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Light Water Reactor Sustainability Program

Digital Infrastructure Industry Engagement

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EXECUTIVE SUMMARY

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

In Fiscal Year 2021, the Light Water Reactor Sustainability Program's Plant Modernization Pathway produced INL/EXT-21-64580, "Digital Infrastructure Migration Framework" [1]. This research proposes the coordination and integration of digital upgrades at nuclear power plant facilities and the utilities that operate them. This research provides a generic technology strategy and is presented from a technology platform point of view. This platform is ultimately the union of an integrated digital infrastructure (DI) and data architecture and analytics (DA&A) applications selected to operate on it. Specific technologies and software applications are researched, developed, implemented, and then integrated to optimize both the performance of the technology and the capabilities of users who leverage it. The ultimate objective is to enhance safety, reliability, and economic performance such that the result provides much more than the sum of its constituent parts. The selection of these technologies is guided by an Integrated Operations for Nuclear–driven Advanced Concept of Operations and associated business case analyses, which are unit, station, and utility specific.

INL/EXT-21-64580 presents a full-scope DI implementation and lifecycle support recommendations that enable a total plant life of 80+ years. Depending upon a unit's operational lifetime, concepts presented in that report can be applied either individually or as partial implementations.

In fiscal year 2022, Idaho National Laboratory researchers worked to engage the nuclear industry to facilitate implementation of Digital Infrastructure research. These efforts were primarily oriented toward communicating the Digital Infrastructure concept and its associated design tenets, as well as communicating how benefits as presented in INL/EXT-21-64580 can be realized. The intent of these efforts is to influence the industry to adopt the DI Migration Framework as proposed using a tailored approach to enable long-term, sustainable, and profitable operation of existing nuclear units.

This report summarizes outreach efforts to both industry wide organizations and specific utilities. Industry organizations that were engaged including the Pressurized Water Reactor Owner's Group, the Nuclear Information Technology Strategic Leadership group, and Light Water Reactor Sustainability Plant Modernization Pathway Stakeholders. Interactions with specific utilities, including Luminant, Dominion, Constellation, Arizona Public Service, and Southern Company, also occurred. The degree of acceptance of the Digital Infrastructure concept has been high and is having a direct influence on industry direction with regard to digital upgrades at existing nuclear stations. These concepts have also begun to draw interest from vendors pursuing new plant builds.

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ACRONYMS

BCA	Business Case Analysis
CRADA	Cooperative Research and Development Agreement
DA&A	Data Architecture and Analytics
DC	Digital Controls
DCS	Distributed Control System
HFE	Human Factors Engineering
HSI	Human-System Interface
I&C	Instrumentation and Control
HTI	Human-Technology Integration
IA	Infrastructure and Applications
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
ION	Integrated Operations for Nuclear
IT	Information Technology
LWRS	Light Water Reactor Sustainability (Program)
MCR	Main Control Room
NITSL	Nuclear Information Technology Strategic Leadership
NSR	Non-Safety Related
OT	Operations Technology
PM	Plant Modernization
PPS	Plant Protection System
PWROG	Pressurized Water Reactor Owners Group
SR	Safety-Related

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Digital Infrastructure Industry Engagement

1. INITIAL IMPETUS TO DEVELOP THE DIGITAL INFRASTRUCTURE CONCEPT

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

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

Figure 1 was developed as part of the SR I&C Pilot Upgrade Project to provide strategic direction and context for the Limerick effort.

Figure 1. Advanced concept of operations model, with the Limerick Safety-Related I&C Pilot Scope outlined in red.

The basic scope of the SR I&C Pilot Upgrade Project within the advanced concept of operations model is outlined in red in Figure 1 and includes:

- A common, SR, Plant Protection System (PPS) platform that will implement the functions of the following Boiling-Water Reactor systems as applications:
  - Reactor Protection System
  - Nuclear Steam Supply Shutoff System—also referred to as the Primary Containment Isolation System in other Boiling-Water Reactors
  - Emergency Core Cooling Systems
- A Non-Safety Related (NSR) platform to host the existing SR Redundant Reactivity Control System function.

This basic scope was established at the inception of the Pilot. At that time, a tenet was established that both the PPS and the NSR DCS will be expandable. The PPS and NSR DCS will become the target platforms onto which the functions of other obsolete I&C systems are migrated. Over time, the number of diverse I&C systems will be substantially reduced. By digitizing I&C plant information and passing it unidirectionally to other data networks, remote monitoring and data analytics capabilities are enabled to further reduce facility total cost of ownership. These opportunities are reflected in the red text items in Figure 1. More details with regard to this effort are captured in:

- Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade, INL/LTD-20-58490 [2]
- Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations, INL/EXT-20-59371 [3]
- Safety-Related Instrumentation & Control Pilot Upgrade – Initial Scoping Phase Implementation Report and Lessons Learned, INL/EXT-20-59809 [4].

This pilot effort established the foundation for DI research at Idaho National Laboratory (INL). As can be seen at the bottom of Figure 1, digital platforms form the technology foundation of the advanced concept of operations. Applications running on those platforms provide the capabilities to run the enterprise of a nuclear plant and communicate the results to operations centers. This bottom-up view is driven from the top-down by what was then labeled the concept of operations model. This concept of operations model is now identified as Integrated Operations for Nuclear (ION) in INL research. This is discussed in more detail in INL/EXT-20-59537, “Analysis and Planning Framework for Nuclear Plant Transformation” [5]. Strategic objectives are established to support ION, which then require that operational capabilities be provided in order to reduce the total cost of ownership. These operational capability needs drive the necessary capabilities of the Digital Infrastructure Migration Framework.

2. SUMMARIZED DIGITAL INFRASTRUCTURE MIGRATION FRAMEWORK

To expound upon the basic DI concept outlined at the bottom of Figure 1, more extensive research was performed by INL LWRS Plant Modernization (PM) Pathway. This resulted in the generation of INL/EXT-21-64580, “Digital Infrastructure Migration Framework” [1]. INL/EXT-21-64580 is a lengthy document, and for those who have not had an opportunity to review it, its contents are briefly summarized in the remainder of this section as well as in Sections 3–4. If the reader has reviewed that document, it is suggested that the reader skip to Section 5.

The simplified DI generic framework diagram proposed for nuclear, as shown in Figure 2, is adapted from the Purdue Enterprise Reference Architecture that has been in generic industry use since the 1990s.

A more detailed depiction of representative technology and connectivity used in implementing DI is provided in Appendix A. When reading through the balance of this document, it is strongly recommended that the reader have separate copies of both of these depictions available for direct reference to aid in understanding.

The subsections below provide:

- A brief description of the generic architecture with regard to industry standard Purdue Enterprise Reference Architecture Digital Network Levels shown in Figure 2 (Section 2.1)
- A brief description of the quality requirements for digital subsystems shown in Figure 2 based on their function (Section 2.2)
- United States Nuclear Regulatory Commission Cybersecurity Levels shown at the far right in Figure 2 (Section 2.3).

The purpose of the DI is to host the comprehensive set of software applications and associated datasets that provide the necessary functionality to enable ION. This comprehensive set of application and datasets is referred to in this report as Data Architecture and Analytics (DA&A).

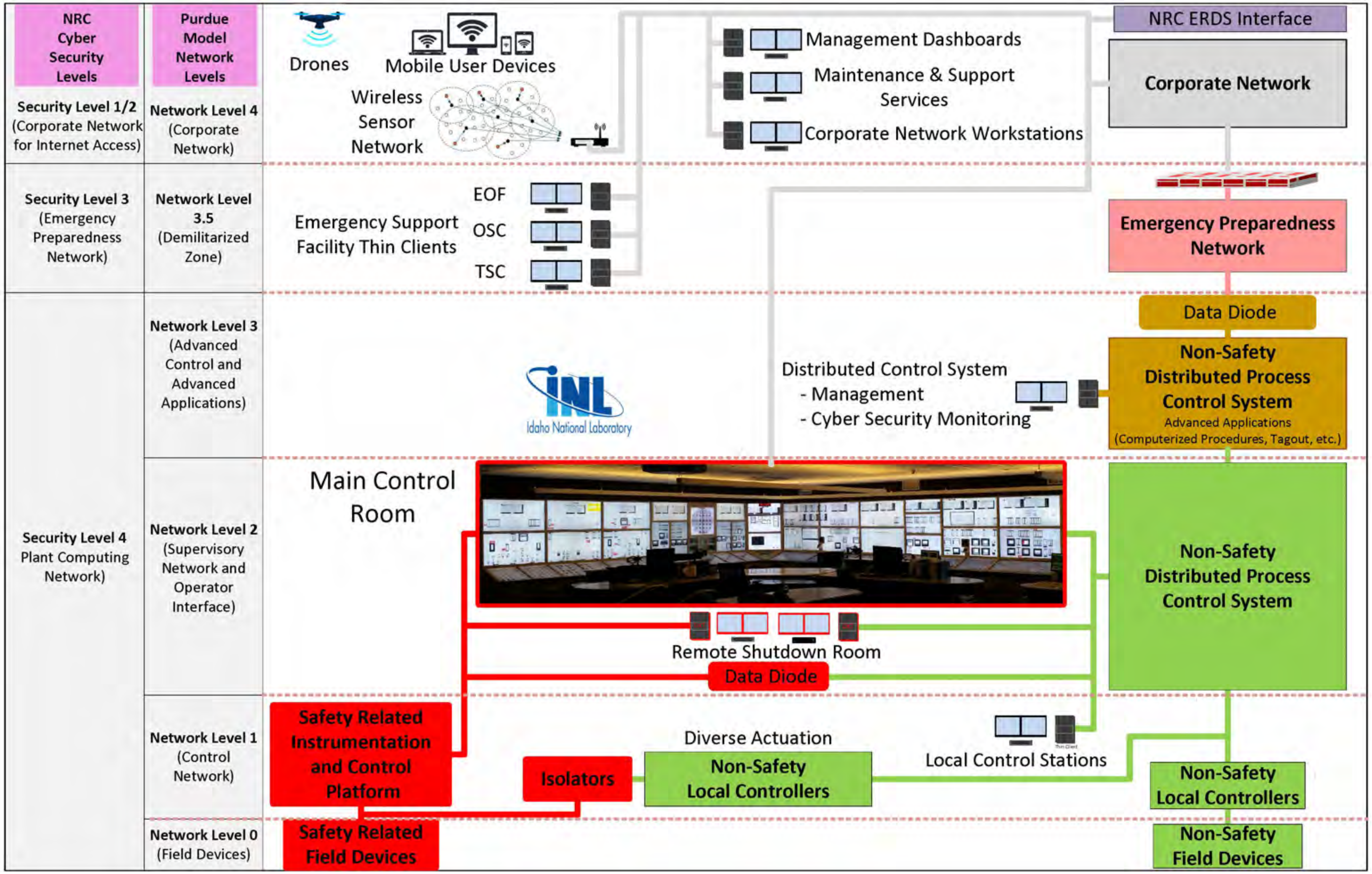

Figure 2. Simplified DI generic framework for nuclear.

2.1 Purdue Enterprise Reference Architecture Levels

INL/EXT-21-64580, Section 2.1 [1] provides a detailed description of each Purdue Network Level (denoted as "Network Level" in the remainder of this document), as shown in Figure 2. A summary of that description is provided below.

- Network Level 0: Field Devices

  SR and NSR field sensors and field device final control elements that connect to, measure, or control plant physical processes.

- Network Level 1: Control Network (Local Control)

  Field hardware and control algorithm execution using:

  - Input and output blocks that receive data from the field and send control signals to Network Level 0 final control elements
  - Control logic modules (controllers) process the data from the input blocks, make logic-based decisions based on automation and control elements within controllers, transmit control signals to the output blocks, present information to Network Level 2, and receive control commands from Network Level 2
  - Local HSIs used for direct local control are encountered at this level when installed.

- Network Level 2: Supervisory Control

  Enables operator to view Network Level 1 monitored processes and provide control signals to those processes. This is the first level that resembles a more traditional information technology (IT) system as leveraged in a DCS. It includes network switches, servers, and HSIs.

- Network Level 3: Advanced Control and Advanced Applications

  Provides additional DCS server capacity with sufficient separation from essential control functions to provide higher level functions. Such applications include computerized procedures and cybersecurity application tools for cybersecurity monitoring.

  This level is considered the top of the control network. It is protected from the higher levels of the network by firewalls and isolated by data diodes. This ensures that intrusion attempts are detected and that no information originating from higher Network Levels can reach the control network and affect controlled processes or modify attributes within the control system.

- Network Level 3.5: Emergency Preparedness Network and Demilitarized Zone

  Hosts emergency preparedness digital capabilities and provides controlled Network Level 4 access to select data stored within the Network Level 3.5 historian through a data buffer, such as a Demilitarized Zone.

- Network Level 4: Corporate Network

  Provides for all the IT services to support operations at the site, including (but not limited to):

  - Connectivity that promotes mass data collection from all digital data sources in the DI from Network Levels 1–3.5 and those collected by wired sources and wireless devices, such as sensors, drones, tablets, and laptops connected at Network Level 4
  - Advanced applications that collect and integrate data sources and perform analyses
  - Presenting data analysis results to utility personnel in support facilities to enable efficient and accurate planning and decision-making across the enterprise

- Enabling capabilities, such as the centralization of support staff in locations remote from a nuclear plant site or the outsourcing of support activities to third parties through either the utility Corporate Network or the internet, to improve efficiency and lower plant total cost of ownership
- Providing continued support of the Nuclear Regulatory Commission Emergency Response Data System interface.

2.2 Digital Systems: Differentiation of Quality Requirements

INL/EXT-21-64580, Section 2.2 [1] provides detailed information with regard to applying appropriate quality controls to each level of the digital infrastructure commensurate with its function and associated requirements for systems that perform those functions. It differentiates between SR I&C systems and NSR I&C systems domains at Network Levels 0–3. It then differentiates the quality requirements for Network Level 3.5 (Emergency Preparedness) and Network Level 4 (Corporate Network). The key concept communicated in this section of INL/EXT-21-64580 [1] is that, while the entire DI needs to be thought of as one aggregate system of separate domains and levels, each domain and level has unique quality requirements that govern each. These need to be clearly understood. While the generic purpose of the quality requirements is the same across all levels, bleeding requirements between domains and levels (e.g., applying SR I&C quality requirements onto NSR I&C systems) is inappropriate and can contribute to significant and unnecessary scope growth and associated cost increases and schedule delays.

2.3 U.S. Nuclear Regulatory Commission Defined Cybersecurity Levels

INL/EXT-21-64580, Section 2.3 [1] provides detailed information with regard to applying appropriate cybersecurity controls to each Network Level of the digital infrastructure commensurate with its function and associated requirements for systems that perform those functions. It relates the cybersecurity levels as defined by 10 CFR 73.54, "Protection of digital computer and communication systems and networks" [6], to the Purdue Network Levels as shown in Figure 2 and Appendix A. The key concept communicated in this section in INL/EXT-21-64580 [1] is that, while the entire DI needs to be thought of as one aggregate system of separate levels, each Purdue Network Level has unique cybersecurity requirements that govern each and need to be clearly understood. While the generic purpose of the cybersecurity requirements is the same across all network levels, bleeding requirements between levels (e.g., applying I&C cybersecurity requirements to Corporate Networks) is inappropriate and can contribute to significant and unnecessary scope growth and associated cost increases and schedule delays.

3. DESIGN TENETS AS APPLIED TO THE DIGITAL INFRASTRUCTURE MIGRATION FRAMEWORK

To establish a consistent direction in the development of a nuclear DI, Section 3 of INL/EXT-21-64580 [1] provides a set of Design Tenets for the DI Migration Framework. These tenets support the technical development and sustainability of the DI as well as the ION objective to enable the long-term economic viability of the industry. Each of the tenets is briefly summarized below.

1. **Define the New State.** Bound an enabling set of digital modifications to enhance safety, reliability, and economic performance such that the result provides much more than the sum of its constituent parts. This elucidates the intended result of the digital modernization with specificity. It is intended to not only bound the scope of the effort but also provide a visible target of enabled capabilities and features (e.g., a largely digital main control room [MCR], nuclear unit, and fleet Power Optimization Center such as the one developed by Luminant [https://www.luminant.com/poc/]).

2. **Ensure the New State is not an End State.** This DI Migration Framework is formulated to support a full-scope, enterprise-wide DI modernization to enable subsequent license renewals to operate existing nuclear plants for a total of 80–100 years. It supports technology refreshes to keep it evergreen and capable of accepting new applications while protecting intellectual property investments (legacy applications and functionality).

3. **Use stable vendor technology with deep and worldwide market penetration.** This includes ensuring that DI vendors have demonstrated the backwards compatibility of their new systems to their legacy system and that vendors have a fully developed intellectual property migration strategy to harvest software application intellectual property when upgrading DI equipment and operating systems.

4. **Create a multi-Network Level DI that:**
   a. Optimizes software application functionality allocation based upon use (e.g., control system software applications are allocated to the proper Network Level)
   b. Controls data flows between Network Levels to permit efficient mass collection, aggregation, storage, trending, correlation, and analysis of all digitized data across the enterprise
   c. Tailors the application of regulatory and other requirements (e.g., quality, reliability, and cybersecurity requirements) based upon functions performed and the placement of those functions within each DI Network Level to minimize implementation and lifecycle costs.

5. **Leverage new digital system capabilities to capture and correlate data from throughout the Digital Infrastructure.** Reduce MCR workload, eliminate remote stations, and improve plant performance and optimize maintenance with trending, diagnostic, and prognostic capabilities.

6. **Support an integrated human factors engineering (HFE) strategy.** Apply a coordinated strategy to address NUREG-0711, "Human Factors Engineering Program Review Model" [7] expectations across multiple phases to achieve the New State, following consistent objectives to eliminate rework.

7. **Leverage the enhanced reliability and availability of digital I&C technology by:**
   a. Use proven operating systems, programming tools, and self-diagnostics to reduce the potential for I&C platform–induced maloperation
   b. Leverage available redundancy and graceful degradation capabilities of modern systems to enable capabilities such as online platform upgrades.

8. **Standardize designs to the maximum extent practical across the entire DI by:**
   a. Using standard building blocks to support supply chain consolidation
   b. Using standard development tools and design processes to reduce costs to implement and maintain the DI and DA&A software applications
   c. Employing one, overarching cybersecurity defensive strategy for the DI and hosted software applications with controls tailored toward specific requirements for each Network Level.

9. **Consolidate disparate I&C systems on two platforms (separate SR and NSR DCS platforms).** This reduces operations and training, parts inventories, supply chain challenges, and standardizes I&C designs going forward to lower total cost of ownership. Commercially available NSR I&C platforms support design redundancy in a way that allows for individual platform part replacements and individual software updates at power. This same redundancy enables full platform technology refreshes at power.

