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Digital Architecture Requirements

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Ken Thomas and Johanna Oxstrand

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EXECUTIVE SUMMARY

The Digital Architecture Pilot Project is a part of the Department of Energy (DOE) sponsored Light-Water Reactor Sustainability (LWRS) Program), and within this program, the Instrumentation, Information, and Control (II&C) Systems Technologies Pathway. This Pathway is being conducted by Idaho National Laboratory (INL).

A major objective of the LWRS program is the development of a seamless digital environment for plant operations and support, integrating information from plant systems with plant processes for nuclear workers through an array of interconnected technologies. The digital architecture is defined as a collection of information technology (IT) capabilities needed to support these digital interconnected technologies.

This collection of IT capabilities must in turn be based on a set of requirements that reflect the intended use of the interconnected technologies. These requirements, simply put, are a statement of what sorts of digital work functions will be exercised in a fully-implemented seamless digital environment and how much they will be used.

This report describes an initial set of requirements for the digital architecture in terms of I&C and IT capabilities needed to support NPP work activities employing new digital technologies identified and developed in other pilot projects within the II&C Pathway. This report presents the user requirements in four areas of nuclear power plant (NPP) digital technologies:

1. Mobile Technology for NPP Field Workers
2. Control Centers
3. Main Control Room
4. Automated Plant Functions

Each of these areas is represented by tables that list the defined user functions that are expected to require significant IT resource support. The tables present a rough estimate of frequency of this usage.

In a later phase of this project, a conceptual model of the digital architecture will be developed based on the performance requirements documented in this report. The model will relate these requirements to the corresponding IT infrastructure components and their respective capacity and performance requirements. A guidelines document for utilities to implement this conceptual model will be developed to assist with the scoping effort for IT upgrades for the support of targeted digital technologies.

This project will ultimately provide guidance for utilities to customize these tables and to estimate the amount of user requirement service they will need. This will provide a basis for a utility to effectively plan the IT infrastructure needed to support the specific digital technologies that they will implement.

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ACRONYMS

AOCC	advanced outage control center
AWP	automated work packages
CBP	computer-based procedures
CCV	correct component verification
Collab.	collaboration
Comm.	communication
COSS	computerized operator support system
CR	control room
DCS	distributed control system
Doc	document
DOE	Department of Energy
EMC	electromagnetic compatibility
EOF	emergency operations facility
EPRI	Electric Power Research Institute
ERF	emergency response facilities
HVAC	heating, ventilation, and air conditioning
INL	Idaho National Laboratory
I&C	instrumentation and control
II&C	instrumentation, information, and control
Inst.	instruction
I/O	input/output
IT	information technology
LWRS	light water reactor sustainability
MDSC	management decision support centers
M&TE	measuring and test equipment
NDE	non-destructive evaluation
NPP	nuclear power plant
OCC	outage control center
OE	operational experience
Ops	operations
OSC	operations support center
R&D	research and development
RUL	remaining useful life

RP	radiation protection
Qual.	qualification
TSC	technical support center
STA	shift technical advisor
Supp.	supplemental

1. INTRODUCTION

1.1 General LWRS and Research Background

The Digital Architecture Pilot Project is a part of the Department of Energy (DOE) sponsored Light-Water Reactor Sustainability (LWRS) Program, and within this program, the Instrumentation, Information, and Control (II&C) Systems Technologies Pathway. This pathway is being conducted by Idaho National Laboratory (INL). The LWRS Program is performed in close collaboration with industry research and development (R&D) programs that provides the technical foundations for licensing and managing the long-term, safe, and economical operation of current U.S. nuclear power plants (NPPs).

A major objective of the LWRS program is the development of a seamless digital environment for plant operations and support by integrating information from plant systems with plant processes for nuclear workers through an array of interconnected technologies. This includes technologies to improve nuclear worker efficiency and human performance; to offset a range of plant surveillance and testing activities with new on-line monitoring technologies; improve command, control, and collaboration in settings such as outage control centers and work execution centers; and finally to improve operator performance with new operator support technologies for the control room (Hallbert & Thomas, 2014).

The digital architecture is defined as a collection of information technology (IT) capabilities needed to support and integrate a wide-spectrum of real-time digital capabilities for nuclear power plant performance improvements. The digital architecture can be thought of as an integration of the separate I&C and information systems already in place in NPPs, brought together for the purpose of creating new levels of automation in NPP work activities. In some cases, it might be an extension of the current communication systems, to provide digital communications where they are currently analog only.

The purpose of this project is to provide insight into what additional IT and I&C capabilities will need to be added to that of the current configurations to support the full suite of digital technologies. This planning will need to take place well in advance of the implementation. Further, these additions could prove to be substantial upgrades and will need to be part of the long-term IT planning process.

This collection of IT capabilities must in turn be based on a set of user requirements that must be supported for the interconnected technologies to operate in an integrated manner. These requirements, simply put, are a statement of what sorts of digital work functions will be exercised in a fully-implemented seamless digital environment and how much they will be used.

This report describes an initial set of requirements for the digital architecture in terms of I&C and IT capabilities needed to support NPP work activities employing the new digital technologies identified and developed in other research efforts with in the LWRS II&C pathway, i.e., the report addresses the DOE milestone M4LW-15IN0603122 – "Complete a report documenting the digital architecture requirements describing the information technology requirements as envisioned to be applied to nuclear power plant work activities". The requirements are stated in terms of user functions rather than IT requirements. For example, a requirement would be for a worker with mobile technology to download a certain number of documents, as opposed to the files sizes and transmission rates of the downloads themselves, which will be determined in next year's task within this Pilot Project.

The report is organized as follows:

Section 1.0 – Introduction and previous related research activities, providing background on the origin and types of NPP work technologies that will need to be supported by the digital architecture.

Section 2.0 – Technical Requirements for digital work functions, presented in four groups:

1. Mobile Technologies for NPP Field Workers – primarily related to technologies for mobile workers involved in work activities throughout the power plant, as opposed to

plant workers in office situations which are already heavily computerized through stationary computer equipment.

2. Control Centers – centralized command and control facilities with dedicated staff for the purpose of directing work and response efforts, such as an outage control center or a work control center. This category also included emergency response facilities.
3. Main Control Rooms – new technologies that will be available to control room operators, over and above those currently provided in the typical control rooms of today. These include functions that operators will use to operate the plant, as well as functions they will use to interact with the plant support staff.
4. Automated Work Functions – new technologies that replace what are currently manually-performed plant work activities. These include new on-line condition monitoring activities, as well as other technologies that eliminate the need for operators and technicians to travel to plant components for the purpose of determining component status data (position, instrument and alarm readings, ambient environmental conditions, etc.)

Section 3.0 – Conclusions, summarizing the insights that have been gained from the data analysis in this project and how certain types of digital technologies will impose requirements on the digital architecture.

Section 4.0 – Path Forward, describing how the technical requirements described in this report will be used in later phases of the Digital Architecture Pilot Project.

1.2 Previous Research Activities

For over five years, the II&C Pathway has worked with utility industry partners to develop digital technologies that will improve nuclear plant performance and extend plant life. Work has been completed in the area of mobile technologies for NPP field workers. Efforts are currently underway in the areas of Advanced Outage Control Center, Automated Work Packages and Computer-Based Procedures, Hybrid Control Rooms, and the On-Line Monitoring projects. Each of development areas are briefly described below.

