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Light Water Reactor Sustainability Program

Process for Significant Nuclear Work Function Innovation Based on Integrated Operations Concepts

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ABSTRACT

The current fleet of U.S. nuclear reactors provide almost 20% of the U.S. electricity supply and over 50% of the emission-free generation. However, due to changing market conditions, many nuclear plants are finding that they are not competitive in the overall electricity market.

At least three major economic reports over the last few years have indicated that many U.S. commercial nuclear plants remain economically challenged and many are in danger of shutting down without federal or state economic assistance.

This report along with previous reports describing the Integrated Operations for Nuclear (ION) business model, documents an approach for implementing work reduction opportunities (WRO) that can drive significant operating cost reductions. ION Generation I refers to work reduction opportunities (technology, process, human performance, governance) that are at a sufficient technology maturity level and could be implemented within 3 – 5 years. This report will document, at a high level, the WROs under consideration, cost to implement, cost to maintain and operating cost reductions realized through implementation.

Results of this analysis show that by investing in the right technology upgrades and driving out the value of these investments through process and governance changes, nuclear plants can be competitive in most markets.

CONTENTS

FIGURES

ACRONYMS

ALARA	as low as reasonably achievable
BPR	business process re-engineering
BWR	Boiling Water Reactor
CAP	Condition Analysis Program
CBM	condition-based monitoring
CCGT	Combined Cycle Gas Turbines
COLR	Core Operating Limits Report
CR	Condition Reporting
CWD	critical work domains
DCS	Distributed Control Systems
DOE	Department of Energy
EP	Emergency Planning
EPRI	Electric Power Research Institute
FTE	full-time equivalents
HSI	Human System Integration
HTE	high-temperature electrolysis
I&C	Instrumentation and Controls
ICAP	Integrated Operations Capability Analysis Platform
IES	Integrated Energy Systems
IFE	Institute for Energy
IFET	Institute for Energy Technology
IO	Integrated Operations
ION	Integrated Operations for Nuclear
IoT	internet of things
KPI	Key Performance Indicators
LCOE	levelized cost of energy
LOTO	Lock Out Tag Out
LTE	Long Term Evolution – Type of 4G cell service
LWRS	Light Water Reactor Sustainability
M&DC	Monitoring and Diagnostic Center
M&TE	Measuring and Test Equipment
MCR	Main Control Room
MTTF	mean-time-to-failure

NEI	Nuclear Energy Institute
NLP	natural language processing
NPP	nuclear power plant
NPV	net present value
NRC	Nuclear Regulatory Commission
O&M	operations and maintenance
PM	preventative maintenance
PTC	Production Tax Credits
PTPG	people, technology, process, governance
PWR	Pressurized Water Reactor
QR	quick response code (computer readable code)
REMP	Routine Environmental Monitoring Program
RFID	Radio Frequency Identification Codes
RP	radiation protection
U.S.	United States
WRO	work reduction opportunities

1. INTRODUCTION AND PURPOSE

The current fleet of United States (U.S.) nuclear reactors provide almost 20% of the U.S. electricity supply and over 50% of the emission-free generation. However, due to changing market conditions, many nuclear plants are finding they are not competitive in the overall electricity market. External causes of this condition include the proliferation of cheap natural gas, government subsidies for renewable energy, and the lack of economic incentives at the Federal, State, and local level that recognize the environmental benefits of nuclear-generated power. One other important reason that many nuclear plants are not economically competitive, however, is the nuclear industry has not broadly applied modern digital technology that can enable process improvements resulting in improved economic operation.

This report, along with previous reports describing the Integrated Operations for Nuclear (ION) business model, documents an approach for implementing work reduction opportunities (WRO) that can drive significant operating cost reductions. ION Generation I refers to work reduction opportunities (technology, process, human performance, and governance) that are at a sufficient technology maturity level and would support plant transformation within 3–5 years. As shown in Figure 1, most of the costs that need to be reduced to implement ION Gen 1 fall in the direct labor category which will be this study's focus. This report will document at a high level the WROs under consideration, cost to implement, cost to maintain, and operating cost reductions realized through implementation. See Appendix B for a detailed breakdown of cost targets for implementing ION Gen 1.

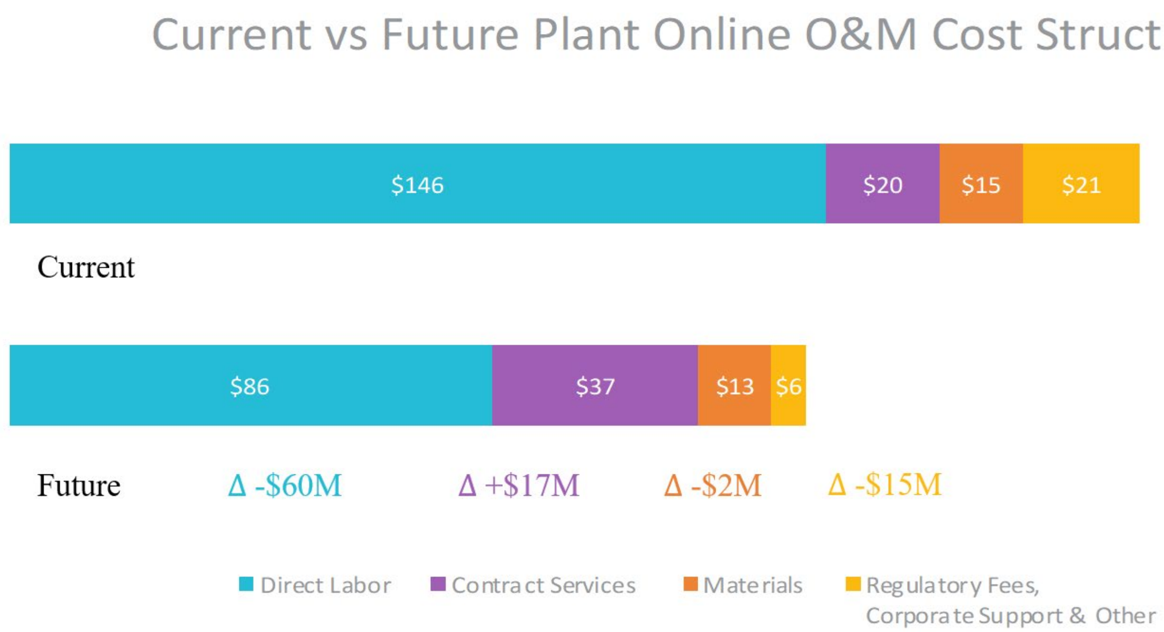


Figure 1. Current and future operations and maintenance (O&M) cost structure.

2. COMPETITIVE POSITION OF U.S. OPERATING NUCLEAR POWER PLANTS

Nuclear plants struggled for many years in their early days of deployment with poor availability which caused them to be marginally competitive. However, over the last 25 years, plant performance issues have been addressed, unreliable equipment has been replaced, and single point vulnerabilities have been corrected. Now nuclear plants have the highest availability of any power source and have improved on their own reliability year after year. Unfortunately, this high reliability has not saved them from serious economic pressures and the non-competitive markets that many of them face.

2.1 U.S. Electric Markets – Economics and Policies

2.1.1 U.S. Electric Markets – Economics and Policies

At least three major economic reports over the last few years [Reference 1,3,7] have indicated many U.S. commercial nuclear plants remain economically challenged, and many are in danger of shutting down without federal or state economic assistance. Examining recent trends shows this is not an empty prediction as Figure 2 demonstrates [Reference 8]. The premature shutdowns of well operated and maintained nuclear plants has been almost exclusively due to poor operating economics.

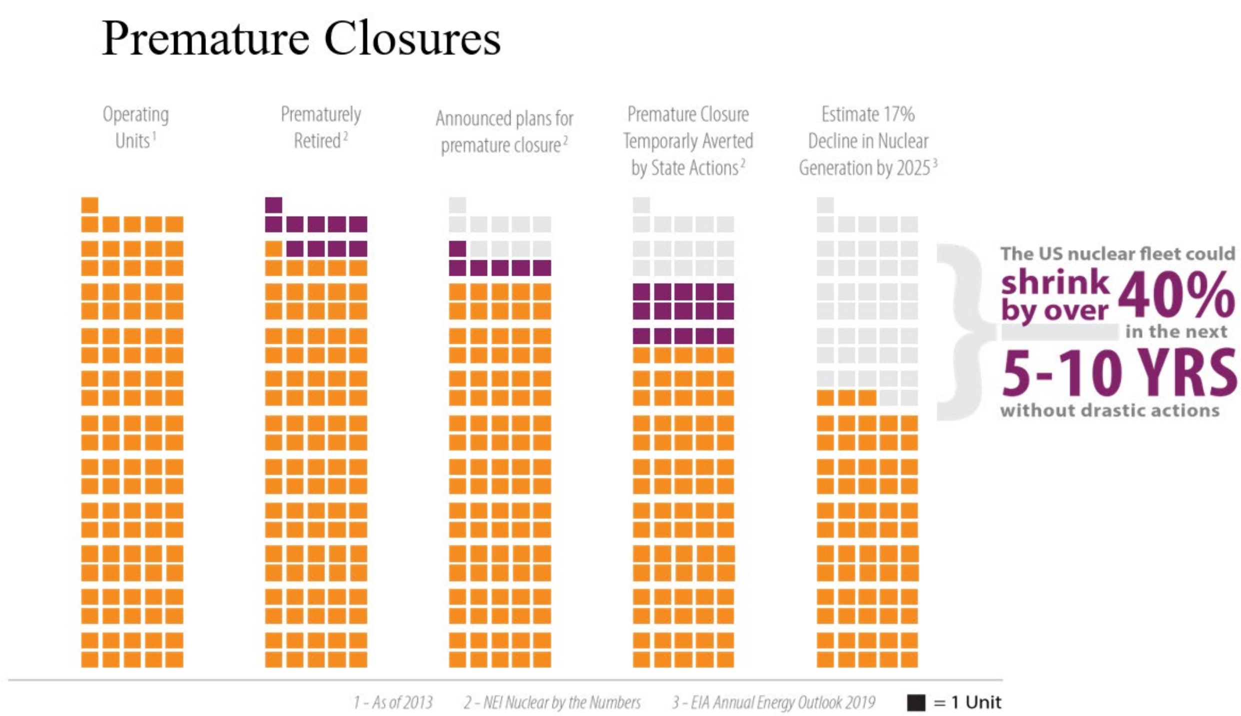
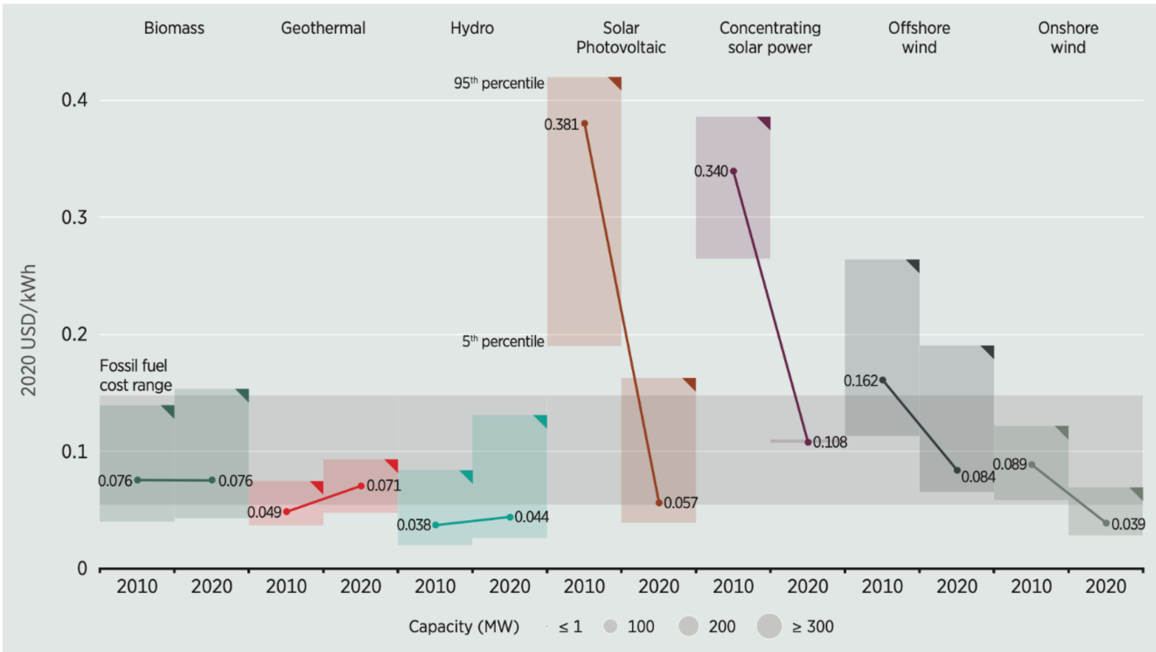


Figure 2. Premature nuclear plant closures.

Renewable energy has seen a dramatic drop in capital cost and according to *Renewable Power Generation Costs in 2020*; between 2010 and 2020, the cost of electricity from utility-scale solar photovoltaics fell by 85% [Reference 2]. Other sources have also demonstrated precipitous reductions in capital and installation costs that do not appear to have reached the bottom yet (Figure 3)and [Reference 4]. Due to its low availability, renewable energy without storage cannot meet the demands of an always on grid.   High-capacity long-term storage is impractical in most locations and remains prohibitively expensive.



Source: IRENA Renewable Cost Database

Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) of 7.5% for OECD countries and China in 2010, declining to 5% in 2020; and 10% in 2010 for the rest of the world, declining to 7.5% in 2020. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Figure 3. Global LCOEs from newly commissioned utility-scale renewable power generation technologies.

In addition to drastic cost reductions, the renewable energy industry has been the beneficiary of government subsidies that were intended to promote renewables in the early stages of deployment. However, these government subsidies, in the form of production tax credits and investment tax credits, have so destabilized electricity markets in some areas that the price of electricity drops into the negative range for many hours of the day. Of course, this kind of electricity market behavior penalizes other generators that cannot compete with negative pricing.

In another arena, cheap natural gas has allowed utilities to shut down coal plants and run combined cycle gas plants to meet their varying load conditions. Even though natural gas produces less pollution than coal, it is still not an emission-free source of electricity. However, when a nuclear plant shuts down due to economic conditions; generally, the power it was supplying to the grid is replaced by natural gas resulting in increased emissions.

For many years, nuclear power was one of the least expensive sources of electricity and, in addition, emitted no pollution or carbon dioxide. Since all current nuclear plants in the U.S. are designed to operate at 100% power, market conditions that enable them to be profitable for only part of the day do not allow them to recover their base O&M costs. Since the costs to operate a nuclear plant are constant whether they operate at 100% or at a lower power level, these conditions create an unsustainable situation for these clean power producers [Reference 5].

Many factors both within and outside the control of the nuclear utilities have contributed to their current unfavorable economic situation. After the Fukushima Daiichi event, the nuclear industry was required by the NRC to install costly backup equipment (portable pumps, generators, and support equipment) to prepare for postulated beyond design basis events. In addition, they were required to set up regional quick response centers stocked with additional emergency response equipment that could be trucked or flown by helicopter to any nuclear plant in the nation that had need of it to respond to a beyond design basis event. Significant plant modifications were also required for each plant in order to connect this emergency equipment to plant systems and for additional safety monitoring equipment. All this equipment and plant modifications required an enormous investment of capital in addition to the ongoing O&M costs required to maintain the equipment and fund the emergency response centers.

As shown in Figure 4, average nuclear plant operating costs have come down by 20% over the last 5 years; however, costs have not dropped by enough to remain competitive in many markets. One reason why nuclear is not currently competitive is nuclear plant owners have not invested in technology as a way of reducing costs while maintaining excellent performance and safety. Most other industries have invested heavily in technological innovations to drive cost down and product quality up. Nuclear plants have been in the situation of responding to capital intensive efforts (such as the response to Fukushima) that did nothing for economic performance but used up capital that could have been used to modernize their plants and reduce O&M costs. Another factor that must be mentioned is the initial reluctance of the industry to apply digital control and safety systems due to unclear regulatory guidelines regarding digital common cause failure. One large digital safety system project was undertaken by the industry, while operationally beneficial was delayed and came in grossly over budget and schedule. This created a chilling effect for future digital modifications that is only now thawing. Now, however, the industry has developed processes and (working with the NRC) established regulatory guidelines that will allow digital systems upgrades in a streamlined manner while still meeting rigorous safety and environmental standards. In fact, several utilities are well underway with projects that will replace analog systems with digital safety systems and in one case fully digitalize the entire control room. As we will cover later in this report, investing in modern digital technology allows changes to the work processes, reduced parts counts, simplified operation and maintenance, and a host of other changes that enables lower O&M costs without sacrificing performance or safety.

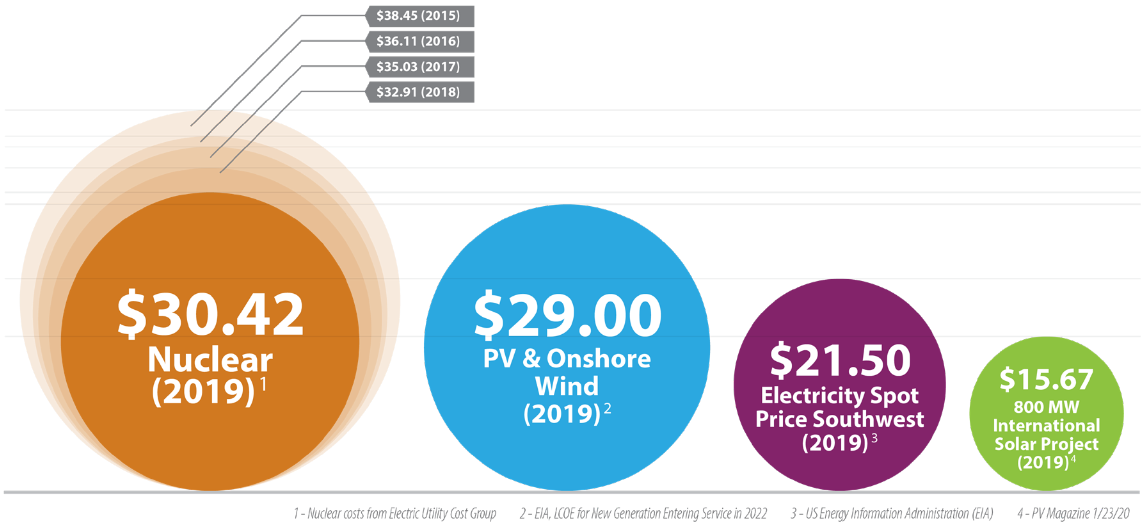


Figure 4. Total average operating costs ($/Mwhr.)