10. **Provide a standard, shared, safety-qualified HSI architecture**. Such an HSI architecture as proposed in Reference 1 would that provides for a flexible solution for the MCR that supports both the interim states and envisioned hybrid New State for the MCR.

11. **Leverage vendor-provided system self-diagnostics**. Self-diagnostics can be used to eliminate technical specification surveillance requirements, calibrations, and identify failures down to the field replaceable unit.
12. **Enable a design once, build many approach.** Methods and techniques described in this report for the development of the DI and DA&A applications along with human-technology integration (HTI) efforts are directly transportable to all nuclear sites within a utility enterprise. By leveraging them in this way, the maximum benefits afforded by ION can be achieved, particularly for a utility that operates a fleet of nuclear power plants. An example of the potential value of employing concepts similar to ION in the North Sea oil and gas industry is provided in Section 3.1.1 of INL/EXT-20-59537 [5]. Forecasted benefits for this oil and gas industry example are in the tens of billions of dollars with a 10× return on investment.

4. PURDUE MODEL DIGITAL INFRASTRUCTURE LEVELS AND CAPABILITIES

To promote a comprehensive understanding of the DI, the layers and their associated functionality are presented in Section 4 [1] from the bottom up with discussion of the connectivity between each successive layer. It should be noted that significant benefits can be realized through a top-down or partial implementation of the DI.

The purpose of Section 4 [1] is to augment the summary information concerning functionality at each Purdue Network Level given in Section 2.1 by:

- Providing a general overview of DI technology at each Network Level for a nuclear plant
- Describing the configuration of each Network Level to support its function and hosted DA&A software applications
- Generically describing the capabilities of envisioned DA&A software applications at each Network Level to maximize the use of digital technology to support ION, including the capabilities available in industry and those being researched by INL as part of the LWRS PM Pathway
- Describing the intended portability of software-based DI configuration and hosted software applications to support DI obsolescence management at each Network Level
- Discussing HSI resources at each Network Level.

The information in Section 4 [1] is detailed and presented over 25 pages in that report, so the reader is referred there for details in this area.

5. OUTREACH TO INDUSTRYWIDE ORGANIZATIONS AND UTILITIES

5.1 Pressurized Water Reactors Owners Group Engagement

The mission of the Pressurized Water Reactor Owners Group (PWROG) is to improve the competitiveness of member plants through the cost-effective resolution of issues common to more than one member and to provide a superior regulatory interface in support of member activities. This mission will be accomplished by maintaining a focus on the following objectives:

- Support safe and reliable plant operations
- Provide an effective regulatory interface
- Effectively leverage the resources of its members, including Westinghouse and Areva NP, which is a major international player in the nuclear energy market recognized for its innovative solutions and value-added technologies for designing, building, maintaining, and advancing the global nuclear fleet

- Provide a forum for joint discussions and resolution of issues common to more than one member
- Provide a mechanism for allocating costs and resources relative to the resolution of owners group issues, whether performed by Westinghouse, Areva NP, or others
- Provide an effective interface with Nuclear Energy Institute, Electric Power Research Institute, Institute of Nuclear Power Operations (INPO), and other industry groups and owners groups on industry issues
- Share best practices and lessons learned among U.S. and international members.

PWROG members became aware of DI research through regular interactions with LWRS Program PM Pathway personnel after INL/EXT-21-64580 [1] was issued. This facilitated an initial virtual presentation of the DI concept to select members of the PWROG on January 17, 2022. This presentation piqued the interest of the Westinghouse Program Director for the PWR I&C and Rod Control Working Groups.

As a result of the January DI presentation, coupled with PWROG interest in other LWRS PM Pathway activities, the DI concept was included in a larger PM Workshop hosted at INL on March 2–3, 2022. This workshop drew diverse industry participation and provided a path for future collaborations with industry. Over 14 attendees from the PWROG, Southern Company, and Sargent & Lundy attended this event. This venue provided the opportunity to present DI research in a more dynamic environment in conjunction with other PM Pathway research, Specific discussions were held regarding how DA&A applications and human-system interfaces (HSI) are integrated within all levels of the DI to maximize their combined utility to enhance nuclear plant safety, reliability, and economic performance such that the result provides much more than the sum of its constituent parts. Breakout discussions were held with workshop attendees to discuss specific enabling technologies such as application of virtualization within the DI. Virtualization enables harvesting intellectual property investments when updating DI building blocks, such as hardware and operating system software, as required to address obsolescence.

As a direct result of this effort, the PWROG requested that a LWRS PM Pathway DI researcher travel to Pittsburgh, PA to present the DI research as documented in INL/EXT-21-64580 [1] at its PWROG I&C Working Group meeting. A detailed presentation lasting several hours was given on July 18–19, 2022. Feedback on this presentation was very positive. In recognition of these efforts, the head of the PWROG agreed to present at the LWRS PM Pathway Stakeholder Engagement Workshop, as discussed in Section 6 below.

The DI presentation made at the PWROG was the most exhaustive presentation produced for this research. It envelopes the DI content presented to the PWROG as well as that presented to Nuclear Information Technology Strategic Leadership (NITSL) (Section 5.2) and at the 2022 LWRS PM Pathway Stakeholder Engagement Workshop. This presentation is captured in Appendix B.

5.2 Nuclear Information Technology Strategic Leadership Group Engagement

NITSL is a nuclear industry group of all nuclear generation utilities that exchange information related to IT management and quality issues and brings together the leaders in the nuclear utility industry and regulatory agencies to address the issues involved with the IT used in nuclear-powered utilities. NITSL maintains an awareness of industry IT-related initiatives and events and communicates those events to the membership. The vision of the NITSL organization, as an INPO Topical Area, provides a forum for leadership and strategic guidance for the consistent and efficient application and support of information technologies, including business and plant systems that enable the nuclear power industry.

In the fall of 2021, INL DI researchers became aware of an opportunity to present the DI Migration Framework concept to members of the NITSL Infrastructure and Applications (IA) Committee as part of a monthly series of lunch and learn presentations. To facilitate the lunch and learn, contact was made with the chairperson for this committee, who is also the Manager of IT, Business Intelligence & Data Analytics at the Palo Verde Generating Station run by Arizona Public Service. An overview presentation of the DI concept was provided to promote understanding and gauge whether there was interest in the larger IA Committee hearing more. The overview presentation was well received but determined to be much larger in scope than what could be covered during a lunch and learn session.

Over several months, INL researchers continued to have conversations with both the NITSL IT Committee chair and Digital Controls (DC) Committee chair (Nick Bryant, who is now the NITSL Communications Officer and an IT Engineer for Southern Company at the Farley Nuclear Generating Plant) about how to best present this concept to NITSL stakeholders. These conversations determined that the optimal venue would be during the 48th NITSL Conference, “Harboring Together during Industry Challenges,” during the week of July 18, 2021.

For the NITSL Conference, LWRS DI researchers were invited to present on two different research subjects. The first presentation focused on research efforts from 2019 as captured in INL/EXT-19-55799, “Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries,” [8]. The second focused on the DI Migration Framework [1]. Each of these is summarized in the subsections below.

5.2.1 Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries

INL/EXT-19-55799 [8] presents advancements that have been made by non-nuclear I&C vendors and potential savings that could be realized by their optimized nuclear industry application. This is directly complementary to the DI Migration Framework. INL/EXT-19-55799 also goes into detail regarding NSR DCS shown in green in Figure 2.

To promote understanding and bound the initial scope for the effort described in INL/EXT-19-55799 [8], a pilot vendor and an associated pilot implementation were chosen as an integrated presentation example for illustration. The pilot implementation included the installation of a standard, NSR DCS platform in four nuclear units. The intent of the pilot effort was to develop and install a target, NSR DCS as part of a program to address I&C obsolescence. INL/EXT-19-55799 [8] presents techniques developed by vendors to enable such an upgrade and potential methods to employ them in a nuclear industry context. The objectives of such an effort are to minimize the utility cost both to upgrade the systems and to put the systems into a repeatable upgrade cycle for future obsolescence management. This enables the utility to maximize the benefits of an expanded use of their DCS as part of a larger plant strategy to eliminate obsolete I&C systems, reduce operating and maintenance costs, and improve operational performance through digitalization.

Attributes of the solution proposed in the research captured in INL/EXT-19-55799 [8] include the:

1. Selection and use of a fully developed, vendor-supported DCS solution with a fully developed strategy for future technology upgrades.
2. Willingness of the vendor to support knowledge transfer to the utility.
3. Migration of functions of legacy I&C systems to the new DCS and retirement of the legacy equipment.
4. An enhanced performance profile through the application of advanced features, such as system diagnostics, fault tolerance, graceful degradation, and improved HSIs.
5. Full integration of the technical solution within the simulators of the impacted nuclear units, which is a technology multiplier that allows for many new capabilities.

For more insight into some of the strategies employed to maximize benefit while minimizing overall project costs, see Figure 3–Figure 5.

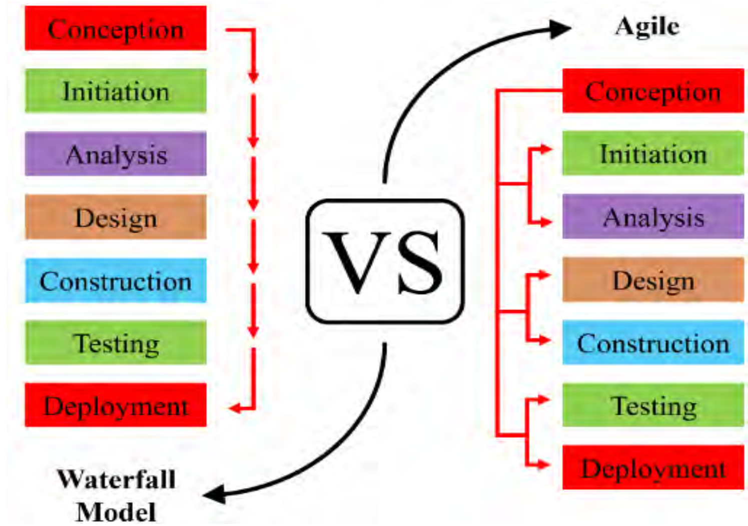

Figure 3. Agile development process vs the waterfall method.

While both processes shown in Figure 3 share the same major steps, the disadvantages of the waterfall process are that it is linear and that it assumes system engineers fully understand the system requirements from the start. Another disadvantage is that such system requirements are envisioned as free standing and that systems built to satisfy them are created from scratch or modified to conform to them. The agile process is more iterative and flexible than the waterfall process. It is also more adept in accepting the attributes of a mature product as a design input to meet the need.

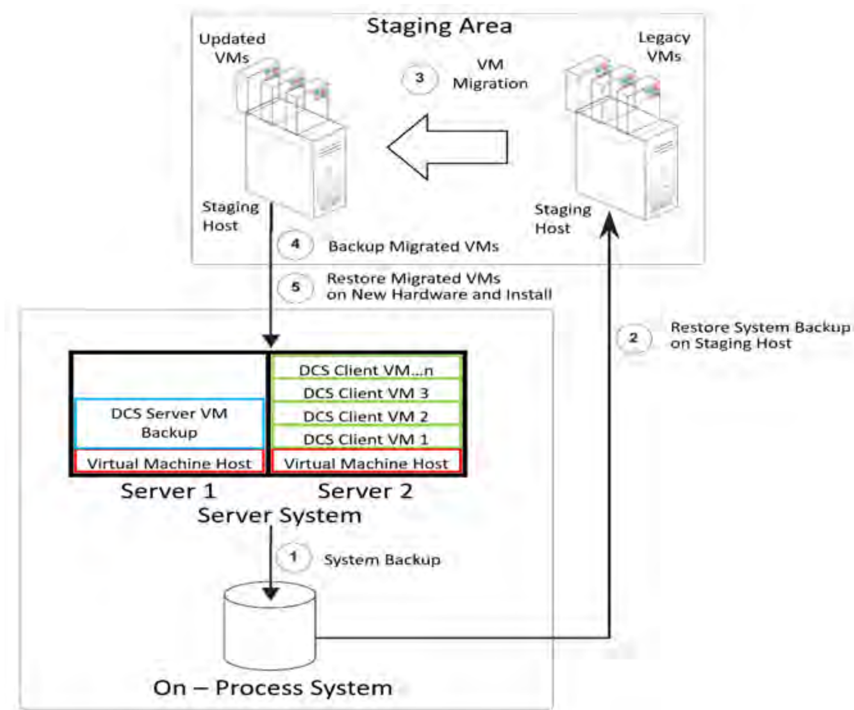

Figure 4. On-process DCS technology updates.

Another key finding in INL/EXT-19-55799 [8] was that DCS modernization is driven by both hardware and software obsolescence. To eliminate the analog obsolescence risks, digital solutions must employ an obsolescence mitigation strategy that leverages incremental upgrades and technology replacements over time in order to ensure that the new technologies do not present a greater obsolescence risk than the original plant systems currently in operation. Such an obsolescence mitigation strategy is shown in Figure 4. A key benefit of such a mitigation strategy coupled with a redundant system design is that the new system does not require the plant to be in outage for an upgrade to the system. This capability is enabled by on-process migration capabilities, as shown in Figure 4, which leverage the redundancy of the DCS to uncouple upgrades from plant outages. Work done during plant outages is more costly and presents schedule risks to the operational cycle of the plant.

Figure 5. Leveraging glasstop simulator for I&C design and procedure development in addition to operator training.

For the pilot project presented in INL/EXT-19-55799 [8], glasstop simulators were implemented at multiple sites. An example is shown in Figure 5. These simulators operate in a manner logically identical to the simulators certified for training and qualification at each unit. The difference is that the operating panels in the glasstop simulator control room mockups were implemented with electronic touch screens that fully emulate actual plant control room panels.

The infrastructure investments made in glasstop simulators and their ability to directly run HSI displays and control logic as implemented on the DCS provide a vehicle to assist future function migrations to the DCS. The glasstops can support design activities such as (but not limited to):

- Rapid prototyping to assess control room console changes electronically early in the design
- For indication and alarm functions to be migrated to the DCS in the control room, these console and display changes could be fully developed for the plant function, directly loaded on the glasstops, and assessed for proper human factors
- Provide early functional assessments of control logic as a risk mitigation.

In nearly all cases, no additional hardware or software purchases are required to support these capabilities beyond periodic system hardware and software upgrades. Simulator DCS hardware and software upgrades should be planned to synchronize with the upgrade of the production DCSs installed in the operating units at each site.

The long-term success of these upgrades also depends on the development of a DCS platform long-term obsolescence mitigation plan. Ideally the vendor would be contracted as a partner for continued and sustained lifecycle management. By doing this, the vendor has a vested, long-term interest in the success of the project. This model of contracting is atypical in the nuclear industry, as normal contracting practices usually follow more of a fixed price structure through initial implementation. This provides no incentive for the vendor and the utility to realize any benefits through minimizing lifecycle costs when addressing inevitable DI-related hardware and operating system software obsolescence.

The pilot utility's experience in deploying a modern NSR DCS demonstrates that, by using innovative techniques and leveraging vendor experience, modern I&C technology used outside of the nuclear industry can be successfully installed in nuclear plants and incorporated into their simulators. Efforts performed during this activity, such as utility training on the vendor system, performing vendor audits, and performing analyses such as a failure modes and effects analysis and a software hazard analysis, helped validate the deployment of this technology in nuclear. These efforts, along with effective utility and vendor teaming, built confidence and enabled the initial implementation. These efforts are foundational and must be sustained to enable subsequent technology migrations.

Increasing nuclear industry confidence in leveraging I&C vendor techniques and resources over time can drive organizational changes that further reduce overall I&C lifecycle support costs and support the long-term economic viability of nuclear power.

For the presentation that was used to present the information in this subsection above, see Appendix C.

5.2.2 Digital Infrastructure

This presentation focused on the 2022 INL Digital Infrastructure Migration Framework Report [1]. It is notable that this presentation was made to a combined session of both the NITSL IA Committee and the DC Committee. It is an explicit objective of LWRS DI research to bring separate groups like these together (to also include utility IT personnel) to think of these different areas as being connected domains within in the one, consolidated, and optimized DI, as proposed in INL/EXT-21-64580 [1].

As this presentation was made essentially at the same time as that made to the PWROG and discussed in Section 5.1, very similar information was presented. The content of the DI as presented to the PWROG as captured in Appendix B envelopes that presented to NITSL. For this reason, the DI slides presented at the NITSL meeting are not provided as they would be duplicative.

5.2.3 Conclusions from NITSL Presentations

The discussions with the audience during both of the presentations centered around how the content of both INL/EXT-19-55799 [8] and INL/EXT-21-64580 [1] could be implemented for a given plant or utility structure and how this research could be leveraged to present the case for modernization to utility and plant management. This indicates that utilities participating at the conference are considering, planning, and performing a host of digital modernizations. The NITSL IA and DC Subcommittee Chairs together determined that the DI concept was worthy of presenting to a combined meeting of both subcommittees as it provides an overarching example architecture to focus these upgrades to enhance safety, reliability, and economic performance such that the result provides much more than the sum of its constituent parts.

Feedback from NITSL participants was very positive, and comments reflected that the research would have an impact on future digital modernization efforts. Example comments included:

- Having an outline of a standard infrastructure, including:
  - A historian
  - Control systems
  - Monitoring systems
  - A partner in the industry to help in patching and maintenance, along with an upgrade strategy, is a good plan
- This was a good, interesting presentation that will spin off additional conversations within future Digital Controls Committee discussions.

These presentations greatly enhanced the NITSL sessions within this vital area of the conference by providing technical content and furthering the efforts of the focus area within these elements.

In recognition of these efforts, the head of NITSL Digital Controls Committee (and now the Communications Officer for NITSL) agreed to give a presentation at the 2022 LWRS PM Pathway Stakeholder Engagement Workshop as discussed in Section 6.

5.3 Utility Engagement

Even before the issuance of the DI Migration Framework Report [1], its contents were previewed to the industry during the 2021 LWRS PM Pathway Stakeholder Engagement Workshop. As a result of that presentation and subsequent report issuance, INL has had many interactions with utilities where its application has been discussed. Several of the more significant interactions are described below.

5.3.1 Luminant—Comanche Peak

INL has established a relationship with Scottmadden and Associates in performing business case analyses for I&C upgrades. Scottmadden collaborated with INL DI researchers to develop a detailed methodology for performing business cases analyses for upgrades. That methodology was then used to perform a business case analysis for the SR I&C upgrade currently being pursued at Constellation's Limerick Generating Station. The methodology and results produced by this effort are captured for industry use in INL/EXT-20-59371, "Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations" [3].

