the Nuclear Power Plant (Reference Plant)

The project consisted of two phases:

- Phase 1: 2022
  - Evaluated industry guidance presented in INL/EXT-21-64580, “Digital Infrastructure Migration Framework”, and techniques captured in INL/EXT-21- 59371 “Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations” to scope a business case study that captures the projected costs and benefits tied to a plantwide DI modernization
- Phase 2: 2022-2023
  - Updated the Business Case described in INL/EXT-21- 59371 “Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernization” as it relates to the plant-wide DI modernization

All figures presented in this report represent the costs associated with upgrades for two units at Reference Plant

Engagement

Analysis Summary

To determine the benefits associated with labor and materials for the digital I&C upgrade, the project team:

- Collected and analyzed more than 96,000 line items of Reference Plant historical work management system data (i.e., Work Management System) from 2015 to 2022 to determine current annual workload for each in-scope system for surveillances and tests, preventive maintenance, and corrective maintenance (non-repetitive) activities
- Developed and analyzed equipment lists for each system through purchase and consumption data from 2015 to 2022, analyzing Work Management System work order data for items over $1,000
- Estimated labor and materials reductions through vendor discussions on maintenance activities and materials to be eliminated with the digital upgrade
- Estimated upgrade costs through vendor discussions and confirmed scope of upgrade
- Inputted the upgrade costs and benefits into the EPRI Business Case Analysis Model to determine net present value and breakeven point

DESCRIPTION	Location	SCHED FREQ	Annual Freq.	Online or Outage	Work Group	Average WO Hours	Total Annual Labor
(RF) VERIFY SETPOINT MS SAFETY	2	550	0.67	N/A	IWCP	1.33	1.77
INC-7653A,COT PRZR LVL	1	550	0.67	N/A	PT	3.47	2.31
INC-7653A,RACK PRZR LVL	1	550	0.67	N/A	PT	3.56	2.37
INC-7653A,XMTR PRZR LVL	1	550	0.67	N/A	MT1	8.50	5.66
INC-7653B,COT PRZR LVL	1	550	0.67	N/A	MT1	3.43	2.28
INC-7653B,RACK PRZR LVL	1	550	0.67	N/A	MT1	3.50	2.33
INC-7653B,XMTR PRZR LVL	1	550	0.67	N/A	MT1	9.78	6.51
INC-7654A,COT PRZR LVL	1	550	0.67	N/A	PT	3.43	2.28
INC-7654A,RACK PRZR LVL	1	550	0.67	N/A	PT	3.50	2.33
INC-7654A,XMTR PRZR LVL	1	550	0.67	Outage	MT1	14.00	9.32
INC-7654B,COT PRZR LVL	1	550	0.67	Online	IC	2.86	1.90
INC-7654B,RACK PRZR LVL	1	550	0.67	Online	IC	3.56	2.37
INC-7654B,XMTR PRZR LVL	1	550	0.67	Outage	MT1	7.00	4.66
INC-7738A,COT PRESZR LVL	1	550	0.67	N/A	PT	3.47	2.31
INC-7738A,RACK PRESZR LVL	1	550	0.67	N/A	PT	7.11	4.73
INC-7738A,XMTR PRESZR LVL	1	550	0.67	N/A	MT1	9.33	6.21
INC-7738B,COT PRESZR LVL	1	550	0.67	N/A	MT1	3.71	2.47
INC-7738B,RACK PRESZR LVL	1	550	0.67	N/A	MT1	7.11	4.73
INC-7738B,XMTR PRESZR LVL	1	550	0.67	Outage	MT1	7.88	5.24
INC-7826A,CCAL PRZR LVL	1	550	0.67	N/A	MT1	9.00	5.99
INC-7826B,CCAL PRZR LVL	1	550	0.67	N/A	MT1	7.11	4.73

Example Labor Analysis for PM Activities

Item #	Description	X	Status	Last Unit Price	Last Price Year	Average Unit Price	Earliest Price Year	Price Increase per Year	Price in Earliest Year	CAGR	Current Unit Price	Qty Inventory	Current Value of Inventory	Quantity used since 2015	Average Annual Expenditure
468899	LIGHT ASSY, INDICATOR, WHITE		ACTIVE	$572.60	2019	$608.39	2019	-$71.58	$644.18	-11.1%	$286.28	1	$286.28	1	$35.79
458267	CIRCUIT, PRINTED, NRA, RTD AMPLIFIER	X	ACTIVE	$21,635.46	2019	$20,616.80	2017	$679.11	$19,598.14	3.4%	$24,351.89	7	$170,463.25	1	$3,043.99
503444	CIRCUIT, PRINTED, NMD-1, MULTIPLIER- DIVIDER	X	ACTIVE	$16,453.05	2022	$15,820.17	2019	$316.44	$15,187.29	2.0%	$16,769.49	4	$67,077.96	1	$2,096.19
457836	PANEL, DISPLAY	X	ACTIVE	$10,000.00	2020	$10,000.00	2020	$0.00	$10,000.00	0.0%	$10,000.00	0	$0.00	2	$2,500.00
471662	TRANSDUCER, ELECTRO PNEUMATIC, 4-20 MA INPUT, 6-30 PSIG OUTPUT, EPDM ELASTOMERS	X	ACTIVE	$7,997.00	2022	$7,424.72	2015	$143.07	$6,852.44	1.9%	$8,140.07	6	$48,840.42	2	$2,035.02
471527	ASSEMBLY,GENERAL;TRANSDUCER PUSHROD	X	ACTIVE	$5,736.00	2019	$5,736.00	2019	$0.00	$5,736.00	0.0%	$5,736.00	5	$28,680.00	8	$5,736.00
240760	RELAY, UNDERVOLTAGE, 120 VAC RATING, CAL RANGE 70-100 V, W/O TARGET	X	ACTIVE	$3,410.63	2020	$3,410.63	2015	$0.00	$3,410.63	0.0%	$3,410.62	3	$10,231.87	2	$852.66
902702	TRANSMITTER,PRESSURE;COPLANAR, GAUGE;4 TO 20 MA;-393 TO 1000 IN H20;NPT;1/2 IN	X	ACTIVE	$3,288.64	2016	$3,288.64	2016	$0.00	$3,288.64	0.0%	$3,288.64	1	$3,288.64	2	$822.16
343816	RESISTANCE TEMPERATURE DETECTOR, DUAL ELEMENT, PLATINUM	X	ACTIVE	$3,185.80	2018	$3,185.80	2018	$0.00	$3,185.80	0.0%	$3,185.80	2	$6,371.60	1	$398.23

Example Material Analysis for PM Activities

Executive Summary

System Scope Matrix

Fxuuhqw#shuirupdqfh#lq#wklv#duhd#lv#idyrudeoh
Fxuuhqw#shuirupdqfh#lq#wklv#duhd#lv#pl{hg
Fxuuhqw#shuirupdqfh#lq#wklv#duhd#lv#xqidyrudeoh
V|vwhp V|vwhp#qrw#vxssruwhg#e|#Yhqgru
WV V|vwhp#kdv#Whfk#Vshf#lpsolfdwlrqv
- Prghuql}dwlrq#rqo|#lqfoxghv#wkh#v|vwhp*v#lqwhuidfh

#	I&C Subsystem	Safety/Non-Safety	Current Platform	Year in Reference Plant LRP	Reliability	Obsolescence	Workload
1	Process Protection System	Safety	7300	2028 – 2029	TS		
2	Nuclear Instrumentation – Safety/Control	Safety	NIS	N/A	TS		
3	Nuclear Instrumentation – RG1.97	Safety	ENFMS	N/A	TS		
4	Solid State Safeguards Sequencer	Safety	SSSS	2028 – 2029	TS		
5	PAMS Variables	Safety	Analog Meters	2028 – 2029	TS		
6	Reactor Vessel Level	Safety	Vendor Multibus (HJTC)	2028 – 2029	TS		
7	Hydrogen Monitoring	Safety	Analog Meters	2028 – 2029			
8	Hot Shutdown Panel	Both	Analog	2026 – 2027	TS		
9	BOP Controls	Both	Analog Meters	2026 – 2027			
10	BOP Controls	Both	7300	2026 – 2027			
11	NSSS Process Control	Non-Safety	7300	2029 – 2030			
12	AMSAC	Non-Safety	Vendor Multibus	2028 – 2029			
13	Turbine Controls Interface	Non-Safety	Analog	2029			

Executive Summary

System Scope Matrix (cont'd)

Fxuuhqw#shuirupdqfh#lq#wklv#duhd#lv#idyrudeoh
Fxuuhqw#shuirupdqfh#lq#wklv#duhd#lv#pl{hg
Fxuuhqw#shuirupdqfh#lq#wklv#duhd#lv#xqidyrudeoh
V|vwhp V|vwhp#qrw#vxssruwhg#e|#Yhqgru
WV V|vwhp#kdv#Whfk#Vshf#lpsolfdwlrqv
- Prghuql}dwlrq#rqo|#lqfoxghv#wkh#v|vwhp*v#lqwhuidfh

#	I&C Subsystem	Safety/Non-Safety	Current Platform	Year in Reference Plant LRP	Reliability	Obsolescence	Workload
14	Containment Atmospheric Monitoring	Non-Safety	Digital	2028 – 2029			
15	Meteorological Monitoring Interface	Non-Safety	Digital	2029			
16	Rod Control Systems	Non-Safety	SSRCS	2029 – 2030			
17	Rod Position Indication	Non-Safety	Vendor DRPI	2026 – 2027			
18	Flux Mapping System	Non-Safety	Vendor MIDS	2031 – 2032	TS		
19	Annunciator System	Non-Safety	Unknown	2026 – 2027	TS		
20	Plant Computer Interface	Non-Safety	Windows PMS	2032			
21	Leading Edge Flow Meter (LEFM) Interface	Non-Safety	Digital	2029			
Excluded from Final Scope							
22	Feedwater Heater Drain Controls	Non-Safety	7300	2031 – 2032			
23	Plant Simulator	Non-Safety	Digital	2032			

Unsupported systems with high reliability risks post a significant cost impact to the site should the system fail.

Executive Summary

Scenario Summary

We modeled the following six scenarios. The results of the baseline scenario are shown on the next few pages

#	Scenario Title	KEY VARIABLE Reliability Challenges Events	Inflation	Material CAGR	Cost to Implement	On-going cost	Labor Benefits occur by year	Annual Material Spend Reduced	Salvage Value (%) of Stranded Inventory	Weighted Avg. Cost of Capital (WACC)
1	**Baseline**	**3 events every 9 years (occurs in the Winter/Summer/ Winter)**	**3.0%**	**15%**	**$250M**	**$100k per year**	**7 FTE reduction in Year 9**	**$700K**	**0%**	**6.0%**
2	Best case	3 events every 6 years (occurs in the Summer/Winter)	4.0%	25.0%	$150M*	$100k per year	12 FTE reduction in Year 9	$800K	10%	6.0%
3	Reliability Challenges	3 events every 6 years (occurs in the Summer/Winter)	3.0%	15%	$250M	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
4	Reduced Cost to Implement	3 events every 9 years (occurs in the Winter/ Summer/Winter)	3.0%	15%	$250M*	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
5	No Reliability Challenges	None	3.0%	15%	$250M	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
6	Elective I&C Modernization	Six days of lost generation during the Winter per year**	3.0%	15%	$100M	$50k per year	2 FTE reduction in Year 5	$100K	0%	6.0%

Note* Assumed the cost of implementation for Non-Safety systems is reduced by $80M either though contract negotiations or public funding grant

Note** Six days was the necessary value of reliability events calculated for the scenario to breakeven (NPV equals $0)

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Executive Summary

Direct Annual Benefits – Baseline Scenario

Digital Modernization of the safety and non-safety I&C systems at Reference Plant results in the following direct annual cost savings resources:

I&C Labor

Six I&C craft resources

One I&C Supervisor

7 FTE Resources[1]

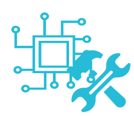
OT Hours

Reduction in labor overtime costs[2]

$98K

Overtime Savings

Materials and Tools



Reduction in the cost of materials[3]

$700K

Materials Savings

$3M **estimated annual cost savings associated with this Digital Modernization**

1. 1470 effective hours annually per FTE.
2. OT hours for Maintenance Planners, Schedulers, and Clerical.
3. Excludes avoided carrying cost of inventory.

Savings are in 2023 dollars.