2.2 Levelized Cost of Electricity for Operating Nuclear Power Plants

2.2.1 LCOE Overview

Levelized cost of electricity (LCOE) represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant. Inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and financial life, and duty cycle. The importance of each factor varies across technologies. For technologies with no fuel costs and relatively small variable O&M costs, such as solar and wind, O&M costs, financing costs, and an assumed utilization rate for each plant type changes nearly in proportion to the estimated capital cost of the technology. For technologies with significant fuel cost, both fuel cost and capital cost estimates significantly affect LCOE. For the current nuclear fleet, the initial capital costs of construction have long ago been paid off so what is left is cost for operations, maintenance, fuel, and ongoing capital improvements. Since fuel costs for nuclear represent a relatively small percentage of the overall cost, the LCOE tracks closely with O&M costs and becomes a useful metric to compare with other energy delivery systems.

The current LCOE for a conventional nuclear plant (identified as the Baseline Scenario in figure 5) is generally uncompetitive with traditional gas combined cycle generation (CCGT). As our analysis shows, conventional nuclear is between $6 and $13 more on an LCOE-basis when only fuel and O&M are considered. When the current ION Gen 1 plant is compared on this same basis, it is only eight cents behind the CCGT as shown in Figure 5.

However, when you factor in sustaining and innovation capital, the ION-1 plant is nearly equal to the CCGT plant.

	Baseline Scenario: **Conventional Nuclear LCOE (O&M and Fuel Only) [Lazard Data]**	Scenario 1: **ION-Gen 1 LCOE (O&M and Fuel Only)**	Scenario 2: **ION-Gen1 LCOE with Sustaining and Innovation Capital**	**Combined Cycle LCOE (J-Frame)**
Generation Source	Nuclear			Natural Gas
Plant Size (MW)	2200			1221
Capacity Factor (%)	89 - 97	93		84
Fuel Cost ($/MMBtu)	0.70 - 0.80	0.65		2.95 - $3.20
Heat Rate (Btu/kWh)	10,400	10,300		6744
Fixed O&M ($/kW-year)	82.8 - 103.1	71.36		5.30 – 7.13
Variable O&M ($/MWh)	2.50 - 3.50	3.00		1.84 – 2.48
Overnight Costs ($/kW)	0	0	455 ($1B investment)	N/A
Interest Rate (%)	N/A	N/A	9.6	N/A
Production Tax Credit (PTC) ($/MWh)	0	0	0	0
Levelized Cost of Energy ($/MWh)	**25.00 - 32.00**	**18.29**	**25.87**	**22.46 – 25.03**
				$18.21 with $2.32 2018 Fuel Cost

- Notes: Information current as of May 2021
- Sources: ScottMadden Analysis, Lazard LCOE and Storage 2020 Report; Webber Energy Group, EIA, General Electric

Figure 5. Preliminary LCOE analysis.

When you further break down the categories where changes have the biggest impact on the LCOE, these five elements are:

- Capital investment
- Production tax credit
- Fuel cost
- Fixed O&M
- Variable O&M.

The team identified seven possible scenarios to understand what would be needed to achieve (or be close to) the target LCOE of Combined Cycle J-Frame Natural Gas Plant. Six of these scenarios require implementing ION Gen 1 Work Reduction Opportunities. A brief description of the six scenarios plus the base case is described below:

- Scenario 1: LCOE described with zero investment capital requirement and a 13% reduction in Fixed O&M costs along with a 7% reduction in fuel costs
- Scenario 2: Significant capital investment to modernize plant equipment and processes
- Scenario 3: Significantly reduced investment capital investment
- Scenario 4: Reduced capital investment and aggressive reduction in Fixed O&M
- Scenario 5: Reduced capital investment and improved cost of capital
- Scenario 6: A nuclear production tax credit
- Scenario 7: Base Case in Figure 5

For each scenario, the plant size, capacity factor, fuel cost, heat rate, and variable O&M were held constant to ensure a consistent comparison.

For Scenario 1, this focuses on a reduction of Fixed O&M costs largely performed through "tightening the belt" by reducing labor costs without any investment in capital. This would result in a reduction of LCOE by $18.29/MWh

For Scenario 2, the investment costs would increase to $1B to support significant investment in plant capital with a reduction of Fixed O&M exactly the same as Scenario 1 (~13%) of $71.36 KW-yr.

For Scenario 3, overnight costs would have to drop dramatically ($455/kw to $186/KW) to hit the target LCOE. Overall investment would drop from $1B to $410M with all other factors remaining the same.

For Scenario 4, the reduction in capital for the site drops from $455/KW to $239/KW. However, this is not quite as large of an impact due to a reduction in Fixed O&M of $6.81/KW-yr (from $71.36/KW-yr to $64.55/KW-yr) providing some savings offset.

For Scenario 5, the Fixed O&M returned to its base case amount of $71.36/KW-yr and the capital reduction is used but it is less than versus the two prior scenarios as a 2% reduction in the interest rate for the investment is used to help offset LCOE.

For Scenario 6, all base inputs were used except for the introduction of a nuclear production tax credit. This credit was applied to the generation from the site with its assumed 93% capacity factor. A value of $2.88/MWh is assumed in order to help drive down the LCOE towards the $21.50/MWh target.

For Scenario 7, this is base case plant as shown in Figure 5.

2.2.2 LCOE Disadvantages for Existing Conventional Nuclear

LCOE has several disadvantages for existing nuclear assets when compared to other zero-emission technologies such as wind and solar.

First, the LCOE ignores the inherent variability of renewable assets (e.g., wind and solar) and the need for more dependable assets to provide backup power. LCOE does not account for the cost of these supporting resources. Since these costs are not included, it can skew the results to show a more favorable LCOE for a renewable asset versus nuclear.

Second, LCOE is heavily impacted by the cost of capital for the project. The cost of capital is influenced by the depreciation schedule for the asset type, with longer-schedule assets seeing a higher rate versus assets that pay back its investment more quickly. Typically, wind and solar projects have depreciation time horizons of 3–5 years, whereas a capital investment in nuclear plant is depreciated over 20–30 years. This discrepancy can have a significant impact on the capital costs for the project and thus the LCOE.

Finally, production tax credits (PTC) can have a significant impact on the LCOE of an asset since it artificially lowers the cost of the asset to make use of the asset more competitive. While this is common practice for renewables such as wind and solar, it has only started to be investigated for use in the nuclear space in recent years. These credits were seen as a way to promote the use of clean energy across the U.S., but nuclear power was not eligible for these credits. Recent federal government action may provide some relief in this area, but it is unclear when these credits would be available.

2.3 Opportunities in Evolving Grid and Non-Grid Roles for Nuclear Power Plants

Traditionally, nuclear plants have supplied the grid with a near continuous flow of electricity 24 hours per day, 7 days per week, and 365 days per year. In fact, nuclear plants in the U.S. are the most reliable form of energy of all energy sources with a capability factor of 92.5% for 2020. That continuous and reliable source of power has enabled the grid to remain stable even during severe weather events or periods of high demand. Whether the nuclear plant was in a regulated area or served as a merchant plant in an unregulated market, nuclear-generated electricity could be relied upon to support the grid given almost any situation.

However, due to changes in the energy supply landscape including cheap natural gas and the proliferation of subsidized renewables, many nuclear plants are struggling to stay in business. Some states have implemented special incentive programs, modeled on renewable energy policies that provide incentives for zero carbon generation from nuclear. However, these programs are at best a bridge to a more permanent solution.

Formerly, grid services (Figure 6) such as frequency response and regulating reserves could only be supplied by energy sources with a spinning turbine, but new inverter technology is allowing these services to be "synthetically" provided by power electronics from energy produced from wind turbines and solar panels. Essential reliability services have formerly been an area where nuclear plants with large spinning turbines could bid for and be paid for providing these services, but this opportunity is changing as well. According to a recent report by the National Renewable Energy Laboratory, *"...we report 2017 market settlement data for ISO-NE and PJM to compare grid services in a way that considers both market depth and prices. In these two markets, operating reserves and essential reliability/ancillary services comprise 2.3% and 3.1% of total settlements, respectively; the remainder of settlements are for energy, capacity, and transmission-related services"* [Reference 13]. Therefore, even if nuclear plants could exclusively provide these grid services, the opportunity for significant economic help is minimal.

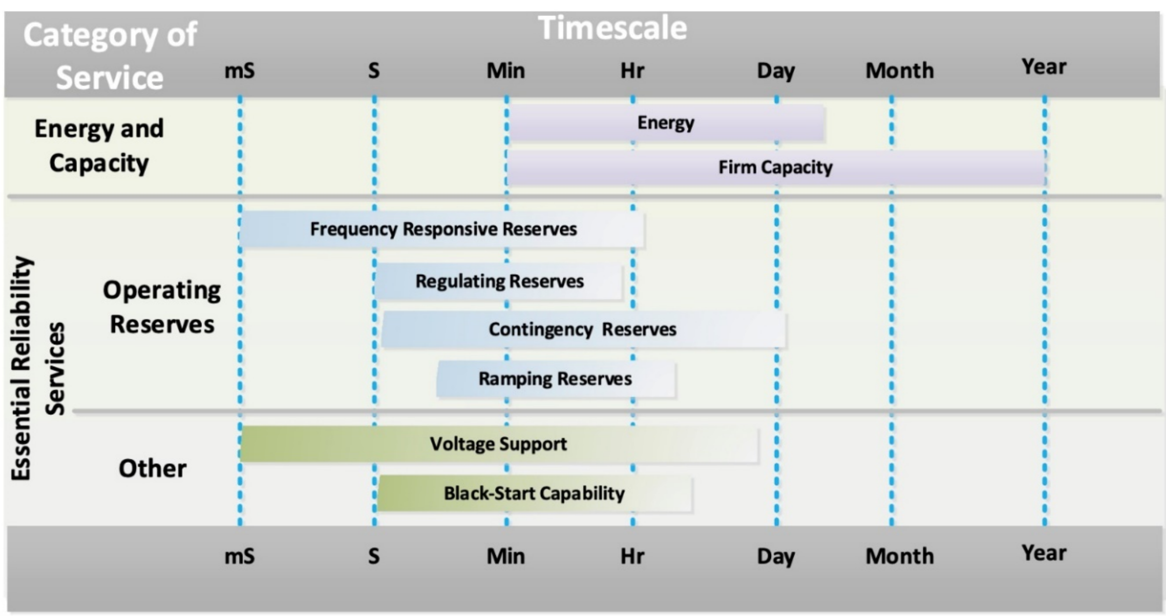


Figure 6. Essential services provided by the U.S. power system.

For non-grid and off-grid opportunities, several interesting possibilities have recently been identified. One is the use of nuclear-generated electricity to provide electric energy to power electrolyzers to produce green hydrogen. This electricity could be taken from the plant directly after the main transformers and before it enters the grid, therefore, avoiding complexities and costs associated with grid access. In addition, steam could be provided from the secondary system of the nuclear plant, transported to the H^2

plant to increase the overall efficiency of the system. These concepts are described further in Section 8.1 of this report.

Another interesting recent development is the use of nuclear-generated electricity to directly power a cyber currency mine. Several nuclear utilities are entering into agreements to supply emission-free electricity to these large data centers, so the cyber currency produced can claim to be green or zero carbon. At least one advanced reactor manufacturer is also considering teaming with a cyber currency mine to produce green financial products when the advanced reactor comes online.

3. ION BACKGROUND

Integrated operations (IO); refers to the integration of people, disciplines, organizations, and work processes supported by information and communication technology to make smarter decisions. In short, IO is collaboration with focus on production. The concept of IO was developed primarily by international oil and gas industries in response to decreasing revenues and increasing operations and maintenance expenses. They were seeking ways to continue the safe operation of critical and complex offshore platforms while minimizing costs. The IO concept is based on the availability of new digital technology allowing for changed work processes and the sharing of data/information between systems and supporting employees.

IO is an approach for solving the challenges of having personnel, suppliers, and systems located remote from each another. IO is about removing the physical boundaries between people, making real-time cooperation across great distances possible. IO involves using real-time data and new technology to remove the divides between disciplines, suppliers, and companies. It is about how information technology that makes remote operations possible can form the basis for new, more effective ways of working. It allows companies to bring the problem to the expert (virtually) rather than having to bring the expert to the problem (traveling to the site to investigate the problem). When working across business and technical boundaries and exploiting real-time data and technology for removing such divisions as time and place, the goal is to ensure better value creation for the future.

Norway's Institute for Energy Technology (IFE), sponsor of the Halden Reactor Project, has been a leader in developing IO principles and methods, along with technologies for enabling such transformations. Formerly they developed a report*, Lessons Learned from Integrated Operations in the Petroleum Industry* [Reference 6], based on their deep understanding of both offshore petroleum production and nuclear plant operations and support.

3.1 Integrated Operations Concept and Application to Nuclear Power

The focus of this research is to deliver to the nuclear industry a means of bringing their operating costs in line with the realities of the electric market by transforming their operating model through business-driven technology innovation. Given nuclear plants have many characteristics similar to offshore oil and gas rigs, implementing ION for nuclear power plants showed promise for doing for the nuclear industry what IO had done for the offshore oil and gas industry—namely recovering economic competitiveness while maintaining safety and production goals.

In collaboration with Xcel Energy Nuclear Generation, the goal is focused on developing a business-driven approach to transforming the operating model of commercial nuclear plants from labor-centric to technology-centric—just as many other industry sectors have done to survive in today's marketplace. The ION framework uses a top-down/bottom-up process to accomplish these objectives.

In order to utilize the ION process, a market-based price point (typically bus-bar cost in \$/MWH) for nuclear generation is set, then used to back out what the maximum total O&M budget of the nuclear fleet should be to support this price. This budget is, in turn, allocated over the nuclear organization in a top-down manner as the starting point of an iterative process. This is referred to as top-down analysis. Work functions are then analyzed for aggressive opportunities to reduce the workload to that which is essential and can be resourced within this O&M budget. This step is referred to as bottom-up analysis.

The streamlined work functions are then configured into a transformed operating model that leverages advanced technology and process innovations, resulting in a small on-site staff focused on daily operations with all maintenance and support functions centralized or outsourced to on-demand service providers. As previously noted, a top-down/bottom-up process for reconciling the future cost of business with the future market price of electric output from a nuclear power plant (NPP) is used to establish a cost basis for the analysis.

To apply IO concepts to a nuclear utility, the Integrated Operations Capability Analysis Platform (ICAP) may be used as a useful tool to identify and document ION transformation plans. This system serves as a repository for the information required to analyze nuclear plant work functions and apply innovative concepts to them. Such information includes descriptions of the work functions, all constraints on those work functions (regulatory, policy, etc.), descriptions of work reduction opportunities regarding individual work functions, a quantification of labor and non-labor savings achieved through those opportunities, and certain risk assessment information regarding pursuing those opportunities. For this project, the work reduction ideas will be identified and evaluated to determine the overall impact on the O&M budget. Future efforts will utilize the ICAP tool to document cost savings and make this information available to the nuclear utility community.

Key features of the ION process include the following:

- Top-down business-driven analysis
- Innovation for what is needed—not what is possible
- New ways of working
- Worker of the future.

The worker of the future (Figure 7) will be much more enabled to perform work more effectively and efficiently by breaking the mold of what has traditionally been the approach to operations and maintenance activities across the site. This new approach looks to enable the worker to be able to use more technology and a broader skillset. Workers will be expected to be multi-skilled and use technology to improve performance. As technology continues to improve, the ability to more effectively identify, plan, schedule, and execute work will minimize a worker's downtime and allow for more work to get done in a standard workday. For a more complete description of ION, please see the reports prepared by DOE on this subject (6,9,12).

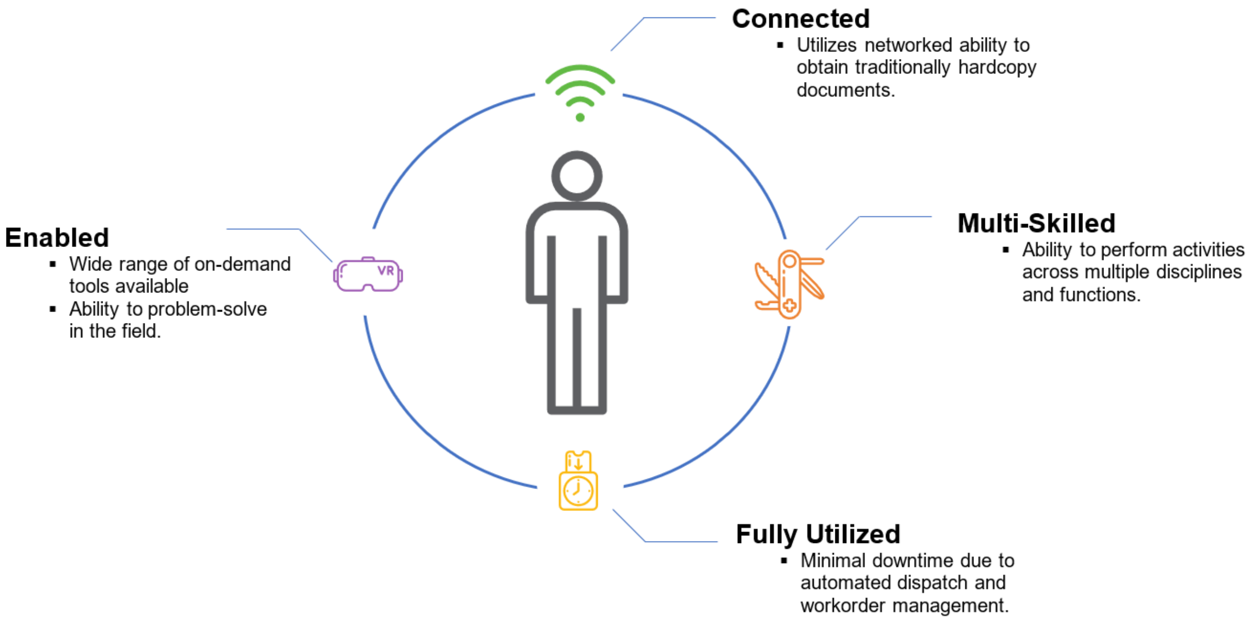


Figure 7. Characteristics of the worker of the future.

3.2 ION Relationship to Business Process Re-Engineering

ION can be confused with other business improvement processes including business process re-engineering (BPR). As shown in Figure 8, the major difference between BPR and ION is that BPR and related process improvement concepts start with the process and seek to make it as efficient as possible. The main problem with this is in many cases the inward focus on process improvement may obscure the full picture of what the company is seeking to accomplish, and which processes are no longer needed and can be completely eliminated. In addition, BPR is backward looking and incremental in its approach so is unable to drive the kind of change required to significantly drive down O&M costs.