Scottmadden, through its interactions with Luminant, became aware of efforts at Luminant to perform a suite of digital upgrades at the Comanche Peak Nuclear Power Plant. Scottmadden then contacted LWRS DI researchers about the applicability of the DI concept to digital upgrades at Comanche Peak and the need to focus this upgrade effort using the DI concept. Three-way communications between Comanche Peak, Scottmadden, and LWRS DI researchers then commenced. This organic activity has since blossomed into a formalized effort to organize digital upgrades at Comanche Peak by leveraging the DI concept and to guide it by performing a business case analysis on the envisioned upgrades to justify their implementation. A nondisclosure agreement has been executed between Comanche Peak, Scottmadden, and INL to facilitate this effort. Efforts to establish a cooperative research and development agreement (CRADA) between INL and Comanche Peak is in progress. LWRS research funding has also been identified and allocated to this effort as a pilot for the industry. FY-22 research efforts in this area are focused on establishing the scope and methodology for performing this business case analysis for DI implementation. Planned FY-23 research efforts are to perform a business case analysis to bound the scope of the initial DI implementation at Comanche Peak. The proprietary, detailed results of this effort will be used for this purpose. A nonproprietary research report is also planned for release to the larger industry in 2023 to promote similar activities elsewhere.

As this work activity and the associated relationships have become more established and formalized, LWRS DI researchers requested that Comanche Peak provide a presentation of this effort at the 2022 LWRS PM Pathway Stakeholder Engagement Workshop, as discussed in Section 6.

5.3.2 Dominion

INL has CRADA in place with Dominion Energy to support their digital modernization efforts at the Surry and North Anna Nuclear Power Stations. INL activities in this area to date have been focused HFE efforts associated with MCR upgrades associated with this digital modernization. Dominion's vision for the MCRs at Surry and North Anna are to leverage digital technology to the maximum extent practicable to maintain and improve operator and plant performance. This was communicated by Dominion during the FY-21 LWRS PM Pathway Stakeholder Engagement Workshop. Since that time, DI researchers have had multiple discussions with Dominion regarding applying the DI Migration Framework concept across both stations to achieve the maximum aggregate benefit of these planned digital modernizations. As of the writing of this report, an additional discussion of how to apply LWRS PM Pathway research to these upgrades has been requested by the manager of subsequent license renewal I&C projects based upon the presentations given during the 2022 LWRS PM Pathway Stakeholder Engagement Workshop.

5.3.3 Constellation

INL has had a CRADA in place with Constellation Energy for several years to support their SR I&C upgrade project at the Limerick Generating Station. In many respects, the Limerick I&C upgrade project formed the foundation of the DI Migration Framework research, as described in Section 1. INL is currently providing significant support for this upgrade in the HFE area. It is INL's understanding that Constellation's long-range plan includes a larger set of digital upgrades at Limerick, but their current focus is on the SR I&C upgrades.

6. 2022 LWRS PLANT MODERNIZATION PATHWAY STAKEHOLDER ENGAGEMENT WORKSHOP

The INL PM Pathway hosted its annual Stakeholder Engagement Workshop on August 16–18, 2022. The primary goal of the workshop was to share INL PM Pathway progress with the nuclear industry in both research and utility-directed work and support the LWRS mission. This workshop included five sessions that are listed below, along with the basic objective and goal of each session:

1. LWRS PM Overview

   Goal: Extend the life and improve the performance of the existing fleet through modernized technologies and improved processes for plant operation and power generation

2. ION

   Goal: Leveraging technology innovation and advanced business process automation to sustain the nuclear fleet

3. DI and I&C

   Goal: Provide an optimized, plantwide, digital infrastructure modernization framework to host digital transformation

4. HTI

   Goal: Provide an assessment methodology to enable nuclear industry to adopt advanced digital capabilities (control system automation, artificial intelligence, machine learning, and modern HSIs)

5. DA&A

   Goal: Eliminating unnecessary operating and maintenance costs by automating and optimizing critical support activities.

The relationship of the four research areas being collectively pursued by the LWRS PM Pathway is shown in Figure 6.

Figure 6. Plant modernization research objectives and goals.

It is key to note that DI provides the foundation to enable plant modernization. All other PM Pathway activities rely on the DI to host DA&A applications and support HTI. ION and associated business case analyses (BCAs) justify the application technology to enhance safety, reliability, and economic performance such that the result provides much more than the sum of its constituent parts. DI research has created and demonstrated the methodologies to perform these BCAs as captured in INL/EXT-20-59371 [3].

The subsections below summarize the specific DI presentations provided during the workshop and the roundtable discussion that occurred afterward.

6.1 Digital Infrastructure Stakeholder Session Presentations

A total of four presentations were provided during the DI Stakeholder Session. The agenda for the session is provided in Figure 7.

Time (EDT)	Topic	Speaker - Organization
14:00-14:05	Introductions	Paul Hunton, INL
14:05-14:25	Research Overview, Objectives, Status, Challenges, New State	Paul Hunton, INL
14:25-14:45	A PWR Owners Group Perspective on Digital Infrastructure	Mike Powell, PWR Owner's Group
14:45-15:05	A Nuclear IT Strategic Leadership (NITSL) Perspective on Digital Infrastructure	Nick Bryant, NITSL Digital I&C & Southern Company
15:05-15:25	Business Case Analysis of Digital Infrastructure at Comanche Peak	Taylor Smith, Luminant Comanche Peak
15:25-15:50	Roundtable/Q&A Discussion	All
15:50-16:00	Session Wrap-up	

Figure 7. Digital infrastructure (I&C) stakeholder workshop session agenda.

6.1.1 Plant Modernization Pathway Digital Infrastructure Overview Presentation

The first presentation was an overview or the DI research provided in INL/EXT-21-64580 [1] and summarized in Sections 2–4above. This presentation was made by Paul Hunton, the INL PM Pathway Principal Investigator for DI and I&C upgrades. The technical content of this presentation is enveloped within the PWROG presentation, as described in Section 5.1 and provided as Appendix B to this report.

6.1.2 Pressurized Water Reactor Owners Group Presentation

The second presentation was made by Mike Powell, the Chairman of the PWROG, titled "A PWR Owners Group Perspective on Digital Infrastructure." This presentation provided an overview of the PWROG, covering its history, mission, and member composition. The intersection between DI and PWROG focus areas was discussed along with the previous meetings held with LWRS PM Pathway researchers in January and March 2022.

Key PWROG takeaways from the DI information provided by INL to the PWROG I&C Working Group (as discussed in Section 5.1) were presented in the Stakeholder Workshop as follows:

The Digital Infrastructure:

- Integrates different domains into one complete infrastructure
- Addresses HFE and cybersecurity across the infrastructure
- Promotes data integration across an enterprise to enable advanced features (e.g., diagnostics and prognostics)
- Promotes facility- and utility-wide standardization and alternative support models (centralized vs. large, and underutilized, site organizations)
- Encourages 80+ lifecycle thinking from the start
- Applies non-nuclear industrial concepts to enable more strategic thinking as contrasted with legacy plant health replacements
- Applies business case analysis techniques to economically justify digital upgrades.

The PWROG presentation concluded that the INL DI approach provides a holistic direction for examining potential upgrades rather than having a series of digital islands. Such takeaways demonstrate significant buy-in from the PWROG regarding the utility of DI Migration Framework research.

The need for further collaborations between PWROG and INL was discussed as the presentation ended. The PWROG is particularly interested in leveraging LWRS PM Pathway research to support upgrade implementation. The PWROG Stakeholder Workshop presentation is provided here as Appendix D.

6.1.3 Nuclear Information Technology Strategic Leadership Presentation

The third presentation was made by Nick Bryant, the Committee Chair for the NITSL Digital Controls Subcommittee, titled "INL Digital Infrastructure Research from a NITSL Digital Controls Perspective." In this presentation the focus areas of NITSL were identified as IA, digital control systems, cybersecurity, and software quality assurance. The DC Subcommittee provides leadership to the industry in the areas of digital plant process monitoring and control equipment throughout its lifecycle. Its priority focus areas include interfaces and processes supporting the effective use of IT in the plant. Key DI concept takeaways from the DI information provided by INL at the NITSL conference in July 2022 (as presented in Section 5.2 above) were listed as follows in the Stakeholder Workshop presentation delivered by NITSL:

- Digitalization (or digital modernization) is more than replacing obsolete components with newer components, as it enables business transformation when applied correctly

- The LWRS DI concept is well suited to help address some of the objectives that NITSL Digital Controls are looking to address
- The LWRS DI concept was able to combine multiple areas of NITSL interest and was presented to an IA and DC joint session
- The DI concept gave a vivid example of the roadmap identified by INL that others can follow
- Multiple utilities are at various stages of the roadmap, which can be at the beginning or somewhere in the middle
- Establishing a standard on the front end to incorporate into subsequent modernization projects aids in success
- Additional discussions into utility Plant Health processes need to occur, especially in terms of lifecycle management (including business case development).

Other items of note identified in the DI Migration Framework Report [1] that were discussed included:

- IT is extending beyond the “typical IT group” but an IT skillset and mindset are necessary for achieving overall DI success
- The challenges between the roles to implement and support across the industry (IT vs operations technology (OT) vs I&C, for example)
- How to keep these individuals up to date with the rapid pace of technology
- With the introduction of more technology (screens, data, etc.), how will governance address what is presented to data consumers and how that data can be used by them? (particularly in the MCR)
- Finding the right place for internet-of things and other mobile wireless devices (i.e., Monitoring and Diagnostic center monitoring).

The presentation ended with a blanket statement that the DI concept represents a good framework that can be utilized and discussed across the industry and can provide a common method for utilities to work together to find digital upgrade solutions. Such takeaways demonstrate significant buy-in from NITSL regarding the utility of DI Migration Framework research. The NITSL presentation is provided here as Appendix E.

6.1.4 Luminant – Comanche Peak Presentation.

The fourth presentation was made by Taylor Smith, the Comanche Peak Licensing Renewal & Long-term Operations Lead as well a Project Manager. His presentation was titled “Business Case Analysis for Digital Infrastructure.” This presentation is an outgrowth of the LWRS DI research collaboration with Comanche Peak, as described in Section 5.3.1.

Comanche Peak is exploring a multiphase digital infrastructure implementation at both units over a series of outages. The objective of these upgrades is to address three main categories:

1. Addressing existing I&C obsolescence and reliability issues with I&C systems
2. Planning for and execute strategic I&C upgrades to enable 30+ years of additional unit life
3. Achieving a modernization multiplier enabled by digital upgrades that support:
    a. Diagnostics and prognostics
    b. Megawatt efficiency gains
    c. Parts and logistics cost reductions
    d. HSI improvements and error reduction

e. Process standardization

f. Centralization and outsourcing of activities (e.g., I&C platform support).

Key DI concept takeaways, as garnered from interactions with INL and Scottmadden, were listed as follows in Stakeholder Workshop presentation delivered by Comanche Peak:

- If the industry followed historical practice, digital like-for-like functionality would be all we'd get
- The Digital Infrastructure concept:
  - Provides a comprehensive framework that envelopes the full scope of Comanche Peak's envisioned modernization effort (top down and bottom up)
  - Enables the modernization multiplier that Comanche Peak is counting on
  - Is a natural enabler to the larger, digital Power Optimization Center capability that Luminant has been developing across their enterprise
  - Is coupled with a business case analysis methodology that utilities don't have an internal process or expertise to perform.

As stated in Section 5.3.1, planned FY-23 LWRS PM Pathway DI research efforts are to perform a business case analysis to bound the scope of the initial DI implementation at Comanche Peak. A nonproprietary research report is planned for release to the larger industry in 2023 to promote similar activities elsewhere. When talking about performing the BCA, the presenter specifically noted the value of the breadth and depth of the effort to be performed and stated that utilities typically do not perform such detailed analyses when kicking off new projects. Comanche Peak sees this effort as foundational to achieving desired project outcomes.

Such takeaways demonstrate significant buy-in from Comanche Peak regarding the utility of DI Migration Framework research. The Comanche Peak Stakeholder Workshop presentation is provided here as Appendix F.

6.2 Roundtable Discussion

After the presentations, there was a roundtable discussion that covered several areas. These are listed below:

- There needs to be a general recognition that many (if not most) of the existing I&C systems in nuclear plants will not support a plant life beyond 60 years. This needs to be recognized and addressed.
- Procedural, organizational, and cultural issues across utilities have a tendency to create a structural inertia that is resistant to change.
- Nuclear project identification and approval processes and procedures are oriented toward addressing particular issues with existing systems and either repairing them or pursuing like-for-like replacements, particularly for SR I&C systems. Industry guidance, such as the INPO "Equipment Reliability Process Description" AP-913, and Mitigating System Performance Index, drive such thinking. This in no way is meant to impugn these processes and procedures from the perspective of their obvious contribution to plant safety and reliability over the years. As many I&C systems are operating at or beyond their original design lifetime, however, they are increasingly difficult and uneconomical to sustain. Further investment in antiquated and fragmented I&C systems also provides no opportunities for leveraging the capabilities of new technologies.
- Session presenters felt that by identifying and vectoring antiquated, standalone I&C systems toward a two-platform solution and working with stakeholders to identify the benefits the integrated set of digitized plant data was one method to help overcome the structural inertia mentioned above. It was also stated that personnel need to think out of the box regarding what can be done with this data. The Comanche Peak presenter specifically identified coordinating with personnel in the Luminant Power

Optimization Center (https://www.luminant.com/poc/) to explore capabilities enabled by further digitizing I&C plant data and using that data at higher levels of the DI.

- Across the nuclear industry, many utilities do not have a consistent set of procedures or organizational structures to manage the I&C portion (Purdue Network Levels 0–3) or the more IT-oriented digital systems (Purdue Levels 3.5 and 4) as one combined DI. The NITSL presenter described how NITSL had taken a survey of industry in this area that identified this challenge. That survey also found that utilities tended to have common goals to perform digital upgrades.

  Methods to address the challenges and achieve these common goals described above included:

  - In addition to using concepts like the DI Network Framework to guide standard designs, there also needs to be a more standard organizational structure to guide standard implementations. A digital modernization organization is needed that includes I&C engineering, IT engineering, and craft organizations that will install and maintain the digital systems. There may be labor relations challenges when setting up such an organization.
  - Early engagement of all DI-impacted stakeholder organizations needs to occur as early in the digital upgrade process as possible. A discussion of relationship challenges between IT and OT/I&C groups identified that one of the root problems is that cross organization engagement occurs too late and frustration ensues. A generic example was discussed where I&C personnel communicated needs to IT personnel late in the I&C design process expecting a very quick turnaround. Such engagement tends to not only lock in suboptimal (or even unsupportable) design decisions on the IT side but also requires a response in a timeframe than does not correlate with IT processes.
  - A true system integrator (an organization, not a specific individual) is needed that can understand the comprehensive nature of the DI, bring together the disparate I&C and IT systems together in the DI, and own the result. Particular attention must be paid to manage the interfaces within the DI.

- Demonstrating a positive business case for digital transformation leveraging the DI concept is the overriding factor that will determine whether these efforts will be authorized for implementation. Project identification and approval process cultural changes, organizational structure improvements, and updated procedures, and standardization are tools to produce a positive business case.

7. CONCLUSION

In FY-22, INL researchers worked to engage the nuclear industry to facilitate the implementation of Digital Infrastructure research. These efforts were primarily oriented toward communicating the DI concept and its associated design tenets, as well as communicating how its benefits can be realized. The intent of these efforts is to influence industry to adopt the DI Migration Framework as proposed using a tailored approach to enable the long-term, sustainable, and profitable operation of existing nuclear units.

This report summarizes outreach efforts to both industrywide organizations and specific utilities. Industry organizations that were engaged included the PWROG, NITSL, and LWRS PM Pathway Stakeholders. Interactions with specific utilities, including Luminant, Dominion, Constellation, Arizona Public Service, and Southern Company, also occurred. The degree of acceptance of the Digital Infrastructure concept has been high and is having the intended direct influence on industry direction with regard to digital upgrades at existing nuclear stations. These concepts have also begun to draw interest from vendors pursuing new plant builds. After the 2022 LWRS PM Pathway Stakeholder Workshop, a small modular reactor vendor reached out to INL for more information on DI, and INL DI researchers are in the process of engaging that vendor.

8. REFERENCES

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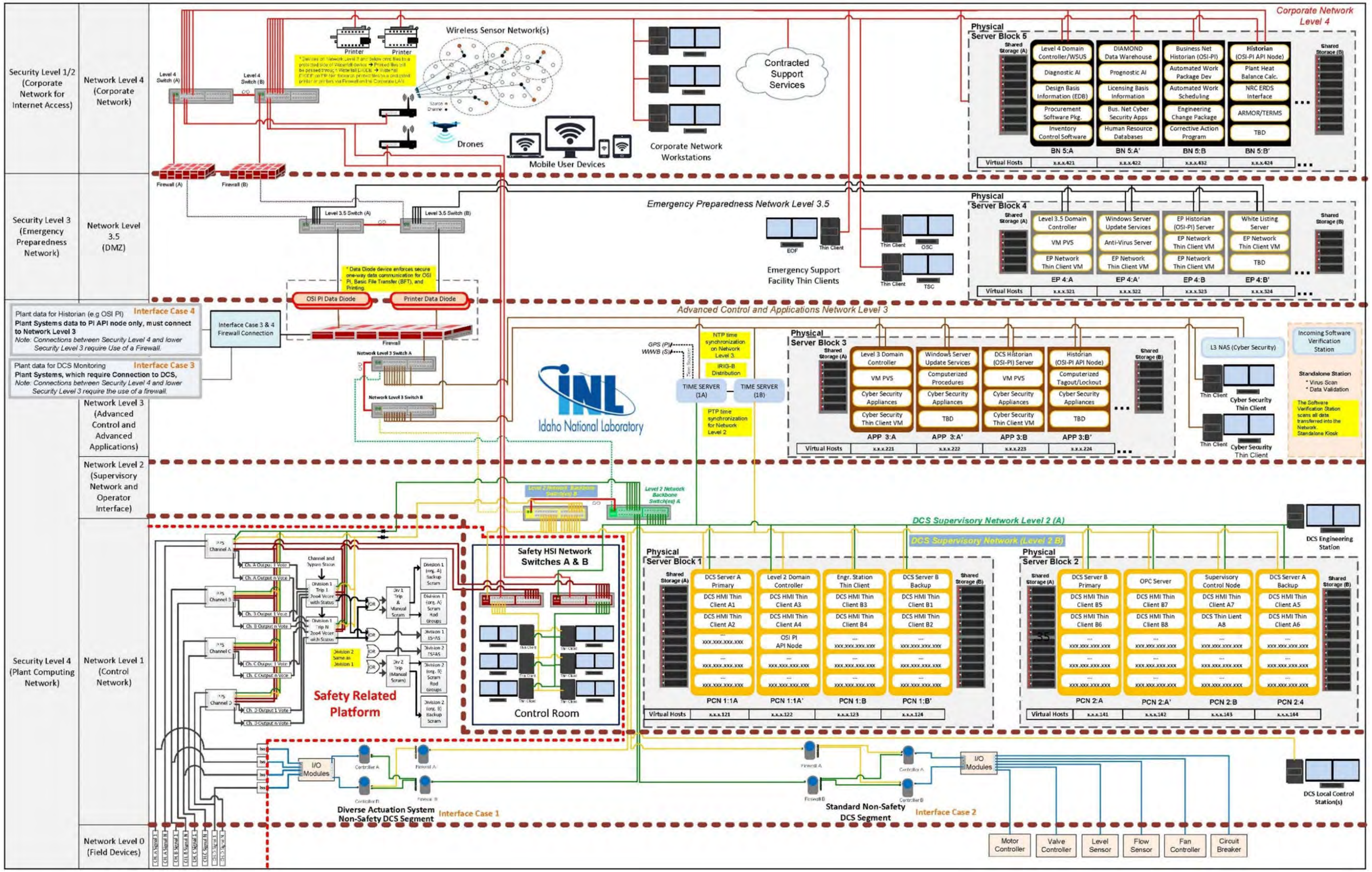
Appendix A

Notional Detailed Digital Infrastructure



Appendix B

LWRS Digital Infrastructure Master Presentation

PWROG I&C Meeting

LIGHT WATER REACTOR SUSTAINABILITY

Paul Hunton
Senior Research Scientist
Idaho National Laboratory

Digital Infrastructure

July 19, 2022

Introduction:

- Paul Hunton
  - Over 30 years of nuclear industry experience
  - Naval Plant Operations and Training (SRO Equivalent)
  - Instrumentation & Control / Main Control Room Digitization (CVN-78 / AP1000)
  - Non-Safety Digital I&C Upgrade Principal Engineer at Duke Energy
  - Instrumentation & Control Modernization Pathway Lead at INL
  - Currently Supporting HFE / Digital Infrastructure on several utility projects

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2

I&C Pilot Upgrade Establishing Pathway for Safety-Related Digital Modernization

- U.S. nuclear utilities have been reticent to pursue needed safety-related I&C upgrades due to perceived licensing risk.
- The NRC issued updated Interim Staff Guidance (ISG-06, Rev. 2) to include an alternate review process for License Amendment requests to address this concern.
- Constellation and the LWRS Program Plant Modernization Pathway are collaborating on a Pilot Safety-Related Digital I&C Upgrade to demonstrate alternate review process viability.
- Upgrade efforts must also be economically viable to promote continued plant operation.
- Implementation timeline for Limerick Generating Station.