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Executive Summary

Indirect Annual Benefits - Baseline Scenario

Upgrading the digital I&C systems will also have indirect benefits to the site. This I&C upgrade scope did not evaluate these additional benefits, but further analysis would provide useful

Non-Direct Labor

2640 hours

Workload Efficiencies

Annual workload savings in addition to FTE reductions across multiple roles

Material and Tools

$100K

Capital Carrying Cost

Annual opportunity cost of maintaining inventory of materials and components related to the system

$22 - $86 Million*

Material Escalation

Avoided escalation cost of materials through remaining plant operating license

Non-Direct Labor

114 hours

Operator Efficiencies

Annual operator efficiencies to support calibrations

(assumed 1 person hour per calibration)

Other Costs

Outage Support Efficiencies

Savings in support of fewer I&C craft laborers required during outage

Other Costs

208-470

Backlog Reduction

Avoided annual maximum number of NRs in backlog reduction

Inventory

$1.4 M

Stranded Inventory

Amount of stranded inventory

Workload efficiencies account for annual operations support hours for non-repetitive WOs (80 hours) and expected CAP reduction for significant Issue Report support. Average hours for a CAP event from prior analysis was 425 hours. Estimate Reference Plant has 4 events per year. Refer to the INL report for more information: https://www.osti.gov/biblio/1662013

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Executive Summary

I&C Upgrade Projected Cash Flow Summary – Baseline Scenario

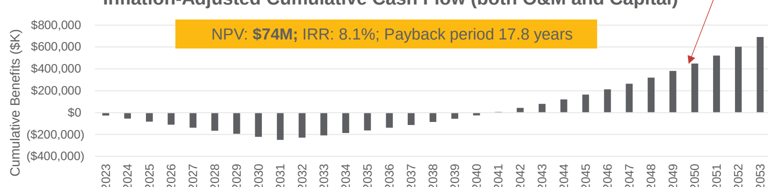
The present value calculation of the benefits identified in the following scenario generated the following results:

~$450M Positive Cumulative Cashflow by 2050

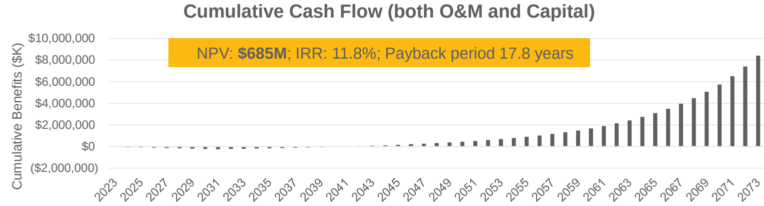
Assumptions and Clarifications:

- One reliability challenge lasting 10 days every 3 years (Winter/Summer/Winter)
  - Lost revenue of winter is $30/MWh*
  - Lost revenue of summer is $300/MWh
- Inflation is estimated at 3.0%
- Materials escalation rate is estimated at 15% (conservative compared to prior site analyses)
- Reduction in carrying cost of inventory is escalated at same rates for material
- Present value of future cash flows discounted 6% cost of capital
- License renewal for Units 1 & 2 will extend operating period ~30 years
- Effective hours for FTEs is assumed at 1470 (accounts for training and PTO)
- Non-I&C labor is assumed to be overtime (OT) hours at 1.5x rate

Inflation-Adjusted Cumulative Cash Flow (both O&M and Capital)



Cumulative Cash Flow (both O&M and Capital)



Note*: ERCOT Feb 2023

If Reference Plant were to extend operations to an 80-year operational period, the cumulative cashflow would be significant.

Both graphics are adjusted for inflation

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Executive Summary

Materials Spend Escalation

While sites across the industry have been working to lower operational costs, material costs have continued to escalate. Rising material expenditures in recent years are largely attributable to increases in unit cost of obsolete components

- A sample analysis was performed to evaluate the compounded annual growth rate (CAGR) for high-impact I&C equipment: power supplies and circuit cards
- Average CAGRs of 13% to 18% were found, though both appear conservative
- Data available through Work Management System for Reference Plant material analysis is from 2015-2022; some equipment was obsolete and increasing in cost prior to 2015
- Prior INL analysis at another US nuclear site found a range of 18% to 24% for I&C equipment with data from 2002-2019

CAGR Analysis - Power Supplies

TSN	Description	CAGR
142490	POWER SUPPLY, REGULATED, 25V, 1A, W/ LOOSE PART MATING CONNECTOR	10.9%
140205	POWER SUPPLY, REGULATED, 0 TO -100VDC, COMPENSATING VOLTAGE, INTERMEDIATE RANGE NUCLEAR INSTRUMENT	12.7%
142488	POWER SUPPLY, HIGH VOLTAGE, DC REGULATED, SOURCE + 300 TO 2500 VDC, 0-10 MA	13.9%
374561	POWER SUPPLY, NEGATIVE, 24 VDC	11.9%
142839	POWER SUPPLY, 15 VDC, +/-5 PCT VOLTAGE ADJUSTMENT, 1.5 A	21.4%
474204	POWER SUPPLY, 5-1000 VDC OUTPUT	8.5%
341006	POWER SUPPLY, DIGITAL RPI	16.2%
470157	POWER SUPPLY, INPUT, 118VAC, OUTPUT 5VDC @ MAX 60A, +/- 12VDC @ MAX 5A, SPIN INELCC UNPOTTED S.O. 0312	44.3%
	AVERAGE POWER SUPPLIES CAGR	**17.5%**

CAGR Analysis - Circuit Cards

TSN	Description	CAGR
502710	CIRCUIT, PRINTED, 7300 NAL SIGNAL COMPARATOR LATEST RECEIVED REV. LEVEL IS REV.9 MINIMUM ACCEPTABLE REV. LEVEL IS REV. 5	4.0%
506347	CIRCUIT CARD ASSEMBLY;NTD,TRACKING DRIVER	1.7%
506346	CIRCUIT, PRINTED, NTD, TRACKING DRIVER,	2.7%
458267	CIRCUIT, PRINTED, NRA, RTD AMPLIFIER	4.0%
503444	CIRCUIT, PRINTED, NMD-1, MULTIPLIER- DIVIDER	2.7%
344706	CIRCUIT CARD ASSEMBLY;PLUG IN,MODULE CALIBRATION;12 V	49.8%
341277	CIRCUIT CARD ASSEMBLY;ALARM	33.1%
140098	CARD, CIRCUIT, PRINTED, AMP. LEVEL	11.0%
	AVERAGE CIRCUIT CARD CAGR	**13.6%**

Executive Summary

Avoided Obsolescence Cost

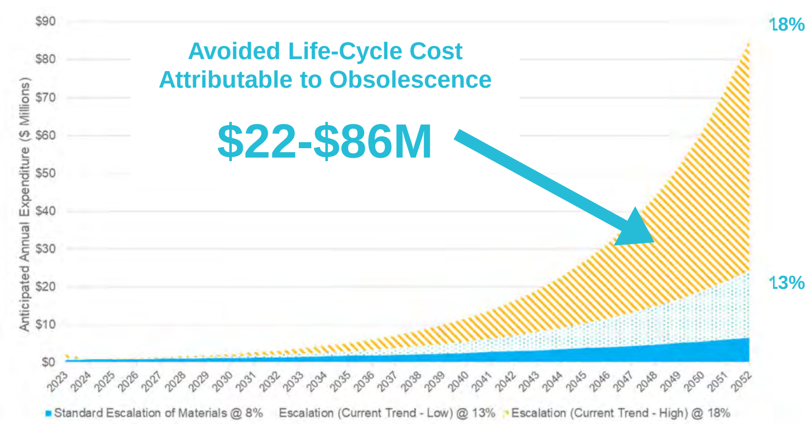
The net present value avoided obsolescence cost range for material expenditures and capital carrying costs enabled by the digital modernization is $22-$86 Million (2023 – 2053 Operating License Period)

Key inputs for NPV:

- Initial 2023 expenditure is the latest estimated component spend that would be avoided with the digital upgrade ($700k)
- 13%-18% Compound Annual Growth Rate on materials cost, based on historical Reference Plant data
- 8.0% used as historic escalation of materials
- 6% cost of capital

NPV:

- Graphically represented as the area under the curves
- Analysis at 13% conservatively assumes component failure rates will remain at historical levels (i.e., reliability will not decrease as the system ages)
- Analysis at 18% reflects the observed historical CAGR (component costs and failure rate trends)



Executive Summary

Summary of Costs and Expected Benefits – Baseline Scenario

		Annual Labor Benefits			Annual Materials Benefits			Modernization Costs	
Type	**Details**	**I&C Craft (FTE)**	**I&C Sup. (FTE)**	**Overtime Labor (hours)**	**Materials Eliminated ($)**	**Inventory Carrying Benefit ($)**	**Escalation Rate (%)**	**Implementation ($)**	**Ongoing ($)**
Safety	Nuclear Instrumentation	3	1	220	$250,000	$88,000	17.5%	$74,000,000	See below
	Process Protection System								
	PAMS Variables								
	Hydrogen Monitoring								
	Reactor Vessel Level Monitoring System								
	Solid State Safeguard Sequencer								
	Hot Shutdown Panel								
	BOP Controls - Safety								
Non-Safety	FW Heater Drain Control	3		1234	$450,000	$88,000		$161,000,000	See below
	BOP Controls - Non-Safety								
	Annunciator System								
	Flux Mapping System								
	Plant Computer								
	AMSAC								
	Containment Atmospheric Monitoring								
	NSSS Process Controls								
	Rod Position Indication								
	Rod Control System								
Other	Plant Simulator	N/A	N/A	N/A	N/A	N/A	N/A	$15,000,000	100,000
	Licensing Costs								
	Training								
Totals		**6 FTE**	**1 FTE**	**1454**	**$700,000**	**$175,000**		**$250,000,000**	**$100,000**

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Executive Summary

Scenario Analysis Key Takeaways

1. If Reference Plant were to miss out on 6 full days (24 hours per day) of generation during the summer at $300/MWh, in the next 20 years after the digital upgrade, the business case would be break-even for the digital I&C upgrade.

	Baseline Case	Worst Case	Break-even
Events	3 events every 9 years (Winter/Summer/Winter) each event is 10 days	No events	1 summer event in the next 20 years resulting in 6 days of lost generation
30-year NPV	$74M	($73M)	$0
Pay-back period	17.8 years	25.7 years	20.4 years

2. With an 8-year implementation timeline, the implementation cost of the upgrade is the most important determinant of a positive business case. Reference Plant should look to challenge the implementation cost and timeline with the vendor and not underestimate the project management, change management and human factors analysis that will be required to support this significant upgrade.

3. The most significant benefit with this upgrade is the avoided escalation cost of materials, specifically circuit cards and power supplies which are growing at minimum of 13.5% and as high as 24% per year and challenging engineering, maintenance and supply chain to source replacement parts/components.

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Executive Summary

Where Can the Business Cases Results be Improved?

Below are some areas that could improve the business case results because the inputs and assumptions were conservative:

#	Variable	Conservative Value (Used in Baseline)	High End Range Possible Value	Notes
1	Escalation rate of material forecasted growth rate based on historical spend	15%	25.0%	We used 15% but based on LGS safety system research CAGR could be 25%
2	Labor Benefit Timeline	7 FTEs reduced by Year 9	12 FTEs reduced by Year 9	Assumed no benefits achieved until Year 9
3	Labor Reduction	7 FTEs	12 FTEs	Possible given higher percentage of equipment replaced
4	Inflation Rate	3.0%	4.0%	
5	Weighted Average Cost of Capital (WACC)	6%	10.0%	Given current interest rates is higher WACC is reasonable
6	Salvage value of inventory	0%	10.0%	Possible salvage value available to Reference Plant on resale of equipment

Areas to Challenge vendor:

- **$150 M to implement modifications to Non-Safety systems**
- **8- year implementation timeline**
- **Safety systems implemented early on during the schedule**

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Executive Summary

Future Significant Modernization Considerations

Project title	Description	Expected benefits	Workload or Positions impacted
Automated planning and scheduling[1]	Using business process automation tools to automate or auto-assist the work planning and scheduling process. Historical plant data, plant operating experience, and changing plant conditions can be used to auto-generate work requests, create work orders, and schedule online or outage work. Automated systems can replace manual searching and compiling plant data formerly used to create and schedule work packages. In addition, the T-Week process is eliminated for engineering, maintenance, supply chain, operations, and work management.	FTE Savings: 7 - 16 O&M Savings: $1.1M - $2.6M	Schedulers WM Coordinator Outage Specialists/Planners Cycle Mgr Maintenance Planners
Advanced training	Advanced training focuses on delivering digitally produced training material in a variety of ways to the worker. These methods can include video of actual job task demonstration, multimedia experience utilizing video, graphics, text, documents, procedure steps, and perspective camera shots. Training that is digitized can be taken anywhere and at any time with little need for the classroom experience. Students can take tests online and submit groups of courses for qualification without any in-person instruction. Operators can also learn about the plant systems, procedures, protocols, and responses in the same way. They can also take advantage of a digitized control room to learn scenarios and keep up with the latest plant modifications	FTE savings: 16 – 24 O&M savings: $2.6M – $3.9M	Operations instructors Technical instructors General instructors Training clerk
Condition based monitoring	Condition-based monitoring (CBM) utilizes online sensors capable of detecting failure modes traditionally found using intrusive testing. Sensors communicate component condition information to a monitoring platform capable of alerting an attendant of an adverse condition or trend. Advanced platforms can diagnose the cause and duration of time to an unacceptable condition. These platforms are also capable of interfacing with the work management system to automatically create, plan, and schedule work orders to address the condition.	FTE Savings: 20 – 39 O&M Savings: $3.3M - $6.4M	Engineers EM & MM Craft I&C Craft Planners Maintenance Supv. Clerks
Remote assistance and automated troubleshooting	Digital video, voice, and collaborative devices free support staff from being required to be present at the site in case of a need to collaborate. It also frees the O&M staff from performing critical work during normal work hours as experts may be available in different time zones or able to assist from home without driving to the facility. With remote support enhanced, support staff can become more specialized, be located in faraway places, avoid dose, mispositions, and safety incidents, and more easily conform to the plant's ideal schedule. Automated troubleshooting is the computerized monitoring and on-board diagnosis of power plant component failure modes. This is accomplished by installing digital technology designed to monitor an individual component's mechanical or electrical parameters like vibration or motor current.	FTE Savings: 29 – 33 O&M Savings: $4.7M - $5.4M	Chem Techs RP Techs Maintenance Supervisors Component Engineers Maintenance/QC

More information on technologies and the full ION report can be found here: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_64103.pdf

Note1: EPRI Nuclear Plant Modernization Business Case: Business Process Automation for Online Work Management". Report 3002020884

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Executive Summary

Next Steps

For Project Team:

- Incorporate feedback from today
- Develop MSWord version industry facing report based on this report (with generic numbers)
- Determine the value of pursing additional business case scope outlined here with collaboration from Reference Plant leadership team

For Reference Plant Leadership Team:

- Challenge implementation cost of Non-Safety systems
- If project is decided on to move forward, engage vendor(s) to perform conceptional design
- Determine if additional business case ideas need to be incorporated into LTO plan

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Sensitivity Analysis

Sensitivity Analysis

Scenario Analysis Key Takeaways

1. If Reference Plant were to miss out on 6 full days (24 hours per day) of generation during the summer at $300/MWh, in the next 30 years after the digital upgrade, the business case would be break-even for the digital I&C upgrade.