In contrast, ION starts with a top-down goal, evaluates the capabilities that are needed to accomplish the goal, and then builds up the work functions necessary to support the capabilities. This approach allows evaluation of technology, process change, governance change, and human performance to be considered on an equal basis so an optimum solution is identified verses just trying to optimize the existing infrastructure. ION is fundamentally forward looking and is well suited for transformational change as it continues to relate all activities back to the primary objective of the enterprise and assess each individual change's specific contribution to its overall success. BPR may be a useful tool when applied in the context of an overall transformational process such as ION. Figure 8 graphically shows the interrelationship between these two processes.

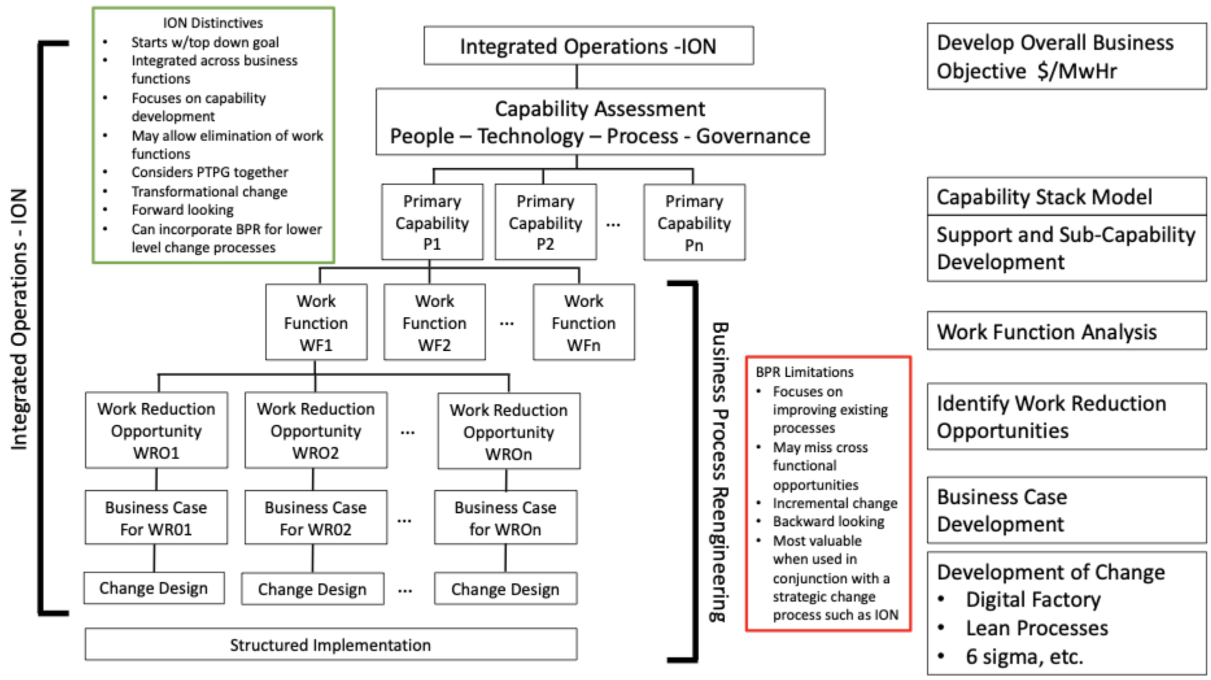


Figure 8. ION compared to business process re-engineering.

4. ION-GEN 1 APPROACH

Implementing ION requires evaluation of all four elements of the business process ecosystem. These elements are:

- People – Employees involved in the operation and management of the business enterprise
- Technology – The tools and systems of hardware, software, and infrastructure that allow a business to create value
- Processes – The way people and technology interact within the guardrails of the business and regulatory environment to create products and services of value to the customer
- Governance – How the enterprise is managed, what rules govern day to day and future actions, and the company's goals both internally and externally imposed.

We call these elements—people, technology, processes, and governance—PTPG for short, and each of these elements must be considered for any transformative change to be successful as shown in Figure 9.

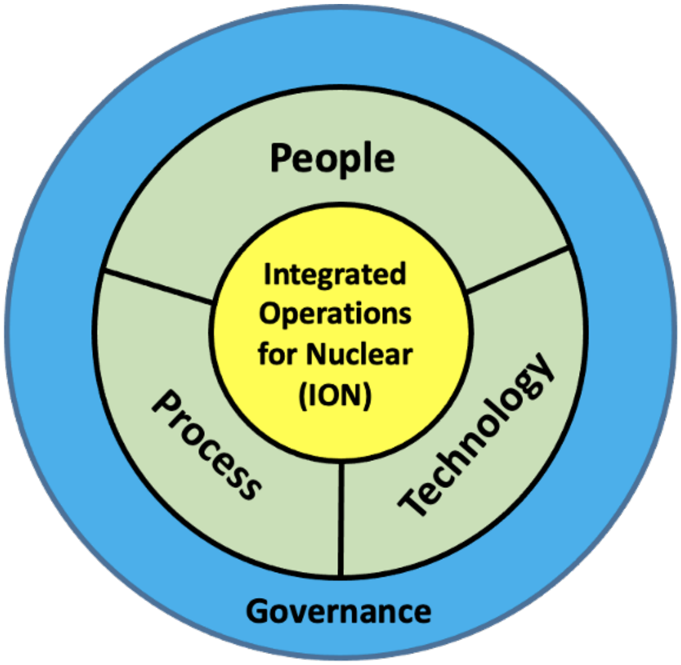


Figure 9. Key elements of ION.

Following are examples of transformation concepts within each one of the PTPG architecture elements:

People

- Bring the problem to the expert
- Consider a new way of working
- Apply virtual training
- Multi-skilled
- Motivation, attitude, courage.

Technology

- Communication infrastructure
- Safety systems and control systems – digital
- Smart procedures
- Remote monitoring
- Decision support – AI/ML, expert systems
- Integrated plant data management system.

Process

- Eliminate work
- Do not automate an inefficient process
- Use human factors engineering based designs
- Digitize the new process.

Governance

- Reduce layers of management
- Remote oversight and assurance reform
- Apply risk-based regulation
- Lean site staff
- Use support staff only when needed.

Many times, transformation projects fail due to an assumption if the right technology is selected, then everything else will work out. However, unless each element of the PTPG model is evaluated and analyzed in context of the remaining elements, project results will suffer. This is true in the case of making a process change while assuming the existing technology will support the change or implementing an organizational change without providing the workforce with the technology tools to implement the change.

For this project as documented in this report, the focus will be on technologies that can be implemented within 3–5 years and are or will be at the appropriate technology maturity level to be implemented within that timeframe. The remaining PTPG elements required to implement these technology elements will not be described in this study but will be evaluated in future research and described in subsequent reports.

In order to analyze available WROs across the plant business environment, plant activities were broken down into 10 critical work domains. These domains represent the areas where most of the O&M work is performed and provide the greatest opportunity for cost reduction (Figure 10).

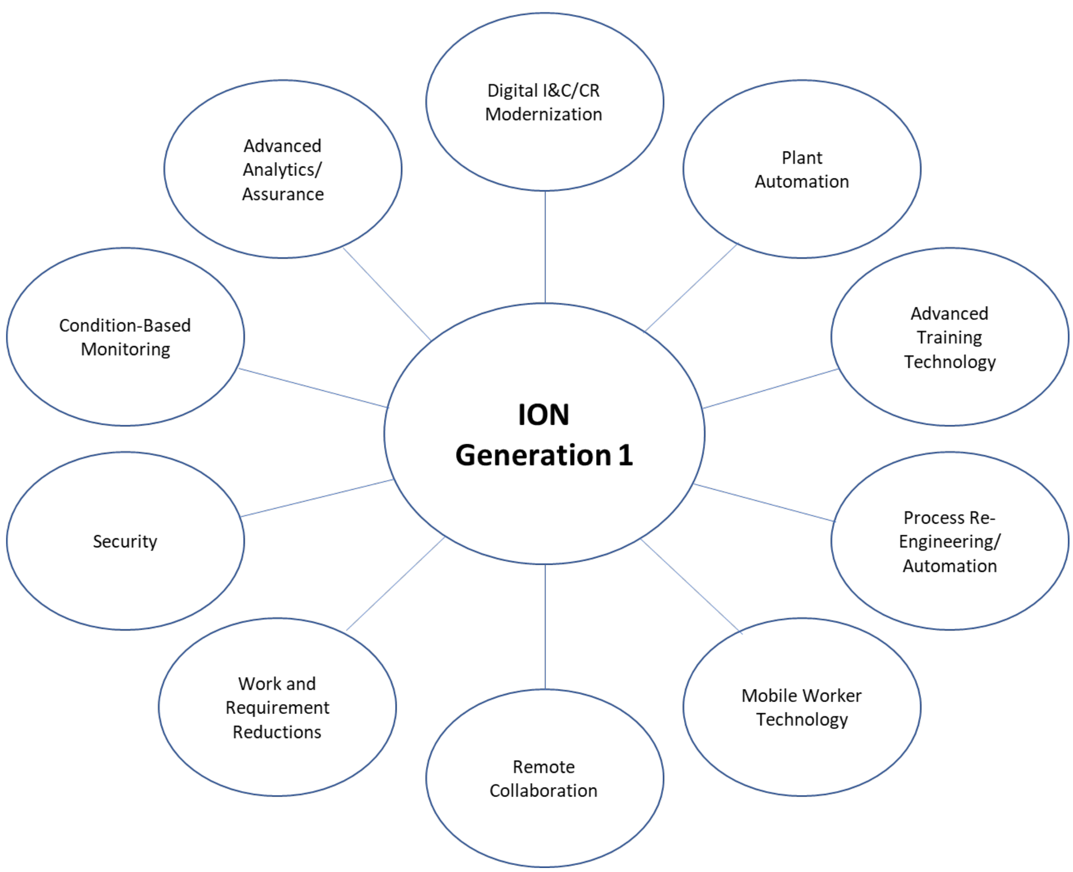


Figure 10. ION Gen 1 critical work domains.

In order to perform this research, DOE enlisted the services of Scott Madden and Associates to analyze the impact of implementing selected work reduction opportunities, the capital cost impacts and likely outcomes for implementing Gen 1 opportunities. They worked closely with the DOE team to identify, categorize, and evaluate these opportunities while utilizing their significant experience and wealth of economic data from years of assisting customers with change processes.

This project focused on the following four key steps to help drive understanding for an approach to improve the competitiveness of nuclear assets based on implementing specific work reduction opportunities as shown in Figure 11.

1. Establish top-down cost targets and ION work reduction opportunities
2. Analyze individual technology and process WROs
3. Rationalize bottom-up impacts with initial top-down estimates
4. Document results for ION Gen 1 opportunities.

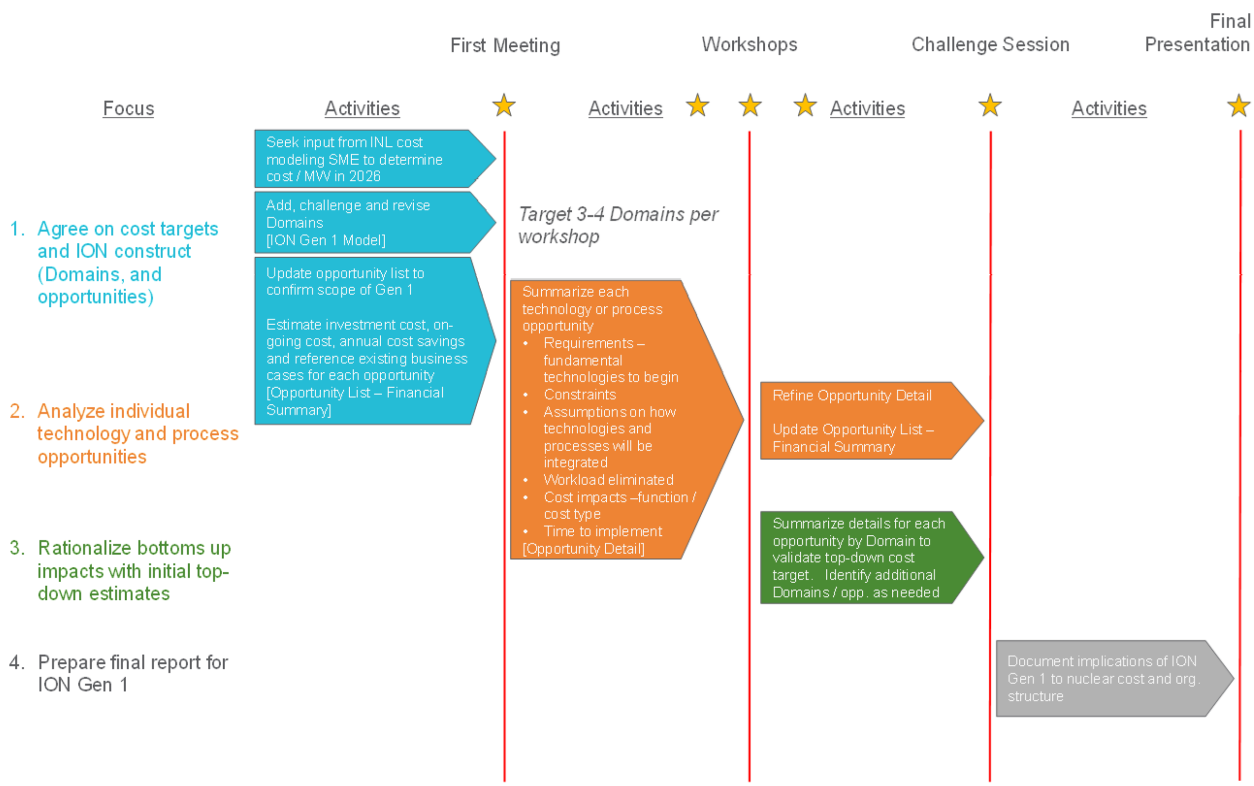


Figure 11. ION Gen 1 research plan.

Step 1 focuses on setting up the baseline for costs in the target year of 2026 (5 years out from present) as well as establishing the 10 critical work domains (CWD) to investigate cost reductions and efficiency improvements. The team also updated the original opportunity list and confirmed scope of Gen 1. The team also estimated:

- Investment cost
- Ongoing cost
- Annual cost savings.

As part of this process, the team referenced existing business cases for each opportunity to ensure they captured all the relevant data necessary.

Step 2 used a set of workshops to build out the opportunities within each CWD. This included identifying:

- Requirements – fundamental technologies to begin
- Constraints
- Assumptions on how technologies and processes will be integrated
- Workload eliminated
- Cost impacts – function and cost type
- Time to implement.

From these workshops the team developed a set of summaries for each technology or process opportunity.

Step 3 focused on summarizing details for each opportunity by CWD and rationalizing the top-down cost targets. The team also identified additional domains/opportunities as needed.

Finally, in Step 4, the team documented a rough order of magnitude savings and where ION Gen 1 WROs would impact nuclear cost and organization structure.

4.1 Work Reduction Opportunities

WROs were identified and categorized into a set of three cost savings categories:

- Materials
- Contract services
- Direct labor
    - Elimination
    - Reduction and consolidation
    - Efficiency gain.

These work reduction opportunities are summarized in Appendix A, ION Opportunity Summary.

As a result of the opportunities identified by the team, the current standard plant staffing model is reduced from an approximate baseline staffing level of 842 full-time equivalents (FTEs) to 475 FTEs, which is approximately a 44% reduction in staffing at the site.

The cumulative work reduction opportunities implemented at the site is estimated to provide a $60 million savings per year. This reduction tracks closely to the percent reduction in FTEs for an estimated 42% savings in labor costs. The largest functional areas that were impacted by the WROs were as follows:

- Maintenance (~$15M) – consolidation and elimination of work
- Security (~$10M) – reduction in requirements
- Engineering (~$9M) – consolidation and outsourcing of work
- Training ($5M) – automation and outsourcing of work.

Section 5 identifies the WROs that were evaluated and provides a short description of the general scope and impact of these changes.

5. ION GENERATION 1 – TRANSFORMATION DOMAINS

For each of the 10 critical work domains shown in Figure 10, the work reduction opportunities that were selected are described in summary detail with a table at the end of each section. This table details the savings type, functions impacted, positions eliminated, and estimated time to implement the change along with any cost savings related to materials or contracts eliminated.

5.1 Condition-Based Monitoring

Nuclear plants today enjoy some of the highest reliability and availability factors in any industrial sector due to the finely tuned maintenance and testing activities that are performed on the plant structures, systems, and components with highly skilled and experienced technicians. They are backed up by similarly competent engineers capable of detecting, diagnosing, and remediating very subtle and complex degradation issues.

In addition to plant maintenance, there are many other types of plant testing and surveillance activities that must be conducted by a highly skilled workforce in order to assure operational readiness in all respects. These include equipment operation, plant configuration management, plant chemistry for fluid systems, radiation protection (RP), security, and plant system health.

These types of activities have historically been conducted as worker-based field activities which involve taking testing and maintenance equipment to the components for procedure-based, intrusive activities. In many cases, data is simply recorded, and no corrective actions prove necessary. On occasion, components are actually degraded during these intrusive activities, leading to what is known as maintenance-induced failures.

Condition-based monitoring (CBM) is an entirely different approach to achieving these end objectives through the use of online sensors that are capable of detecting the failure modes the intrusive testing is used to find. These sensors communicate this condition information back to a monitoring platform that is capable of recording and alerting the responsible organizations of the degrading condition. Advanced platforms can diagnose the cause of the degradation and predicting the time until unacceptable performance, or an operational parameter will exceed its limit. These platforms are also capable of interfacing with the plant work management system to automatically create, plan, and schedule work orders when necessary.

The obvious advantage of CBM is it is not labor-intensive, occurs on a continuous basis, and focuses plant resources only on situations where interventions are needed, and thus avoiding maintenance-induced failures and unnecessary wear on equipment through unneeded testing. CBM is available today for a variety of plant testing and surveillance activities, limited only by the availability of sensors to detect the failure modes and conditions now managed by labor-intensive field activities.

5.1.1 CB-01 Chemistry Monitoring Reductions

There are many liquid and gaseous systems in a nuclear plant in which the chemistry of the fluid is critically important to the function of the system and the long-term preservation of the systems components. While there are a few automated sampling and monitoring systems in nuclear plants today, the majority of them are sampled manually through sample lines, a specimen is collected, and then analyzed usually back in a chemistry laboratory within the plant. This work method is labor-intensive, has high knowledge and skill requirements, and is susceptible to human performance issues. In some cases, it potentially exposes the scientists and technicians to hazardous substances.

Existing and new in-line sampling and analysis can automate a significant portion of this plant activity. Once installed, these systems pull either a continuous or intermittent sample, analyze for controlled parameters, and then return the samples to the fluid stream or dispose of them in some controlled waste process. They transmit the results to a monitoring data base for processing including alerts for actionable results, initiation of work requests, routing for approvals, and archiving for plant records.

