TECHNICAL REPORT

NEI 20-08

Strategic Project Management Lessons Learned & Best Practices for New Nuclear Power Construction

Revision 1

Prepared by the Nuclear Energy Institute
November 2025

Revision Table

Revision	Description of Changes	Date Modified	Responsible Person
0	Initial Issuance	04/2020	Marcus Nichol
1	Document updated to align with subsequent materials, correct any inconsistencies, and serve as a public entry point for the NEI deployment materials	11/2025	Benjamin Holtzman

Acknowledgements

This document was informed by discussions with various past and recent large project stakeholders (owners, EPC contractors, and original equipment manufacturers), the Department of Energy Office of Nuclear Energy, and other industry players. NEI acknowledges and appreciates the contributions of NEI members and other organizations in providing input, reviewing and commenting on the document.

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Executive Summary

Revision 1 of NEI 20-08, *Strategic Project Management Lessons Learned & Best Practices for New Nuclear Power Construction* updates and aligns the original document with the five Implementation Guides (IG 01 – IG 05) which were published between 2021 and 2024 to provide a harmonized collection of guidance to support successful nuclear project development and delivery. This document is intended for an expanding population of stakeholders, project sponsors, investors, and end users (e.g., utilities, industrial companies, information technology firms). These entities across the new nuclear power (NNP) project lifecycle face exposure to cost and schedule overruns, counterparty disputes, and non-completion risks. The best practices and lessons learned presented here provide practical guidance to reduce uncertainty, improve coordination, and strengthen investor confidence - helping ensure new nuclear projects are delivered on time, on budget, and with greater financial credibility.

All projects and programs require leadership, commitment, and inspiration from top management to be successful. This is especially so for a First of a Kind (FOAK) NNP construction project. This report focuses on the lessons learned and subsequent best practices to be considered and applied in a systematic manner by stakeholders planning and preparing for an NNP project to increase the likelihood of successful outcomes. This report does not provide a comprehensive framework for implementing an NNP, however it does provide best practices that if implemented, will create the foundation for the nuclear industry's success. The Nuclear Energy Institute (NEI) is issuing this report and its associated Implementation Guides for use by entities that are planning for the construction of NNP projects, to be used to supplement the entity's framework for NNP deployment.

The energy sector has seen the emergence and convergence of multiple priorities that are driving an acute interest in new nuclear deployment. First, there is a surge in electricity demand, a significant departure from the relatively flat consumption of recent decades driven, in part, by the energy needs for Artificial Intelligence (AI) computing for hyperscale cloud computing data centers. Second, there is a renewed focus on national security needs for energy security and energy independence. Third, industrial end-users require reliable, resilient power that can be deployed adjacent to the load, sometimes in remote applications not connected to the existing grid. Fourth, corporate decarbonization commitments, including those made by the major industrial producers and hyperscale data providers, are driving adoption of and investment in new nuclear development as the best clean energy alternative. Fifth, state governments and universities are looking to support demonstrations of new technologies and train the workforce of tomorrow. These and other reasons are driving demand in real time and independent studies conclude that there is a large market opportunity for cost competitive, firm, dispatchable, and reliable energy sources, including nuclear energy.

Today, nuclear energy accounts for almost 20% of the U.S. electricity generation, and, when viewed as part of a clean energy portfolio, nuclear energy produces more of the country's electricity than any other zero-carbon emissions source. Nuclear energy is a low carbon baseload dispatchable form of electricity generation that can operate 24/7 to meet the needs of America's growing electricity demand. The nuclear energy industry is taking action to enable nuclear energy to meet the market through the continued operation of existing reactors and the commercialization of advanced reactors, which could be called upon to provide more than 300 GW of new nuclear generating capacity by 2050.

Plans are being established to deploy new nuclear generation as a potential option to meet the forecasted increased demand and clean energy commitments. This includes an array of technologies such as large reactors, small modular reactors (SMRs) and micro-reactors that are light-water cooled and

non-light-water cooled SMRs (e.g., molten salt, gas, sodium). Smaller reactors have the potential to complement the market for larger nuclear reactors and provide new options with their flexibility and lower upfront costs. As of the writing of this revision, there are over 60 new nuclear projects being planned across North America with several projects having received regulatory approvals, and more are constantly being announced. NNPs are large complex projects that face many challenges such as the availability of skilled resources, financing, and supply chain capacity. This report identifies 14 areas of construction best practices including 59 best practices and 89 lessons learned that have been critical in the successful execution of previous large complex projects.

New nuclear power deployments, like all megaprojects, have had numerous examples of cost and schedule overruns as well as examples of projects that were executed on-time and on-budget. When reviewing projects that experienced cost and schedule overruns, it was determined that they failed to apply one or more of the best practices and lessons learned denoted herein. Potential owners (e.g., utilities, hyperscalers, industrial users) must consider the drivers of nuclear project risk when planning new projects to minimize the risk of cost and schedule overruns. Although there have been large infrastructure projects implemented in recent times (particularly in oil/gas, chemical, and extraction industries), there has been limited recent construction of NNPs as most of the current operating nuclear reactors were built in the 1970s and 1980s. This next wave of NNPs will require development including resources, capabilities, and experience. Some of the important principles gleaned from both successful and failed industrial megaprojects both outside of but relevant to, and within the nuclear power industry are included in this document.

In developing this work, it became clear that these best practices and lessons learned had been known for many years and that projects applying them were successful. This effort reviewed existing industry frameworks and guidelines for NNP deployment, lessons learned from recent NNP projects, and other complex megaprojects. This document consolidated these insights into a single reference, identifying the best practices needed to address recurring challenges and providing practical guidance on how to implement them within current industry frameworks and guidelines.

The purpose of this report is to compile and describe the best practices that will reduce project risk and better enable future NNP projects to be built with a high level of predictability, safely, on-time and on-budget. There have been more than 100 reference documents over the past several decades that have identified the lessons learned from past megaprojects (nuclear and non-nuclear), both positive (what went well) and negative (what went wrong). From these documents, 89 lessons learned were identified and 59 construction best practices were then documented that would address the 89 lessons learned. The 59 construction best practices were then categorized into 14 areas. Five (5) implementation guides have been developed to address each of the 14 areas and associated best practices, the mapping of which is illustrated below. The implementation guides provide guidance for senior management and executive leadership to ensure these best practices are incorporated. This document provides the "what" and the IGs provide the "how."

Best Practice Area	Implementation Guide
1. Design Maturity and Details Required for Construction 2. Realistic Cost and Schedule Baselines	IG 01, “Design Completion and Reliability of Schedule and Cost Estimations to Support Construction Decisions”
3. Organizational Challenges are Tougher than Technical Issues 4. Collaborative instead of Confrontational Contracting Strategies 5. Aggressive Risk and Opportunity Management instead of Risk Shedding Approach	IG 02, “Organizational Challenges, Collaborative Contracting Strategies, and Aggressive Risk and Opportunity Management”
6. Extreme Ownership and Leadership from the Top 7. Ingrained Large Nuclear Construction, Quality, and Safety Culture and Mentality 8. Experience of Stakeholders 9. Managing Project Internal and External Stakeholders	IG 03, “Extreme Ownership, Experience of Stakeholders, Owner Led Integrated Project Team, and Ingrained Nuclear Construction Quality and Safety Culture Mentality”
10. Recognizing what FOAK Is 11. Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue 12. Modularization Potential Benefits and Drawbacks	IG 04, “FOAK Planning Considerations, Construction Shiftwork/Productivity, and Modularization”
13. Integrated Project Schedule, Owner Control, and Simplified Reporting System 14. Rigorous Configuration Management and Design Change Control	IG 05, “Project Management, Integrated Project Schedule and Reporting Systems, and Configuration Management / Design Control”

Among these areas, the need for Extreme Ownership and leadership from the top was identified as the most important success factor. In the case of an NNP project, Extreme Ownership means the owner is always accountable for the outcome. Thus, the owner must put in place people, processes, governance and procedures that establish clear accountabilities and responsibilities for the benefit of the project.

In order to validate and confirm the findings and best practices derived from the industry documents, independent case studies were developed, considering eleven (11) additional large FOAK projects spanning commercial nuclear power plant construction, nuclear facility decontamination and decommissioning (D&D), municipal infrastructure, and a government science facility that were built on-time and on-budget. These case studies include:

1. River Bend Nuclear Power Station Unit 1
2. St. Lucie Nuclear Power Station Unit 2
3. Palo Verde Nuclear Power Station Units 1, 2, and 3
4. Watts Bar Nuclear Power Station Unit 2
5. Rocky Flats D&D Project
6. Selected Steam Generator Replacement & Refurbishment Projects
7. Spallation Neutron Source (SNS) Accelerator Project
8. 2012 London Olympics Site and Facilities Infrastructure
9. WPPSS 2 Washington Public Power Supply System Nuclear Unit 2
10. Barakah Nuclear Energy Plant
11. Muskrat Falls Generating Station

These large FOAK projects spanned a period of nearly 40 years from the early 1980s to the present. They all dealt with similar challenges involving large scope, new technologies, complicated interfaces, changing regulatory requirements, and numerous project stakeholder organizations. The case studies confirmed the industry documents through a common thread that key lessons learned and best practices that supported success involved an owner-led integrated project team approach, reinforced with extreme leadership and commitment by top management stakeholders.

The 2020s have seen new nuclear technologies advancing from design concepts to reality, and the end of the decade is seeing the beginning of a wave of nuclear innovation that will change how the future is powered. The construction of these first advanced reactors has begun. Building these first reactors on-time and on-budget will be an important factor in enabling the scaling of new nuclear deployment.

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1 INTRODUCTION

1.1 Complexity of New Nuclear Projects

The construction of a new nuclear power (NNP) project is a large and challenging undertaking. As with other industrial megaprojects (those with value of $1 billion or more), these ventures are not merely scaled-up versions of smaller projects; they are fundamentally different in their organizational complexity and inherent fragility. Research on hundreds of megaprojects over four decades (References 6 and 58) from a variety of capital-intensive industries shows that megaprojects tend to have bimodal outcomes—they are either brilliant successes or abysmal failures, with very few in between. This fragility, which arises from the complex dependencies between a myriad of interrelated activities, means that even small, seemingly manageable issues can trigger a cascade of failures that manifest in extensive schedule delays, cost overruns, and in more extreme cases project operability issues or abandonment. For an NNP to succeed without significant cost or duration growth, it must be managed with a deep understanding of these systemic risks and a commitment to best practices that build institutional certainty and resilience.

Nuclear projects have regulatory requirements and complex project collaborations involving numerous international participants and production locations that add even greater challenges. Corporate and individual stakeholders involved with planning, executing, and managing NNP projects must address many variables both within and external to the project. The implementation of best practices for successfully completing an NNP project needs to be established during the early project planning and organizing phases. Doing so establishes the cornerstone for a solid foundation based on proven concepts and practices.

Projects consist of two main phases: planning and execution/delivery. The planning phase is when the vision of the project is laid out, where ideas can be researched, analyzed, and tested. It is also where the detailed plan for execution needs to be developed. Significant money must be spent to properly develop a project to the point of a final investment decision (FID) - this can be up to 30-40% of the total project cost in some cases. As noted below, often projects that spend more money ahead of FID in detailed planning are better planned and executed (fewer delays), resulting in an overall lower project cost.

To ensure a project is properly defined, it must be developed through three interdependent work streams that must be braided together before a project is sanctioned. The first is the Basic Data stream, which involves gathering and stabilizing all fundamental technical information, such as the final reactor design, site characteristics, and regulatory requirements. The second is Project Shaping, a strategic process of allocating project value to align the diverse interests of all stakeholders – a "stakeholder" is any person or group that may be positively or negatively impacted by an NPP project. This is to minimize the potential for future turbulence and to ensure that the "deal" is understood and acceptable to all relevant parties. The third is Project Execution Planning (through the Front-End Loading [FEL] process), which entails the meticulous preparation of all project components, including supply chain management, constructability analysis, and detailed project controls. This integrated approach, first identified in a seminal 1988 study of megaprojects (Reference 6), provides the robust foundation needed to navigate the challenges of the execution phase. The stage/phase gate and FEL process are discussed further in IG 01 (Reference 38) and NEI 24-07 (Reference 48).

The use of a thorough and disciplined stage gate (or phase gate) approach of FEL – also referred to as Front-End Planning (FEP) – is a major predictor of project success. Studies consistently show that projects with weak FEL often experience cost growth of 50% or more, while those with high-quality FEL are far more likely to be completed approximately on budget and schedule, because they have better planning. The allure of moving faster early in the project is a common pitfall that undermines success as the pressure to accelerate a project can lead to critical planning stages being rushed or bypassed entirely (Reference 58), resulting in inadequate understanding at all levels of the project team. Shortcuts taken in the planning stages inevitably lead to unexpected scope changes, rework, waste, expense, and lost schedule in the delivery or execution phase.

The execution phase is when most of the costs are incurred and when the project becomes most vulnerable to disruptions. By proper planning and preparation, the risk of the project experiencing disruptive events is reduced. Projects can overcome the "blind spots and potential obstacles" by embracing the best practices and lessons learned, and applying a disciplined, empirically validated approach to deliver the next generation of new nuclear power plants on time and on budget (Reference 59).

As observed by the historical figures shown in **Exhibit 1.1** below, applying these past best practices has never been more relevant.

Exhibit 1.1, Yesterday's Lessons are Prelude to Today

Those who cannot remember the past are condemned to repeat it…
George Santayana

It's a form of insanity to repeat the same steps over & over and to expect a different result…
Albert Einstein

1.2 Purpose

New nuclear power deployments, like all megaprojects, have had numerous examples of cost and schedule overruns as well as examples of projects that were executed on-time and on-budget. In developing this work, it was discovered that these best practices and lessons learned had been known for many years and projects that implemented them were successful. These strategic project management lessons learned and best practices were scattered across numerous white papers, reports, and documents describing past nuclear power projects. These project management lessons learned and best practices define the strategic elements that should be considered during early project planning to establish a strong foundational plan based on proven concepts and practice.

The relevance and importance of applying these past best practices to NNP projects is widely recognized by industry leaders and researchers as providing positive effects for a successful outcome. This NEI report is meant to provide a single document that consolidates and organizes key strategic lessons learned and best practices into a single document to readily facilitate understanding and application to new projects. For the purposes of this report, NEI defines lessons learned and best practices as:

- Lessons learned generally connote some recognition of past problems and processes that resulted in poor performance, which in turn led to adopting a practice that addressed and corrected the problem. Lessons learned also tend to be more strategic in nature by addressing doing the right things.
- Best practices do not always necessarily or directly reflect lessons learned. These generally connote a continuous improvement process where technology, experience, or training has enabled an improvement to progress from good to better to best. Best practices can be tactical in nature by addressing how to do things right.

A review of over 100 reports and interviews with nuclear industry stakeholders was distilled to develop the top lessons learned and best practices. These industry reports and white papers, spanning several decades, have been assessed as the primary basis for this NEI report along with the experience and judgment of industry experts. References used as the basis for this report that are available for public access are hosted on the NEI new nuclear deployment website at www.nei.org/deployment.

This report serves as a reference for decision-makers across the NNP project lifecycle who share responsibility for project outcomes. For these organizations, applying these construction best practices and lessons learned is not only a matter of operational excellence, but a means to reduce counter-party default risk and improve the likelihood of project completion. The adoption of these practices enables stronger alignment across stakeholders, ensuring that strategic risks are managed proactively from the top down.

1.3 Current Situation and History

The U.S. and Canada are experiencing a renewed interest in developing and building new nuclear power plants including conventional large reactors, small modular reactors (SMRs), and microreactors. National policies are being refined to create the foundations for success for these safe and non-carbon emitting energy sources. However, concerns over past NNP construction performance must be addressed to attract customers and investors.

The U.S. nuclear industry has successfully constructed 129 units and received licenses to begin commercial operation. History shows that over 80% of these completed construction projects did so using an owner led integrated project team approach.

In the 1980s, the U.S. nuclear industry supported over 70 projects simultaneously. This was done with manually operated paper management systems before the automated systems of today. The knowledge and best practices that created this success can be used to create a foundation for future success. However, not without intentional effort.

When reviewing projects (nuclear or nonnuclear megaprojects) that experienced cost and schedule overruns, it was determined that they failed to apply one or more of the best practices and lessons learned denoted herein. Typically, projects that have failed to apply these learnings have done so for one of three main reasons:

1. organizational hubris
2. external pressures that hinder proper implementation
3. a lack of knowledge about how to implement them effectively

This document is designed to help projects overcome these historical root causes of cost and schedule overruns by providing practical guidance for applying best practices and thereby minimizing risk.

As noted in Reference 35, there were several primary root causes that caused systemic issues at the Vogtle Units 3&4 project. Some of these root causes are beyond the control of the project as they are externalities (e.g., COVID-19, expiration of tax credits, changes to regulatory requirements). Other root causes noted below (a subset of all root causes) could have been addressed by some of the best practices and lessons learned in this document and implementation guides.

- Incomplete design
- Limited constructability review
- Inadequate detail in integrated project schedule
- Inflexible timelines
- Poor project controls system
- Inadequate quality assurance / control practices
- Improper documentation standards
- Poor risk assessment

The cost overrun challenges experienced at Vogtle are not unique to recent U.S. nuclear megaprojects either. The recent European EPR-1600 projects (e.g., Olkiluoto-3, Flamanville-3, and Hinkley Point C) and Asian projects (e.g., Sanmen 1-2 [AP1000], Barakah 1-4 [APR-1400], Kundankulam 1-2 [VVER-1000], Kakrapar 3-4 [PHWR-700]) have all experienced cost and schedule challenges of some level. While there are significant differences between these projects, these project outcomes highlight the value and importance of considering these best practices and lessons learned early into the project plan.

1.4 Synopsis of Lessons Learned and Best Practices

Section 3 of this report distills the research and analysis into the strategic lessons learned and best practices for planning, organizing, and management success of any large project, with a focus on the unique requirements of commercial nuclear construction. The 89 lessons learned and the 59 best practices were then grouped into fourteen (14) areas and mapped into their applicable Implementation Guides that provide more detailed discussions, historical context, and conclusions regarding lessons learned and best practices that are keys to planning and organizing a successful project.

Each of the 14 areas is highlighted in a subsection of Section 3. A synopsis identifying lessons learned is provided at the end of each of the 14 subsections in a text box. Stakeholders planning an NNP project are encouraged to use this checklist for planning and setting up a project plan and organization for success. Appendix C contains a matrix for all the best practices detailing who between the owner; original equipment manufacturer (OEM); and engineering, procurement, construction (EPC) parties are responsible for the implementation of each of the 59 best practices. The responsibilities will need to be adapted to a project on a contract specific basis, but the table will help all stakeholders avoid gaps or delays by reducing ambiguity on which parties have a stake in each best practice.

Exhibit 1.2, Summary of 59 Best Practices

Implementation Guide 01 (Reference 38)	
Best Practice	**Best Practice Area**
1. Ensure that the design is complete including all vendor design submittals and thoroughly planned for construction prior to field deployment. 2. Identify that all the design and constructability issues have been resolved. 3. Confirm the design is released for construction without any holds. 4. Verify all the procurement has been finalized to support construction. 5. Validate the ITAAC process (as applicable) has been fully integrated into the design prior to commencing construction activities.	Design Maturity and Details Required for Construction (Section 3.2.3)
6. Validate that the cost and schedule baselines reflect the lessons and guidance parameters learned from previous projects. 7. Ensure the NNP project stakeholders have applied rigorous risk and estimate accuracy evaluations that recognize FOAK and project maturity. 8. Recognize the existing industry limitations in determining management reserve and contingency guidance for NNP project cost estimating.	Realistic Cost and Schedule Baselines (Section 3.2.4)

Implementation Guide 02 (Reference 39)	
Best Practice	**Best Practice Area**
9. Establish an integrated organization that facilitates teamwork and open communications. 10. Develop an organization training plan. 11. Identify and develop the integration plan interfaces and transitions. 12. Engage industrial psychologists to assist in conducting project team building and training, and independent assessments of project team members.	Organizational Challenges are Tougher than Technical Issues (Section 3.1.2)
13. Create a fair and flexible contracting framework that recognizes the status of design and licensing maturity. 14. Establish a “hybrid” contracting strategy plan that aligns incentives. 15. Embrace a collaborative vs. confrontational contracting approach. 16. Define contractual target cost terms. 17. Establish meaningful schedule milestones that incentivize meeting or beating schedule dates.	Collaborative instead of Confrontational Contracting Strategies (Section 3.1.3)
18. Develop an integrated risk identification and management program led by the owner. 19. Avoid re-assigning the project risk to primary contractors.	Aggressive Risk and Opportunity Management instead of Risk Shedding Approach (Section 3.1.4)

Implementation Guide 03 (Reference 40)	
Best Practice	**Best Practice Area**
20. Develop a plan for the life of the project to: 1. Design it to build it, 2. Build it to test it, 3. Test it to operate it. 21. Create an organization with resources for an integrated and singular focus NNP project team. 22. Establish clear roles, responsibilities, and authorities within the project structure.	Owner Led Integrated Project Team (Section 3.1)
23. Identify and empower an experienced, motivated and passionate project leader. 24. Define clear project mission and goals.	Extreme Ownership and Leadership from the Top (Section 3.1.1)
25. Embrace a quality acceptance plan based on NUREG 1055 that includes ASME NQA -1 and other requirements. 26. Develop a resource plan with skilled craft labor and experienced supervisory personnel. 27. Establish a Safety Conscious Work Environment (SCWE) culture across all stakeholder organizations. SCWE attributes include: Leadership clearly committed to safety, Open and effective communication across organizations, Employees feel personally responsible for safety, Organization practices continuous improvement, Reporting systems are clearly defined and non-punitive, Actions demonstrate safety is valued over other priorities, Mutual trust fostered between employees and organization, Organization is fair and consistent in responding to safety concerns, Training and resources are available to support safety. 28. Establish a project mentality that includes: Personal accountability, Procedure compliance, Technical inquisitiveness (questioning attitude), The willingness to stop in the face of uncertainty.	Ingrained Large Nuclear Construction, Quality, and Safety Culture and Mentality (Section 3.1.5)
29. Review internal and external stakeholders' NNP project experience. 30. Ensure all stakeholders are entrenched with the details of the NNP project. 31. Create clear NNP project mission, goals, and accountabilities for all Stakeholders. 32. Ensure organizational structure has an adequate focus on document control integration and defines a clear structure to support the culture of an SCWE.	Experience of Stakeholders (Section 3.2.2)
33. Develop a Stakeholder Management Program to address and control internal and external stakeholders that contains stakeholder identities, has prioritized the stakeholders, and includes a communication management plan. 34. Proactively engage all stakeholders on an ongoing basis.	Managing Project Internal and External Stakeholders (Section 3.3.5)

Implementation Guide 04 (Reference 41)	
Best Practice	**Best Practice Area**
35. Identify the FOAK project elements that are essentially different in scope or in detail from previous stakeholder experience. 36. Develop strategies to mitigate the pitfalls from a lack of learnings. 37. Identify the transition phases and effectively address the interface challenges between the design, construction and testing activities.	FOAK Project Parameters and Challenges (Section 3.2)
38. Understand the details of the design, licensing mechanism, construction plan, workforce, contract terms, and stakeholders of the NNP project that differ from any previous NNP project experience. 39. Identify and address project participants' experience with the licensing requirements. 40. Ensure adequate contingencies are contained in the baseline to recognize the FOAK NNP project.	Recognizing what FOAK Is (Section 3.2.1)
41. Develop work schedules that are consistent with the available labor pool, address lessons learned for efficiency and fatigue, and meet project needs. 42. Evaluate available licensing processes to achieve maximum cost and schedule benefits.	Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue (Section 3.3.3)
43. Compare the efficiencies and benefits of modularization for applicability to those achieved with a stick-built approach. 44. Evaluate cost/benefit of modularization early in the front-end engineering and design phase for each new project site based on the transportation and logistics study for that site. Then ensure the design and procurement strategies are properly driven and matured per the modularization plan.	Modularization Potential Benefits and Drawbacks (Section 3.3.4)

Implementation Guide 05 (Reference 42)	
Best Practice	**Best Practice Area**
45. Ensure that the integrated project team organizing policies and procedures stress clear direction for roles, accountability, communication, leadership, and ownership. 46. Ensure that the Organization embodies good teamwork and communications integrated with a balanced risk management approach. 47. Develop PM tools consistent with the detail necessary to optimize stakeholder communication and management of the project.	Project Management Involves Art and Science (Section 3.3)
48. Establish a joint project management office (PMO), that includes the owner, OEM, and EPC contractor. The PMO addresses both the project controls and project management functions that includes the project management operations center and is maintained by a dedicated owner-controlled staff. 49. Collocate members of the integrated project team (IPT) organization with the PMO. 50. Develop an integrated project schedule (IPS). 51. Produce timely and transparent progress updates of the IPS. 52. Perform regular variance reporting from baseline and address and correct baseline variances. 53. Develop project management systems designed with simplicity and avoid complexity. 54. Data is forward looking and does not overwhelm ability to focus on critical information. 55. Nuclear plant outage mentality is focused on communications and transitional periods. 56. Stakeholders' performance systems maintain a balance with complexity and simplicity.	Integrated Project Schedule, Owner Control, and Simplified Reporting System (Section 3.3.1)
57. Establish and maintain configuration management and design change control plans. 58. Develop a central configuration management design authority. 59. Establish a rigorous inspection and test plan.	Rigorous Configuration Management and Design Change Control (Section 3.3.2)

1.5 Case Studies Reviewed

In addition to analyzing the industry documents, the team developed summary level (3 to 4 page) case studies for 11 completed large First-of-a-Kind (FOAK) projects, which are presented in Section 4. The intent of the case studies was to confirm and reinforce the findings from the industry document reviews through an independent review of these 11 projects. These case studies span commercial nuclear power plant construction, nuclear facility decontamination and decommissioning (D&D), municipal infrastructure, and a government science facility, all of which have the same or similar requirements of a NNP project.

1. River Bend Nuclear Power Station Unit 1
2. St. Lucie Nuclear Power Station Unit 2
3. Palo Verde Nuclear Power Station Units 1, 2, and 3
4. Watts Bar Nuclear Power Station Unit 2
5. Rocky Flats D&D Project
6. Selected Steam Generator Replacement & Refurbishment Projects
7. Spallation Neutron Source (SNS) Accelerator Project
8. 2012 London Olympics Site and Facilities Infrastructure
9. WPPSS 2 Washington Public Power Supply System Nuclear Unit 2
10. Barakah Nuclear Energy Plant
11. Muskrat Falls Generating Station

The case studies included large FOAK projects which spanned a period of 40 years from the early 1980s to the present. They all dealt with similar challenges involving complex scope, new technologies, complicated interfaces, changing regulatory requirements, and numerous project stakeholder organizations. The case studies identified fifteen (15) keys to success or best practices. The following table in **Exhibit 1.3** below summarizes the top fifteen (15) keys to success and things that went well that span all eleven case study projects:

Exhibit 1.3, Keys to Success and What Went Well across Case Study Projects

Common Keys to Success Across Case Studies	
1	Utility owner led / integrated project team
2	Experienced, passionate leadership & extreme ownership from the top
3	Intense up-front planning & integrated project schedule
4	Clear definitions of roles & responsibilities
5	Best athlete for the job approach
6	Collaborative contracting strategies
7	Teamwork, open communications, and no surprises
8	Completed detailed design before construction
9	Ingrained nuclear quality and safety culture
10	Understanding FOAK and design maturity status
11	Aggressive risk management
12	Crane utilization, over the top, and pre-assembly techniques
13	Simplified and timely project performance reporting
14	Rigorous configuration management and change control
15	Management of internal and external stakeholders

The fifteen (15) keys to success closely align with and confirm the findings from the review of the industry documents. The top two common keys that led to success (and facilitated overall positive performance in all areas on these past successful projects) involved an owner-led integrated project team approach (reinforced with experienced, passionate leadership) and extreme ownership by top management stakeholders. Analysis shows that these created the foundation for the other top keys to success shown on **Exhibit 1.3** that align well (but not exactly) with and reinforce:

- The 59 best practices discussed summarized in **Exhibit 1.2**
- The fourteen categories of lessons learned and best practices identified and discussed in **Section 3**
- The summary of 89 lessons learned outlined in **Appendix A**
- The breakdown of the best practices are noted in **Appendix B** by Implementation Guide
- Which parties are responsible for implementing which best practice are noted in Appendix C

While the common keys to success were present in all case studies, there were aspects of specific cases that may not always be appropriate to implement in an NNP project. In these instances, details were added to indicate when aspects of a case study may have resulted in cost and schedule delays (e.g., aspects of the 2012 London Olympics Site and Facilities Infrastructure case study that when implemented negatively impacted Hinkley Point C). Care was taken to ensure the best practices and lessons learned identified reflect information that can be applied to NNP projects generically.

It is important to recognize that as outlined in **Section 2.1**, current industry resources with large and/or FOAK NNP project experience is limited and less robust than it was last century when the U.S. constructed 129 NNP units. It is unlikely that any single organization can muster an “A-Team” of leaders and managers with the needed experience and qualifications for FOAK NNP projects. History recommends the strategic practice of adopting a “Best Athlete for the Job” strategy when planning and shaping the organization for a FOAK NNP project.

Under the leadership of the owner using a Project Management Organization (PMO) approach, it does not matter what project positions are filled by what project organization (i.e., the owner, EPC, or OEM stakeholders). A successful NNP integrated project team needs the most qualified candidate and best athlete for the position. Additionally, all project leadership and management positions demand an owner/project centric attitude that places project success priorities in alignment with parent company priorities and expectations. Participating organizations will need the authority to manage risks for their assigned scope. A process will be needed to resolve situations where the mitigation of an organization’s scope risk would not result in the overall project success. The risk mitigation process should ensure that project success will result in individual and corporate stakeholder success.

Additionally, history shows that establishing an integrated organization that facilitates teamwork and open communications across both multi-corporate and stakeholder culture is easier said than done. Experts in industrial psychology should be engaged to conduct project team building and training, and to perform assessments of the personalities, strengths, and weaknesses of project team members. Continuous attention to the psychology and health of a large project organization is a key lesson learned when not done and a best practice when done well as it is critical for success.

2 BLIND SPOTS AND POTENTIAL OBSTACLES TO RECOGNIZING LESSONS LEARNED AND IMPLEMENTING BEST PRACTICES

In **Section 1**, the review of industry documents identified 89 lessons learned and 59 best practices which were then grouped into 14 areas. Then 11 additional large projects were reviewed and case studies completed which identified 15 keys to success that closely aligned with and confirmed the 14 areas from **Section 1**. In this section, past troubled and less successful projects are reviewed to determine what factors led to performance and execution problems or hindered organizing the project for success. Through the identification of “blind spots” that have created obstacles in the past, future projects can avoid these same pitfalls to deliver a project on-time and on-budget.

- Inadequate Experience with Nuclear Industry FOAK Projects – Inexperience with nuclear projects and their associated requirements result in underestimation of the importance of the hard lessons learned from previous nuclear design and construction projects. Coupled with the optimism of a new project, this lack of experience can result in a reluctance to accept the unique risks of NNPs.

- Owner Corporate Cultures and Successful Project Mindsets - The structures, procedures and staff-support organizations in an operating nuclear company are set up to assure safety and optimize continuous operations and excellence in performance. Running a large complex project requires a different mindset. It also takes a unique skillset to be able to handle the continuous stream of interruptions and dislocations that can create a chaotic atmosphere on a complex construction project.

- Human Emotions, Personalities, and Leadership - It is human nature to try to conform to the expectations of the parent corporations, regulators, and public utility commissions. As a result, project organizations may become focused on meeting these perceived expectations and develop blind spots to the actual conditions of the project. It takes a leader with unusual humility and wisdom to recognize their own limitations and establish an environment that encourages open communications and collaboration. Such leadership also requires that the information routinely produced by the project accurately reflects true project conditions and flows up to leadership in an understandable and digestible manner. This leadership capability and style are essential to project success.

- Strategic Planning and Tactical Execution Considerations – Project stakeholders always need to keep in mind that strategic planning is doing the right things and tactical execution is doing things right. Tactical corporate procedures dealing with *how* things are done in the short term are generally easier to change than strategic corporate policies dealing with *what* should be done in the long term. Establishing the appropriate strategic and long-term policy and cultures requires a good leader, not just a good manager, with a grasp of the big picture to see through blind spots and facilitate actions for what is needed for project success in a dynamic environment.

These blind spots and obstacles have been demonstrated in the past and resulted in utility owners and contractors adopting practices that inhibited teamwork, dissuaded open communications, and clouded information transparency, resulting in negative impacts on cost and schedule performance and providing similar lessons learned. The synopsis of 89 lessons learned presented in **Appendix A** and the 59 best practices outlined in **Exhibit 1.2** are designed to assist NNP stakeholders with planning and organizing in a manner that facilitates recognition and understanding of these blind spots, obstacles, and challenges.

In summary, industry stakeholder recognition and understanding of these lessons learned and best practices have been focused on tactical elements of project execution. Strategic elements are often in-line with existing corporate missions and available resources, and not what is necessary for project success. Recognizing and understanding these lessons learned and best practices lie at the very heart of developing the strategic cornerstone of the foundation of good planning and project initiation.

2.1 Inadequate Experience with Nuclear Industry Large FOAK Projects

There were more than 70 nuclear plants under construction at the same time in the U.S. during the 1980s. Most of the people involved with these past projects have retired or left the industry and there is a limited workforce with the experience and the knowledge to plan and organize an NNP project for success. The root causes of this include:

- The current operating nuclear electric utilities are likely to be the owners and developers of NNP plants. Most of these utilities do not have corporate leadership and/or personnel with experience in large NNP plant design and construction given the dearth of NNP projects over the past 30 years. The same is true for interested non-utility owners for new nuclear deployment.

- As the nuclear industry transitioned from NNP projects to operating and maintaining the current fleet, significant market consolidation has resulted in only a few U.S. AE/EPC firms and OEM suppliers with nuclear construction experience remaining. Those that exist with a nuclear pedigree have decreased infrastructure and staff needed to complete large NNP plant design and construction projects.

- Very few nuclear operating utility stakeholders have extensive experience in the strategic and tactical dimensions for project management of a large FOAK NNP project. When project tools such as earned value management, risk management, quality control and quality assurance programs are needed, firms outside the utility are frequently retained and often do not have large NNP FOAK experience.

- Very few training programs exist for developing nuclear qualified craft as well as engineering programs that focus on NNP plant design and construction.

- The current pool of resources with NNP plant design and construction experience is limited. It is difficult to overcome this lack of experience base by hiring alone.

- Non-nuclear clients (e.g., non-nuclear utilities, industrial users, hyperscalers) are interested in deploying new nuclear generation, but also lack either or both megaproject and nuclear specific experience.

An NNP project is challenging throughout the project's lifecycle, because of this lack of experience in nuclear project development design and construction. Additionally, the accuracy and conformance to regulatory, design, safety, QA/QC, and construction requirements in the nuclear industry are more rigorous than in conventional construction industries. Habits and tendencies developed during a career at conventional industrial design and construction projects can leave individuals with intolerance for the intrusion of QA/QC and regulatory oversight into the construction process.

The lack of NNP plant project experience is amplified from a lack of awareness of the existence of a robust set of lessons learned and best practices from previous nuclear design/construction projects, and in a reluctance to believe that such considerations are necessary. This, in turn, has tended to hide recognition of the existence of these problems until the project is under way and failing. The lack of understanding of the need to consider the lessons learned and best practices can be traced directly to the lack of large project construction experience – nuclear or non-nuclear.

Conversely, the new reactor designs being deployed have less nuclear safety related scope than earlier designs. More of the turbine island and balance of plant is commercial grade systems, structures and components (either non-safety related or non-safety related with special treatment). This will allow the use of more commercial construction practices and experience, and lowers the need for nuclear capability throughout the supply chain and construction. However, the implementation of this bifurcated quality program will be a new FOAK challenge.

2.2 Owner Corporate Cultures and Successful Project Mindsets

Observations and experience have shown that most major power utilities are appropriately conservative. Nuclear operating companies must be conservative due to the importance of public and worker safety, the need for reliable and highly available operations, and the nuclear regulatory framework in which they operate. The structures, systems, components, processes, procedures, and resources in an operating nuclear electric company are organized to optimize continuous operations and excellent performance. The legal and contracting departments have established low risk policies and practices to support and accomplish work. The legal framework and culture of a regulated utility generally does not provide for risky ventures. The tendency therefore is to develop pre-approved contractual vehicles that attempt to shed risk to the contractor. Since operations and maintenance projects usually involve small, short term, and controllable risks, this approach can result in good performance and reasonable risk exposure. When confronted with an activity containing large inherent risk, like a long term NNP project, the natural response of an operating nuclear utility executive is to shed the risk to a qualified contractor.