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2. With an 8-year implementation timeline, the implementation cost of the upgrade is the most important determinant of a positive business case. Reference Plant should look to challenge the implementation cost and timeline with the vendor and not underestimate the project management, change management and human factors analysis that will be required to support this significant upgrade.

3. The most significant benefit is the avoided with this upgrade is the avoided escalation cost of materials, specifically circuit cards and power supplies which are growing at minimum of 13.5% and as high as 25% per year and challenging engineering, maintenance and supply chain to source replacement parts/components.

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Sensitivity Analysis

Scenario Summary

We modeled the following six scenarios. The results of the baseline scenario are shown on the next few pages

#	Scenario Title	KEY VARIABLE: Reliability Challenges Events	Inflation	Material CAGR	Cost to Implement	On-going cost	Labor Benefits occur by year	Annual Material Spend Reduced	Salvage Value (%) of Stranded Inventory	Weighted Avg. Cost of Capital (WACC)
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2	Best case	3 events every 6 years (occurs in the Summer/Winter)	4.0%	25.0%	$150M*	$100k per year	12 FTE reduction in Year 9	$800K	10%	6.0%
3	Reliability Challenges	3 events every 6 years (occurs in the Summer/Winter)	3.0%	15%	$250M	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
4	Reduced Cost to Implement	3 events every 9 years (occurs in the Winter/ Summer/Winter)	3.0%	15%	$250M*	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
5	No Reliability Challenges	None	3.0%	15%	$250M	$100k per year	7 FTE reduction in Year 9	$700K	0%	6.0%
6	Elective I&C Modernization	Six days of lost generation during the Winter per year**	3.0%	15%	$100M	$50k per year	2 FTE reduction in Year 5	$100K	0%	6.0%

Note* Assumed the cost of implementation for Non-Safety systems is reduced by $80M either though contract negotiations or public funding grant

Note** Six days was the necessary value of reliability events calculated for the scenario to breakeven (NPV equals $0)

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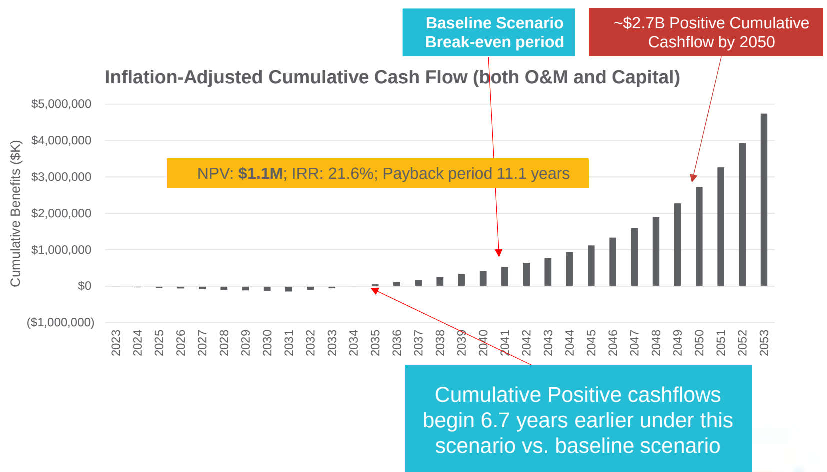
Sensitivity Analysis

Projected Cash Flow Summary – Best Case Scenario

Under this best-case scenario, lower implementation costs, a higher growth rate in material costs, greater realized labor benefits, and higher projected losses from reliability events mean the project has a predicted NPV of $1.1B and an IRR of 21.6%

Assumptions and Clarifications:

- Implementation costs $100M lower than the baseline - $250M to $150M - due to contract negotiations or through obtaining a public grant
- Material CAGR of 25% instead of baseline's 15%
- Inflation of 4.5% compared to baseline of 3%
- Labor benefits of 12 FTEs eliminated by Year 9 instead of seven under baseline scenario
- Reliability challenge events occur once every two years instead of the baseline of three
- Equal number of summer and winter reliability events rather than two winter per summer event
- For reliability events, same as assumptions as the baseline for:
  - Lost revenue of winter is $30/MWh
  - Lost revenue of summer is $300/MWh
  - 0% $/MWh escalation rate
  - Obsolescence issues take 10 days to resolve per unit
  - Started scenario of revenue loss in 2029
- Same assumptions of baseline scenario for:
  - Annual on-going costs of $100K
  - Cost of capital of 6%



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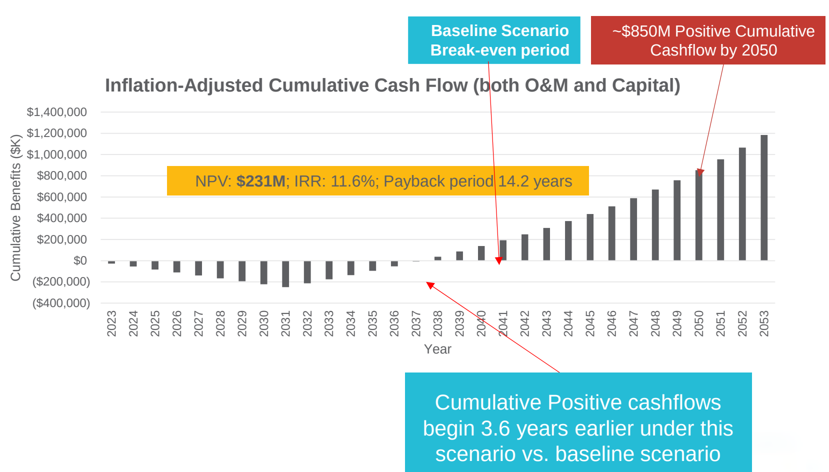
Sensitivity Analysis

Projected Cash Flow Summary – Reliability Challenge Scenario

This scenario uses the projection of higher losses from reliability events with all other variables remaining the same as in the baseline case which gives the project a predicted NPV of $231M and an IRR of 11.6%

Assumptions and Clarifications:

- Reliability challenge events occur once every two years instead of the baseline of three
- Equal number of summer and winter reliability events
- For reliability events, same as assumptions as the baseline for:
  - Lost revenue of winter is $30/MWh
  - Lost revenue of summer is $300/MWh
  - 0% $/MWh escalation rate
  - Obsolescence issues take 10 days to resolve per unit
  - Started scenario of revenue loss in 2029
- Same assumptions of baseline scenario for:
  - Inflation of 3.0%
  - Material CAGR of 15%
  - Implementation costs of $250M
  - Annual on-going costs of $100M
  - Realized labor benefits of reduction of seven FTEs by Year 9
  - Cost of capital of 6%



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Sensitivity Analysis

Potential Reliability Issues that Could Cause Loss of Generation Scenario

Based on SME discussions, the following systems pose reliability concerns for Long-Term Operations:

1. **Flux Mapping** – TR 13.2.24 covers this system. There are two flux map versions currently used. One is the BEACON which uses plant computer points uses magic and tells Operations how the core is performing. The second is Moveable Incore Detector system (MIDS). MIDS is used quarterly to verify BEACON is still accurate. If unavailable, Operations can't verify operation of BEACON. Without the ability to flux map, there are certain cases where we couldn't perform Surveillance Requirements.
2. **AMSAC** – Not a TS or TRM system but is SISL. If unavailable, Reactor Operators will brief on what actions AMSAC does, and in the event AMSAC setpoints were to be reached, Operations would take mitigating actions.
3. **Core Exit Thermocouple (CET) - PAMS** – LCO 3.3.3 divides CETs into quadrants. If an entire quadrant is unavailable (meaning both Train A and B unavailable in the quadrant), then Operations has 7 days to restore, and if not restored in 7 days, we need to be in Mode 3 in 6 hours and Mode 4 in 12 hours. If just one train is unavailable, then it's a 30-day spec and if not restored a PAM report shall be submitted. It also feeds a PAM condition if just one train and a required HL temp indicator are out (same 7-day spec as above). CETs also are part of the Power Distribution Monitoring System (see Flux Mapping part above).
4. **RVLIS - PAMS** –same as the CET discussion above. One train out, 30 LCO. Both trains INOP is the 7-day or shutdown LCO. Both CETs and RVLIS also play a part in decision making in the ERG strategies and procedures, as well as EAL calls.
5. **H2 Monitoring** – Containment Atmosphere Monitoring – currently NOT functional –Used in accident conditions. FRC-0.1A Response to Inadequate Core Cooling has a step to check containment hydrogen concentration. The bases of that step says if this system is unavailable, Operations would take samples from the Containment PIG rad monitor. This information is used to determine how Operations would eliminate the hydrogen.
6. **Solid State Safeguards Sequencer** – Per LCO 3.8.1 is an SI Sequencer is Inoperable then Operations has 24 hours to restore (or IAW RICT), if not restored, 6 hours to Mode 3. If a BO sequencer is Inoperable, Operations would declare the respective EDG INOP Immediately. EDG being Inoperable is a 72-hour completion time.
7. **Annunciators** – specifically the Sequence of Events Recorder – Some annunciator windows are TS/TRM related. They deal with RCS leakage, AFD monitoring, and QPTR monitoring. Either way, CR and field operators will have additional comp measures to perform to monitor indications more frequently. As far as the SER, ABN-740A/B Section 4 has a note "Loss of power to SER output relay cards disables the First Out Annunciators on 1-ALB-6C". This means Operations have no indication an RPS signal that was processed by SSPS.
8. **Loose Parts** – thinking of eliminating system – There is really no action for us to take in ABN-910 until Engineering has verified there is a loose part that has been caught or is just wandering about wreaking havoc on the RCS. TR 13.4.31 is a 30-day LCO. Reference Plant has had LPMS out of service in the past, and if it cannot be fixed in the 30 days, it is not a problem. Often, it is scoped into the outage. Also doesn't prevent operations from changing Modes since we can use TR LCO 13.0.4.

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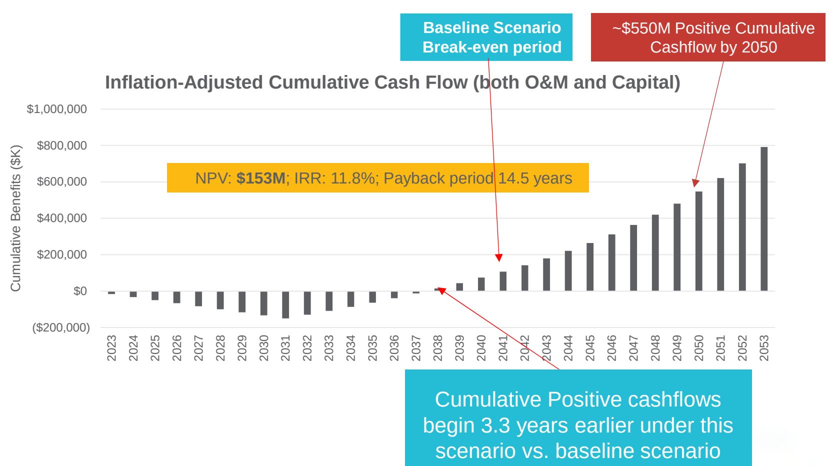
Sensitivity Analysis

Projected Cash Flow Summary – Reduced Cost to Implement

In the expedited timeline scenario, the costs of implementation are reduced from $250M to $150M through contract negotiations or obtaining a public grant, meaning the project has a projected NPV of $153M and an IRR of 11.8%

Assumptions and Clarifications:

- Implementation costs reduced by $100M from $250M to $150M due to contract negotiations or through obtaining a public grant
- For reliability challenge events, the same assumptions as the baseline are maintained:
  - Events occurring once every three years
  - Two winter events for every summer event
  - Lost revenue of winter is $30/MWh
  - Lost revenue of summer is $300/MWh
  - 0% $/MWh escalation rate
  - Obsolescence issues take 10 days to resolve per unit
  - Started scenario of revenue loss in 2029
- Same assumptions of baseline scenario for:
  - Inflation of 3.0%
  - Material CAGR of 15%
  - Annual on-going costs of $100M
  - Realized labor benefits of reduction of seven FTEs by Year 9
  - Cost of capital of 6%



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Sensitivity Analysis

Projected Cash Flow Summary – No Reliability Events

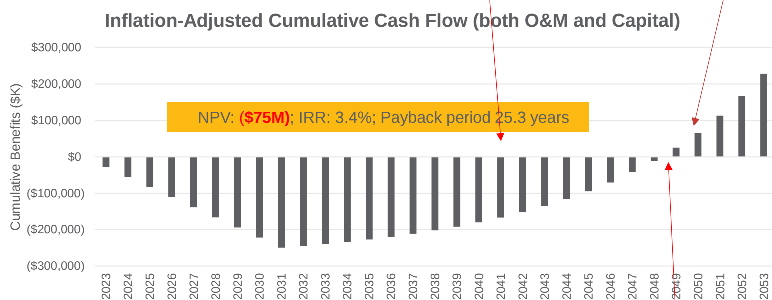
Under this scenario, Reference Plant does not have a reliability challenge resulting in a lost revenue opportunity over the 30- year period of operations, which gives the project an NPV of (\$75M) and an IRR of 3.4%