Limerick Generating Station

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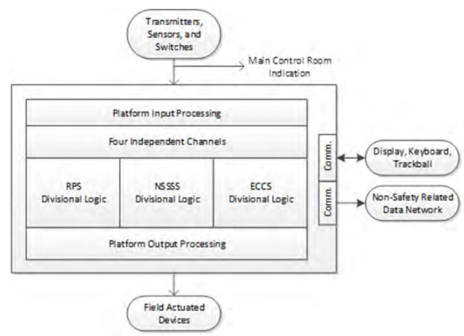
3

Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade

- LWRS Program researchers in collaboration with industry, developed a design concept and requirements to support the upgrade of Safety-Related I&C Systems.
  - Safety system and non-safety distributed control system functional requirements “baselines” that enable improved safety, reliability, and reduced cost.
  - License Amendment Request framework document describes a modern design concept and conforms to the NRC’s ISG-06 alternate review process.
- Report has been made publicly available to promote similar upgrades:
  - INL/EXT-20-61079: Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade)
  - Available on OSTI: https://www.osti.gov/biblio/1755891

Simplified Digital Plant Protection System Architecture



LWRS researchers working with industry have developed a simplified digital architecture that reduces part counts by almost 75% and significantly reduces safety system costs

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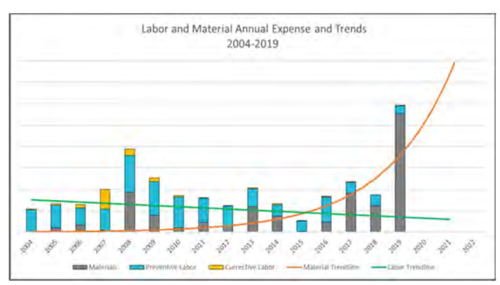
4

Business Case Analysis Methodology

- Business Case Analysis (BCA) developed in conjunction with Pilot I&C Upgrade design concepts.
- A comprehensive analysis of legacy system lifecycle cost drivers was performed.
- Expected benefits of the digital upgrade were quantified.
- Combined with utility estimated project costs, the BCA provided compelling data to support continued Pilot Upgrade efforts.
- Report has been made publicly available to promote similar upgrades:
  - INL/EXT-20-59371: Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations
  - Available on OSTI: https://www.osti.gov/biblio/1660976



BCA Identifies that Costs to Maintain Current I&C Systems are Increasing

Business Case Analysis Research directly supported Constellation’s economic justification for pursuing safety-related upgrades

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5

Expansion of I&C Upgrade Concept to a comprehensive Digital Infrastructure

- Digitalization is occurring all over the utility enterprise (I&C, logistics, emergency preparedness, security)
- Plant maintenance processes and culture have served the industry well, but are biased to create functional and digital "islands"
  - Plant Health process for I&C (10 CFR 50.65: Maintenance Rule, AP-913: Equipment Reliability Process Description, MSPI)
  - IT **vs.** OT
- Different rules exists for these islands (e.g., quality, cybersecurity)

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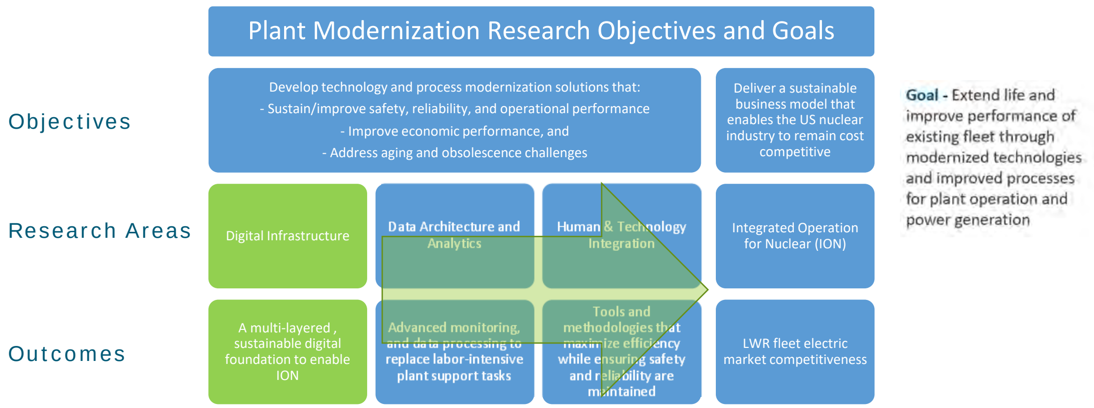
6

Digital Infrastructure and LWRS Plant Modernization

The LWRS Program **Plant Modernization** pathway conducts R&D, **provides guidance for full-scale implementation** and **communicates the results** to other nuclear power stakeholders that significantly reduce the technical and financial risks of modernization

The Digital Infrastructure provides the overarching technology foundation for Plant Modernization.



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7

What are Utilities Thinking?

(August 24, 2021 – Stakeholders Workshop)

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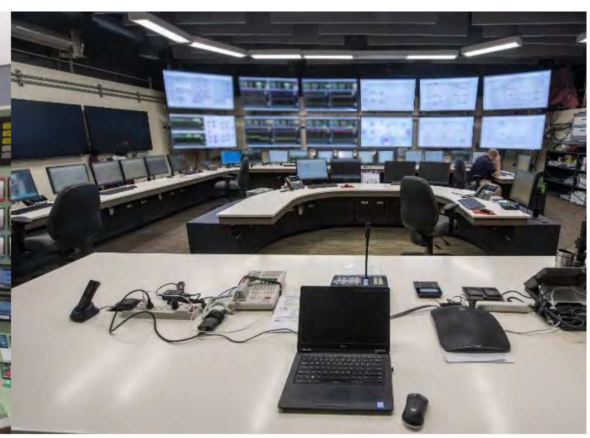
8

Control Room Modernization (leveraging Vogtle Unit 3)

Farley Unit 1 MCR



Vogtle Unit 3 MCR

- Raymond Herb, SNC
- Digital Principal, Central Design

Southern Nuclear

9 9

9

The Challenge

Paul Phelps
Director Nuclear Projects - SLR

Image created by Ahmed Banafa, retrieved from https://www.linkedin.com/pulse/spacex-dragon-crew-journey-digital-transformation-ouabi/ on June 4, 2020

Dominion Energy

10

Digital I&C Vision

- Vision
  - Full replacement of major I&C systems at Surry and North Anna Power Stations
    - Phased approach
    - Digital team -> Operations, I&C, Engineering, Management
    - Surry will lead -> North Anna to lag
  - Standardize on a common SR and NSR Platform
  - Upgrade the MCR to soft control system
    - Build a second Simulator
  - Upgrade Technical Specifications/UFSAR
  - Intend to use NISP-EN-04 (DEG) and ISG-06 Rev. 2

Dominion Energy

11

What are Utilities Thinking?

- Digitalization is occurring all over the utility enterprise (I&C logistics, emergency preparedness, security)
- Plant maintenance processes and culture have served the industry well, but are biased to create functional and digital "islands"
  - Plant Health Process for I&C
  - IT **vs.** OT
- Different rules exists for these islands (e.g., quality, cybersecurity)

How does Nuclear "pull it all together" to achieve maximum benefit?

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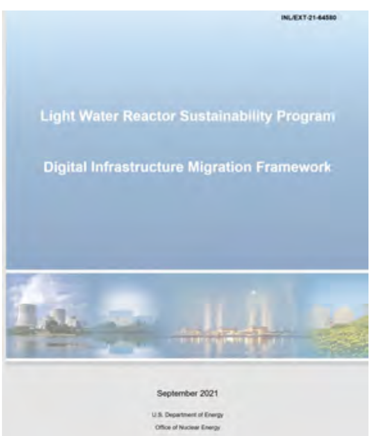
12

Digital Infrastructure Research Report



- The Digital Infrastructure Migration Framework Report details concepts presented today
  - Provides a roadmap for maximizing digital investments
  - Provides the foundation for additional research
    - Digital Infrastructure hosts Data Architecture and Analytics applications
      - What features/applications are needed?
      - Where do they best reside on the Digital Infrastructure
    - Human-Technology Integration
    - Business Case Analyses of activities directed toward the New State

INL/EXT-21-64580 Is publicly available
https://www.osti.gov/biblio/1822876-digital-infrastructure-migration-framework-report

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The Digital Challenge & Design Tenets

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The Digital Challenge

- Digital upgrades are different
  - They are not “once and done” activity like replacing/upgrading a pump
  - The don’t “solve” the obsolescence problem
    - They eliminate some (analog I&C equipment, antiquated digital systems)
    - They create others, such as:
      - Infrastructure obsolescence (equipment and associated utility software/firmware)
      - Potential for “stranded” software applications (if tied to specific infrastructure)
      - Creating a “solution” before understanding the problem.
- How does industry reap the benefits of digital technology while avoiding the pitfalls that it can create?

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Design Tenets

- Establish design tenets (adapted from Merriam/Webster):

  A set of principles generally held to be true, especially those held in common by members of a profession.

1. Define the "New State"

   Envelopes the full range of physical & logical infrastructure that supports applications that to deliver capabilities to maintain/improve safety & performance while lowering cost of ownership

2. Ensure the "New State" is not an "End State"

   The proposed digital infrastructure is formulated to support a full-scope, enterprise-wide modernization to extend plant life to a total of 80-100 years. It supports "technology refreshes" to keep it "evergreen" and capable of accepting new applications while protecting intellectual property investments (legacy applications/functionality)

3. Use stable vendor technology with deep and worldwide market penetration.
   - Demonstrated backward compatibility
   - Vendor developed intellectual property migration strategy (harvest applications/data and re-use)

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Design Tenets

4. Create a Multi-Level Digital Infrastructure
   - Optimize software application functionality allocation based upon use (e.g., control system software applications are allocated to the proper Network Level
   - Control data flows between Network Levels to permit the efficient mass collection, aggregation, storage, trending, correlation, and analysis of all digitized data across the enterprise
   - Tailor application of regulatory and other requirements (e.g., quality, reliability, and cybersecurity requirements) based upon functions performed and placement of those functions within each Network Level
5. Leverage new digital system capabilities to capture and correlate data from throughout the Digital Infrastructure
   - Reduce MCR workload with new data and control capability
   - Eliminate remote stations
   - Improve plant performance and optimize maintenance with trending, diagnostic, and prognostic capabilities
6. Support an integrated Human Factors Engineering strategy
   - Address NUREG-0711: HFE Program Model
   - Standardize HSI's across the enterprise.

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Design Tenets

7. Leverage the enhanced reliability and availability of digital I&C technology
   - Use proven operating systems and programming tools to reduce the potential for I&C platform induced maloperation
   - Leverage available redundancy and graceful degradation capabilities of modern systems
   - Leverage self-diagnostic features
   - Reduce part counts (up to 75% vs analog equipment being replaced)
8. Standardize design across the entire Digital Infrastructure
   - Standard building blocks support supply chain consolidation
   - Standard development tools and design processes reduce implementation, maintenance, and configuration control costs of both the Digital Infrastructure and application software.
   - One overarching cybersecurity defensive strategy (Minimum number of "types")
9. Consolidate disparate I&C systems toward a two-platform solution
   - Safety I&C Platform
   - Non-safety I&C platform which can also serve as a diverse actuation system.

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Design Tenets

10. Provide a standard, shared, safety-qualified HSI Architecture that provides for a flexible solution for the MCR that supports both interim states and the envisioned, hybrid "New State." Design redundant I&C systems to allow for part replacement up to system refresh at power.
11. Leverage vendor-provided system self-diagnostics to eliminate technical specification surveillance requirements, calibrations, and identify failures down to the field replaceable unit.
12. Establish a "design once, build many" approach transportable to all nuclear sites within a utility enterprise. This maximizes efficiency and can even support centralizing of utility digital system support and/or support outsourcing service models.

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Digital Infrastructure: Simplified Build

- Presented logically from an I&C point of view (bottom-up)
- Purdue Model used to relate these efforts to larger industrial control applications
- Cross referenced to the NRC's Regulatory Guide 5.71 cybersecurity layers
- Addresses existing digital "domains" within the larger Digital Infrastructure

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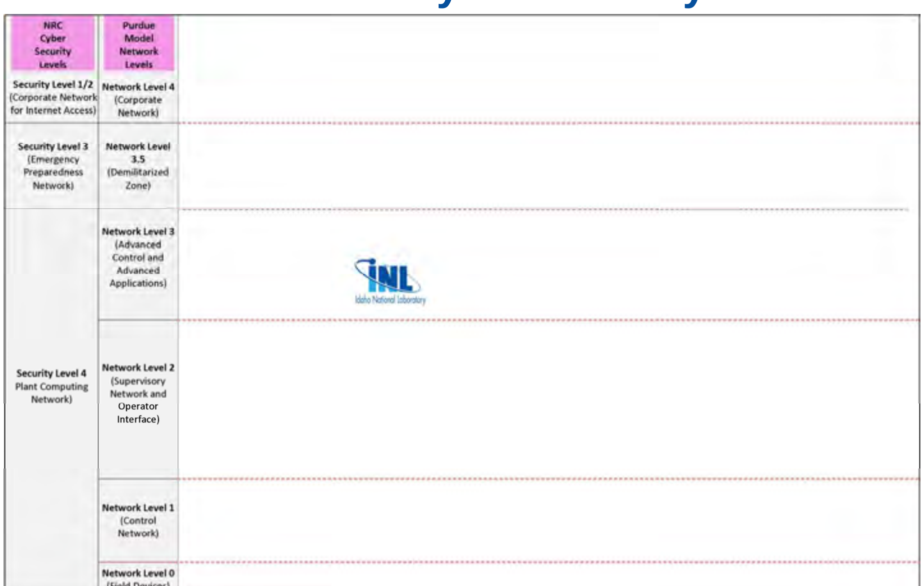
Purdue Model and NRC Cyber Security Levels



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Safety System Field Devices

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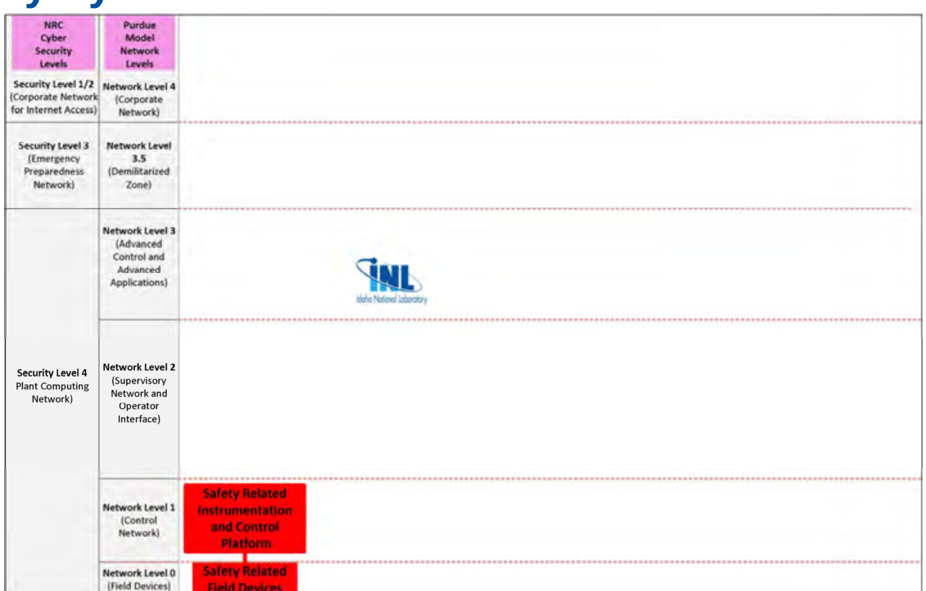
Safety System Platform



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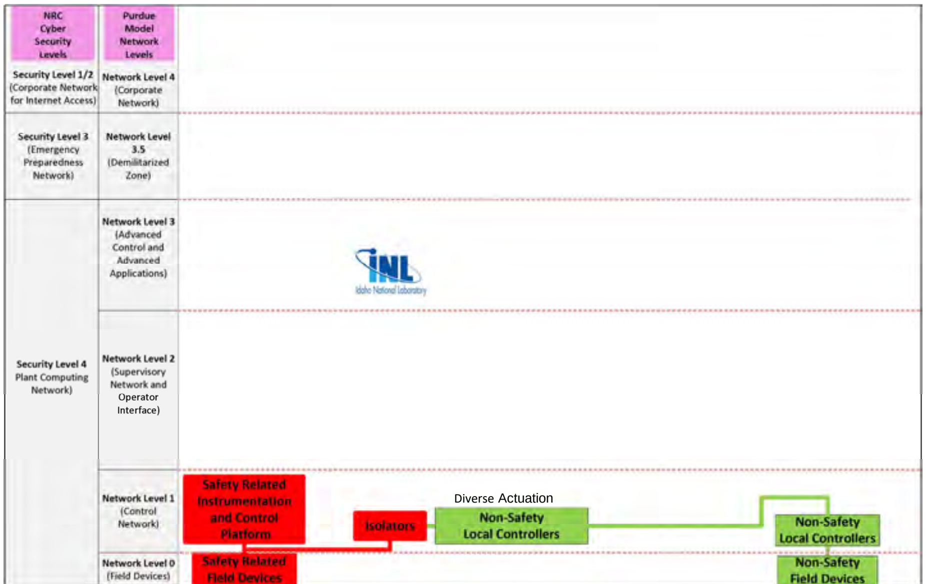
Non-Safety Field Devices and Network Level 1 Platform