1.2.1 Mobile Technologies for NPP Field Workers

Virtually all plant work activities are conducted under the control of rigorous work processes that convey the required job quality and technical requirements. Up until now, these work processes have generally relied on printed paper to present information to the plant workers and to serve as the medium to direct execution and recording of the specific tasks of the work activities. However, paper (as a medium) has the obvious limitations of not being interactive with real-time information sources; it is inflexible in its usage, leaves room for interpretation; and is incapable of enforcing its printed requirements. Technologies that have replaced the use of paper processes in the office environment have not been as easily adapted to field worker requirements (Farris & Medema, 2012).

The II&C Pathway has developed basic mobile technology capabilities needed by an NPP field worker in performing typical plant work activities. It includes general work process instructions, component identification capability, wireless communications to transmit and receive real-time information, audio, picture and video streaming, and use of heads-up, hands-free displays for workers involved in hands-on work. These capabilities can be combined to support the work flow of standard NPP work processes. These technologies together serve as the basic platform for the use of automated work packages and computer-based procedures, a current development effort described later in this report. A future development effort will add a new capability for mobile workers known as augmented reality, which is the superimposition of abstract or invisible information onto the field of view that is in a heads-up display or hand-held device. For example, a color-gradient representing the strength of a radiation field can be displayed over the field of view to enable a worker to avoid high dose areas.

1.2.2 Advanced Outage Control Center

The outage control center (OCC) is the central command and control point for executing NPP outages. There is a vast variety of information communicated both within the OCC and between the OCC coordinators and different plant organizations on a daily basis. For example, the coordinators have to ensure that all supporting organizations are aware of changing needs and are responding to accordingly. The coordinators typically have to leave their positions in the OCC several times a shift to attend coordination meetings back in their functional support centers and are not available for coordination with other OCC positions during those times (St. Germain et al., 2014).

The II&C Pathway is developing a range of communication, coordination, and collaboration technologies that will constitute an Advanced Outage Control Center (AOCC). These technologies will allow the OCC staff to more quickly obtain work status, identify outage schedule threats, make timely decisions, communicate changes to the organization, and respond to emergent problems. These include technologies to conduct interactive meetings with participants in other locations. The technologies will allow the entire OCC to share information as it develops in response to an emergent issue and they will allow the OCC coordinators to meet electronically with their respective functional support centers without having to leave the OCC. The technologies will also update all affected work management systems as decisions are made on how to resolve problems. Finally, they will provide the outage managers with the true status on the progress of work and the implementation status of outage plan changes from the OCC managers and coordinators.

These same technologies are also beneficial to other types of control centers, such as work control centers, management decision support centers, and emergency response facilities.

1.2.3 Automated Work Packages and Computer-Based Procedures

There are many advantages to transferring from a paper based work order and procedure process to a computer-based process. Vast amounts of information, such as plant configuration, operation mode, and other active work order information can be presented to the field worker in a succinct and easily comprehensive manner. Human performance tools (e.g., place-keeping and correct component verification) can be integrated in the computer system and hence become a natural part of the work flow rather than additional steps to the work execution. These will allow the field workers to maintain focus on the tasks at hand and to perform them safely and effectively (Oxstrand et al., 2014).

Automated work packages and computer-based procedures are both forms of computer-based work instructions and they share many of the same features. They typically differ in the degree of formality and rigor by which they must be executed. They can each be used in a stand-alone manner or they can be combined such that the automated work packages present a sequenced set of custom work instructions and standard procedures. The following are some of the important features of these technologies (Agarwal et al., 2014):

- Integrated human performance tools
- Real-time correct component verification
- Verification of worker qualifications
- Verification of correct M&TE and calibration status
- Integration with real-time plant data and system status
- Ability to download needed reference documents
- Seamless transitions to other procedures

- Computational aids and validation of results
- Embedded job aids – reference material, training material, and operating experience reports
- Automatic information insertion and verification of plant response
- Remote concurrences and authorizations
- Ability to transparently transmit work status to control centers

The II&C Pathway is developing a set of automated work packages technologies which integrate the computer-based procedure technologies to enable the work flow of complex plant work activities. These technologies are intended to operate in a wireless communication environment, although they can function in a near-time (sync station) environment if necessary.

1.2.4 Hybrid Control Rooms

Hybrid control rooms are ones that have a mixture of traditional analog II&C technology and newer digital technology. More and more digital conversions of analog II&C systems will be undertaken by U.S. nuclear utilities as concerns over reliability and component aging continue to accrue. The cumulative effect for the current operating nuclear plants will be an ever-increasing presence of digital systems in the LWR control rooms, although it is unlikely that all of the analogy systems will be upgraded to digital (Hallbert & Thomas, 2014).

The II&C Pathway is developing new technologies for hybrid control rooms that will assist operators in two main ways. The first is new operator interface technologies that provide enhanced means of conducting normal, abnormal, and emergency operations in a hybrid control room setting. These include such technologies as computer-based procedures, advanced alarm systems, computerized operator support systems, task-based displays, group view displays, and others (Boring et al., 2012 and 2013).

The second area is technologies for operators to more effectively interact with plant support processes. These technologies are similar to those for mobile workers and control centers, in that they enable the control room to communicate and direct field support activities of an operational nature (Le Blanc et al., 2014).

1.2.5 On-line monitoring – active and passive

As NPP systems begin to be operated during periods longer than originally anticipated, the need arises for more and better types of monitoring of material and component performance. To reduce labor costs, there is also a need to move from periodic, manual assessments and surveillances of physical components and structures to centralized on-line condition monitoring. This is an important transformational step in extending the lives of NPPs. It enables continuous, real-time assessment of emerging degradation for plant components. It also provides the ability to gather substantially more data through automated means and to support automated cause analysis (diagnostics) based on component fault signatures. In addition this technology includes prognostic models to determine the “remaining useful life (RUL)” of components and structures, to justify continued operation over the short term to that of extended plant life.

The II&C Pathway is conducting research on diagnostic and prognostic models for certain active plant components, such as emergency diesel generators, large power transformers, and large induction motors. This research is being conducted as part of a project led by the Electric Power Research Institute (EPRI), which has developed a comprehensive on-line condition monitoring technology known as the Fleet-wide Prognostic and Health Management (FW-PHM) Software Suite. EPRI is also involving other research organizations to develop to a broad library of diagnostic and prognostic models for a variety of plant components life (Agarwal et. al, 2014).

The II&C Pathway is also conducting research with Vanderbilt University on on-line monitoring of passive components. The current focus is the development of a framework for health diagnosis and prognosis of aging NPP concrete structures subject to physical, chemical, and mechanical degradation, by integrating modeling, monitoring, data analytics, and uncertainty quantification techniques.

Together, these two development efforts will provide effective on-line conditioning monitoring for a large percentage of NPP components and structures (Agarwal & Mahadevan, 2014).

2. TECHNICAL REQUIREMENTS

As previously mentioned, the technical requirements for the NPP digital architecture consist of the expected digital work functions of a fully-developed seamless digital environment for a NPP. These requirements are identified by the previous and ongoing research and development activities of the II&C Pathway. They consist of the prototype capabilities that have been developed and demonstrated with utility partners to-date, as well as anticipated new capabilities that are logical extensions of the current digital work functions and will be developed in future projects.

The other major factor concerning the technical requirements is how much the digital work functions will be used. The sum total of the usage at a given time will drive the capacity requirements of the IT infrastructure to maintain acceptable throughput and time response of all of the digital work functions. The estimates used in this report are based on expert knowledge of both II&C Pathway researchers and the industry collaboration partners.