Assumptions and Clarifications:

- No reliability challenge event over the next 30 years of operations
- Same assumptions of baseline scenario for:
  - Inflation of 3.0%
  - Material CAGR of 15%
  - Annual on-going costs of \$100K
  - Realized labor benefits of reduction of seven FTEs by Year 9
  - Cost of capital of 6%
  - Implementation costs of \$250M
  - Annual on-going costs of \$80K

Baseline Scenario Break-even period

~\$66M Positive Cumulative Cashflow by 2050



Cumulative Positive cashflows begin 7.5 years **later** under this scenario vs. baseline scenario

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Sensitivity Analysis

Projected Cash Flow Summary – Elective I&C Modernization

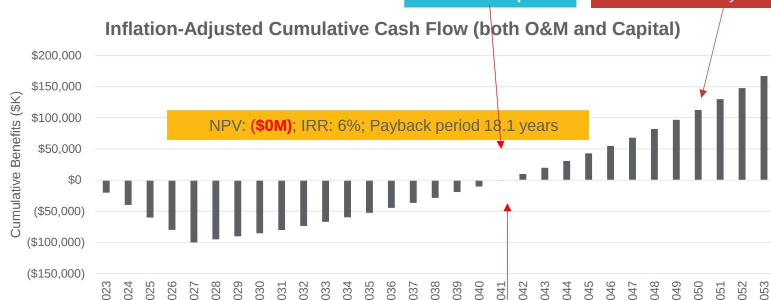
Reference Plant completes the elective I&C modernization scope, which excludes 11 I&C subsystems with technical specifications and unfavorable performance

Assumptions and Clarifications:

- Six days of lost Winter generation annually due to reliability events
- Value of 11 specific elective I&C modernizations** were not included from the baseline financial analysis
  - Cost/benefits of specific system scope upgrades excluded from the model*
  - Cost of implementation lowered from \$250M to \$100M
  - Net benefits in materials reduced from \$700 to 100K
- Time period for implementation decreased from eight years to four years
- Labor benefits reduced from seven FTEs by year 9 to two FTEs by Year 5
- Inventory holding cost benefits reduced from \$89K to \$25K
- Same assumptions of baseline scenario for:
  - Inflation of 3.0%
  - Material CAGR of 15%
  - Annual on-going costs of \$40K
  - Cost of capital of 6%

Baseline Scenario Break-even period

~\$110M Positive Cumulative Cashflow by 2050



Note* System scope upgrades that were not included in the financial analysis were #1-8, #12, and #18-19 listed in slides 7 and 8

Note** Systems eliminated from analysis were Tech Spec and Red reliability systems from page 7 & 8

Cumulative Positive cashflows begin in the same year under this scenario vs. baseline scenario

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Sensitivity Analysis

Scenario Summary – Output of Results

We modeled the following six scenarios:

#	Scenario Title	KEY OUTPUTS: Payback Period (Years)	KEY OUTPUTS: NPV	KEY OUTPUTS: IRR (%)	Key Changes to Baseline
1	Baseline	17.8	$74M	8.1%	N/A
2	Best Case Scenario	11.1	$1.1B	21.6%	3 reliability challenge events in 6 years; Inflation 4%; Material CAGR 25%; Cost to Implement $150M; 12 FTE reduction in Year 9
3	Reliability Challenges	14.2	$231M	11.6%	3 reliability challenge events every 6 years
4	Reduced Cost to Implement	14.5	$153M	11.8%	Cost to Implement reduced from $250M to $150M
5	No Reliability Events	25.3	($75M)	3.4%	No reliability challenge event during the next 30 years of operation
6	Elective I&C Modernization	18.1	$0*	6%	Costs/Benefits of elective I&C modernizations were not included in the financial analysis

The largest impact to the business case result is the potential lost generation from a reliability challenge event preventing Reference Plant from earning revenue during a high demand period

Note* The scenario breaks even (NPV $0) with six days of lost annual generation in the Winter

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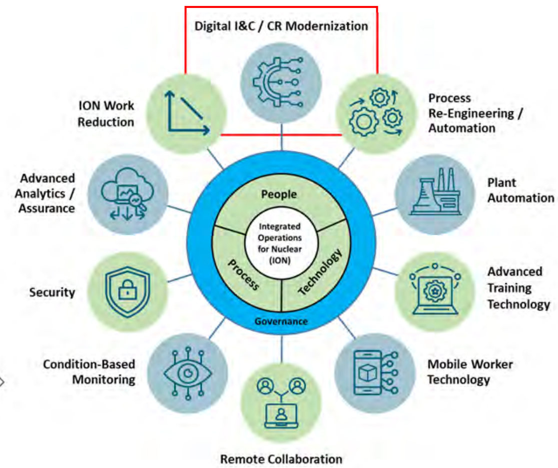
Alignment to ION Model

Alignment to INL ION Model

The current Digital I&C upgrade scope is limited in its focus on digital modernization and alignment to INL's integrated operations for nuclear (ION) model. To gain a more positive business case, further analysis into broader ION modernization is recommended.

- ION proposes a rethink and overhaul of plant operations. ION details projects, upgrades, and modifications that will create pathways for O&M savings (i.e., work reduction opportunities)
- License extension to 60 or 80 years will require:
  - Replacement of aging and obsolete I&C systems
  - Organizational changes
  - Hardware, software and process digital transformation
- ION was designed to reduce O&M spending while upgrading systems and processes that will attract and retain talented workers and make the plant viable for decades to come
- Work domains guide execution of the ION strategy and help to organize the many changes needed to the technology, processes, and the workforce organization

License Extension → I&C Upgrades → Digital Transformation → Digital Workers



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More information on technologies and the full ION report can be found here: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_64103.pdf

Alignment to INL ION Model (cont'd)

INL's ION research found a 66% probability of achieving a positive net present value (NPV) for digital I&C upgrades.

- While the Reference Reference Plantusiness case did not present a positive business case, there were several aspects of the ION digital I&C upgrade scope that were not included in the vendor's proposal for Reference Plant
  - Computer based procedures: the digitalization of detailed approved procedures with embedded process workflow
  - Digital document review and archiving: document digitization software automatically converts all printed files, office documents, procedures, etc., into sortable and searchable files
  - Mobile devices and mobile video: smartphones, tablets, and wireless video cameras; plant personnel can use these mobile devices to monitor, track, and trend component information that is captured by digital components
  - Component identification technology: quick response (QR) codes, optical character recognition (OCR) technology, and radio frequency identification (RFID); can be used for item identification, time-tracking, document management, etc.

Technology Evaluated	Reference Plant I&C Scope	ION I&C Scope
Digital I&C Systems	20 systems plus some interfaces Limited data linkage	35+ interfaces Significant data linkage
Computer-Based O&M Procedures		✓
Digital Document Review & Archiving		✓
Communication Network	✓	✓
Mobile Devices & Mobile Video		✓
Large Overhead Displays	✓	✓
Component Identification Technology		✓

Investing in the digital I&C infrastructure provides the essential foundation for enabling future technologies and data-driven decisions that bring greater benefits. Taking this first step will position the site to meet future needs of extended operation and cost competitiveness.

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More information on technologies and the full ION report can be found here: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_64103.pdf

Future Research Considerations

The vision for future efforts is to analyze an ION operating model complete with additional scope to realize additional benefits in operations and cost. For example, data from the I&C upgrade can be used for remote troubleshooting via the POC.

Current Scope

- I&C Upgrades for 20 systems that focus on cost benefit analysis of replacing materials (e.g., obsolete circuit cards) and maintenance and planning labor (e.g., calibrations) associated with workload of maintaining the old systems that will be eliminated via I&C upgrades

Realized Benefits

- Materials Spend
- Maintenance Labor
- Operations Efficiencies
- Human Performance Improvement (and Reduced Risk)

Potential FY23 Research Scope

+ Include additional systems to upgrade (e.g., the Fire Protection system, RCP vibration monitoring) could realize additional benefits by reducing workload and material spend associated with maintaining existing system(s)
+ What systems should or should not be pursued based on business case?
+ What is the optimal schedule for implementation to generate the best business results?

+ Includes digitalization of additional data points in the plant and using this data to modernize plant operations
+ Operator manual data collection is eliminated, freeing up field operators to complete other work
+ Automation of operator actions would improve operator response times and human performance, ultimately reducing risk to the plant

More information on technologies and the full ION report can be found here: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_64103.pdf

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Future Research Considerations: Expanded Benefits Examples

Operator Efficiencies

- Electronic procedures for certain operations procedures (e.g., startup, operator walkdowns) would streamline record keeping and data entry for both field and control room operators
- Increased field indications with digital outputs would reduce field operator time to find leakages and reduce shift operator rounds. Indications on the secondary side could identify operational efficiencies that increase generation
- Technology adoption could reduce or eliminate operator rounds (e.g., Spot the dog robot, gauge readers, drones)
- Automated operator actions to increase response times. For example:
  - RCS leakage calculation
  - Calimetrics
  - Pump operability tests
  - Steam generator tube rupture response
  - Reactor shutdown

Human Performance Improvement (and Reduced Risk)

- Errors from routine data collection (e.g., indicator reading, manual data recording) would be reduced or potentially eliminated with digital data points and trending
- Automated operator actions with "checks" during the process would greatly improve human performance and also reduce plant risk
  - Short-duration operator actions (e.g., steam generator tube rupture) are time-based, and current manual practices create operational risk and regulatory risk – even potential for a monetary fine – if actions are not completed during the designated time frame. Automating these actions reduces these risks
  - Several tests and procedures with specified criteria can be automated and set to notify Operators if criteria is within or out of tolerance

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Project Overview and Approach

Project Approach

May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | ... | May 2023

Phase 1 | Phase 2 | Next Steps

Phase 1: Planning and Scope Development

- Identify New State Target (Stakeholder needs assessment) that identifies optimal technologies to address obsolescence and necessary functionality
- Define advanced concept of operations to support New State
- Performance attributes for digital infrastructure systems that support New State
- Establish key vendor attributes (e.g., viable technology to provide performance attributes, formal lifecycle management)
- Adapt existing data collection templates for use (as necessary)
- Develop Business Case Analysis timeline & identify participant resource needs for Phase 2 BCA (SR I&C upgrade/Full package)
- Engage potential vendors for walk-downs and provide input to digital transformation scope (Owner engages vendors)

Dec: Progress Report (primarily SR I&C)

May 2023: Utility Specific Final Report (full scope)

Phase 2: Business Case Analysis

- Data mine all sources of cost data and process to I.D. existing costs and drivers (cost analysis)
- Identify/refine performance attributes to enable optimal CONOPS/New State performance/cost goals
- Perform Business Case benefits analyses for identified in-scope systems and components
- Estimate implementation and Ongoing Cost Data for upgraded/new systems
- Validate vendor-walk-down scope
- Business Case Analysis (using industry tool)
- Utility specific presentation and report
- Industry facing presentation and report

Estimation of Benefits Approach

Kick off meeting → Gather Data and Conduct Interviews → Develop CBA Workbook (Benefits) → Review preliminary ROM-level estimate → Challenge Sessions (Cross-functional working meetings) → Adjust → Acceptance

Next Steps

- LAR Activities
- Implementation Planning

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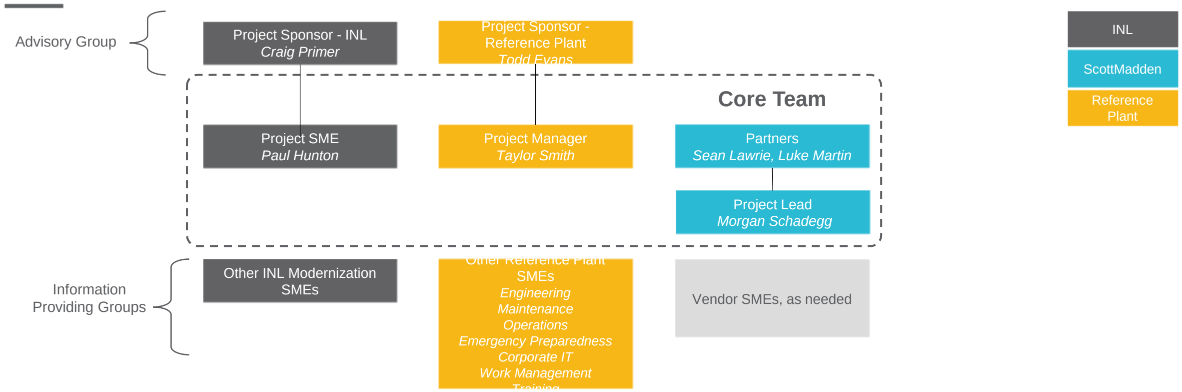
Project Team



The INL team:	The Reference Plant team:	The ScottMadden team:
▪ Provided research input for each stage of the project ▪ Reviewed outputs and supporting documentation and provide feedback ▪ Scheduled and facilitate validation meetings with the appropriate advisory group, as needed	▪ Provided necessary access to system data and information ▪ Engaged and coordinate plant resources, as needed	▪ Collected and analyze the necessary inputs ▪ Revised the templates for information collection and validation ▪ Developed, input data, and revise documentation as needed based on Reference Plant and INL SME feedback