The design and construction of NNP projects is a different business model requiring cultures and strategies that are not aligned with existing operational models. Construction of an NNP project brings inherent risks requiring contracting strategies that need to consider which entity is capable of managing and mitigating different kinds of risks. Ultimately, these risks cannot be completely shed due to laws and regulations that govern nuclear facilities. These requirements force the owner/licensee (in most cases this will be the operating utility company) to be in total control of and completely responsible for bringing the project to commercial operation. In other words, the risks of constructing a nuclear plant cannot be shed; they must be strategically aligned, shared, and tactically managed and mitigated.

The strategic elements for an electric utility in operating environments are generally not aligned with the strategic elements necessary to successfully construct an NNP project. The same is true for many other prospective non-utility client owners of new nuclear generation. Operational excellence requires continuous reaction to predictable activities. A complex construction project is characteristically a continuous stream of interruptions and dislocations that can create a chaotic atmosphere.

Even though a successfully constructed operating nuclear plant is an enormously valuable asset to any company, the processes necessary to achieve this end are counter to the corporate culture. Decisions made by the construction project manager will likely conform to the corporate model even though it may run counter to the goal of successfully constructing a new nuclear plant. Changing organizational cultures requires an excellent leader with a grasp of the big picture to see through blind spots and facilitate (sometimes controversial) actions needed for success. To implement changes in culture, the leader must be less reactive and more aggressive than they would be when involved in the routines of an operating company.

One change from the 1970s and 1980s when the U.S. last built numerous nuclear projects, is that there were fewer nuclear OEMs. At the time, there were very limited nuclear OEMs that each had multiple plants under construction. Today, there are a lot of new nuclear OEMs – some who were part of the previous builds, and some new to nuclear - all of whom are currently trying to build their FOAK projects. Even with recent new build experience, the industry today does not have staff with first-hand experience successfully delivering megaprojects (nuclear or non-nuclear) and should leverage experiences of their EPC partners (assuming the EPC partner does have this experience). Successful NNP projects blend successful megaproject delivery experience with nuclear quality, design, licensing and construction expertise.

2.3 Human Emotions, Personalities, and Leadership

The nuclear industry in the United States began as electric utilities were completing the construction of all the modern coal fired power plants and the installation of the electrical grid, and then transitioned to design and construction of the nuclear power plants that serve the country to this day. In the past, utilities were both operating companies, as well as design and construction management companies. At that time, there was still a great deal of corporate knowledge and strategies that would inform the decision-makers about the best way to proceed in a new construction venture. This knowledge and the associated strategies were carried over from the coal fired power plants and electricity grid construction to the construction of nuclear power plants, which led to the completion and operation of 129 U.S. nuclear reactors.

Today, nuclear electric utilities have become specialized nuclear operating companies. Their focus is the safe and reliable operation of their existing nuclear assets. If they are in a regulated market, they are very sensitive to the needs of the public service regulators in addition to the requirements of the NRC. If they are in a merchant market, in addition to the requirements of the NRC, they are very sensitive to the needs of the marketplace where competition is an ongoing challenge resulting in constant pressure to reduce costs.

Corporate officers and managers have achieved high levels of success in their chosen careers. In general, most of these individuals will have advanced in the corporate hierarchy during a period in which no NNP plants have been constructed by their respective companies. As a result, they lack first-hand knowledge from the prior nuclear plant building phase.

It is human nature to conform to the expectations of an organization’s leadership and culture. Over the course of career advancement, organizational norms and behaviors become ingrained. It takes strong professional discipline and objectivity to make decisions that are sometimes contrary to popular opinion, including pressure to decide positively on items that may be misinformed or underdeveloped for the sake of perceived project expediency. Even though stakeholders may have read documents and participated in training workshops that describe lessons learned and best practices, there is a strong tendency to ignore suggestions that challenge established corporate directives or long-standing practices. This situation leads to overconfidence, erosion of project management discipline, and organizational blind spots reinforced by groupthink. Leaders at all levels must therefore cultivate a willingness to seek perspective and apply proven management methods.

In addition, there will be stakeholders within the organization that have become enamored with certain technology options. If these individuals are in sensitive positions within the organization, they can skew the decision-making in a way that leads to outcomes that have not received adequate technical and/or economic consideration. Decisions such as selecting teaming partners, subcontractors, and nuclear vendors with inadequate review and governance can set the company on a path to failure before the project really starts. Processes need to be implemented to remove such biases from project planning decisions.

2.4 Strategic Planning and Tactical Execution Considerations

The positive outcome of an NNP project is only partially determined by tactical success. Most lessons learned documents were written by stakeholders based on experience with actual construction projects. As a result, they focused on the execution of the project once it has been established. Therefore, the focus of most lessons learned documents are on tactical issues associated with project execution. Additionally, most good managers will focus on things they can control or manage. They will gravitate to short-term tactical activities where performance variances lead to root cause and process improvement results that generally align with corporate culture, policies, and expectations. Stated another way, tactical corporate procedures dealing with *how things are done* in the short term are generally easier to address than strategic corporate cultural issues that address alternative approaches and *what things need to be done better*.

It is generally recognized that quality is more a function of organization fundamentals than of the execution of the work. As Dr. Deming's bead box analogy describes, if the fundamentals of the project are poorly crafted no amount of effort can result in success. In a similar way, an NNP construction project that has been organized with flawed strategies that results in dysfunctional contracting vehicles, optimistic schedules, unrealistic cost estimates, and inadequate understanding of the details of the design cannot succeed, regardless of how intensely one follows the tactical elements of the project. This leads to recognizing that the more important issues governing the success or failure of an NNP construction project are the strategies that recognize past lessons and successful practices to establish the resulting organizational structure and development plan for the project.

The course of an NNP project is set by the strategic decisions made during the planning phases at the outset of the project. Once the project is formed it is extremely difficult to reorganize the project if a problem is noted. Therefore, the focus of an organization proposing an NNP construction project should be on making proper strategic decisions that hold the most promise to achieve the goal of efficiently and cost effectively constructing nuclear plants. These strategic decisions deal with what *should be done* in the long term or doing the right things. This should then set the tactical framework for *doing things right*.

Again, establishing or changing strategic and long-term policy and culture requires a strong leader with a solid understanding of megaproject development as well as a grasp of the big picture to see through blind spots and facilitate actions for what is needed for success.

3 STRATEGIC LESSONS LEARNED AND BEST PRACTICES FOR SUCCESS

This section distills the research and analysis into what the top strategic lessons learned and best practices are for planning, organizing, and management success of any large project, with a focus on the special needs of commercial nuclear construction. The research and analysis provide detailed discussions, historical context, and conclusions regarding lessons learned and best practices that are keys to planning and organizing a successful project.

It is important to recognize some considerations regarding lessons learned and best practices. Section 1.2 defines best practices and lessons learned.

Lessons learned and best practices seldom have a one-to-one problem and solution relationship. Several lessons learned often were contributing factors to the development of a related best practice. The identification and compilation of 89 lessons learned and 59 best practices in this report illustrate this relationship. A synopsis of lessons learned is provided at the end of each category in a text box and summarized into a list of 89 lessons learned in **Appendix A**. **Exhibit 1.2** provides a summary of 59 best practices to readily facilitate understanding and application to NNP projects and maps them to the respective Implementation Guide. Additional details on the various Implementation Guides are in Appendix B and which parties are responsible for each best practice in Appendix C. **Exhibit 3.1** provides a summary of identified lessons learned in this **Section 3**.

Exhibit 3.1, Summary of Identified Lessons Learned

Sub Section #	Sub Section Description	# of Lessons Learned Identified	# of Best Practices Identified
3.1	**Project Organization, Owner Led Integrated Project Team, and Best Athlete Approach**	5	3
3.1.1	Extreme Ownership and Leadership from the Top	4	2
3.1.2	Organization Challenges are Tougher than Technical Issues	5	4
3.1.3	Collaborative Instead of Confrontational Contracting Strategies	5	5
3.1.4	Aggressive Risk and Opportunity Management Instead of Risk Shedding	4	2
3.1.5	Ingrained Large NNP Construction, Quality, and Safety Culture	6	4
3.2	**First of a Kind (FOAK) Project Parameters and Challenges**	4	3
3.2.1	Recognizing what FOAK Is	3	3
3.2.2	Experience of Stakeholders	5	4
3.2.3	Design Maturity and Details Required for Construction	7	5
3.2.4	Realistic Cost and Schedule Baselines	6	3
3.3	**Project Management Involves Art and Science**	4	3
3.3.1	Integrated Project Schedule, Owner Control, and Simplified Reporting Systems	13	9
3.3.2	Rigorous Configuration Management and Design Change Control	4	3
3.3.3	Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue	6	2
3.3.4	Modularization Potential Benefits and Drawbacks	4	2
3.3.5	Managing Project Internal and External Stakeholders	4	2
	Totals	**89**	**59**

Stakeholders planning an NNP project should use the information in this report and its associated Implementation Guides for planning and setting up a project plan and organization for success. Best practices outlined in this section are listed in relative order of potential cost and schedule impact from top (most impact) to bottom (least impact).

3.1 Project Organization, Owner-Led Integrated Project Team and Best Athlete Approach

New nuclear power projects in the U.S. will include FOAK facilities and all NNP projects will have FOAK attributes to some degree. These projects require substantial resources and span many years in duration between planning, development, licensing, design, procurement, construction and commissioning. Key stakeholders include the owner/licensee/operator; investors and lenders; EPC firms; OEM suppliers; the NRC; and state/local regulators. Establishing a cohesive project organization with clear leadership, alignment of purpose, and effective coordination among these parties is often more challenging than addressing the technical issues themselves.

Executive, professional, administrative, and construction craft personnel will come and go, and organizational structures and roles will evolve and change across the project EPC life cycle. Nearly 100 NNP project organizations were reviewed in the development of this report. Various project organization leadership models have been tried, where roles and responsibilities vary across the owner/licensee, EPC, and OEM stakeholders. The one absolute constant is that the regulator (e.g., Nuclear Regulatory Commission [NRC] in U.S.) and the state Public Utility Commissions will hold the owner/licensee responsible for public safety and the economic outcome of the project. While the NRC may have issues with the EPC or OEM, it will look to the utility owner for what it did or did not do as the responsible licensee. [1]

Nuclear projects are large, complex undertakings that span years from start to finish. In order to prevent dysfunctional behavior, the project must establish clear roles, responsibilities, and authorities across the project structure. Since the roles and responsibilities evolve with the phases of the project, the project organization must have a clear and well thought out plan for the life of the project.

Responsibility cannot be assigned without granting the authority to act. This needs to be linear with no overlap or duplication. The design of a nuclear plant considers all aspects of the plant construction, commissioning, operation and decommissioning. For a successful project, the organizational focus needs to be:

1. Design it to build, operate, and maintain it
2. Build it to test and inspect it
3. Test it to operate it

Roles and responsibilities must be clearly defined, aligned with the project mission and participant capabilities, and formally documented within contractual agreements. It should be expected that individuals and organizations within the project may try to maximize their scope on the project. Whether this is a conventional contracting relationship or an integrated project team, people will naturally try to optimize their positions. This is where leadership needs to focus on interactively defining each organization and individual’s position, role, and responsibility on the project. Adherence to the best athlete philosophy will help minimize project risk.

Industry data and experience clearly show that an owner-led integrated project team approach is the best strategic organization practice that has achieved the greatest degree of success for NNP and other construction FOAK projects. Indeed, it is the single most important element required for a successful NNP project. This conclusion is outlined below and reinforced with the Successful Project Case Studies provided in **Section 4**.

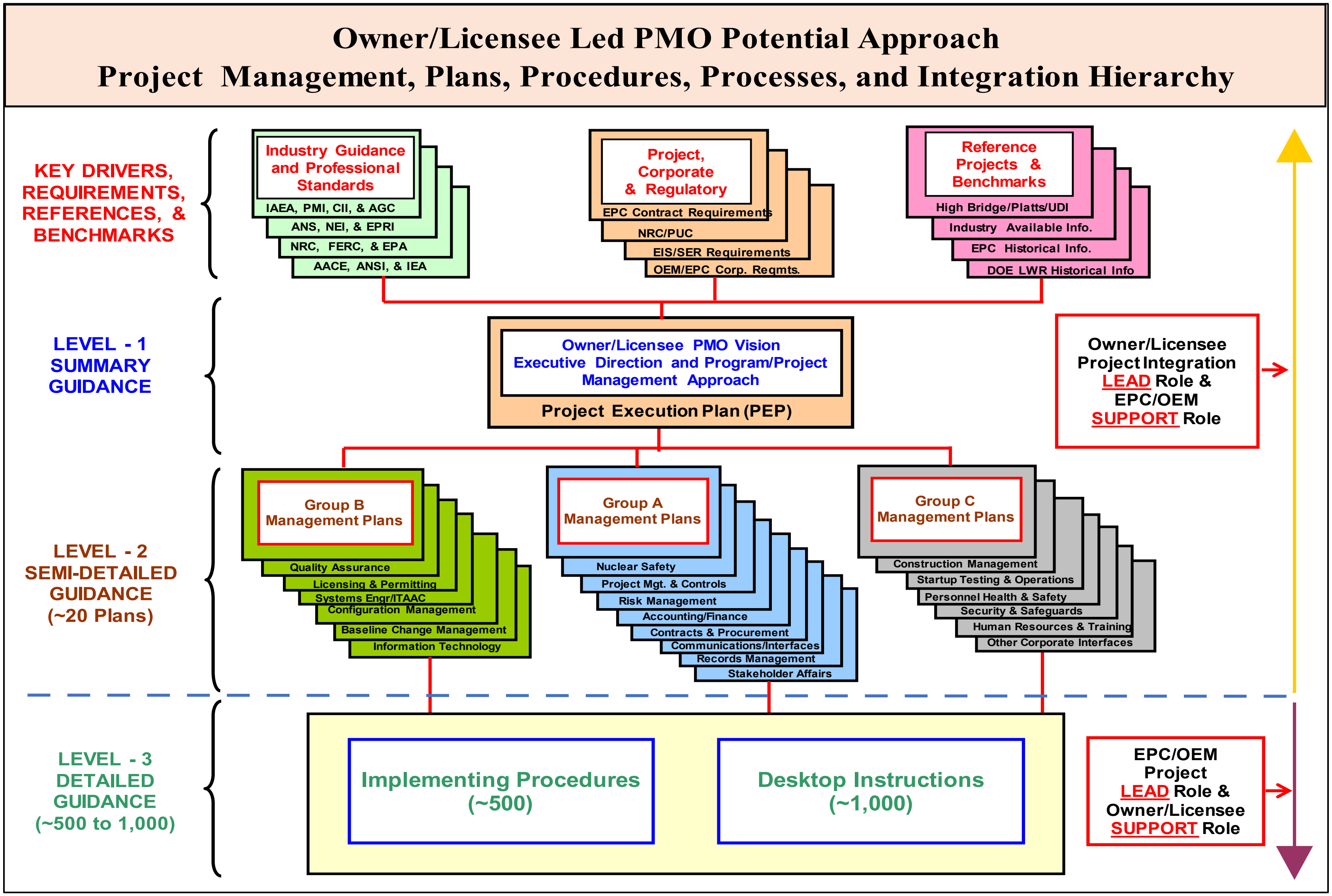
As outlined in **Section 2.1**, current industry resources with large FOAK NNP project experience is limited and less robust than it was last century when the U.S. constructed 129 NNP projects. It is unlikely that any single organization can muster an “A-Team” of leaders and managers with the needed experience

[1] This is quite apart from the NRC’s behavior at operating plants where all plant stakeholders are governed by 10 CFR 21, Reporting of Defects and Non-Compliance.

and qualifications for FOAK NNP projects. History recommends the strategic practice of adopting a "Best Athlete for the Job" strategy when planning and shaping the organization for a FOAK NNP project. Under the leadership of the owner using a Project Management Organization (PMO) approach, it does not matter what project positions are filled by what project organization (i.e., the utility, EPC, or OEM stakeholders). A successful NNP integrated project team needs the most qualified candidate and best athlete for the position. Identifying the best athlete should consider both the qualifications of the individual and the qualifications of the organization supplying the individual. Project goals must be aligned to contract incentives to ensure all participants are behaving in a manner that supports project success while also supporting corporate priorities and expectations. Participating organizations will need the authority to manage risks for their assigned scope. A process will be needed to resolve situations where the mitigation of an organization's scope risk would not result in the overall project success. The risk mitigation process should also ensure that project success will result in individual project organization stakeholder success.

There are many considerations for how to develop a PMO with roles and responsibilities being integrated across the project stakeholder organizations. Each corporate stakeholder on an NNP project has policies and procedures governing its activities. Typically, adopting a PMO approach embraces some key concepts where high-level plans/processes are owner-led and common, across all project stakeholder entities, while detailed procedures/practices will be controlled by the performing corporate stakeholder. **Exhibit 3.2** outlines a potential high-level approach and integration hierarchy for the structure of plans, policies, and procedures for a PMO approach. The owner led PMO will need transparent access to all supporting cost, schedule, risk, and change management information to verify performance reporting. All supporting organizations would use common project controls software systems to support full integration. Work breakdown structures (WBS) would be designed to facilitate higher level consistency while allowing for different lower level details to meet corporate stakeholder requirements. Detailed procedures and work instructions would be governed by the EPC and OEM corporate practices.

Exhibit 3.2, Owner Led PMO Potential Approach and Integration Hierarchy



<u>Key Lessons Learned</u> 3.1 Project Organization, Owner Led Integrated Project Team, and Best Athlete Approach

- **An owner-led Integrated Project Team (IPT) is the single most important element required for a successful NNP project. The majority of the FOAK projects successfully completed and current active NNP projects have adopted the owner led IPT approach.**
- **These facilities span significant technical, organizational, regulatory, and financial parameters that are the responsibility of the owner/licensee.**
- **The NRC and the state Public Utility Commissions look to the owner/licensee as the accountable entity for public safety and the economic outcome of the project.**
- **Adopt a "Best Athlete for the Job" approach when planning and shaping the organization for a NNP project. A successful NNP integrated project team needs the most qualified candidate and best athlete for each position**.
- **All project leadership and management positions demand an owner/project centric attitude that places project success priorities in alignment with parent company priorities and expectations.**

How to implement the best practices and lessons learned described in Section 3.1 is provided in IG 03.

3.1.1 Extreme Ownership and Leadership from the Top

The deployment of NNP projects is intense and challenging. All essential elements for success are pushed to extreme limits. In many ways, a multi-year and multi-billion-dollar NNP project is like a military campaign. It requires an experienced, motivating and passionate project leader whose clear and visible extreme ownership and leadership from the top is essential. The Case Study for the successful River Bend NNP completion in 1985 is presented in **Section 4.1**. In it, Dave Barry (retired president of Shaw Nuclear and River Bend site vice president and manager of the site engineering group) shared the following thoughts and insights:

> *"Clear project goals and management leadership are crucial for a large and complicated nuclear project with millions of design and construction interfaces. Planning and managing activities with a leader in charge of all the pieces makes all the difference. Establishing and communicating clear and unifying goals that transcended corporate and group cultures and individual personalities will create a unique and very successful level of integration and cooperation."*

A relevant leadership example is the U.S. Navy's Seal Teams, one of the highest-performing military units in the world. In their book "Extreme Ownership," retired SEAL officers Jocko Willink and Leif Babin share the vital leadership principles that have enabled Seal leaders and their teams to achieve extraordinary results and explain how these insights can be applied to achieve success in all aspects of business and life. In high-pressure situations, decisions and actions have an immediate impact and often decide the outcome of a mission. On the battlefield, this could mean the life or death of team members, with implications for the mission. In business, this could determine if a project or company sinks or prospers.

The success of Seal Team operations is built on individual traits: knowledge, ability, dedication to excellence, and teamwork - made possible by great leadership at all levels. This foundation also applies to business and life. A true leader takes 100% ownership of everything in his domain of influence, including the outcome and everything that affects it. This is the most fundamental building block of leadership that cuts across all other principles. It applies to leadership at any level, in any organization. Great leadership does not mean always knowing the answer and directing by personnel knowledge or preference. Great leadership means listening to all viewpoints, gathering knowledge quickly from more informed team members and making decisions based on the mission goals and success criteria. When something goes wrong, a true leader does not find excuses or blame others. He puts aside his ego, takes full responsibility for the outcome, and reviews what he must do differently as a leader to create success. If an under-performer is dragging the team down, it is the leader's role to train and mentor the person. If people are not doing what they should, it is the leader's responsibility to clarify the mission and action plan, get people's commitment and equip them to perform their roles. Every NNP needs a charismatic, experienced, and passionate project leader like General Eisenhower from World War II or Chief of Staff Collin Powell from the 1990 Gulf War or a US Navy Seal Commander. See **Exhibit 3.3** showing General Eisenhower addressing troops on D-Day.

Exhibit 3.3, General Eisenhower Addressing Troops on D-Day

Passionate leadership is only effective when they're experienced and able to provide direction enabling project success. In the context of an NNP project, one way is to focus on aligning with known best practices and lessons learned as they fit the unique requirements facing each specific NNP project. Effective extreme leadership is not the owner dictating against known best practices without good reason after weighing the trade-offs associated with such a decision simply because "that's how they prefer it done." The Institute of Nuclear Power Operations (INPO) denotes the principles of effective leadership that can be applied whether an NNP project is in development, being deployed, or in operation (Reference 66).

In the case of an NNP, Extreme Ownership means the owner is always accountable for the outcome. Thus, the owner must put in place people, processes, governance and procedures that establish clear accountabilities and responsibilities for the benefit of the project.

Lessons Learned: 3.1.1 Extreme Ownership and Leadership from the Top

- **A multi-year and multi-billion-dollar NNP project is like a military campaign.**
- **It requires the leadership of an experienced, motivated, and passionate project leader who is focused, visible, listens to advice, provides clear direction, and has extreme ownership.**
- **An extreme leader takes 100% ownership of everything in his domain of influence, including the outcome and affective behaviors.**
- **The leader does not find excuses, does not blame others, has no ego, and takes full responsibility. This is the most fundamental building block of leadership that cuts across all other principles.**

How to implement the best practices and lessons learned described in Section 3.1.1 is provided in IG 03.

3.1.2 Organization Challenges are Tougher than Technical Issues

Establishing an integrated organization that facilitates teamwork and open communications across multi-corporate and stakeholder cultures can be challenging. Experts in organizational effectiveness should be engaged to support team development, strengthen collaboration, and provide independent perspectives on team dynamics and capabilities. Past lessons learned and the best practice of the organization's continuous attention to the psychology and health of a large project organization is critical for success.

The inherent cultural and human nature challenges associated with large NNP projects are obvious. The complexity of managing the organization resources is compounded by the sheer magnitude of information interfaces across licensing, design, procurement, construction, commissioning, and quality functions. Identifying, integrating, and managing the significant size and complexity of interfaces between design products (calculations, drawings, specifications) and supplier detailed design information required for construction and operation (vendor data, manufacturing drawings, calculations, manuals, and other submittals) is a staggering management and communication challenge.

Management systems and tools have evolved to assist with this organization management and communication process. However, history has proven that people are human, and their decisions have cascading consequences that result in unexpected more serious problems than the initiating technical challenge – this is also often true even when the initiating challenge was not technical. Various industry white papers and root cause analyses have concluded that inadequate organization training, deficient communications, and poor management decision-making led to the eventual outcome and seriousness of the issue or challenge.

A large new nuclear project organization is, by definition, an organization that is managing a complex and demanding undertaking. Periods of high activity and competing priorities are inevitable - whether meeting recurring deliverable deadlines, addressing schedule deviations, responding to audits, or managing unforeseen events. Human nature often leads individuals to avoid confrontation or minimize communication issues rather than address them directly. In practice, organizations may attempt to resolve personnel or coordination challenges by restructuring or modifying processes, which can conceal rather than correct underlying issues. In a major nuclear project, these behaviors can undermine performance if not promptly identified and managed in a structured and transparent systematic manner to maintain alignment, accountability, and project effectiveness.

Lessons Learned: 3.1.2 Organization Challenges are Tougher than Technical Issues

- **The complexity of managing the organization elements is compounded by the sheer magnitude of information.**
- **Identifying, integrating, and managing the interfaces is a staggering job.**
- **History has proven that people are human, and their decisions have cascading consequences that result in unexpected more serious problems.**
- **Establishing an integrated organization that facilitates teamwork and open communications across multi-corporate stakeholders is paramount to success.**
- **Continuous attention to the psychology and health of a large project organization is a key lesson when not done and a best practice when done well as it is critical for success.**

How to implement the best practices and lessons learned described in Section 3.1.2 is provided in IG 02.

3.1.3 Collaborative Instead of Confrontational Contracting Strategies

Projects should focus on collaborative contracting strategies (teamwork building) instead of legal-dominated (risk minimization) contracting strategies. Suppliers of material, equipment, and services for an NNP project are retained through contracts with varying terms. Technical and regulatory requirements define a project design and scope basis. Commercial terms and conditions define the contractual and legal parameters that bind the buyer and seller to price, schedule, and other performance terms.

Fixed price or lump sum contracts require a completed and proven stage of detailed design maturity. It is a tremendous task for large, complex projects to identify, integrate, and manage the millions of interfaces between design, procurement, manufacturing, construction and operations. FOAK, or close-follower, projects will not have the detailed, issued for construction (IFC) drawings until they have fully incorporated the entire set of vendor technical submittals, and site-specific design modifications. This is a substantial task that is necessary to establish the basis for a fixed price agreement. Attempts to use fixed price contracts with poorly defined scope have routinely compelled suppliers to incorporate extensive contingencies or protective assumptions to cover unknowns, often leading to cost escalation and schedule disruption once those assumptions are tested and deemed inaccurate during execution. In such circumstances, project emphasis shifts from collaborative problem-solving to contractual administration and dispute resolution - outcomes that erode collaboration, overall project performance, and are inconsistent with a team-oriented delivery model. Regardless of contracting strategy, poor scope definition results in change orders, erosion of trust and collaboration, and unintended contract adjustments.

Our historical lessons and experience indicate that owner/licensees and construction contracting organizations must work exceedingly well together in order to create a fair and flexible contracting framework that recognizes the status of design and licensing maturity. It is essential that all IPT stakeholders are incentivized to ensure the success of the project. This generally results in some kind of "hybrid" contracting strategy where there is a combination of contract types including cost plus, unit cost, target cost, and firm fixed price or lump sum price driven by the level of design maturity and complexity of interfaces with other installation contractor scopes. This approach applies to both the two-step 10 CFR 50 licensing process and the single stage 10 CFR 52 licensing process. The 10 CFR 52 process requires prior NRC approval for some construction-generated changes to the design that introduces new risks to the construction schedule.

Simply stated, project teamwork has routinely been in the past and will likely be in future inversely proportional to the thickness of contract terms and conditions, e.g., more contract details create more guarded and less open relationships and effective communications. **Exhibit 3.4** illuminates this lesson of how fixed price contracts do not guarantee price or success to contain costs for the owner when change orders are aggressively and successfully administered by contractors. History shows that fixed price contracts have created conditions on large capital projects that are adverse not only to cost and schedule, but also to quality, communication, openness, and teamwork goals. Contract terms should foster successful outcomes, not just plan how to punish contractors upon failure. The litigious nature of construction work often leads to a closed management approach that is unwilling to identify deviations and minor discrepancies in the work product.

Exhibit 3.4, Fixed Price Contracts Do Not Guarantee Price or Success

Incentive Schedule Milestones: An owner's top project leaders must embrace a win-win contracting philosophy to deal with this. They need to embrace a collaborative vs. confrontational contracting approach based on contractors deserving to make a fair profit while they also have accountability to perform and deliver their work scopes in a quality and safe manner according to contract schedule and price terms. In addition to defining contractual target cost terms, history shows that cost effective schedule performance is by far the biggest driver of cost performance. Establishing meaningful schedule milestones that incentivize meeting or beating schedule dates is a repetitive lesson and practice in providing a project foundation for success.

The River Bend Nuclear Project completed by Gulf States Utilities (GSU) in 1985 provides a good example of this, as covered more in **Section 4.1**. Their contracting strategy established a set of 100 contract construction schedule incentive/penalty milestones with three or four milestones and dates defined in each of the 24 quarters that made up the 72-month schedule. Nearly $250 million (adjusted to 2025 dollars) in incentive fees (at the time almost 10% of the total estimated project cost) were established to create win-win solutions and to rally project resources around near term and meaningful goals. Incentive fee parameters included distribution to corporate entities and to professional and construction craft personnel. Teamwork and focus on schedule goals was truly galvanized as part of a proud project culture to accomplish work on schedule.

This collaborative contracting strategy incorporating schedule milestone incentives played a big role in River Bend completing construction on time in 72 months (6 years) compared to 120 months (10 years) being experienced by most NNP projects across the industry at the time.

Lessons Learned: 3.1.3 Collaborative Instead of Confrontational Contracting Strategies

- **Develop contracting strategies to engage owners and contractors for FOAK NNP projects success. The more rigid the terms - the more mature the scope requirements must be defined – a near impossibility for a FOAK project.**
- **Large, complex FOAK projects have millions of interface documents and supplier specifications requiring interfaces that need to be controlled.**
- **The lack of maturity will require hybrid strategies and collaboration, or both organizations will set up large change order organizations that will hamstring the project and create significant schedule delays.**
  - **Owners need to create win-win contracting strategies to address the inherent impacts of immature project details.**
- **Project leaders must embrace collaborative rather than confrontational strategies for project success.**
- **Establishing meaningful schedule milestones that incentivize meeting or beating schedule dates is a repetitive lesson and practice in providing a project foundation for success.**

How to implement the best practices and lessons learned described in Section 3.1.3 is provided in IG 02.

3.1.4 Aggressive Risk and Opportunity Management Instead of Risk Shedding Approach

Project risk is an unavoidable aspect of every NNP project. Experience from prior nuclear projects construction shows that the NRC consistently holds only the owner licensee responsible for all aspects of a nuclear project. As a result, the owner licensee is the single point of contact with the regulator. Since risk cannot be shed to others, it needs to be managed from the top down. The public and corporate customers of the nuclear power plants electric generation do not care about the source of cost or schedule overruns. Customers hold ONLY the owner/operator accountable for the cost of electricity. Due to inexperience with large projects, there is a temptation for owners to avoid project risk by contractually re-assigning the risk to primary contractors supporting the owner/operator. The negative effect on project performance of risk shedding rather than risk management has been clearly demonstrated on numerous past NNP projects.

The Project Management Institute (PMI) identifies a continuous process of Risk Management. It is shown diagrammatically in **Exhibit 3.5** and it consists of four major process steps.

Exhibit 3.5, Risk Management Process

1. Identify Risk
2. Assess Risk
3. Control Risk (Develop and Execute a Control Strategy)
4. Review Results (Continually Review Status of Risks).

This is a continuous process throughout the life of the project. Risks are constantly identified, assessed and managed. There are four generalized strategies for controlling risk. They are shown in **Exhibit 3.6** as:

1. Transfer or Share the risk (with stakeholders)
2. Avoid the Risk
3. Reduce the probability of occurrence and the severity of the risk
4. Accept the risks that are judged to have minor impact.

Exhibit 3.6, Risk Management Strategies

The problem with risk shedding occurs when the risk is transferred to another project entity that does not have the ability or capacity to control the risk. An example of ineffective risk shedding would be to assign all project schedule risk to the reactor vendor. The reactor vendor has little control over most of the project's schedule performance. It is therefore invalid to "shed" the risk by assigning it to the reactor vendor or any organization that cannot sufficiently address the problem.

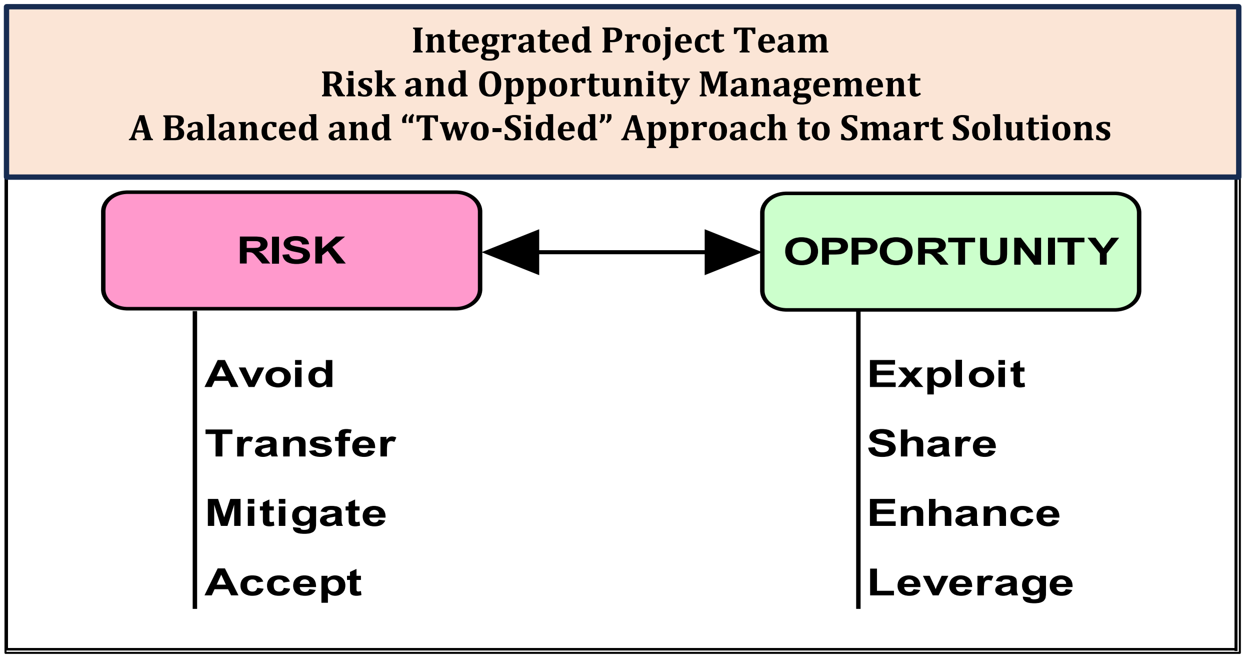
Ultimately risk can only be addressed by proactive measures to first identify and then manage them. These measures include changing the approach to the work, adjusting the logical sequencing of the work, altering technology, adding resources to achieve the desired result on time and the like. Risk management requires active engagement by the project leader and the ability to adjust the project approach to mitigate the risk. If the risk is transferred to an organization that is compartmentalized by contract terms, risk management will not be an ongoing practice but an episodic inefficient project challenge. The only way to successfully execute a nuclear design and construction project is through schedule performance and the only way to assure that is through an active and ongoing integrated project risk management program. Reference 60 provides best practices for establishing a risk register process and identifies the set of top risks that are commonly identified by early mover new nuclear projects.

In the end, the project risk resides with the licensee. It behooves the licensee to engage in an active and inclusive risk management approach that assigns risks to organizations that are best suited to address them and to follow up, helping in any manner required to ensure that the risk is well managed. For risks that cut across all participants, it is necessary for the licensee to manage the risk across all organizational elements.

History shows that large NNP projects require an integrated risk identification and management program led by the owner. Stakeholders closest to the risk understand potential impacts and interfaces in their area of responsibility but not across the total project.

The owner/licensee must establish and control an integrated project risk register across all project stakeholders to prevent risks from being compartmentalized and not fully understood. Accompanied with aggressive teamwork within an integrated project team organization, risk will be managed to assure the success of the project. Additionally, smart identification and management will turn risks into opportunities, as summarized on **Exhibit 3.7.**

Exhibit 3.7, Integrated Risks and Opportunity Management



<u>**Lessons Learned**</u>: 3.1.4 Aggressive Risk and Opportunity Management Instead of Risk Shedding

- **Project risk is an unavoidable aspect of every project and risk should be managed from the top down.**
- **Attempting to shed risk to other entities creates a false security for the owner and corrodes project cohesion and performance.**
- **Successful execution of a nuclear design and construction project ultimately requires schedule performance through an active and ongoing integrated project risk management program.**
- **The owner/licensee must establish and control an integrated project risk register across all project stakeholders to prevent risks from being compartmentalized and not fully understood.**

How to implement the best practices and lessons learned described in Section 3.1.4 is provided in IG 02.