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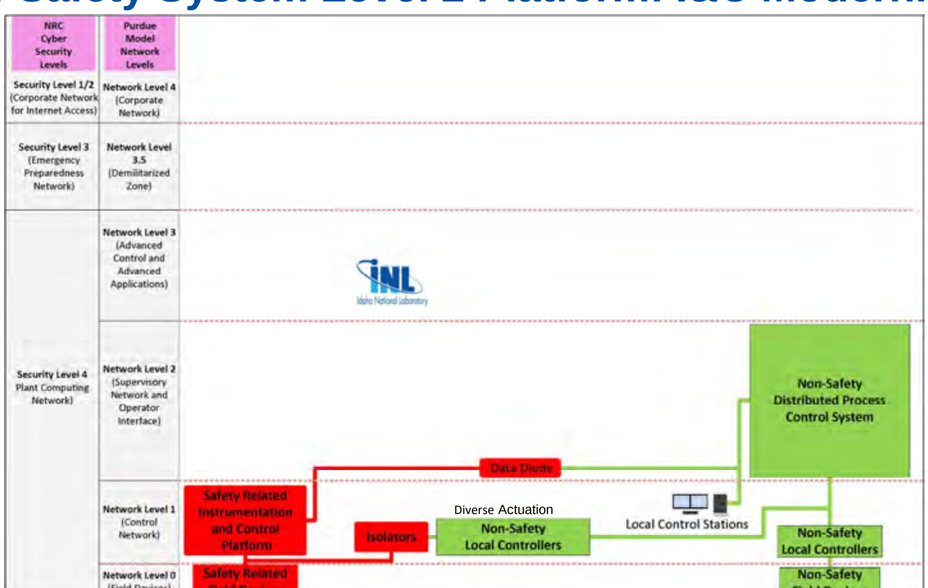
Non-Safety System Level 2 Platform: I&C Modernization



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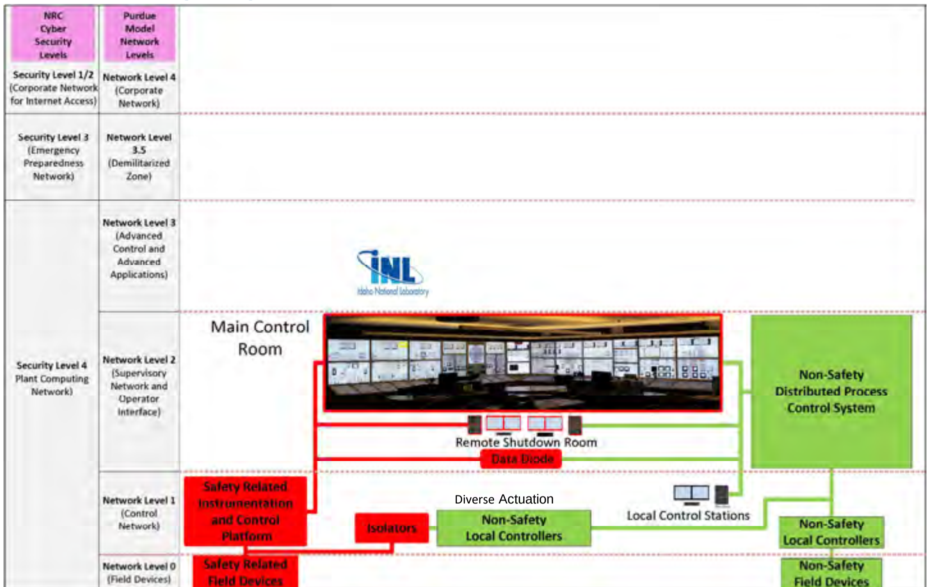
Shared Safety System HSI Interface



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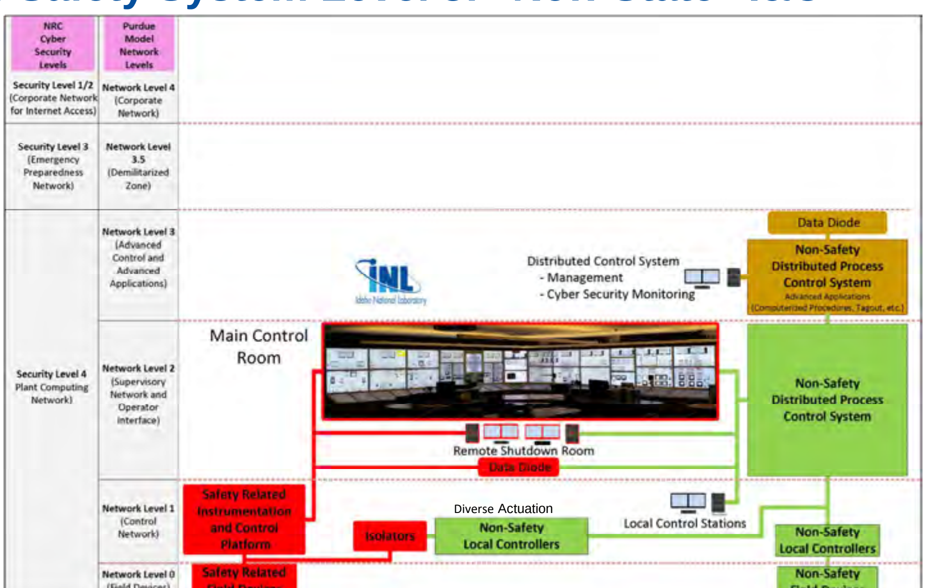
Non-Safety System Level 3: “New State” I&C



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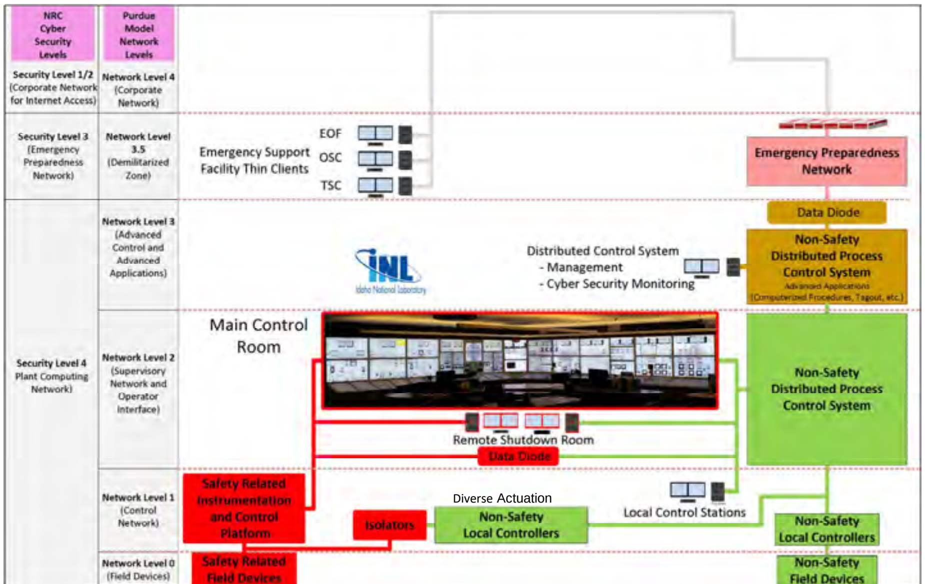
Emergency Preparedness Network / Demilitarized Zone



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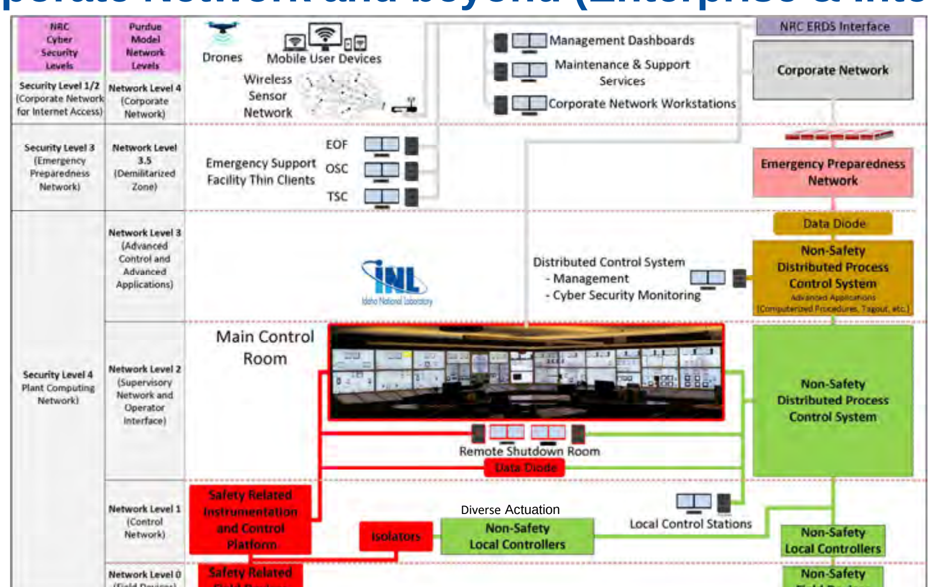
Corporate Network and beyond (Enterprise & Internet)



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Digital Infrastructure Cyber Security Requirements

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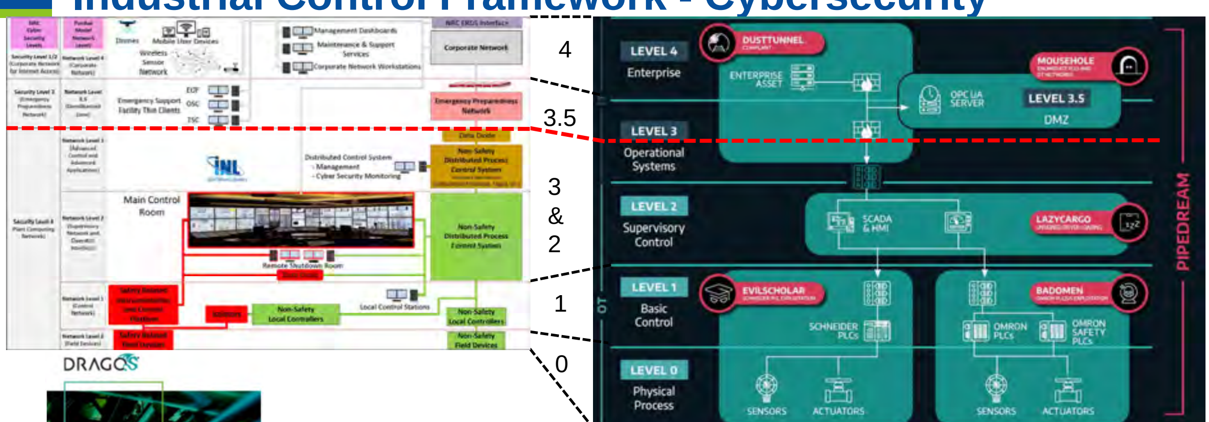
Digital Infrastructure Directly Relatable to Worldwide Industrial Control Framework - Cybersecurity



DRAGOS

Recent Industry Whitepaper on Emergent Cybersecurity Threat: “PipeDream”

One overarching cybersecurity defensive strategy designed in

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Digital Infrastructure Identification and Allocation of Applications

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Digital Infrastructure: The Host of Data Architecture & Analytics Applications

- Digital Infrastructure (hardware and utility software/firmware)
  - Data communications protocols
  - Operating Systems to run applications
  - Self-diagnostics
  - Cybersecurity and platform configuration management
  - **Most sensitive to technology changes**
- Data Architecture & Analytics Applications (manages data, executes functions and creates/stores information)
  - Software based
  - **Represents the bulk of intellectual property investments**

Need Capability to Decouple Applications from Infrastructure

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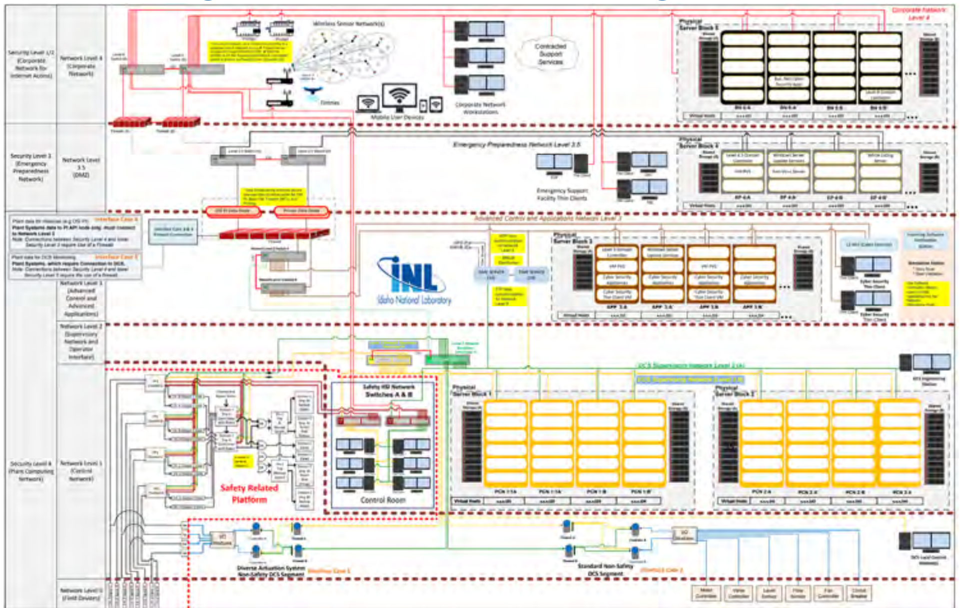
Detailed Digital Infrastructure Diagram



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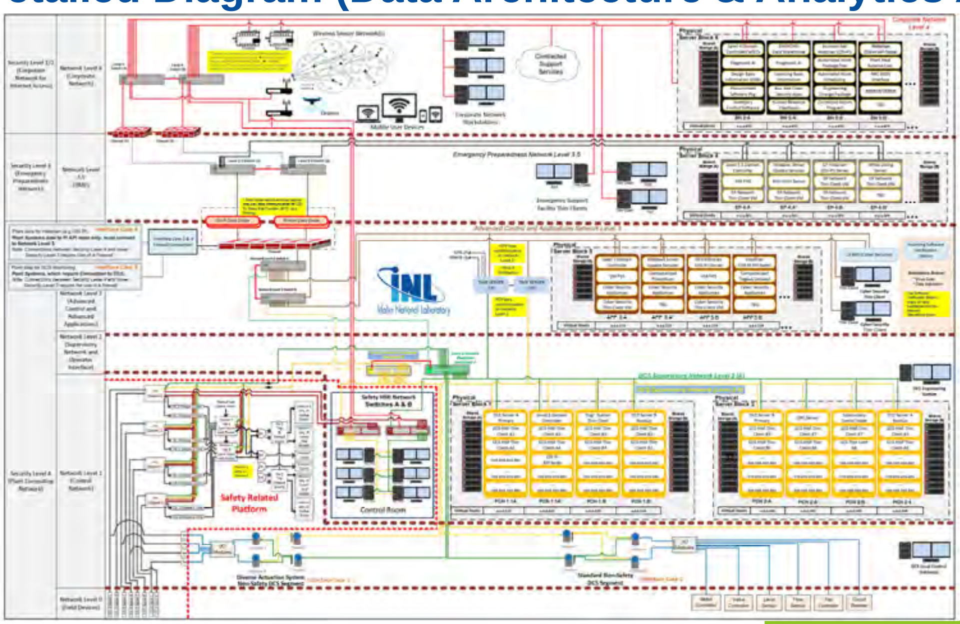
Detailed Diagram (Data Architecture & Analytics Apps)



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Capabilities of Each Level of the Digital Infrastructure

For each Purdue Model Level, a more detailed discussion is provided in the areas of:

- Configuration of the equipment
- Software enabled features
- Human-system Interfaces

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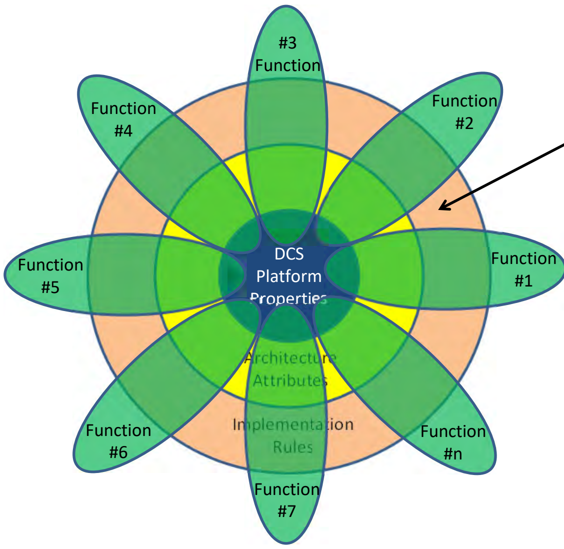
Example of Level Capabilities: Non-Safety DCS Levels 0&1: Local Control



No Critical functions Overlap. Use separate controllers.

Site Specific DICSP 50.59 evaluations build on each other over time as appendices to the Base Platform documentation

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Digital Infrastructure Quality Requirements

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Digital Systems – Differentiation of Quality Requirements

Tenets:

- All digital domains must be of high quality
- Use of different quality standards for different domains is required and appropriate.
- Blurring the lines of quality between domains increases project risks.

Application:

- I&C Systems:
  - The basic quality objectives for I&C systems resident in Network Levels 0 - 3 and the methods to achieve them are generic. Simply stated, I&C systems are designed to achieve high reliability and availability so that the systems they monitor and control can be safely operated and produce desired results or products. Quality assurance requirements and associated levels of documentation required to demonstrate quality requirements are satisfied are tailored to risks associated with the potential consequences of I&C system maloperation.