Labor Benefits Approach

To determine the benefits associated with labor for the digital I&C upgrade, the project team:

- Collected and analyzed Reference Plant historical work management system data (i.e., Work Management System) from 2015 to 2022 to determine current annual workload for each in-scope system in the following areas:
  - Surveillances and Tests
  - Preventive Maintenance
  - Corrective Maintenance (non-repetitive)
- Reviewed and validated annual workload to support each system with Reference Plant staff
  - Interviews were conducted with SMEs
  - Resource quantities and labor hours were reviewed and validated at the work order level
- Estimated percent workload reductions for each system based on the WO tasks expected to be eliminated with the upgrade
  - Workload eliminations were confirmed with vendor and SMEs
  - Results were consolidated by system to determine total workload reductions in each functional area
- Consolidated total workload reductions to determine potential reduction of FTEs
  - I&C Maintenance Craft hours were determined as significant hours were reduced
  - I&C Supervision was considered due to the number of FTEs reduced for I&C craft
  - Planners, schedulers, and clerical maintenance did not have enough hours to reduce FTEs; however, labor hours were determined to be reduced for each of these groups in the form of overtime hours

DESCRIPTION	Location	SCHED FREQ	Annual Freq.	Online or Outage	Work Group	Average WO Hours	Total Annual Labor
(RF) VERIFY SETPOINT MS SAFETY	2	550	0.67	N/A	IWCP	1.33	1.77
INC-7653A,COT PRZR LVL	1	550	0.67	N/A	PT	3.47	2.31
INC-7653A,RACK PRZR LVL	1	550	0.67	N/A	PT	3.56	2.37
INC-7653A,XMTR PRZR LVL	1	550	0.67	N/A	MT1	8.50	5.66
INC-7653B,COT PRZR LVL	1	550	0.67	N/A	MT1	3.43	2.28
INC-7653B,RACK PRZR LVL	1	550	0.67	N/A	MT1	3.50	2.33
INC-7653B,XMTR PRZR LVL	1	550	0.67	N/A	MT1	9.78	6.51
INC-7654A,COT PRZR LVL	1	550	0.67	N/A	PT	3.43	2.28
INC-7654A,RACK PRZR LVL	1	550	0.67	N/A	PT	3.50	2.33
INC-7654A,XMTR PRZR LVL	1	550	0.67	Outage	MT1	14.00	9.32
INC-7654B,COT PRZR LVL	1	550	0.67	Online	IC	2.86	1.90
INC-7654B,RACK PRZR LVL	1	550	0.67	Online	IC	3.56	2.37
INC-7654B,XMTR PRZR LVL	1	550	0.67	Outage	MT1	7.00	4.66
INC-7738A,COT PRESZR LVL	1	550	0.67	N/A	PT	3.47	2.31
INC-7738A,RACK PRESZR LVL	1	550	0.67	N/A	PT	7.11	4.73
INC-7738A,XMTR PRESZR LVL	1	550	0.67	N/A	MT1	9.33	6.21
INC-7738B,COT PRESZR LVL	1	550	0.67	N/A	MT1	3.71	2.47
INC-7738B,RACK PRESZR LVL	1	550	0.67	N/A	MT1	7.11	4.73
INC-7738B,XMTR PRESZR LVL	1	550	0.67	Outage	MT1	7.88	5.24
INC-7826A,CCAL PRZR LVL	1	550	0.67	N/A	MT1	9.00	5.99
INC-7826B,CCAL PRZR LVL	1	550	0.67	N/A	MT1	7.11	4.73

Example Labor Analysis for PM Activities

Project Overview and Approach

Materials Benefits Approach

To determine the benefits associated with materials and equipment for the digital I&C upgrade, the project team:

- Developed and analyzed equipment lists for each system through purchase and consumption data from 2015 (earliest available) to 2022 utilizing Work Management System-generated reports and design documents
- Analyzed Work Management System work order data for items over $1,000
- Selected a sample set of Location #s to perform additional analysis for power supplies and circuit cards
  - Available purchase history was examined to determine escalation trends for each sample item
  - The average escalation rate was calculated at 13.6% to 17.5%
- Identified potential equipment items to be eliminated with the upgrade, confirming with the vendor
- Reviewed and validated results with INL and Reference Plant
- Applied a 20% factor for miscellaneous and sundry materials

Example Material Analysis for PM Activities

Item #	Description	X	Status	Last Unit Price	Last Price Year	Average Unit Price	Earliest Price Year	Price Increase per Year	Price in Earliest Year	CAGR	Current Unit Price	Qty Inventory	Current Value of Inventory	Quantity used since 2015	Average Annual Expenditure
468899	LIGHT ASSY, INDICATOR, WHITE		ACTIVE	$572.60	2019	$608.39	2019	-$71.58	$644.18	-11.1%	$286.28	1	$286.28	1	$35.79
458267	CIRCUIT, PRINTED, NRA, RTD AMPLIFIER	X	ACTIVE	$21,635.46	2019	$20,616.80	2017	$679.11	$19,598.14	3.4%	$24,351.89	7	$170,463.25	1	$3,043.99
503444	CIRCUIT, PRINTED, NMD-1, MULTIPLIER- DIVIDER	X	ACTIVE	$16,453.05	2022	$15,820.17	2019	$316.44	$15,187.29	2.0%	$16,769.49	4	$67,077.96	1	$2,096.19
457836	PANEL, DISPLAY	X	ACTIVE	$10,000.00	2020	$10,000.00	2020	$0.00	$10,000.00	0.0%	$10,000.00	0	$0.00	2	$2,500.00
471662	TRANSDUCER, ELECTRO PNEUMATIC, 4-20 MA INPUT, 6-30 PSIG OUTPUT, EPDM ELASTOMERS	X	ACTIVE	$7,997.00	2022	$7,424.72	2015	$143.07	$6,852.44	1.9%	$8,140.07	6	$48,840.42	2	$2,035.02
471527	ASSEMBLY,GENERAL;TRANSDUCER PUSHROD	X	ACTIVE	$5,736.00	2019	$5,736.00	2019	$0.00	$5,736.00	0.0%	$5,736.00	5	$28,680.00	8	$5,736.00
240760	RELAY, UNDERVOLTAGE, 120 VAC RATING, CAL RANGE 70-100 V, W/O TARGET	X	ACTIVE	$3,410.63	2020	$3,410.63	2015	$0.00	$3,410.63	0.0%	$3,410.62	3	$10,231.87	2	$852.66
902702	TRANSMITTER,PRESSURE;COPLANAR, GAUGE;4 TO 20 MA;-393 TO 1000 IN H20;NPT;1/2 IN	X	ACTIVE	$3,288.64	2016	$3,288.64	2016	$0.00	$3,288.64	0.0%	$3,288.64	1	$3,288.64	2	$822.16
343816	RESISTANCE TEMPERATURE DETECTOR, DUAL ELEMENT, PLATINUM	X	ACTIVE	$3,185.80	2018	$3,185.80	2018	$0.00	$3,185.80	0.0%	$3,185.80	2	$6,371.60	1	$398.23

Project Overview and Approach

Other Labor and Non-Labor Benefits Approach

Non-Direct Reducible Labor

- Where cumulative data or regulatory requirements or specificity of roles did not support an FTE reduction, these reductions were examined to determine if overtime benefits could be reduced
- Overtime benefits were taken for maintenance planners, schedulers, and clerical staff
- Where overtime hours are not applicable and labor cannot be reduced, workload efficiencies are captured. These hours could then be deployed to complete other work and potentially reduce other FTEs in other work groups

Capital Carrying Cost

- Historical component pricing data and current inventory levels were analyzed to determine current value of inventory held by the corporation for the station. Historical escalation rates were utilized to determine future value of inventory. Lost opportunity cost of capital was determined at a rate of 25%
- Other carrying costs were examined and determined by the team to be unrealized by the project, including annual depreciation, supply chain and warehousing factors (fixed cost), property taxes (not applicable), insurance, and one-time write-down costs (components can be utilized at other facilities)
- Included inventory tax rate as part of the cost of capital

Material Escalation due to Obsolescence

- Extensive data and historical pricing analysis was conducted to determine material escalation rates of individual components to determine if obsolescence was a factor in rising system costs

Other Areas Examined

- Backlog reduction was not reviewed for this analysis, but prior analyses have showed backlog reduction from this type of upgrade
- Training content and delivery reduction was examined and determined that no appreciable training reductions would be realized in either operations or maintenance training regimens

Project Overview and Approach

Key Assumptions

The following are key assumptions made for the analysis:

- Base inflation rate for labor and materials – 3.0%
- Materials escalation rate of 15% (conservative compared to prior site analyses)
- Reduction in carrying cost of inventory is escalated at same rates for material
- Present value of future cash flows discounted at 6% cost of capital
- License renewal for Units 1 & 2 will extend operating period to 30 years (Unit 1 – 2050; Unit 2 – 2053)
- Effective hours for FTEs is assumed at 1470 (accounts for training weeks & PTO)
- Non-I&C labor is assumed to be OT hours at 1.5x rate (planners, schedulers, and clerical work)
- "Other" accounts for modernization costs for training, simulator implementation, and regulatory costs
- For each non-repetitive WO, support hour assumptions were applied to the labor hours. These support hours are not captured in the Work Management System WO tasks.

Support Activity	Type	Group	Role	# of People	Hours per Person	Total Hours
Pre-Job Brief/Prep	MA	I&C	Craft	1	0.25	0.25
Pre-Job Brief/Prep	MA	I&C	Supervisor	1	0.25	0.25
Pre-Job Brief/Prep	OP	Shift Ops	SRO	1	0.25	0.25
Pre-Job Brief/Prep	OP	Shift Ops	RO	1	0.25	0.25
Scheduling	MA	Maint Prep	Scheduler	1	1	1
Prepare work package & Coordination	MA	Maint Prep	Planner	1	4	4
Print Out Procedures & Work packages	MA	Maint Prep	Clerical	1	0.13	0.13
WO Closeout	MA	I&C	Supervisor	1	0.25	0.25
Maintain Records	MA	Maint Prep	Clerical	1	0.25	0.25
			Total per Work Order	**9**	**6.63**	**6.63**

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Business Case Analysis

Business Case Analysis

Implementation Costs

The following rough order of magnitude (ROM) estimates were given for one-time costs of the digital I&C upgrade for the in-scope systems.

Vendor ROM					
Implementation	**Install Year(s)**	**System Cost**	**Design Change**	**Installation**	**Total**
Phase 1: DCS / Non-safety BOP / Safety PAMS / DADS	2026 – 2027	$80,000,000	$25,000,000	$30,000,000	**$85,000,000**
Phase 2: Process Protection / PAMS / AMSAC	2028 – 2029	$35,000,000	$10,000,000	$15,000,000	**$60,000,000**
Phase 3: NSSS Control	2029 – 2030	$20,000,000	$4,000,000	$8,000,000	**$32,000,000**
Phase 4: Rod Control / DRPI / Flux Mapping	2031 – 2032	$50,000,000	$10,000,000	$20,000,000	**$70,000,000**
Regulatory / Licensing	-	-	-	-	**$3,000,000**
				Total	**$250,000,000**

Ongoing costs for the modernization were determined to be minimal.

- Software licensing is estimated at $100,000 per year
- Ongoing maintenance activities would be covered by remaining I&C craft and did not add significant additional labor hours

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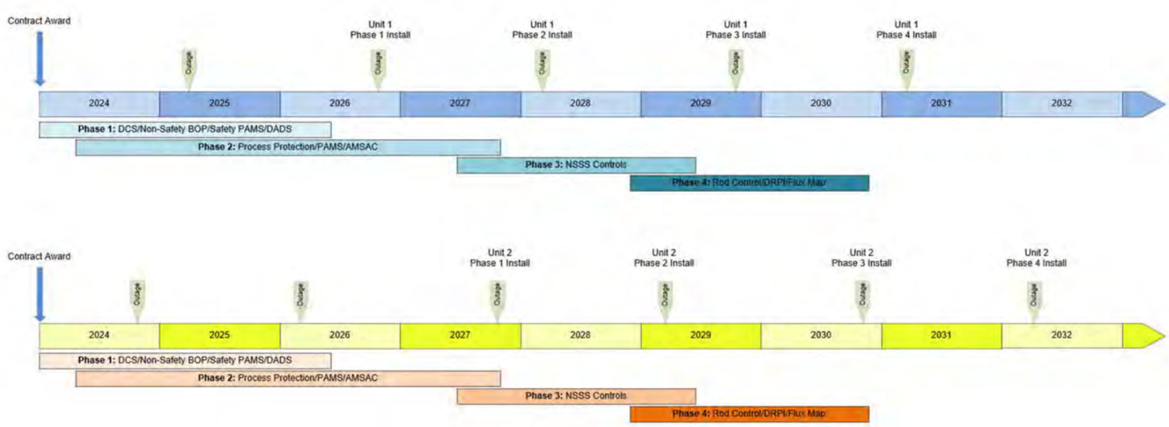
Business Case Analysis

Proposed Vendor Implementation Schedule

The following is the vendor recommended implementation schedule based on the in-scope systems for the digital I&C upgrade.

Unit 1 & 2 – High Level I&C Modernization Schedule



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Implementation Schedule Considerations

While not evaluated yet for this business case, there are several factors that need to be considered when determining the implementation schedule for the digital I&C modernization.