While these technical requirements are a good starting point to begin planning the needed digital architecture, it is recognized that they will evolve over time as new digital work functions are developed and new insights are gained into how much usage within a given NPP is likely. Therefore, these technical requirements should be thought of as a flexible framework that describes what is known today, can accommodate the identification of new work functions that result from future research efforts, and can be customized for a specific utility scope of implementation at any given time.

2.1 Mobile Technology for Field Workers

Computer technology is used extensively throughout nuclear plant work functions, but, up to now, has been largely restricted to office areas. A large portion of the plant staff has to conduct work in locations throughout the nuclear plant where computers and terminals are not readily available. This is particularly difficult for workers who have to move from location to location to conduct their jobs. In these cases, the workers are not able to take advantage of digital technologies to improve their efficiency and work quality, but rather must rely on paper copies of their work instructions and references.

Technologies are now available, and more are being developed, that will enable mobile field workers to take advantage of digital processes throughout plant locations, such as the ones listed in Section 1.2.2. Automated Work Packages and Computer-Based Procedures. Over the next few years, rapid deployment of these technologies is expected to capture efficiency and human performance benefits. Having a digital architecture that can support the full number of mobile plant workers will be a significant challenge.

2.1.1 Basis of Requirements

Virtually all plant work activities are conducted under the control of rigorous work processes that convey the required job quality and technical requirements. To date, these work processes have generally relied on printed paper copies to present information to the plant workers and to serve as the medium to direct the execution and documentation of the specific tasks of the work activities. However, paper as a medium has the obvious limitations of not being interactive with real-time information sources. It is inflexible in its usage, leaves room for interpretation, and is incapable of enforcing its printed requirements.

Technologies that have replaced the use of paper processes in the office environment have not been easily adapted to field worker requirements. The primary difficulty in providing plant workers with technology to improve their performance has been the fact that the workers must move about the plant in sometimes relatively inhospitable environments for digital technology (e.g., temperature extremes, radiation, radio frequency interference, and confined spaces). Also, there has been no practical way to connect these devices for real-time interactions to assist mobile workers.

However, it is not enough to simply provide field workers with mobile technologies. These technologies must be integrated into the plant work processes and must be able to access real-time plant information.

Further, they must provide the ability for real-time interaction and collaboration with workers in other locations, in particular those who are coordinating overall plant operations, such as those in the NPP control room or outage control center. To address these needs, the solution is to literally embed the field worker in the digital plant processes and digital plant systems with wearable and hand-held technologies, such that the worker is an integral and connected part of the seamless digital environment supporting plant operations and related activities.

There will be a significant amount of demand on the information technology infrastructure to accommodate the daily activities of so many workers using digital technologies.

2.1.2 Description of Requirements

Field workers have two basic types of mobile technology requirements. The first is related to general requirements that any worker might have while being in the plant. These would be things like being able to initiate standard work processes at field locations, such as initiating a corrective action report, submitting a work request, generating a component deficiency tag, or requesting a fluid leak evaluation. There are other types of technologies that provide workers with location-related information, such as proximity to hazards, boundaries of restricted zones (e.g., radiation and radiography tests). Still others are general capabilities to access documents, communicate either by voice or video, or transmit video of plant problems.

The second type of requirement relates to the specific work tasks for which the workers are in the field locations to perform. Such work tasks are performed using documented work instructions and procedures, typically contained in some type of work package. In the future, work packages will be digital to provide a range of efficiency and human performance features. Many of these features will require real-time access to data sources and support real-time communications for collaboration. Others will be self-contained on the user device (e.g., tablet or other handheld device) and will require only periodic downloads and uploads to obtain and report information related to the work processes.

2.1.3 Requirements Tables

The following tables reflect the user requirements for nuclear plant field workers for general field requirements and for field tasks. The numbers in each column represent how many times that function is estimated to be performed plant-wide on a daily (24 hour) basis.

2.1.3.1 General Capabilities

There is a set of general technology capabilities that are needed by all plant workers in the conduct of their daily activities on site. Table 1 reflects a typical plant staffing level by major organization. At a given time, only a portion of that population is on site. The numbers depicted in Table 1 represent a particularly busy time in a refueling outage, such as when safety systems are being returned to operational status and there are still a number of contractors on site.

The technology activity listed in Table 1 represents an expected portion of the on-site work force who would be simultaneously using a given resource, such as real-time video collaboration, augmented reality, and voice communications. Augmented reality is where invisible or abstract data is transmitted to a worker portable device (such as a tablet) to make visible some phenomena in the worker's proximity, such as the strength of radiation fields superimposed on real-time video of the area.

Please note where the data value is " * ", this value is intentionally left out. Such would be the case in Table 1, where a plant would not want to list the activities of the Security organization, and for that matter, their activities would not likely be part of the general work processes anyway.

Table 1. General Capabilities

Control Center Functions	Number	Max on Site	Worker Location	Collaboration	Augmented Reality	Voice
Operations	140	80	80	5	20	7
Maintenance	200	160	160	8	40	10
Chemistry	30	20	20	2	5	2
RP	50	30	30	3	8	3
Engineering	150	130	130	5	33	8
Security	*	*	*	*	*	*
Safety Assurance	30	25	25	2	6	2
Supply Chain	75	60	60	3	15	4
Facilities	25	20	20	2	5	1
Utility Total	900	525	525	30	131	45
Augmentation Staff	1000	700	700	0	175	50
Suppliers	200	160	160	8	40	10

2.1.3.2 Work Packages

Work packages are presented in Table 2 and 3 in terms of the number that would be executed on one of the busiest days (24 hour period) in the life of the plant, typically occurring during a refueling outage. The major categories of work packages are computer-based procedures (CBPs), automated work packages (AWPs), tag-outs and clearances for personnel protection and equipment control, Operations (Ops) Rounds, and Clearance Sign-In's.

The estimates for the functions listed in the tables are multiples of the number of work packages that are executed in a day. For example, for correct component verifications (CCVs) related to computer-based procedures, it is estimated that there would be five per package, on average. (900 X 5 = 4500) Other types of functions that are estimated are qualification checks, measurement and test equipment (M&TE) checks, controlled document downloads, ad hoc job aids (e.g. training information), plant data values, real time collaboration sessions, work status, and step progress transactions.

Table 2. Work Packages, part 1

Work Instr.	No. in 1 Day	CCVs	Qual. Checks	M&TE Checks	Controlled Doc. Downloads
Work Packages	900	4500	1800	225	180
Tag-Outs	100	1000	0	0	0
Ops Rounds	24	960	800	0	0
Clearance Sign-In's	800	0	800	0	0

Table 3. Work Packages, part 2

Work Instr.	Ad Hoc Job Aids	Plant Data	Collaboration	Work Status	Progress Transactions	Sign-In's
Work Packages	450	4500	135	4500	180,000	
Tag-Outs	0	0	0	1000	1000	
Ops Rounds	0	240	0	120	240	
Clearance Sign-In's	0	0	0	0	0	1600

2.2 Control Centers

Nuclear plants have a set of special facilities that are used to manage work activities and coordinated responses to certain plant operational and safety challenges. Two of the most common types of facilities are the Outage Control Center and the Work Control Center. Other types are what are known as Emergency Response Facilities (ERFs), consisting of the Technical Support Center (TSC), the Operations Support Center (OSC), and the Emergency Operations Facility (EOF). There are other types of functional control centers, such as those dedicated to certain functional areas during outages, and there is the more general management briefing centers that are used by the plant management staff to conduct the plan of the day meetings and the on-site safety review group.