Technology Requirements:

- In-line sampling systems
- Advanced analysis systems
- AI/ML based algorithms

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Chemistry and Environmental	Chemistry Technicians	6	6–12 months	$1.0M

5.1.2 CB-02 Implement Condition-Based Maintenance

As NPP systems begin to be operated during periods longer than originally anticipated, the need arises for more and better types of monitoring component performance. This includes the need to move from periodic, manual assessments, and surveillances of physical components and structures to centralized online condition monitoring. This is an important transformational step in the management of NPPs. It enables real-time assessment and monitoring of physical systems and better management of active components based on their performance. It also provides the ability to gather substantially more data through automated means and to analyze and trend performance using new methods to make more informed decisions regarding maintenance strategies. The capability to determine the remaining useful life of a component to justify its continued operation over an extended plant life will be particularly important.

Technology Requirements:

- Wireless network
- Sensors for all failure modes addressed by time-based testing and maintenance
- Diagnostic and prognostic analytics.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Engineering	Engineers	4	18–24 months	$6.4M

5.2 Advanced Analytics/Assurance

Probably the single factor that drives nuclear plant resource requirements so much higher than any other form of electric generation is the amount of data collection and analysis to support assurance activities related to the possession of nuclear materials. Assurance in this sense is defined as determining the plant is compliant with all committed technical, operational, and regulatory requirements. Assurance also involves determining whether organizational and business objectives are being achieved. In any case, assurance is a closed loop process for any given commitment or obligation by collecting data indicative of actual performance, analyzing the data with respect to an acceptance criteria, reviewing and reporting the performance through a set of management controls, initiating corrective action for deficient performance, and then monitoring for improved and acceptable performance.

As described in Section 5.1, much of the data collection across all of the various plant operational and support activities can be performed by condition-based monitoring technologies. These data can be collected and organized for any assurance activity using the process described above.

The analysis activities for assurance are typically complex, require highly educated and experienced workers, and take considerable time. However, they are also highly repetitive and amenable to automation. This can be done through a variety of analysis technologies from traditional deterministic computer software programs to the emerging capabilities of artificial intelligence and machine learning (AI/ML). The analysis automation can also be coupled to technologies that automate the reporting, review, transmittal, and archiving of the analysis records further reducing the labor requirements for nuclear and business assurance.

5.2.1 AA-02 Reactor Core Design and Fuel Optimization

Reactor core design is a complex analysis process that must consider a number of factors, including intended fuel cycle length, energy requirements, core operating limits, commercial fuel characteristics, fuel assembly distribution within the core, measuring and testing requirements, and ultimately fuel discharge and long-term storage. Fuel optimization involves determining the energy (enrichment) requirements and core position for each fuel assembly (>190 assemblies for a large reactor) with the cost of nuclear fuel increasing with higher enrichment. Further, each reactor fuel cycle has specific reports that predict all pertinent reactor behavior over the course of the fuel burn. This is typically published in document known as a core operating limits report (COLR). All of this is accomplished by experienced reactor engineers highly familiar with the reactor operating parameters and limits.

Advancements in AI/ML technology will greatly reduce the effort to design reactor cores and ensure fuel optimization, taking advantage of the long histories of core loads on these mature reactor facilities in training the AI/ML systems. Furthermore, this technology will be able to adjust to the results of analyses based on the operating histories of the units, again getting data through automated data collection means, to ensure the nuclear plant control rooms have up-to-date reactor design, fuel, and reactor physics guidance at all times.

Technology Requirements:

- AI/ML systems for core analysis

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Operations/ Reactor Engineering	Reactor Engineers	2	12–18 months	$0

5.3 Digital I&C/Control Room Modernization

In spite of a significant number of digital systems now having been implemented in operating nuclear plants, there have been no large-scale changes to the layout or function of their control rooms. Nuclear utilities have understandably been reluctant to undertake significant control room upgrades or modernization projects in consideration of cost, regulatory risk, and impact on the large investment in procedures, training programs, and other support functions that may be impacted by large upgrades. Also, there is a general desire to retain the high degree of operator familiarity with the current control room arrangements and thereby avoid potential human performance issues associated with control board configuration changes.

Introducing digital systems into the control rooms creates opportunities for improvements in control room functions that are not possible with analog technology. These improvements are actually enabled by the new digital I&C systems even though many times these features go unused. This is especially true of what is called distributed control systems (DCS), in which plant parameters are digital variables that can be used and displayed in multiple ways that are beneficial to operators. This is opposed to analog technology in which a parameter is generally available in just one place on the control boards.

Current human performance engineering principles and techniques are able to leverage these capabilities to support more effective operator performance, resulting in a more human-centered main control room. And these techniques can be applied on a proportional basis for a hybrid control room (mixture of analog and digital I&C technologies), not requiring a full-scope approach to control room modernization, such as refurbishing or replacing an entire main control room. Rather, these improvements can be accomplished through gradual and stepwise related projects that are carried out when digital I&C systems are implemented to replace analog I&C systems to address near-term reliability and operational needs.

5.3.1 DG-01 Maintenance Testing and Surveillance Reduction

Current nuclear plant I&C protection systems require substantial periodic surveillance testing in compliance with the plant's Technical Specifications. These tests are designed to confirm that the systems can perform their credited design functions. There are numerous such tests such that some of them are being conducted virtually every day. The protection systems must be declared inoperable if they cannot perform these functions or if surveillance tests have not been satisfactorily performed within the prescribed time limits. These tests require a significant field and control room coordination and can impose some plant production risk (e.g., reactor trip) of themselves. When surveillance test results do not meet acceptance criteria, both Operations and I&C Maintenance must react very quickly to diagnose the problem, troubleshoot the degraded components, and make any necessary replacements/repairs. Then the surveillance test is repeated until satisfactory results are obtained. Meanwhile, the plant is in the associated Technical Specification Action Statement that could require control room actions up to reactor shutdown if the surveillance test is not successfully completed in the time allowed.

Modern digital protection systems have a number of features that can self-perform the types of health checks currently done in surveillance testing. In some cases, these are performed continuously. In other cases, they can be performed on demand at any desired interval. There are even means of verifying acceptable channel calibrations by cross-checking with redundant instrument channels or cross-checking related plant parameter instruments.

Not only is considerable labor saved with these digital I&C self-checking features, but there are also other benefits as well. Confirmation that the protection features are working is obtained far more frequently than with conventional surveillance testing. The testing is safely performed by software and is not intrusive, leading to configuration errors. These systems also offer diagnostics that quickly allow the I&C technicians to locate failed components (e.g., circuit boards) and replace them, thus minimizing inoperable time on the failed circuit. All of this adds up to improved reliability and availability of the protection systems while lowering plant O&M costs.

Technology Requirements:

- High-bandwidth wireless networks
- Computer-based procedures
- Digital I&C safety system
- Digital document review and archiving.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Operations	I&C Technicians	15	36–60 months	$2.5M

5.3.2 DG-02 Digital Control Room/Operational Efficiency

Modern digital I&C systems in combination with other digital applications can enable significant efficiencies in completing these tasks. This includes reducing the time for field support of these activities for Auxiliary Operators (AOs) and maintenance technicians. The result is labor savings for control room operators, field support, and oversight, including [Reference 14]:

- More efficient control room and related field operations, reducing the time to execute plant evolutions. Higher levels of automation allow operators to initiate sequences of commands while remaining in an overall monitoring and oversight state.
- Reduced administrative burden for the operations staff due to logging and archive features of the digital technologies.
- Reduced effort to deal with component failures, resulting in operator workarounds and other operational burdens, due to the inherent reliability of the digital systems and the elimination of discrete devices and alarms.
- The Human System Integration of digital systems to standardize and simplify the operation of systems as opposed to the array of devices across the control rooms of operating plants.
- Task-based displays to bring the plant data and controls for a given plant evolution to a single or cluster of nearby displays that eliminates the need for operators to move about the boards to access discrete devices.

The cost avoidance of this WRO reflects reduced staffing in operations, engineering, maintenance, and regulatory compliance by eliminating a number of different tasks involved with plant operations and support of control room functions. Operators, if needed to for ancillary purposes such as emergency response, can be redeployed to other support tasks when not needed in normal control room operations. Other support tasks related to degraded control room functions, whether they are engineering or regulatory compliance issues, are avoided by the reliability and operator self-service features of a digital control room. These reductions have a significant leveraged effect given they are performed on a 24/7 basis for multiple units.

Technology Requirements:

- High-bandwidth wireless networks
- Mobile devices

- Large overview displays
- Component identification technology (QR codes, OCR, and RFID)
- Mobile wireless video cameras.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Multiple	Multiple	25	36–60 months	$4.1M

5.3.3 DG-03 Analog I&C Work Elimination

The I&C and protection systems are composed of thousands of discrete devices with logic devices, control devices, interlocks, and permissive relay contacts spread through a large number of electrical cabinets, interconnected by thousands of cables. Support of legacy I&C systems, including the control room HSI, requires substantial maintenance and engineering efforts. Often these items must be addressed expeditiously as plant control functions are in a degraded condition, thus impeding plant operational control. They sometimes result in certain Technical Specification required functions to be inoperable, forcing the plant into prescribed Action Statements to address the degraded conditions, up to potentially a forced reactor shutdown.

Modern digital I&C systems for control, protection, and control room features eliminate these discrete devices and the significant workload they represent for maintenance and engineering. Such control and protection features are never really lost because they are implemented in software and can be quickly restored in any digital failure scenario. In the event of failure of human-system interface (HSI) equipment, such as displays, keyboards, etc., these functions can temporarily be assigned to other functioning HSI equipment in the control room while the degraded component is quickly replaced. None of this involves intrusive component troubleshooting and repair and can typically be done with the systems online. The expense of the replacement parts is also minimized, with replacements typically being standard circuit boards, displays, power supplies, etc. compared to the large volume of expensive discrete logic devices.

Technology Requirements:

- Digital components.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Operations	Maintenance Planners and Schedulers, I&C Craft	9	36–60 months	$1.5M

5.3.4 DG-04 Obsolescence/Spare Parts Cost Reduction

Obsolescence of discrete I&C parts is a huge issue in maintaining the legacy analog control and protection systems of nuclear plants, including the thousands of devices on the control boards of a conventional control room. These devices are subject to declining support by their suppliers due to the general industry transition to modern digital systems resulting in low volume sales. In many cases, they are no longer commercially available, and the nuclear plants are maintaining them or are having third parties re-engineer and fabricate replacement parts. This is very expensive, especially when it entails qualifying them for safety-related use.

Modern digital systems altogether eliminate the obsolescence and spare parts issues by basing all control and protection function is software. The efforts to find spare parts or remanufacture them are thus avoided, including the substantial escalation in prices utilities are paying for these parts. The labor savings for these obsolescence efforts are bundled in the FTE reductions for DG-03 (see Section 5.3.3). The non-labor savings are reflected in the table below.

Technology Requirements:

- Digital components.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Materials	Maintenance	N/A	N/A	36–60 months	$0.9M

5.4 Plant Automation

Many labor-intensive nuclear plant work activities are candidates for automation through existing and emerging technologies. Some work activities can be entirely eliminated by installing technology that performs the task on a time-prescribed basis. Other work activities might still require some worker intervention but key aspects of it can be performed by technology. In both cases, in addition to the cost savings, human error is reduced.

The business case for plant automation must consider both the acquisition and installation costs of the technologies, as well as ongoing maintenance of the technologies and periodic upgrades or replacements. However, this has proven to be cost-effective in many industry sectors and it is a matter of identifying those key opportunities in nuclear plants.

5.4.1 PA-01 Workflow enabled Clearance and Tagging, Lock Out Tag Out (LOTO)

Due to the significant number of manually performed work activities in a nuclear plant, there is a commensurate amount of clearance and tagging activities to ensure worker safety and equipment protection. The clearance and tagging activities are likewise labor intensive, requiring multiple layers of checking and independent verification such that workers are not exposed to dangerous energy levels. Given that these work activities are performed over and over, the clearance packages can be standardized and applied through automation. With new ways of positively verifying that tags have been applied to the correct components, and that those components have been placed in the correct configuration (e.g. breaker is open), then much of the checking and independent verification can be eliminated.

In addition, as work activities become automated, there will be a proportional decrease in the number of work activities that require worker protection, further contributing to the savings.

Technology Requirements:

- Smart padlock that immediately communicates unauthorized opening

- Digital clearance and tagging tools (e.g., electronic tags system)

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Operations	Tag-out Planner	2.0	24-48 months	$0.3M

5.4.2 PA-02 Tool Calibration Consolidation

Create industry wide centralized or regionalized organization to calibrate all maintenance, RP, and chemistry tools. This WRO will seek to eliminate internal calibration services by maintenance shops or central labs and move this service to specialized contractors.

Technology Requirements:

- None.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Contract Services Outsourcing	Maintenance	N/A	0	6–12 months	$0.3M

5.4.3 PA-03 M&TE Controls - Tool Tracking

Tools and testing devices can be effectively tracked with modern identification technologies such as bar codes and RFIDs. These smart equipment tags serve multiple purposes. First, they can be used to ensure that the right tools and testing devices are used by matching their ID tags to what is required by the work package. For instance, before a smart procedure will allow a worker to proceed, all M&TE must be registered with the work package to ensure they are the correct ones. Worker qualification to use those particular tools and test devices can likewise be automatically verified at the same time, as the workers also register themselves in the work packages as the work performers.

A second consideration is in loss-prevention of a nuclear plant's very expensive tool inventory. Nuclear plants have historically experienced a surprising percentage of tools that become unaccounted for following work activities, especially during outages. These ID tags can again be used to track the path and location of tools as they are transported throughout the plant and maintain the association of the workers who checked them out. The tags can be configured in a tamper-proof manner, much the way retail stores control their inventories. These tags, along with relatively inexpensive technology that registers their transit from room-to-room in the plant, will provide a real-time tracking capability for these tools, with their location known at all times.

Technology Requirements:

- Auto-assisted monitoring
- Bar codes or RFID tags
- Ability to track what equipment was worked on using tool (traceability in the event that a tool is mis-calibrated)

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Multiple	Multiple	3.0	24–48 months	$0.4M

5.4.4 PA-04 AI Auto-Assist Condition Reporting Analysis

Analysis of condition reports is a large labor commitment for nuclear plants mostly involving highly compensated professional workers. This analysis is regulatory required through a plant's Quality Assurance Program, to ensure that conditions adverse to quality, as well as trends of repeated problems, are addressed and precluded. This problem analysis and trending is labor-intensive.

There is opportunity to apply emerging capabilities in artificial intelligence and machine learning (AI/ML) to conduct this analysis and trending. One associated technology, Natural Language Processing (NLP) can process the historical records of problems and then apply AI/ML to identify the causes, extent of conditions, repeat problems, and even corrective actions. These capabilities can further be interfaced with the work management system to automate planning and scheduling of the corrective actions when they involve field work.

Technology Requirements:

- NLP capable of automatically recommending corrective maintenance work orders or pre-determine a set of options to choose from
- Screening Corrective Action Program (CAP) items, including identification of need for human judgement
- Deep learning artificial intelligence.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Multiple	Multiple	8.0	24–48 months	$1.4M

5.4.5 PA-05 Autonomous or Assisted Inspections (Drones and Robots)

There is a variety of technologies that can automate nuclear plant inspections to eliminate or greatly reduce the current labor effort to conduct them. This includes fixed sensors, drones, robots, fixed cameras, and other sensory and measurement devices. The effort to conduct these inspections often involves support activities such as developing work packages, conducting pre-job briefings, erecting scaffolds, implementing safety measures, independently verifying data collection, post-processing data, and archiving work packages.

Technology in place can also collect data more frequently if that provides benefits. This allows earlier detection of degrading conditions and provides more time and options for remediation of the conditions. Finally, there is a reduction in maintaining a trained and qualified workforce to conduct these inspections manually, which amounts to considerable avoided cost over time due to normal turnover and attrition of the workforce.

Technology Requirements:

- Drones and autonomous robots
- Charging points placed throughout plant.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Engineering	Engineers	2.0	12–18 months	$0.3M

5.4.6 PA-06 RP Surveys and Job Coverage

The nuclear plant Radiation Protection (RP) organization expends considerable effort in maintaining up-to-date radiation surveys for all rooms in the radiation control area (RCA). This consists of taking various types of readings in each room for general area dose rates, surface contamination, and airborne concentrations. This is assisted by some fixed monitors. There are various technologies that can assist, if not eliminate, the manual efforts to collect the readings and annotate them on the survey maps for each room. This could be a combination of fixed instruments along with use of robotics to collect physical specimens such as air samples and surface smears. This information can be automatically transferred to the survey maps, which in turn, can be automatically routed for review and approval, and then posted electronically at the entrance to the individual rooms as well as on the plant information system.

Plant maintenance and testing in high dose areas is usually monitored by a RP technician physically present in the room. The purpose is to provide close, real-time monitoring of dose conditions and worker ALARA practices. However, this ties up a RP technician for the duration of the activity even though the technician's attention is not needed during certain times when activity is low. This is particularly burdensome during outages when there are so many concurrent jobs requiring coverage. A solution to this is RP remote monitoring where advanced remote collaboration technology is used to enable the technician to monitor multiple jobs from a central location, relying on cameras, communications, and local instruments to provide an equivalent level of oversight of the work as when on location. This has the added benefit that no dose is received by the RP technician, thus lowering overall job dose.

Technology Requirements:

- Area dose rate monitors/badges
- Wi-Fi/LTE
- Drones and/or robots

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	RP	RP Technician	5.0	12–24 months	$0.8M

5.4.7 PA-07 ALARA Planning

Dose estimates are prepared for virtually all work activities that are conducted in the RCA. These dose estimates are prepared by experienced RP technicians who take into account historical records of similar work, current dose readings the specific nature and duration of the work activity, the number of people present, and any shielding that is present. From this dose estimate, assignments are made for the type of dose and contamination protections that will be required, such as anti-contamination suits, respirators, step-off pads, local and telemetric dose instruments, additional shielding, etc. In addition, dose and dose-rate limits are established, as well as stay-times and prescribed use of low dose waiting areas. Finally, this information is transferred to a radiation work permit (RWP) for the workers and is automatically downloaded into the electronic dosimeters worn by the workers when they sign-on to the RWPs.

This work is highly repetitive and follows an established set of rules and guidelines. Moreover, there is a long history of RP planning for these repeating work activities, as well as the actual dose records for these jobs, thereby confirming the effectiveness of the planning. This is an ideal application for emerging AI/ML applications that can learn the rules, guidelines, and job histories, and acquire the current dose condition and work requirements, to automate RP ALARA planning. Integration of data across the plant applications will facilitate transfer of this information into the RWPs.