3.1.5 Ingrained NNP Construction, Quality, Safety Culture and Mentality

NNP construction, quality, and safety culture is substantially different than an operating nuclear plant culture. The individuals involved with construction are creating the safety basis for the plant rather than preserving it while operating within all regulatory frameworks. It therefore requires a more creative and activist approach that expects challenges and finds creative ways to overcome them. It requires skilled craft labor and experienced supervisory personnel focused on strict compliance with the design requirements. The lack of an ingrained NNP construction, quality, and safety culture mentality and experience will undo the efforts to align management of the project with the needs of nuclear construction and license commitments.

All FOAK NNP plants are constructed in the U.S. with the approval of the federal government via its agent the Nuclear Regulatory Commission (NRC). The approval is granted after a specific and laborious engineering and design licensing process that has set forth an acceptable nuclear safety design basis for the plant. Deviations from this design, whether intentional or inadvertent, without prior approval are not permitted. Therefore, the construction of a nuclear power plant requires discipline and thoroughness. It also requires a degree of openness and self-criticism.

Construction companies have responded to the declining nuclear marketplace and have generally slimmed their nuclear infrastructure staffing down to the labor and supervisory requirements for commercial, industrial, nuclear O&M, and nuclear decommissioning projects. They have also reduced costs by offshoring design to distributed engineering centers in countries with skilled engineers but lower wages for projects when doing so does not impact export control or local content requirements. Construction workforce is not impacted by this as that workforce is preferred to be sourced as locally as possible. This reduces labor costs and results in an improved competitive position in the market.

The NRC prepared NUREG-1055 in 1984 in response to a request from Congress to explain why nuclear construction projects were suddenly beset with quality problems. Quality is defined as conformance to the requirements. After the Three Mile Island accident in 1979, the NRC changed many of the requirements for nuclear power plant design. NUREG-1055 (Reference 4) is an important and relevant lessons-learned and good practices document. It documents both good project and failed project characteristics.

A common attribute of projects that failed was the lack of prior nuclear experience in one or more of the major participants. This was attributable to the lack of appreciation for the rigor and the complexity of the compliance and record-keeping requirements for nuclear plant construction. Since that NUREG-1055 was prepared in 1984, the difference between commercial/industrial construction companies and experienced nuclear construction companies has grown wider.

Since the late 1970s, the US commercial nuclear industry has evolved an approach to construction that is known as the Safety-Conscious Work Environment (SCWE). Regulations and standards have evolved over the last 40 years providing requirements that were not fully developed or available during previous construction programs. Attributes of these project cultures are the force of regulation and enforcement requirements and are different from conventional construction projects. On August 25, 2005, the NRC issued an NRC Regulatory Issue Summary (RIS) providing guidance for establishing and maintaining a safety conscious work environment (Reference 54).

The formalities embodied in this approach will generate confusion and inefficiencies unless carefully explained to new employees. Organizations that are not used to the formality of the NRC required management approach will find the necessary tools and systems will cause extreme difficulties with the requirements of managing the paperwork load. In summary, SCWE Workplace Priorities are as follows: [2]

1. Safety
2. Quality

[2] "Push It to Move It," D. Amerine, Second Edition, Silver Tree Publishing, 2019

3. Schedule
4. Cost.

Critical elements of a safety conscious work environment include:

1. Leadership clearly committed to safety
2. Open and effective communication across organization(s)
3. Employees feel personally responsible for safety
4. Organization practices continuous improvement
5. Reporting systems are clearly defined and non-punitive
6. Actions demonstrate safety is valued over other priorities
7. Mutual trust fostered between employees and organization
8. Organization is fair and consistent in responding to safety concerns
9. Training and resources are available to support safety.

The safety requirements for each project evolution need to be carefully explained and execution of the work needs to be planned and performed in accordance with the plan. Feedback to the planning process is required to inform management of the effectiveness of the planning processes. When anyone is uncertain of the safety of a process, their concerns need to be examined and addressed prior to conducting the subject evolution. Process improvements and improved work practices need to be documented and fed back into the planning process.

Quality is the conformance with requirements. The quality assurance at all levels of the supply chain is mandatory since the as-built plant must accurately match the safety basis documents approved by the NRC. Quality needs to be built into the plant as well as documented thoroughly and accurately in the data. The regulations establish the requirements and ASME NQA-1 and other implementing requirements. This process is thorough and binding. It is not done properly until the records documenting construction have been accurately and reliably stored in the filing system.

Schedule conformance on a nuclear project is vital due to the complexity and interconnectivity of the construction process. It is a tool to complete the work efficiently and needs to be embraced by all levels in the construction team. In a nuclear culture team, adherence to the schedule is fundamental to the performance of all work. It is not used punitively but rather to enhance worker safety and work progress. The schedule is essential in tracking performance and controlling the workflow of the project.

Cost control is essential to maintaining project budgets for the work. Ironically, schedule conformance does more for cost containment than procurement activities. Even so, the procurement process must ensure the purchasing of materials components and subsystems meet the specifications at a reasonable price. Nuclear procurement is not a bargain-hunting process but rather an effort to obtain products and services that meet the design requirements at reasonable prices. It is a false economy to provide noncompliant material or services because the cost is less than qualified suppliers.

An NNP construction, quality, and safety culture and mentality MUST not only embody the SCWE approach but also includes the following attributes:

1. Personal accountability
2. Procedure compliance
3. Technical inquisitiveness

4. The willingness to stop in the face of uncertainty.

It is a requirement that companies involved in nuclear construction projects must have these features and characteristics ingrained in both processes and in personnel. It is management's responsibility to ensure that these characteristics exist.

History shows that all nuclear projects need to establish this SCWE culture across all stakeholder organizations as a foundation practice to assure project success. Without it, project teams are at high risk for having unwanted execution quality and documentation problems develop. Training new construction craft – especially without nuclear construction experience - to understand and actively buy into the SCWE is a significant challenge. The initial site training must be reinforced daily via pre-job briefs, daily safety training moments and first line supervision behaviors and communications. While all project participants must understand the SCWE, it is the first line construction supervisors who will make it happen or break it. These supervisors need extra training, corrective action support and periodic observation and coaching.

NUREG 1055 and RIS 2005-18 outline critical requirements, lessons, and practices and should be required reading and a formal element in any FOAK new nuclear project training program.

Lessons Learned: 3.1.5 Ingrained Nuclear Construction, Quality, and Safety Culture Mentality

- **NNP project construction culture is substantially different than operating plant culture requiring discipline, thoroughness, openness, and self-criticism.**
- **Skilled craft labor and experienced supervisory personnel must be focused on strict compliance with the design requirements.**
- **The US commercial nuclear industry has evolved into an approach to construction that is known as the Safety-Conscious Work Environment (SCWE).**
- **Nuclear construction mentality MUST not only embody the SCWE approach but also include personal accountability, procedure compliance, technical inquisitiveness (questioning attitude), and the willingness to stop in the face of uncertainty.**
- **All nuclear projects need to establish this SCWE culture across all stakeholder organizations as a foundation practice to assure project success.**
- **NRC NUREG 1055 and NRC RIS-2005-18 Guidance outline critical quality and safety requirements, lessons, and practices and should be required reading and a formal element in any new nuclear project training program.**

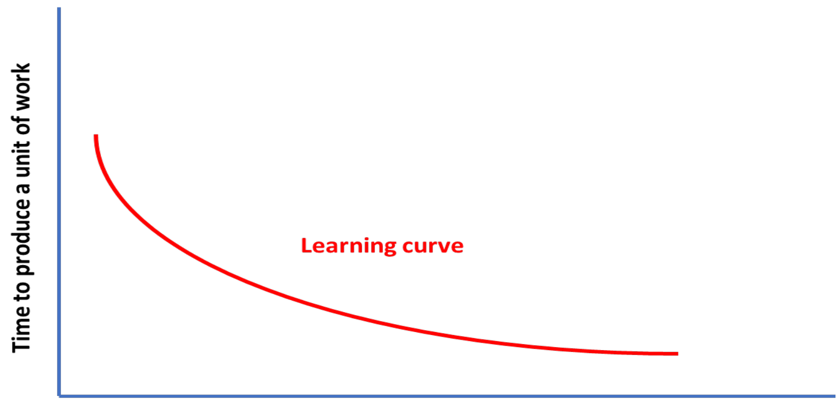
How to implement the best practices and lessons learned described in Section 3.1.5 is provided in IG 03.

3.2 First of a Kind (FOAK) Project Parameters and Challenges

Industrial applications have long recognized the value of repetitive work skills in driving reductions in cost and schedule while maintaining quality and safety. The learning curve for any activity is the decrease in the average work to produce a unit of product over the repetition of performing the work. **Exhibit 3.8** below shows a diagram of the concept. NEI's *Fast Follower Framework for New Nuclear Deployment* (Reference 48) outlines the arrangement that likely maximizes a project's ability to incorporate learnings to move down the learning curve toward Nth of a Kind faster, and how to achieve a larger learning rate that enables a steeper learning curve to realize greater benefits at the same deployment unit.

In the U.S. nuclear industry, the learning curve has most commonly applied to repetitive industrial activity rather than construction projects. This is because most nuclear construction projects in the 1970s and 1980s did not use standardized designs, precluding much of the value of the learning curve. It is expected that the learning curve will be more applicable to the deployment of future NNP plants due to the use of standardized designs, increased modularity, and more recent international experiences in nuclear deployment.

Exhibit 3.8, Theoretical Learning Curve



Stated simply, any work process that is performed repetitively with a positive learning rate ultimately achieves a theoretical minimum time to produce the work based on the details of the work in the processes used to perform it. When the process is changed a new learning curve begins with the final time to produce a unit of work reduced to a new target. This relationship has been well-studied in industries as varied as aerospace, shipbuilding, automotive fabrication and a host of others.

A First-of-a-Kind project is defined as a project that is essentially different in scope or in detail from previous experience. Therefore, it has inherent inefficiencies built into the project. For this reason, most of the lessons learned from the initial GEN II construction projects focused on standardization so that the learning curve for the work could apply. There are limits to this process because numerous site differences and externalities will pertain to each project. However, the benefits of standardization of plant design are widely recognized in the nuclear industry. NEI's *Fleet Deployment Models for Standardized New Nuclear Deployments* (Reference 49) describes how a large build-out of standardized nuclear power plants creates an opportunity for the development and utilization of fleet operations models that realize greater effectiveness, efficiency, and cost savings over models utilized in the existing nuclear power plant fleet.

A recent example of this approach is the Barakah Nuclear Energy Plant in the United Arab Emirates, where four identical APR-1400 units were developed under a coordinated fleet-model strategy. Through standardized design, staggered but parallel construction, and centralized governance under the Emirates Nuclear Energy Corporation (ENEC), the Barakah program achieved consistent quality, predictable performance, and measurable learning-curve improvements across units. Additional details on the Barakah project are in Section 4.10.

While all projects have some FOAK risk, the hiatus in nuclear construction in the U.S., and uniqueness of advanced nuclear reactor designs that are expected to be deployed in the next decade increase the challenge of FOAK construction projects. The lack of consistent direct experience deploying NNPs will result in inefficiencies and unexpected challenges in the deployment of new nuclear plants. As more experience in NNP deployment is realized and positive learnings incorporated, projects will get more efficient and have an increased likelihood of deploying on-time and on-budget.

Lessons Learned: 3.2 First of a Kind (FOAK) Project Parameters and Challenges

- **A First-of-a-Kind (FOAK) project is defined as a project that has an essential difference in scope or in detail from previous experience.**
- **Differences between construction projects can reduce the value of the learning curve.**
- **Consider all NNP projects to have FOAK aspects unless it is the same design, at the same site, with the same project participants.**
- **FOAK aspects result in inefficiencies and unexpected challenges in the design and construction of new nuclear plants.**

How to implement the best practices and lessons learned described in Section 3.2 is provided in IG 04.

3.2.1 Recognizing What FOAK Is

It is important to realize that a FOAK project involves more than the selected reactor technology. Simply selecting a light water reactor (LWR), as the basis for the project, does not assure that the details of the design and construction are understood well enough to obviate FOAK risk. The amount of FOAK risk for a new nuclear construction project is related to how much and how recent identical (and to an extent similar) experience (e.g., project team members, technology, processes and procedures) is incorporated into the project. The contingencies included in the baseline must recognize that unless the companies involved have worked together multiple times to build an identical power plant, there are FOAK risks inherent in the process.

For example, despite their operational expertise, very few current nuclear operating companies have any recent experience building a nuclear plant. The individuals, the tools, and the procedures in place were developed after the companies' nuclear plants were constructed. Very few nuclear design or construction companies in the market today have successfully executed a nuclear design and construction project from start to finish using their existing personnel, tools, and procedures. The details of the design, including site-specific modifications, and the complexities of integration of an unfamiliar set of interfaces all represent a FOAK risk to those doing it for the first time in decades. Finally, the entire supply chain has evolved into delivering parts to support the repair and replace service industry devoted to maintaining operating nuclear power plants and not NNP construction.

Aside from the details of design and construction, the NRC staff is inexperienced in nuclear design and construction. The original nuclear power plants in operation today were designed and constructed under various revisions of 10 CFR 50, Domestic Licensing of Production and Utilization Facilities. Under that licensing regimen, the licensee submitted a Preliminary Safety Analysis Report (PSAR) for the NRC to review. The PSAR identified the site characteristics and the safety basis for the plant and if the NRC agreed that the plant design could be executed safely, a Construction Permit allowing construction to begin was issued. During construction, the Final Safety Analysis Report (FSAR) was prepared and if it was found acceptable and if the construction was completed in accordance with the FSAR, an Operating

License was issued, and the plant was allowed to begin operations. This process was vulnerable to intervener activism. Any issue raised during the construction and FSAR review would delay the issuance of the operating license costing the project literally hundreds of millions of dollars. This ruse was used successfully to delay and force the cancellation of numerous nuclear projects in the previous century.

During the hiatus in nuclear construction, the NRC responded to criticisms and promulgated 10 CFR 52, Licenses, Certifications, and Approvals for Nuclear Power Plants. 10 CFR 52 is an alternative to the two-step licensing process of 10 CFR 50 with a single license. The 10 CFR 50 process grants a Construction Permit that requires less upfront information compared to the information needed for a Combined Operating License under the 10 CFR 52 process, but the 10 CFR 52 process is a single stage licensing process and does not have the additional opportunity for delays with receiving the Operating License. This eliminated the vulnerability to intervention implicit in 10 CFR 50. However, it produced a new licensing process that has only been successfully used to construct two NNPs (i.e., Vogtle Units 3 and 4). The NRC has undertaken rulemaking (Reference 55) to make both Part 50 and Part 52 more efficient. While more work is needed to accelerate NRC reform (Reference 56), projects will always need to be prepared with high quality applications and engage early in the licensing process to ensure the approval of a design that can be constructed and inspected – thereby eliminating extremely difficult rework and delay.

One might be tempted to consider all reactor designs that have successfully completed the NRC's Design Certification process to be Nth-of-a-Kind (NOAK) designs, but that would be incorrect. While design certification confirms that the safety-related aspects of a design have been fully evaluated and approved by the regulator, it does not represent completion of the detailed engineering necessary for construction. Significant design work remains following certification, particularly for systems outside the certified scope, such as site-specific adaptations, vendor interfaces, and balance-of-plant details. Furthermore, if the certified design has not yet been deployed, new challenges may emerge during first-time construction that are independent of the material reviewed by the regulator—who assesses safety, not constructability. Consequently, even after receiving regulatory approval, all projects retain some degree of FOAK risk associated with execution and deployment.

New suppliers also represent FOAK risk that is often requested by governments and/or private owners to maximize local content in order to stimulate the local supply chain and economy, as well as increase local support for the project (e.g., Made in USA). The use of new vendors adds FOAK execution risk and needs to be assessed as part of the overall risk for the project. Standing up new suppliers (local or not) creates FOAK risk from both an on-time delivery aspect and quality challenge. Furthermore, additional costs are incurred to standup the new suppliers as not all aspects of the supply chain can easily be established and new vendors may or may not be as qualified or experienced, potentially resulting in a suboptimal delivery strategy.

The most difficult aspects are complex equipment with strict quality requirements, items that require large capital investments, and items with intellectual property constraints. Conversely, many other supply chain components are commonly supplied locally usually ones with non-safety or commercial fabrication requirements that are not critical path for the project (e.g., no one ships concrete around the world). The supply chain for a project must be optimized to drive down cost, provide high quality components/materials, and yield the highest probability of project success.

For the learning curve analogy to apply as much as possible to any aspect of deployment (design, procurement, construction, etc.), it must be identical to the previous experience in that area. Any difference in experience or in execution details represents a FOAK risk that needs to be accounted for in planning the project.

<u>**Lessons Learned**</u>: 3.2.1 Recognizing what FOAK Is

- **For the learning curve analogy to apply as much of the design and construction as possible must be identical to the previous experience of the leadership team and workforce.**
- **Any difference in experience or in execution details represent a FOAK risk that needs to be accounted for in planning the project.**
- **The contingencies included in the baseline must recognize that unless the companies involved have worked together to build an identical power plant, there are FOAK risks inherent in the process.**

How to implement the best practices and lessons learned described in Section 3.2.1 is provided in IG 04.

3.2.2 Experience of Stakeholders

Another FOAK risk involves the experience of the stakeholders. This is more than the design and construction teams on the project. It includes all the stakeholders involved in the project whether directly or indirectly. As described in **Section 3.3.4**, management of the stakeholder activities during the project is a major issue. However, the lack of experience with a nuclear design and construction project is an even more daunting handicap. A vigorous outreach and training program may be necessary for external and for internal stakeholders. Problems arising from clashing assumptions and misunderstandings among the stakeholders need to be avoided. Unless the stakeholders are all familiar with the details of a nuclear project, the risks of delays and intervention are high.

The primary risk is internal stakeholders. The lack of experience in working together across corporate interfaces, and the lack of experience of the individuals within each stakeholder group are serious risks. However, the lack of experience with external stakeholders cannot be ignored. Regulators, investors, corporate executives, local citizen groups and a host of others may enter the project with inadequate or non-existent expectations or understanding.

Designing and constructing a nuclear plant involves numerous interfaces and interconnections. Individuals within the cooperating organizations who are unfamiliar with these complexities may overlook emerging issues or integration challenges. Developing accurate work scopes, logical sequencing, and realistic durations requires both disciplined project management practices and access to relevant nuclear or large-project experience. Insufficient experience can increase the likelihood of errors or unrealistic assumptions. Accordingly, project success depends on applying proven methods, incorporating experienced insight where possible, and fostering a learning environment that transfers knowledge across the team.

Commercial nuclear power plants in the U.S. are constructed with the specific approval of the U.S. Nuclear Regulatory Commission and all design deviations from the licensing basis must be avoided or specifically approved by the regulator. Experience with large, non-nuclear projects - particularly those that have made of best practices in construction and project management - can be beneficial, however, the peculiarities and requirements of nuclear plant development and construction must be clearly understood. The interfaces, record keeping and need for rigorous conformance to the design input at a nuclear plant are inadequately appreciated in other industrial applications. Likewise, experience with nuclear operations does not qualify an organization to lead a new nuclear megaproject construction. Megaproject deployment experience married with a firm understanding of nuclear licensing, quality, SCWE, regulatory compliance, and rigorous design conformance is needed for a successful project

The procedures, tools and corporate culture of the stakeholders need to address the specific nuclear project requirements. Schedule adherence must be accomplished by careful planning, accurate, well-rehearsed, and execution rather than by cutting corners and hiding mistakes. Many industrial applications are robust enough to tolerate a degree of nonconformance. While nuclear plants are probably more carefully designed than other industrial applications, the requirements of nuclear oversight and public expectations mandate conformance with all requirements. Companies and individuals within that organization that are not familiar with these realities are certain to have performance issues when trying to execute a nuclear project. If most of the entities involved in the nuclear plant design and construction are unfamiliar with nuclear requirements, the project will experience delays and cost over runs for work stoppages and rework necessary to achieve acceptable performance.

The openness and interactive nature of the safety conscious work environment is unusual in many industries. However, it is mandatory on a nuclear project. This represents a new corporate culture for many organizations, and if they become involved in the nuclear design and construction project, it is certain to lead to many upsets and delays. The individuals within the stakeholder organizations will have challenges working in this new environment. These challenges will result in longer than expected durations of effort caused by confusion and misunderstandings. If these delays and work effort are not understood at the outset, the durations and effort required for each scheduled element will be overly optimistic.

The understanding of the nuclear construction mentality should not be assumed. It will be necessary to train and direct the stakeholders in a proactive manner to avoid conflicts. Interest in deploying NNP projects is growing, and no single organization has all the experienced staff necessary to perform all roles required for deploying an NNP project. The project leadership needs to recognize this, and establish resources and mechanisms to address the lack of nuclear experience. It will be an area requiring constant effort to avoid adverse project impacts. Resource, labor, and training strategies must formally address how to apply lessons and practices from the past to ensure that this lack of experience is dealt with successfully.

Lessons Learned: 3.2.2 Experience of Stakeholders

- **Management of the stakeholder activities during an NNP project is a major issue.**
- **Lack of experience with a nuclear design and construction project is an even more daunting handicap. Unless the stakeholders are all familiar with the details of a nuclear project, the risks of delays and intervention are high.**
- **Experience with only large non-nuclear industrial projects is insufficient for approaching a nuclear construction project. It must be augmented with keen nuclear lessons and practices.**
- **The interfaces, record keeping and need for rigorous conformance to the design input at a nuclear plant are inadequately appreciated in other industrial applications.**
- **The openness and interactive nature of the safety conscious work environment is unusual in many industries and represents a new corporate culture for many.**

How to implement the best practices and lessons learned described in Section 3.2.2 is provided in IG 03.

3.2.3 Design Maturity and Details Required for Construction

A mature design consists of a design that is largely complete including all site-specific design changes and vendor design submittals, and then thoroughly planned for construction. Most references on lessons learned focus on the need for the design to be completed before construction begins, but a completed design by itself is not adequate – the design must also incorporate vendor design details. This also means that constructability reviews are completed, construction sequencing is set, and design interfaces are resolved. The failure to have all the design and constructability issues resolved is the most impactful of the lessons to be learned from previous projects as design completion isn't the most costly aspect of a project but it casts the longest shadow in that redesign work causes cascading cost implications through new procurements, additional labor, regulatory submittals, etc. The delays forced by field changes and reevaluations of already approved designs are the most damaging to both the schedule and the cost of construction.

As the Japanese experience demonstrates a completed design must include all vendor data. Japanese nuclear projects routinely begin with the engineering completed, procurement finalized, vendor data incorporated, and all construction planning completed. While it is true that some of this thoroughness is possible because of standardized designs, it is also true that each project benefits by the incorporation of lessons learned from prior experience. Each project is faced with many small changes and improvements that pose many of the same challenges as a first-of-a-kind design. To approach the efficiency of the Japanese construction programs, a mature nuclear design must include all of the procurement effort to identify and select qualified vendors for systems, commodities and components and to incorporate all of their specific interface data into the design. Additional details on how to set up a learning organization and how to maximize positive learnings is in Reference 48.

The GEN II nuclear plants built in the U.S. during the 1970 to 1990 time period were generally new bespoke designs that suffered from a lack of design maturity. The technology was in a state of flux as competition for the market drove the designs toward more economical solutions. At the time, the regulations were in a chaotic state of development that forced many design changes and confusion. While new nuclear plants in Japan, South Korea, and France benefited from their homogeneous cultures and an integrated industry contractor and regulatory relationships, the U.S. had a more heterogeneous, competitive culture where owner preferences in plant design and equipment negated replication. Of the 129 US nuclear plants completed and put into operation, few were completed with no design changes resulting in NOAK economies and benefits. Palo Verde Units one, two, and three for Arizona Public Service accomplished a successful degree of no design changes. Additionally, Callaway and Wolf Creek also used the same design under the Standardized Nuclear Unit Power Plant System (SNUPPS) initiative. Some of the lessons learned from SNUPPS could be reapplied today. Since these two plants were built in parallel, they did not see huge savings from learning but did save a reported $214M from standardization (Reference 61). Additional benefits from standardization are discussed in Reference 49.

Exhibit 3.9 provides a generic summary of the approximate number of and the key interrelationships between primary NNP project deliverables. There are literally millions of points of failure that can stop construction if proper design execution and configuration management are not accomplished. Engineering for an NNP project consists of several hundred people. Construction activities at a nuclear site for a large project can involve 2,500 to 5,000 people at a time. Failures during construction traced to incomplete or ill-considered designs result in extremely large cost penalties.

Exhibit 3.9, Project Deliverables and Managing Design-Construction Interfaces

Summary of Nuclear Power Plant Design/Engineering/Procurement/Construction Deliverables
Managing Configuration of Millions of Data Interfaces & Revisions are Crucial for Success

Engineering & Design Products	Approx. Number		Approx. Number	Vendor Data for Detail Design
Piping, Mechanical, Electrical Systems	100		500	Specifications - Engineered Equipment
Major Equipment Components	2,000		500	Specifications - Engineered Off the Shelf
Engineering Calculations	10,000		1,000	Purchase Orders - Equipment/Material
P&ID Flow Diagrams	500		100	Contracts - Labor/Equip/Material
Control Logic Diagrams	500		16,500	Vendor Technical Submittals (average 15 submittals per P.O. & contract)
Elementary Wiring Diagrams	1,000		165,000	Vendor Detailed Data Documents (average 10 documents per submittal)
Construction Drawings	20,000		4,125,000	Vendor Document Pages to Review, Check, & Incorporate in Design (average 25 pages per document)

3-D computer model technology assists but does not replace rigorous human review to assure fidelity

The current regulatory environment has stabilized around a paradigm that is not familiar to those that previously built GEN II plants in the 1970s – 1990s and has resulted in unanticipated negative impacts on the construction process. The 10 CFR Part 52 licensing protocol has a combined construction and operating license prior to the beginning of construction. Construction activities are inherently complex and minor deviations from the design are routinely tolerated. However, under 10 CFR 52 each deviation represents a potential licensing impact and therefore results in a lengthy and thorough examination by the design organization and by the regulator. These interruptions in the construction work processes can be extremely burdensome especially if the review requires a substantive modification to the COL or rework in the field. Given that the project team will be held to the drawing tolerances and specifications in the licensing basis (e.g., ITAAC) by the NRC, the project team (especially the constructor) should carefully review the licensing basis commitments to ensure they can meet them and have a clear picture of the objective quality evidence that will be required as verification of completion - waiting until active construction is much too late. Advanced Work Packaging should include the steps to collect all data and witness points needed to demonstrate meeting all licensing commitments. There are changes being implemented in Reference 55 and additional improvements proposed in Reference 56 to ensure an efficient deployment process. Stated another way, applying operating nuclear plant standards and requirements designed for outage modifications to a new plant construction effort will result in significant cost and schedule impacts that do not improve safety, quality or standardization and are not consistent with desired overall economic outcomes for bulk installation during new construction.

It is a tremendous task for FOAK projects to identify, integrate, and manage the millions of interfaces between design products (calculations, construction drawings, specifications), and supplier detailed design information required for construction and operation (vendor data, manufacturing drawings, calculations, manuals, and other submittals). FOAK projects cannot have detailed, released-for-construction drawings until they have assimilated these millions of vendor technical submittal elements into released for construction installation drawings. Modern tools such as CAD based information management systems can only assist to the extent that they are fully used prior to the beginning of construction. The most powerful of these information management tools are extremely labor-intensive in the set up in execution of the design. There is a direct relationship between the power of these tools to the effort required to use them. The design effort must be focused on construction and to the extent possible must identify and resolve all construction issues prior to their release for construction.

In summary, FOAK new nuclear plants in the U.S. must apply the lessons learned and practices that recognize the need to have design accomplished before starting construction. Political, human nature, and publicity pressure to “get shovels in the ground” to show progress need to be pushed back.

Lessons Learned: 3.2.3 Design Maturity and Details Required for Construction

- **Design maturity to support construction consists of a design that is complete including all vendor design submittals incorporated in detail and thoroughly planned for construction.**
    - **To achieve this design maturity, essentially all procurement activities need to be completed prior to the start of construction.**
- **Constructing a nuclear plant consists of a highly complex, interrelated set of activities that must be executed in order and in accordance with the design.**
- **A completed design by itself is not adequate.**
- **NPP projects do not have detailed, released-for-construction drawings until they have assimilated the millions of vendor technical submittal elements into released for construction installation drawings.**
- **The design effort must be focused on constructability, and to the extent possible must identify and resolve all construction issues prior to their release for construction.**
- **New nuclear plants in the U.S. must apply the lessons learned and practices that recognize the need to have a design completed through ITAAC (Inspections, Tests, Analyses, and Acceptance Criteria) incorporated into the design and planned into the work packages before starting construction.**

How to implement the best practices and lessons learned described in Section 3.2.3 is provided in IG 01.

3.2.4 Realistic Cost and Schedule Baselines

NNP projects begin with a great deal of enthusiasm and optimism. It is a very natural tendency to underestimate the scope and duration of work, especially if optimistic stakeholders “don’t know what they don’t know” and do not have the experience to appreciate the risks involved. Engineers and technology providers tend to be very confident in their chosen fields. They are rightly proud of their technology offering which tends to result in blind spots regarding the effort required to complete a project. Owner’s staff suffer from a natural human desire to take aggressive unrealistically low-cost estimates at the outset of a project in order to win the approvals necessary from corporate management and/or public utility regulating authorities. This optimism bias is especially prevalent when owners and OEMs fail to involve EPCs (and other stakeholders who have experience executing projects) early enough in the project.

All the above coupled with the lack of nuclear construction experience, and made worse by beginning construction without sufficient design details, create blind spots and result in pressure on the project that leads to the need to find a way to minimize the project cost estimate and financial baseline. All lessons learned on previous projects wind up being ignored and the go-or no-go decision is based on a purely theoretical cost estimate.

These pressures result in unrealistic schedules, unworkable contracts and cost saving steps that doom project performance. In the absence of nuclear project design/construction experience, it is easier to surrender to these economic cost drivers than to lead a vigorous defense of the needs for adequate funding and resources during the project planning phase to achieve project success. The lessons learned from other projects are forced to the side in order to get the project funded.

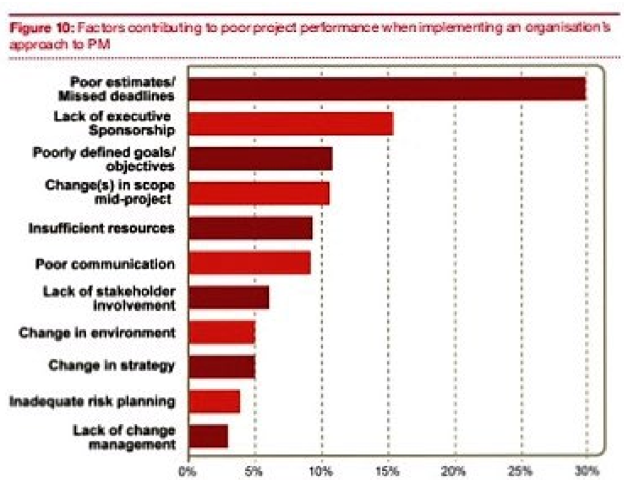
An excerpt from Reference 19 (**Exhibit 3.10)** is the 2012 Price Waterhouse Cooper (PWC) Insights and Trends regarding Current Portfolio, Program, and Project Management Practices. It was presented in the PWC third global survey on the current state of project management. It compiled survey results from executives and managers at 1,504 companies spanning essentially all industries. As shown below on **Exhibit 3.10,** this report states that poor estimates in the planning phase continue to be the single largest cause for poor performance in projects and the single largest worsening trend, representing 32% of responder feedback as the #1 problem.

Exhibit 3.10, PWC 2012 Global Survey of Causes for Poor Project Performance

"Poor estimates in the planning phase continue to be the single largest cause for poor performance in projects and the single largest worsening trend."

- ✓ 2012 PWC Global Survey – 1524 Companies
- ✓ Updated from 2004 Survey
- ✓ Poor Estimates in Planning Phase still #1
- ✓ 2004-2012 increased from 17% to 32%

Source: Price Waterhouse Cooper, "Insights and Trends: Current Portfolio, Program, and Project Management Practices: The third global survey on the current state of project management" - 2012



The commercial nuclear power industry does not have a unified or consistent set of guidelines that govern determination of contingency for cost estimate accuracy as a function of design maturity or management reserve to address discrete risk issues. Owners/licensees, EPC firms, and OEM firms all have their internal policies and guidelines that govern how to develop cost estimate contingencies to cover cost estimate accuracy and potential discrete risk issue impacts from detailed bottom up and parametric top down perspectives.

However, public domain information and guidance spanning many industries is available regarding estimate contingency required to cover cost estimate accuracy and risk considerations for a large project. **Exhibit 3.11** below summarizes the recommended per cent range for project contingency as provided from various organizations including Westinghouse, the Chemical Industry, NASA, and the Association for the Advancement of Cost Engineering (AACE).

Exhibit 3.11, Industry Guidance Regarding Cost Estimate Contingency Determination

Mega- Project Planning Project Internal Accuracy & Contingency Considerations Industry Guidance for Conventional and First of a Kind (FOAK) Facilities						
Project Phase or Design Maturity Status	Industry, Corporate, or Project References Recommended Internal Accuracy Contingency Allowance Per Cent Ranges					
	Westinghouse Estimating Guide for Advanced Technology		Chemical Industry Guide	NASA Estimating Guide	AACE International Guidance or Conference Paper/Publication	
	Standard or Conventional Facility	Experimental or FOAK Facility	Standard or Conventional Facility		FOAK and Evolving Technology	Standard or Conventional Facility
Planning or Feasibility Study	20% - 30%	Up to 50%	30% - 60%	50% - New Design, beyond State of the Art	50% - 100% and up New Design, Limited Data	25% - 40%
Conceptual Design Complete	15% - 25%	Up to 40%	17% - 26%	35% - New Scale, within State of the Art	30% - 70% New Concept Bench Scale Data	18% - 30%
Preliminary Design Complete	10% - 20%	15% - 25%	8% - 15%	25% - New Hardware, based on Preliminary Design	20% - 35% Small Pilot Plant Data Available	8% - 15%
Detail Design Complete	5% - 15%	10% - 20%	3% - 6%	15% - Modification to Existing Hardware	5% - 20% Full Size Facility Operated	5% - 10%

These represent top down parametric guidelines that are driven by the level of design maturity and the type of project (conventional or FOAK) involved. While spanning different industries and project complexities, these industry authorities recommend contingency allowances in the 50% to 100% range at the early planning feasibility stage, 40% to 70% in the conceptual design stage, and 10% to 25% in the definitive design and construction stage for FOAK projects.

Proactively addressing contingencies early and developing clear strategies to address them are important ways to mitigate these potential concerns. Additionally, projects should consider estimating potential contingency costs with greater specificity. Instead of applying the top-down uncertainty estimate to the overall project, sum the uncertainty for each major process and component to determine the overall project contingency. This can help determine more accurate estimates and enable more accurate potential sources of risk.