2.2.1 Basis of Requirements

The various types of control centers have many requirements in common. For example, the control centers must be able to:

- Develop and communicate work plans and issue resolution plans,
- Quickly and accurately obtain the status of work items and plant conditions, and assess the impact and adjust plans,
- Quickly make a sound decision and then communicate that to all affected parties, and
- Monitor the actions resulting from the decision and make adjustments to the plan as needed to effectively resolve the challenge.

There are several distinct communications paths that must be actively maintained, including information flow into, across, and out of the control center. Multiple types of communications must be supported, including voice, data, video, interactive collaboration, and others.

Control centers today rely heavily on printed paper to communicate, including work schedules, status reports, and task lists. They require a number of standing and as-needed meetings where people come from various organization locations to attend briefings and status meetings. The control center conducts a constant stream of small informal discussions among the staff there, interspersed with briefings and status meetings for all involved organization, observed critical tasks (video streaming from the field), and monitor status of tasks on critical path.

Many organizations dedicate individuals just to serve as points-of-contact for this purpose. These individuals are usually assigned to the control center and have dedicated work space there. They participate in meetings and discussions there representing their organization in providing input to decisions. They, in turn, communicate these decisions, task requests, and information requests back to their home organizations by phone, radio, or in person by traveling back to their organizations.

Considerable staff is dedicated to manually obtaining and processing work status, to make adjustments to schedules and plans, and to identify items requiring management attention.

2.2.2 Description of Requirements

Technology can greatly benefit control centers by enabling managers and staff to focus on important issues and decisions while much of the information gathering, analysis, and detection of problems is performed by automation. It must also enable effective and efficient collaboration among parties in different locations.

The control center will have an array of large interactive displays oriented to be visible and legible for the control center staff work spaces.

Control center staff will be able to communicate in a variety of ways. They will be able to communicate individually from their work spaces, using voice, video, and collaborative technologies using desktop displays. They will be able to hold video meetings with select groups of people from their desks. They will be able to participate in control center-wide briefings and status meetings that use the large displays to engage a large group in a focused discussion. These large group sessions will allow the active participation of remote parties.

Status of work activities will be sent automatically to the control centers, directly from automated work packages as steps are signed off as completed. The status would be processed by scheduling programs that will identify significant delays and their impacts, and alert control center managers to the need for action.

Field workers will have a means to immediately notify a control center of an emergent issue that needs attention. These notifications will be entered into a dynamic list on a large interactive display that will alert the control center staff and allow them to enter into a real-time video discussion with the field workers to gain a firsthand understanding of the issue and to gather additional information. This will include the use of video to see the issue directly. Other parties can be added to the discussion if needed, such as Engineering or off-site suppliers.

Issue management software will allow the entire organization to work under a common work package that contains all information about the issue. This software will provide immediate access to all individuals needing information about the issue, both on-site and off. This software will facilitate turn-over meetings and enable new team members to get up to speed quickly with the history of the issue.

2.2.3 Requirements Tables

The following tables reflect the basis of usage for each of the types of control centers found at a nuclear plant, i.e., OCC, WCC, Satellite Work Centers, and Craft Shops. The number of items addressed per control center is too large to properly present in one table, hence the Outage/Work Control Center table is broken up into two parts (see Table 4 and 5). A separate table (Table 6) is used to discuss requirements related to management decision support centers.

2.2.3.1 Outage/Work Control Center

The OCC is the central command and control point for executing NPP outages. It is staffed 24/7 during outages and accommodates 12 to 15 managers and coordinators from the site and fleet organizations supporting the outage. These positions are typically grouped according to organization and informally interact with one another to coordinate their specific work activities and problem resolutions. Various types of meetings are held on a regular schedule each shift to communicate outage status, share information on upcoming activities and emergent issues, and verify with each organization that they are prepared to support the upcoming activities.

In consideration of all of these coordinating activities, there is a significant need for advanced technologies to facilitate the information flow into, across, and out of the OCC. These include technologies to conduct interactive meetings with participants in other locations, including work locations in the plant. These technologies will allow the entire OCC to share information as it develops in response to an emergent issue. They will allow the OCC coordinators to meet electronically with their respective functional support centers without having to leave the OCC. They will update all affected work management systems as decisions were made in how to resolve a problem. Finally, they will provide the overall outage managers with the true status on the progress of work and the implementation status of outage plan changes from the OCC managers and coordinators.

The Work Control Center (WCC) is similar in nature to the OCC, and is the facility that typically handles real-time maintenance and testing while the unit is on-line. It sometimes serves as a work release point during outages, working in conjunction with the OCC. The WCC has similar technology needs as the OCC in coordinating and communicating work status and work plans.

Satellite Work Centers handle detailed coordination for work teams within a given organization. They work in conjunction with the OCC and WCC to carry out work direction from these centers. Again, their technology needs are the same in that they are in the same communication loops as the OCC and WCC. A typical Satellite Work Center is the Operations Tag-Out and Clearance function.

Craft Shops are typical of the Maintenance organization, in which they provide technical support to the craft teams. Again, they are involved in the same communication loops and need the same technology.

Table 4 below reflects a typical amount of communication activity for these control centers based on the busiest 24 hour period in a refueling outage. The collaboration sessions (briefings, streaming video, smart board, text messages) represent the typical traffic that would occur during a day. Voice communication is taken to be a dedicated resource for each worker in the center. Other parameters (remote concurrence, work status triggers, work status updates) are proportional to the amount of work activity in progress.

In the tables below, an " * " indicates that the function is covered by either a currently available capability (plant computer) for plants today or is covered by the numbers from the Outage Control Center.

Table 4. Outage/Work Control Center, part 1

Control Center Functions	No.	Staff/ Center	Briefings	Streaming Video	Voice Comm.	Text Messages	Remote Concurrence
Outage Control Center	1	12	12	20	12	1152	1000
Work Control Center	1	6	2	6	6	576	0
Satellite Work Centers	11	2	44	66	22	2112	0
Craft Shops	6	2	0	36	12	1152	5000

Table 5. Outage/Work Control Center, part 2

Control Center Functions	Doc Downloads	Supplier/ Contractor Interface	Plant Data/Status	Smart Board Collaborations	Work Status Triggers	Work Status Updates
Outage Control Center	120	2	*	24	2000	800
Work Control Center	60	1	*	6	*	*
Satellite Work Centers	20	44	*	66	*	*
Craft Shops	20	0	*	24	*	*

2.2.3.2 *Management Decision Support Center*

Management Decision Support Centers (MDSCs) are similar in function to the OCCs and WCCs, in that they require access to real-time plant and work activity information. However, they typically function at a higher level of work direction, communicating general direction in terms of plant operation and problem resolution actions as opposed to detailed work management information.

Most nuclear plants have a management plan-of-the-day meeting each morning and would be more effective in a dedicated space with communication and collaboration technologies. This space could be shared by the on-site safety review committee, which is often called on to approve risk-significant plant activities.

The Emergency Response Facilities (ERFs) are required by the plant's emergency plan and likewise would benefit from enhanced communication and collaboration technologies. These consist of the Technical Support Center, the Operations Support Center, and the Emergency Operations Facility. There is considerable interaction among these three centers during a plant emergency, as well as with the control room and the satellite work centers.