Technology Requirements:

- Trend analysis software
- Automated personnel dose monitors

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	RP	ALARA Specialist	2.0	12–24 months	$0.3M

5.4.8 PA-09 Decontamination Robotics

Decontamination activities are performed whenever there is radioactive material (contamination) where it is not wanted. It comes from both planned activities, such as when radioactive fluid systems are opened for maintenance, as well as from degraded plant components, such as leaking valves and pipes. Contamination is not only a danger to the person who comes in contact with it, but that person is likely to spread it to clean areas and thus expose other workers to it. Most plants maintain very high standards of clean floor space and component surfaces. What contamination cannot be reasonably removed is controlled very tightly.

Decontamination activities consist mostly of manual efforts to spray down, wipe down, collect the water, and dispose of it properly. This work, in addition to being labor intensive, exposes the workers to dose and potential contamination spreading, and thus must be highly controlled. There are a variety of robotics that are increasingly capable of performing human-level tasks in terms of mobility and dexterity and can likely perform many of these decontamination activities. These robots could also be human assisted in some cases, with technicians directing and articulating the robots from a remote, clean environment. In time, through on-board AI/ML capabilities, these robots would learn to perform these tasks more autonomously. Recognizing that the robots themselves could also spread contamination, they would be monitored, stored, and recharged in an appropriate area of the RCA.

Technology Requirements:

- Area dose monitors
- Robotics for contamination smears
- Isotope analyzers
- Mapping application.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	RP	RP Technicians Decon Technicians	5.0	12–18 months	$0.5M

5.4.9 PA-10 IPAWS EP - Alert Notification

Most is not all nuclear plants operate an emergency siren system as part of their emergency plan for significant emergency events. These sirens are meant to alert the public that an event is underway and for them to use media and other means to get instructions. The sirens are located throughout the emergency planning zone (EPZ) of the plant and require a good deal of maintenance to keep in good operational order. They are also tested on a frequent basis and degraded performance, measured in terms of the number of siren failures on-demand, is reported to the NRC and is subject to regulatory action. Even in the best of cases, the effectiveness of the siren system depends on people hearing the siren over some distances from inside their home or car, over whatever background noises and distractions they have.

In todays' world a much more effective way of getting word to people is through their personal devices connected to the internet and communication services. This is known as Integrated Public Alert & Warning System (IPAWS). This system is operated by the Federal Emergency Management Agency (FEMA) and allows warning messages to be pushed to personal devices such as mobile phones, among other capabilities. In addition to the resident public, anyone passing through the affected area and in communication with those cell towers would get the notification. It is also recognized that friends and relatives would quickly relay messages to persons that might not otherwise receive them.

Use of IPAWS, though an Emergency Plan change, would allow the plant to abandon the current siren system, eliminating the considerable labor and expense of testing and maintaining it, as well as the effort to report results and deal with any regulatory actions.

Technology Requirements:

- LTE.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Security	None	0	6–12 months	$0M

5.4.10 PA-11 Crew Scheduling

Crew scheduling is a repetitive work item consisting of matching upcoming maintenance and testing tasks to the week and daily availability of qualified crews. Most jobs have a long history of being handled by a consistent crew, but some jobs have unique features that might require qualifications and skills from other crews. In addition to assigning jobs to crews, their daily and weekly capacity to accept a certain number of jobs depends on the availability of crew members, affected by scheduled training, vacation, ancillary duties, etc. In some cases, there are options to increase crew availability through augmented workforce or authorization of overtime.

Crew scheduling is typically conducted by experienced personnel who have other skills in broad demand and thus could be more effectively utilized if this activity could be automated. The activity follows a prescribed set of rules and guidelines, as well as historical precedents, that lends itself very well to AI/ML applications. The work management system provides a rich set of data for the AI/ML learning. It is well within the current capabilities of this technology to assign most of the plant activities to the correct crew and to balance their work schedules, as well as identify the few remaining cases that might need review and decisions by an experience scheduler. In time, the AI/ML application would learn how to schedule these cases.

Technology Requirements:

- Application connecting multiple databases.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Operations	Operations Scheduler	1.0	12–24 months	$0.2M

5.5 Process Re-Engineering and Automation

Once the necessary work functions have been identified by evaluating the critical work domains, process re-engineering and automation can be applied to each remaining work function in order to improve its efficiency. Work functions that involve moving large amounts of data and evaluating previous plant work documents to plan future jobs are ideal candidates for significant process improvements. With computer-based procedures, real-time data can be used to guide the craft into the correct steps and prevent issues such as using the wrong procedure or losing track of the proper steps in the procedure. Documenting work performed and archiving the work activities can be as simple as pushing a button at the end of the job performance.

5.5.1 PR-01: Automated Planning and Scheduling

Using business process automation tools to automate or auto-assist the work planning process will allow easier and more accurate planning of work activities. In fact, historical plant data, plant operating experience, and changing plant conditions can be used to auto-generate work requests, create work orders, and schedule online or outage work. Automated systems can replace the tedious manual searching and compiling plant data formerly used to create work packages. For Gen 1 analysis, it is assumed a small crew remains to oversee process and handle exceptions.

In addition, the T-Week process is eliminated (engineering, maintenance, supply chain, operations, and work management.)

Technology Requirements:

- Business process automation tools that can: initiate or screen work requests, create and schedule work packages, assign work packages to crews, and complete QA/archive of post-work documentation
- Common failure mode tracking
- AI/ML using NLP.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Elimination	Work Management	Maintenance Scheduler (Outage, Maintenance I&C)	16	12-24 months	$2.5M

5.5.2 PR-02: Computer-based Procedures – Digitization and Workflow

Nuclear plants require detailed approved procedures for almost all plant operations and maintenance activities according to NRC regulations. These procedures must be created, updated, revised, distributed, controlled, and archived in order to meet strict assurance requirements. These mostly manual systems currently in use across the nuclear fleet require large amounts of manpower in order to manage the procedure process successfully. This work reduction opportunity will take advantage of electronic procedures to reduce the labor required to keep the procedures up to date. Multi-skilled operators will be used to update procedures, and low-value procedures will be simplified or eliminated.

Technology Requirements:

- Procedure digitization through computer-based procedure tools with embedded process workflow.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Elimination	Procedures	Operations Procedure Writers	5	24-48 months	$0.8M

5.5.3 PR-04: Campaign Maintenance

Traditional maintenance at most nuclear plants is managed by large on-site crews of discipline specific craft workers that address corrective and preventive maintenance activities as they come up. There may be periods of time where certain disciplines are overloaded and other times where shop foremen are looking for tasks to keep the craft workers busy. Campaign maintenance is about consolidating certain types of component work into brief work periods for online work conducted similar to a short outage. A discipline or component specific traveling off-site crew will visit the plant on a scheduled basis and perform the work and then leave. This relieves the plant of the need to have this level of resource in the baseline staffing of the plant. It also provides an outsource opportunity for cost savings.

Candidate components for campaign maintenance need to be identified but could include such components such as manual-valve, motor-operated valve testing and repair or instrument calibration.

Technology Requirements:

- Integrated scheduling software capable of tracking across the fleet or units.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Elimination	Maintenance	Craft	20	24-36 months	$3.1M

5.5.4 PR-05: Records Management

Managing nuclear plant records involves managing documentation from creation to archiving. This process lends itself to automation once the plant data management systems can communicate with each other. This WRO will substantially automate records preparation, archiving, and retrieval through digital technologies. This functionality will be built into every instance of a WRO that requires records management features as part of its function. Automating this process and providing for verification of correct parts used, M&TE validation and timekeeping processes can also be automatically performed and can notify the craft person at the time of job performance of any deviations rather than waiting days or weeks for job closeout to identify problems.

Technology Requirements:

- Records automation tools capable of sort and search
- Digitize all records (print, film, drawings, correspondence).

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Engineering	Engineering Clerk, Records Management Clerk	2.0	12-18 months	$0.3M

5.5.5 PR-07: Enhanced Contracts Craft Hiring

Nuclear plants bring in large numbers of craft workers for outages and will be using traveling craft teams to perform campaign maintenance. Currently, many of these craft workers require additional technical training or skills certification in order to perform the required activities on the site. This training burden currently falls on the site training organization to provide which increases costs and many times delays the ability to start the task at the scheduled time. This WRO will reduce training and qualification burden through labor contracts that ensure a higher level of skill is available for represented workers. Some unions have signaled they are willing to take on this level of training and have it reflected in the wages for the affected job classifications. This would be facilitated by a more modern technology base in the NPP, reflecting the technologies taught in technical schools as opposed to the training NPPs must conduct for their antiquated technologies such as analog control systems.

Technology Requirements:

- None.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Training	Training Project Specialist	1	6–12 months	$0.2M

5.6 Mobile Worker Technology

The burden in conducting field work in nuclear plants has grown substantially over the decades of commercial nuclear power operations as work practices have been enhanced to improve personnel safety, accuracy in work execution, and assurance of equipment reliability. With nuclear safety as the paramount objective, striving for excellence in these outcomes is beyond question. However, for the most part, this involves a tradeoff with work efficiency in that more and more time-consuming requirements have been placed on workers to ensure these outcomes. In many cases, multiple workers are assigned to tasks that could be accomplished by a single worker for the sole purpose of peer checking the work and results. These extra layers of assurance are also dependent on flawless human performance and so they too are subject to human error and are not always effective. The practical result of this for the industry is that work quality and work efficiency are somewhat mutually exclusive. This is a major contributor to the current non-competitive position of nuclear power.

Fortunately, existing and emerging technologies for mobile workers can resolve this tradeoff between quality and efficiency. Many of the work execution and human performance tasks can be transparently automated within the technology and the workers can then focus their time and attention on the aspects of the job that require their skills and knowledge. The result is more efficient work with less labor resources, with the same or higher levels of assurance in work quality and safety. These technologies include:

- smart work packages that either execute or enforce human performance practices
- technologies for identifying the correct components to be manipulated
- wireless communications for real-time job status and remote support
- wearable cameras for remote oversight
- real-time retrieval of additional information needed
- real-time coordination and task approvals from remote parties such as the control room
- automation of tedious tasks such as calculations and entering data into tables

These technologies have been integrated and packaged into wearable forms that allow workers to comfortably and safely move through the plant to conduct their assigned field activities.

5.6.1 MW-01 Automated Troubleshooting

Modern plant components that are digital based typically have onboard monitoring and diagnostic features that can replace a lot of the testing and troubleshooting that is now conducted manually. Typically, these features cover the major failure modes of the component, conduct constant health checks (several times a second), diagnose faults, failures, and degraded conditions, and report these results out to established monitoring points on a real-time basis. For this reason, they eliminate a lot of troubleshooting activity by pinpointing which subcomponents are degraded. Many times, this degradation is reported in very early stages in which the component might still be performing its design basis functions.

While the most notable examples of this are in modern digital I&C systems that can pinpoint circuit board failures, these capabilities are present in other smart devices such as plant instruments/sensors, circuit breakers, component controllers (valves, motors, etc.) and other such equipment. Modern digital systems also eliminate a large number of components by simply converting their functions to command displays. For example, eliminating physical switches on control boards and replacing them with a command touch panel display obviously eliminates the need to ever troubleshoot these components.

The labor eliminated by automated troubleshooting is much greater than the field time. There are a number of support tasks that also have to be done. A troubleshooting task using a standard or custom procedure must be developed, especially in cases where plant risk must be managed. This must have organizational review, including Operations. Sometimes technical meetings must be called to conduct the review and planning, depending on the difficulty of the troubleshooting. Added to all of this is the back-end processing of the work package and review of the troubleshooting results.

Technology Requirements:

- On-board diagnostics.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Maintenance and Engineering	CMO Craft Rapid Response Engineers	9.0	36–60 months	$1.5M

5.6.2 MW-02 Remote Plant Support

Nuclear plants maintain a number of experts within their staff to ensure that there is a rapid response to issues that affect nuclear safety or production. While these functions are at times critical to meeting regulatory obligations and continuing to generate power, they are not core functions related to daily plant operations and typically needed only infrequently.

Remote plant support using advanced digital remote collaboration technologies will allow a nuclear plant to use central or contract resources for this specialty expertise on an on-demand basis. Further, the remote collaboration technologies will enable remote parties to effectively interface with the station activities without having to travel to the sites and experience the delays that travel would involve.

The cost savings enabled by such arrangements are much more than the direct time charges of these experts. It is also the avoided cost of maintaining full time resources for specialty expertise, including recruiting, hiring, training, non-productive time, maintaining backup for when a resource is unavailable, and repeating these costs whenever turnover in these positions occur. It often means that a station has access to a much more experienced expert who is involved in a variety of issues across the industry and not just what happens at one station or fleet.

Technology Requirements:

- Virtual/Augmented Reality (VR/AR) headsets.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Multiple	Multiple	22.0	12–24 months	$3.5M

5.6.3 MW-04 Fieldwork Task Consolidation

For fieldwork tasks that cannot be automated (such as adding oil to components), the efficiency of these tasks can be improved with mobile technologies, as well as consolidated and performed by multi-skilled workers. The technologies are what enable a multi-skilled worker to be successful in that they can reduce the training, knowledge, and skill a person has to have to perform a given task. A common example is the AED technology that is now available in many public places that enables a non-medical person to successfully apply a defibrillator to a person with a coronary emergency. The machine itself guides the person through the procedure and is able to determine if it is being applied correctly. This type of technology will allow a more generalized plant field worker to correctly accomplish a variety of specialized tasks.

This concept applies to the set of field workers in Operations, Chemistry, RP, Engineering, and perhaps Security who perform some sort of rounds involving physical manipulations or other such actions. Workers from these groups typically pass through the same areas of the plant tending only to the tasks in their discipline. Significant efficiencies are available as a mult-skilled worker, with technology that guides the work, so they can perform the tasks of multiple groups.

Technology Requirements:

- Multi-skilled worker
- VR/AR headsets
- Tablets

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Multiple	Multiple	7.0	12–24 months	$1.2M

5.6.4 MW-05 Automated or Self Personnel Dose Coverage

Work activities that occur in high dose areas of the plant typically have a Radiation Protection technician accompany the crew into the area to monitor their activities, ensure that ALARA practices are being observed, and detect any change in conditions from the dose plan for the job. This ties up an RP technician for the duration of the job and results in the added dose the RP technician receives. This is particularly burdensome during outages when there are so many concurrent jobs requiring coverage.

A solution to this is RP remote monitoring where advanced remote collaboration technology is used to enable the technician to monitor multiple jobs from a central location, relying on cameras, communications, and local instruments to provide an equivalent level of oversight of the work as when on location. This has the added benefit that no dose is received by the RP technician, thus lowering overall job dose.

In many cases, the workers themselves can monitor their dose and changing radiological conditions with wearable technologies. This includes electronic dose instruments that they already wear plus technology that guides the workers to observe the ALARA plan for the job. This could include estimated work times for portions of the work procedures that effectively monitor their stay-times and tell them if they are on schedule with the work. It could compare ambient dose to what is planned for the job and detect changing conditions, especially when there are plant configuration changes such as opening valves and piping systems. It could remind workers not actively involved in the work to move to the low dose waiting areas. The technology, perhaps AI/ML based, could perform much of the observation and coaching roles of an RP technician.

Technology Requirements:

- Area dose rate monitors and badges
- Wi-Fi/LTE
- Cameras
- AI/ML

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	RP	RP Technicians	5.0	12–24 months	$0.8M

5.6.5 MW-06 Field Work Preparation and Coordination

A substantial portion of the work time allocated to field work, particularly maintenance and testing activities, is consumed in job preparation and job coordination activities. These requirements have been imposed over the decades of nuclear power operations in an increasing fashion to deal with personnel safety concerns, nuclear safety concerns, potential disruption of power production, and regulatory compliance. An accepted rule of thumb in the industry for nuclear maintenance scheduling is that only about 30% of the time allocated to jobs is actual hands-on work. There is significant time to be gained back through mobile worker technologies.

Existing and emerging technologies allow us to completely rethink how we achieve the preparation, coordination, and quality aspects of field work that are key to achieving the essential outcomes in nuclear power operations. In keeping with the ION concept, this involves new and more efficient ways of working that still ensure all vital outcomes are obtained. For example, rather than extended pre-job briefs that attempt to cover in advance all the concerns of the activities, smart work packages can insert these precautions into the work stream as they are encountered in the job progression. This is far more effective than a warning that was spoken several hours before. There are similar improvements to all the coordination, real-time procedure step approvals, reporting of job status, obtaining supplemental job information, notifying support groups, closing out work packages, and so forth. Capturing the 70% of the allocated job time that is consumed in these activities will make a sizable impact on the required staffing to accomplish them.

Technology Requirements:

- Smart work packages and procedures
- Mobile work platforms (e.g. tablets)
- Pre-Job Briefing Software embedded in smart work packages

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Maintenance	Multiple	5.0	12–24 months	$0.8M

5.7 Advanced Training Technology

Classical training through classroom instruction has been the norm for nuclear plants since their beginning and remain the staple of the nuclear industry. However, with communication, computing, and electronic storage capabilities proliferating, many industries have moved away from traditional classrooms to online learning and virtual environments. The benefits are obvious: more student focused, better learning outcomes, lower overhead, more efficient use of technical experts, and less expensive. The ION Gen 1 review looks at several different areas where technology solutions already exist to assist in streamlining the delivery of training material to the nuclear plant staff.

5.7.1 AT-01 Operations Training Modernization

Operations training is one of the most important training areas for nuclear utilities since proficiency must be demonstrated on an ongoing basis and poor operator exam outcomes cannot be tolerated. Modern training delivery systems provide the opportunity to not only meet training objectives but actually improve outcomes and reduce cost. It is proposed that nuclear plants use modern simulations to enhance realism to improve training effectiveness and accelerate time to proficiency. Simulator exercises can be digitized, so they can auto-update due to changing plant conditions and modifications. In addition, simulations can be simplified to be self-service where trainees can select which simulations to run and be automatically tested using computer-based analysis systems. This self-testing feature will ensure license candidates are ready to stand for the NRC operator qualification exams. Eye tracking software and other technologies can be used to evaluate operating procedures and suggest procedure improvements.

Technology Requirements:

- Full digitization of simulations with auto-update software.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Training	Operations Trainers	8.0	12-24 months	$1.0M

5.7.2 AT-02 Technical Training Modernization

Technical training may benefit the most from fully digitalizing the plant and then using advanced delivery methods to prepare the plant staff for their work functions. It is recommended the nuclear plants modernize initial and continuing training through self-directed simulations and computer-based training.

Given the need to recruit early career and highly skilled employees, nuclear managers need to recognize the classical classroom delivery of training or skill development may not be the candidate's experience from their technical schools and university preparation. In addition, replacing antiquated analog systems in the plant with modern digital systems will eliminate the need for custom non-standard training on legacy systems and components. Using advanced technology will allow reduction in the amount of instructor-led training courses for non-licensed operators and technical training programs. This training transformation will apply to technical training for maintenance, RP, chemistry, and engineering.