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Digital Systems – Differentiation of Quality Requirements

- I&C Systems (continued):
  - Safety I&C Systems Standards (sample)
    - 10 CFR 50.55a(h): Protection and Safety Systems
    - Multiple general design criteria (GDC)s in 10 CFR 50 Appendix A
    - Specific quality assurance criteria in 10 CFR 50, Appendix B
    - Multiple Branch Technical Positions (BTP-7-14, BTP 7-19)
    - Modifications follow DI&C-ISG-06, Rev. 2: Licensing Process
    - IEEE-603: Criteria for Safety Systems for Nuclear Power Generating Stations
    - IEEE-279: Criteria for Protection Systems for Nuclear Power Generating Stations

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Digital Systems – Differentiation of Quality Requirements

- Non-Safety I&C Systems (Importance)
  - Non-safety I&C systems, while not tasked with performing RPS and ESFAS functions, are no less important when it comes to achieving the objective of a commercial nuclear plant. This objective is a safe, reliable, and economical source of heat to generate electricity (typical use) or to enable other industrial processes (e.g., emerging commercial production of hydrogen). If non-safety I&C systems cannot provide highly reliable and available control of balance-of-plant (BOP) systems to meet these objectives, existing nuclear plants will be shut down and new ones will not be built.
- Non-Safety I&C Systems (Quality)
  - NRC Generic Letter 84-01
    - Follow GDC-1 including the quality program that has been reviewed by the NRC for the particular site/unit.
    - "it is the staff view that normal industry practice is generally acceptable for most equipment not covered by 10 CFR 50, Appendix B."
  - Result
    - This does not make non-safety, BOP I&C systems "lower quality" or result in them being less reliable or available than safety-related I&C systems.
    - This affords a utility much more flexibility to adopt well-proven, more modern I&C system and software application techniques with requisite quality at a lower cost.

Don't Blur the Line between Safety & Non-Safety

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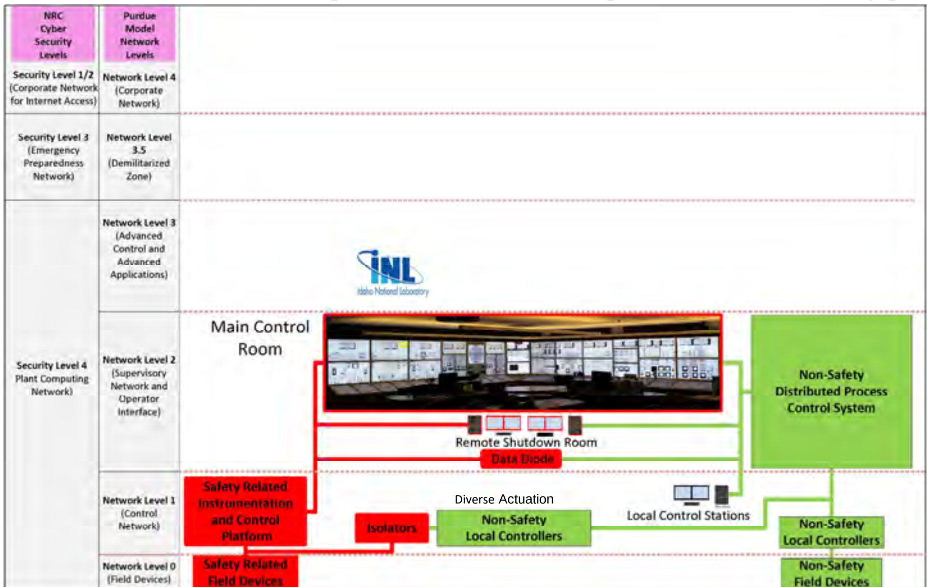
Core I&C Platforms (use native capabilities only)



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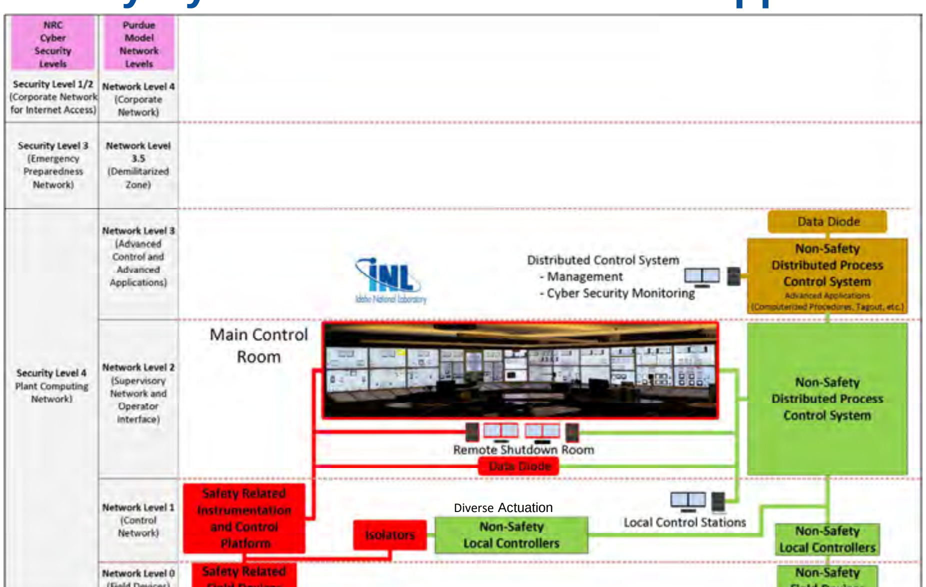
Non-Safety System Level 3: Advanced Applications



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Digital Systems – Differentiation of Quality Requirements

- Support Networks: Emergency Preparedness/DMZ and the Corporate Network
  - Not I&C Systems
    - Provides no direct means of controlling plant equipment or indications directly used by operators to perform control functions
    - Industry and NRC standards for I&C system quality, reliability, and availability do not apply
  - But they are used to meet regulatory & business requirements
    - EP Network
      - Satisfies NUREG-0696: Functional Criteria for Emergency Response Facilities. If these criteria are not met, this can put a plant in a Limiting Condition for Operation.
      - Falls within 10 CFR 73.54: Cyber Security Rule
    - Corporate Network:
      - Feeds the Emergency Response Data System (ERDS) per 10 CFR 50, Appendix E: Emergency Planning and Preparedness for Production and Utilization Facilities
      - NUREG-0654: Emergency Planning and Preparedness for Production and Utilization Facilities requires that an implementation Plan be submitted to the NRC (including hardware/software and transmitted data points)
      - This network "runs the business" of a nuclear site (work packages, inventory, sourcing, etc.)

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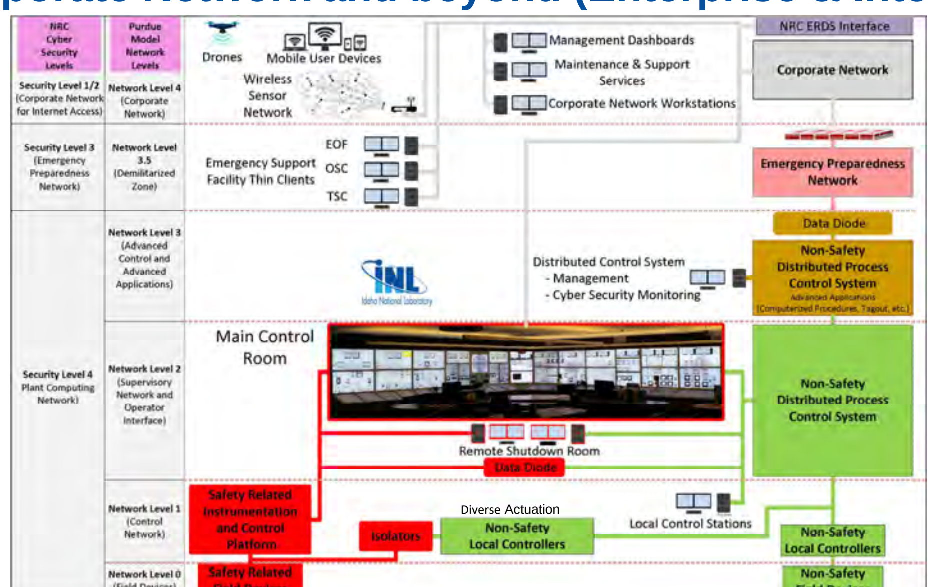
Corporate Network and beyond (Enterprise & Internet)



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Digital Infrastructure
Human-Technology Integration

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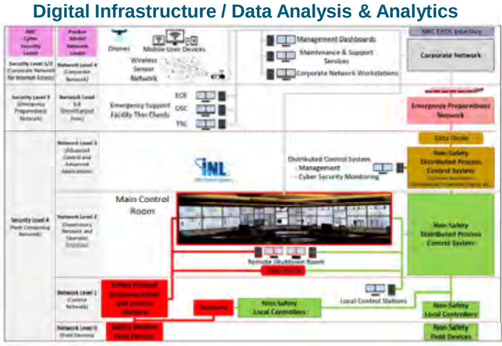
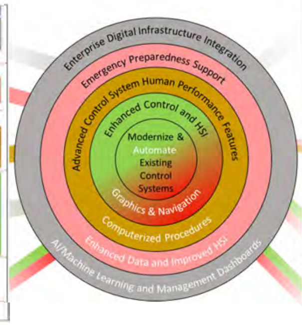
Digital Infrastructure & Human and Technology Integration

Digital Infrastructure / Data Analysis & Analytics



Leveraging collaborations with utilities, Advanced Concept of Operations research activities, and State-of-the-Industry technologies, develop an optimized, plantwide Digital Infrastructure modernization framework to host a digital transformation.



Human and Technology Integration

Enterprise Advanced Concept of Operations
- Create a new state vision across the enterprise.
- Develop guidance and requirements for integrating / optimizing maintenance and support functions.
- Apply human factors engineering (HFE) principles and advanced methods to support optimal human and technology integration across the enterprise (use of advanced decision support and advanced work management systems) that improve safety, reliability, and reduce cost.

Concept of Operations for Operator / Emergency Preparedness (EP) Support
- Create a new vision for plant operation and EP support.
- Integrate HFE research, standards and guidance, to direct the configuration of technology to improve safety, performance, situation awareness, and reduce workload.

Concept of Operations - Control System Human-System Interface (HSI)
- Apply HFE principles and advanced methods to support optimal human and technology integration of vendor capabilities.

Concept of Operations - Digital Modernization
- Apply function and task analysis methods to ensure HFE principles are addressed when implementing new I&C functionality (automation).

Develop an assessment methodology that enables the nuclear industry to adopt advanced digital capabilities (control system automation, artificial intelligence, machine learning, and modern HSIs) to achieve the objectives of Integrated Operations for Nuclear.

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Closeout

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Digital Infrastructure Benefits

- Integrate disparate digital system "islands" into a single, cohesive, data centric framework of "domains" that work separately **and together**
- Enables a "New State" that is much more than the sum of its constituent parts:
  - Fully leverage digital technology capabilities demonstrated in other industries
  - Accept new technologies as they become available in the marketplace and developed by research to enable extended plant operations to 80+ years from initial license date.
- Must be designed with obsolescence management addressed from the start
  - Maximize value of initial intellectual property investments (harvestable)
  - Protect those investments while enabling new capabilities

Support an Optimized Enterprise Concept of Operations

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Digital Infrastructure Next Steps

- Strategic direction for the remainder of plan life (80+)
  - What is **your** site/utility target "New State" – with **specificity?**
    - With available technology (Version 1.0)
    - Enabled by research and industry advancements (Version 2.0 and beyond)
  - Is **your** organization/culture aligned with this strategic direction?
    - Who owns the Digital Infrastructure – by name?
    - Is each domain represented in a data centric Digital Infrastructure Group
    - Centralized and/or outsourced support?
  - Has **your** organization clearly established domain boundaries and standards for each?
    - Quality
    - Cyber Security
    - System Configuration Control / Management (maintain current living documents)
  - Who is **your** management champion to ensure sustained commitment
    - For initial implementation (multi-phase/year implementation)
    - For care and feeding **for the remainder of plant life** (evergreen)

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Takeaways

- The Digital Infrastructure provides a vertically integrated data highway to enable O&M cost reductions for Nuclear as it has for other industries.
- Such vertical integration:
  - Requires holistic thinking (bottom-up and top down)
  - Requires organizational disruption (this is meant to be **positive**)
  - Requires the adoption of an "evergreen" mentality (to mitigate digital obsolescence).
  - Requires a complementary evaluation of station/utility operations to define the "New State". Will applications hosted by the Digital Infrastructure:
    - Just digitize suboptimal or antiquated processes to maintain existing cultural expectations (do what we do now, only "better"), or
    - Be critically evaluated in a way that meets **requirements** and sustains/enhances performance at lower cost.

Digital Infrastructure is just that - Infrastructure

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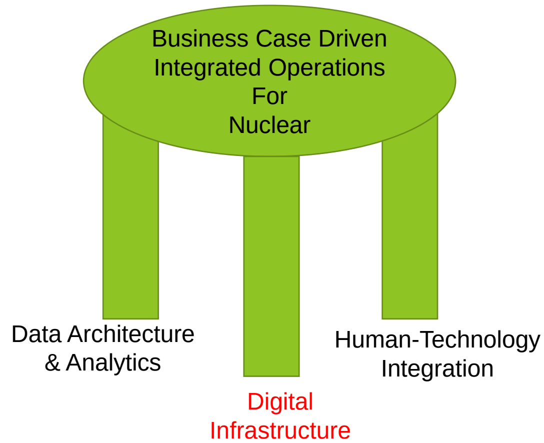
Plant Modernization Enabled "New State"



The LWRS Program Collaborates with Utilities and Vendors to Make Progress

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Summary of Plant Modernization I&C Research Reports

- Transition non-safety/balance of plant I&C functions to one digital platform
  - **Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries**: (https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_20014.pdf)
- Transition current safety-related I&C functions to one digital safety platform:
  - **Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade**: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_27502.pdf
  - **Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations**: https://www.osti.gov/servlets/purl/1660976
  - **Safety-Related Instrumentation & Control Pilot Upgrade Initiation Phase Implementation Report**: (https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_26667.pdf)
- **Digital Infrastructure Migration Framework**
  - https://www.osti.gov/biblio/1822876-digital-infrastructure-migration-framework-report

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Questions / Comments?

Thank you!

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Appendix C

NITSL Presentation – Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries

NITSL 2022

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Robert England - INL

Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries

July 18, 2022

Introduction:

- **Robert England**
  - Naval Reactors Facility Dry Storage Engineer and Lead Quality Assurance Engineer
  - Idaho National Laboratory Advanced Test Reactor DCS System Engineer
  - Idaho National Laboratory ICS Cybersecurity Information System Security Manager (ISSM)
  - Idaho National Laboratory Instrumentation & Control Researcher in the Nuclear Science and Technology Directorate
    - Monitoring, Diagnostics and Automation Laboratory Lead
    - LWRS Plant Modernization Researcher – I&C Emphasis
    - Other Responsibilities: Nuke Cyber Outreach to Brazil, Argentina and Chile; Cyber Digital Twin Research
- **Paul Hunton**
  - Over 30 years of nuclear industry experience
  - Naval Plant Operations and Training (SRO Equivalent)
  - Instrumentation & Control / Main Control Room Digitization (CVN-78 / AP1000)
  - Non-Safety Digital I&C Upgrades at Duke Energy
  - Instrumentation & Control Modernization Pathway Lead at INL

2

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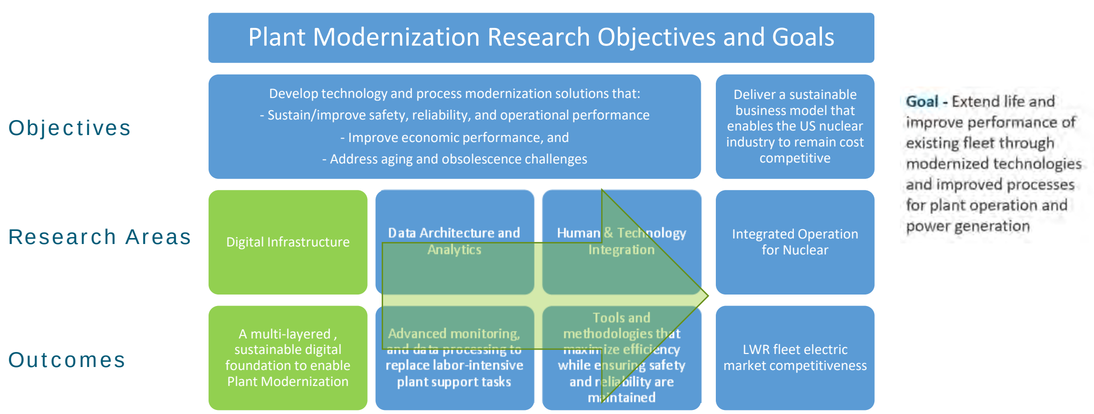
Digital Infrastructure and LWRS Plant Modernization

The LWRS Program **Plant Modernization** pathway conducts R&D, **provides guidance for full-scale implementation** and **communicates the results** to other nuclear power stakeholders that significantly reduce the technical and financial risks of modernization

The Digital Infrastructure provides the overarching technology foundation for Plant Modernization.



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Nuclear I&C Modernization: Application of Techniques Employed in Other Industries

- Research leveraged utility operating experience and lessons learned in selecting a non-nuclear Distributed Control System (DCS) I&C vendor and deploying their technology in four nuclear units.
- Researched selected vendor processes and experience that minimize deployment and periodic DCS upgrade costs via a repeatable obsolescence management cycle
- Research identified key vendor attributes and necessary utility activities to optimize the implementation and lifecycle support of a non-safety DCS in a nuclear environment
- Collaborators included Duke Energy and Honeywell Process Solutions

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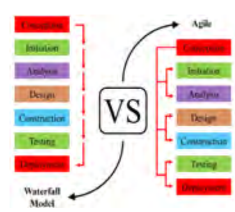
Pilot Distributed Process Control System Initial Development and Installation

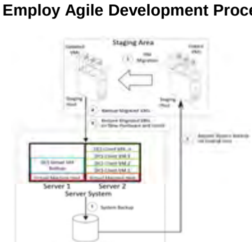
Attributes of this solution include:

1. Selection and use of a fully developed, vendor-supported DCS solution with a fully developed strategy for future technology upgrades.
2. Willingness of the vendor to support knowledge transfer to the utility.
3. Migration of functions of legacy I&C systems to the new DCS and retirement of the legacy equipment.
4. An enhanced performance profile through the application of advanced features such as system diagnostics, fault tolerance, graceful degradation, improved Human Machine Interfaces (HMI), etc.
5. Full integration of the technical solution within the simulators of the impacted nuclear units. This is a technology multiplier that allows for many new capabilities.



Employ Agile Development Process

Coordinated Design/Licensing Strategy



On-Process DCS Technology Updates

Leverage Glasstop Simulator for I&C Design, Procedure Development in Addition to Operator Training

5

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Modernization Overview of an Installed DCS Leveraging Vendor Developed Techniques

Key Factors that Drive DCS Modernization

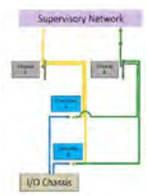
- Hardware Obsolescence
  - Operations Technology (OT)-based digital I&C hardware platform will not be supported after 7 to 10 years from its original release date.
- Software Obsolescence
  - OT-based software also becomes obsolete over time.