Table 6 presents the amount of expected usage of these technologies during the busiest settings, which are either event driven or are held on a regular schedule for a finite period, such as a plan-of-the-day meeting. The logic for the amount of usage is the same as for the control centers discussed above.

Table 6. Management Decision Support Centers

Management Control Center	Plant Data/ Status	Briefings	Streaming Video	Voice Comm.	Text Messages	Doc. Downloads	Remote Collab.
Management Decision Support Center	50	2	5	12	100	20	4
Technical Support Center	500	15	2	15	150	20	2
Operations Support Center	500	10	10	10	150	10	4
Emergency Operations Facility	500	15	2	15	150	20	4

2.3 Main Control Room

The technology of the main control room of a nuclear plant is critical to safe and productive operation of the facility. In operating plants today, much of the technology is analog reflecting decades-old instrumentation and controls. Some new technologies were introduced in the late 1980s in response to certain issues that were identified in the Three-Mile Island accident. Otherwise, there has not been much innovation in technology for operators and control rooms are operated the same way they were 40 years ago.

2.3.1 Basis of Requirements

It is recognized that human performance in the control room has probably reached its limits as far as achieving higher performance. The limits of the current technology require operators manipulate individual devices in prescribed sequences such that operator attention is completely absorbed in the details of operational tasks. This has at times created tunnel vision for operators such that they were not able to adequately monitor other situations that were occurring within the plant. Technology can improve situational awareness and provide for better plant monitoring.

The control rooms also require a high level of manual device manipulation compared to any other modern power or process facilities which have upgraded their control room technologies. This also requires certain operator skills that are learned through repetition and are not easily acquired by new operators. Higher levels of control room automation would relieve operators of performing so many tedious tasks and would allow them to divide their time better between task execution and plant monitoring.

With the current technology, operators are still susceptible to simple human errors such as reading the wrong indicator or manipulating the wrong switch. They are also still prone to commit procedure errors such as omitting steps or making computational errors. A better means of reinforcing operator protocols and human performance expectations is needed.

Control room supervisors and managers also need better means of monitoring the actions of reactor operators and provide more effective oversight. Similar, Shift Technical Advisors would benefit from technology that helped them better understand the plant situation and trends.

A distributed control system (DCS) is perhaps the biggest enabler of operator performance improvement when it is implemented in a manner to enable control automation. Many plants are pursuing either partial or full implementation of DCS systems to address certain plant operational issues. However, the full capability of these systems has not been exploited and there remains much potential within these systems to improve plant control and operator performance.

Modernization of the protection systems (reactor protection system, engineered safeguards features actuation system) might be desirable from the standpoint of reliability or resolving obsolescence issues, but it not particularly a high priority with respect to improving operator performance. This is because the protection systems do not have a significant operator interface, since its actions are taken automatically, and it by nature operates very infrequently.

2.3.2 Description of Requirements

A DCS is generally contained within the plant I&C systems and typically does not exercise any of the IT capabilities. It interfaces to control board and field devices through both a data bus and through direct connections through I/O cabinets. A DCS typically provides data to the plant process computer , which in turn, provides a slightly-delayed copy of this data out to the business network for general access outside of the control room. The plant computer is integrated into the DCS in some cases.

An advanced alarm system is another important new technology to improve plant monitoring and operator situational awareness. These systems are able to filter or suppress low-priority alarms and improved information presentation. Further, they can be integrated with a DCS to provide a seamless transition between the detection of a plant abnormal condition and the instigation of a procedure-based response to mitigate the plant upset. An advanced alarm system will communicate through the plant I&C architecture and will not generally interface directly with the plant IT infrastructure.

Computer-based procedures can be used in a stand-alone mode or interfaced directly to the DCS to provide various levels of control automation. In either case, they can also enforce operator protocols with embedded human performance tools. Computer-based procedures will mostly communicate within the plant I&C system, but it is possible that they would make external calls to data sources located in the plant IT infrastructure.

Large display screens will be used to provide better plant overviews and to improve collective situational awareness. The screens will be dedicated to either the plant I&C architecture for display of operator information or to the IT infrastructure for display of general process and business-level information. The business-level data functions would be similar to what is typical in control rooms today for access of plant work processes, general facility information, and external information such as weather maps.

A new category of control room technology is that of a computerized operator support system (COSS), which is a collection of capabilities to assist operators in monitoring overall plant performance and making timely, informed decisions on appropriate control actions for projected plant condition. These systems aid in assessing the current plant status, safety margins, and deviations from expected operations. These systems will mainly communicate with the plant I&C infrastructure and otherwise use self-contained data bases on dedicated servers, such that they do not serve as bridges between the IT infrastructure and the plant I&C infrastructure. However, they will need dedicated servers and communications equipment within the control room complex (or other secure location) as the platform for these functions.

Related to COSS technology is the use of physics-based simulators to detect plant operational anomalies by continuous comparison of actual plant performance to that predicted by the simulator. Some of these will be faster-than-real-time simulators where it will be possible to predict where the plant is going operationally and how long the operators have to intercede in undesirable plant trends. Like the COSS technology, these simulators will have dedicated IT features that are not connected to the general plant IT infrastructure, but rather are resident on a dedicated platform within the control room complex.

2.3.3 Requirements Tables

The main control room requirements tables are presented in two tables (Table 7 and 8), the first being the functions that operators will use in plant operations (operator support technologies), such as reactor operator, senior reactor operator, and shift technical advisor (STA). The second being those which operators will use to interact with the plant support staff (operator interface technologies).

2.3.3.1 Operator Support Technologies

Operator support technologies are functions that allow operators to easily and conveniently interact with the plant work processes in the context of plant operations. The functions they are able to execute are very similar to those that are available to plant workers and plant staff located in a control center.

Table 7 depicts that maximum amount of concurrent usage of these functions, as limited by the amount of operations staff on duty during a typical shift. For example, in a two unit control room, there would nominally be four reactor operators. A single operator could only execute one step of one procedure at a time, even though there might be several procedures in progress for a particular plant evolution. The other functions are represented by estimates of the likely amount of concurrent usage of that particular function.

Table 7. Operator Support Technologies

CR Team Member	Shared Procedures	Real-Time Collaboration	Video Streaming	Remote Concurrence	Work Status Update	Doc. Downloads
Reactor Operator	4	1	4	2	10	5
Sr. Reactor Operator	4	1	4	1	10	2
Shift Supervisor	4	1	2	0	10	2
STA	4	1	0	0	0	2
Shift Manager	4	1	2	0	0	2
Equipment Operators	4	1	0	0	0	5
Shift Support	0	0	0	0	10	10

2.3.3.2 Operator Interface Technologies

Operator support technologies represent new control room innovations that enhance operator performance and reduce human error. Table 8 represents a set of new capabilities that are envisioned for modernized control rooms. These capabilities, however, will interface to the plant I&C systems (and related components) as opposed to the plant data and information systems as is the case with the other tables of this report. They are therefore an additional burden on these plant I&C systems in the form of data requests and must be accounted for in maintaining adequate system response time for plant control functions.

The plant I&C systems that are impacted are the DCS, the general I&C system (e.g. single loop controllers), the plant alarm systems (including the annunciator system), the plant process computer, component monitoring systems (e.g. turbine vibration monitoring), the plant event recorder, and what is termed the plant supplemental information network. This last item represents a future network of new instruments and plant data devices that provide supplemental (not needed for plant operation) data for purposes of plant monitoring, fault diagnosis, prognostics, and other such capabilities.