Some ideas would be to develop and link on-demand video and just-in-time training concepts into electronic work packages which are viewed, as needed, prior to task execution. On-the-job training can be streamlined through use of modern training tools and delivery methods (e.g., 360 video, VR, scenario-based training, and hands on training facilities).

Technology Requirements:

- 360 video
- VR, scenario-based training
- Learning management system capable of delivering training.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Training	Technical Trainers	6.0	12–24 months	$1.0M

5.7.3 AT-03 General Training Modernization

General employee training and other general training is well positioned to move to an online digital, self-serve format. Most, if not all, of this material could be delivered online in a YouTube type format using digital verification of attendance and/or testing. Preparation and delivery of this material could be handled as a corporate function and/or contracted to a vendor who specialized in this area. Another benefit of virtual training could be the elimination of a large training facility and the staff to keep it in operation. Instructor-led training could be conducted virtually as necessary but could feature the best subject matter expert available for improved quality of training.

Technology Requirements:

- 360 video cameras
- VR, scenario-based training
- Learning management system capable of delivering training.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Training	Training Support	3.0	12–24 months	$0.5M

5.7.4 AT-04 Training Records Automation

Automation and online delivery of training can enable the automation of training records currently done manually. Operations training records and other technical certifications are very critical to demonstrate the plant is being operated and maintained according to regulations. Automated systems that collect and verify training has been completed can be integrated into the records management system without any manual manipulation required. Currently, much wasted time is used in querying and searching various data bases to turn around and enter this information manually into another database.

Technology Requirements:

- Record keeping software linked to a learning management system
- Linked qualifications to completed courses.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Training	Clerical	1.0	12–24 months	$0.1M

5.8 Remote Collaboration

Developing high-speed communication networks has allowed technology solutions never before imagined. One of the important ways to reduce O&M cost for nuclear plants is to automate processes that have previously been done partially or completely manually. Formerly, when an expert was needed to troubleshoot an equipment problem, that expert had to travel to the site and observe the problem directly in order to determine a solution. Now, technology exists where the expert can observe the problem remotely using interactive video and even connect with the machine remotely to diagnose the problem. This section will look at a few opportunities where remote collaboration can add value and actually reduce the cost of performing tasks manually. There are more opportunities for remote collaboration to benefit nuclear plant operation and maintenance, but they will be explored in future research.

5.8.1 RC-01 Remote Rad Monitoring

The Routine Environmental Monitoring Program (REMP) samples and evaluates environmental samples to determine if any contamination is present due to the presence of a nuclear plant nearby. In order to automate this process, automated or auto-assisted tools can be used to capture remote radiation monitoring data. One idea is to use a passive monitoring system—a network of passive radiation monitoring systems that reports data about radiological conditions in the environment. Another could be the use of sensors that could be fixed rather than in mobile vans or use of drones to fly through and measure the plume in the case of a release.

Technology Requirements:

- Drone – controlled and operated from a location on-site
- Automated radiation survey tools that can be mounted on vehicles – these survey tools would measure and send or store data without needing a technician to operate.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction Elimination	RP	RP Technician	10.0	18–24 months	$1.6M

5.8.2 RC-04 Engineering Outsourcing

Using remote communication systems, engineers can be virtually present anywhere there is a camera and communication device. This WRO would be to outsource engineering activities for mechanical, structural, and civil design engineering tasks and outsource design engineering scope for electrical and I&C modifications. In addition, other engineering functions could be outsourced including design, component engineering, and programs support, where this service is not needed on a full-time basis and is more economical than supporting an in-house engineering staff.

Technology Requirements:

- None.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Engineering	Engineers	12.0	24–36 months	$1.1M

5.9 Work/Requirement Reduction

One important category of cost management for nuclear plants is to simply reduce or eliminate work tasks that are deemed to provide low value with respect to key outcomes of nuclear safety, production, personnel safety, and compliance. This can be accomplished in a variety of ways. Many work requirements are actually imposed by the utility itself to address past needs, and perhaps haven't been reevaluated in light of market cost pressures. For example, certain activities might have some value but do not need to be performed on the frequency they are now. In other cases, needed work activities can be outsourced to capable suppliers that can perform them as effectively for lower cost. This is particularly true of activities that are performed infrequently and do not justify maintaining the needed expertise in-house.

It should be noted that there are certain work requirements that are imposed through regulatory compliance reasons or through the industry itself as best practices. Some of these might be demonstrated to not provide value commensurate with the cost and might be relaxed through coordinated industry action. In other cases, there might be more effective ways of conducting them that still meet requirements. These types of savings are not credited in ION Gen 1 but might be pursued in work reduction opportunities in ION Gen 2.

5.9.1 WR-02 Rad Effluent Monitoring (Environmental)

This area is regulatory-required monitoring of potential radioactive material in the environment external to the plant. There are a number of fixed and variable sampling points in a prescribed perimeter around the plant. Some of these have in-place instruments and in other cases technicians go to these points and take readings. Also, certain samples of water, vegetation, milk, and other substances that could contain radioactive material attributable to the nuclear plant are collected. After decades of monitoring, little to no activity has ever been discovered in the environment, with the exception of some tritium issues in groundwater that were addressed ten or more years ago.

One opportunity in this WRO is to reduce the frequency of monitoring and analyzing samples, based on the historical results. There is work remaining to determine whether this can be accomplished within current regulatory processes. A second opportunity is to outsource this work to national companies who can conduct the work more efficiently, as several utilities are already doing. The savings here would be the avoided costs in maintaining the workforce and facilities to conduct this monitoring program in-house.

Technology Requirements:

- Fixed radiation monitors (IoT)
- Software analysis tools to display radiation data, alarms, and support REMP reporting.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Emergency Planning (EP), Chemistry/ Env.	Sr Site EP Specialist / Site EP Specialist Enviro Specialist	3.0	24–36 months	$0.5M

5.9.2 WR-04 Licensing Work Reduction

Operating License changes are sometimes needed to achieve cost-savings ideas in addition to other important purposes such modernizing the plants or addressing newly identified safety issues. Yet, licensing work itself is expensive and requires highly specialized expertise both in plant designs and regulatory processes.

At least two opportunities exist in this WRO. The first is to reduce the workload of licensing and regulatory research and information gathering through technology, especially emerging capabilities with AI/ML. For example, the data reviews and document collections that are needed to support an NRC inspection can be substantially automated. The second opportunity is to outsource some amount of licensing and regulatory compliance work when it is highly standardized in the industry. There are a number of companies who offer such services that have deep experience and economies of scale in conducting these activities for multiple utilities.

Technology Requirements:

- Collaboration technology (e.g., Microsoft Teams) to interface these resources to plant staff where needed.

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Licensing	Licensing Specialist	1.0	12–24 months	$0.2M

5.9.3 WR-07 Reduction in Managerial Overhead

The nuclear industry excellence model is based on a significant degree of work oversight, much of which is provided by line management. Also, the current nuclear business operating model and organization maintains an extraordinary number of high-specialized experts in-house, which means that the managers must have the technical competence to manage and provide oversight to these functions. In addition, managers and supervisors are given a lot of ancillary duties at nuclear plants that require considerable time commitments, such as conducting job observations, participating in the emergency response organization, taking certain outage management roles, etc. This has led to spans of control that are typically narrower than power generation industry counterparts.

The ION Gen 1 business operating model will require far less supervisors and managers than the current model through use of technology for oversight, assurance, and compliance activities, which is believed to be a sizeable component of a plant's O&M budget. A second consideration is relying on outsourcing to offload the day-to-day management of activities that drive the need for so many management technical competencies. That said, the plant management team will have to possess enough technical competency to manage the outsourcing contracts and remain ultimately responsible for the quality of the work.

Technology Requirements:

- None

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Reduction / Elimination	Multiple	Multiple	51.0	12–60 months	$8.3M

5.10 Security

The security domain was reviewed, and ideas were evaluated to utilize technology to improve performance and efficiency thereby reducing costs. Given the sensitive nature of this type of information, only the resulting outcome will be reported here. Additional details will be provided in an appropriately restricted appendix to be issued at a later date.

5.10.1 SE-01 Security Technology Work Reduction Opportunities (consolidated)

Cost Savings Type	Functions Impacted	Positions Impacted	FTEs Eliminated	Time to Implement	$ Eliminated
Direct Labor Efficiency Gain	Security	Security Staff	39	12–36 months	$6.2M

6. ION GENERATION 1 OPTIMIZED NPP ORGANIZATION

Current nuclear plant organizational structures are based on the increasing level of historic systems, features, and processes that were required to be added to nuclear plants to address safety and reliability issues due to national and international safety events. However, as the plants have matured and addressed previous operational issues, the plant organization did not change, except to add additional responsibility both to the plant and central organizations.

When a utility implements the work reduction opportunities as outlined in this report, process changes can be implemented that result in streamlined or eliminated work processes allowing a drastic reordering of the organizational structure.

The work reduction opportunities outlined in this study will require significant leadership buy-in, capital investment, process redesign, and change management. The potential work reduction opportunities enable the company to not only reduce the size of the organization (internally, and externally) but also move a significant number of positions and functions to a central model due to remote work collaboration.

The revised structure of the organization is built around the premise the plant organization has all the resources to operate 24/7, and all other resources are support services that take care of the longer-term planning, schedule, and equipment health aspects of the plant. Depending on the operating model of the NPP, some resources can be located off site and/or be centralized to support the 24/7 operations and maintenance of the plant.

6.1 Organizational Structure

Appendix D shows a model organization chart for a one site, two-unit plant at a nominal 1000Mw per unit. Specific details regarding discipline breakdown have been omitted for the sake of clarity. There are significant opportunities to incorporate cross-functional positions that have traditionally been functional positions (i.e., RP techs and maintenance techs) into the plant operations positions.

6.2 Service Contracts

New types of service contracts and product support contracts will need to be added to support the ION Gen 1 business model. These tasks will primarily support the engineering and maintenance functions for specialty services. These contracts are characterized by certain provisions that allow a utility to outsource highly important work functions without concern for effectiveness in sensitive operational, safety, regulatory, and business outcomes. They would include such business advantages as:

- Seamless integration with the plant staff through advanced digital collaboration technology, including effective participation in critical field activities from a remote location.
- Services available immediately and on-demand with task authorizations handled outside the normal flow of work. The plant would call on these resources with the same ease of calling a support person in the utility organization.
- Creative arrangements allow a service or supplier organization to assume technical risk, relieve the plant of certain capital investments, and basically pay for the outcomes such as component performance and availability, rather than for the component itself.

Of course, the service or component supplier will need to be adequately compensated for these more flexible and effective business arrangements. However, in many cases, enabling the utility to avoid the ongoing expense and management attention to maintain these highly technical and evolving competencies will more than offset these contract costs, especially as these suppliers can spread their costs over a wide customer base.

A detailed breakdown of services by online or outage or specialty will need to be conducted through future ION Phase 2 work with a partner utility to determine the linkage and need for services after the reduction of internal labor.

The premise of the increase of contractor services is based on a significant amount of work volume in engineering and maintenance that will enable the outsourcing of non-baseline work to a supplier to perform on behalf of the NPP. Additionally, this opportunity could be available for the U.S. fleet of reactors and would benefit by relying on an industry expert supplier. These costs could be shared between utilities. For example, all turbine services for an outage could be performed by one vendor for the U.S. industry.

7. ION GENERATION 1 AGGREGATE BUSINESS CASE

The investment to support a modernization of the NPP is based on a reduction of fixed O&M spend by approximately 13% to a cost of $71.36/kw-year. Figure 12 shows the impact of the capital investment on the levelized cost of energy.

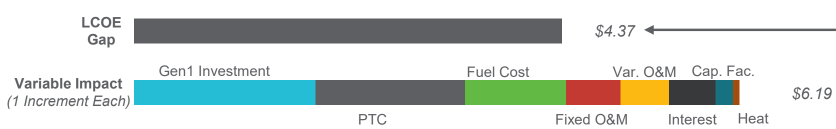
	Scenario 2: **ION-Gen1 LCOE with Sustaining and Innovation Capital**	Scenario 3: **Significantly Reduced Capital**	Scenario 4: **Reduced Capital, Aggressive Reduction of Fixed O&M**	Scenario 5: **Reduced Capital, Improved Cost of Capital**	Scenario 6: **Nuclear Production Tax Credit**
Generation Source	Nuclear	Nuclear	Nuclear	Nuclear	Nuclear
Plant Size (MW)	2200	2200	2200	2200	2200
Capacity Factor (%)	93	93	93	93	93
Fuel Cost ($/MMBtu)	0.65	0.65	0.65	0.65	0.65
Heat Rate (Btu/kWh)	10,300	10,300	10,300	10,300	10,300
Fixed O&M ($/kW-year)	71.36	71.36	64.55*	71.36	71.36
Variable O&M ($/MWh)	3.00	3.00	3.00	3.00	3.00
Overnight Costs ($/kW)	455 ($1B investment)	186 ($410M investment)	239 ($525M investment)	273 ($500M investment)	455 ($1B investment)
Interest Rate (%)	9.6	9.6	9.6	7.6	9.6
Production Tax Credit (PTC) ($/MWh)	0	0	0	0	$2.88
Levelized Cost of Energy ($/MWh)	**25.87**	**21.49**	**21.51**	**21.68**	**21.50**

Figure 12. Preliminary LCOE analysis.

7.1 LCOE Sensitivity Analysis

The LCOE sensitivity analysis was run to identify what factors significantly changed the potential outcome to make LCOE of nuclear competitive to alternative sources of electricity (Figure 13). The most significant variable that determined a different answer was the interest rate/cost of the cost of capital.

Variables	ION-Gen1 LCOE with Sustaining and Innovation Capital	Increment Change	LCOE Impact
Capacity Factor (%)	93	1%	$0.18*
Fuel Cost ($/MMBtu)	.65	.10	$1.03
Heat Rate (Btu/kWh)	10300	100	$0.065
Fixed O&M ($M)	157	10	$0.555
Variable O&M ($/MWh)	3	0.5	$0.50
Total Capital Investment ($M) (Sustaining + ION Gen 1)	1,000	250	$1.855
Interest Rate**** (%)	9.6	1	$0.47*
Production Tax Credit (PTC) ($/MWh)	0	1	$1.53**
Levelized Cost of Energy ($/MWh)	**$25.87 (Gen-1 LCOE)** –	**$21.50 (Target LCOE)** =	**$4.37 (LCOE Gap)**



Notes: * Non-linear LCOE impact, however, LCOE incremental difference is minor. Example: For Capacity Factor, changing from 93% to 94% results in a $0.18 difference in LCOE. Changing from 94% to 95% results in a $0.17 difference in LCOE
** Non-linear LCOE impact is moderate between increments. Example: For PTC, changing from 0 to 1 $/MWh results in $1.41 difference in LCOE. Changing from 1 to 2 $/MWh results in $1.56 difference in LCOE
*** The effect of combining different variable changes will not be exact, but it will be very close (i.e., within a few pennies)
**** Interest rate assumed 60% debt financing and 40% equity. Rates from Lazard: Debt 8% and Cost of Equity 12%.

Figure 13. LCOE sensitivity analysis results.

7.2 Investment Cash Flow

The overall investment to support the project and reduce O&M dollars is estimated to be $410M. This investment is primarily for digital hardware to support a digital control system including sensors and control systems. This is approximately $150M of the estimated $349M investment.

These estimates shown in Appendix C are defined as Class 1 estimates. From industry operating experience these estimates are within the industry tolerance for estimating of +100% or −50%.

The remaining $61M capital investment is identified as a contingency and will need to be further refined and identified in future research. For a full breakdown of investment capital by initiative please see Appendix C.

7.3 Ongoing Technology Costs

Ongoing technology costs to support the capital investments were estimated in this study by each investment/initiative type. The details of the estimates are shown in Appendix C.

These ongoing costs are primarily estimated to be ongoing software-as-a-service costs to support primarily computer-based digital software and systems, such as digital controls and monitoring and surveillance systems.

The overall estimated annual additional technology and services costs are estimated to be $17M; with a potential for $2.0M reserved for potential outsourced engineering support. These identified spends are identified in Appendix C. All estimates are +100%/-50% and will need to be validated through future research.

8. POSITIONING FOR ION GENERATION 2

As described earlier, ION Gen 1 evaluates technologies that are presently available or will be available within 5 years and are at a technology maturity level that will support implementation in an operating NPP at that time. ION Gen 2 will seek to take the O&M cost savings further by evaluating technologies, processes, and regulatory changes that may not be available for at least 10 years.

Some Gen 2 ideas might include:

- Replacing station emergency diesel generations with advanced batteries
- Eliminating all mechanical relays in the plant by using software routines within the integrated safety and control system for interlocks, permissives, and latching circuits
- Eliminating all instrument and service air systems by upgrading valves to be electronically controlled and actuated
- Increasing the use of artificial intelligence/machine learning systems to perform administrative and repetitive tasks related to monitoring, surveillance, and assurance
- Using remote monitoring, operation, and maintenance of plant support equipment
- Implementing on-site manufacturing of replacement parts through additive manufacturing.

As ION Gen 1 concepts are validated and implemented, performance data and implementation lessons learned will be collected and used to plan for Gen 2 upgrades. Future research will evaluate which innovation opportunities are more likely to yield the most O&M cost reductions along with maintaining and improving plant safety and performance.

8.1 Additional Revenue with Integrated Energy Systems

Recent changes in the U.S. energy market, such as low natural gas prices and increased electricity production for subsidized renewable energy sources, have led to financial challenges for existing light-water reactors. Many utility owners have elected to decommission their plants rather than continue using them as consistent sources of clean baseload power due to the non-economic climate for grid electricity. Utilities are investigating the integration of plant secondary systems directly with production systems in order to generate additional products through technologies such as hydrogen electrolysis or water desalination. Recent DOE studies [Reference 10, 11] considered the technologies associated with these integrated energy systems (IES) activities, as well as market analyses for these secondary products.

There are currently three IES projects underway with industry partners. Exelon and Energy Harbor will be hosting low-temperature electrolysis units in the 1–3 Mw size range while Xcel Energy is designing a high-temperature electrolysis (HTE) unit that will use steam extracted from the secondary system of the plant in the 250Kw size. These pilot projects will demonstrate the practicality of siting a hydrogen generation system co-located at a nuclear plant while also providing needed hydrogen for on-site plant uses. Additional pilot projects are planned of larger sizes and will be demonstrated at both PWR and BWR nuclear units (see Figure 14).