Consideration	Description
Vendor Input	Input from the vendor(s) to determine their thoughts on implementation based on their experience and knowledge of the systems.
Safety vs. Non-Safety	There could be benefit to modernize non-safety systems first, gathering lessons-learned prior to modernizing safety systems.
Plant Risk	Risk posed to the plant should be a factor in deciding an implementation schedule. Evaluating aspects such as reliability, obsolescence, and whether or not the current system is supported by the vendor is critical before moving forward.
Benefits	Determining which systems provide the highest benefits could be a strategy for determining implementation schedule to gain more benefits up front, thus resulting in more cost savings early on.
Capital Outlay	Regulated and non-regulated utilities could have differing priorities based on capital expenditures.

Using the BCAM

The EPRI Plant Modernization Business Case Analysis Model (BCAM) was used to assess the digital I&C modernization effort.

- The BCAM was used to create a cost-benefit analysis for the implementation of the digital I&C systems. Prior to using the BCAM, the team:
  - Prepared basic inputs for the analysis
  - Analyzed data provided by Reference Plant (via Work Management System) and summarized costs to maintain current technology for each system in scope
    - Labor rates are standardized across the industry by labor group
  - Identified potential cost savings which aligned to each system given the scope of the upgrade
    - These were logged in the BCAM as either internal direct labor (i.e., PMs, SVs, Corrective Maintenance) or as other material costs (e.g., power supplies, circuit cards)
    - Costs were annualized, and benefits start to occur at the Year 5 when the modernization is scheduled to complete
  - Inputted the cost of implementation based on vendor estimates and schedule
    - Implementation costs are spread out between year 0 to 5 based on vendor implementation schedule
  - Net Present Values (NPVs) are calculated using a 6.0% costs of capital, a 30-year investment horizon (plant operating license), and a 4.5% inflation rate

- For more information on the EPRI BCAM model, please see the EPRI Business Case Analysis Model (BCAM) v2.0 report

Benefit Estimate Details

Workload to Support Existing I&C Infrastructure

The current labor hours to maintain each system is outlined below. For this upgrade scope, only I&C Craft labor hours and Other Support hours (in overtime costs) were eliminated. Other work group labor hours were not determined to be eligible for cost savings (e.g., mechanical maintenance, electrical maintenance, engineering, operations).

I&C System	Estimated Annual Labor (Hours)								
	Total (PM, Surveillance, NR)								
	I&C Craft	External Contractor (I&C Craft)	Total I&C Craft	Shift Ops	Mech. Maint. Craft	Elec. Maint. Craft	Reactor Engr.	All Other Support	Total
Nuclear Instrumentation	1,785.6	0.0	**1,785.6**	0.0	7.0	0.0	493.3	103.1	**2,389.0**
Process Protection System	888.5	0.0	**888.5**	0.0	0.0	0.0	3.0	92.8	**984.3**
PAMS Variables	2,101.7	0.0	**2,101.7**	28.7	0.0	0.0	0.7	54.2	**2,185.3**
Hydrogen Monitoring	264.6	0.0	**264.6**	0.0	0.0	0.0	0.0	9.0	**273.7**
Reactor Vessel Level Monitoring System	163.2	0.0	**163.2**	0.0	0.0	0.0	0.0	14.5	**177.7**
Solid State Safeguard Sequencer	881.8	0.0	**881.8**	512.6	88.5	4.9	5.0	76.6	**1,569.4**
Hot Shutdown Panel	25.8	0.0	**25.8**	564.8	0.2	0.0	5.3	18.0	**614.1**
BOP Controls	1,175.5	0.0	**1,175.5**	158.4	21.1	0.0	2.6	172.8	**1,530.4**
Annunciator System	474.4	0.7	**475.1**	0.0	23.4	0.0	0.0	268.0	**766.5**
Flux Mapping System	81.0	1.1	**82.1**	0.0	2.3	0.0	789.0	19.7	**893.1**
Plant Computer	1,012.2	0.0	**1,012.2**	0.0	2.0	0.0	16.0	184.5	**1,214.7**
AMSAC	139.0	0.0	**139.0**	0.0	0.0	0.0	0.0	5.8	**144.8**
Containment Atmospheric Monitoring	1,304.6	0.0	**1,304.6**	0.0	1.0	0.0	0.4	48.1	**1,354.1**
NSSS Process Controls	443.1	0.0	**443.1**	0.0	5.3	0.0	13.7	47.6	**509.7**
Rod Position Indication	249.4	502.5	**751.9**	7.2	0.0	2.0	9.2	40.9	**811.2**
Rod Control System	30.3	0.5	**30.8**	148.3	39.4	0.5	0.9	15.7	**235.6**
Sub-Total	**11,020.7**	**504.8**	**11,525.5**	**1,420.0**	**190.2**	**7.4**	**1,339.1**	**1,171.4**	**15,653.6**
Feedwater Heater Drain Controls	1,272.1	0.0	**1,272.1**	20.9	237.8	0.0	0.0	142.0	**1,672.8**
Total	**12,292.8**	**504.8**	**12,797.6**	**1,440.9**	**428.1**	**7.4**	**1,339.1**	**1,313.3**	**17,326.4**

Benefit Estimate Details

Applicability I&C Upgrade Benefits on Direct Labor Workload

The following table provides an example of how labor benefits were calculated in the BCAM. Each system was evaluated for PMs, SVs, and NRs to estimate how much of the current work could be eliminated.

Task Description	Modernization Effort Providing Benefit	Duration of Activity	% of Activity Eliminated	Comments
PM Activities – AMSAC	Non-Safety	149.7	60%	Eliminated calibrations, power supply replacements
NR Activities - AMSAC	Non-Safety	23	50%	Assumed 50% reduction of NR labor
PM Activities - Annunciator System	Non-Safety	1.78	100%	Eliminated calibration
NR Activities - Annunciator System	Non-Safety	764.6	75%	Assumed 75% reduction of NR labor (almost all torubleshoot alarms)
PM Activities - BOP Controls (non-safety)	Non-Safety	916.8	81%	All BOP PMs. Eliminated calibrations, power supply replacements
NR Activities - BOP Controls (non-safety)	Non-Safety	225.15	50%	Attributed 50% of BOP NR labor for non-safety. Assumed 50% reduction of NR labor
PM Activities - Containment Atmospheric Monitoring	Non-Safety	900.8	37%	Eliminated most calibrations
SV Activities - Containment Atmospheric Monitoring	Non-Safety	0	0%	No SV calibrations show labor hours; used 0
NR Activities - Containment Atmospheric Monitoring	Non-Safety	189.4	50%	Assumed 50% reduction of NR labor (lots of troubleshooting, erractic readings, etc.)
PM Activities - FW Heater Drain Controls	Non-Safety	11140	15%	Eliminated most calibrations, positioner replacement, etc.
SV Activities - FW Heater Drain Controls	Non-Safety	898	21%	Eliminated Calibrations
NR Activities - FW Heater Drain Controls	Non-Safety	411	100%	Eliminated NRs associated with replacement (manometer fluid, controller WOs, etc.)
PM Activities - Flux Mapping	Non-Safety	38.66	100%	Eliminated calibration and power supply refurb
SV Activities - Flux Mapping	Non-Safety	174.29	100%	Eliminated calibration
NR Activities - Flux Mapping	Non-Safety	92	50%	Assume 50% reduction of NR activities
PM Activities - NSSS Process Control	Non-Safety	564.1	35%	Eliminated calibrations, power supply replacements
SV Activities - NSSS Process Control	Non-Safety	18.6	100%	Eliminated calibrations
NR Activities - NSSS Process Control	Non-Safety	156.6	50%	Assume 50% reduction of NR activities
PM Activities - Plant Computer Interface	Non-Safety	47.18	100%	Eliminated all PC activities
NR Activities - Plant Computer Interface	Non-Safety	1181	100%	Eliminated all PC activities
PM Activities - Rod Control	Non-Safety	290	3%	Eliminated calibrations, power supply replacements
SV Activities - Rod Control	Non-Safety	20	0%	Nothing eliminated
NR Activities - Rod Control	Non-Safety	30.9	50%	Assume 50% reduction of NR activities
PM Activities - Rod Position Indication	Non-Safety	531.3	29%	Eliminated calibrations, power supply replacements
SV Activities - Rod Position Indication	Non-Safety	16	0%	Nothing eliminated
NR Activities - Rod Position Indication	Non-Safety	331.7	50%	Assume 50% reduction of NR activities

Benefit Estimate Details

Direct Labor Reductions

The I&C craft and I&C supervisor are considered positions potential for reduction based on the amount of labor hours eliminated. For the planning, scheduling, and clerical work associated with the non-repetitive work, overtime hours were considered as potential for cost savings .

- The total labor savings for the digital I&C upgrade are estimated to be:
  - 6 I&C Craft
  - 1 I&C Supervisor
  - 655 OT Planning hours
  - 166 OT Scheduling hours
  - 663 OT Support hours
  - 1,454 OT I&C Craft hours
- The annual reducible labor savings from the digital I&C modernization is estimated to be $1.4M

Functional Area	WC ID	Work Category	Total Estimated Site Savings (person hrs)	Are Site Savings Harvestable? (Yes/No)	% Harvestable for Site (%)	Total Estimated Site Savings (FTEs)	Total Estimated Added Site Labor (FTEs)
Operations	OP.1.	Perform Field Operations	114	No		0.000	0.000
	OP.2.	Conduct Control Room Operations	-			0.000	0.000
	OP.3.	Support Work Management	-			0.000	0.000
	OP.4.	Perform Planning Activities	-			0.000	0.000
	OP.5.	Perform Support Activities	680	No		0.000	0.000
	OP.6.	Participate in Requalification Training	-			0.000	0.000
	OP.7.	Participate in Initial Training	-			0.000	0.000
	OP.8.	Oversee and supervise department personnel	-			0.000	0.000
Maintenance	MA.1.	Perform Maintenance Activities	9,337	Yes	95%	6.003	0.000
	MA.2.	Support Work Management	166	Yes	0%	0.000	0.000
	MA.3.	Perform Planning Activities	665	Yes	0%	0.000	0.000
	MA.4.	Perform Support Activities	663	Yes	0%	0.000	0.000
	MA.5.	Participate in Training	-			0.000	0.000
	MA.6.	Calibrate Maintenance and Test Equipment	-			0.000	0.000
	MA.7.	Oversee Maintenance Program Implementation	-			0.000	0.000
	MA.8.	Perform Site Services/Commercial Maintenance	-			0.000	0.000
	MA.9.	Perform Reactor/Refuel Services	-			0.000	0.000
	MA.10.	Perform Turbine Services	-			0.000	0.000
	MA.11.	Oversee and supervise department personnel	2,080	Yes	100%	1.000	0.000
Engineering	EN.1.	Perform Engineering activities	-			0.000	0.000
	EN.2.	Monitor and report	-			0.000	0.000
	EN.3.	Perform Support Activities	720	No		0.000	0.000
	EN.4.	Oversee and Manage Engineering Programs	-			0.000	0.000
	EN.5.	Training Activities	-			0.000	0.000
	EN.6.	Perform cyber security activities	-			0.000	0.000
	EN.7.	Oversee and supervise department personnel	-			0.000	0.000
Performance Improvement	PI.1.	Track and Trend Performance	300	No		0.000	0.000
	PI.2.	Perform Support Activities	-			0.000	0.000
	PI.3.	Oversee and supervise department personnel	-			0.000	0.000
Corrective Action Program	CA.1.	Conduct/participate in investigations	240	No		0.000	0.000
	CA.2.	Monitor and manage records	-			0.000	0.000
Procedures	PR.1.	Manage procedure/program documents	-			0.000	0.000
	PR.2.	Oversee and supervise department personnel	-			0.000	0.000
Nuclear Fuels	NF.1.	Core Reload Design	-			0.000	0.000
	NF.2.	Safety Analysis and Non-Reload Safety Analysis	-			0.000	0.000
[illegible]	[illegible]	...egy, Procurement, Budgeting, and	-			0.000	0.000
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[illegible]	[illegible]	...gement and Strategy	-			0.000	0.000
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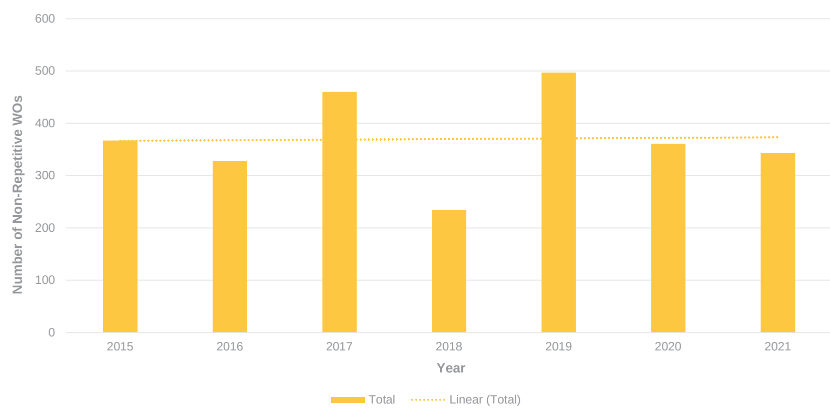
Modernization Effort	Total Harvestable Site Savings (person hrs)	Total Added Site Labor (person hrs)	Total Harvestable Central Savings (person hrs)	Total Added Central Labor (person hrs)	Total Harvestable Site Savings (FTE)
Safety	3,059.48	-	-	-	1.961
Non-Safety	4,900.52	-	-	-	3.039

Benefit Estimate Details

Backlog Benefits

The team also analyzed the number of non-repetitive Work Orders by year from 2015 through 2021 (data was pulled in late 2022, so there was not a full year of data for 2022). The trend remains relatively flat.