The amount of concurrent usage of these functions is, in some cases, limited by the control room staffing, as was the case for Table 7 above. For example, for computer-based procedures, this would be limited by the number of operators (four reactor operators in a two-unit control room). In other cases, there would be wholesale transfer of data, as in the case of an alarm management system getting a refreshed set of alarm data from the alarm system (i.e. one entire scan).

Table 8. Operator Interface Technologies

Advanced Technologies	DCS	General I&C	Alarm Systems	Process Computer	Monitoring Systems	Event Recorder	Supp. Info Network
Computer-Based Procedures	4	4	0	4	0	0	4
Task-Based Displays	4	4	4	4	0	0	4
Alarm Management	0	0	400	4000	0	0	0
Group View Displays	100	50	200	50	50	0	0
COSS	1000	500	5000	4000	100	4000	100
Plant Status Monitoring Systems	100	50	0	50	0	0	1000
Virtual Sensors	0	0	0	0	0	0	1000
1st Principles Simulators	100	50	0	0	20	0	50
Remote Panel Display/Operation	0	50	50	0	0	0	20

2.4 Automated Plant Functions

Automated plant functions employ technology to replace manually-performed work activities. Automated plant functions include various types of plant, system, and component monitoring technologies, as well as technologies that perform active functions such as sampling and analyzing a fluid stream.

A new type of plant sensor application is to augment the plant instrumentation that was designed for normal and emergency operations with additional sensors that eliminate the need for human surveillance activities. If implemented in a cost-effective manner (low installation cost and low ongoing maintenance cost), these can be an attractive alternative to periodic manual surveillances.

2.4.1 Basis of Requirements

Nuclear plants are challenged to reduce operating costs. Labor represents the largest component of a plants operating and maintenance cost. Nuclear plant staffing levels are mostly driven by the large amount of tasks that have to be manually performed. In addition to the direct labor costs to perform these tasks, there are overhead costs hiring and training skilled workers, having sufficient staff to cover around-the-clock functions, supervisory oversight and direction, human performance concerns, and a large variety of employee support requirements (e.g., time away, fitness-for-duty, and behavior observation) In addition, there are proportional concerns in using human agents, such as personnel safety concerns, radiation dose, fatigue, and environmental exposures.

In many cases, new technologies can offer more cost-effective and higher quality options to perform these plant functions. They can provide continuous or on-demand coverage of the function and be set up to respond as needed to plant conditions as they are sensed.

These types of technologies have a somewhat consistent configuration. They are typically located at the process location, although some rely on remote sensors so that they can be located outside a harsh environment (for operational requirements or ease-of-maintenance). They either perform an analytical function locally or transmit data back to a central server for processing there. In either case, results are transmitted to both data bases and plant staff for awareness and further evaluation.

2.4.2 Description of Requirements

On-line condition monitoring systems employ non-destructive evaluation (NDE) sensors to acquire data that correlates to specific degradation mechanisms. This data is then processed for purposes of pattern matching, diagnostics, or prognostics (remaining useful life). The sensors are connected to the processors over instrument lines or by using dedicated digital communication lines. Wireless data transmission is also an option. Once the signals are processed, the technologies communicate with other data repositories over the IT infrastructure. This can be relatively frequent data sampling (in the MHz range) or relatively infrequent (on the order of minutes or hours). The low sampling rates are sometimes used to conserve battery life for sensors that don’t have external power sources.

Other types of monitoring technologies are concerned near-term requirements such as the position of components, such as whether manual valves are open or closed. These technologies will typically communicate over dedicated digital communication lines or over wireless connections.

Automated work functions also include analytical processing technologies. For example, a plant might install an in-line chemistry sampling system in lieu sending a technician to obtain a sample from a sample line and then transport it back to a chemistry laboratory for analysis and results processing. These types of technologies will typically use dedicated instrument lines for the required data points, but will use more general IT infrastructure to communicate results to data bases and monitoring stations.

2.4.3 Requirements Tables

The requirements for automated plant functions are divided into two tables; On-line monitoring requirements are those that pertain to condition monitoring of plant components, and Automated Work Functions requirements are those that provide operating information from plant components or represent the automation of a work function that previously was performed manually.

2.4.3.1 On-Line Monitoring

On-line Monitoring is divided into active and passive components. A number is given for the estimate of how many such components will eventually be monitored. For each component, an average number of sensors is given, which is related to either the number of different types of sensors that might be used to monitor a particular component (e.g. vibration and temperature) or the number of sensors required to cover a large passive component, such as a containment structure. The transmission rate is a rough estimate of the frequency for which data updates are needed. This is generally a function of the needed sample rate for effective monitoring of degradation. These rates can actually vary widely and would need to be set for the specific application. These transmissions might also include health-check information about the monitoring equipment and need to be frequent enough for operators to be aware of any problems with the monitoring systems.

Table 9. On-Line Monitoring

Components/Structures	Numbers	Avg. No. of Sensors	Transfer Rate
Active Components	500	48	2/min
Passive Components	100	25	1/hour

2.4.3.2 Automated Work Functions

Automated work functions are divided into several types of capabilities. Component position indicators provide a means of accurately knowing the position of active plant components that are not otherwise equipped with remote position indication. These would include valves, dampers, breakers, and switches. Today, the position of these components must be manually checked by sending operators into the plant to visually verify their positions, and this is quite costly and time-consuming.

New operating parameters can be enabled by low-cost instrumentation that is reliable for long periods of time without maintenance. These are parameters that were not originally included in the plant I&C systems, but can be very beneficial in new control and operator support technologies.

Local gauges and indicators and have to be checked by operators dispatched to these locations, often done as part of operator rounds. This function provides this data remotely, similar to position indication.

Temporary instrumentation is another example of transmitting operating data back to the control room. An example would be temporarily monitoring ambient temperature in an area where the heating, ventilation, and air conditioning (HVAC) system is degraded.

Plant sampling packages are where specialized in-line instrumentation has replaced manual tasks to obtain process samples and transport them back to a laboratory to analysis and disposal.

Remote dose monitors is now a common practice for utilities to have continuous coverage in certain plant areas that were not originally covered by area dose monitors. In some cases, this is as simple of mounting electronic dosimeters that have data communication capability. Many times these are hardwired with instrument cable. In the future, it will be advantageous for these to communicate over a wireless data network so that they can be easily moved about the plant to where needed.

The remainder of the table entries represents various components throughout the plant that were originally intended to be operated or observed locally, but where remote access would enable new efficiencies.

The table headings are similar to those above, providing an estimate of the number of such functions, the average number of monitoring points, and an average transmission rate.

Table 10. Automated Work Functions

Types	Number	No. of Points	Trans Rate
Component Position	2000	1	Once every 15 min
Operating Parameters	200	1	Once/sec
Temporary Instrumentation	20	1	Once/sec
Plant Sampling Packages	50	10	On-demand > once/hour
Data Transmission for Local Gauges	1000	1	On-demand > once/hour
Data Transmission for Local Alarm Panels	100	100	On-demand > once/hour
Data Transmission for Local Control Panels	100	15	On-demand > once/hour
Remote Dose Monitors	200	2	Once/sec

3. CONCLUSIONS

The research documented in this report has proven to be useful in understanding the aggregate impact that all of the envisioned technologies under the II&C Pathway will have on the plant information infrastructure. It is certain that this infrastructure will have to support new types of capabilities and significantly increased volumes of existing types of capabilities in the future. These new requirements must be estimated in terms of their nature and their volume in order that a sound planning process for a future digital architecture can be conducted.