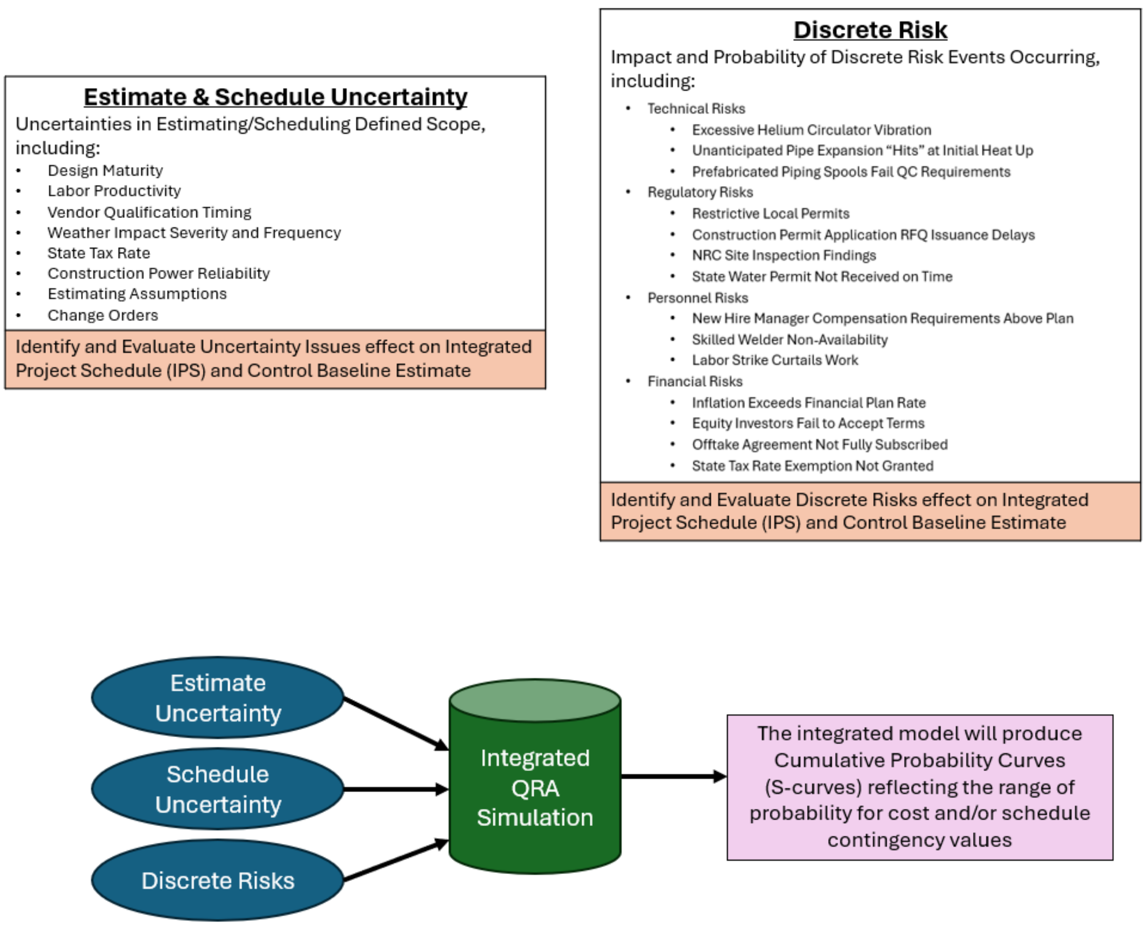
The key to developing realistic cost and schedule performance baselines is to realistically recognize the design maturity and FOAK risk issues inherent in the NNP deployment enterprise. Integrated risk management processes must address both general uncertainties impacting estimate/schedule accuracy (management reserve) and discrete risks (contingency).

Contingency is derived from an assessment of the project's risks and uncertainties. It is allocated to the project as part of the budget and is expected to be spent as part of project execution. Not spending parts of the contingency results in the project coming in under budget. On the other hand, management reserve is a fund set aside for low or uncertain probability events that could have a high impact -

because they are outside the control of the project participants. These funds are not expected to be spent as part of project execution, and are controlled at a higher level than the project itself (e.g., board of directors, or specific executives not part of project execution).

Unfortunately, history shows that new nuclear FOAK projects generally do not reflect these lessons and guidance parameters. Based on this, NNP project stakeholders must observe these lessons and apply rigorous risk/estimate accuracy evaluations that reflect FOAK and the level of project design maturity. The implementation guides provide guidance on developing realistic contingency and management reserve allowances for cost estimates and schedules, and how to set reasonable stakeholder expectations about those estimates and schedules.

Exhibit 3.12, Integrated Risk Management Addressing Contingency



Lessons Learned: 3.2.4 Realistic Cost and Schedule Baselines

- **History shows that new nuclear FOAK projects generally do not reflect the lessons and parameters indicated in public domain cost, schedule, and risk management guidance documents and standards.**
- **The lack of nuclear construction experience creates blind spots and results in pressure on the project that leads to the need to find a way to minimize the project cost estimate and financial baseline.**
    - **NNP project stakeholders must observe these lessons and apply rigorous risk and estimate accuracy evaluations that reflect practices that recognize FOAK and the level of project design maturity.**
    - **These pressures result in unrealistic schedules, unworkable contracts and cost saving steps that doom project performance.**
- **NNP projects need to take advantage of the tools and practices developed for characterizing cost estimates and schedules.**
- **Developers and owners of NNP projects must utilize available industry guidance sources, recognize the uncertainties and risks in FOAK estimates/schedules, and adopt risk and opportunity management strategies to be applied for future Nth of a kind projects.**

How to implement the best practices and lessons learned described in Section 3.2.4 is provided in IG 01.

3.3 Project Management Involves Art and Science

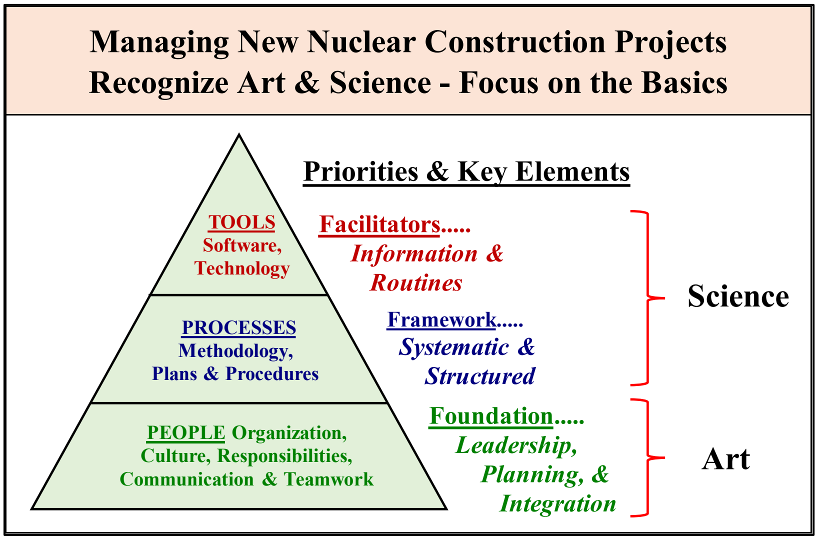
Project management has received much attention lately as a result of poor performance on projects. It is perplexing that with hundreds of industry project management lessons learned white papers, customer benchmarks, project management procedures, and professional society published guidelines that so many large projects still find themselves in trouble. As outlined in the Project Management Institute's *A Guide to the Project Management Body of Knowledge*, various elements contribute to project success spanning cost, schedule, quality, risk and resources. The key is good organization teamwork and communications integrated with a balanced risk management approach.

Project Management is a people and communication challenge. A large nuclear project involves 1,500 to 5,000 people working together for a common purpose – Vogtle Units 3 & 4 peak construction had more than 9,000 people on site. Problems will arise from all corners at a pace that will overwhelm a disorganized management team, especially if too much data clouds clear decision-making information. The key to managing a Megaproject is to assemble an IPT that spends quality time to develop a fully vetted project baseline budget and schedule. Then to execute the project by rigorously focusing on maintaining schedule.

Project management practices must rely on sophisticated tools to manage all the parts and pieces involved in an NNP project. The key is to strike the proper balance with summary and detailed information that allows details for those stakeholders that need them and fewer details for those that do not need them. Achieving clarity regarding near-term schedule goals is a key facet in assuring that the average engineer or construction worker understands and feels accountable for what is needed and expected. A "rolling wave" schedule concept is discussed later that focuses on what is needed to facilitate this goal.

On projects where sophisticated tools and processes have been implemented, extensive data from computer software tools tends to provide a false sense of security where managers think more detail means more confidence. Quite the contrary, more detail can create information overload while the fundamentals of basic project management tend to be missed. Many large projects have created a detailed project management infrastructure of tools and systems without a balance of forward-looking cost and schedule summary metrics. Project management decision-making information involves an enormous amount of data, process flows, and system requirements. Project management key elements can be summarized as involving the people, processes, and tools of a project organization as shown on **Exhibit 3.13**.

Exhibit 3.13, Project Management Key Elements are Art and Science



Experience with current project management software is that it supports the smart and judicious application of the latest technology. However, software tools need to be applied with a graded approach so that project management and support resources do not become data maintenance clerks maintaining too much detail that provides too little value. It is important to recognize that tools and processes make up the tangible dimension of "science" for project management. Much software exists off the shelf for estimating, scheduling, and risk management. These tools need to be integrated so that there is a single, auditable, and common source of truth. The people and organization elements represent the less defined dimension of project management "art."

As project size and complexities rise, people and organizational interfaces increase requiring effective communication using clear and simple reporting and analysis. A good organization with a great leader will overcome imperfect project management systems and tools. Project management stakeholders must understand that they are leaders to facilitate planning and integration… they are not system data administrators.

Lessons Learned: 3.3 Project Management Involves Art and Science

- **The integrated project team ensures accountability, communication, leadership, ownership, and clear direction.**
- **Each of these behaviors are commonalities associated with the three project management key elements covering people, processes, and tools.**
- **Large complex NNP projects involve an enormity of science-based tools providing a huge amount of data, process flows, and system information to facilitate the project leader in decision-making.**
- **Care must be taken to ensure the leader and project management staff do not become data clerks maintaining too much detail that provides too little value.**

How to implement the best practices and lessons learned described in Section 3.3 is provided in IG 05.

3.3.1 Integrated Project Schedule, Owner Control, & Simplified Reporting Systems

Integrated Project Schedule - History shows that the key element in a project management system infrastructure for a FOAK NNP is the integrated project schedule (IPS). It serves as the basis for executing and managing all project activities of the owner, EPC contractor, and OEM suppliers. NNP projects involve an array of labor, material, and equipment resources. Construction craft manual labor can total 20 to 30 million hours or more on a large project. With the project non-manual labor effort for engineering, professional, and administrative resources for a large FOAK new nuclear project being in the 10 to 20 million-hour range or more, this results in a grand total of 30 to 50 million project labor hours spanning as much as 10 years. This equates to a peak staffing of at least thousands of both construction craft and non-manual personnel for the total project organization spanning owner and contractors on site and in remote office locations - Vogtle Units 3 & 4 peak construction had more than 9,000 people on site. During peak construction periods this means that monthly total labor hour expenditures are about 1,000,000 hours per month.

Timely and transparent progress updates of the IPS are critical to assure that:

- Project resources are working on the right activities to support the schedule and
- Variances from baseline plans are addressed and corrected

Another lesson and proven practice is creating a formal Project Management Office (PMO) with collocated members from the integrated project team (IPT) organization. This PMO needs to be coupled with a project management operations center that serves as the room/location where all project management status information is maintained by a dedicated PMO staff. This provides a project command location where updated real time information regarding the overall status of the project is always available, including high level performance dashboards and progress visibility for any details.

Experience shows that having a contractor solely in charge of the IPS is an inherent conflict of interest. The owner must have overall responsibility for establishing, updating, and changing the IPS, even in cases where a subset of these activities are delegated to contractors. This is needed to ensure that progress information and changes are transparent and in accordance with IPS administrative rules. It provides the visibility for stakeholder accountability and keeps all players honest. The owner stakeholders responsible for leading the PMO and operating the IPS must be qualified and have the experience with project management art and science needed to create an effective operation. In summary, lessons show that project management strategic best practices to be followed include:

- Developing an integrated project schedule (IPS)
- Performing progress updates in a timely and transparent manner
- Establishing a project management office (PMO)
- Creating a project management operations center
- Establishing that the owner is leading and in charge of the above items

Simplified Reporting Systems – All complex megaprojects, including new nuclear projects, require powerful automation systems and tools to address the thousands of elements and details needed to plan, schedule, estimate, report, and manage activities spanning ten years and millions of construction pieces and parts. Certain project stakeholders and specialists need the skills and experience to implement project management systems and produce needed planning and output reports. However, it must be recognized that the average worker is not concerned with nor capable of digesting enormous data reports or understanding the picture of activities that are two to three years or more away… that is the job of management. The average engineer and construction stakeholder just want to know what is expected of them this week and this month.

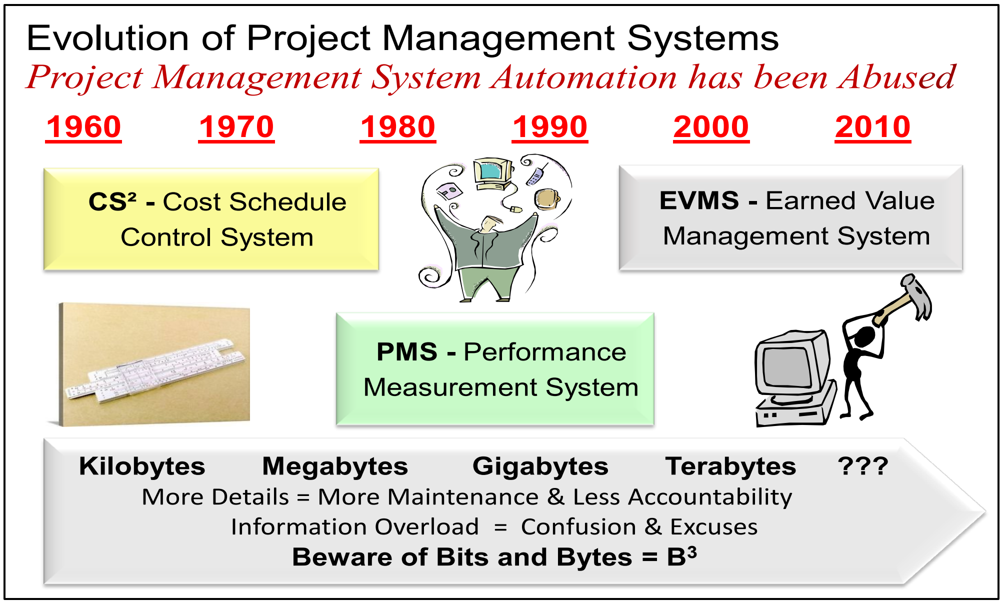
As with all industries, NNP projects have been affected in positive and negative ways by the evolution of automated project management systems and software. Many features allow project teams to assess parameters and potential outcomes regarding schedule and cost in ways not possible in the past. Projects often forget the history lessons that should focus on the foundation and priorities reflected earlier in **Exhibit 3.13**. As tools and technology have increased in sophistication they often create unexpected negative impacts:

- The capability and flexibility of software has been abused
- Data overwhelms ability to focus on critical information
- Increased data/automation has decreased stakeholder accountability
- Digital capabilities have created a sterile/impersonal process and reduced effective communications
- A nuclear outage mentality has driven systems into producing more detail that is not required

As shown on **Exhibit 3.14** summarizing the evolution of project management systems, the proliferation of systems and data over the last 50 years is staggering. Over 100 new nuclear plants were constructed in the 1970s and 1980s without this power and capability. Schedules, estimates, and performance reports were either prepared manually or generated once a week following data updates to the main frame computer in headquarters. Total site project controls staffing for scheduling, cost, and reporting organizations totaled about 50 to 60 personnel with most functions/reports being prepared manually.

With all of today's automation, the site project controls organization for new nuclear and other mega-projects averages over 100 personnel. Given the amount of detailed information in automated files, data maintenance has grown to be a significant effort. An overlooked consequence is that data maintenance is primarily dealing with accounting for the past and what has occurred, rather than with forward looking planning and integration to support efficient progress next steps.

Exhibit 3.14, Evolution of Project Management Systems and Automation



As captioned at the bottom of **Exhibit 3.14**, history shows that project management leadership and stakeholders need to beware of bits and bytes (B^3). They must be cautious to prevent increased levels of management system detail and automation from decreasing stakeholder ownership and accountability as a result of too much data hiding pertinent decision-making information. Lessons learned show you must keep a focus on basic blocking and tackling project management processes and not become enamored by the glitter of fancy and voluminous reports. History repeatedly shows us the wisdom of applying the lessons of KISS… keep it short and simple or keep it simple stupid.

This KISS perspective is stated many ways by numerous historical experts. New-nuclear stakeholders need to be mindful of the wisdom in these messages:

- W. Edwards Deming: Father of Total Quality Management
  - Just because you can measure everything doesn't mean you should
- Albert Einstein: Scientist
  - Everything should be made as simple as possible
- Benjamin Franklin: Founding Father
  - Time Is Money
- Leonardo Di Vinci: Artist and Inventor
  - Simplicity is the ultimate sophistication
- Kelly Johnson: Lockheed "Skunk Works" Manager for U-2, SR 71 Blackbird, & other aircraft
  - Design jet aircraft simply so they can be maintained by an average mechanic

Historical experience underscores the value of a fully integrated schedule and disciplined owner oversight. The St. Lucie Unit 2 project demonstrated that a comprehensive master schedule—linking engineering, procurement, construction, and startup—supported by early system turnover and rigorous change control, can deliver a nuclear unit within a defined 74-month construction window from first nuclear concrete to commercial operation. These same principles form the foundation of today's digital integration tools, where 4D scheduling, BIM, and model-based project controls further strengthen integration across design, supply chain, and operations.

Project early warning systems represent another class of digital tools that enable early detection of deviations from planned performance. Early identification of emerging issues is critical to minimizing the magnitude of their impact and reducing overall project risk. Project developers can identify and anticipate potential issues across a range of scenarios and develop mitigation strategies accordingly. This capability can be enhanced by tools such as artificial intelligence, digital twins, and 4D construction technologies allowing potential downstream impacts (direct and interdependent) to be quickly identified, quantified, and mitigated. However, these tools are effective only when the design is sufficiently mature and interdependencies among construction activities are fully understood.

In summary, digital tools and integrated project management systems can provide measurable benefits to projects by enhancing adaptability and responsiveness during project execution. Project management systems should be designed for simplicity and usability to ensure effective use. Stakeholders must maintain a careful balance between functionality and manageable complexity.

Lessons Learned: 3.3.1 Integrated Project Schedule, Owner Control, and Simplified Reporting Systems

- **A project management office (PMO) should be established with collocated members from the integrated project team (IPT).**
  - **A project management operation center should be established where updated real time information regarding the overall status of the project is always available.**
  - **The PMO project management operations center should be maintained by a dedicated owner-controlled staff.**
- **A key element for a FOAK NNP project is the integrated project schedule (IPS).**
- **The IPS is the basis for executing and managing all project activities of the owner, EPC contractor, and OEM suppliers in an open transparent manner to provide visible stakeholder accountability.**
- **In simple terms, data has overwhelmed most NNP projects.**
- **The onset of new improved systems to generate reams of data is beneficial and detrimental at the same time.**
- **The benefit is the ability to track millions of bits of data.**
- **The detrimental part is that much of the data is non-essential and the additional resources are burdensome and costly.**
- **Most of the data is historical and of little benefit for forward looking decision making.**
  - **Past performance is not necessarily indicative of future progress.**
- **The digital computer era allows complexity to flourish (B^3).**
- **Stakeholders must be cautious and maintain a balance with complexity and simplicity.**

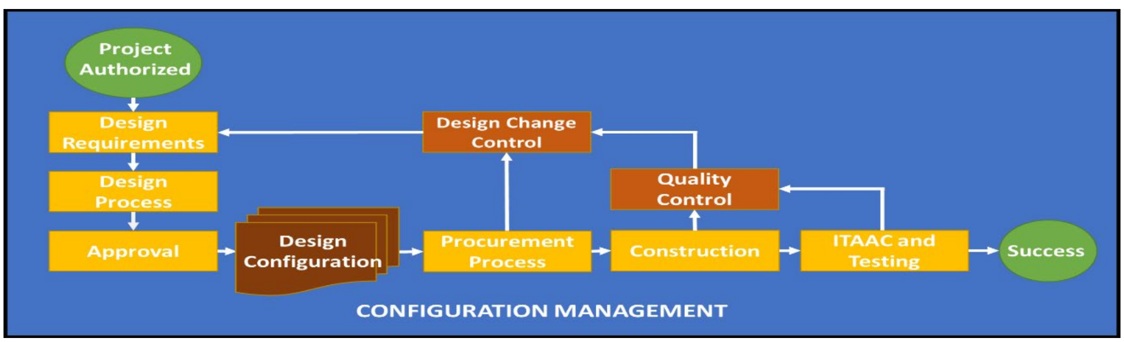
How to implement the best practices and lessons learned described in Section 3.3.1 is provided in IG 05.

3.3.2 Rigorous Configuration Management and Design Change Control

It is inevitable that there will be differences in the as-executed construction process and the intended design. Configuration management and design change control are the processes used to resolve the discrepancies and to document the as-built configuration of the plant. The ability to maintain an accurate record of what was constructed relative to what was committed to the licensing documentation is a key element in successfully completing a nuclear project. Failure to do this has resulted in the inability to receive permission to operate the plant upon completion.

Configuration management design processes assure that no deviations from the approved design are accepted in the as-built condition of the construction project. **Exhibit 3.15** shows diagrammatically the major features of a nuclear design project under 10 CFR 52. The process on the left of the Exhibit shows the steps from project authorization through approval by the NRC. Once approved, the design configuration contains the attributes necessary to demonstrate that the constructed plant meets the approved design requirements. Configuration management uses basic tools. First, design change control is the process that accepts, modifies, or rejects any deviation from the design configuration that occurs during procurement or construction phases. It also reviews and processes the deviation reports and noncompliance reports generated by the quality control process. The design change control process compares the change against the design requirements and the design process the results and changes, if necessary, the change will also be approved by the regulator. For this reason, a central configuration management design authority is essential to monitor the performance of procurement and construction activities to ensure no unexamined deviations are permitted.

Exhibit 3.15, Configuration Management and Design Change Control in the Project



Accurate configuration management is essential and mandated by regulatory requirements to receive approval for operation. The case of the Zimmer nuclear plant described in NRC NUREG-1055 (Reference 4 and **Exhibit 3.15**) is an extreme example of what can occur if configuration management and design change control fail. Although the Zimmer nuclear plant was completed, the record-keeping to prove that the as built design met the design requirements was lacking. The chaotic construction process coupled with insufficient design change control and configuration management led to the ultimate failure of the project. The Zimmer power plant today is a coal plant with an abandoned nuclear reactor (construction completed but not approved for operation) on site.

At the time of construction, the NRC has approved the design for operation subject to final inspection of the construction work. These inspections are performed under the formalized process identified in regulations as Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC) for projects using Part 52. As defined in 10 CFR 52.97(b), the ITAAC are identified in the combined license and are necessary and sufficient, when successfully completed by the licensee, to provide reasonable assurance that the facility has been constructed and will operate in conformity with the combined license, the provisions of the Atomic Energy Act, as amended, and the Commission's rules and regulations. This process can only be successfully completed if the ITAAC are properly developed and if the configuration management of the construction process has resulted in a finished product that conforms to design requirements.

Regardless of the regulatory process used (10 CFR 50 or 10 CFR 52), configuration management is an essential and rigorous element of the project management systems. The quality control and quality assurance programs work together with the configuration management system to achieve an operable nuclear plant. Quality is the conformance with the requirements. Configuration management is the processes necessary to identify and resolve any non-conforming condition and accurately documenting the as-built condition of the plant.

Some design changes are the result of incomplete design, or realities in the field that were not anticipated, and can be mitigated by having a more mature design prior to beginning construction, more detailed construction plans or developing mockups to test high risk evolutions before they become critical path. However, there are also voluntary design changes based on a pursuit to improve the performance of the design or reduce the cost or schedule of the project. Although well intentioned, these voluntary design changes can often have the opposite effect, and result in unanticipated delays in the schedule, sometimes by producing unexpected cascading effects on the project.

Lessons Learned: 3.3.2 Rigorous Configuration Management and Design Change Control

- **Configuration management and design change control are the processes used to resolve discrepancies and to document the as-built configuration of the plant.**
- **A central configuration management design authority is essential to monitor the performance of procurement and construction activities to ensure no unexamined deviations are permitted.**
- **Accurate configuration management is essential and mandated by regulatory requirements to receive approval for operation.**
- **The 10 CFR 52 combined license approval process requires a rigorous ITAAC (Inspections, Test, Analyses, and Acceptance Criteria) plan. If 10 CFR 50 makes more sense for a project, a vigorous Regulatory Outreach Program is required to inform the NRC staff.**

How to implement the best practices and lessons learned described in Section 3.3.2 is provided in IG 05.

3.3.3 Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue

The overall scope of technology, labor, equipment, and material associated with large light water reactor (LLWR) NNP projects is enormous. Plant arrangements and redundant engineered safety systems result in significant bulk quantities and congested workspaces that create limits on the pace of construction installation that drive schedule duration and overall costs. These LLWR NNP projects have typically adopted various combinations of overtime, extended work weeks, and multiple shifts with the goal to reduce schedule durations and related costs. Additionally, off-site system/component modularization techniques have evolved to reduce schedule duration and costs by conducting off-site manufacturing and factory assembly of mechanical/electrical assemblies/modules integrated with on-site structural construction installation activities.

SMR technology offerings are based on various reactor cooling and steam generation design concepts. These are aimed at reducing the size and quantities of systems and components and increasing what scopes can be factory manufactured and shipped to the site rather than stick-built at the site. Many designs include passive safety concepts to additionally reduce construction quantities. While SMRs and microreactors are smaller in capacity to LLWRs, the designs face similar challenges and must have a plan to address the best practices and lessons learned herein. For instance, labor congestion issues and schedule efficiencies for SMR and microreactor NNP construction remain as critical to achieve required economic capital cost performance expectations.

Developing the work week, hours per day, and shift basis approach for an NNP project schedule is a challenging task. There is no one size fits all approach that will provide an optimum solution. History shows that intensive planning and evaluation of many past practices is required to develop a realistic plan and approach that addresses local labor pool, travel times, competing projects, fatigue, work continuity, and other factors. The primary need for utilizing a combination of overtime, extended work weeks, and multiple shifts in the past has been to improve cost/schedule labor efficiency and reduce schedule durations and related costs. This need remains a significant reality for future NNP projects. Additionally, many NNP projects have evaluated and concluded that offering 50-hour work weeks was necessary to compete with other construction projects (power and industrial) and to attract the necessary numbers of qualified construction workers.

NNP projects will involve organized union labor and open shop labor pools, and these facts must be recognized. Regardless of the labor pool, history has shown that work continuity and labor fatigue resulting from extended work weeks and 2nd shift work cause major productivity losses. As discussed earlier, spending more hours per person over a prolonged time period creates a point of diminishing returns where the additional hours do not contribute to more production due to fatigue. This has been studied and documented many times over the past.

Using a 1st and 2nd shift approach with each shift working 5/10s for a 50-hour work week may define a mathematical basis for achieving a 25% schedule reduction by working 25% more hours in any given work period. However, the productivity losses, fatigue factors, absenteeism, and work management continuity impacts using this approach are significant. A search of public domain information was performed regarding the productivity impacts of overtime/extended work week and second shift work. Industry guidance and White Papers generally view that a combined extended work week and second shift program should be used sparingly to implement critical path corrective action or alleviate congestion. References 24 and 43-47 contain relevant material and insights.

<u>Productivity Loss Due to Overtime/50 Hour Extended Work Week</u> – Reference 24 is a very comprehensive study and provides information from various industry leadership sources including the US Bureau of Labor Statistics (BLS), Construction Industry Institute (CII), US Army Corps of Engineers (COE), The Business Roundtable, AFL/CIO building and construction trades, American Society of Civil Engineers (ASCE), Mechanical Contractors Association, National Electrical Contractors Association (NECA), and other sources. *These suggest a productivity loss of about 30% will be experienced when working more than 40 hours/week using a single shift of 5 workdays at 10 hours per day and 50 hours/week for an extended period of 12 weeks or more. A craft labor productivity loss of 25% to 30% is likely for the 5/10s 50-hour work week approach.*

Productivity Loss Resulting from Extended Shift Work – 2nd Shift Continuity Inefficiencies (Reference 44) is a study of 2nd Shift Work Impact on Construction Labor Productivity published in 2005 in the ASCE Journal. ***It suggests an approximate 13% productivity loss due to shift work for a project performing 20% to 30% of the work on a second shift.*** Experience indicates a 15% impact due to the 2nd shift effort is likely. This was also the 2nd shift impact value used by the AFL/CIO and major EPC contractors in 1979 as part of their study for developing the Nuclear Power Construction Stabilization Agreement (NPCSA) and Alternating 4/10s shift work approach instead of the 5/10s approach.

Labor Efficiency/Shift Work Lessons and Practice Conclusions - These prolonged 5/10s and 50 hour work week fatigue factors coupled with 1st/2nd shift continuity work penalties or negative “Lessons Learned” from nuclear industry experience last century united the AFL/CIO Building and Construction Trades Department, Bechtel, Ebasco, Stone & Webster, and United Engineers to adopt the Alternating 4/10s Shift Work Approach and Nuclear Power Construction Stabilization Agreement (NPCSA) in the early 1980s (Reference 1). This approach was evaluated as a better work week and shift schedule approach to mitigate these productivity/fatigue/continuity losses and accelerate schedules with higher confidence and reduced risks.

Lessons Learned: 3.3.3 Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue

- **NNP arrangements and redundant engineered safety systems result in significant bulk quantities and congested workspaces that create limits on the pace of construction installation that drive schedule duration and overall costs.**
- **As all deployments of SMR and microreactor designs have FOAK risks and may have construction quantity and congestion issues, the labor and schedule efficiencies for NNP construction are as critical as with LLWR designs to achieve required economic capital cost performance expectations.**
- **The primary need for utilizing a combination of overtime, extended work weeks, and multiple shifts in the past has been to improve cost/schedule labor efficiency and reduce schedule durations and related costs.**
- **Numerous comprehensive industry studies indicate a productivity loss of about 30% will be experienced when working more than 40 hours/week using a single shift of 5 workdays at 10 hours per day and 50 hours/week for an extended period of 12 weeks or more.**
- **The Nuclear Power Construction Stabilization Agreement (NPCSA) from the late 1970s (Reference 1) evaluated the Alternating 4/10s Shift Work Approach as a better work week and shift schedule approach to mitigate these productivity/fatigue/continuity losses and accelerate schedules with higher confidence and reduced risks.**
- **Both 10 CFR 50 and 10 CFR 52 are available to the owner for NNP implementation. The Owner must review the pros and cons of each and apply the appropriate one for their project plan.**

How to implement the best practices and lessons learned described in Section 3.3.3 is provided in IG 04.

3.3.4 Modularization Potential Benefits and Drawbacks

History shows that modularization and sub-assembly of systems and components can achieve cost and schedule reductions, whether performed on-site (but outside final installations locations) or at an off-site assembly facility. Coupling reduced labor congestion to achieve better labor productivity with working construction activities in parallel enables such cost and schedule reductions. Sub-assembly techniques coupled with stick-built and over the top construction practices can result in equal or more improved cost and schedule performance compared to modularization - modularization is not always the best solution. There are benefits and drawbacks that need to be carefully considered for each project.

- Modularization should avoid changes to the licensing basis.
- Modularization is a site-specific approach based on the transport and logistics study.
- Modularization can apply to any aspect of the design (e.g., nuclear island, turbine island, balance of plant).
- Modularization opportunity drives detailed design.
- Experienced EPCs should prepare the modular execution plan after analyzing the transport and logistics study.
- The main benefit from properly implemented modularization is schedule certainty in the field. With field schedule certainty comes cost certainty.
- Additional benefits from off-site modularization include lower peak on-site craft so lower field costs (per diem, transport, housing, temporary construction facilities); less site congestion so improved safety; higher worker productivity and safety in the controlled fabrication yard environment.

Modularization benefits for construction cost and schedule efficiency require complete, released for construction, detailed design maturity. For a FOAK NNP, this demands significant early design, procurement, and manufacturing integration along with early spending to ensure that modularization is done right the first time. Gaining the cost and schedule efficiencies from a construction modularization approach has been proven with NNP projects in Japan, South Korea, France, and other markets where Nth of a kind replication and standardization have been achieved. When deploying multiple units at the same site, modules are usually already ordered and fabricated before any learnings from the first unit can be incorporated into the design (additional details on the incorporation of learnings can be found in Reference 48).

As a practical matter, modules may or may not be the optimal solution for a project. While modules will require additional materials and setup to ship to site (as the module has to be lifted, transported, and received at site), the use of modules may or may not make the project overall use more materials and set-up (or cost more) as existing labor and fabrication yard infrastructure must be considered. Some other factors include: site location and accessibility, site labor productivity and availability, site weather considerations, material sourcing options and tariff implications, available module assembly locations, module yard wage rate compared to site, module yard productivity, etc.

All nuclear deployments are a combination of modules and stick construction activities at the site – even heavily modularized designs. No matter the level of optimized modularization, projects must use proven designers, fabricators and heavy haul vendors to ensure the modularization effort is properly executed.

SMR technology offerings are based on various reactor cooling and steam generation design concepts aimed at reducing the size and quantities of systems and components, with many designs including passive safety concepts to additionally reduce construction quantities. While smaller in capacity compared to LLWR designs, some smaller capacity SMR nuclear steam supply systems still involve components approaching the dimensions and sizes of LLWR system components. As all initial deployments of SMR and microreactor designs have FOAK risk and may have significant construction quantity and congestion issues, the labor and schedule efficiencies for NNP construction are as critical to achieve required economic capital cost performance expectations. SMR and microreactor modularization cost and schedule benefit expectations must recognize that the FOAK status and relative immaturity of the technology design concepts involved will limit initial economic benefits.

<u>Lessons Learned</u>: 3.3.4 Modularization Potential Benefits and Drawbacks

- **Gaining the cost and schedule efficiencies from a construction modularization approach have been proven with NNP projects in Japan, South Korea, France, and other markets where Nth of a kind replication and rigid standardization have been achieved.**
- **Sub-assembly techniques coupled with stick-built and over the top construction practices can result in equal or more improved cost and schedule performance compared to modularization.**
- **Benefits for construction cost and schedule efficiency using modularization techniques require complete detailed released for construction detailed design maturity.**
- **SMR and microreactor modularization cost and schedule benefit expectations should be adjusted to recognize that the FOAK status and relative immaturity of the technology design concepts involved will limit initial economic benefits.**

How to implement the best practices and lessons learned described in Section 3.3.4 is provided in IG 04.

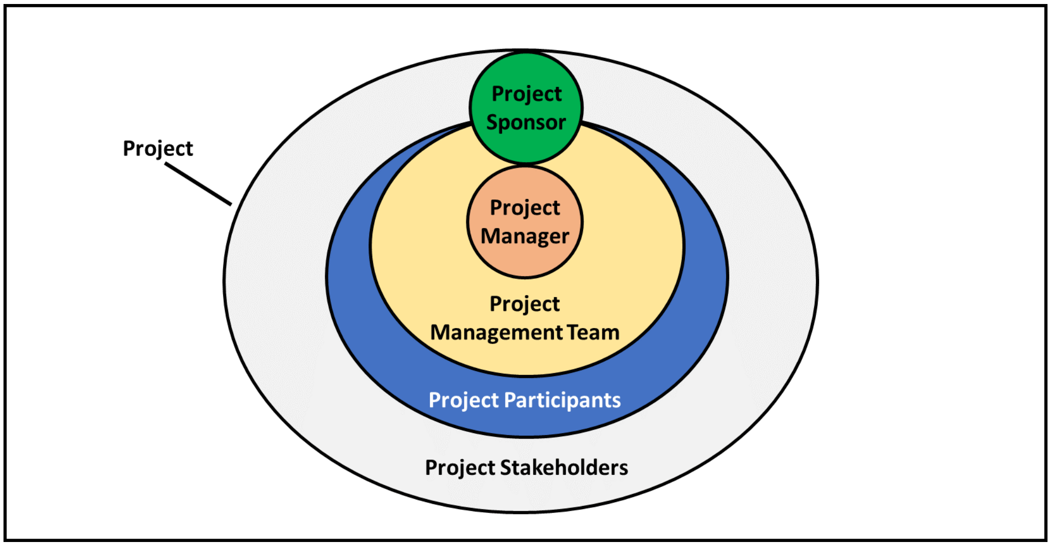
3.3.5 Managing Project Internal and External Stakeholders

The full-time responsibility of the Project Manager is to manage the relationship and the expectations of the project stakeholders. As previously noted, a “stakeholder” is any person or group that may be positively or negatively impacted by an NNP project.

Stakeholders may be inside or outside the project organization. **Exhibit 3.16** (Reference 62) shows diagrammatically the stakeholders associated with the project. They include the:

1. Sponsoring organization(s)
2. Active project team members
3. Nuclear Regulatory Commission
4. Utility regulatory agencies (FERC, PUC, etc.)
5. The public
6. General Public (customers)

Exhibit 3.16, Relationship of Project Stakeholders to Project Team



The reactor construction program in the 1970s and 1980s was hampered by external stakeholders including people and organizations who were affected by the construction and/or the operation of the nuclear plant. The NRC regulatory process is very open to input from external stakeholders. This is a requirement of their public mission to assure the safety of the environment and the population surrounding nuclear facilities. This process was abused by the political opponents of nuclear energy and the vulnerability of the 10 CFR 50 licensing process in the past. That vulnerability can be exploited by raising endless objections to the safety of nuclear power while the owner/operator is exposed to carrying charges on the debt incurred during the construction process and was an important consideration in the development of the single stage 10 CFR 52 licensing process. Regardless of which licensing pathway is being utilized by the project, in order to successfully complete a nuclear design and construction project the project team needs an active Stakeholder Management Program to address all stakeholder concerns.