Benefit Estimate Details

Summary Costs by System - Materials

The current materials costs to maintain each system is outlined below. Only materials with a last purchase price of over $1000 were evaluated, and a 20% factor was applied to account for items of lesser costs. For this upgrade scope, I&C materials associated with maintaining the current – mostly analog – systems were eliminated. Most of the equipment costs are from power supplies and circuit cards.

I&C System	Estimated Materials Spend					
	Estimated Average Annual Materials Spend ($)	Estimated Recent Maximum of Annual Materials Spend ($)	Estimated % Eliminated Materials	Estimated Average Annual Materials Spend Eliminated ($)	Estimated Recent Maximum of Annual Materials Spend Eliminated ($)	Year of Estimated Recent Maximum Materials Spend
Nuclear Instrumentation	$43,183	$91,283	10%	$4,318	$9,128	2022
Process Protection System	$156,209	$156,209	98%	$153,085	$153,085	2022
PAMS Variables	$82,469	$88,243	83%	$68,449	$73,242	2022
Hydrogen Monitoring	$0	$0	0%	$0	$0	n/a
Reactor Vessel Level Monitoring System	$0	$0	0%	$0	$0	n/a
Solid State Safeguard Sequencer	$21,310	$31,254	34%	$7,245	$10,627	2020
Hot Shutdown Panel	$3,437	$3,437	0%	$0	$0	2022
BOP Controls	$27,147	$35,977	77%	$20,903	$27,702	2019
Annunciator System	$16,388	$29,045	29%	$4,753	$8,423	2020
Flux Mapping System	$104,239	$209,200	65%	$67,756	$135,980	2021
Plant Computer	$8,213	$14,504	100%	$8,213	$14,504	2018
AMSAC	$681	$681	0%	$0	$0	2022
Containment Atmospheric Monitoring	$11,137	$25,963	64%	$7,127	$16,616	2019
NSSS Process Controls	$39,347	$81,827	55%	$21,641	$45,005	2021
Rod Position Indication	$5,165	$20,403	94%	$4,855	$19,179	2022
Rod Control System	$11,099	$11,099	86%	$9,545	$9,545	2022
Sub-Total	**$513,759**	**$767,623**		**$377,891**	**$523,036**	
Feedwater Heater Drain Controls	$319,396	$500,000	100%	$319,396	$500,000	2022
Total	**$833,155**	**$1,267,623**		**$697,287**	**$1,023,036**	

Benefit Estimate Details

Materials Reductions

Materials were evaluated per system to estimate what could be eliminated with the digital I&C upgrade. Percent of material avoided represents the estimates based on average annual material purchases for the system. The CAGR of materials was estimated at 13.5% to 17.5%.

Material	Modernization Effort Providing Benefit	Annual Purchases of Material	Percent of Material Purchases Avoided	Material Price Escalation Rate
FW Heater Drain Controls	Non-Safety	$ 319.4k	94%	15%
Annunciator System	Non-Safety	$ 16.39k	29%	15%
Flux Mapping	Non-Safety	$ 104.24k	65%	15%
Rod Position Indication	Non-Safety	$ 5.17k	94%	15%
Rod Control	Non-Safety	$ 11.10k	86%	15%
Containment Atmospheric Monitoring	Non-Safety	$ 11.14k	64%	15%
AMSAC	Non-Safety	$ .68k	0%	15%
NSSS Process Control	Non-Safety	$ 39.35k	55%	15%
BOP Controls - Non-Safety (50% of BOP Controls Annual Spend for non-safety)	Non-Safety	$ 13.57k	77%	15%
Plant Computer Interface	Non-Safety	$ 8.21k	100%	15%
Process Protection System	Safety	$ 156.21k	98%	15%
Nuclear Instrumentation	Safety	$ 43.18k	10%	15%
Solid State Safeguards Sequencer	Safety	$ 21.31k	34%	15%
PAMS Variables	Safety	$ 82.47k	83%	15%
BOP Controls - Safety (50% of BOP Controls Annual Spend)	Safety	$ 13.57k	77%	15%
BOP Controls - Safety (hot shutdown panel)	Safety	$ 3.44k	0%	15%

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Benefit Estimate Details

Most Beneficial I&C Systems

The following systems were found to be the most beneficial from a labor and material elimination standpoint:

Rank	System	Annual I&C Labor Benefits (hours)
1	Feedwater Heater Drain Controls	2270
2	Plant Process Computer	1228
3	BOP Controls (Safety + Non)	983
4	PAMS	730

Rank	System	Annual Material Benefits ($)
1	Feedwater Heater Drain Controls	$319,396
2	Process Protection System	$156,210
3	Flux Mapping	$104,240
4	PAMS	$82,470

There are several factors that make these systems the most beneficial, including

- System and component obsolescence
- System reliability
- System workload
- Modernization scope

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Appendix

DETAILS BY SYSTEM

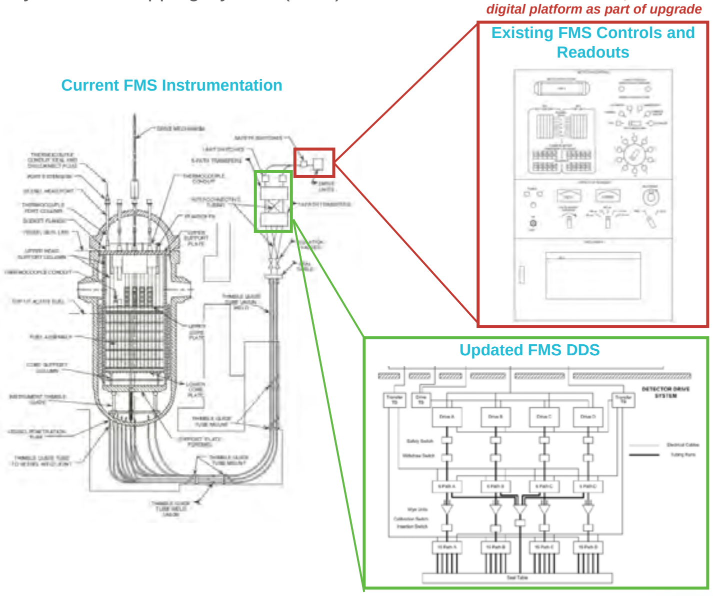
Reference Plant Digital Upgrade Business Case Analysis: Flux Mapping System (FMS)

Scope of the Upgrade

Our Understanding

- The upgrade includes:
  - New electronics for the Flux Mapping Console (FMC) and Detector Drive System (DDS), utilizing existing cabinets, field wiring and terminations
  - Replacement of the current FMC with the LabVIEW™ real-time monitoring and control system
  - Replacement of the drive units and transfer devices in the DDS
- The upgrade does not include any updates to other FMS instrumentation

To be removed and replaced with a digital platform as part of upgrade



Existing drive units and transfer devises to be replaced with newer drive units and transfer devices as part of upgrade

Scope of the Upgrade

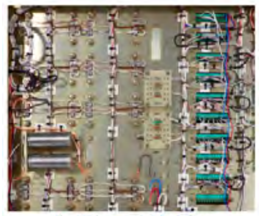
Our Understanding

- The existing NI Protection equipment will be replaced with updated, analog Protection equipment
- The existing NI Wide-Range equipment will be retired?

Examples of Updated, Analog NI Protection Equipment

New source range drawer with factory-installed high voltage cutoff upgrade

Improved card cage with captive screws



New NIS drawers restart the clock on aging wiring and components.

Digital meters upgrade – Factory-installed during a new drawer build

Scope of the Upgrade

Our Understanding

- As part of the upgrade, all components of the existing main control room annunciators, including the Beta Hathaway alarm boxes, will be replaced with one consolidated and integrated alarm system
- All of the sensors and detectors that feed data to the main control room annunciators will remain in place, unless they are being impacted by the upgrade of another I&C system

Current Analog MCR Annunciators

Digital upgrade

Example of Annunciator Lampbox Graphic

Scope of the Upgrade

Our Understanding

- The existing plant computer system will be updated with a datalink to the DCS to integrate additional points. By the end of implementation, The DCS will be used for all plant computer points and controls implemented in earlier phases; thus, the plant computer will be eliminated by the end of the upgrade
- As part of the upgrade, hardwired signals that interface to the plant computer will be removed and sent via the DCS data network and converted to graphic displays
- Plant computer stations will remain in place

Current Plant Computer Interface Example

Digital upgrade

The plant computer is eliminated as part of the upgrade. Operator workstations are still in place, but DCS displays are used for all plant computer points.

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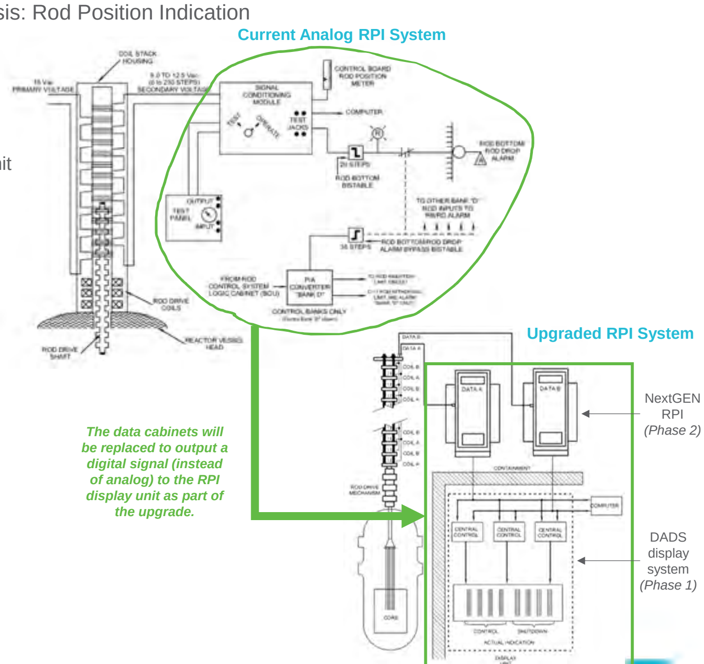
Scope of the Upgrade

Our Understanding

- Reference Plant upgraded Rod Position Indication (RPI) cables in 2006 and the RPI data cabinet electronics for Unit 1. Unit 2 is not upgraded
- Phase 1: Indication display in the control room will be updated to the DADS displays system. The DADS indications linked to the DCS to house rod positions and maintain rod position historical information
- Phase 2: Install Next Generation RPI. At this point, all setup for rod drop testing (e.g., going into containment) is eliminated



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Reference Plant Digital Upgrade Business Case Analysis: Post Accident Monitoring System (PAMS)

Scope of the Upgrade

Our Understanding

- Remove analog PAMS indicators in the control room and replace with digital displays on the safety I&C platform via a PAMS Operator Module (OM)
- PAMS signals will be read by the safety I&C platform and sent via datalink
- If connecting to sensors at the source, only prime standard alignment calibrations will remain; all other calibrations associated with the analog equipment are eliminated
- Hydrogen monitoring integrated into PAMS display

Example Safety Display Installation

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Reference Plant Digital Upgrade Business Case Analysis: Hydrogen Monitoring

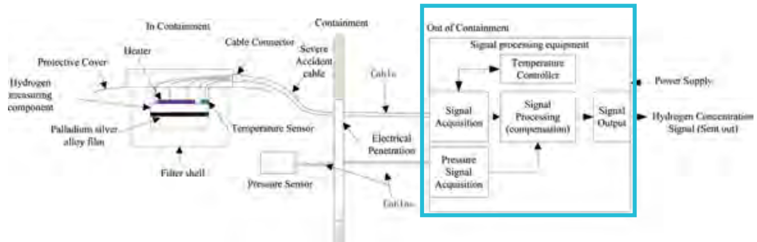
Scope of the Upgrade

Our Understanding

- The upgrade would replace the signal processing electronics portion of the Hydrogen Monitoring system and would interface into the existing sampler (inside containment)
- The new signal processing portion would be integrated into PAMS for display
- The new system will be installed as an associated circuit, powered from the safety cabinet, but will not necessarily be qualified to perform a safety-related function

The digital upgrade would replace only the signal processing portion of the Hydrogen Monitoring system

Example Hydrogen Monitoring System Configuration



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Reference Plant Digital Upgrade Business Case Analysis: NSSS & BOP Controls

Scope of the Upgrade

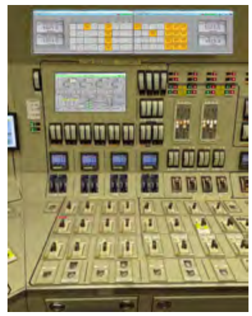
Our Understanding

- Scope includes an upgrade of the 7300 system for both safety controls (migrated to the safety-related digital I&C platform; e.g., Hot Shutdown Panel) and non-safety (migrated to the non-safety DCS)
- Non-safety: All current electronic hardware is being replaced with the upgrade to digital. Physical indications are removed and replaced with touch screen displays (which indications will be determined in later analysis)
- Existing manual auto stations would be upgraded
- Safety: Control room interfaces need further evaluation to determine if future state of controls is software-based or not

Current Analog Control Board

Digital upgrade

Example of Control Board Updates



Reference Plant Digital Upgrade Business Case Analysis: Process Protection System

Scope of the Upgrade

Our Understanding

- Process protection sets are currently analog 7300 cabinets 1-4 and will be replaced with the safety-related digital I&C platform process protection system
- The safety-related digital I&C platform system will be installed in the existing cabinets and retain the existing interfaces to the field wiring and the SSPS
- The field wiring and sensors stay in place and the upgrade is only digitalizing the cabinet to the safety-related digital I&C platform

Scope of the Upgrade

Our Understanding

- The current analog HW-based platform will be replaced with the safety-related digital I&C platform safeguards sequencer system (with SW-based components)
- Assumption that the upgrade eliminates all maintenance associated with the old hardware

Key Questions

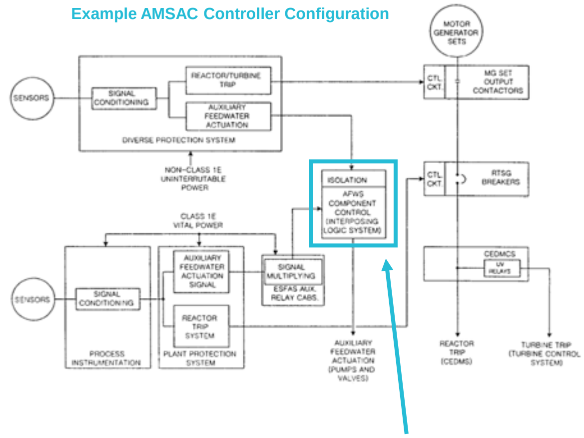
- Is there any mechanical maintenance with the system that would be eliminated with the upgrade (i.e., maintenance on breakers)? No

Scope of the Upgrade

Our Understanding

- Diverse Actuation System (DAS) will replace the current AMSAC digital system with the non-safety DCS

Example AMSAC Controller Configuration



The digital upgrade will replace the existing (old) digital controller with a new digital controller.