The grouping of plant activities and technology functions into four main categories of mobile technologies for plant workers, control centers, control room technologies, and automated plant functions makes the process of estimating the digital architecture manageable in that many similar activities can be grouped into like functions. Thus, this taxonomy provides a useful and efficient framework for grouping like requirements. There are some plant activities that do not fit as well within this structure, but they are minor on a volume comparison basis and their exclusion will have a very minor effect on the design and dimension of the digital architecture.

The data in the various tables associated with the four categories of plant functions have been estimated by individuals with direct nuclear plant experience in these work areas, or are participating in research activities that would provide insight into these numbers. They are meant to be “roughly right” estimates, to establish an order of magnitude rather than a precise value. This is all that is required for the digital architecture planning process because any greater degree of precision would be offset by other factors in implementation that cannot be determined at this time.

It is also recognized that the numbers will be refined as these emerging technologies become better defined through ongoing R&D efforts as well as eventually being commercialized. It is expected that his report will be revised from time to time to update these numbers as greater insight is developed. Moreover, it is not the numbers in this report that ultimately matter, but rather the numbers determined by an individual utility for their specific implementation scope. Guidance for customizing these tables will be part of the Digital Architecture Implementation Guideline that will be produced in the third and final year of this pilot project.

Not surprisingly, it has been determined that the largest burden on the digital architecture will come from the use of computer-based procedures and automated work packages for several reasons. First, virtually all activities that interact with the physical plant are formally controlled by one or the other of these forms of written work instructions, to ensure that have been reviewed for quality, plant risk, and cross-discipline interaction. Second, the information contained in these applications is needed by any number of related plant activities, everything from work status to plant performance data. Finally, the work activities related to these applications are mostly scattered throughout the plant locations and will require mobile communications to convey this information in real-time. This represents a new dimension in plant information technology both in type and volume.

New control room technologies present a special case of digital architecture impact in that they access information from the plant I&C systems rather than the general plant information systems. These are separate and distinct types of burdens, although they might possibly come together at the point of the plant process computer, depending on how information is served out of this computer for general plant support data requirements. It will require special engineering efforts to ensure that the plant I&C systems are not unduly burdened by these new capabilities.

Some new technology requirements can be classified as both intensive and intermittent. These would be the Management Decision Support Centers, and in particular the Emergency Response Facilities (ERFs). Since activation of these facilities is a very rare occurrence, most of the technology impact would come from emergency drills. The Outage Control Center is also intermittent, although for a more extended time period than the ERFs. And, it is possible that a plant emergency would occur during an outage, although most normal outage activities would be curtailed during this time.

This research effort has also provided an understanding in to what degree different technologies impose a burden on the information technology infrastructure. Some are best represented by a steady-state value that is limited by the number of workers involved. A good example is the use of computer-based procedures in the control room, which proceed around the clock throughout the year, with the information traffic limited to what a relatively-fixed operator crew can do. Other technologies are driven by maximum plant work loadings, such as what occurs during the busiest times of refueling outages.

All this illustrates the difficulty in determining the maximum impact of the digital architecture requirements on the information technology infrastructure. These considerations will be evaluated during the second year of the pilot project in which the Digital Architecture Conceptual Model will be developed.

In summary, this research report provides the digital architecture requirements to enable an objective basis for planning the necessary information technology infrastructure for a future digital nuclear plant. It is flexible in that the parameters that drive it can be easily adjusted as the understanding of the functional capabilities is sharpened over time. It will enable the next step of defining a conceptual model for the digital architecture by providing a documented basis of what and how much the plant workers will do with the emerging NPP digital technologies.

4. PATH FORWARD

This report documents user requirements for advanced digital technologies in terms of how they provide functions in the various work settings of a nuclear power plant. This is the starting point to determine the Digital Architecture that will have to be in place to support these technologies in an integrated fashion across the nuclear plant organization. It should also be noted that these requirements are stated as they are understood at this time, based on the research and development that has been conducted through the II&C pilot projects to date. Undoubtedly, new requirements will be identified in future pilot projects as well through future input from industry stakeholders. Also, it is expected that there will be further refinement of the requirements usage estimates that are provided in this report as the scope of likely utility implementation is further defined. The report will be updated when such requirements are determined to have a material effect on the formulation of the supporting Digital Architecture.

As the next step, a gap analysis will be conducted to determine where typical NPPs are today in terms of deploying the required Digital Architecture. This will be accomplished using surveys and on-site assessments with partnering nuclear utilities to determine to what extent they could support the future digital technology environment with their existing I&C and IT structure, and where gaps exist with respect to the full deployment of technology over time. This information will be compiled and summarized, along with general observations and recommendations. It will be used in the next phase of this pilot project to prioritize where focus is needed in defining and providing guidance for enhancing the digital architecture of nuclear plants. The member companies of the II&C Utility Working Group will be solicited to serve as benchmark sites both for the surveys and on-site assessments. An effort will be made to include a range of operational circumstances such as large fleets, multi-unit sites, and single unit sites. The range would also cover various degrees of current digital technology implementations.

The approach will be to compare a station's current IT infrastructure to a projection of how well it could support the future requirements listed in the Digital Architecture Requirements Report. This will be by both the type of capability and the capacity to support full-scale implementation of the digital technologies. The information will be organized into tables for comparison among the surveyed stations. The specific identities of the stations will be withheld in any draft or final documents produced. A summary of this information will be published as the Digital Architecture Gap Analysis Report, to be published by September 30, 2015. This report will be a key input to a later project task of developing a guidance document for implementing the Digital Architecture conceptual model.

A conceptual model of the Digital Architecture will be developed based on the performance requirements documented in the Digital Architecture Requirements Report. The model will relate these requirements to the corresponding IT infrastructure components and their respective capacity and performance requirements. For example, if a certain number of real-time remote collaboration sessions using streaming video are conducted concurrently, what is the required bandwidth for a wireless communication system and what is the required plant area coverage? In addition to requirements, constraints will also be identified such as electromagnetic compatibility (EMC) concerns in the vicinity of sensitive electronic equipment.

The various technical components of the conceptual model will be identified and scoped for development. The conceptual model must be flexible and modular, so that it can be implemented either partially or fully, depending on the need of the utility and the types of digital technologies they desire to implement. The conceptual model must also relate in a natural understandable manner to the existing information technology architectures found in today's operating nuclear plants.

A guidelines document for utilities to implement the Digital Architecture Conceptual Model will be developed to assist with the scoping effort for IT upgrades for the support of targeted digital technologies. This document will reflect the combined experience and expertise of the participating utilities in how to assess the desired performance levels of the digital technologies and translate them to the performance requirements of the conceptual model in its implemented form. As mentioned previously, the guidelines will allow for a graded approach so that only the components needed to support the targeted technologies need be considered. The guidelines will be general and flexible enough to fit within the respective utilities' corporate standards and policies for IT implementation.

The Digital Architecture Gap Analysis Report will also be used to provide guidance on determining the relative effort and cost for a given utility to expand its current IT infrastructure to that required for the digital technologies that they desire to implement. This is the determination of the incremental cost over the cost of present capabilities for a target digital work environment. From this information, a general business case can be derived based on the benefits expected from digital technologies, many of which are being documented in a separate pilot project. It is expected that this business case information will be of interest to senior utility leadership in assessing the potential of these technologies to actually lower the cost of operation.