Stakeholder management is a key component to the successful delivery of any project. Its importance is amplified in the case of nuclear power. Stakeholder management consists of four steps:

- Identify stakeholders
- Prioritize stakeholders
- Establish communication management plan
- Proactively engage stakeholders

Effective stakeholder management is a shared responsibility led by the project manager and supported by the entire project leadership team. Stakeholders include both individuals and organizations, some of whom are formally engaged through contractual or regulatory mechanisms, while others exert external influence on the project’s environment or outcomes. Traditional communication plans often emphasize internal roles, responsibilities, and authorities, but effective stakeholder management requires extending these plans to include structured engagement with external parties. The project organization must identify, analyze, and prioritize stakeholders based on their level of influence and interest, and establish tailored communication and engagement strategies to maintain alignment, transparency, and trust throughout the project lifecycle.

The NRC will act as the formal review and comment agency for intervener stakeholder communication. However, active community outreach and stakeholder engagement must seek to minimize the NRC's formal interaction with external stakeholders.

The acceptability of nuclear power today is far greater than it was last century. In the past the unknowns of nuclear power added anxiety to a wide range of external stakeholders. In the intervening period of 40-years of safe and reliable nuclear plant operation in the U.S., much of the concern has faded away. To be sure, there are still people and organizations who oppose nuclear power under any circumstances, but today, more concern is focused on air pollution and greenhouse gas emissions than on the impact of nuclear power.

The greatest focus and effort must be placed on stakeholders who directly influence the success of the project. Stakeholder issues must be identified, addressed and dealt with promptly. Issues that are ignored can rapidly develop into major threats to the project. Communication with stakeholders needs to be interactive. The project manager needs to listen and understand stakeholder concerns and issues. Some issues are real and deal with project performance, but others will be emotional and/or based on misconceptions. In this case, the project manager must be patient, humble, compassionate, open, and honest with fact-based responses that respect the audience's emotions in order to gain the trust and acceptance of the stakeholders.

In cases in which the stakeholder concerns are global rather than specific (i.e., opposition to nuclear power under any circumstance), legal remedies are available as a last resort to save the project. An example of this is in the Seabrook reactor experience. At the height of the antinuclear movement an antinuclear group known as the Clamshell Alliance rose up in opposition to the construction of the Seabrook reactors. Reasonable and interactive approaches were tried to no avail while the Clamshell Alliance intervened in the NRC outreach program with repetitive, unresolvable issues. In the end the utility sued each individual member of the Clamshell Alliance for obstruction. When the economic realities of their opposition became clear, the Clamshell Alliance dissolved and Seabrook unit one went into operation.

It is uncertain whether such opposition will rise against new nuclear power projects in the future. The nuclear industry's safety and performance record over the past 40 years has been exemplary, and without NNP projects in the news the issue has receded from its dominance in the public arena. This is especially true in areas around existing nuclear power plants where support for nuclear energy is the strongest. The benefits to the local population from nuclear power plants are well understood by local residents. In fact, new nuclear plant projects proposed in the 2000s routinely had more supporters in the public meetings than opponents. Careful stakeholder management programs can effectively enhance the situation and reduce one of the major risk factors in deploying new nuclear projects. However, a prudent project manager prepares a contingency plan against more aggressive intervener stakeholders.

New design technologies will have new perceived risks. SMRs, microreactors, and non-light water technologies may stimulate new concerns from those in the 1970s and 1980s. The NNP leaders must be prepared to discuss the attributes and benefits of the technology planned for their NNP project. Early community and stakeholder engagement remains a key component of successful project deployment.

Lessons Learned: 3.3.5 Managing Project Internal and External Stakeholders

- **Project leadership must focus on any individual or group that may affect or be affected by a decision, activity, or outcome of the project.**
- **The NRC approval process for NNP projects is very open allowing for any individual stakeholder to exercise the safety and environmental mission of the regulators.**
- **To successfully complete a nuclear design and construction project the project leadership team needs an active Stakeholder Management Program to address all stakeholder concerns.**
- **A rigorous stakeholder management plan contains four key components including (1) Identify stakeholders, (2) Prioritize stakeholders, (3) Establish a communication management plan, and (4) Proactively engage stakeholders.**

How to implement the best practices and lessons learned described in Section 3.3.5 is provided in IG 03.

4 CASE STUDIES AND INSIGHTS FROM PAST SUCCESSFUL FOAK PROJECTS

This section contains summary level (3 to 4 page) case studies for 11 completed large FOAK projects spanning commercial nuclear power plant construction, nuclear facility decontamination and decommissioning (D&D), municipal infrastructure, and a government science facility.

1. River Bend Nuclear Power Station Unit 1
2. St. Lucie Nuclear Power Station Unit 2
3. Palo Verde Nuclear Power Station Units 1, 2, and 3
4. Watts Bar Nuclear Power Station Unit 2
5. Rocky Flats D&D Project
6. Selected Steam Generator Replacement & Refurbishment Projects
7. Spallation Neutron Source (SNS) Accelerator Project
8. 2012 London Olympics Site and Facilities Infrastructure
9. WPPSS 2 Washington Public Power Supply System Nuclear Unit 2
10. Barakah Nuclear Energy Plant
11. Muskrat Falls Generating Station

These large FOAK projects spanned a period of nearly 40 years from the early 1980s to the present. They all dealt with similar challenges involving enormous scope, new technologies, complicated interfaces, changing regulatory requirements, and numerous project stakeholder organizations. **Exhibit 1.3** summarizes the top fifteen keys to success that span all eleven case study projects.

It must be recognized that this summary of the top fifteen (15) keys to success and things that went well that span all eleven case study projects presented on **Exhibit 1.3** were not designed to exactly match the fourteen (14) subsections in **Section 3** that discuss lessons learned and best practices. The authors of these case studies merely summarized their experience and recollection of the positive elements that made a difference and resulted in success. Compiling the common big picture attributes resulted in the 15 top items identified.

The top two common factors that led to success (that facilitated overall positive performance in all areas on these past projects) involved an owner-led integrated project team approach (reinforced with experienced, passionate leadership) and extreme ownership by top management stakeholders. Analysis shows that these created the foundation for the other top keys to success shown in **Exhibit 1.3** that align well with (albeit not exactly) and reinforce:

- The best 59 practices discussed summarized in **Exhibit 1.2,**
- The fourteen categories of lessons learned and best practices identified and discussed in **Section 3**, and
- The summary of 89 lessons learned outlined in **Appendix A.**

It is important to recognize that as outlined in **Section 2.1**, current industry resources with large and/or FOAK NNP project experience is limited and less robust than it was last century when the U.S. constructed 129 NNP projects. It is unlikely that any single organization can muster an “A-Team” of leaders and managers with all the needed experience and qualifications for FOAK NNP projects. History recommends the strategic practice of adopting a “Best Athlete for the Job” strategy when planning and shaping the organization for a FOAK NNP project.

Under the leadership of the utility owner using a Project Management Organization (PMO) approach, it does not matter what project positions are filled by what project organization (i.e., the utility, EPC, or OEM stakeholders). A successful NNP integrated project team needs the most qualified candidate and best athlete for the position. Additionally, all project leadership and management positions demand an owner/project centric attitude that places project success priorities in alignment with parent company priorities and expectations. Participating organizations will need the authority to manage risks for their assigned scope. A process will be needed to resolve situations where the mitigation of an organization’s scope risk would not result in the overall project success. The risk mitigation process should ensure that project success will result in individual and corporate stakeholder success.

Additionally, history shows that establishing an integrated organization that facilitates teamwork and open communications across multi-corporate and stakeholder cultures is easier said than done. External experts in industrial psychology must be engaged to conduct project team building and training, and to perform independent assessments of the personalities, strengths, and weaknesses of project team members. Continuous attention to the psychology and health of a large project organization is a key lesson learned when not done and a best practice when done well as it is critical for success.

4.1 River Bend Nuclear Power Station Unit 1

4.1.1 Background

On August 29, 1985, the Nuclear Regulatory Commission (NRC) issued Gulf States Utilities Company (GSU) a license to load fuel at its River Bend Station (RBS) Unit-1. Construction of this 940-megawatt nuclear power generating facility was accomplished in 72 months/6 years, measured from the start of reactor mat reinforcing steel placement to loading of nuclear fuel in the reactor vessel. This represents a notable success in an industry where similar projects in the 1980s were requiring 120 months/10 years and longer to complete.

Many project management factors contributed to developing construction momentum and achieving an on-time and accelerated schedule duration at River Bend. As is often the case, the framework for the positive results achieved at RBS reflected a combination of traditional concepts and unique, innovative approaches. The cornerstones for achieving successful schedule performance included:

- An owner/licensee led integrated management and craft labor organization located at the site designed to aggressively manage risks, promote open communications, and avoid surprises
- A contracting strategy and site organization that recognized the status of design maturity and emerging changes to implement NRC requirements following the March 1979 TMI accident
    - An integrated schedule incentive milestone framework designed to foster teamwork, cooperation and schedule focus across owner, contractor, and craft stakeholders
- A management and information control system designed to achieve accountability at all levels of stakeholders with a focus on keeping progress goals and reporting information clear and simple

RBS is located on the Mississippi River near St. Francisville, Louisiana approximately 24 miles northwest of Baton Rouge. The plant is a 940-MW boiling water reactor (BWR 6 model) supplied by the General Electric Company (GE). Gulf States Utilities was the primary owner and licensee/operator of the plant, with Cajun Electric Power Cooperative of Louisiana owning 30 percent. RBS is currently owned and operated by Entergy. Stone & Webster Engineering Corporation (SWEC) was the engineer-constructor for the plant. Construction management and the majority of construction was performed by SWEC, with 13 percent of the work being subcontracted.

4.1.2 Lessons to Learn

Project Management Leadership and Integrated Project Team Approach – Large and complex projects can easily evolve into unwieldy administrative organizations where responsibilities become shared or unclear. GSU and SWEC corporate and project leadership were committed to an integrated team approach. This included the GE NSSS supplier and the AFL-CIO labor organization management team. Key stakeholder managers from these organizations were co-located at the site to assure management expectations were clear, and that open communications and teamwork flourished. Bill Cahill was the GSU Senior Vice President and Project Director. Bill is remembered for his vision:

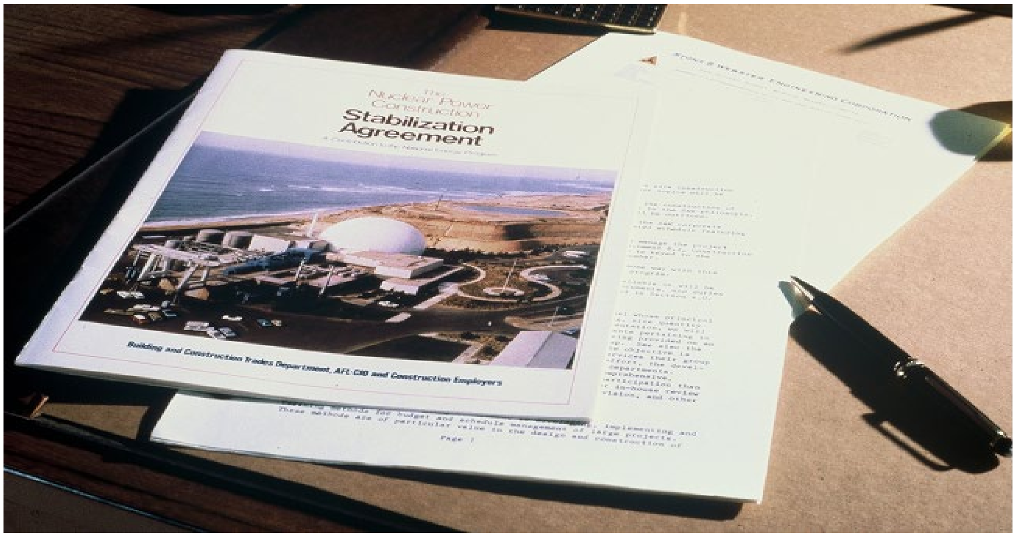
> *"River Bend is a sink-or-swim-together organization… I don't want my utility owner and contractor stakeholders to be blaming each other. There are no win-lose outcomes for me, only win-win. I expect our stakeholders to work together to communicate well, avoid surprises, and mitigate problems. With quality and safety being absolute, working together for schedule adherence will assure that cost performance follows the plan. Like our founding father Ben Franklin said, time is money."*

RBS and all U.S. new nuclear projects at the time had to deal with many design changes to implement NRC requirements following the March 1979 TMI accident. RBS implemented an on-site integrated engineering group comprised of SWEC, GSU, and GE stakeholders from home office and the field. This site engineering group worked the alternating 4/10s shift schedule to provide support to construction crafts 7 days a week. It had the authority to coordinate with the NRC and develop design details required for construction work packages needed to support the schedule, making a big difference in RBS overall schedule performance.

Many U.S. nuclear projects in the 1970s and 1980s were plagued with costly work stoppages and schedule delays due to management-labor issues. A nation-wide partnership of the U.S. Department of

Labor, power utility owners, the unions affiliated with the Building and Construction Trades Department of the AFL-CIO, and a group of four constructors (including SWEC) worked together in 1977/1978 to think outside the nuclear industry box. They established a policy framework for planning and executing large commercial nuclear projects to accomplish a lower risk approach to project execution. As a result, the Nuclear Power Construction Stabilization Agreement (NPCSA) and Alternating 4/10s Shift Work approach were developed, and the NPCSA was executed in April 1978. See **Exhibit 4.1.**

Exhibit 4.1, Nuclear Power Construction Stabilization Agreement (NPCSA) signed in 1978



This agreement documented the vision and best practice for efficient labor resource utilization

The NPCSA and the alternating 4-10s shift work labor plan provided the innovative ingredients to the overall RPS integrated team and project management approach. GSU was the first utility owner to implement this national agreement. It provided for improved labor-management teamwork and harmony through uniform work rules for all crafts that prohibited strikes or lock outs. It also outlined the innovative Alternating 4/10s Shift Work approach where two alternating labor crews each worked four ten-hour shifts followed by 4 days off. This resulted in the following key schedule and risk enhancements:

- 40% more workdays, i.e. 360 vs. 260 days/year
- Reduced overall schedule, i.e. about 25% to 35% shorter
- Reduced overall cost, i.e. about 15% to 25% less
- Reduced craft manpower peaks, i.e. about 25% to 35% lower
- Reduced craft congestion & improved labor productivity
- Avoided fatigue and productivity loss of sustained 50-hour work weeks
- Reduced craft absenteeism of 3% to 4% compared to national norm of 8% to10%

For additional information and insights regarding this topic, see Reference 1 outlining parameters of the NPCSA, Reference 21 outlining the Alternating 4/10s shiftwork approach, and References 24 and 43-47 outlining construction productivity impacts due to fatigue from extended work weeks and shift work.

<u>Contracting Strategy and Integrated Schedule Milestone Incentive Framework Designed to Foster Teamwork</u> – GSU and SWEC worked together to create a contracting framework that recognized the need for flexibility to deal with NRC changes stemming from the TMI accident, while assuring all

stakeholders had accountability to perform and deliver their work scopes in a quality manner. Indeed, RBS was a FOAK project. It recognized that fixed price contracts could create conditions adverse to communication, openness, and teamwork goals, and that project teamwork was inversely proportional to the thickness of contract terms and conditions. The parties wanted to facilitate a project focus on management and production rather than contracts and legal jousting.

In addition to defining contractual target cost terms, GSU and SWEC recognized that schedule performance was by far the biggest driver of cost performance. A set of 100 contract construction schedule incentive/penalty milestones were developed with three or four milestones and dates defined in each of the 24 quarters that made up the 72-month schedule. Nearly $200 million in incentive fees (at the time almost 10% of the total estimated project cost) were established to create win-win solutions and to rally project resources around near term and meaningful goals. Fee parameters included distribution to corporate entities and to professional and construction craft personnel. Teamwork and focus on schedule goals was truly galvanized as part of a proud project culture to accomplish work on schedule.

Dave Barry, retired president of Shaw Nuclear, was the RBS site vice president and manager of the site engineering group for SWEC. He shared the following thoughts and insights:

> "*Clear project goals and management leadership are crucial for a large and complicated nuclear project with millions of design and construction interfaces. Planning and managing activities with a leader in charge of all the pieces makes all the difference. The milestone schedule incentives established clear and unifying goals that transcended corporate and group cultures and individual personalities, to create a unique and very successful level of integration and cooperation."*

<u>Clear and Simple Management Planning and Reporting information</u> – Large nuclear projects like RBS need powerful automation systems and tools to address the thousands of activities and details required to plan, schedule, report, and manage activities spanning ten years and millions of construction pieces and parts. However, it must be recognized that the average worker is not concerned with nor capable of digesting activities that are two to three years or more away… that is the job of management. Engineers and construction stakeholders just want to know what is expected of them this week and this month.

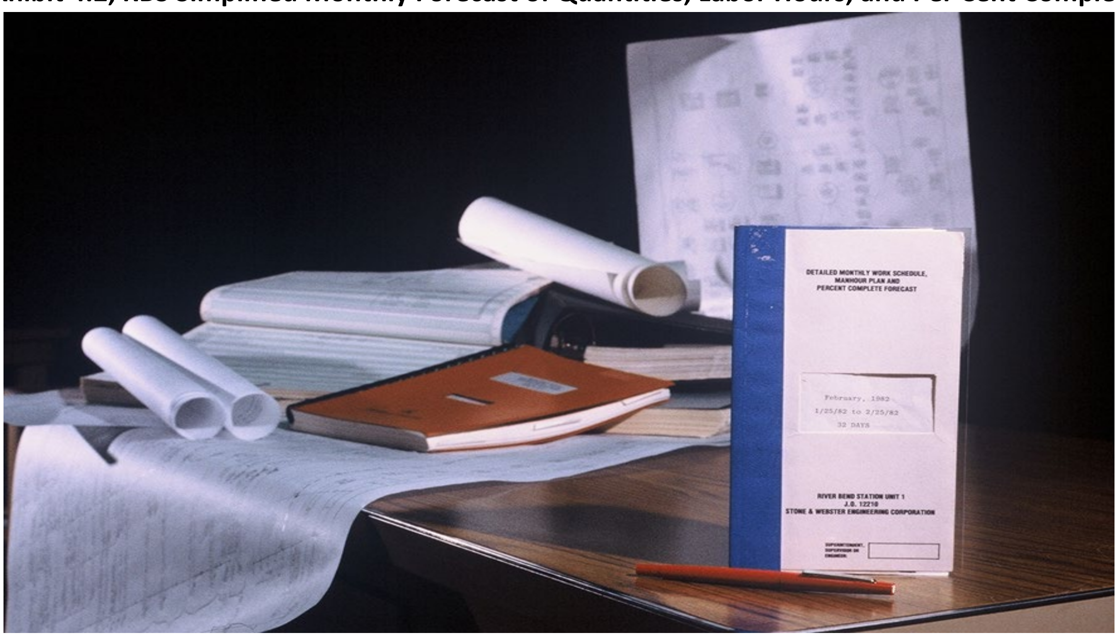
A key objective of the RBS project control, cost, and scheduling system was to simplify and reduce the number of information sources that engineers and craft supervisors had to be familiar with to understand the specific quantity and per cent complete goals they must achieve in the near-term. The planning engineer assigned to a specific building or discipline in the organization acted as the filtering and funneling mechanism to achieve this goal. This single source approach helped to assure that the alternating shifts were working towards the same goals by increasing the likelihood that common viewpoints would be established using a reduced number of well-designed reports. Overall clarity, consistency, and timeliness were most important in providing an effective planning and control system with accountability and corrective action at all levels.

RBS success in this area was the result of measures taken by management to prevent the volume of paperwork required to status the job from clouding individual accountability and confusing near-term weekly/daily work priorities. Supervisors responsible for daily work execution were not expected to digest inordinate amounts of data. All work for the week/month was scheduled to condense and clarify the planned work accomplishments expected from each supervisor and crew. A monthly 90-day detailed look ahead process was used to validate availability of design details released for construction along with equipment and labor resources needed to support progress plans for the next month. A relatively condensed Monthly Forecast planning package of information was produced identifying quantity and per cent complete goals for each commodity group along with craft hours by building or system.

Planning and directing the activities of 3,000 crafts and 2,000 professional and administrative staff is a challenge for any mega-project. This was more so at RBS with the alternating A and B work shifts and production ongoing 7 days a week and 360 days a year. We had to develop an approach that made work goals clear and simple. The Monthly Forecast of quantities, hours, and per cent complete was a routine that really helped facilitate understanding, cooperation, and success… it was our planning Bible.
Ken Aupperle, RBS on-site Superintendent of Cost and Scheduling

For additional information and insights on this topic, see Reference 4 describing the construction management, planning and scheduling approach used at RBS. Also, see **Exhibit 4.2** of the RBS Simplified Monthly Forecast and Work Plan.

Exhibit 4.2, RBS Simplified Monthly Forecast of Quantities, Labor Hours, and Per Cent Complete



This monthly forecast was a best practice that supported the RBS accelerated schedule

River Bend 1 - Summary of Keys to Success and What Went Well

- **An owner/licensee led integrated management and craft labor organization located at the site designed to aggressively manage risks, promote open communications, and avoid surprises.**
  - **This included the GE NSSS supplier and the AFL-CIO labor organization management team. Key stakeholder managers from these organizations were co-located at the site to assure management expectations were clear and that communications flourished.**
- **Thinking outside the nuclear industry box and establishing a policy framework for planning and executing this large commercial nuclear project to accomplish a lower risk and significantly reduced schedule duration approach.**
  - **The Nuclear Power Construction Stabilization Agreement (NPCSA) and Alternating 4/10's Shift Work approach were developed and implemented.**
- **A contracting strategy and site organization that recognized the status of design maturity and emerging changes to implement NRC requirements following the March 1979 TMI accident.**
  - **An integrated schedule incentive milestone framework designed to foster teamwork, cooperation and schedule focus across owner, contractor, and craft stakeholders.**
- **A management and information control system designed to achieve accountability at all levels of stakeholders with a focus on keeping progress goals and reporting information simple.**
  - **A key objective of the RBS project control, cost, and scheduling system was to simplify and reduce the number of information sources that engineers and craft supervisors had to be familiar with to understand the specific quantity and percent complete goals they must achieve in the near-term.**

4.2 St. Lucie Nuclear Power Station Unit 2

4.2.1 Background

The Florida Power and Light (FP&L) St. Lucie Nuclear Plant began concurrent construction on two 890 Megawatt electric (MWe) pressurized water reactor Units in 1970 for Unit 1 and 1971 for Unit 2. Each Unit utilized Combustion Engineering Nuclear Steam Supply and Auxiliary systems and Westinghouse Turbine Generators. The information in this case study is substantially drawn from Ebasco (L. Tsakiris) and FP&L (W.B. Derrickson) presentation given to the nuclear industry at large in 1984 and 1983 respectively.

St. Lucie Unit 1 was steadily completed and started commercial operation in December 1976. Due to lower than estimated electrical demand, construction work was delayed by FP&L on St. Lucie Unit 2 in 1972. However, work on Unit 2 engineering, safety assessment reports, and engineered materials procurements continued with the result that the NRC issued a SER for the PSAR in 1974 and a Limited Work Authorization in 1975. Construction work on Unit 2 resumed briefly in June 1976 and stopped again in four months. Construction began in earnest in June of 1977 after the NRC issued an unrestricted construction permit. Unit 2 achieved a 74-month time span from start of concrete in 1977 to commercial operation in August of 1982. This was 3.5 years better than the industry average over the same time period. It was also a rare accomplishment in the era spanning the Three Mile Island (TMI) nuclear plant accident.

There were numerous major challenges imposed by circumstances not fully under the control of the Project Team during this remarkably short construction period. Despite those problems, during the course of the project the percentage complete and milestone progress was constantly, on schedule, near schedule, or ahead of schedule and always ahead of industry averages. This project's success and the L. Tsakiris paper had a positive impact on the Japanese Nuclear Program. They took many of these concepts, plus modularization, and showed the world what could be done.

This was accomplished despite issuance of numerous new regulations by the NRC (TMI), a 1979 hurricane which did considerable damage to the Reactor Auxiliary Building, labor problems, and an NRC schedule review that concluded that the best that could be done was to complete the plant more than a year later than scheduled. More specifically:

- Electric load demand on the FP&L systems was stable or increasing at a rate far less than originally predicted by FP&L load studies

- Intervenor hearings, some of which caused construction and regulatory delays

- Hurricane David seriously damaged vital construction equipment as well as the reactor auxiliary building in September 1979 when the site was 26 percent overall construction completed. This resulted in at least a 13-week loss of prior critical path schedule leading to planned startup in 1982.

- The 1979 TMI nuclear accident which resulted in an extremely negative stakeholder environment, great uncertainty, regulatory delays, and eventually numerous proposed mid construction changes in nuclear plant design requirements some of which were mandated for completion prior to start of fuel loading or entry into commercial operation

- There was pressure from numerous sources, on the NRC to require many design changes during the final licensing (FSAR and other) reviews, and on the project team staff from a multitude of internal and external sources to alter the design during the mid to late construction period

- The NRC set a schedule for performing final license reviews based on an internal to NRC projection of fuel loading by December 1983 (13 months after the site schedule to achieve commercial operation) In February 1981, the NRC accepted and docketed the Final Safety Analysis Report (FSAR) and the Environmental Report (ER) late, but much earlier than originally proposed. This however, resulted in an extraordinarily short period for NRC review (9 months), if the site was to meet the fuel loading milestone.

4.2.2 Lessons to Learn

Implementation of a Mutually Beneficial Commercial Contract Strategy – FP&L implemented a Time and Materials Contract when hiring Ebasco as the AE/C for the project team.

Project Owner Leadership and an Integrated Project Team - FP&L implemented an Owner Led team with Ebasco for the construction of both St. Lucie units. FP&L and Ebasco used the best athlete approach (recruiting internal and external to the two organizations) for mutual selection of personnel to fill all key positions in the organization. The Ebasco Site Superintendent for construction reported to the FP&L Site Manager and maintained close liaison with the Ebasco core home office project organization. The Ebasco home office project organization was segregated into its own office spaces. This home office space segregation had numerous benefits in communications, improved interface among disciplines, and enhanced project team goal congruence. It also ensured full time participation from all assigned project personnel. At the construction site, Ebasco and FP&L personnel integrated into one organization. Ebasco's supervisory construction staff was under the overall direction of an FP&L Site Manager. The functions which FP&L intended to influence most directly were under utility supervisors also reporting to the Site Manager. Overall most supervisory and non-manual personnel were Ebasco employees. The ratio of utility to Ebasco was about 30% FP&L and 70% Ebasco. The functions in the day to day construction operations, engineering, and testing were under the direction of Ebasco supervisors but also reported to the Site Manager. Nonetheless, the owner integrated several FP&L people into these groups as well. The ratio of Ebasco to utility in this area was 97% to 3 %.

Project Planning, Estimating, and Scheduling - Earlier US nuclear plants (pre-1972) were achieving close to 30% per year construction completion. By 1975, that completion rate had decreased to a little over 15% per year, and that downward trend continued. St. Lucie 2 was an exception, achieving a 25% per year rate of construction completion in 1980. The key was planning. St. Lucie demonstrated that even with increased regulation, high rates of production could be achieved with very detailed early planning completion. The optimization of the construction effort was a direct result of that early planning and the innovative thinking that went into the overall construction plan and schedule, see **Exhibit 4.3.**

The innovative thinking resulted in the now common construction approach of using a large heavy lift crane throughout construction on site and the "top-off" or "open top" method of construction for containment and other structures.

Between 1976 and 1977 a team of Ebasco and FP&L very experienced construction supervisors (most from the St Lucie Unit 1 construction team) developed what became known as the Project Master Schedule (for start of concrete to fuel load milestone activities). All major milestones were identified and fixed. The schedule was an integrated engineering and construction plan including all logic. The schedule philosophy was to monitor all activities and all materials deliveries to the early start date. This approach provided margin which later proved useful in minimizing the impact to construction schedule caused by factors outside the project control.

An integrated team of Unit 1 experienced construction personnel conducted a detailed review of the overall design for Unit 2. The object of the review was to recommend areas where design enhancements could be made that would improve construction productivity and costs. As a result, about 250 items were addressed and incorporated into the Unit 2 design. In addition, an engineering team was commissioned to review all Unit 2 changes whether from backfit, operations requests, regulatory requirements, etc., in order to ensure their correct disposition for Unit 2. Over 1000 items were considered and about 350 were incorporated into the Unit 2 design.

A significant contributor to timely completion of Unit 2 was the plan to turn over components and systems to FP&L. This plan included, as a primary objective, the earliest possible acceptance of equipment, components, and partial systems in order to enable early testing and problem identification. This plan required significant early on-site presence of FP&L operations personnel more than 35 months prior to fuel load. This was not a token workforce but rather a sizeable commitment of about 100 people. This Startup/Construction Accelerated Turnover Program (SCAT) identified portions of total systems for early turnover and scheduled those. Approximately 500 packages for turnover were implemented in a priority sequence and scheduled. The SCAT program was integral to FP&Ls standard of early acceptance of components and partial systems so that start-up problems could be identified and resolved with minimal impact to the scheduled fuel load milestone.

Change Control Review Board - Early in the initiation of the overall St. Lucie project for both units it was recognized by project management from both companies that continual increases in the scope of the project would make it impossible to routinely achieve milestone dates. It was decided to jointly establish a change control review board with participation from engineering, construction, operations, and project management. The objective of the group was to review changes arising out of licensing commitments, system enhancements, and operations improvements. The review board was to determine whether it was best to implement an item before core load or to defer to a backfit status (post core load) in order to not impact construction, turnover, and start-up. In general, the criteria employed by the review board was that if the item was needed in order to operate a system, or if it was a licensing commitment promised for completion prior to core load, it would be worked on for implementation prior to the core load date. This ensured a reasonably defined scope and helped assure realistic schedule dates.

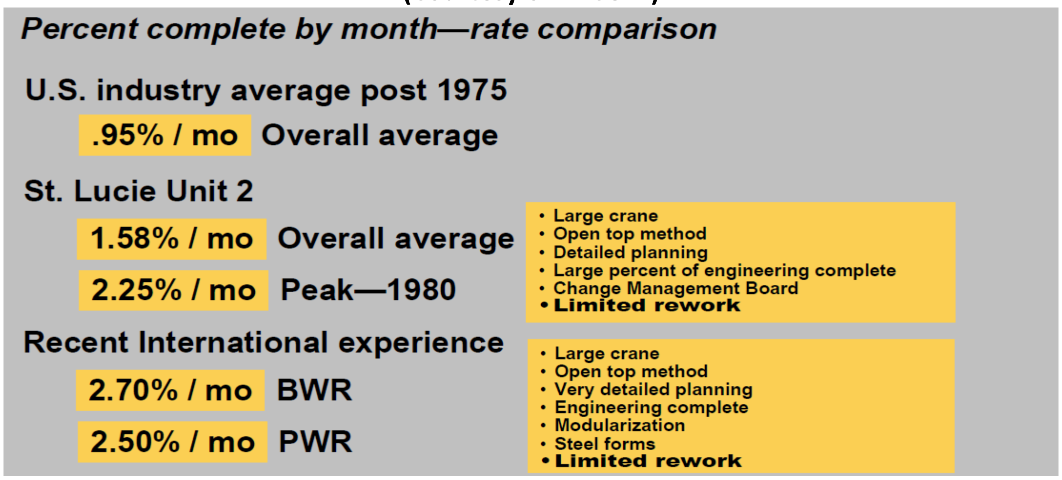
Accelerated FSAR Preparation and Review Cycle by the NRC - The Utility, the AE/C, and the NSSS Vendor jointly established a Design Defense/FSAR Interface Team. The team prepared a detailed defense/interface document with the intent to prevent ratcheting of license requirements in the final NRC review process and to guide the defense team and aid the NRC with its FSAR review. The defense document was a three-party joint assessment of the St. Lucie Unit 2 final design against the NRC Standard Review Plan requirements. This resulted in an early completion of the NRC Review for FSAR and ER and NRC approval of those documents

Engineering, Licensing, and Critical Materials Procurement Completion while Construction Delayed - When construction was delayed in 1972, a bold decision was made jointly by FP&L and Ebasco to continue engineering, licensing, and materials procurement without delay in accordance with the previously established schedules. When construction resumed in 1977, the result was that 75 percent of detailed design was completed and 40 percent of engineered materials were already delivered to the site. This completed detailed design status before resuming construction was a key factor in the successful schedule and cost outcome for construction.

As mentioned earlier, **Exhibit 4.3** shows that St. Lucie 2 monthly performance was about twice that being achieved by other US industry plants. Also, St. Lucie 2 performance was approaching that of ongoing international NNP projects where they had achieved Nth of a kind basis and repetition coupled with modularization, detailed planning, and completed design to support reduced durations and accelerated schedule performance.

Exhibit 4.3, Summary Comparison of Monthly Construction Per Cent Complete Performance

(Courtesy of AECOM)



St. Lucie 2 - Summary of Keys to Success and What Went Well

- **Implementation of a Mutually Beneficial Commercial Contract** - FP&L implemented a Time and Materials Contract when hiring Ebasco as the AE/C for the project team.
- **Project Management Leadership and Integrated Project Team Approach** – FP&L implemented an Owner led which was also totally integrated between FP&L and Ebasco for the construction of both St. Lucie units. FP&L and Ebasco used a best athlete mutual selection criterion for personnel to fill all key positions throughout the combined construction organization.
- **Project Planning Estimating, and Scheduling –** optimization of the construction effort was the result of early completion of engineering detailed design, early very detailed planning, early procurement of engineered materials for availability onsite, a credible schedule developed by experienced engineering and construction staff, and early turnover of systems, partial systems, and components from construction to operations for early testing and problem identification
- **Change Control Board –** The Utility and the AE/C jointly established a Change Review/Control Board to thoughtfully manage and restrict project scope changes
- **Accelerated FSAR Preparation and Review by the NRC** – The Utility, the AE/C, and the NSSS Vendor jointly established a Design Defense/FSAR Interface Team. The team prepared a detailed defense/interface document with the intent to prevent ratcheting of license requirements in the final NRC review process and to guide the defense team and aid the NRC with its FSAR review. This resulted in an early completion of the NRC Review for FSAR and ER and NRC approval of those documents
- **Engineering, Licensing, and Critical Materials Procurement Early Completion while Construction Start Delayed -** When construction was delayed in 1972, a bold decision was made jointly by FP&L and Ebasco to continue engineering, licensing, and materials procurement without delay in accordance with the previously established schedules. This completed detailed design status before resuming construction was a key factor in the successful schedule and cost outcome for construction.

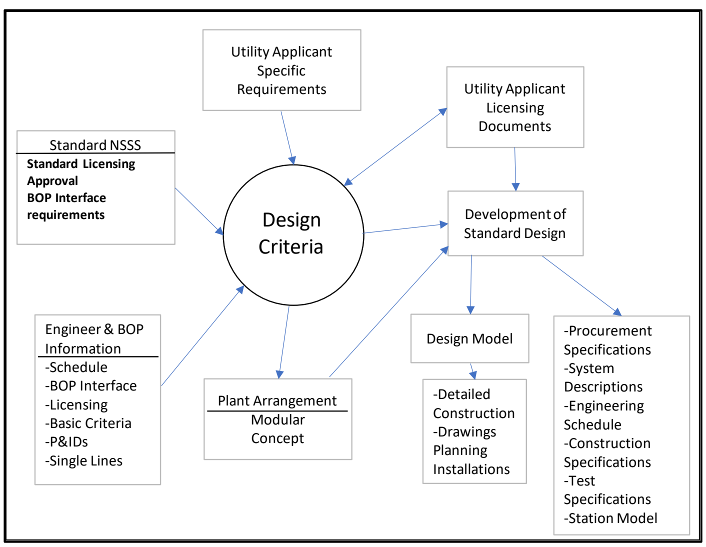
4.3 Palo Verde Nuclear Generating Station - Units 1, 2, and 3

4.3.1 Background

Palo Verde Nuclear Generating Station (PVNGS) consists of three (3) identical 1270 Megawatt electric (MWe) nuclear power plants. The initial construction permits for all three (3) units were issued on May 25, 1976. The three units were initially scheduled for fuel load with a staggered schedule. Twelve months stagger between unit one and unit two and a twenty-four-month stagger between unit two and unit three. The Nuclear Regulatory Commission (NRC) issued the Arizona Nuclear Power Project (ANPP) a license for Fuel Load approval for the three units in December 1984; December 1985; and March 1987 on units one, two, and three respectively. Construction of these three 1270-megawatt nuclear power generating facilities was accomplished in 129 months (10 years and 9 months), measured from the start of construction of Unit One to the loading of nuclear fuel in the reactor vessel of Unit Three. This represents a notable success in an industry where similar projects in the 1980s were requiring 120 months (10 years) and longer to complete a single unit.