Scope of the Upgrade

Our Understanding

- The sensors in the containment building will feed into the non-safety DCS platform
- The current analog indicators for the containment atmospheric monitoring system will be converted to digital and displayed on the DCS platform in the main control room

Scope of the Upgrade

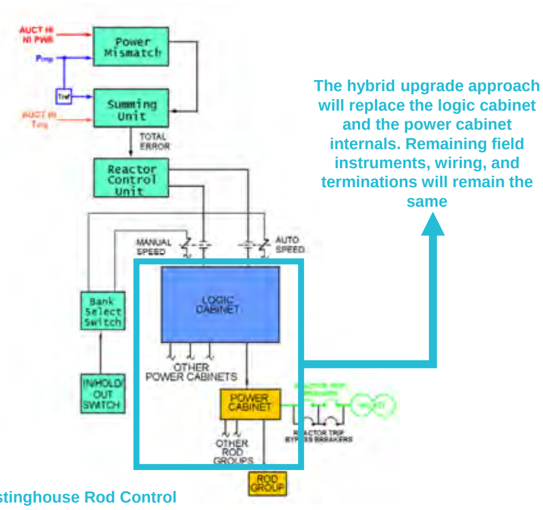
Our Understanding

- New level control instruments are required for each heater; a digital positioner will replace the existing pneumatic positioner on the normal and alternate control valves
- New sensors will be brought in for level and pressure signals
- Manual auto stations, selector switches, level indicators, and annunciator panel will be removed and replaced with soft controls and display graphics in the main control room
- Redundant DCS controllers will be installed in the current BOP cabinets

Scope of the Upgrade

Our Understanding

- The existing rod control system (RCS) is replaced with the Advanced Rod Control Hybrid (not a full digital replacement), leveraging the features and functions of a digital RCS, while maintaining the cabinets, system architecture and power electronics
- The Logic Cabinet is upgraded to a DCS logic controller panel to control and coordinate rod control operations and the Power Cabinet is upgraded with replacement components to enhance the operation of regulating the power to the control rod drive mechanism coils. Field wiring and terminations are not replaced.
- Several open decisions in the control room, such as if the physical controls for control rod drive would remain physical or would be digitized to buttons on graphics



The hybrid upgrade approach will replace the logic cabinet and the power cabinet internals. Remaining field instruments, wiring, and terminations will remain the same

Westinghouse Rod Control System Block Diagram

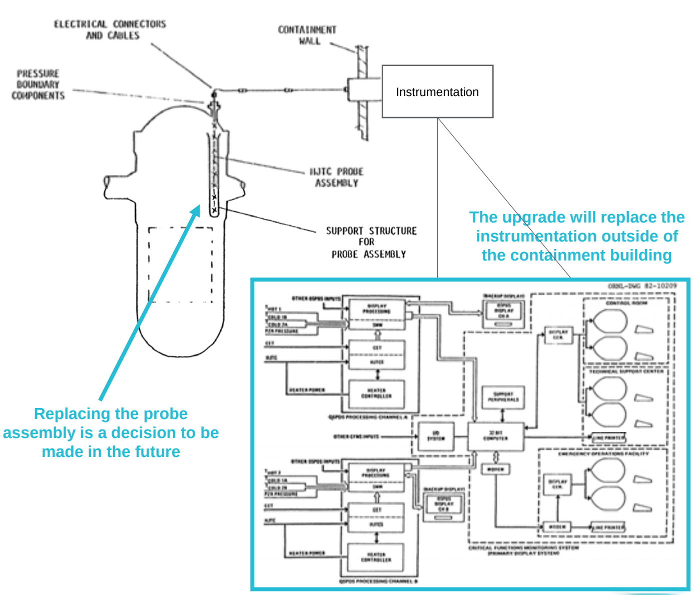
Source: https://www.nrc.gov/docs/ML1122/ML11223A391.pdf

Scope of the Upgrade

Our Understanding

- The Reactor Vessel Level Monitoring (RVLM) signal processing system is on an obsolete digital platform and will be replaced with a new digital platform
- Heater power supply should be replaced as part of signal processing upgrade
- Existing probe can be reused or replaced (decision to be made)
- New equipment installed into existing cabinets
- The upgraded signal processing electronics would be integrated into a single integrated Post Accident Monitoring System (PAMS).

Example RVLM system



The upgrade will replace the instrumentation outside of the containment building

Replacing the probe assembly is a decision to be made in the future

Source: https://technicalreports.ornl.gov/1982/3445605701648.pdf

Scope of the Upgrade

Our Understanding

- Turbine Control and protection system interface was recently replaced at Reference Plant; the system will remain separate but have datalinks into non-safety DCS Interface design decisions will need to be made
- Leading Edge Flow Meter (LEFM) interface – not discussed
- Meteorological Monitoring interface – not discussed

Source: https://technicalreports.ornl.gov/1982/3445605701648.pdf

17. APPENDIX C: DIGITAL INFRASTRUCTURE BUSINESS CASE ANALYSIS BRIEFING PAPER

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Briefing Paper

Author: Paul J. Hunton
August 2023

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Digital Infrastructure Business Case Analysis

Quantifying Expected Savings to be Achieved by Implementation

Context of Research

The Digital Infrastructure (DI) shown in Figure 1 provides a comprehensive, physical, and logical digital foundation to transform the current labor-centric concept of operations to one that is technology centric. This enables efficient and extended operation of the existing nuclear fleet at a much lower total cost of ownership while maintaining or enhancing operational safety and high plant operating capacity factors. The DI consists of multiple levels. Each level is established based upon the functions performed on it and associated DI requirements to enable those functions.

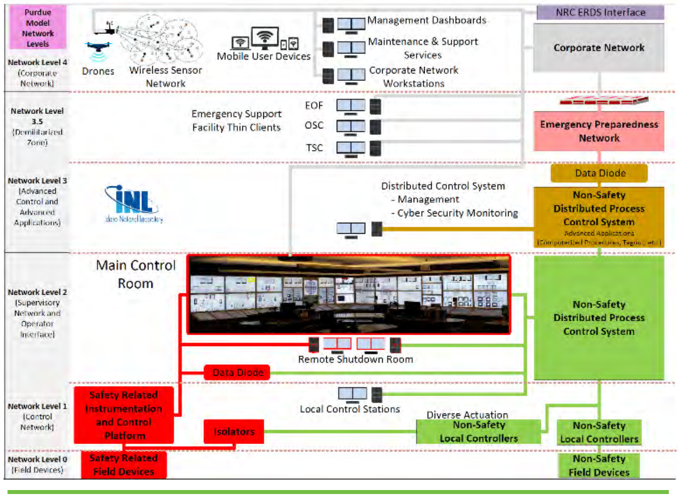

Figure 1. Digital Infrastructure

Summary of Research Efforts Results

The Comanche Peak Nuclear Power Plant (CPNPP) is exploring digital upgrades to address instrumentation and control (I&C) obsolescence problems by deploying a two-platform solution as shown at the bottom of Figure 1 in red and green. CPNPP is also considering deploying Data Architecture and Analytics (DA&A) applications on other levels of the DI. These efforts together are intended to extend the operational life of the nuclear plant in an economically advantageous manner. For this reason, such upgrades need to be evaluated within the envisioned advanced concept of operations shown in Figure 2.

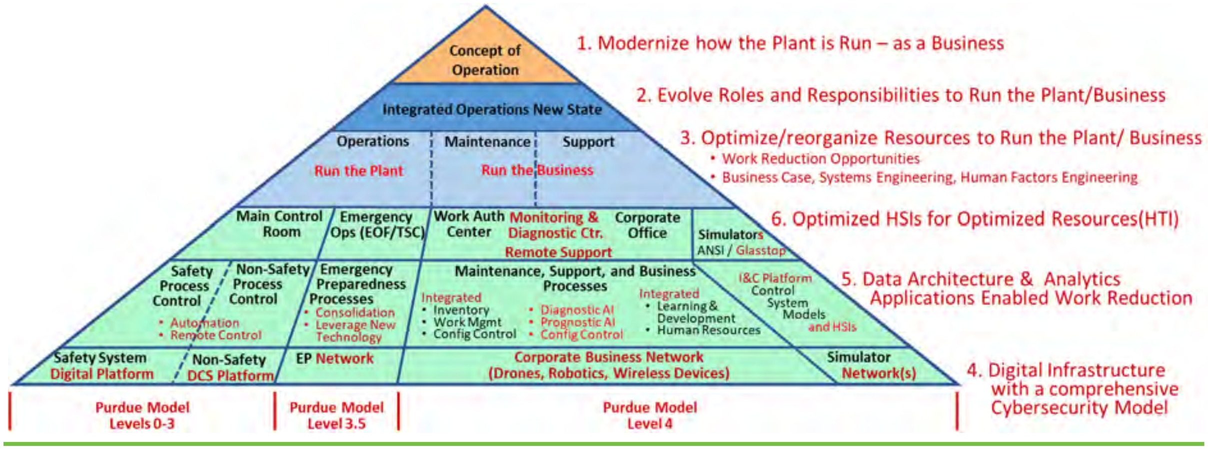

Figure 2. Advanced Concept of Operations

Proposed digital upgrades of existing I&C systems were evaluated using a bottom-up approach to address obsolescence and to provide new capabilities. This included a deep dive into costs associated with existing systems. Digitally enabled work reduction opportunities (WROs) identified by LWRS Integrated Operations for Nuclear researchers working with industry were also evaluated using at top-down approach to identify cost drivers and then to identify DA&A applications to be applied to address them. Select WROs were then applied to CPNPP.

U.S. DEPARTMENT OF ENERGY

Results

Table 1 captures the forecast order of magnitude savings for the digital I&C upgrades, assuming an 8-year implementation timeline. This estimate assumes that a “do nothing” approach will result unplanned outages.

Scenario Baselines	Payback Period	Net Present Value	Rate of Return
30 Years of Continued Operation	17.8 years from start	$74M	8.1%
50 Years of Continued Operations	17.8 years from start	$685M	11.8%

Table 1. Instrumentation and Control System Business Case Analysis Results

Table 2 captures the forecast order of magnitude implementation costs and enabled savings for select DA&A application deployments on the DI within 3-5 years after approval to implement.

WRO Category	WRO(s)	NPV (20 years)	Probability of Positive NPV
Mobile Worker Technology	Automated Troubleshooting	$17.3M	100%
	Remote Plant Support/Remote Assistance		
Condition Based Monitoring	Implement Condition-Based Maintenance	$37.9M	95%
Advanced Training Technology	Operations Training Modernization	$5.9M	87%
	Technical Training Modernization		
	General Training Modernization		
	Training Records Modernization		
Software Application Assisted Business Processes	Automated Planning and Scheduling	$5.9M	75%
TOTAL		**$67M**	**88%**

Table 2. Representative Work Reduction Opportunity Business Case Analysis Results

Next Steps

INL is working to advance DI development and utilization through DA&A application deployments to achieve the benefits identified in Tables 1 and 2 above. To accomplish this, INL is developing an Integrated Operations for Nuclear Work Reduction Opportunity Realization Strategy. This strategy lays the foundation to achieve these benefits by grouping and prioritizing WROs so that specific technologies can be identified and targeted to realize the forecasted business case results. This strategy will be made available in the near future. Specific example technologies that are available for deployment will be identified and described in the realization strategy report. The realization strategy report will provide a roadmap for identification of a more comprehensive set of specific technologies in fiscal year 2024 to achieve business case savings for the benefit of industry.

Acknowledgments

INL would like to thank Comanche Peak Power Company, LLC for agreeing to participate in this research and allowing the research team to use the CPNPP as a basis of this research for industry. This research makes no commitments for Comanche Peak Power Company. ScottMadden Management Consultants were also engaged by INL to enable performance of the business case analysis documented in the research report.

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More on the LWRS Program: https://lwrs.inl.gov/

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