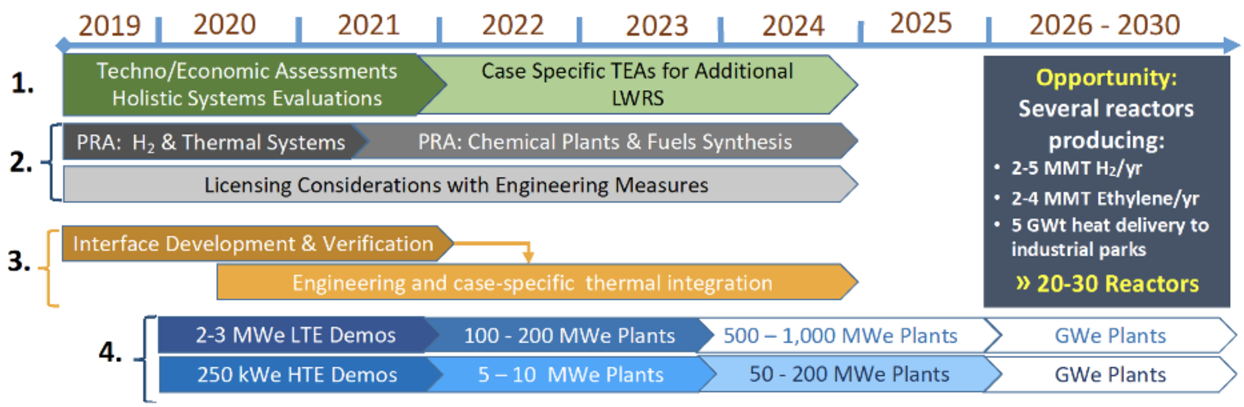


Figure 14. Plan for pilot deployment of IES.

Additional uses of nuclear derived heat are being investigated including the production of various chemical feedstocks, generation of ammonia, polymers, and synthetic fuels. Nuclear heat can also be transferred to nearby industrial or chemical facilities where it can replace heat generated by burning fossil fuels. The low-operating temperature of current light-water reactors limit the scope of replacing the heat needed for many large industrial processes including steel and concrete. Many advanced reactors under development will be much better suited to provide the energy at the proper temperature for these processes.

9. SUMMARY

Plants have an urgent need to reduce cost of electricity up to a third to remain in the electric market. This cannot be done with incremental business improvement, rather it calls for transformation of the nuclear business operating model based on innovations being adopted in virtually all other industry sectors.

We have applied a methodology known as ION, a top-down business-driven approach to positioning a nuclear plant at its market-driven price point through applied innovations available in the next 5 years. This study was conducted with support from Scott Madden Management Consultants and based on decades of experience in applying these types of innovations to improve nuclear plant business efficiency.

We have specifically identified work reduction opportunities that collectively can create this level of cost reduction based on innovations that are deployable in the next 5 years. This study was conducted on a normalized two-unit nuclear plant at 1000 MW per unit, based on industry data. The result of this study is the production cost for this plant went from 30 $/MWH to 21 $/MWH, roughly achieving the goal of a one third O&M cost reduction. These are described and assigned cost reductions in terms of reduced staffing and non-labor savings. We have also estimated the capital investment for these innovations at approximately $410M.

We have run sensitivity studies on these analyses and determined assumptions on discount rate and the amount of needed capital investment to produce the most certainty in the numbers. It is also sensitive to the assumed labor and expense savings produced by the individual work reduction opportunities, although there is an averaging effect (some higher, some lower) among the complete set of work reductions opportunities that might dampen the net effect.

To further refine this study, validations on all the work reductions assumptions, as well as the capital investment estimates, will be conducted in a future phase of this research.

10. ADDITIONAL RESEARCH

This research is based on WROs that are currently available or available within the next 5 years. In addition, these WRO opportunities were evaluated based on knowledge obtained by Scott Madden and Associates and DOE researchers without significant input from utility partners. To increase the confidence level of the ION Gen 1 WROs, a significant validation effort is needed. A project for the following year is planned to involve at least two utility partners to validate this research result and develop an initial implementation plan. The overall purpose of this research is to connect technology, process changes, human performance improvement, and governance changes to reduce the O&M costs for the operation of the current fleet of nuclear plants. Without significant change in the environment of lower energy rates, a large portion of the existing fleet is or will be facing economic challenges in the near future. Therefore, research to identify a pathway to profitability for these clean energy generators is of utmost importance.

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Appendix A

ION Opportunity Summary

#	ION Generation	Capability Area	Domain	Work Reduction Opportunity
AA-01	II	Support the Plant	Advanced Analytics / Assurance	Inventory Optimization
AA-02	I	Support the Plant	Advanced Analytics / Assurance	Fuel Optimization
AA-03	II	Support the Plant	Advanced Analytics / Assurance	H&S Analytics
AA-04	I	Support the Plant	ION Work Reduction	Implement Contractor Spend Management Solutions
AA-05	II	Support the Plant	Advanced Analytics / Assurance	Eng. Equip Reliability
AA-06	N/A	N/A	N/A	N/A
AA-07	II	Support the Plant	Advanced Analytics / Assurance	FP&A functions - P2P
AA-08	N/A	N/A	N/A	N/A
AA-09	II	Support the Plant	Advanced Analytics / Assurance	HR - Recruiting
AA-10	N/A	N/A	N/A	N/A
AT-01	I	Support the Plant	Advanced Training Technology	Operations Training Modernization
AT-02	I	Support the Plant	Advanced Training Technology	Technical Training Modernization
AT-03	I	Support the Plant	Advanced Training Technology	General Training Modernization
AT-04	I	Support the Plant	Advanced Training Technology	Training Records Automation
AT-05	N/A	N/A	N/A	N/A
CB-01	I	Operate the Plant	Condition-Based Monitoring	Chemistry Monitoring Reductions
CB-02	I	Maintain the Plant	Condition-Based Monitoring	Implement Condition-Based Maintenance

#	ION Generation	Capability Area	Domain	Work Reduction Opportunity
CB-03	I	Maintain the Plant	ION Work Reduction	Reduce Plant Modification Volume
CB-04	N/A	N/A	N/A	N/A
DG-01	I	Operate the Plant	Digital I&C / CR	Surveillance Reduction
DG-02	I	Operate the Plant	Digital I&C / CR	Digital Control Room / Ops Self-Support
DG-03	I	Maintain the Plant	Digital I&C / CR	Analog I&C Work Elimination
DG-04	I	Operate the Plant	Digital I&C / CR	Obsolescence/Spare Parts Cost Reduction
IW-02	I	Operate the Plant	ION Work Reduction	Rad Effluent Monitoring (Environmental)
IW-04	I	Support the Plant	ION Work Reduction	Licensing Work Reduction
IW-07	I	Support the Plant	ION Work Reduction	Reduction in Managerial Overhead
MW-01	I	Maintain the Plant	Mobile Worker Technology	Automated Troubleshooting
MW-02	I	Maintain the Plant	Mobile Worker Technology	Remote Troubleshooting
MW-03	I	Maintain the Plant	Mobile Worker Technology	VR / AR for Design Engineering
MW-04	I	Operate the Plant	Mobile Worker Technology	Fieldwork Task Consolidation
MW-05	I	Operate the Plant	Mobile Worker Technology	Automated Personnel Dose Coverage
MW-06	I	Maintain the Plant	Mobile Worker Technology	Electronic Job Briefs, Approvals, Sign-ons
PA-01	I	Operate the Plant	Plant Automation	Workflow enabled Clearance and Tagging / LOTO
PA-02	I	Maintain the Plant	Plant Automation	Tool Calibration Consolidation
PA-03	I	Maintain the Plant	Plant Automation	M&TE Controls - Tool Tracking
PA-04	I	Support the Plant	Plant Automation	AI Auto-Assist Condition Reporting Analysis
PA-05	I	Maintain the Plant	Plant Automation	Autonomous or Assisted Inspections (Drones and Robots)

#	ION Generation	Capability Area	Domain	Work Reduction Opportunity
PA-06	I	Operate the Plant	Plant Automation	RP Surveys
PA-07	I	Operate the Plant	Plant Automation	ALARA Planning
PA-08	I	Operate the Plant	Plant Automation	Battery Storage-Based Black-Start Capability
PA-09	I	Maintain the Plant	Plant Automation	Decontamination Robotics
PA-10	I	Support the Plant	Plant Automation	IPAWS EP - Alert Notification
PA-11	I	Support the Plant	Process Re-Engineering / Automation	Crew Scheduling
PR-01	I	Maintain the Plant	Process Re-Engineering / Automation	Automated Planning & Scheduling
PR-02	I	Support the Plant	Process Re-Engineering / Automation	Computer-based Procedures - Digitization and Workflow
PR-03	I	Maintain the Plant	Process Re-Engineering / Automation	Fix It Now - Multi-skill Maintenance
PR-04	I	Maintain the Plant	Process Re-Engineering / Automation	Campaign Maintenance
PR-05	I	Support the Plant	Process Re-Engineering / Automation	Records Management
PR-07	I	Maintain the Plant	Process Re-Engineering / Automation	Enhanced Contracts Craft Hiring Costs
RC-01	I	Operate the Plant	Remote Collaboration	Remote Rad Monitoring
RC-03	I	Support the Plant	Remote Collaboration	Centralized Nuclear Oversight
RC-04	I	Support the Plant	Remote Collaboration	Eng. Outsourcing
SE-01 to SE-10	I	Operate the Plant	Security	Various Technology Solutions

Appendix B

Cost Target Information

Direct Labor by Function	Typ. Direct Labor Spend ($M)	High — Confidence Level Based on Supporting Opportunities — Low Target Reduction %	Cost Target ($)
Site Leadership	$1,800,000	0%	$0
Plant Management	$0	0%	$0
Operations	$22,000,000	20%	$4,400,000
Maintenance	$43,000,000	35%	$15,050,000
Work Management	$5,100,000	70%	$3,570,000
Radiation Protection	$5,000,000	60%	$3,000,000
Chemistry & Environmental	$5,500,000	60%	$3,300,000
Engineering	$18,500,000	50%	$9,250,000
Employee Concerns	$120,000	0%	$0
Training	$8,000,000	60%	$4,800,000
Performance Improvement	$1,200,000	80%	$960,000
Security	$20,400,000	50%	$10,200,000
Procedures	$900,000	100%	$900,000
Emergency Preparedness	$1,800,000	25%	$450,000
Licensing/Reg. Affairs	$1,200,000	0%	$0
Nuclear Oversight	$840,000	60%	$504,000
Organizational Effectiveness	$300,000	0%	$0
Nuclear Fuels			
Business Operations	$1,200,000	0%	$0
Prob. Risk Analysis	$2,000,000	0%	$0
Records Management	$1,000,000	80%	$800,000
Project Management	$700,000	20%	$140,000
Quality Control	$2,400,000	100%	$2,400,000
Warehouse	$3,300,000	30%	$990,000
Totals	$146,260,000		$60,714,000

Appendix C

Innovation Investments

#	Innovation Investment	Affected Opportunities	Investment Cost *(Capital)*	Ongoing Cost *(O&M)*	Comments
Software					
1	Digital document review and archiving	DG-01, PR-05, AT-04	$6,000,000	$300,000	PR-05: Records digitization software capable of sort and search Assumes 5% ongoing software support cost
2	Tool traceability software	PA-03	$3,500,000	$15,000	PA-03: Ability to track what equipment was worked on using tool (traceability in the event that a tool is mis-calibrated)
3	NLP CAP screening software	PA-04	$10,000,000	$375,000	PA-04: Software should include identification of need for human judgement
4	Failure mode identification and work request creation software	PA-04, PR-01, AA-05	$2,200,000	$150,000	PA-04: Must be capable of automatically learning / recommending corrective maintenance action based on historical data and failure mode information PA-04: Should use Deep Learning AI
5	Business process automation software - Corrective maintenance planning and scheduling	PR-01, PR-04	$10,000,000	$60,000	PR-01: Software should initiate and support screening of work requests, create and schedule work orders, assign work to crews, and help support streamlined QA/Archive of post-work documentation PR-04: Integrated scheduling software capable of tracking across the fleet or units
6	Supply Chain business process automation tools	AA-07, AA-09	$4,000,000	$150,000	AA-07/09: Software should optimize price, inventory, and cycle times
7	Common failure mode tracking	PR-01	$4,000,000	$150,000	Develop / configure enterprise asset management tools to use standard codes for failure mode tracking across nuclear plant assets

#	Innovation Investment	Affected Opportunities	Investment Cost *(Capital)*	Ongoing Cost *(O&M)*	Comments
8	Improved Automated Chemistry SKID technology	CB-01	$9,000,000	$150,000	CB-01: Will capture substantive chemistry data / sample types; reference EPRI Business Case for PWR Full Skid Implementation cost - $7.5–7.9M. Includes hardware, testing/installation, design engineering labor. Ongoing vendor support of ~400hrs/yr + 50k in parts/media
9	Dose trend analysis software	PA-07	$1,500,000	$100,000	
10	AI imagery analysis software	SE-07	$1,500,000	$125,000	
11	Mapping application	PA-11	$2,500,000	$100,000	
12	Mobile worker platform software	MW-06, PR-02, AT-03	$7,000,000	$250,000	Mobile platform should include forms, procedures, and reference materials and facilitate just-in-time training
13	Inventory management software	AA-01	$5,000,000	$100,000	
14	Remote collaboration tools	RC-02, IW-04, IW-06	$7,000,000	$200,000	
15	Fuel optimization software	AA-02	$2,500,000	$100,000	
16	Health and safety analytics software	AA-03	$2,500,000	$50,000	
17	Assurance analytical software	RC-05	$2,500,000	$100,000	
18	Contractor spend management tool	AA-04	$2,000,000	$100,000	
19	Digital simulator and modern training platform	AT-01, AT-02	$9,500,000	$100,000	
20	Training modernization modules - platform and content development	AT-01, AT-02	$4,500,000	$100,000	

#	Innovation Investment	Affected Opportunities	Investment Cost *(Capital)*	Ongoing Cost *(O&M)*	Comments
21	Modern Learning Management System (LMS)	AT-02	$2,500,000	$100,000	Assumed 50k setup costs + first year license; ongoing: $15/user/month; 450 users
22	ML capable of automating high-expense labor	AA-06	$8,000,000	$150,000	
Hardware					
25	Mobile devices (smartphones and tablets)	DG-02, MW-04, MW-06	$3,000,000	$264,000	Assumes 800 total mobile devices, one for each worker, and additional devices to support specific functions, such as training and maintenance. Assumes $1K per mobile device. Assumes 33% equipment replacement and replenishment rate.
26	Large overview displays	DG-02	$30,000	$4,500	Assumes 15 total overhead displays at $2,000 each. Cost of each display may vary due to added functionality (e.g., touch inputs). 15% equipment replacement and replenishment rate
27	Mobile wireless video cameras	DG-02, SE-02	$600,000	$90,000	Assumes 400 total cameras $1.5K each. Assumes 15% equipment replacement and replenishment rate.
28	Digital components	DG-03	$5,000,000	$750,000	Assumes 15% equipment maintenance rate
29	On-Board diagnostics	MW-01	$8,000,000	$1,200,000	Assumes 150% equipment maintenance rate
30	VR/AR headsets	MW-02, MW-03, MW-04, AT-02	$135,000	N/A	Assumes 30 total headsets at $4,500 each. Price includes kits for additional functionality.
31	Smart padlock	PA-01	$125,000	$12,500	Assumes 500 total smartlocks at $4,500 each. PA-01: Smart padlock should immediately communicate unauthorized opening.
32	Digital clearance and tagging tools (e.g., Tags Pro system)	PA-01	$6,000,000	$1,500,000	Assumes 15% equipment maintenance rate and 5% equipment replacement rate
33	Calibration tools	PA-02	$3,000,000	$750,000	Assumes 20% equipment maintenance rate and 5% equipment replacement rate

#	Innovation Investment	Affected Opportunities	Investment Cost *(Capital)*	Ongoing Cost *(O&M)*	Comments
34	Smart sensors able to track status of tool	PA-03	N/A	N/A	Feature should be embedded in tools themselves
35	Drones and autonomous robots	PA-05, RC-01, SE-01, SE-07, PA-11, AA-01	$2,300,000	$960,000	Assumes 30 drones at $45K each and 10 robots (e.g., Spot) at $95K each. Assumes $500K to hire drone pilots. Assumes 15% equipment maintenance rate and 5% equipment replacement rate. RC-01: Drone – controlled and operated from a location on-site.
36	Area dose rate monitors/badges	PA-06, MW-04, PA-11	$600,000	$120,000	Assumes 5% equipment maintenance rate and 15% equipment replacement rate
37	Automated personnel dose monitors	PA-07	$2,800,000	$700,000	Assumes 400 total mobile devices; one for each applicable worker, and additional devices to ensure coverage in case of breakage. Assumes 20% equipment maintenance rate and 5% equipment replacement rate.
38	IoT sensors	IW-02, SE-01, PR-03	$10,000,000	$3,000,000	Assumes 20% equipment maintenance rate and 10% equipment replacement rate
39	Automated radiation survey tools	RC-01	$500,000	$150,000	RC-01: Automated radiation survey tools that can be mounted on vehicles – These survey tools would measure and send or store data without needing a technician to operate. Assumes 20% equipment maintenance rate and 10% equipment replacement rate.
40	Isotope analyzers	PA-11	$400,000	$40,000	Assumes 10% equipment maintenance rate
41	Battery UPS	PA-08	$4,200,000	$420,000	Assumes 10% equipment maintenance rate
42	Security features	SE-06	$3,000,000	$300,000	Assumes 10% equipment maintenance rate

#	Innovation Investment	Affected Opportunities	Investment Cost *(Capital)*	Ongoing Cost *(O&M)*	Comments
Infrastructure					
43	Plant Wi-Fi/LTE	All except: SE-02/05/08-10, CB-03, IW-03, IW-05	$9,000,000	$900,000	Assumes 10% equipment maintenance rate
44	Digital I&C safety system	DG-01	$180,000,000	$1,800,000	Assumes 1% equipment maintenance rate
45	Component identification technology (QR Codes, OCR, RFID)	DG-02, PA-01, PA-03	$50,000	$5,000	Assumes 5% equipment maintenance rate and 5% equipment replacement rate
46	Device charging station network	PA-05, RC-01, SE-01, SE-07, PA-11, AA-01	$1,500,000	$225,000	Assumes 10% equipment maintenance rate and 5% equipment replacement rate. Charging points placed throughout plant and compatible with wide assortment of drones and robots.
47	Security Features	PA-12	$1,500,000	$225,000	Assumes 10% equipment maintenance rate and 5% equipment replacement rate
	Sub-Total of Identified Investment Technologies	-	$348,940,000	$13,866,000	-
	Contingency	-	$61,060,000	$2,000,000	-
	Additional Engineering Support			$1,200,000	
	Total Investment Capital	-	$410,000,000	$17,066,000	-