Many project management factors contributed to developing construction momentum and achieving accelerated schedule durations at PVNGS for the three units. PVNGS used a “slide along” approach where each unit is identical and constructed from the same set of drawings. The system functions were developed as modules with each building housing the modular function. Construction was primarily stick-built, open top as possible, and maximization of preassembled pipe sections and skid components. A standard plant design for all units was frozen at construction start. **Exhibit 4.4** below represents the PVNGS standard design flow. Changes required evaluation against a pre-developed acceptance criterion based on safety needs, functionality needs or a licensing requirement.

Exhibit 4.4, Palo Verde Nuclear Generating Station Standard Design Flow Chart



PVNGS was a large complex project and one of three Generation II nuclear projects that was undertaken in the last century that provided an opportunity to achieve Nth OF a Kind (NOAK) performance. Browns Ferry Nuclear Plant owned and operated by the Tennessee Valley Authority and Oconee Nuclear Station owned and operated by Duke Power Company are the only other three-unit nuclear projects in the U.S. that provided an opportunity for NOAK. PVNGS is unique in that the units are stand alone, do not share systems, structures, or components, and the site is defined as a dry site. As is often the case, the framework for the positive results achieved at PVNGS reflected a combination of traditional concepts and unique, innovative approaches.

The cornerstones for achieving successful project performance included:

- Coordination by an owner/licensee led integrated management team with the engineer - constructor for all balance of plant scope and NSSS supplier located at the site designed to aggressively manage risks, promote open communications, and avoid surprises.

- A project plan was developed involving stakeholders that encompassed scope definition, design and interface criteria, project procedures, detailed engineering, procurement, construction and startup planning.

- Participation at all levels of management was essential in the review of the overall project performance as it relates to safety, quality, schedule, budgets and accomplishments of major project milestones and objectives.

The Palo Verde Nuclear Generating Station (PVNGS) consists of three nominal net 1270 MWe nuclear power units located at a desert site approximately 50 miles west of Phoenix, Arizona. Each unit is identical and features a Combustion Engineering (C-E) Standard System 80 pressurized water reactor (PWR) Nuclear Steam Supply System (NSSS); a General Electric six-flow, tandem-compound turbine generator; and concrete, mechanical forced-draft cooling towers. PVNGS is a participant project called the Arizona Nuclear Power Project (ANPP) with Arizona Public Service Company (APS) responsible for the construction, startup, testing and operation of the three-unit complex. Bechtel Power Corporation (Bechtel) was the engineer-constructor for the plant.

4.3.2 Lessons to Learn

<u>Project Management Leadership and Integrated Project Team Approach</u> – Large and complex projects can become mired by the development of siloes in organizations where information, tools, and performance goals become internal to individuals and not for the success of the project. APS, Bechtel and project leadership were committed to an integrated team approach. This included the C-E NSSS supplier and the AFL-CIO labor organization management team. Frequent coordination meetings were held among APS, Bechtel and C-E to review design, procurement and construction activities and to identify and resolve problems. Bill Stubblefield was the Project Manager. Bill was a hands-on in the field insightful “extreme” manager with a clear vision for safety, quality, open communications and teamwork.

PVNGS and all US new nuclear projects at the time had to deal with many design changes to implement NRC requirements following the March 1979 TMI accident. An important engineering tool for verification of the adequacy of the plant design was the use of a detailed scale model. The model enabled design review, provided a three-dimensional guide for construction planning, and was used for elimination of interferences, review of design changes to minimize costs and schedule delays, the conduct of maintenance reviews including access, time studies, equipment replacement, resolution of equipment placement problems, clarification of interface criteria and a reduction in man hours for the preparation of isometric drawings.

The construction of PVNGS was completed by Bechtel Construction Incorporated. Many of the management tools utilized for the design and engineering phases were used during construction such as the coordination and design review meetings, preparation of a construction plan, and the use of the model to assist in the construction planning and problem resolution. Some of the more important construction techniques used at PVNGS included:

- Maximized use of pre-assembled structures & piping sections using on site pre-assembly areas and pipe welding shops, preassembly of delivered components such as condenser sections, instrument racks, pipe supports, and large pipe spools.
- Utilized experience gained on Unit 1 for Units 2 & 3 construction by transfer of key people or by training of the new personnel by those who gained experienced on Unit 1.
- Use of embedded steel framing in the walls such that it could provide support for such items as pipe and duct.
- Use of a labor stabilization agreement which provided uniform working conditions, processes for handling grievances, and appropriate no strike-no lockout provisions.
- The utilization of standardized, approved designs using one set of drawings for the three units permitted increased worker efficiency and a high utilization of construction equipment.
- Use of computerized planning and scheduling tools available for control of costs and schedule.
- Availability of suitable storage facilities for proper handling of components prior to installation.
- Common pipe racks and instrument racks to permit low cost structural supports for pipe and instruments.
- Use of oversized polar crane girders and supports (800T capacity) to support a temporary trolley to assist in installation of heavy components such as the steam generators and reactor vessel.
- Use of a concrete batch plant and associated icehouse located on site along with an independent test laboratory. Concrete was placed at night to the maximum extent possible to avoid interference with other operations and to allow lower ambient temperatures which Is necessary during the hot summer at a desert site.
- Use of monolithic placement of the base mats (Units 2 & 3) and the preparation of forms (and their reuse) at a nearby onsite area reduced form work costs.
- Use of an onsite coating facility to minimize coating damage repairs.
- Decision to use only Quality Class 1 materials for concrete, reinforcing steel, weld rod and instrument fittings to eliminate the extensive administrative controls that would be needed to assure proper material segregation.
- Establishment of a resident engineering staff on site to expedite design changes and handling of non-conformances.

The integrated project team played a significant role in the construction phase with active participation at all levels of management up to and including senior management. These coordinated and planned efforts of the involved parties resulted in substantial improvements in the construction work. As an example, wire and cable pulling rates on Unit 3 were 25% more productive than on Unit 2 and 40% better than in Unit 1. The use of a standard design and a single set of drawings produced significant improvements in productivity as construction progressed from unit to unit.

PVNGS was constructed on a three-shift forty (40) hour work week schedule. The first two shifts were for production with sixty (60) percent of the skilled craft workforce on the first shift and forty (40) percent of the skilled craft workforce on the second shift. The third shift provided set up and support activities to allow optimum production, facilitate housekeeping, maintain fire watch, and supply material needs.

Contracting Strategy and Framework Designed to Foster Teamwork – ANPP with APS as the agent developed a contracting framework that recognized the need to deal with a FOAK project. As such, fixed price contracts could create conditions adverse to communication, openness, and teamwork goals, and that project teamwork was inversely proportional to the thickness of contract terms and conditions. The parties wanted to facilitate a project focus on management and production rather than contracts and legal jousting.

The decision to either select an engineer-constructor or an engineer-construction manager was given considerable attention. After much study by ANPP, it was concluded that the engineer-constructor approach was most appropriate because (1) it permitted the concept of unified responsibility, (2) it minimized the number of communication and coordination interfaces; a key concern and (3) permitted more efficient use of crafts.

Subsequent to the selection of the engineer constructor, the project along with consultants, prepared a comprehensive specification for the procurement of the Nuclear Steam Supply System (NSSS) and related initial core and reload fuel. After several months of evaluation, Combustion Engineering, Inc. was selected to provide three, System 80, standardized NSSS's, associated support systems and fuel for the first core and first reload. The triad was formed with teamwork and the focus on schedule goals was truly galvanized to accomplish work on schedule.

Clear and Simple Management Planning – The project from its inception, stressed safety first, closely followed by quality. This was reinforced throughout the design, construction, startup and operation of PVNGS. With these policies and the objectives of operability, maintainability, and availability in mind, the PVNGS was designed and constructed as standard units to reduce the time from construction to operation. Standardization concepts such as identical units built from a single set of drawings and a design freeze at about the time construction was started, were used to develop appropriate criteria for a standard modular plant design. Inherent in this effort were the experiences gained from earlier nuclear plants to extract the good practices and to avoid wherever possible the problems of the past.

Recognizing it is the people who accomplish tasks, PVNGS provided an environment which allowed a close working relationship among the highly motivated people assigned early in the project from the utility, the architect-constructor and NSSS supplier. Mutual participation by technical personnel, craft labor, and senior management was critical to completion of the design, construction and operation of the PVNGS units within acceptable budget and schedule limits.

In summary, most of the success of PVNGS must be attributed to the effectiveness of the integrated project team, the dedication and competency of the personnel working on the project, and the continuity that was maintained by the assignment of key personnel to the project for extended periods, many since its inception. The use of appropriate and effective management tools, a full spectrum of management participation, and the flexibility to do what was best when it was needed in the face of changing conditions allowed for continuous improvements across units. In fact, the Arizona Corporation Commission's auditor estimated that the project management team saved ratepayers over $300 million through their actions (Reference 63). The adherence to the initial project objectives of safety, quality, operability, maintainability, and availability contributed to the success of this project. The result is that the PVNGS is one of the lowest cost nuclear projects constructed in the U.S during the same time frame. All three units were successfully completed in less than the average time of other comparable plants. Unit 1 was completed in fourteen months less than average and the other units followed in substantially improving the average time for completion.

<u>Palo Verde 1, 2, &3 - Summary of Keys to Success and What Went Well</u>

- **PVNGS is a 3-identical unit plant and used a "slide along" construction approach where each unit is identical and constructed from the same set of drawings.**
- **PVNGS construction provided the opportunity to achieve Nth of a Kind (NOAK) performance.**
    - **Browns Ferry Nuclear Plant owned and operated by the Tennessee Valley Authority and Oconee Nuclear Station owned and operated by Duke Power Company are the only other three-unit nuclear projects in the U.S. that provided an opportunity for NOAK.**
- **Construction was primarily stick-built, open top as possible, and maximization of preassembled pipe sections and skid components.**
- **A standard plant design for all units was frozen at construction start.**
- **Coordination by an owner/licensee led integrated management team with the engineer - constructor for all balance of plant scope and NSSS supplier located at the site designed to aggressively manage risks, promote open communications, and avoid surprises.**
- **A project plan was developed involving stakeholders that encompassed scope definition, design and interface criteria, project procedures, detailed engineering, procurement, construction and startup planning.**
- **Participation at all levels of management was essential in the review of the overall project performance as it relates to safety, quality, schedule, budgets and accomplishments of major project milestones and objectives.**
- **Maximized use of pre-assembled structures & piping sections using on site pre-assembly areas and pipe welding shops, preassembly of delivered components such as condenser sections, instrument racks, pipe supports, and large pipe spools.**
- **Utilized experience gained on Unit 1 for Units 2 & 3 construction by transfer of key people or by training of the new personnel by those who gained experienced on Unit 1.**
- **Use of embedded steel framing in concrete walls such that it could provide support for such items as pipe and duct.**
- **Use of a labor stabilization agreement which provided uniform working conditions, processes for handling grievances, and appropriate no strike-no lockout provisions.**
- **The utilization of standardized, approved designs using one set of drawings for the three units permitted increased worker efficiency and a high utilization of construction equipment.**

4.4 Watts Bar Unit 2

4.4.1 Background

In 1973 the Tennessee Valley Authority (TVA) began construction on two Westinghouse, 1170 Megawatt electric (MWe) pressurized water reactor. These units were construction at the TVA Watts Bar site. Construction was stopped on both units in 1985 with the civil structural construction having been basically completed. Watts Bar Unit 1 completion restarted in 1992 and Unit 1 began commercial operation in May of 1996. Unit 2 was determined to be approximately 80% complete at the time construction was stopped in 1985. TVA resumed construction on Unit 2 in October of 2007 with an expectation of commercial operations in late 2012. In 2011, it was recognized the project was not progressing to meet the expectation, resulting in a root cause analysis, a new Estimate to Complete, a new schedule, and a new management team to complete the project.

Defining the scope of work to complete construction of Watts Bar Unit 2 at the time of the restart of construction was a major complexity as the unit had become a spare parts repository for Watts Bar Unit 1 and other TVA sister plants. Numerous corrective actions applied to Unit 2 as well as regulatory requirement changes that had occurred in the interim time between stopping construction and the restart of the construction program had to be investigated and factored into the cost estimate and schedule. In addition, in the eleven years between the completion of Unit 1 and restart of Unit 2, many of the experienced personnel from Unit 1 either retired or left TVA. Unit 2 was a FOAK project for TVA.

TVA resumed construction on Unit 2 in October of 2007 with an expectation of commercial operations in late 2012. Project completion began with a relatively small TVA Project Management organization overseeing a large Engineer, Procure, and Construction (EPC) contractor that had the overall responsibility for completing the required scope of work for Unit 2. In 2011, it was recognized the project was not progressing to meet the defined project milestones outlined in contract approval for completion. This resulted in a root cause analysis (RCA) to be performed that was shared with the industry. Key attributes identified were:

- Organizational and management capabilities being misaligned with unique project characteristics.
- Low initial estimates and impeded planning resulting from a lack of understanding of the work to be done.
- Not executing a robust execution plan or fully utilizing available capabilities.
- Inadequate oversight and project assurance.

4.4.2 Lessons to Learn

Project Management Leadership and Integrated Project Team Approach –Watts Bar experienced several stoppages and starts of work over the history of the project. Several significant lessons learned came to light in the re-focus of the project in 2011. At the forefront of these lessons learned was the identification of organizational and management capabilities being misaligned, a new Estimate to Complete, a new schedule, and a new management team to complete the project. TVA corporate and project leadership were committed to an integrated project team and a best athlete approach. Mike Skaggs, Executive Vice President in charge of the project, indicated TVA was, "…putting in place a highly skilled, experienced team in nuclear construction and project management as we develop our completion plan for unit 2 at Watts Bar." The new management team included a new TVA Project Director to provide leadership in engineering, construction, and startup, and an integrated project controls organization to develop and manage the estimate and schedule. Due to the unique project characteristics and the storied history of the Watts Bar Project many lessons learned were incorporated into the completion efforts including

(1) Organize for success, (2) Develop the estimate based on detailed analysis, (3) Develop a clear execution strategy, (4) Measure what needs to be achieved, (5) Manage risk, (6) Value oversight, (7) Engage the workforce, (8) Strengthen and expand operational readiness program, (9) Strengthen departmental operational readiness, (10) Ensure likeness of Unit 1 and Unit 2, and (11) Develop and implement a program to ensure the adequacy of operational procedures

Project Planning, Estimating, and Scheduling - It is well known that in order to establish a project plan, a reasonable scope of commodities, based on known quantities or estimates from similar installations, must be established. The use of estimates must be tracked and replaced with known quantities when predecessor activities are completed (i.e., design engineering or other discovery) in order to refine and improve the project plan and schedule. Discovery activities should be driven to closure early to aid in the refinement of the project scope. The implications of emergent work or deficiencies (process or program deficiencies discovered during installation, inspection, or testing) should be promptly understood with an extent of condition review to reduce the impact to the overall project plan. Lastly, a well-defined scope and cost control process that defines the identification and quantification of variances (with minimum limits), as well as review and approval requirements, must be in place early in project execution so that adjustments can be made by project leadership to reduce or eliminate impact to the overall project plan.

A practical schedule to drive and measure the project completion is a necessity, and a strategy for making the schedule is the foundation. It is neither expected nor practical to begin a multi-year large project with a detailed schedule through to the end of the project, but it is expected and necessary to define the phases/milestones and their objectives and to have sufficient detail in the near term phases to measure progress and productivity. Simple phases for a large project would be Design, Bulk Construction, System Completions, System Testing, Integrated Testing, and Commissioning, and these phases would have some overlap. Milestones would be major project evolutions or tests, such as the Cold Hydro or Hot Functional Test. Support actions, such as procurement, process development, planning, and others could also be labelled phases and would be scheduled as well. The level of detail would depend on the criticality of completion order, but even in the commodity bulk work phases, the order of commodities and/or areas would be defined well enough to reduce interferences and keep worker population efficient in each area. The level of detail would increase as the project would transition from bulk construction to system completion and would increase more as the critical handoffs from construction to testing occur and through the testing window.

Aside from the need to have a robust suite of metrics and measures for production, cost, and schedule, as well as processes for scope and cost control, a key lesson for Watts Bar Unit 2 was the need for well-defined rules of credit for value earned. Large value commodities are usually broken down into process elements since their installations will span reporting periods. An example would be the installation of a cable raceway, and the elements could be the raceway itself, the supports, mounting hardware, quality control inspections, work approvals, material acquisition, closure reviews, etc. The value of performing (and receiving credit for) each of those elements must closely match the effort expended to support accurate measurement of production/productivity. Otherwise, it is likely the elements with the highest earned value per effort will be done first, leaving a high number of partial completions that require the bulk of the process effort (ex - raceways hung on temporary supports).

Community Relations - A positive relationship with the public was highly valued by the project and TVA. Communication presentations and tours were conducted for TVA customers, state and federal government officials, and other public leadership. These included a presentation on the benefits of nuclear power, how a typical nuclear unit works, the Watts Bar 2 Project status, a guided tour of the unit, and a working lunch and Q & A session with project leadership. Based on the feedback from the attendees, these sessions were extremely helpful to understanding the project and nuclear power.

One of the most positive things the Watts Bar Unit 2 project did for public relations was forming a Community Action Panel. This panel consisted of officials from the local governments in the surrounding areas, community and business leaders, and individuals (local or from industry groups) who had asked questions or expressed concerns about the completion of the unit. The panel met at least quarterly from inception through the completion of the project and is expected to meet on a regular basis going forward. The objective was to establish an open dialog with the membership on the project status and challenges, allow them to see the unit firsthand, and provide a forum to ask questions, express concerns, and get answers from the project leadership team directly. This forum and dialog was a key to developing understanding and advocacy among the community and business leaders and, although the individuals with concerns did not necessarily become proponents of the project or nuclear power, they did express appreciation for the opportunity to have their concerns heard and addressed in what was considered a genuine, open discussion with project leadership.

Startup Test Personnel - Startup testing is the final barrier to detect and correct issues with the design and installation of the components and systems. Component test procedures are usually written generically to apply to general classifications of components, such as electrical circuits, instrument loops, valves, etc. With general instructions, the execution will require competencies and skills from the technicians who perform the tests, as well as competency in troubleshooting. Deficiency percentages are not high, but one single issue ultimately will fail the entire test (for example, one misplaced wire in a circuit of 100 termination points results in a full failure of the test).

The project experienced some challenges with some of those generic tests due to the experience of the workforce. Functional testing of electrical and instrument circuits was the most prominent challenge, as issues were identified in pre-operational testing that should have been corrected during the component tests. Investigations and interviews revealed that the 15 years since the last new unit startup program had eroded the knowledge and skills to perform thorough circuit functional testing and troubleshoot deficiencies using a generic procedure and the circuit schematic diagram.

The project assigned new leadership and other seasoned personnel to provide assistance and oversight to the conduct of the tests and to the troubleshooting. These personnel were screened and verified to have the skills and experience in the testing, and many had the experience from the testing of the first Watts Bar unit. Improvement was observed in both the quality of the testing conduct and the productivity and timeliness of completions.

Oversight - One very useful tool deployed after the project was resumed was a Project Assurance Group, responsible for independent oversight of key project elements (cost, schedule, production). The objective was to provide executive management advice and perspective from experienced personnel who were completely independent from production management to ensure reporting on progress was accurate and reliable. This group performed interviews of key personnel, reviewed metrics, performed field walk-downs to verify completions, looked for hidden backlogs, reviewed time and cost reporting, and provided periodic written reports to the Sr. Vice President of Watts Bar on observations, deficiencies, and improvement opportunities. This ongoing effort was supplemented with reviews from industry experts that were similar to the INPO and Nuclear Safety Review Board (NSRB) practice that monitors the performance of operating units. The Nuclear Construction Review Board (NCRB) assessed project performance 1 - 3 times per year and provided recommendations on organizational as well as overall project improvement opportunities.

Paper Closure - Some work packages were too large in scope, vague in instruction, and complex in structure. This resulted in problems for the field in completing and documenting the work. Confirmation of work completion required additional layers of verification (not required by process) and additional personnel to accomplish those reviews and corrections. It was not uncommon to identify work or inspections that remained incomplete during those reviews.

The structure/content of the work packages should be a collaborative effort between construction craft, management, support engineers, and planners keeping the end and final closure in mind. Pilot packages should be prepared, worked, and put through the closure process prior to beginning bulk construction.

Documentation standards and expectations should be communicated and taught to the responsible field personnel so that the closure reviews can be accomplished with minimal rework. Work packages must include the requirement and a checklist to keep the documentation up to date with the work status, along with a cost/duration contingency that recognizes the FOAK aspects of the project.

Watts Bar 2 - Summary of Keys to Success and What Went Well

- **Project Management Leadership and Integrated Project Team Approach – Finishing a partially completed NNP that had been delayed for over 20 years was challenging, especially understanding the real condition of the plant. Organizational and management capabilities were misaligned and the estimate/schedule to complete was unrealistic. TVA corporate and project leadership fervently adopted an integrated project team and best athlete approach.**
- **Project Planning, Estimating, and Scheduling - Establishing a valid project plan requires a realistic scope and estimate of construction commodities. A practical schedule to drive and measure the project completion is part of the foundation for the plan. Well defined rules for receiving credit for value earned are essential for success.**
- **Community Relations – An informed set of external local stakeholders is very important and helpful. Understanding issues and benefits of nuclear power creates a base of support. TVA established a comprehensive and successful communication program to accomplish this.**
- **Startup Test Personnel - Startup testing was the final barrier to correct issues with the design and installation of the components and systems. Functional testing of electrical and instrument circuits was the most prominent challenge. The project assigned new leadership and other seasoned personnel to provide oversight to the conduct of the tests and to the troubleshoot.**
- **Oversight – A Project Assurance Group was established to conduct independent oversight of key project elements (cost, schedule, and production). This group performed interviews of key personnel, reviewed metrics, performed field walk downs to verify completions, looked for hidden backlogs, reviewed reporting, and provided reports to the Sr. Vice President of Watts Bar on observations, deficiencies, and improvement opportunities. This ongoing effort was supplemented with reviews from industry experts similar to the INPO and Nuclear Safety Review Board (NSRB) practice that monitors the performance of operating units.**
- **Paper Closure - Some work packages were too large in scope, vague in instruction, and complex in structure. This resulted in problems for the field in completing and documenting the work. The structure/content of work packages should be a collaborative effort between construction craft, management, support engineers, and planners keeping the end and final closure in mind. Work packages must include requirements and a checklist to keep the documentation up to date with the work status, along with a contingency that recognizes project FOAK aspects.**

4.5 Rocky Flats Decontamination & Decommissioning (D&D) Project

4.5.1 Background

The Rocky Flats Plant (RFP) was a U.S. manufacturing complex that produced nuclear weapons components in the western United States, near Denver, Colorado. The facility's primary mission was the fabrication of plutonium pits, which were shipped to other facilities to be assembled into nuclear weapons. RFP was operated from 1950 to 1992 by the Dow Chemical Company, Rockwell International, and EG&G. The complex was under the control of the U.S. Atomic Energy Commission (AEC), succeeded by the Department of Energy (DOE) in 1977.

RFP supporting operations included the recovery of Pu and uranium from retired weapons components, processing Pu scraps and Pu residues to purify the Pu for use in weapons. In December of 1989, the Department of Energy curtailed Pu operations at Rocky Flats due to safety and environmental concerns. The DOE anticipated that plant operations would resume shortly after a new contractor had taken over the management and operation of the Site. Therefore, the Pu facilities were maintained in a production configuration with Special Nuclear Material (SNM) in the glovebox lines ready to resume operations. The resumption of nuclear operations was delayed due to persistent safety concerns.

In 1991, an interagency agreement between DOE, the Colorado Department of Health, and the EPA outlined multiyear schedules for environmental restoration studies and remediation activities. President Bush made the decision in 1992 to suspend nuclear weapons production, and later eliminated the Rocky Flats weapons production mission entirely. As a result of the uncertainty and evolving Rocky Flats mission from 1989 to 1993, a large inventory of Pu was left in an indeterminate storage configuration. Subsequently, the Site mission evolved from a standby status and period of improving safety and deactivating unused equipment, to the final DOE decision to accelerate the D&D of the Site. In 1994 the site was renamed the Rocky Flats Environmental Technology Site (RFETS), reflecting the changed nature of the site from weapon production to environmental cleanup and restoration.

Cleanup began in the early 1990s, and the site achieved regulatory closure in 2006. The cleanup effort decommissioned and demolished over 800 structures; removed over 21 tons of weapons-grade material; removed over 1.3 million cubic meters of waste; and treated more than 16 million gallons of water. Four groundwater treatment systems were also constructed. Today, the Rocky Flats Plant is gone. The site of the former facility consists of two distinct areas: (1) the "Central Operable Unit" (including the former industrial area), which remains off-limits to the public as a CERCLA "Superfund" site, owned and managed by the U.S. Department of Energy, and (2) the Rocky Flats National Wildlife Refuge, owned and managed by the U.S. Fish and Wildlife Service.

Kaiser-Hill (ICF Kaiser and CH2MHill) was awarded management, cleanup, and closure responsibility for the RFETS in July 1995. At that time, the Site had the largest plutonium (Pu) inventory of any Department of Energy facility. The Site also had a significant quantity of highly enriched uranium (HEU). These special nuclear materials (SNM) required characterization, stabilization, packaging for long-term storage, consolidation, repackaging/over-packing into approved shipping containers, and removal from the site before Kaiser-Hill could focus on the deactivation, decommissioning, decontamination, and demolishing (D&D) of the site’s nuclear facilities. The Department of Energy declassified the site’s SNM inventory in 1994. When Kaiser Hill assumed responsibility for RFETS, the SNM inventory included 12.9 metric tons of Pu and 6.7 metric tons of enriched uranium.

Over the course of the 10 years from 1995 to 2005, Kaiser-Hill embarked upon a first-of-a-kind cleanup and closure contract. Many factors contributed to the radical and significant acceleration of this closure project. Compared to the baseline schedule and budget of 70 years and $36 billion, the project completed 60 years early and $29 billion dollars under budget at 10 years and $7 billion. Being a first of a kind cleanup and closure contract, the several key strategies and practices were implemented that directly impacted the success of this project. At the top of this list were an integrated project team and management commitment and leadership from the top.

> *"As I reflect back on over 35 years of working in the DOE/NNSA Nuclear complex, one of my most rewarding roles was as a member of the RFETS Closure Project leadership team. The sheer volume and significance of the multitude of challenges we faced was overwhelming. Yet, in every situation, and over the course of a 10-year project, the dedicated and committed members of this team developed creative and innovative solutions to every challenge we encountered"*
>
> David Del Vecchio, Senior Project Manager on the RFETS Leadership team

4.5.2 Lessons to Learn

Management leadership and commitment from the top - This core success attribute was evident from the start of the project through to its completion. Despite limited management changes over the course of the project, when changes did occur, the new project leaders were fully committed to the project team and the overall success of the project. This was an attitude and characteristic of all the key project leaders.

Attracting and retaining highly qualified expertise for every facet of the project – Taking the time and spending the money to hire and retain appropriately qualified personnel for all key project positions (leadership as well as mid-level management) is critical to project success. Being a first of a kind cleanup and closure presented the project with very diverse and varied challenges. Carrying out the project required expertise in waste management, groundwater remediation, environmental restoration, and orphan bi-products that had never been dealt with before. Due to the nature of the skills required, utilization of industry forums and executive recruiters was needed to acquire the personnel to accomplish the project scope. Detailed position descriptions and qualification requirements were established to aide in this recruiting effort. Once candidates were identified and screened, aggressive and lucrative compensation packages were offered to attain and retain these key resources. Post hire performance must be closely monitored on an individual and sub-project level to assure performance and pace are aligned with the end state. All performance weaknesses must be immediately corrected.

Continuous communication and collaboration with all stakeholders - Continuous communication and collaboration with the customer and stakeholders is a requirement for success. At the inception stage of the project, communication plans must be established that cover the full gambit of all stakeholders. Obtaining buy-in from the stakeholders on the type, frequency, and scope of the communication plan is critical. Routine communications with all stakeholders (DOE, NNSA, EPA, RCRA, Regulators, local politicians, the public, etc.) must maintain an open an interactive dialogue to address project progress updates, problems encountered, public perception, and community impacts. Establishing trust early with your stakeholders through regular and frank communication is of significant importance to maintain project support.

Establishing clear roles, responsibilities, accountabilities, and authorities (R2A2) - Establishing agreed to project and stakeholder Roles, Responsibilities, Accountabilities, and Authorities is critical for project success. This specifically includes limiting oversight and control by the customer and regulators to only that which is required by law/order. Despite establishing routine communication and an open dialogue, the contractor must be allowed to manage the project and the problems as they best see fit. Micro-management is counter-productive and will result in increased project cost and schedule.

Reaching agreement up front on the project end state and the stewardship therein - At the start of the project, discuss and reach agreement with required stakeholders on the project end state. This includes specific details of what the end state is and is not. There can be no surprises at the conclusion of the job, where the contractor claims victory in achieving the end state, and there is a stakeholder in disagreement. It is also critical to discuss impacts from the achieved end state: for example, D&D means working yourself out of a job and reduced spending in the community. Develop and communicate the actions that will be taken to identify work opportunities for displaced employees, transitioning the workforce, and re-industrializing the site where appropriate. Stakeholders, the customer and the contractor must share a common goal and end state, understanding interim milestones and overall schedule. While this seems mundane, without it, project success is unlikely. Appropriate details of the plan and path to the end state are required to control expectations and timeline. When appropriately established goals and end state are achieved, everyone shares in the success and the failures along the way.

Establishing and reporting regularly on key metrics that achieve the agreed to end state - Develop and reach agreement with required stakeholders on key metrics that support the project goals and end state. Report progress against the metrics regularly, communicating the successes as well as failures, including planned corrective actions to mitigate challenges, to all stakeholders.

Appropriately incentivizing the contractor to reward schedule acceleration and cost savings - Appropriate incentive and profit-sharing objectives drive performance and help to establish and maintain a completion mentality. First of a kind projects are wrought with known and unknown risks and challenges, together which drive the project schedule and cost. Incentivizing a contractor commensurate to the risk and challenge on a project creates a driver to bring the best and brightest minds to the task at hand, while inspiring creativity in finding solutions to never before solved problems. Shift work was utilized to accomplish schedule acceleration where single-shift resource profiles did not meet the schedule. Daily turnover meetings between shifts were also conducted with senior project leadership present to understand progress achieved as well as setbacks experienced. Certain work crews that consistently achieved better than planned performance was shared across the project on for similar work scope to capitalize on their particular expertise. Incentives were established for all project team members, including manual personnel, on a sliding scale that focused on schedule acceleration and project cost. The result being the earlier the overall end date was achieved and at what total project cost, the greater the reward for every employee. Note that safety and environmental performance were also heavily factored into the completion criteria to avoid schedule and cost pressures driving behaviors that injured employees and/or negatively impacted the public or the environment.

<u>Rocky Flats - Summary of Keys to Success and What Went Well</u>

- **Integrated project team.**
- **Management leadership and commitment from the top.**
- **Attracting and retaining highly qualified expertise for every facet of the project.**
- **Continuous communication and collaboration with all stakeholders.**
- **Establishing clear roles, responsibilities, accountabilities, and authorities (R2A2).**
- **Reaching agreement up front on the project end state and the stewardship therein.**
- **Establishing and reporting regularly on key metrics that achieve the agreed to end state.**
- **Appropriately incentivizing the contractor to reward schedule acceleration and cost savings.**

4.6 Selected Steam Generator Replacement (SGR) and Refurbishment Projects

4.6.1 Background

Steam Generator Replacements (SGRs) were performed in Japan and in France before the large wave of U.S. industry replacements. The French nuclear industry tracked replacement outage performance and established a formal lesson learned program. These facilitated steady reductions in French SGR outage durations during the 1980s and 1990s. It was beneficial that all the French SGRs were performed for the same utility owner, EDF. From the late 1990s French experience and lessons learned were shared with US SGR contractors through annual conferences.

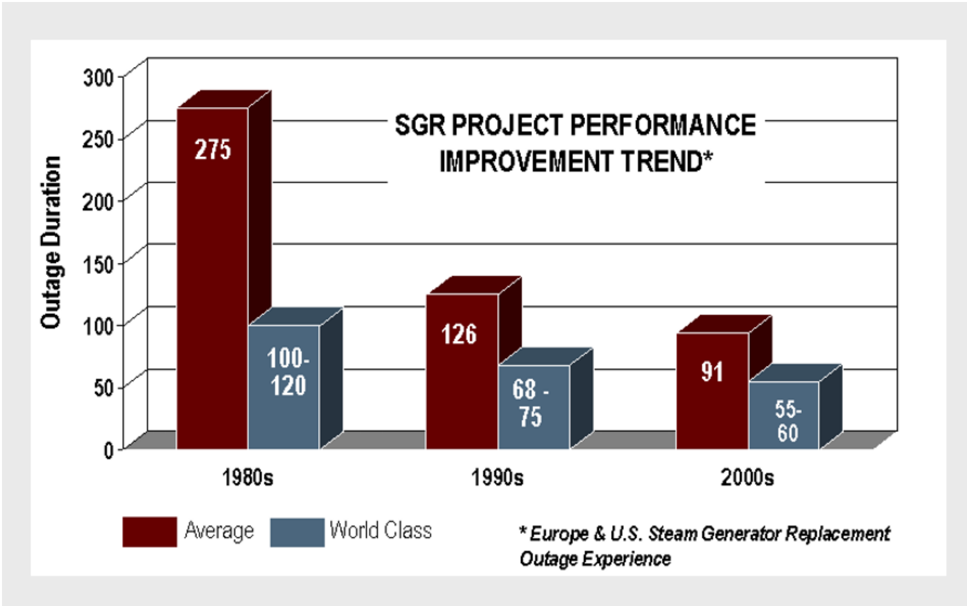
Overall, the US industry has performed 58 SGR projects over a 35-year period from 1979 to 2015. The first U.S. SGR project was in 1979 for Surry Unit 2 with an outage duration of 560 days. All SGR outage durations performed prior to 1985 (seven total) were over 210 days in duration. The first U.S. SGR performed in less than 200 days was Indian Point Unit 3 in 1989 at 140 days. After that, outage durations steadily improved over the next 25 years through 2015. The next scheduled SGR in the U.S. being Watts Bar Unit 2 scheduled for 2023.

The U.S. nuclear Industry and SGR contractors were very successful at steadily improving all aspects of SGR performance over the course of a twenty-five-year performance window (1990 through 2015) as shown in **Exhibit 4.5.** In summary:

- Outage durations of less than 90 days were routinely achieved from 1995 through 2000,
- Outage durations of less than 80 days were routine in the early 2000s, and
- Outage durations of less than 70-days were achieved from mid-2000 to 2015.

The U.S. record outage duration was 55 days achieved by Bechtel at Comanche Peak Unit 2.

Exhibit 4.5, US and Europe SGR Performance Improvement Trend [3]



These project performance and duration improvements are the result of Nth of a Kind (NOAK) learning curve application, industry sharing of information, and repetition of planning and management techniques that standardized SGR project best practices based on lessons learned.

4.6.2 Lessons to Learn

The factors that resulted in this nuclear industry success story were consistent between various utility Owners and primarily two industry Contractors, making it an industry achievement. Nuclear utilities that faced upcoming SGRs due to deteriorating SG tube conditions followed similar patterns of planning and implementation.

From the utility owner's point of view, the following lessons were applied, and practices were used to steadily improve outage performances:

- Assigning Project Management Teams early and placing an emphasis on learning from previous projects and industry lessons learned. Many utilities went outside their organizations for leadership with large modification management experience with an emphasis on previous SGR experience.

- Allowing for long planning periods. This was partially driven by lead times for Steam Generator tubes and Steam Generator fabrication, but the industry also realized the value of long-term detailed installation planning.

- Placing an emphasis on quality of planning and having a high-quality outage schedule.

[3] URS Presentation at 2009 Platts Conference titled- Engineering & Construction Projects- Experience and lessons Learned. Used with permission from AECOM Power E&C.