Vendor Validated On-Process System Migration Activity

- DCS Architecture Overview and Migration Enablers
  - Backwards compatibility
  - Intellectual property protection
  - Decoupling of Control Network upgrades from Supervisory Network upgrades
- On-Process Migration: Supervisory and Control Networks

Basic DCS System Architecture

Simplified DCS Supervisory Network Architecture



Single Redundant Control Network Segment


Redundant I/O Modules

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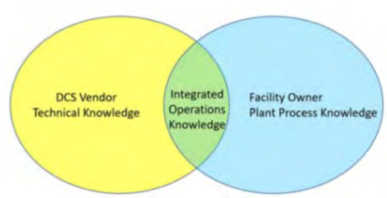
Generic Migration Planning and Execution

Develop a DCS Platform Migration Plan

Develop a DCS Platform Migration Strategy

Roles and Responsibilities for the Facility Owner and DCS Vendor



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Optimizing I&C Modernization in a Nuclear Environment

- **Vendor Selection & Collaboration**
  - Identifying key properties to be provided by the DCS to enable vendor product selection.
  - The ability to employ the selected DCS without customization.
  - The willingness of the vendor and utility to team to develop DCS detailed requirements and configuration instructions.
  - The ability to incorporate the DCS seamlessly into the plant simulators.
  - The size, market penetration, historical experience, and resource depth of the vendor.
  - The ability of the vendor to maximize the protection of utility intellectual property investments.
  - The ability of the vendor to act as an I&C Systems Integrator.
- **Utility Personnel Training on the Selected Platform**
- **Audit Vendor Design and Lifecycle Support Processes to Ensure Acceptability for Leveraging in Nuclear**
- **Enabling an Optimal Utility/Vendor Organizational Structure by Modifying Processes to Leverage Vendor Capabilities**
  - Optimizing Utility/Vendor Organization
  - Optimizing Utility Processes to Enable the Optimal Organizational Structure

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Conclusion

This research presents advancements that have been made by non-nuclear I&C OT vendors and savings that could be realized by their optimized application in the nuclear industry. It identifies techniques for nuclear utilities to leverage vendor processes and experience to minimize utility costs for initial DCS deployment as well as for periodic technology migrations that address obsolescence. Application of these techniques will aid utilities in overcoming the institutional inertia impeding the large-scale implementation of digital technology in the nuclear industry. Key attributes required to accomplish technology migrations at minimum cost include leveraging vendor developed processes while at the same time protecting past intellectual property investments. Proper application of these techniques maximizes the benefits of expanded use of DCSs as part of a larger plant strategy to eliminate obsolete I&C systems, reduce O&M costs, improve operational performance, and maximize personnel utilization through digitalization. Modification of current industry processes and procedures to leverage vendor tools and techniques will further minimize utility costs.

Methods to accomplish technology migrations of the DCS are highly developed and employed in nonnuclear critical infrastructure. These methods are provided as part of the vendor's self-funded product lifecycle support strategy. In fact, technology migration of DCS Supervisory Network hardware, software and Control Network firmware with the nuclear plant at power (on-process) is not, in and of itself, an overly risky activity. The method to perform on-process migrations as presented herein is well defined and has been successfully implemented in non-nuclear critical infrastructure. By enabling on-process migrations in nuclear, it is possible to decouple non-safety DCS technology migrations and other system changes from outages.

Significant efficiencies can be achieved by performing these upgrades in non-outage periods. Planning and execution of these upgrades outside of outage periods also reduces outage risk and enables performing other work that may require an outage that could not otherwise be supported.

The pilot utility's experience in deploying a modern non-safety DCS demonstrates that by using innovative techniques and leveraging vendor experience, modern I&C technology used outside of the nuclear industry can successfully be installed in nuclear plants and incorporated into their simulators. Efforts performed during this activity, such as utility training on the vendor system, performing vendor audits, and performing analyses such as a FMEA and a SHA helped validate deployment of this technology in nuclear. These efforts, along with effective utility and vendor teaming, built confidence and enabled the initial implementation. These efforts are foundational and must be sustained to enable subsequent technology migrations.

Increasing nuclear industry confidence in leveraging I&C vendor techniques and resources over time can drive organizational changes that further reduce overall I&C lifecycle support costs and support the long-term economic viability of nuclear power.

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Five Key Takeaways for I&C Modernization

- Derived from I&C Modernization research and collaborations.
- Objective is to define a success path for I&C modernization for sustainable operations
- Ongoing 'first mover' projects are confirming findings.

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1. Maintaining the legacy I&C systems is not the least cost option.

- The number of diverse discrete parts is huge.
- The cost escalation rate for spare parts is much higher than standard escalation rates.
- Specialized knowledge must be maintained on each individual system.

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2. All I&C functions can be migrated to two standard platforms (safety and non-safety).

- Better approach than like-for-like system replacement.
  - Result is much more than the sum of its parts (integrated solution).
  - Standard designs lower implementation costs
- Most maintenance & surveillance functions disappear or become automated.
- Collapses diverse I&C lifecycle support structure to two platforms.
  - Major reduction in discrete parts, spare parts, procedures, supply chain and training costs.
- Digital I&C platform data available for diagnostics/prognostics

Current State

Target State

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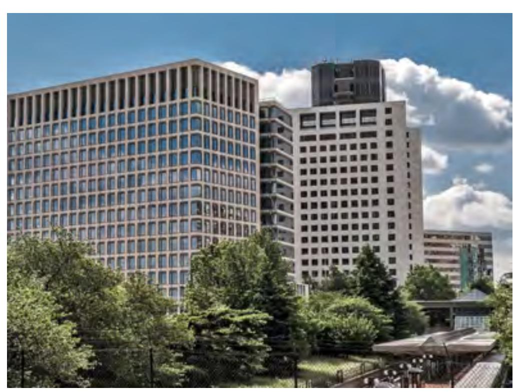
3. Licensing of safety I&C upgrades is not the barrier it was once thought to be.

- Alternate ISG-6 process and RIS 2002-22, Supplement 1 addresses issues identified in previous LARs for safety-related I&C.
- Resolves licensing risk earlier in the process.
- Limerick protection upgrade will demonstrate cost and schedule stability.
- Improved guidance for safety-related I&C upgrades under 50.59.



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4. Significant operator performance improvement is available with control room digital technology.

- Digital technology can substantially improve human performance and efficiency.
- Alarm response is greatly improved.
- Information can be configured for specific tasks.
- Advisory systems can assist in plant monitoring.
- Operator situational awareness is much higher.
- Remote human actions can be consolidated into the control room

Transition or Hybrid State

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5. Future I&C obsolescence can be cost-effectively managed with a life-cycle strategy.

- Current hardware functions will be implemented as software to avoid obsolescence
- Migratable software-based logic will never become obsolete.
- Design coupled with leveraging vendor developed processes for digital obsolescence management manages cost

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Questions / Comments?

Thank you!

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Detailed Virtual Migration Explained

Figure 14. Base System Diagram

Step 1: Server Pair Synchronization

The redundant DCS VM server pair must be synchronized to ensure that Server A reflects the same configuration as Server B, where the server migration will start. All clients will be connected to Server A for continuing production operations.

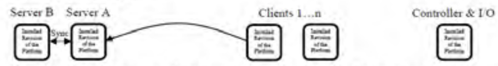

Figure 15. Step 1: Synchronization of Configurations Between Servers is Performed and All Clients are Connected to Server A.

Step 2: Copying Server Configuration to Backup Storage

Backup storage of some type must be established on the Supervisory Network. This will retain the end user configuration / database. In step 2, the customer configuration is copied from Server B and stored on the backup storage.

Figure 16. Step 2: System Configuration is Backed-Up for Installation on the Updated Platform.

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Pilot Vendor Platform Lifecycle and Backwards Compatibility Management

Table 1. Honeywell Experion® Release History.

Release	Microsoft Operating System: Version	Microsoft Operating System: End of Extended Support	Honeywell Software: Support Level	Honeywell Software: Released	Honeywell Software: Withdrawn from Sale	Honeywell Software: Latest Point Release	
Experion R30x	WS2003 Server SP2	Jul 14, 2015	Phased Out	1Q2006	3Q2010	R301.3 Dec 2008	Coordinated Hardware/Software Major Release
	XP SP3	Apr 08, 2014					
	SQL2000 SP4	Sep 04, 2013					
Experion R31x	WS2003 Server SP2	Jul 14, 2015	Phased Out	2Q2008	2Q2012	R311.3 Aug 2009	Software Feature Upgrade Minor Release
	XP SP3	Apr 08, 2014					
	SQL2005 SP3	Apr 12, 2016					
Experion R40x	WS2008 Server 32bit SP2	Jan 14, 2020	Phased Out	3Q2010	2Q2014	R400.8 Dec 2015	Coordinated Hardware/Software Major Release
	Windows 7 32bit SP1	Jan 14, 2020					
	SQL2008 SP3	Jan 08, 2019					
Experion R41x	WS2008 Server R2 64bit SP1	Jan 14, 2020	Phased Out	2Q2012	3Q2018	R410.9 April 2016	Software Feature Upgrade Minor Releases
	Windows 7 64bit SP1	Jan 14, 2020					
	SQL2008 R2 SP2 32bit	Jan 08, 2019					
Experion R43x	WS2008 Server R2 64bit SP1	Jan 14, 2020	[illegible]	2Q2014	NA	R430.6 Oct 2016 R431.5 Mar 2018 R432.2 Sep 2017	
	Windows 7 64bit SP1	Jan 14, 2020					
	SQL2012 SP2 32bit	Jul 12, 2022					
Experion R50x	WS2016 Server 64bit	Jan 11, 2027	[illegible]	1Q2017	NA	R500.2 Aug 2017 R501.4 Dec 2018	Coordinated Hardware/Software Major Release
	Windows 10 IoT Ent LTSB 2016	Oct 13, 2026					
	SQL2014 SP2 64bit	Jul 09, 2024					
Experion R51x	WS2016 Server 64bit	Jan 11, 2027	Current	1Q2018	NA	R510.3 Jul 2018	Software Feature Upgrade Minor Release
	Windows 10 IoT Ent LTSB 2016	Oct 13, 2026					
	SQL Server 2017 Standard	Oct 12, 2027					

Table 2. Pilot Vendor Support for Control Network Hardware & Software (Honeywell)

Controller Name	Released	Migration Path	Year Path Available	Lifecycle
CB	1974	C300/EHPM	2014	40
EC	1976	C300/EHPM	2014	38
RCD	1976	C300/EHPM	2014	38
MFC	1977	C300/EHPM	2014	37
IPC 620	1978	C300	2012	34
AMC	1987	C300/EHPM	2012	25
PM	1988	APM	2013	25
APM	1991	HPM	2013	22
FSC	1996	Safety Manager	2004	8
HPM	1996	EHPM	2013	17
UC	1997	C300/EHPM	2014	17
C200	1998	C300	2016	18
HC900	2000	N/A	Current	18+
Safety Manager	2004	N/A	Current	14+
C300	2006	N/A	Current	12+
MLPLC	2008	N/A	Current	10+
C200E	2010	C300	2016	6
RC500	2011	ControlEdge RTU	2013	7+
ControlEdge RTU	2013	N/A	Current	5+
EHPM	2013	N/A	Current	5+
ControlEdge PLC	2016	N/A	Current	2+
UOC	2017	N/A	Current	1+
Safety Manager SC	2018	N/A	Current	1+

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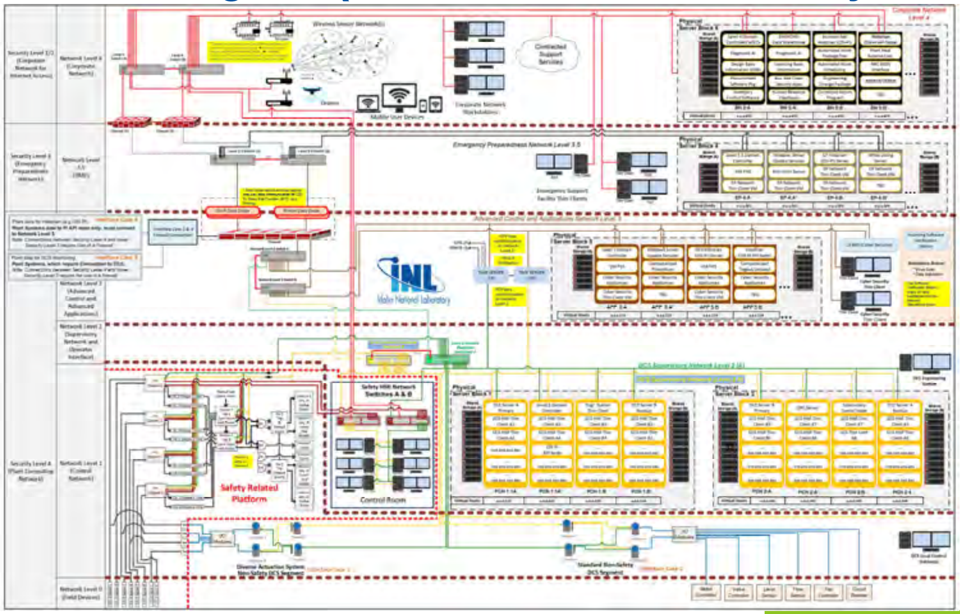
Detailed Diagram (Data Architecture & Analytics Apps)



Digital Infrastructure Research Report

- The Digital Infrastructure Migration Framework Report details concepts presented today
  - Provides a roadmap for maximizing digital investments
  - Provides the foundation for additional research
    - Digital Infrastructure hosts Data Architecture and Analytics applications
      - What features/applications are needed?
      - Where do they best reside on the Digital Infrastructure
    - Human-Technology Integration
    - Business Case Analyses of activities directed toward the New State

INL/EXT-21-64580 Is Publicly Available
https://www.osti.gov/biblio/1822876-digital-infrastructure-migration-framework-report

Digital Infrastructure Benefits

- Integrate disparate digital system "islands" into a single, cohesive, data centric framework of "domains" that work separately **and together**
- Enables a "New State" that is much more than the sum of its constituent parts:
  - Fully leverage digital technology capabilities demonstrated in other industries
  - Accept new technologies as they become available in the marketplace and developed by research to enable extended plant operations to 80+ years from initial license date.
- Must be designed with obsolescence management addressed from the start
  - Maximize value of initial intellectual property investments (harvestable)
  - Protect those investments while enabling new capabilities

Support an Optimized Enterprise Concept of Operations

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Summary of Plant Modernization I&C Research Reports

- Transition non-safety/balance of plant I&C functions to one digital platform
  - **Addressing Nuclear I&C Modernization Through Application of Techniques Employed in Other Industries**: (https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_20014.pdf)
- Transition current safety-related I&C functions to one digital safety platform:
  - **Vendor-Independent Design Requirements for a Boiling Water Reactor Safety System Upgrade**: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_27502.pdf
  - **Business Case Analysis for Digital Safety-Related Instrumentation & Control System Modernizations**: https://www.osti.gov/servlets/purl/1660976
  - **Safety-Related Instrumentation & Control Pilot Upgrade Initiation Phase Implementation Report**: (https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_26667.pdf)
- **Digital Infrastructure Migration Framework**
  - https://www.osti.gov/biblio/1822876-digital-infrastructure-migration-framework-report

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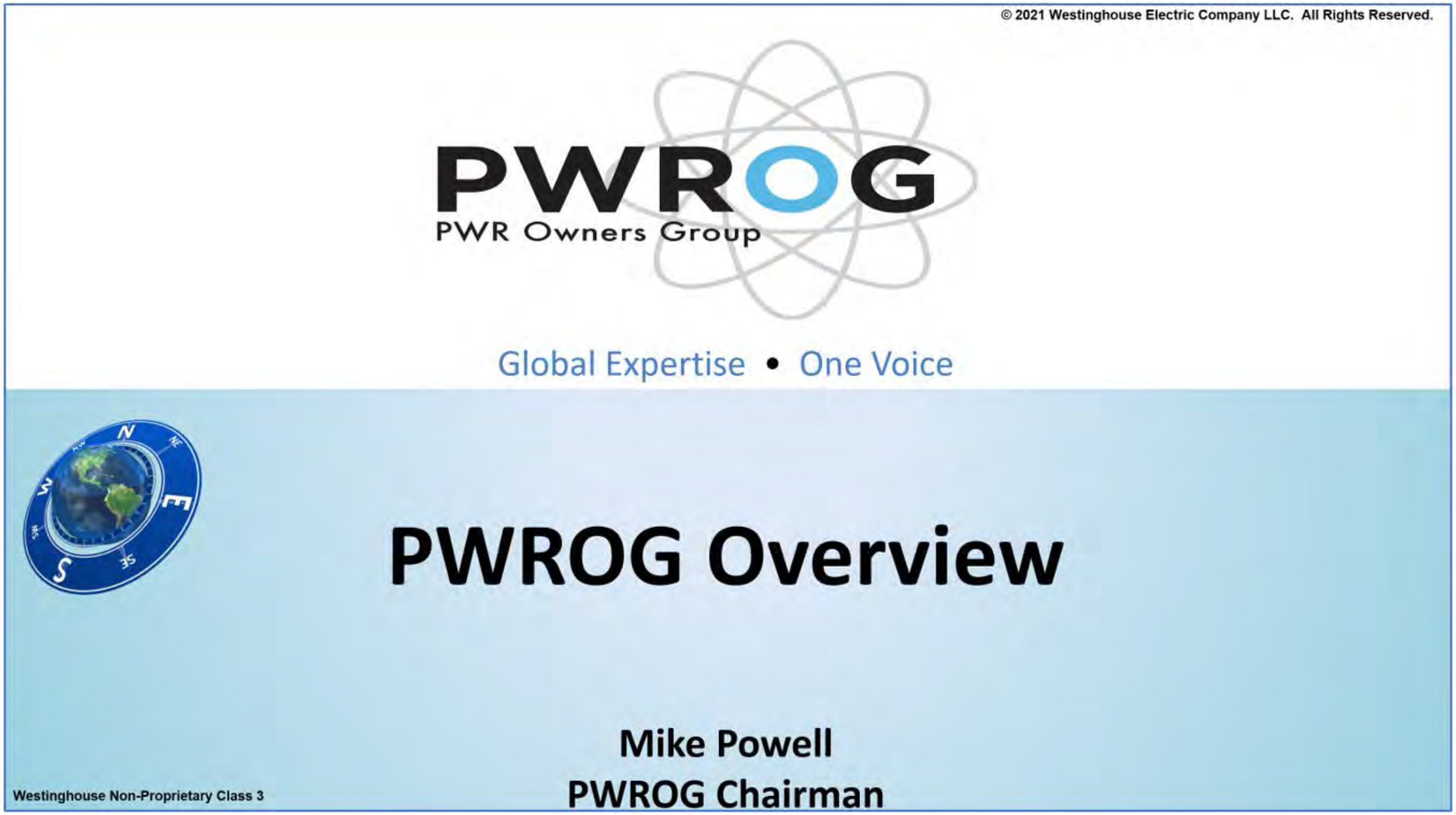
Appendix D

Pressurized Water Reactor Owners Group Stakeholder Needs Workshop Session Presentation



PWROG Timeline

PWROG
PWR Owners Group

1979	2000	2002	2006
OEM Owner Groups Form Three vendor owner groups form following the Three Mile Island Event: WOG, B&WOG, and CEOG.	**Westinghouse/CE** While owned by British Nuclear Fuels of the United Kingdom, Westinghouse purchases CE from ABB to bring two of the original three U.S. based PWR designers under one umbrella.	**WOG (including CE now)** Westinghouse and CE owner groups merge to form a new Westinghouse Owners Group (WOG)	**PWROG** The WOG partnered with Framatome and the original B&WOG to form the PWROG that exists today

2

PWROG Mission

PWROG
PWR Owners Group

The mission of the PWROG is to improve the competitiveness of member plants through cost-effective resolution of issues common to more than one member and to provide a superior regulatory interface in support of member activities.