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APPENDIX A:
List of Mobile Work Package Features

Description of Typical Features for Mobile Work Packages

Correct Component Verification – Use of bar codes, optical character recognition, RFIDs, computer vision, or other identification technologies to verify that the correct component has been identified to be worked on. This includes confirming this to the worker and confirming that the component matches the targeted component(s) listed in the computer-based work instructions.

Smart Place-Keeping – Automatically take the performer to the next applicable step in the task sequence as well as automatically entering of performer identification (obtained by scanning the performer's employee badge) on the steps of a computerized procedure or work instruction. This includes recording the time of step execution. It prevents working steps out-of-order unless an authorized override function is invoked. Similar actions are performed for other users of the instructions, including concurrent and independent verifiers, quality control inspectors, and licensed operator authorizations.

Smart Branching – Simplified step logic present conditional statements as binary questions to reduce the performer's mental workload. Based on the answer to the question the performer will be taken to the next applicable step while the steps not applicable are automatically marked as such.

Computational aids/verification – Based on performer input, previous decisions made, and/or result from previous conducted steps calculations will be conducted automatically and the result will automatically be compared to the acceptable range. If result is out of range, the performer has to either correct the input used in the calculation or override the result.

Remote concurrent verifications – Performer streams a video feed of the step execution, which is viewed concurrently (real-time) by the verifier. When step is complete, the verifier verifies the correct execution direct from his location. The performer's instruction (on the mobile device at the work site) is automatically updated with the verification and the performer moves on to the next step.

Detection of procedure conflicts – Automatic tracking of active procedures and task status as well as real-time plant status updates (including lockout/tagouts). If a potential conflict is detected the performers will be warned and required to stop work until the conflict is resolved. Ultimately, the automation should be able to provide planners solution suggestion. The planners resolve the potential conflict and updated versions of instructions are pushed to the performers' devices.

Mode-sensitive procedures – Access to the plant system ensures that the instruction/work order automatically updates to fit the current plant operating mode. If a conflict is detected between the task and the operating mode, the performer and planners will be notified.

Real-time data acquisition – Automatic incorporation of operating mode, plant status (e.g., lock-out/tag-out), and other active procedures. Real-time updates as any parameter change and provide context sensitive information to the performer. Automatically guide the performer to the revised path of task execution.

Seamless transition to other procedures – Automatically and seamlessly take the performer to the next applicable step even if the next step is in another procedure. If required, the performer has to read and acknowledge the prerequisites, limitations, and precautions for the new procedure before proceeding to the action step. When appropriate, the performer will automatically be brought back to applicable step in the original procedure.

Remote authorizations – Automatic notifications to supervisors or other relevant staff lined up to conduct the authorization. The notification contains the relevant information (e.g., task, step, conditions, and photos) needed to conduct the authorization. When the authorization is made, the performer is automatically notified and allowed to proceed with the task.

Real-time work status updates – Supervisors, work planners, independent verifiers, and others can receive real-time status updates for specific tasks, such as critical path items during an outage. We work instruction system sends automatic notifications with status updates when trigger points has been reached in the procedure.

Work coordination triggers – Automatic notifications and hands offs between different organizations (e.g., control room operators and field workers) while performing a shared task. This provides a smooth and efficient workflow with minimal delays due to communication lag.

Streamlined job preparation and pre-job brief – Automatically tailored pre-job briefs to best prepare for task at hand. Provide just-in time training in forms of videos, photos, P&IDs, OE sheets, etc. to further aid in the preparation for the job.

Time-monitoring for time sensitive actions –The work instruction provides aids, such as grouping if actions, visible time monitoring, and warnings to prepare the performer for and support the performer during time sensitive actions.

Monitoring for continuously applicable steps – Automatically tracks continuous applicable steps and notifies the performer if conditions change in a manner that affects the step in any way. Also, provides reminders to check the continuously applicable step.

Verification of worker qualifications – When logging on to the work instruction system the performer will provide identification in some manner, e.g., by scanning the barcode on his/her badge, enter name, or enter worker identification number. The performer's identification will be used to verify that the performer's qualifications match the requirements for the task at hand.

Verification of M&TE – Automatically verify that the M&TE to be used to perform the task match the requirements for the task at hand. This will both ensure that the available equipment in correctly calibrated for the task.

Real-time access to reference documents and OE – Easy access to drawings, OE sheets, and other reference documentations directly on the mobile device while at the work site in the plant. Documentation is linked to specific steps if relevant as well as at searchable and accessible at any time from the plant's document archive.

Real-time package modification – If needed, validated modifications to the active work package can be pushed to the devices used to conduct the task. The performer will be notified by the change before continuing the task with the modified instruction.

Collaborating through video modification – The performer streams a live video feed from the work site, which is viewed by others in remote locations. This is an efficient way for example, to assess unexpected conditions in the plant, monitoring the execution of a critical task, or performing a remote concurrent verification of a task performed in the field.

Real-time risk assessment – Ability to assess the overall effect on plant risk of procedures and work packages in concurrent use, and as compared with the current and upcoming plant configuration. This includes detecting work activities on protected equipment, potential interaction of multiple work activities, and knowing the timing of critical steps in procedures relative to other plant conditions.

Plant situational awareness – Ability of a work crew to know be aware of current or changing plant conditions that might affect their work. For example, a crew could be immediately aware of redundant equipment becoming unavailable and therefore would not subject the plant to further risk. Likewise, they could be immediately aware of changing conditions such as emergent safety hazards.

APPENDIX B:
List of Advanced Control Center Features

Briefing Technology – an array of displays that are visible and legible from anywhere in the control center, used to convey information during shift status meetings during outages and other event-driven plant response efforts. This displays would also be available to those participating in the briefings from remote locations using electronic means.

Streaming Video – part of the briefing technology that brings live pictures of work activities or other monitoring requirements into the control centers. These can be from fixed cameras dedicated to certain work activities or part of the mobile technologies for field workers, for when they have special field conditions they need to convey to the control center.

Voice and Text Communications – standard types of mobile communications but able to use a variety of communication media, such as voice over internet (VOIP) or internet radio (ROIP), depending on the conditions in the plant affecting mobile communication technologies.

Remote Concurrences/Authorizations – Rather than having to have a second person at a job site just for the purpose of concurrent verifications, this can be done by streaming video to a second person who can provide this service for multiple jobs. This capability can also be used for certain organizational approvals of work steps, such as concurrence in a field procedure by a licensed operator.

Document Downloads – the ability to access needed documentation from any source, including document management systems or from mobile field workers. This precludes the need to provide these documents in advance when the need is not certain.

Supplier/Contractor Interface – the ability of suppliers and contractors to fully participate in supporting the work evolutions and related discussions from remote locations, using the electronic technologies of the control center.

Plant Data/Status – Real-time operational data being displayed in the control center related to plant configuration, Technical Specification compliance, defense-in-depth measures, and protected equipment.

Smart Board Collaborations – Use of smart boards and similar technologies to conduct collaborations with remote parties by being able to draw and annotate diagrams, pictures, etc. with the images being displayed in both (or multiple) locations.

Work Status Triggers – Embedded instructions in computer-based procedures and automated work packages that transparently send messages to control centers and other parties that jobs have progressed to predefined points, which in turn enable other work activities to proceed.

Work Status Updates – Similar to work status triggers, these are transparent messages that inform the control center (or directly into scheduling tools) the status of work activities, such as job start time, percent of job completion, job complete, etc.