- Using readiness tools such as formal readiness reviews at multiple points during the planning period, vertical slices of the integrated outage schedule, use of training mock-ups, and outage meeting rehearsals. In short, planning and readiness were taken very seriously.

- Open sharing and cooperation between the Utility Owners through industry conferences, publications and benchmarking during other's outages. For a period of years, Owner's participated in annual round tables forums with each exchanging best practices.

- Placing a value on previous SGR experience in selecting Project Management team members.

- Choosing contracting strategies that considered industry lessons learned and realistically considered that contracting strategies affect behaviors.

- Implementing strategies to involve plant departments/functions in outage planning and execution for the SGR.

- Encouraging teamwork and cooperation including in some cases completely integrated Owner/Contractor outage organizations.

From the Contractor's perspective, the following lessons were applied, and practices were used to steadily improve outage performances:

- Innovation- The development of different outage approaches and means of access to containment internals. Also, innovations in welding, NDE heavy rigging, training etc.

- Use of state-of-the-art metrology technologies to assure highly accurate component movement paths and exact component fit-ups.

- Comprehensive and prescriptive processes and programs.

- Lessons Learned databases coupled with a comprehensive disposition process, usually integrated with the project's corrective action program.

- Comprehensive readiness reviews that included industry third party participation.

- Standardized metrics, meeting structures and communications plans.

- Innovative labor approaches with improvements in leadership effectiveness, training, planning participation and rehearsals/practice.

- Repeated use of experienced and proven vendors and subcontractors.

- Comprehensive material logistics and space planning.

- Most importantly, the use of a detailed planning regimen for each project. The Construction Industry Institute (CII) has recommended that planning costs as a percentage of Total Installed Cost (TIC) be in the range of 1% to 2%. Japanese nuclear constructors have previously reported planning costs as 3% to 5% of TIC with excellent performance results. U.S. SGRs typically employed twenty-four (24) to thirty-six (36) month engineering/planning periods before each outage which resulted in 2.5% to 4% of TIC for planning costs, also with very predictable and repeatable results. SGR planning typically resulted in very high-quality and detailed work packages, high-quality integrated outage schedules and employed multiple readiness reviews at set periods (e.g. T-24, T-18, T-12 and T-6).

- Project Management and Construction Management development programs to assure adequate experience to achieve outage performance goals. These programs included laddered assignments with increasing experience and mandated knowledge of industry/company/project lessons learned databases. One company required a newly assigned PM to review and develop preliminarily disposition actions for over 1000 SGR lessons learned within six weeks of assignment. For each outage an emphasis was placed on use of experienced personnel and craft from previous SGRs.

These above owner and contractor lessons and practices resulted in the following improvements and success stories:

- Reduced durations and costs including schedule driven escalation and hotel loads
- Increased SGR project outage predictability for financial forecasts
- Increased consistency of performance
- Nth of a Kind standardization and repeatable processes across owners and contractors

<u>Multiple SGR Projects - Summary of Keys to Success and What Went Well</u>

- **Assigning Project Management Teams early and placing an emphasis on learning.**
- **Investing time, resources, money for long planning and preparation periods.**
- **Placing an emphasis on quality of planning and having a high-quality outage schedule.**
- **Open sharing and cooperation between the Utility Owners through industry conferences, publications and benchmarking during other's outages.**
- **Encouraging teamwork and cooperation including integrated Owner/Contractor organizations.**
- **Innovations in welding, NDE, rigging, training, and state-of-the-art metrology technologies.**
- **Comprehensive and prescriptive processes and programs.**
- **Repeated use of experienced and proven vendors and subcontractors.**
- **Emphasis on use of experienced personnel and craft from previous SGRs.**

4.6.3 Specific SGR Project Examples

Several SGR projects are discussed below to provide specific data, lessons learned, and best practices.

Calvert Cliffs Unit 2 SGR

Owner: Constellation Energy

Scope: Replace four (4) Steam Generators

Year: 2002

Result: Scheduled for 84 Days and Completed in 66 Days Breaker to Breaker

Key Takeaways:

1. Project performance can be attributed to lessons learned and corrective actions from Unit 1 SGR performance (Scheduled for 77 Days and Completed in 123 days)

2. Key success elements were a) an integrated outage schedule, b) contract revisions that implemented an integrated project organization and contractor incentives, c) change to SGR experienced project leadership, d) implementation of the Task Manager concept, e) implementation of Executive Oversight and Management Oversight Boards, f) having a Dedicated Issue Response Team and g) craft incentives.

Ft. Calhoun Refurbishment Outage

Owner: Omaha Public Power District (OPPD)

Scope: Comprehensive EPU involving Steam Generators, Pressurizer, Reactor Vessel Head, Low Pressure Turbines and Main Transformers

Year: 2006

Result: Completed five (5) days ahead of schedule and $40M under budget.

Key Takeaways:

1. Detailed planning and fostering teamwork amongst stakeholders were critical to success. Ross Ridenoure, VP and CNO of OPPD reflected on this SGR project as follows:

   "We spent literally hundreds of thousands of man-hours on our planning-everything from detailed outage planning, identifying and quantifying risks, developing contingency plans and mitigation strategies. Effective teamwork, communications, planning, and respectful but firm "pushback and problem resolution" were essential. These concepts were promoted via a "One Team" message prior to and during the project to ensure that the organization was ready and able to execute their plans."

2. An intense multi-year planning and preparation phase for the outage involved tremendous focus by all stakeholders to leverage past lessons learned into the schedule, design, and construction techniques.

Callaway SGR

Owner: AmerenUE

Scope: Replace four (4) Steam Generators

Year: 2005

Result: Scheduled for 67 Days and completed in 63 days Breaker to Breaker

Key Takeaways:

1. Platts Global Energy Award 2006 ENR/McGraw Hill Construction Project of the Year
2. Client credited a) Contract Structure, b) Teamwork and Team Building- “One Team”
3. Project was completed within 1% of budget set five (5) years earlier and four (4) days ahead of schedule.
4. Project also won two safety awards including Washington Group International’s Safe Project of the Year 2005.

References:

1. AmerenUE Presentation to INPO Supplier Workshop March 29, 2006- Recipe for Success- The Right Mix for Large Nuclear Projects

Diablo Canyon Unit 1

Owner: Pacific Gas & Electric (PG&E)

Scope: Replace four (4) Steam Generators

Year: 2009

Result: Completed in 67 days Breaker to Breaker

Key Takeaways:

- Nuclear industry standard practices and collaboration contributed to twenty- five years of continuous improvement.
- Instilled confidence in nuclear industry performance leading into the nuclear renaissance.
- From 1979 at 560 days to 55 days- a double order of magnitude improvement in project performance, however, new nuclear projects did not utilize resources that were familiar with SGR experience or nuclear energy lessons learned. We started the nuclear renaissance from scratch.

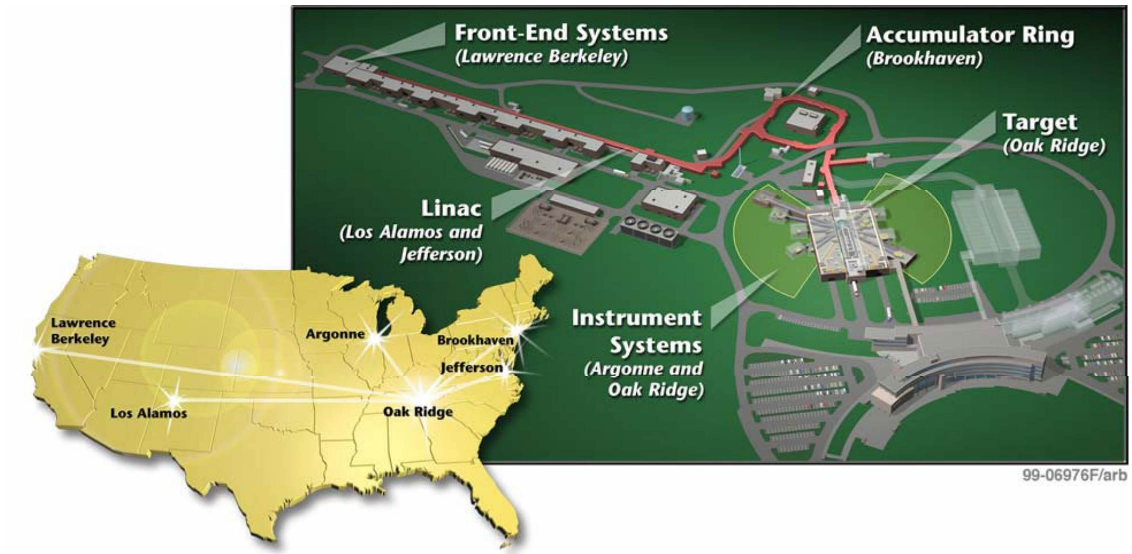
4.7 Spallation Neutron Source (SNS) Accelerator Project

4.7.1 Background

The Spallation Neutron Source (SNS) project is a $1.4 billion US Department of Energy (DOE) science project success story that was completed under budget and ahead of schedule from 1999 to 2006. The purpose of the SNS project was to design, construct, and commission into operation an accelerator-based, pulsed neutron research facility that would be substantially better than any other facility in the world. This one-of-a-kind, scientifically and technologically advanced facility would provide important scientific capabilities for basic research in many fields, including materials science, life sciences, chemistry, solid-state and nuclear physics, earth and environmental sciences, and engineering science.

The project objectives were to complete, by the end of June 2006, a facility capable of greater than 1 megawatt of proton beam power on target at a total project cost of $1,411.7 million. In August 1996, DOE recognized the need for the SNS Project, but it was not until 1999 that aggressive funding began. At that time, the project was baselined for completion in June 2006; construction began in December 1999. Even through one major change in technology during the project, all completion criteria were achieved in May 2006, one month ahead of schedule. The project was completed under budget, at $1.405 billion, producing a cost saving of approximately $6.5 million. **Exhibit 4.6** provides a basic layout arrangement of the SNS facility indicating the responsibilities for the six national laboratories involved with the project.

Exhibit 4.6, SNS Facility Arrangement and Scope Responsibilities



In 1999, the SNS site was nothing more than 80 acres of woods. From the outset, the technical precision necessary for installation of much of the facility equipment mandated adherence to stringent facility design and construction standards. Project management routinely planned and coordinated the often simultaneous construction efforts of 26 different general contractors and more than 40 suppliers and service providers to ensure that critical project cost, schedule, and technical milestones were met. In total, 14 facilities were constructed that house the technically advanced research machines and equipment, including a 1,050-ft-long linear accelerator (linac), ion beam transport tunnels, a proton beam accumulator ring, target building, a central laboratory and office building, and 26 electrical substations.

Annual budgets for this project were fixed at initiation of construction. An aggressive project completion schedule drove the accomplishment of many activities in parallel rather than serially. For example, on-going general construction of facilities took place while (1) installation and commissioning of the front-end systems was under way, (2) design for the next stage of the equipment (the linac) was being finalized, and (3) R&D for the final stage—target systems—was still being performed.

Throughout the project, the Project Team remained committed to meeting, or exceeding, the cost, schedule, and technical objectives. In May 2006, delivery of SNS ahead of schedule and under budget achieved the DOE mission need and the scientific community’s need for an accelerator-based, pulsed neutron research facility that is substantially better than any other facility in the world.

4.7.2 Lessons to Learn

A clear mission-need and program support from the top are imperative - High-cost projects will always be challenging, but it is essential that support from DOE-SC, Congress, and the scientific community never wavers.

Project Management Leadership and Integrated Team Approach – It is important to build a strong, effective project management organization early. It is imperative that the project management team have a project (vs program) mentality. Although some managers may have success in building the mission need, it does not necessarily ensure success in execution. The transition from conceptual design to project execution must be considered when filling key roles. In addition, the project management team must consist of experienced professionals, project and team builders, chief schedule drivers, and communicators; these people must be able to plan the staffing transitions at the end of the project. Early establishment of effective project leadership will establish the right vision and will attract qualified staff. In addition, project leadership must have the authority to make decisions in a timely manner.

The complex technical and management integration of the design, construction, fabrication, installation, and testing of SNS was successfully achieved through:

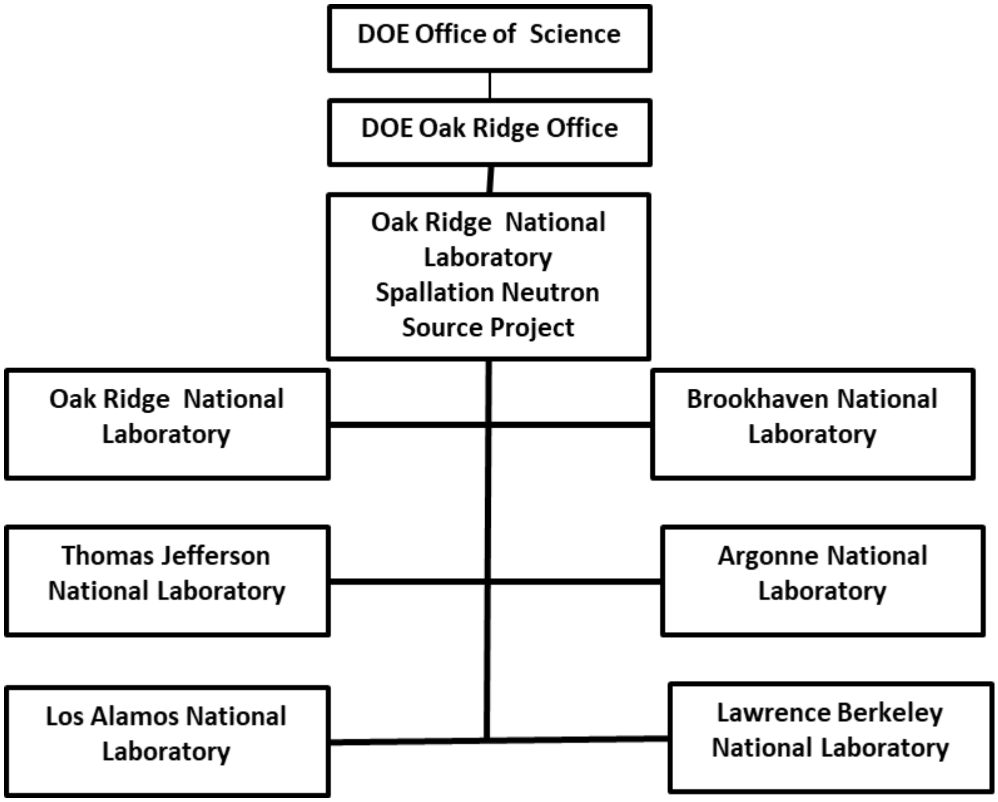
1. An integrated partnership of the DOE customer, and its federal representatives in the field, with the IPT of technical experts from the partner laboratories' managing contractors and a large AE/CM joint venture;
2. Integrated, electronically adaptable management information systems developed by the central project management team and used by all participating partners;
3. Integrated planning through joint development of project management and control plans, integrated schedules, flexible funding approaches, centrally controlled budgets and reserve funds, and verifiable design and performance requirements; and
4. Integrated, centrally managed change control and configuration management.

The SNS Project was a mammoth undertaking. The $1.4 billion project took seven years to complete and consisted of a 660,000-ft^2 building complex and associated scientific and technical systems. Successful design and construction of SNS involved resolution of complex scientific, technical, and construction challenges never before dealt with in any of these communities. Managing all of these challenges required innovative and effective project management. To meet these challenges, an unprecedented organizational partnership was established— six national DOE laboratories and a commercial architect-engineer/construction manager (AE/CM), Knight-Jacobs Joint Venture.

This partnership provided a tremendous foundation of technical and management strength, capability, and flexibility to support a complex, successful project. However, the partnership presented challenges as well. Each organization had its own systems and procedures, and the varied geographical locations of the partners complicated communications efforts.

SNS was an innovative, collaborative project comprised of six geographically dispersed DOE national laboratories, all responsible for significant scope. The overall project was integrated and managed by an Integrated Project Team (IPT) collocated at the construction site at ORNL. This integrated organizational structure is displayed in **Exhibit 4.7**.

Exhibit 4.7, SNS Integrated Project Team



The IPT was led by DOE Project Director Les Price and lead-contractor (ORNL) Project Manager Thom Mason, Associate Laboratory Director for ORNL. Together they shared responsibility for the overall successful execution of the SNS Project, including:

- Executive-level management of the research and development (R&D), design, construction, and transition to operations of the SNS facility to ensure that all mission requirements were fulfilled on schedule in a safe, cost-efficient, and environmentally responsible manner.

- Full financial authority and accountability for developing budgets and controlling SNS work within approved baselines and for controlling changes to approved baselines in accordance with established change control procedures.

Carl Strawbridge, deputy project manager and responsible for project controls, procurement, safety, quality, business, and human resources, assisted the associate laboratory director in day-to-day project management. Additional project management was conducted by three division directors (accelerator systems, experimental facilities, and civil facilities) within the SNS organization at ORNL and the Senior Team Leaders/Project Managers at each participating laboratory.

These directors were responsible for integrating design and fabrication and for managing the scientific, engineering, and technical staff performing the installation, testing, and commissioning of hardware in their area of responsibility. The directors were held accountable for performing their work safely and within budget and schedule.

Multi-laboratory partnerships with clear responsibilities and centralized budget authority can be successfully used for new, big-scale projects - One of the keys to the success of the SNS was being able to effectively align and use resources at partner labs, which extended the range of expertise and achieved a better product and allowed a slower, deliberate operations staff ramp-up. The success of a collaboration project in general, however, depends on the following:

- Strong leadership in the lead lab that will ultimately operate the facility. This is necessary to establish and enforce workable rules for collaborating, monitoring, and encouraging progress with all subprojects and for arriving at management decisions that equally respect the needs of the overall project and each of the subprojects.

- Technical expertise and strong systems integrator capability by the lead lab to manage integration and interfaces.

- Excellent communications between all partners with frequent and well-organized meetings, using state-of-the-art media technology.

- Strong support and commitment by the top management of each of the partner lab to accept institutional ownership and accountability, allocate adequate support (largely dedicated workforce), and help achieve project goals.

- A virtual single-site organization/approach; a structured but simple agreement (memorandum of agreement) should be used to describe how the project will work.

- Influence by the lead lab on the partner labs' performance fee and key staff evaluations.

Many project management tools and processes are needed to manage project performance, but processes alone are not sufficient to effectively manage project performance. Constant, unrelenting control of costs and scheduling using disciplined management systems is a must. This should include:

- Maintaining and measuring against an aggressive schedule.
- Planning work to fully use the annual budget authority.
- Ensuring that the project's annual funding profile is appropriate from the beginning.
- Obtaining competent, independent assessment and advice is imperative:
  - using ad hoc reviews as needed for specific problems and
  - using routine, disciplined peer review processes on all aspects of the project. This ensures that lessons learned from other projects are routinely incorporated, and it is an excellent tool for understanding and managing risks and vulnerabilities.
  - Ensuring that vendor management is performed by experienced personnel.
  - Planning carefully, anticipating problems, actively managing changes, and staying on top of the details.
  - Keeping an eye on things such as EAC and risk; planning for known risks and unknowns to achieve performance objectives.
  - Managing contingency centrally; this is an important risk mitigation approach.
  - Establishing and incentivizing performance for risk minimization, such as incentive contracts (especially civil construction) and creation/retention of reserves by partners.

Planning for commissioning and operations should take place early - Early planning for commissioning is needed to ensure cost estimates are within the TPC and to recruit operations staff. Additionally, the facility long-range upgrade strategy should be established early on between DOE and the Lab in enough detail to guide design decisions and facilitate future scope enhancements.

Innovative HR programs are key for successful recruiting and retention of staff - During the early several years of the project, there were difficulties in recruiting candidates and securing rapid acceptance and relocation. Candidates perceived that the Project could be subject to cancellation and were unwilling to leave stable employment and/or to lose compensation including pay and/or benefits. The DOE-SC chartered a team, the Working Group, to develop a proposal for assisting SNS in recruiting. The team was composed of representatives from the Headquarters and Operations Offices and contractors with expertise in project management, compensation with expertise in variable pay plans, benefits with expertise in retirement plans, and recruiting. As a result, the DOE-SC director approved implementation of the SNS Project's Human Resources (HR) Working Group's recommendations which became known as the SNS HR toolkit.

The toolkit included variable pay options, service-based benefits, and nonqualified tax-deferred retirement plan. SNS has experienced success in recruiting and retaining highly skilled staff to fill over 300 positions to date with an acceptance rate of about 85% and a turnover rate of about 4%. The SNS HR toolkit contributed to this success and effectively minimized issues associated with attracting highly qualified individuals to fill key positions. The toolkit use mitigated perceived differences in vacation and retirement benefits and eliminated the need to grant exceptions, base pay increases, and other actions that result in inequities. The cost impact of using these tools is negligible, and in some cases, recurring cost were avoided.

Safety requires the unrelenting attention and commitment of management and labor - It is extremely important to place emphasis on a rigorous safety culture from the beginning. The safety program must be "Workforce friendly". SNS's approach to this included an on-site nurse's station for quick attention to work-related injuries which was also available for non-work-related injuries. This helped maintain an environment that encouraged event reporting. Frequent "celebrations" were used to recognize workers with good safety performance. In addition, crafts participated in the Job Hazard Analyses and work process development.

The safety program must also be "Management driven". There must be a commitment from DOE, Laboratory management, the Construction Manager, and the subcontractors that safety is #1 priority. Actions by SNS included:

- Only contractors with good safety records could bid.
- "White Hat" oversight was utilized.
- Safety inspections were made by the Construction Manager's corporate and insurance company.
- A Master ES&H plan was used for all site work.
- Precursor events were tracked and trended.

Acknowledgments – This SNS Case Study of Keys to Success and What Went Well is based on:

- The first-hand involvement in the project by Carl Strawbridge, SNS deputy project manager 1999 to 2006

- Public domain document, 2007 DOE Summary of SNS Project Success and Nomination to PMI for Project of the Year, 35-page report
- Public domain document, 2006 DOE SNS Project Completion Report, 260-page report

4.8 2012 London Olympics Infrastructure and Facilities Project

4.8.1 Background

In 2005, the International Olympic Committee selected the London proposal to host the 2012 Olympic and Paralympic Games over four other bids. The initial cost was to be £2.375 bn based on a preliminary estimate and some negotiating with the governmental decision makers.[4] After the award, detailed design and infrastructure decisions needed to be made. The Olympic Delivery Authority (ODA) was established in April of 2006 to oversee and manage the infrastructure projects and the execution of the 2012 Olympic and Paralympic Games.

The selected site was a largely derelict and polluted site in Stratford, East London. The ODA's scope of work included the deconstruction and land remediation of the 400-hectare site, the construction of around 20km of roads, 13km of tunnels, around 30 bridges and new utilities infrastructure. It also oversaw the construction of 14 permanent and temporary sporting venues, a broadcast center, media center – for commercial use after the Games – the construction of the Athletes' Village, the creation of 80 hectares of parklands, gardens and public open space as well as huge transport improvements, including the Docklands Light Railway extension station and infrastructure works (sewers, potable water power and communications). [5]

The ODA selected a delivery partner CLM, – a private sector consortium comprising of a partnership from the three parent companies of CH2M Hill, Laing O'Rourke and Mace – and formed an integrated project team with the team members integrated at all levels within the organization, from the Executive Management Board down to the execution elements. The ODA team then produced a detailed baseline cost and schedule report that was published in November 2007. It identified the entirety of the scope including work elements associated with the Games themselves. The Total Project Cost for the 2012 Olympics and Paralympics was increased to £9.298 bn. The infrastructure program represented £8.099 bn of that total.

The ODA had an inherent advantage over other large, disruptive infrastructure projects. It was constructing the venue for a national celebration event. The prestige and economic value of hosting an international event like the Olympics instilled in all the stakeholders a sense of value and worth. Even so, the ODA team needed to satisfy a diverse host of stakeholders including government, media, local residents, and an interested general populace. It needed to establish communication mechanisms to appease all stakeholders and to assure governmental bureaus that they were providing value for the money. However, the galvanizing effect of working toward a worthwhile goal was easily instilled in all the participants in this effort.

[4] "London Olympics exceed initial budget by £6.50bn," by Alex Hern, BBC News, Feb. 1, 2007
[5] APM Project Management Awards, Winner's Case Study, BNFL Award 2012, C

In 2011, the ODA reduced the expected construction program's cost to £6.856 bn and brought the program to a successful conclusion in March 2012 for a total project cost of £6.714 bn. [6] This represents a cost savings of £1.835 bn over the 2007 authorization. The ODA was an ad hoc organization assembled quickly to perform a single, albeit complex, task. After the creation of the formal baseline for the program, the ODA performed admirably to bring the complex of projects to a successful conclusion ahead of schedule and under budget.

4.8.2 Lessons to Learn

Assemble an Integrated Project Team - The first, and arguably most important, aspect of this successful performance was the assembly of an integrated project team. The ODA managers incorporated the CLM managers at all levels of the decision making and execution levels of the organization. ODA led from the top and ensured coordination not only across the project levels but between all the various stakeholders. This eliminated the jurisdictional disputes and inefficiencies caused by multiple discrete organizational structures within a program. It also established a single language terminology.

Establish and Validate the Project Baseline - One of the activities of the Integrated Project Team (IPT) was to develop the cost and schedule baseline. This was a top down/bottom up exercise that sought to identify all the program elements, and fully examine and develop the set of deliverables required for each project of the program. There were 70 discrete projects with more than 1000 elements in the work breakdown structure (WBS). The schedule run on Primavera P6 was the common language of truth. All levels of the IPT agreed on the validity of the schedule. If it is not on the schedule, it is not real. 50 major projects dominated the effort and they were constructed on a complex of over 600 Land Areas (LA). These LAs were in close proximity to each other and conflicts and interferences were common. They needed to be carefully managed to avoid work stoppages or dangerous situations. [7]

The approach was informed by the experience of previous Olympic construction programs. The planning addressed the integration issues:

- Infrastructure and Venues work in parallel in a small area of land
- Key milestones for Infrastructure and Venues were driven from various project interfaces
- Design interfaces could lead to a project interface on site
- Principal Contractor methodology (site boundaries) and handovers of areas of land was a key interface factor
- Works by others in Principal Contractor areas could create disruption or re-sequence of work [4]

The method to address these issues was to identify the delivery partner, CLM, as the lead for the program schedule. The main features of the approach were as follows:

- Establish a suite of processes, meeting structure, reports and assurance framework
- Understand the interfaces using drawings, scope documents and the drivers for key deliverables
- Using weekly strategic and monthly detail integration meetings to review interfaces or understand and capture new ones

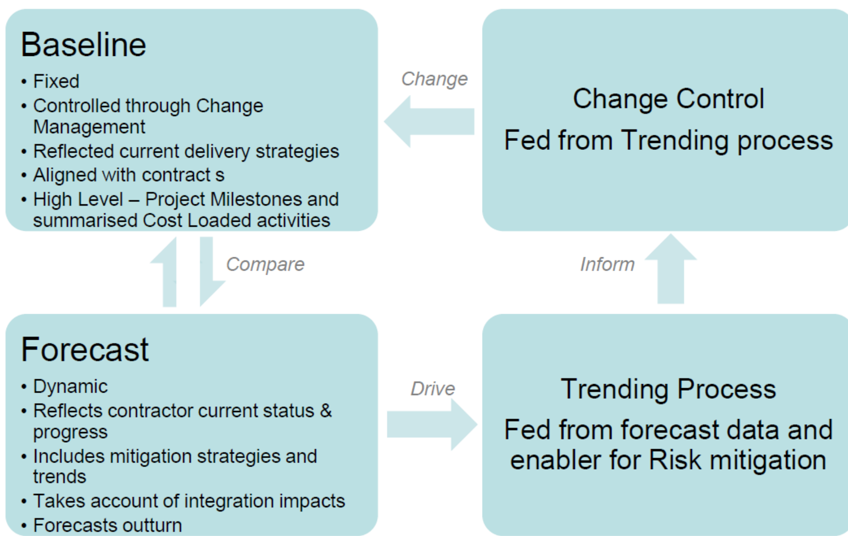
[6] "The London 2012 Olympic Games and Paralympic Games: post-Games Review," Report by the Comptroller and Auditor General, UK National Audit Office, Dec. 5, 2012
[7] "Olympics Lessons Learned Event Presentation slides, Section 2: Project Controls," Energus, Lillyhall, Cumbria, Feb. 21, 2013

- Capture the timing of the interface, the type, and the cost and schedule impact to successor activities or projects *(trend and raise changes)*
- Implement in P6 using specific processes/procedures/Coding structures
- Intensive tracking and monitoring

All teams were involved in monitoring and managing interfaces through regular co-ordination meetings and reporting.

Integrated Planning Approach to Assure On-Time Delivery - With ~50 individual projects to provide the venues and infrastructure for London 2012, the challenge was to ensure that plans were integrated and to avoid 'surprises' during delivery. A level 2 schedule was created to capture the key interfaces and progressively build the plan as detail became available. In parallel, a comprehensive process was established to identify, capture and coordinate integration across the program. The cost effectiveness of the solutions was increased by undertaking detailed monthly issues analysis of program level interfaces; this enabled appropriate, coordinated and timely mitigation.

Exhibit 4.8, Integrated Planning



An Earned Value Measurement System to Allocate Resources - Earned Value (EV) was chosen by the Olympic Delivery Authority (ODA) to objectively and consistently measure project performance across the London 2012 construction program. Combining scope, schedule and cost measurement into an integrated system allowed program-wide progress to be established efficiently and gave early warning of potential performance issues. Early warning allowed rapid deployment of mitigation actions or amended delivery strategies, and this became one of the key enabling factors for the program's ultimate success.

Vigorous Risk Management Approach Completed Venues 12-months Ahead of Schedule and Under Budget - The ODA was given a daunting task. The risks to success were great with a heavily contaminated site, worsening economic conditions, multiple stakeholders and the eyes of the world's press ever present. Key to the success of the ODA's approach was a risk management process that included a clear risk hierarchy (allowing the right people to manage the right risks), a robust quantified risk analysis controlling contingency allocation and a healthy balance of review, assurance and audit promoting an ‘honest’ culture of risk awareness.

Design Reviews of Cross-Border Projects Ensured Consistent and Coordinated Design Approvals – With so many venues and so many Land Areas in close proximity, design reviews and approvals could have resulted in conflicts and interface issues. This was addressed on the Park by establishing an independent approval body – the Olympic Infrastructure Technical Approval Authority (OITAA) – to represent the five London Host Boroughs and act as an independent single point of contact for the design review process. This enabled access to a pool of specialists to ensure compliant designs and encouraged innovation.

ODA’s Commitment to Quality Set the Overall Tone for the Project - Delivery Partner Project Managers fostered the effort, ensuring that all parties contributed to the quality agenda, and that that effort was recognized from the outset. The demand for high quality construction on the Olympic Park was established very early in the development program. This requirement was enforced by Quality Workshops for all personnel and an attitude of select simple materials and high-quality construction. “Do it Once; Do it Right” was the message. A vigorous Quality Assurance program sought to capture systematic problems to avoid quality failures.

The Integration of the Construction was Complex - The venues for the Olympic games are sports arenas, stadia, open areas for shooting, archery and waterways for whitewater events and skulls. However, they could have gotten into trouble with aggressively creative architectures requiring difficult to source and/or work within the field. Accordingly, the designs were purposely kept simple and utilitarian using easily procured materials. The principle “invest once, invest wisely” was established early in the program to ensure the best possible quality was clearly evident during, and after, the Games. Most of the infrastructure has been repurposed after the Games and are now part of a revitalized area of London.

Direct Connection with the Supply Chain - The ODA proactively reached out to involve people in Tier 1 suppliers and beyond at all levels – management to workface. They established rigid control and assured outputs for objectives, standards and reporting toolset but not prescriptive about *how* they are delivered. They all benefitted from a collaborative framework and procurement was consistent utilizing program-wide practices.

Enjoyed the Benefit of a Motivated Work Force - As mentioned before, the London Olympics was an event that generated considerable national pride. It should not be underestimated the value that accrued to the program because everyone involved at all levels was committed to its success providing a key motivation for labor resources. For the London Olympics, this was a relatively easy attitude to engender in the work force, but it is an essential part of every project. People want more out of life than working for a paycheck. If the project team can generate genuine enthusiasm for the end result, getting the interactive and open communication that is necessary for a successful project becomes easier to achieve.

Proactive Stakeholder Outreach Program - During this program, the ODA oversaw or managed the following projects:

- Infrastructure
    - Powerlines
    - Utilities

  - Enabling Works (Sewer improvements, Water and Storm Drainage)
  - F10 Bridge
  - Other Structures, Bridges and Highways
  - Prescott Lock Waterways
  - Landscaping
- Venues
  - Olympic Stadium
  - Aquatics Center
  - Hockey Stadium
  - Velopark
  - Handball/Indoor Sports Arena
  - Basketball
  - Fencing
  - Water Polo
  - Eton Manor – Rowing
  - Wembley Arena – Badminton
  - Royal Artillery Barracks - Shooting
  - Non-Olympic Park Training Venues
  - Venues Reconfiguration
- Transportation Assets
  - Stratford Regional Station
  - Docklands Light Railway
  - West Ham Station
  - Thornton's Field Line
  - North London Line
  - Other Transport Capital Projects
- Athletes Village

Exhibit 4.9 - Infrastructure Work for the London Games

ODA established a vigorous, transparent communication system within the IPT and for reporting out to other stakeholders. The system consisted of:

- Construction Integration Teams to understand and capture the interface
- Integration Planners to implement the interface in P6
- Both teams to monitor the interface through meetings and regular reporting
- Regular weekly/bi-weekly co-ordination meetings with project teams
- Identification of 3rd Party representatives and regular meetings
- Infrastructure/Venue directorates responsible for park integration
- Monthly Executive level meetings to discuss Amber/Red integration issues

Captured Lessons Learned for Future Reference - Effective Project Closeout should include a detailed summary of the lessons learned. This is often ignored in the rush to demobilize after completing. The ODA captured all of the lessons from this successful program on a Lessons Learned website. [8]

[8] https://webarchive.nationalarchives.gov.uk, archived Oct. 3, 2016

4.8.3 Unique Insights Limited Future Applicability

There are also aspects of the 2012 London Olympics that have already been applied to Hinkley Point C, which have not helped the project deliver on-time and on-budget success. These aspects are being detailed herein so that future projects do not inappropriately apply them as well (e.g., Great British Nuclear SMR initiative).

- The London Olympics used a horizontally split subcontracting arrangement. Civil/Structural subcontractor built the building and then moved on to the next venue. Separate contractors for HVAC, electrical, mechanical, etc. then followed and installed the kit in the building. This works fine for the type of venue needed for the Olympics, however this does not work for the open top construction of a nuclear reactor building where all these contractors must work side-by-side, in parallel, as the reactor building is built and kitted-out floor by floor.

- Too many subcontracts. With too many subcontractors comes too many interfaces, too many hand-offs, and too many claims of interference.

2012 London Olympics Infrastructure and Facilities Project – Summary of Keys to Success and What Went Well

- **Assemble an Integrated Project Team**
- **Establish and Validate a realistic Project Baseline**
- **Implement an Earned Value Measurement System to Allocate Resources**
- **Vigorous Risk Management Approach Completed Venues 12-months Ahead of Schedule and Under Budget**
- **Design Reviews of Cross-Border Projects Ensured Consistent and Coordinated Design Approvals**
- **ODA's Commitment to Quality Set the Overall Tone for the Project**
- **Recognition that the Integration of the Construction was Complex**
- **Establish Direct Connections with the Supply Chain**
- **Enjoyed the Benefit of a Motivated Work Force**
- **Implement a Proactive Stakeholder Outreach Program**
- **Captured Lessons Learned for Future Reference**

4.9 Washington Public Power Supply System Nuclear Unit 2 (WPPSS 2)

4.9.1 Background

The Washington Public Power Supply System (WPPSS) was founded in 1957 to guarantee electric power to the Pacific Northwest. It primarily distributed the electricity generated by the Bonneville Power Administration (BPA) that had control over the Government-funded hydroelectric dams built on the Columbia River. In the 1960s, load growth projections included the construction of aluminum bauxite plants to support the region's burgeoning aircraft industry. The refining of aluminum from bauxite is an energy intensive process and is only profitable in areas where electrical power is plentiful and inexpensive. This coupled with the economic growth in the region resulted in load growth projections that indicated that demand would double every decade. This would rapidly outstrip the potential capacity of the existing hydroelectric dams. In order to attract this industry to the region, the BPA produced an aggressive plan to supplement the output of the hydroelectric generation with a collection of thermal power plants, primarily nuclear.