3

PWROG Membership Composition

PWROG PWR Owners Group

1,800 MEMBERS

180 PWR UNITS

Ameren
American Electric Power
Angra I
Arizona Public Service
Barakah NPP
Beznau
Borssele
Constellation
Dominion
Duke
EDF
Sizewell B

Electrabel
Energy Harbor
Entergy
Evergy
Florida Power & Light (FPL) / NextEra
Hokkaido Electric Power Company
Japan Atomic Power Company
Kansai Electric Power Company
Korea Hydro & Nuclear Power
NPP Krško
Kyushu Electric Power Company
Luminant Power

Pacific Gas & Electric
PSEG
Ringhals 2,3,&4
Shikoku Electric Power Company
Southern Nuclear Operating Company
South Texas Project (STP) Nuclear Operating Company
Spanish Utilities (ANAV & CNAT)
Taiwan Power Company
Temelin
Tennessee Valley Authority
Xcel Energy

4

Westinghouse Non-Proprietary Class 3

Our Major Focus Areas

PWROG PWR Owners Group

Post-TMI
- ERG Developmt
- Technical Specifications Improvements
- Use of PRA

Post-Chernobyl
- Improvements to licensing basis change process
- Generic SAMG development

1990-2011
- Risk-informed initiatives
- License extensions
- Ctmt Sump Integrity (GSI-191)
- Reactor vessel integrity

Post-Fukushima
- FLEX
- Enhanced SAMGs
- Seismic and external flooding re-evaluations

Examples of Current Industry Issues

- **Digital Instrumentation and Control (I&C) Implementation**
- Risk-Informed Changes
- Materials Management and Technology
- **Plant Modernization**
- **Flexible Power Ops**
- Advanced Technology Fuel
- Supporting 60 & 80 year License Renewals

5

Westinghouse Non-Proprietary Class 3

Importance of Plant Modernization for PWROG

- As displayed by our focus areas, our membership is increasingly focused on plant modernization due to:
  - Equipment Reliability and Obsolescence Issues
  - Move to 80 year plant life or longer
- Given the broad-based interest in plant modernization, common solutions to modernizations are preferred due to improved economics
- Lessons learned in new technologies can be shared and across members to improve reliability and overall improvement of capacity

6

Westinghouse Non-Proprietary Class 3

Takeaways from Collaboration with INL

- Following participation at the January 2022 PWROG I&C Working Group, the INL hosted a visit of PWROG members in March 2022
- INL has great capabilities via their programs in the Light Water Reactor Sustainability Program
  - I&C Architecture (Digital Infrastructure)
  - Data Architecture & Analytics
  - Human & Technology Integration Tools
  - Risk Informed Applications
- There are many products already available for implementation

As the Digital Infrastructure provides the foundation for and integrates the INL capabilities above, INL was requested to present Digital Infrastructure research at the July PWROG Meeting

7

Westinghouse Non-Proprietary Class 3

Takeaways from Collaboration with INL

- From the July PWROG ICWG Presentation on Digital Infrastructure:
  - Integration of different domains into one complete infrastructure
  - Addresses human factors engineering and cyber security across the infrastructure
  - It promotes data integration across an enterprise to enable advanced features (e.g. diagnostics/prognostics)
  - Promotes facility/utility wide standardization and alternative support models (centralized vs. large (and underutilized) site organizations)
  - Encourages "80+" lifecycle thinking from the start
  - Applies non-nuclear industrial concepts to enable more "strategic" thinking as contrasted with legacy "plant health" replacements
  - Applies business case analysis techniques to economically justify digital upgrades

The INL Digital Infrastructure approach provides a holistic direction for examining potential upgrades rather than having a series of 'digital islands'

8

Westinghouse Non-Proprietary Class 3

Future Collaboration Opportunities

- Moving forward, it is important for the PWROG and INL to continue to collaborate
- While INL is an industry leader focused in research and development, the PWROG is primarily focused on implementation
- The results of seamless cooperation between organizations will lead to significant cost savings for utility members and improved operation
- Near term activities include:
  - Continued enhanced communication between organizations
  - Agreement to identify opportunities for collaboration focused on handoff between R&D and Implementation

9

Westinghouse Non-Proprietary Class 3

PWROG
PWR Owners Group

Global Expertise • One Voice

Questions?

Appendix E

Nuclear Information Technology Strategic Leadership Stakeholder Needs Workshop Session Presentation

Introduction

- **Nick Bryant**
  - IT Engineering Analyst at Joseph M. Farley Nuclear plant
    - Supporting site infrastructure, wired and wireless, various innovation efforts and digital modernization projects into the plant
  - Recently served as Co-Chair and Chair for NITSL Digital Controls Sub-committee

2

NITSL

- Nuclear Information Technology Strategic Leadership (NITSL) is a forum to provide leadership and strategic guidance for information technology in the nuclear industry
- Our purpose is to coordinate a consistent direction in industry-wide initiatives and serve as an interface for communications with regulators and industry groups
- The focus areas of NITSL fall into these process initiatives:

Software Quality Assurance (SQA) | **Cyber Security**
Digital Control Systems | **Infrastructure and Applications**

3

NITSL – Digital Controls Sub-committee

- The Digital Controls (DC) sub-committee provides leadership to the industry in the area of digital plant process monitoring and control equipment throughout its lifecycle.
- Focus areas of priority include interfaces and processes supporting the effective use of Information Technology in the plant

4

LWRS Digital Infrastructure Concept

- The Light Water Reactor Sustainability (LWRS) Digital Infrastructure concept is well suited to help address some of the objectives that NITSL Digital Controls are looking to address
- Digitalization (or digital modernization) is more than replacing obsolete components with newer components, it enables business transformation when applied correctly
- This digitalization is occurring all over the industry

5

LWRS – NITSL

- The LWRS Digital Infrastructure concept was able to combine multiple areas of NITSL interest: it was presented to an I&A and DC joint session.

> "Good presentation, interesting stuff. It spurns off additional discussion that we can have within our NITSL DC discussions"
> ~ *Participant Feedback*

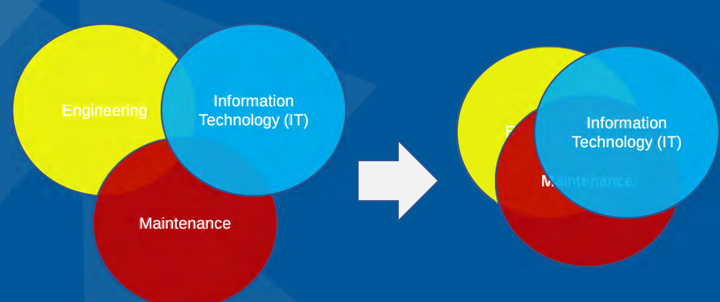
> "Having an outline of standard infrastructure, including historian, control system, and monitoring systems, and a partner in the industry to help in patching and maintenance, along with upgrade strategies, is a good plan"
> ~ *Participant Feedback*

- This concept also helped identify many of the common challenges/gaps the NITSL participants also encounter to reach modernization

6

LWRS – NITSL

- How are utilities approaching/designing a modernization strategy with this LWRS concept in mind?
- How do you support and implement it?



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LWRS – NITSL

- The Digital Infrastructure concept gave a vivid example into the roadmap identified by INL that others can follow
- Multiple utilities are at various stages of the roadmap which can be at the beginning or somewhere in the middle
- Establishing a standard on the front end to incorporate into subsequent modernization projects aids in success
- Additional discussion into utility Plant Health processes especially in terms of life cycle management (incl. business case development)

8

LWRS – NITSL

- Information Technology is extending beyond the “typical IT group” but a skillset and mindset that is necessary for success
- Identified the challenges between the roles to implement and support across the industry (IT vs OT vs I&C, for example)
- How to keep these individuals “up to date” with the rapid pace of technology

9

LWRS – NITSL

- With the introduction of more technology (screens, data, etc.), how will governance be addressed on what they can use
- Finding the right place for IoT and other mobile wireless devices (i.e., Monitoring and Diagnostic center monitoring)

10

LWRS – NITSL - Summary

- The Digital Infrastructure concept presents a good framework that can be utilized and discussed across the industry
- There are challenges to implementing a modernization plan which majority of the utilities encounter but we can work together for solutions

11

Questions / The End

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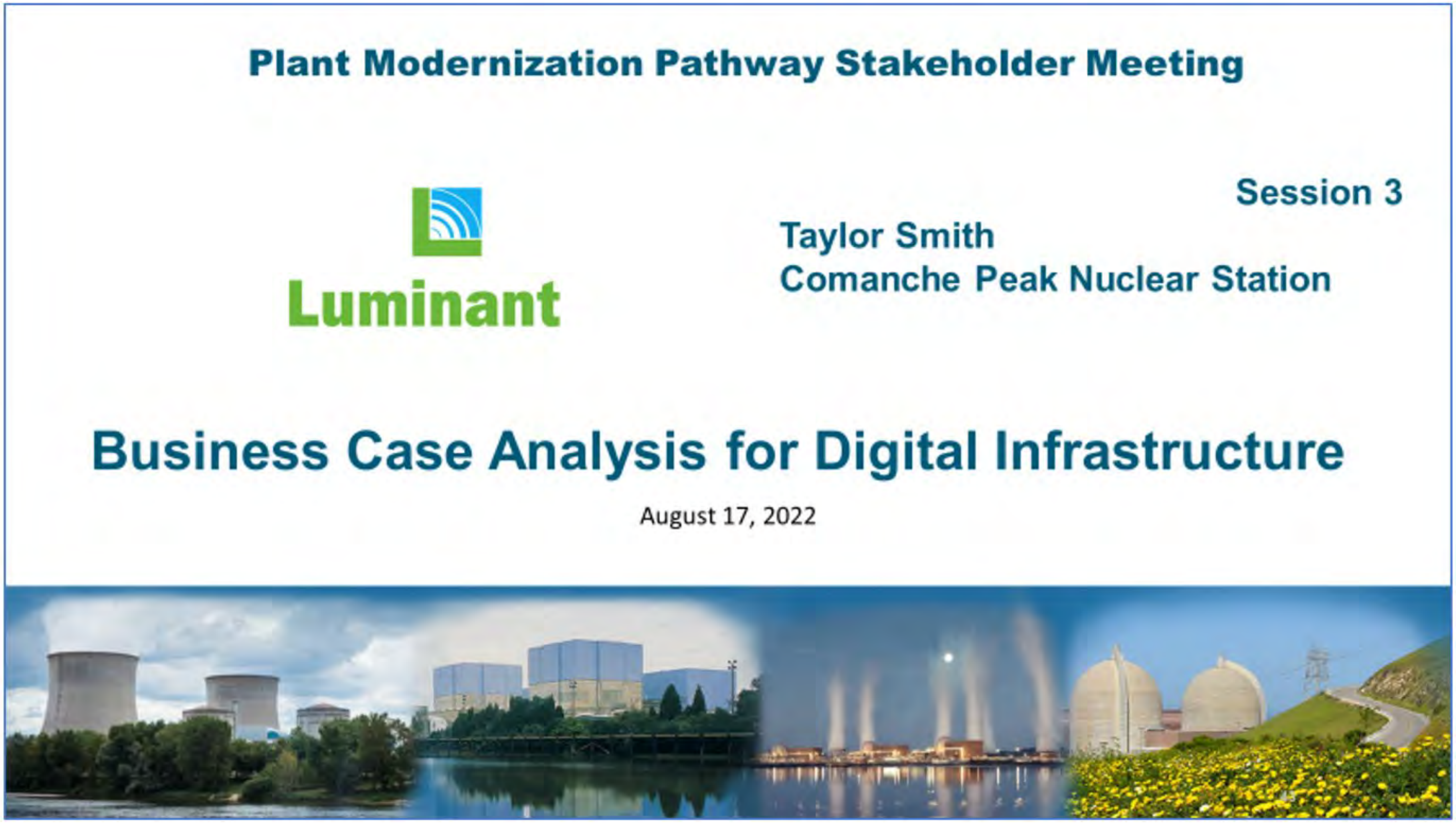
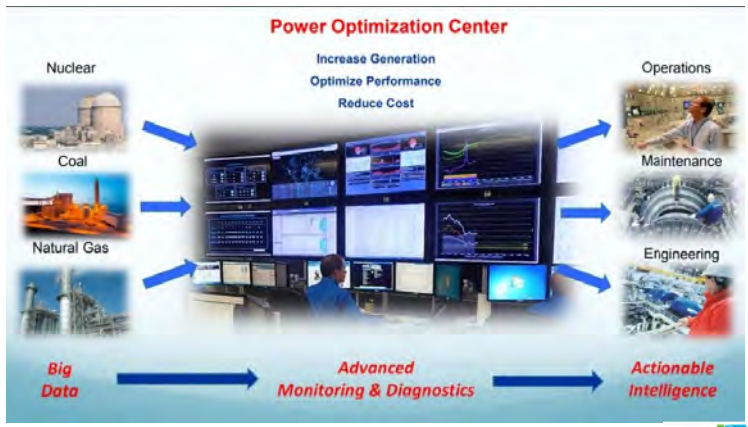
Appendix F

Comanche Peak Stakeholder Needs Workshop Session Presentation



Comanche Peak Digital Modernization Activities to Date

- Digital upgrades to date:
  - Main and feedwater turbines
  - Generator controls
  - Plantwide WiFi
- Luminant Fleetwide Monitoring:
  - Internal
  - Fee for service for other utilities
  - Plant Optimization Center – use



Luminant

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Challenges/Goals

- Challenges
  - Find the optimized solution that addresses all three categories below:

Obsolescence/Reliability	Long Range Planning	Modernization Multiplier
Post Accident Monitoring	Safety-Related 7300 Repl.	Diagnostics/Prognostics
In-Core Monitoring	Non-Safety 7300 Repl.	MW efficiency gains
Annunciator systems	Rod Control	Parts/logistics reduction
AMSAC	Plant Computer	HSI improvements / error reduction
Containment Monitoring	Solid State Protection System	Standardization of Processes
Hydrogen Monitoring	Feedwater Heater Drain Controls	Centralization/outsourcing

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INL Engagement on Digital Infrastructure

- If the industry followed historical practice, digital like-for-like functionality would be all we'd get.
- Introduced to Digital Infrastructure INL Research Through ScottMadden and Associates
- The Digital Infrastructure comprehensive framework that envelopes the full scope of Comanche Peak's envisioned modernization effort (top-down and bottom-up)
- It enables the "Modernization Multiplier" that Comanche Peak is counting on.
- Is a natural enabler to a larger POC capability.
- Is coupled with a business case analysis methodology. Utilities don't have an internal process or expertise to perform.

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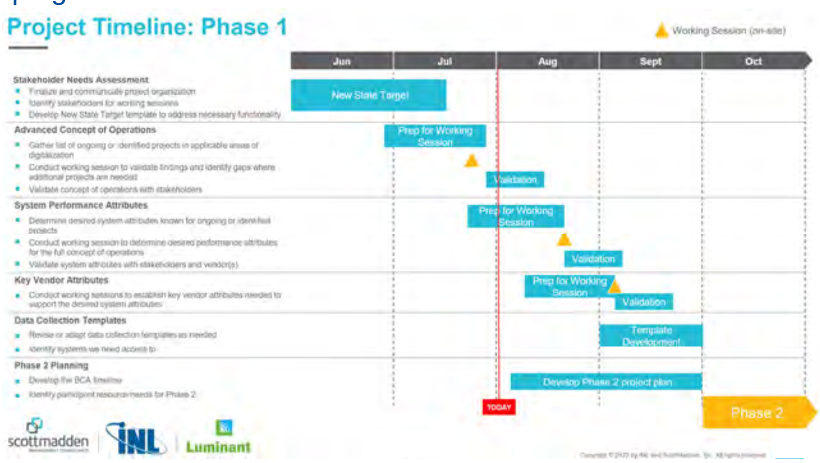
Applying The Digital Infrastructure Concept at Comanche Peak

- Scoping of the Modernization Effort and Associated Business Case Analysis



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Scope of near-term effort – (Top-down view)

- Identify New State Target (Stakeholder needs assessment) that identifies optimal technologies to address obsolescence (bottom up) and necessary functionality (Top down)
- 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)
- Engage potential vendors for walk-downs and provide input to digital transformation scope (participating utility engages vendors)
- 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)

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Scope of near-term effort – (Bottom Up View)

- Face to face meetings and telecons
  - Telecons and face to face meetings: engineering, operations, maintenance, projects, scheduling, training, supply chain, contracts
  - Detailed walkdowns with Westinghouse and Framatome (NDAs being put in place)
  - Face to Face Meeting on-site with ScottMadden.
  - Additional on-site face to face with INL/ScottMadden scheduled.
- Adapt existing data collection templates for use (as necessary) to support business case data collection.

Project Scoping Effort and Business Case Analysis Plan Targeted for End of September

Luminant

7

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Planned Future Scope

This includes:

- Data mining all sources of cost data and process to I.D. existing costs and drivers (cost analysis)
- Identifying/refining performance attributes to enable optimal CONOPS/New State performance/cost goals
- Performing Business Case benefits analyses for identified in-scope systems and components
- Incorporating estimated implementation and Ongoing Cost Data for upgraded/new systems as provided by the participating utility and their selected vendor(s)
- Validating vendor-walk-down scope
- Completing the Business Case Analysis (using industry tool)
- Producing a utility specific presentation and report: May 2023 to support FY24 and beyond planning at Comanche Peak.
- Producing an industry facing presentation and report: September 2023

CRADA being put in Place to formalize activities between Comanche Peak and INL

Business case research effort is a key enabler for Comanche Peak

Luminant