Appendix D

Potential ION Generation 1 Organization Structure–Single Site Dual Unit Model

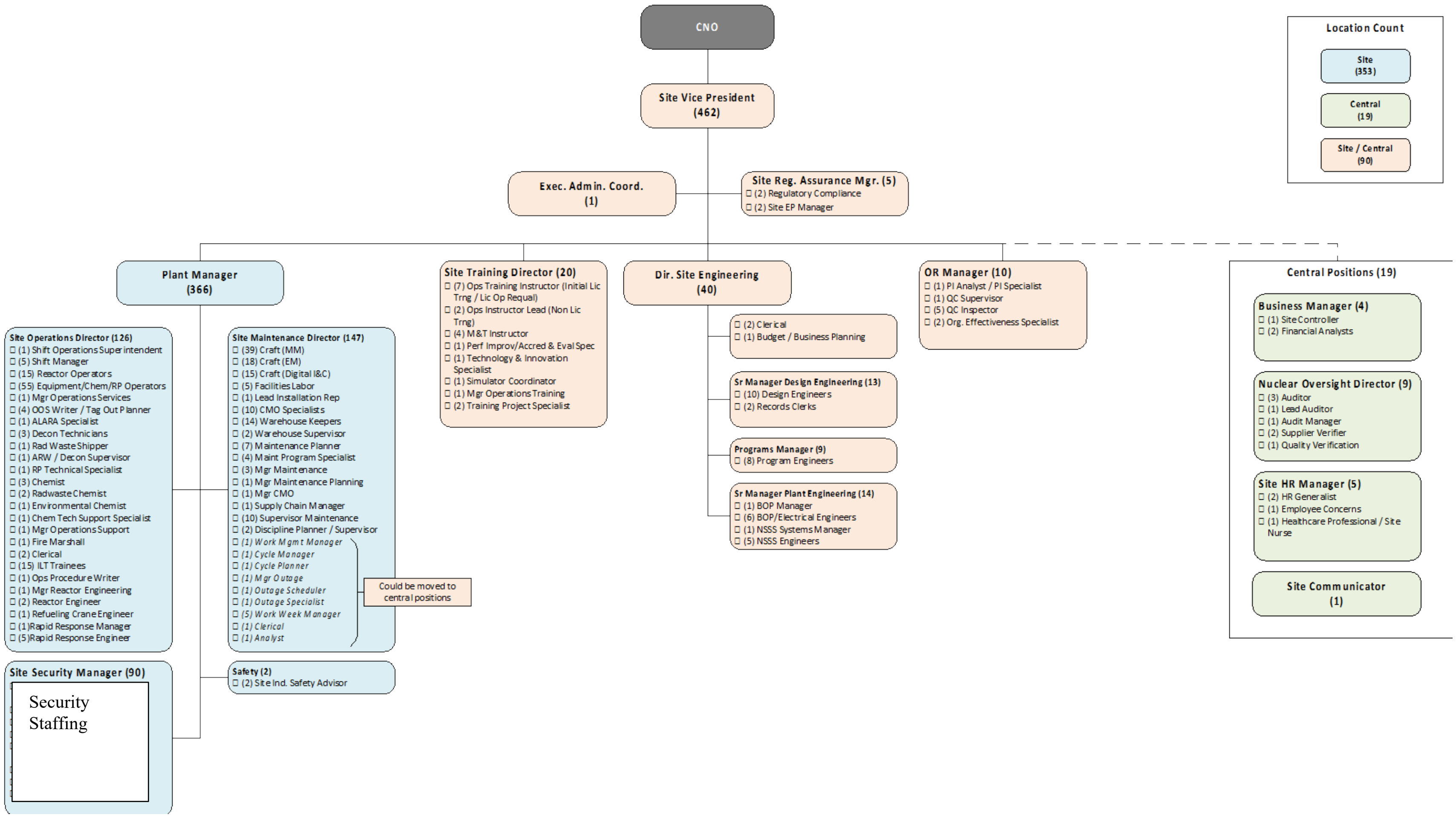

Figure D-1. Detailed organization chart.

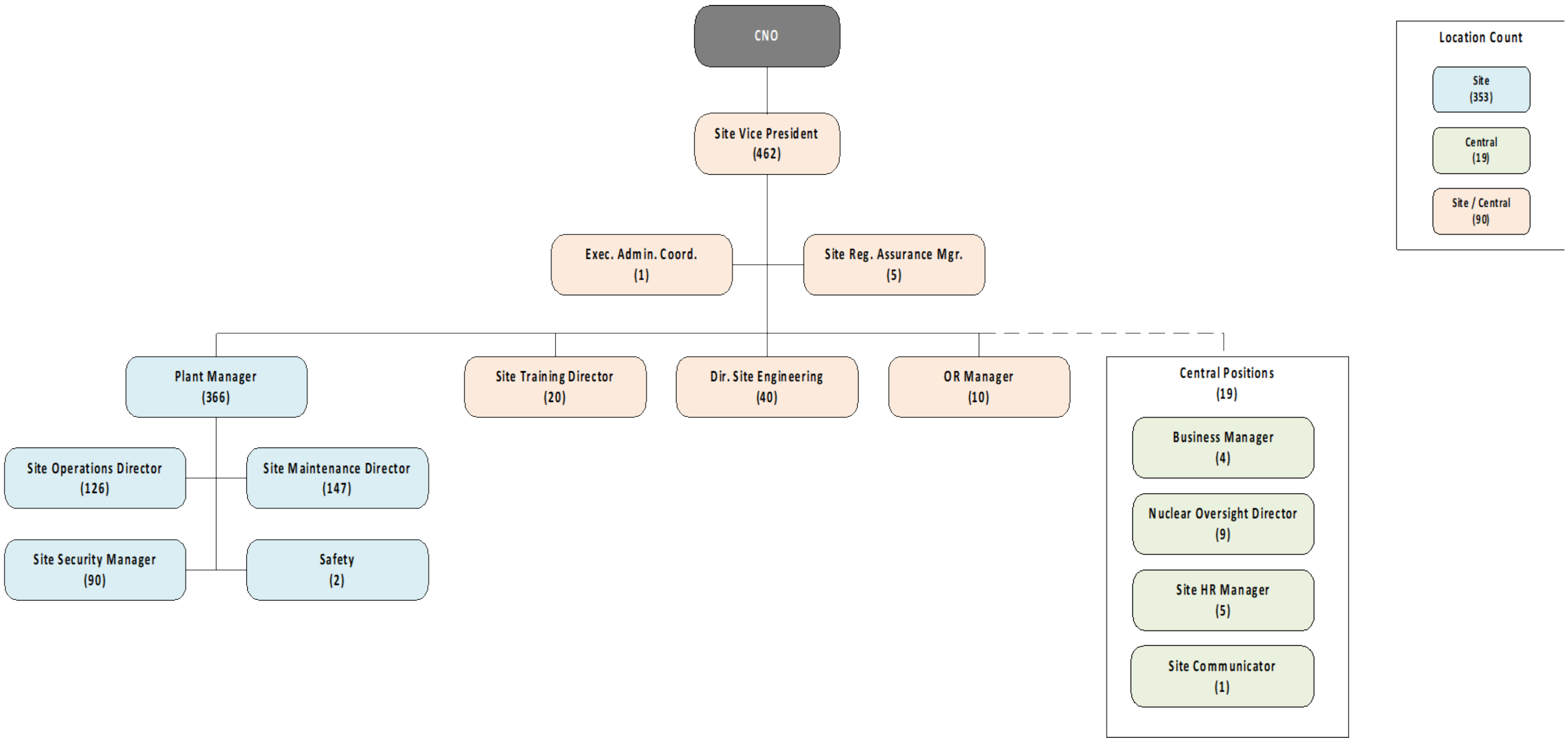

Figure D-2. Summary organization chart.

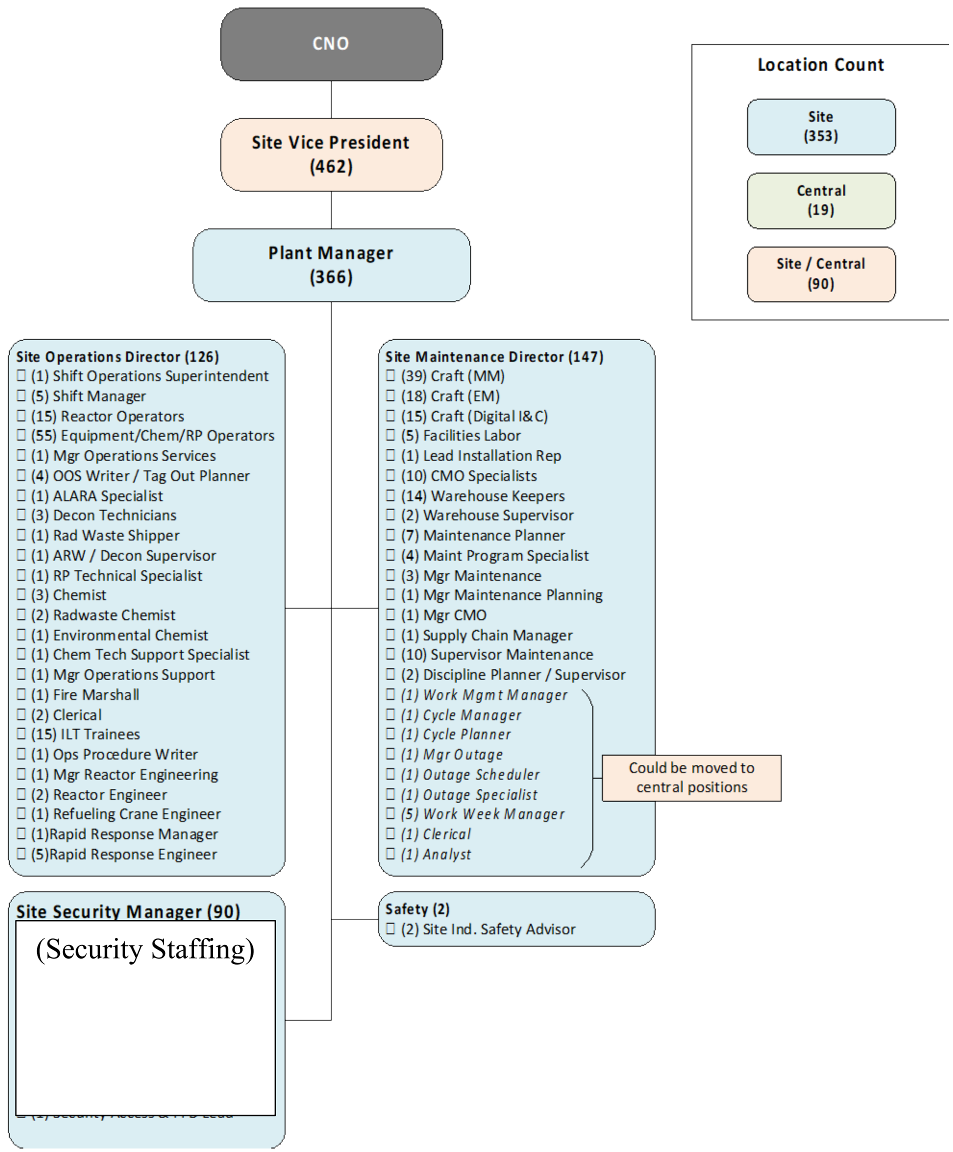

Figure D-3. Plant manager organization chart.

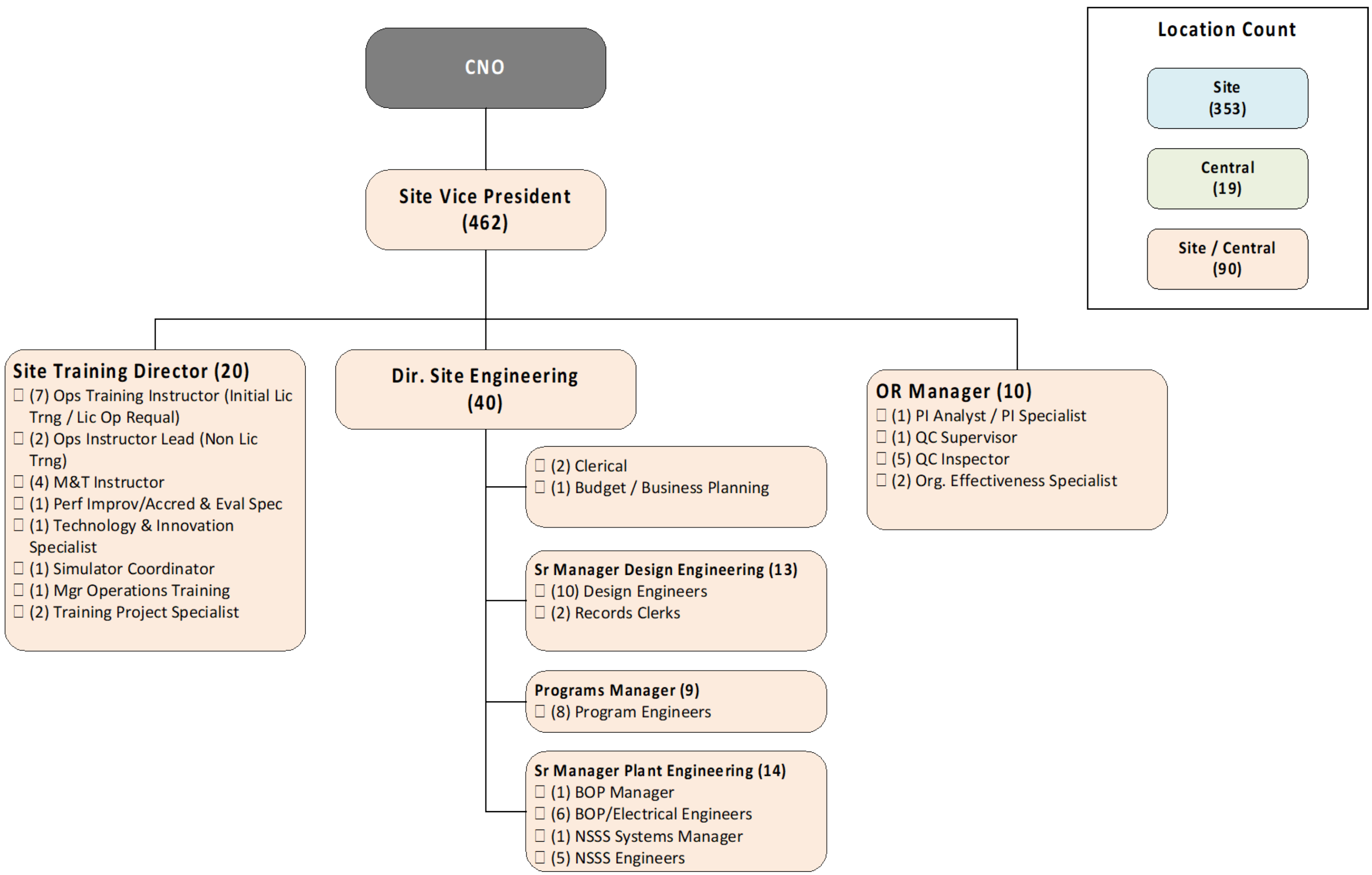

Figure D-4. Training, Engineering, OR organization chart.

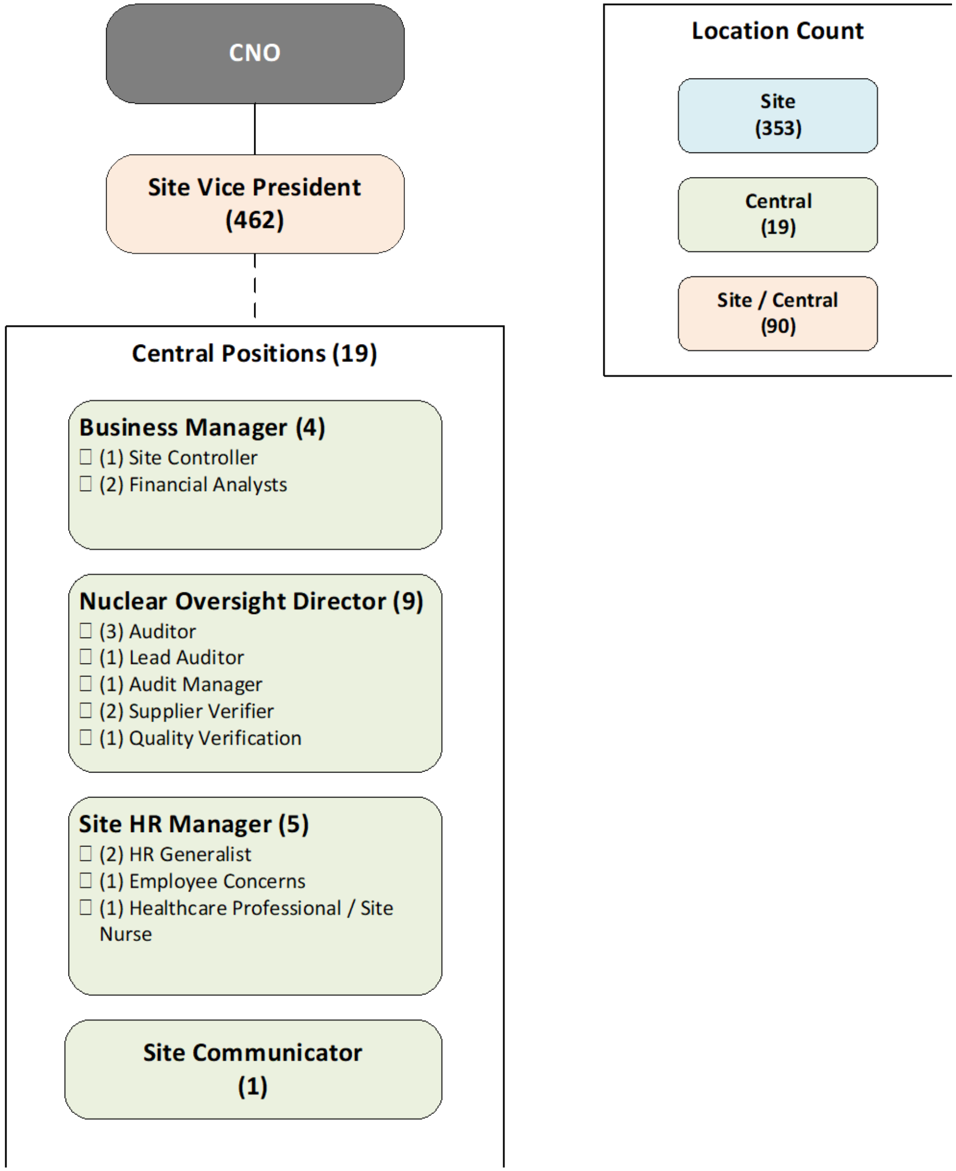

Figure D-5. Central Positions organization chart.