Using the time-honored practice, WPPSS issued individual requests for proposals in 1968 for the first three nuclear projects (the only ones financially backed by BPA). Using the competitive mindset for procuring commodities, the projects were awarded to three different reactor vendors, two PWRs and one BWR, and three different design/construction teams. Worse yet, the projects were envisioned as “Fast-Track” construction projects wherein construction would take place while the engineering was still being performed. This was considered state-of-the-art at the time but could be accurately described as “construct-at-risk” projects. If something interrupts the flow of information from the engineering team to construction crews, the entire process fails. This was a risk that no one considered seriously in the early nuclear power program.

At the time of the WPPSS projects, the nuclear industry had just entered the chaotic period in which the regulations changed often. The Atomic Energy Commission (AEC) had the dual role of promoter and regulator of this new energy source and had funneled government resources in support of it. In 1975, the AEC had been replaced by the Nuclear Regulatory Commission with the sole mission of regulation. The NRC exerted itself and a wide range of new and revised rules appeared over the next decade. Compliance was mandatory and designs had to be revised regardless of the impact. This destroyed the flow of information from engineering to construction and worse, it often resulted in significant rework or additions to the scope of the project. The “Fast-Track” construction teams would be left waiting in the field for design changes that were never anticipated. These changes usually required additional engineering analysis and design revisions to demonstrate full compliance. Rework and field changes to already installed structures, systems and commodities were unavoidable.

The 1970s were a turbulent time to design and construct nuclear plants. While universally supported at the beginning of the decade, a determined anti-nuclear PR assault eroded public support by the end of the decade. The Three Mile Island Unit 2 accident in 1979 further damaged the credibility of nuclear power in the U.S. and resulted in a new wave of design requirements and modifications. Economically, the 1970s were dominated by two recessions and runaway inflation. Interest rates were in the double-digit range making the tax-exempt bond issued by WPPSS (backed by BPA) extremely costly. This caused the plans for the aluminum smelting industry in the Pacific Northwest to collapse and a general slowdown in the region’s electrical load growth. This all resulted in the gradual realization that the BPA plan and for the WPPSS nuclear program was in economic peril.

4.9.2 Lessons to Learn

The WPPSS nuclear program violated most of the rules for managing mega-projects offered in this report. First, the managers of WPPSS did not realize that they were embarking on a mega-project. Their experience in the business of building large, thermal, electrical generating plants was essentially non-existent. Their experience with nuclear plants was totally non-existent, as were most of the rest of the nation’s utilities in 1968. The WPPSS management team selected three different reactor designs so they could not apply lessons learned from one unit to the next. They engaged three separate design-build teams so there could be no process efficiencies by sharing resources from one project to the next. The teams would be in active competition for local sparse resources throughout the decade. Most of the labor was imported and did not have the proper nuclear construction mindset. Rather than building an integrated project team with strong licensee leadership, they purposely farmed out numerous small contracts to local companies to foster local support for the project. This resulted in a construction force consisting of hundreds of contractors, actively competing among the System's projects for resources.

Exhibit 4.10, Columbia Generating Station (WNP-2)

Only WNP-2 survived this onslaught of bad news. It was designed and constructed during the same bad economic times. It also had numerous design changes after construction had begun forced by new or revised NRC regulations or reactor vendor revisions to the safety basis design. It was beset with the same QA problems that dominated early nuclear projects when the quality standards of nuclear were understood or not properly applied. The TMI-2 accident happened in 1979 forcing uncertainty about what new regulations the NRC would promulgate. Mt. St. Helens exploded in 1980 covering the construction site with sticky ash. It suffered from labor walkouts of the pipe fitters in the 1975 – 1977 timeframe (that, not coincidentally, occurred during the construction of the Alaska oil pipeline). Indeed, the project was hit with a BWR-specific problem in that the dynamic response of the suppression pool piping had been under-estimated by GE forcing a massive redesign of the piping supports in the already constructed suppression pool. Yet, WNP-2 (now called the Columbia Generating Station) was completed and went into commercial operation in 1984.

<u>Establishment of an Owner-Lead Team</u> - WPPSS performed the construction management of the WNP-2 project. The unsuccessful projects were contractor-led teams and whereas both contractors were experienced nuclear construction companies, they lacked the direct interface with the most important stakeholder: the licensee. WNP-2, on the other hand, had a direct line of communication with the Licensee. Moreover, the Licensee had a better relationship with the local contractors and supply chain, that helped to overcome the lack of nuclear supply chain availability in the Pacific Northwest.

<u>Design Maturity</u> – While far from ideal, WNP-2 benefitted somewhat from the fact that the A-E had developed the plant design for the Nebraska Public Power District as a potential second unit for the Cooper Nuclear Station. That plant was never approved but the conceptual design work was applied to the WNP-2 proposal. Therefore, much of the engineering had been initiated prior to the beginning of the project.

Another contributing factor was the way the project dealt with the numerous pipe fitters' walkouts. Because of the piping problems a decision was made to continue forward without installing the piping., As a result of this decisions the construction managers shutdown all construction at the site. As described by Frank J. Patti who was the Chief Nuclear Engineer for the WNP-2 engineering company at the time,

> *"…the idea was that the other trades would put pressure on the pipe fitters to come back. Also, the construction team did not want to engage in work arounds that would make the construction inefficient."* [9]

This preserved the logic in the construction sequencing and provided time for the engineering team to catchup with construction. This eliminated some of the risk associated with the "Fast-Track" construction approach. Therefore, much of the rework experienced by the other projects was avoided by WNP-2.

<u>Established a Valid Baseline Construction Schedule</u> - At the time of selection, the design A-E was in the process of completing a nuclear construction project for the Nebraska Public Power District. They had a validate real-world construction schedule at the outset of the project. Although the subject plant was an older version of the GE BWR, a fully vetted construction schedule was available at the beginning of construction. Most of the assumptions were overcome by events, but the logics in the sequence were firm. At the time, schedules were produced manually with automated tools only becoming available near the end of the construction. This made changes to the baseline extremely problematic. The approach to the labor upsets caused by strikes described above also served to preserve the logics underpinning the baseline.

WNP-2 also benefitted somewhat from the fact that the post-TMI regulations were more impactful on the PWR designs of WNP-1 and WNP-3. WNP-1 was under an additional challenge since the reactor design was by the same manufacturer as TMI-2.

<u>Cost was the Final Determining Factor -</u> In the end, the decision to finish WNP-2 was financial. The project cost estimate in the 1981 Washington Public Power Supply System, Annual Report for the five nuclear projects are shown in **Exhibit 4.11** below. With the load growth, it became obvious that the BPA plan for aggressive electrical capacity growth in the region had become unnecessary. WNP-4 and WNP-5 were cancelled first since they had no funding source. These were followed by WNP-1 and finally WNP-3. WNP-2 went online in 1984 and has been operating ever since. It was renamed Columbia Nuclear Station in 1998.

Exhibit 4.11, WPPSS Nuclear Projects Summary

	WNP-1	WNP-2	WNP-3	WNP-4	WNP-5
Original	$1.104 B	$0.507 B	$0.993 B	$3.377 B	NA
1981 Est.	$4.268 B	$3.216 B	$4.532 B	$5.510 B	$6.261 B

[9] Telephone interview conducted Nov. 7, 2019

The WPPSS WNP-2 experience is informative in that it demonstrates the benefits of:

- Licensee involvement and leadership (WPPSS was only directly involved in WNP-2)
- Design completion before construction (WNP-2 started with a conceptual design)
- The value of maintaining the logic of the construction sequencing (no work arounds during labor dispute)
- The benefit of an Integrated Project Team approach (by its utter absence from these failed projects)

The partial application of only some of the rules of this report resulted in dramatically different results. The lesson of the WPPSS experience is not that, even in the face of daunting challenges, a nuclear project can succeed if approached with the proper approach.

<u>Washington Public Power Supply System – WNP-2 - Summary of Keys to Success and What Went Well</u>

- **Assembled an Owner-Lead Construction Project Team**
- **Design maturity was advanced at project outset**
- **Took a pro-active approach to schedule compliance**
- **Maintained good relations with local supply chain**

4.10 Barakah Nuclear Energy Plant

4.10.1 Background

> *"In 50 years, when we might have the last barrel of oil, the question is: when it is shipped abroad, will we be sad? If we are investing today in the right sectors, I can tell you we will celebrate at that moment."* – His Highness Sheikh Mohamed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi and Deputy Supreme Commander of the Armed Forces, in his address at the 2015 Government Summit

The Barakah Nuclear Energy Plant is in the Al Dhafra Region of the Emirate of Abu Dhabi, United Arab Emirates (UAE) on the Arabian Gulf, approximately 53 km west-southwest of the city of Ruwais. Developed by the Emirates Nuclear Energy Corporation (ENEC), the plant is the cornerstone of the UAE Peaceful Nuclear Energy Program. The plant has four APR1400 reactors and supplies ~25% of the UAE's electricity needs, while preventing the release of 21 million tons of carbon emissions per annum.

Construction of the plant commenced in July 2012, following the receipt of the Construction License from the UAE regulator, the Federal Authority for Nuclear Regulation (FANR), and a No Objection Certificate from Abu Dhabi's environmental regulator, the Environment Agency – Abu Dhabi (EAD). In 2015, ENEC submitted the Operating License Application (OLA) for Units 1 and 2 on behalf of the operating subsidiary, Nawah Energy Company. FANR issued the Operating License for Unit 1 to Nawah in February 2020 and began fuel load and start-up that same year. Since then, Units 2, 3, and 4 have each successfully completed their own fuel loading and start-up. Today, all four units are in commercial operation (2020, 2021, 2022, and 2024), providing the UAE with clean, reliable, and abundant electricity powered by nuclear energy, marking a new era of energy production for the nation.

At the peak of construction, more than 20,000 workers were based in Barakah, and the plant was the largest nuclear energy construction globally. Yet, what makes the UAE Peaceful Nuclear Energy Program truly unique is that it has been developed in line with the highest international nuclear safety standards, with the first unit licensed for operations in a little over a decade. While there have been challenges, as would be expected with a program of this size, scale and complexity, there have been a series of key principles and activities that have enabled this level of achievement. The project's success has stemmed from a well-crafted strategic development framework, specifically:

- Development of a comprehensive national policy and subsequent adherence to its principles:
    1. A commitment to the highest standards of safety and security.
    2. Open collaboration with responsible nations and international agencies to incorporate international best practices and lessons learned.
    3. A commitment to transparency and active public engagement.
    4. A commitment to the highest international standards for nuclear safeguards and nuclear nonproliferation.
- Smart and informed technology and partner selection, providing an opportunity to incorporate learnings from the reference plants and a systematic approach to developing four units in a parallel, yet staggered approach.
- A centralized organization that has evolved into a leading enterprise.
- Establishment of a focused and efficient governance structure that meets the highest international standards of quality, safety, security and operational transparency.
- Commencing local capacity building at the start of program inception.
- Collaboration with industry organizations.
- Active development of a local nuclear supply chain.

As a result, the UAE has emerged as a leader in new build peaceful nuclear energy development and provides a new model for nuclear energy financing.

4.10.2 Lessons to Learn

<u>Development of a comprehensive national policy and subsequent adherence to its principles</u> - The journey of the UAE Peaceful Nuclear Energy Program commenced in 2006 with a study into the nation's energy demand and supply projections. Strong economic and social growth in the UAE resulted in a significant surge in energy demand. The need was clear: the UAE required new power generation technologies to produce safe, clean and reliable electricity to power its growth over the coming decades. A comprehensive process analyzed all proven generation technologies against a series of strategic criteria that included the capacity to contribute to energy security, diversification and environmental sustainability. The study resulted in selecting peaceful nuclear energy and renewable energy as complementary technologies to power the UAE's future.

In April 2008, the UAE Federal Government published the *UAE Policy on the Evaluation and Potential Development of Peaceful Nuclear Energy*. This foundational document articulated a clear policy and principles that have been fully adhered to throughout the UAE Program's development. There are several primary principles that provide the overarching direction for the life of the program.

1. Commitment to the Highest Standards of Safety and Security. In only a decade, the UAE has evolved from a new entrant in civil nuclear programs, to a reputed nuclear developer that has established a culture of operational transparency and high nuclear safety and quality standards. This approach has meant that the UAE vision of delivering peaceful nuclear energy has been reached efficiently and effectively. Leadership focus and commitment, along with a team of remarkable UAE national and international experts working in close collaboration with international entities, enabled – over the span of a decade – the steady progress to become the 33rd nation to commence nuclear operations for peaceful purposes.

2. Open collaboration with responsible nations and international agencies to incorporate international best practices and lessons learned. From the start, the UAE has worked in conjunction with the IAEA on its nuclear policy, which is built upon the most exacting standards of nuclear safety, transparency, security and non-proliferation. Fuel load was completed following receipt of the Operating License for Unit 1 from the UAE regulator, FANR, and international endorsements from the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO). After which, ENEC and its operating subsidiary Nawah have undergone inspections missions, and peer reviews, from these and other bodies. All have been aimed at ensuring the highest international standards have been met throughout.

Exhibit 4.12, ENEC Celebrates the Achievement of 75 Million Safe Work Hours without a Lost Time Injury

As a member of the IAEA since 1976, the UAE reached a new phase of involvement in the agency when the country launched the UAE Peaceful Nuclear Energy Program. Based on UAE government requests, the IAEA has conducted more than 11 major international review missions to ensure the UAE Program and the nuclear infrastructure in the country comply with IAEA standards in safety, security and non-proliferation. The UAE was the first nation to undertake phase three of the comprehensive International Nuclear Infrastructure Review (INIR) in 2018, receiving positive feedback along with areas for improvement, which have since been addressed prior to the commencement of operations.

3. A commitment to transparency and active public engagement. After a decade of development, operational transparency remains fundamental to the UAE program. It enables the UAE to receive nuclear energy experts and authorities from around the world and instills the unique mindset of continuous improvement and lessons learned from the global nuclear energy industry within the UAE program.

In 2010, the UAE established the International Advisory Board (IAB), an independent panel of reputed international experts led by Hans Blix, former IAEA Director General for four consecutive mandates from 1981 to 1997. From 2010 to 2018, the IAB reviewed the progress of the UAE in achieving and maintaining the highest standards of safety, security, non-proliferation, transparency and sustainability. The group of internationally recognized experts in the fields of nuclear safety, security and non-proliferation met with all of the entities involved in the development of the program. They raised any and all questions and captured their views in publicly available reports. But most importantly, they made the program improve in every way.

Deep engagement and transparency across the program's stakeholders has also been fundamental to its strong reputation and high level of support within the UAE community. From the outset, ENEC has engaged extensively with UAE residents, businesses and government through a range of channels including public forums, events, school and university visits – focusing first on awareness and understanding of nuclear energy and the UAE Program, as well as responding to any stakeholder issues or concerns as they arise. Stakeholder perceptions and awareness levels are regularly monitored through research programs, with the results used to inform ongoing outreach efforts.

ENEC has always prioritized communications – particularly in challenging times. In the days, weeks and months following the accident at Fukushima Daiichi, communications efforts were intensified to inform, educate and reassure the program's key stakeholders of the critical issues and events as they unfolded. Similarly, when ENEC revised its program timeline to ensure safe operational readiness preparations, openness and transparency around this safety-focused decision led the way. It is perhaps then of little surprise that trust in the UAE peaceful nuclear energy program is high across the board. There has consistently been a high level of confidence amongst stakeholders in the UAE's ability to deliver a world-class program.

4. A commitment to the highest international standards for nuclear safeguards and nuclear nonproliferation. The UAE is fully committed to upholding its non-proliferation commitments. The UAE joined the Non-Proliferation Treaty in 1995, has been a member of the IAEA since 1957, and cooperates with the Missile Technology Control Regime. In 2010, the UAE ratified the IAEA Additional Protocol to the Safeguards Agreement. The UAE is a partner-nation on the Global Initiative to Combat Nuclear Terrorism and a signatory to the Proliferation Security Initiative, which is aimed at stopping shipments of weapons of mass destruction, their delivery systems, and related materials worldwide.

In 2009, the U.S. and the UAE signed a bilateral agreement for peaceful nuclear cooperation that enhanced international standards of nuclear non-proliferation, safety and security, known as the 123 Agreement. Under the terms of the agreement, the UAE gained access to significant capabilities and experience in the peaceful use of nuclear energy. This has provided support to the UAE in developing its peaceful nuclear energy program to the highest standards of safety, security and non-proliferation and opened opportunities for U.S. firms to be active participants in the UAE program. Cooperation with the U.S. and other countries has been a vital contributor to the success of the UAE Peaceful Nuclear Energy Program and the Barakah Nuclear Energy Plant to date.

5. Smart and informed technology and partner selection, providing an opportunity to incorporate learnings from the reference plants and a systematic approach to developing four units in a parallel, yet staggered approach. The technology selected for the Barakah Nuclear Energy Plant was chosen as a result of a robust selection process with safety, quality, efficiency, and reliability at its core. The APR1400 is the latest generation technology, meeting the most stringent safety standards, having achieved international accreditations, including design certification by the U.S. Nuclear Regulatory Commission (NRC), and having been approved for use by the UAE's national regulator, the Federal Authority for Nuclear Regulation (FANR). The reference plant for Barakah, Shin Kori 3 in South Korea, has been commercially operating safely and steadily for more than three years and has provided vital operating experience and lessons learned that have greatly benefitted the development of the Barakah plant.

ENEC selected the APR1400 following an exhaustive evaluation process by a 75-member team of experts. In 2009, a panel of international nuclear experts with more than 600 years in collective industry expertise selected the consortium led by the Korea Electric Power Corporation (KEPCO) for plant construction and delivery.

KEPCO was the obvious candidate for the UAE because of its position as a leader in nuclear safety, its plant reliability and its commitment to deliver its know-how to a new generation of Emirati nuclear leaders who, 10 years later, guide the journey to delivering clean electricity to the UAE.

6. A centralized organization that has evolved into a leading enterprise. A 2009 royal decree established ENEC to develop a peaceful nuclear energy program to meet the UAE's growing energy demands. The company's mission is to deliver safe, clean, efficient and reliable electricity to the UAE grid; develop its people and build sustainable nuclear sector capability; and ensure full alignment with the UAE's energy strategy.

As the centralized organization responsible for delivering the Barakah Nuclear Energy Plant, ENEC has continually delivered on a series of significant milestones over the past decade. This includes selecting and receiving approval of the plant site, applying for and receiving the Construction License for all four units, establishing workforce development programs and adopting state-of-the-art training technologies.

Due to ENEC's unwavering commitment to the highest international standards since the early days of the project, the UAE has emerged as an example for other nations considering the development of new build peaceful nuclear energy programs. Today, the four units of the Barakah plant are complete.

7. Establishment of a focused and efficient governance structure that meets the highest international standards of quality, safety, security and operational transparency. A new governance structure based on the three companies – ENEC, Nawah Energy Company and Barakah One Company – builds on the lessons learned since 2009. Each with its own area of focus and responsibility, these companies work together to support and deliver the Barakah project in accordance with the highest international standards.

Nawah was established in May 2016 with a mission to safely and reliably generate electricity from nuclear energy to power the growth of the UAE. It is responsible for operating and maintaining the four units at Barakah, making it one of the newest operators in the global nuclear energy industry.

Nawah is a multinational, multicultural and Emirati-led company. It has a growing team of experts dedicated to supporting the UAE Nationals who are shaping the success of the nation’s nuclear energy industry. Nawah achieved several important milestones that include completing a comprehensive series of preoperational tests that evaluate the plant’s systems to ensure that they operate as designed. These tests were completed before loading nuclear fuel.

In October 2016, ENEC and KEPCO signed a joint venture agreement that builds on their successful relationship. The agreement establishes KEPCO as a long-term partner in the UAE’s nuclear energy program and allows the nation to benefit from KEPCO’s demonstrated performance as a safe and quality-driven nuclear constructor and operator.

The joint venture agreement also established Barakah One Company and made KEPCO a minority shareholder in that company as well as Nawah. Barakah One Company is responsible for managing the Barakah Nuclear Energy Plant’s commercial interests, securing project financing from institutional and commercial lenders, and receiving funds for the electricity generated at the plant. Shortly after Barakah One Company was established, it signed a power purchase agreement with the Abu Dhabi Water and Electricity Company, now the Emirates Water and Electricity Company, establishing a pricing structure for the electricity produced at the plant.

8. Competency and Focus Maximize Benefits. The governance structure with three focused companies is an efficient and effective way to grow the UAE’s nuclear energy sector. While the companies work collaboratively to support Barakah, ENEC continues to oversee project delivery and UAE program development, while Nawah and Barakah One Company focus on their unique areas of expertise and responsibility. This ensures that work focused on construction, development, testing, operations, maintenance and financing is executed in a safe, efficient, coordinated and timely manner.

As the Barakah Nuclear Energy Plant nears full completion and operations, these companies position the UAE program for long-term growth, sustainability and success.

9. Commencing local capacity building at the start of program inception. ENEC and Nawah used unique and innovative methods to develop the workforce that were responsible for operating, maintaining and supporting the Barakah Nuclear Energy Plant.

ENEC has two full-scope APR1400 training simulators at its Simulator Training Center at Barakah. These simulators are among the most advanced nuclear training devices in the world and the first of their kind in the Middle East. Using complex modeling of the reactor core and advanced instrumentation and control systems, the simulators replicate the actual environment and conditions that operators in the plant’s control room would experience in a real-world situation. These devices also provide the opportunity for reactor operators to experience unplanned events that they would not be exposed to during day-to-day operations.

Simulator training plays a critical role in preparing the UAE’s workforce to operate the four reactors at the Barakah Nuclear Energy Plant. It also complements a comprehensive training program that supports personnel in attaining their reactor operator (RO) and senior reactor operator (SRO) certifications, as well as their continuous training needs.

Many talented UAE nationals, including a number of women, have completed an exhaustive three-year training program and have been certified by FANR as Senior Reactor Operators (SROs) and Reactor Operators (ROs). They represent the first Emirati professionals in this advanced field of the peaceful nuclear energy sector.

The initial fuel load in March 2020 was led by a team of highly trained and FANR-certified fuel operators, with over 90% participation of Emirati experts who were previously trained in the APR1400 technology in South Korea. This team led the transfer and loading of the 241 fuel assemblies into Unit 1 in preparation for start-up and subsequent operations.

10. Collaboration with Industry Organizations. The UAE Peaceful Nuclear Energy Program benefits from the expertise and operational experience of the global nuclear energy industry. The UAE adopted best practices from operators around the world and from industry organizations, including the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO).

ENEC also joined the Nuclear Energy Institute (NEI) as an international member, gaining valuable perspectives and learning in real time through access to and collaboration with relevant committees and working groups.

11. Active development of a local nuclear supply chain. ENEC worked with local companies to upgrade their processes and systems to become qualified as a nuclear-approved supplier under international certification standards. ENEC and KEPCO also held regular Supplier Forums to ensure local companies were informed about upcoming opportunities and were educated on the steps required to register for the tendering process for the Barakah Nuclear Energy Plant.

More than 2000 UAE companies were contracted for the delivery of products and services at Barakah, with contracts committed to the value of $4.8 billion. Companies including Emirates Steel, National Cement, Dubai Cable Company (DUCAB), National Marine Dredging Company, Western Bainoona Group, and Hilalco. Through its work with local companies, ENEC is not only supporting existing UAE businesses but also contributing to the development of the local economy while stimulating the growth of industry in the UAE.

The Program has also benefited the nuclear economies around the world. In the US alone, since the program’s inception, more than $2.75 billion has been committed through contracts with 175 US suppliers located in 33 states and Washington D.C. Additionally, ENEC, Nawah and Barakah One Company together employ more than 1,000 US citizens as full-time employees and as independent and affiliated consultants.

12. Emerging as a Leader in New Build Peaceful Nuclear Energy Development. The four units at the Barakah Nuclear Energy Plant make the site one of today’s most advanced nuclear energy facilities and set the bar for new nuclear construction and development around the world. Upon the successful completion of fuel loading at Unit 1, the UAE officially became a peaceful nuclear energy operating nation – the first in the Arab World, and the 33rd globally to achieve this level of national intellect and sophistication in nuclear energy development. The UAE continues its journey towards operational excellence, generating clean baseload electricity, and the continued development of the UAE program.

Barakah Nuclear Energy Plant - Summary of Keys to Success and What Went Well

- **Development of a comprehensive national policy and subsequent adherence to its principles**
- **Smart and informed technology and partner selection, providing an opportunity to incorporate learnings from the reference plants and a systematic approach to developing four units in a parallel, yet staggered approach**
- **A centralized organization that has evolved into a leading enterprise**
- **Establishment of a focused and efficient governance structure that meets the highest international standards of quality, safety, security and operational transparency**
- **Commencing local capacity building at the start of program inception**
- **Collaboration with Industry Organizations**
- **Active development of a local nuclear supply chain while still relying on many international best athletes**

4.11 Muskrat Falls Generating Station

4.11.1 Background

The Muskrat Falls Generating Station (MFGS) in Newfoundland and Labrador in Canada was conceived as part of a broader plan to expand the province's hydroelectric capacity. Nalcor Energy was tasked with leading this initiative. In 2012, the provincial government sanctioned the Lower Churchill Project, which included construction of an 824 MW hydroelectric station, a 1,100-kilometre transmission link with an undersea cable, and supporting transmission assets. The original schedule promised first power in 2017, but the project was not declared complete until April 2023, six years late.

From the outset, the project was marked by optimism bias and strategic misrepresentation. The sanctioned budget of $7.4 billion was based on aggressive assumptions, with insufficient contingency and no management reserve. By the time the project was completed, the final cost had escalated to approximately $13.5 billion. Nalcor pursued an Engineering, Procurement, and Construction Management (EPCM) model, initially led by SNC Lavalin. However, SNC Lavalin struggled to meet staffing and schedule commitments, forcing a shift to an integrated management model directly overseen by the owner.

Despite Nalcor's experience in operating smaller hydro facilities, the organization lacked the internal expertise to manage a megaproject of this scale. It relied heavily on contractors, who had experience with megaprojects in the oil and gas sector, but many of whom lacked relevant northern hydro experience.

A probability analysis was undertaken for cost and schedule. A Commission of Inquiry undertaken by the Newfoundland government into the cost and schedule overruns ultimately concluded that Nalcor had knowingly understated costs and downplayed risks (P50 cost and P5 schedule probability). The Commission risk analysis gave the project a 1% probability of meeting the publicly announced schedule for meeting first power. Dr. Bent Flyvbjerg, a noted expert in megaprojects who testified to the Commission, noted that the risk analysis was adversely affected by optimism bias and political bias through strategic misrepresentation. These biases are typical “when project teams want their projects to be approved so they deliberately exaggerate benefits and understate costs.”

Furthermore, the provincial government lacked the capacity or inclination to exercise effective oversight. The project estimates released to the public did not include any management reserve or IDC. This led to the public misunderstanding the size of the project, and the repeated increases in project budgets and schedules that were rebaselined to incorporate overruns – thereby eroding public trust.

The Commission’s 2020 report found that decision-making was undermined by optimism bias, political considerations, and a culture that discouraged dissent, resulting in a fundamentally flawed project approval and execution process.

4.11.2 Lessons to Learn

Although the Muskrat Falls project is largely remembered for its failures, some practices contributed positively to its eventual completion. Nalcor developed a project controls framework that included integrated cost and schedule baselines, reporting systems, and change management procedures. These tools provided some level of structure and visibility throughout the project, even if they were not always applied consistently.

Independent assessments also proved valuable. Ernst & Young was engaged to review cost and schedule risks early in the project, and their analysis identified both strengths and weaknesses, prompting some adjustments. Similarly, risk identification workshops helped to surface major concerns such as labor availability, contractor performance, and archaeological considerations.

The project also demonstrated adaptability. When SNC Lavalin proved unable to meet its commitments, Nalcor altered the management model to take a more direct role. Later, when a contractor’s poor performance created severe delays, Nalcor replaced them with local contractors to stabilize progress. Finally, in technical terms, the project did achieve its engineering objectives. By 2023, Muskrat Falls was fully commissioned and supplying 824 MW of renewable electricity. The construction of the long transmission link, completed amid the COVID-19 pandemic, was a significant achievement.

However, the difficulties faced by the project vastly outweighed the successes. Cost and schedule estimates were knowingly understated, with nearly half a billion dollars in identified strategic risks excluded from the sanction estimate. Contingencies were far below industry norms, and risk modeling gave the project only a one percent chance of meeting the promised schedule. Governance and oversight failures compounded these issues, with Nalcor withholding key information from the provincial government and avoiding independent review by the Public Utilities Board. The organization’s leadership fostered a culture of political bias and optimism bias, suppressing realistic assessments and discouraging dissent.

The Commission’s report (Reference 57) spared no one involved in the project.

> *Nalcor knew, or should have known, that the Project budget would be inadequate and knowingly understated the cost estimates at the time of sanction (referred to as “Decision Gate 3” or “DG3”) in December 2012. Nalcor’s DG3 estimate was clearly influenced by optimism bias, strategic misrepresentation and political bias. To a significant extent, the culture and processes at Nalcor were shaped by its first Chief Executive Officer (CEO). He had a strong belief in the merits of the Project, which was*

> *reflected in the approach of the Project Management Team (PMT). This resulted in a combination of unrealistic optimism, a willingness to misrepresent costs, schedule and risk, and an inability to change course when things were going wrong.*

Execution risks added further strain. Inadequate site readiness, adverse weather, insufficient infrastructure, and labor shortages delayed work, while Indigenous protests, environmental concerns over methylmercury, and the COVID-19 pandemic introduced additional disruptions. Contracting decisions, particularly the award of the powerhouse and spillway package to Astaldi, created cascading failures and costly disputes. Ultimately, the financial burden fell on residents, with cost overruns translating into an estimated $10,000 per capita liability and electricity rate increases that eroded public trust.

The Muskrat Falls project illustrates the risks of poor governance and project management.

Muskrat Falls - Summary of Keys to Success and What To Learn

- Strong project controls and independent reviews provided some transparency and structural support, though their use was inconsistent.
- Cost and schedule estimates were knowingly understated, and risk modeling was ignored, leading to inevitable overruns.
- Contracting strategies, particularly the reliance on a contractor with significant FOAK aspects for project, created severe performance and claims issues.
- Governance and oversight were deeply flawed, with owner withholding critical information and avoiding independent scrutiny.

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APPENDIX A SUMMARY OF LESSONS LEARNED COMPILED FROM SECTION 3 (89 ITEMS)

Section 3 Summary of Identified Lessons Learned			
Sub Section #	**Sub Section Description**	**# of Lessons Identified**	**IG #**
3.1	**Project Organization, Owner Led Integrated Project Team, and Best Athlete Approach**	5	03
3.1.1	Extreme Ownership and Leadership from the Top	4	03
3.1.2	Organization Challenges are Tougher than Technical Issues	5	02
3.1.3	Collaborative Instead of Confrontational Contracting Strategies	5	02
3.1.4	Aggressive Risk and Opportunity Management Instead of Risk Shedding	4	02
3.1.5	Ingrained Large NNP Construction, Quality, and Safety Culture	6	03
3.2	**First of a Kind (FOAK) Project Parameters and Challenges**	4	04
3.2.1	Recognizing what FOAK Is	3	04
3.2.2	Experience of Stakeholders	5	03
3.2.3	Design Maturity and Details Required for Construction	7	01
3.2.4	Realistic Cost and Schedule Baselines	6	01
3.3	**Project Management Involves Art and Science**	4	05
3.3.1	Integrated Project Schedule, Owner Control, and Simplified Reporting Systems	13	05
3.3.2	Rigorous Configuration Management and Design Change Control	4	05
3.3.3	Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue	6	04
3.3.4	Modularization Potential Benefits and Drawbacks	4	04
3.3.5	Managing Project Internal and External Stakeholders	4	03
	Total Lessons Learned Identified	**89**	

<u>Lessons Learned</u>: 3.1 Project Organization, Owner Led Integrated Project Team, and Best Athlete Approach (5 items)

- **An owner-led Integrated Project Team (IPT) is the single most important element required for a successful NNP project. The majority of the FOAK projects successfully completed and current active NNP projects have adopted the owner led IPT approach.**
- **These facilities span significant technical, organizational, regulatory, and financial parameters that are the responsibility of the owner/licensee.**
- **The NRC and the state Public Utility Commissions look to the owner/licensee as the accountable entity for public safety and the economic outcome of the project.**
- **Adopt a "Best Athlete for the Job" approach when planning and shaping the organization for an NNP project. A successful NNP integrated project team needs the most qualified candidate and best athlete for each position**.
- **All project leadership and management positions demand an owner/project centric attitude. that places project success priorities in alignment with parent company priorities and expectations.**

<u>Lessons Learned</u>: 3.1.1 Extreme Ownership and Leadership from the Top (4 items)

- **A multi-year and multi-billion-dollar NNP project is like a military campaign.**
- **It requires the leadership of an experienced, motivated, and passionate project leader who is focused, visible, listens to advice, provides clear direction, and has extreme ownership.**
- **An extreme leader takes 100% ownership of everything in his domain of influence, including the outcome and affective behaviors.**
- **The leader does not find excuses, does not blame others, has no ego, and takes full responsibility. This is the most fundamental building block of leadership that cuts across**

<u>Lessons Learned</u>: 3.1.2 Organization Challenges are Tougher than Technical Issues (5 items)

- **The complexity of managing the organization elements is compounded by the sheer magnitude of information.**
- **Identifying, integrating, and managing the interfaces is a staggering job.**
- **History has proven that people are human, and their decisions have cascading consequences that result in unexpected more serious problems.**
- **Establishing an integrated organization that facilitates teamwork and open communications across multi-corporate stakeholders is paramount to success.**
- **Continuous attention to the psychology and health of a large project organization is a key lesson when not done and a best practice when done well as it is critical for success**.

<u>Lessons Learned</u>: 3.1.3 Collaborative Instead of Confrontational Contracting Strategies (5 items)

- **Develop contracting strategies to engage owners and contractors for FOAK NNP projects success. The more rigid the terms - the more mature the design and scope requirements must be defined – a near impossibility for a FOAK project.**
- **Large, complex FOAK projects have millions of interface documents and supplier specifications requiring interfaces that need to be controlled.**
- **The lack of maturity will require hybrid strategies and collaboration, or both organizations will set up large change order organizations that will hamstring the project and create significant schedule delays.**
  - **Owners need to create win-win contracting strategies to address the inherent impacts of immature project details.**
- **Project leaders must embrace collaborative rather than confrontational strategies for project success.**
- **Establishing meaningful schedule milestones that incentivize meeting or beating schedule dates is a repetitive lesson and practice in providing a project foundation for success.**

<u>Lessons Learned</u>: 3.1.4 Aggressive Risk and Opportunity Management Instead of Risk Shedding
(4 items)

- **Project risk is an unavoidable aspect of every project and risk should be managed from the top down.**
- **Attempting to shed risk to other entities creates a false security for the owner and corrodes project cohesion and performance.**
- **Successful execution of a nuclear design and construction project ultimately requires schedule performance through an active and ongoing integrated project risk management program.**
- **The owner/licensee must establish and control an integrated project risk register across all project stakeholders to prevent risks from being compartmentalized and not fully understood.**

<u>Lessons Learned</u>: 3.1.5 Ingrained Nuclear Construction, Quality, and Safety Culture Mentality (6 Items)

- **NNP project construction culture is substantially different than operating plant culture requiring discipline, thoroughness, openness, and self-criticism.**
- **Skilled craft labor and experienced supervisory personnel must be focused on strict compliance with the design requirements.**
- **The US commercial nuclear industry has evolved into an approach to construction that is known as the Safety-Conscious Work Environment (SCWE).**
- **Nuclear construction mentality MUST not only embody the SCWE approach but also include personal accountability, procedure compliance, technical inquisitiveness (questioning attitude), and the willingness to stop in the face of uncertainty.**
- **All nuclear projects need to establish this SCWE culture across all stakeholder organizations as a foundation practice to assure project success.**
- **NRC NUREG 1055 and NRC RIS-2005-18 Guidance outline critical quality and safety requirements, lessons, and practices and should be required reading and a formal element in any new nuclear project training program.**

<u>Lessons Learned</u>: 3.2 First of a Kind (FOAK) Project Parameters and Challenges (4 items)

- **A First-of-a-Kind (FOAK) project is defined as a project that has an essential difference in scope or in detail from previous experience.**
- **Differences between construction projects can reduce the value of the learning curve.**
- **Consider all NNP projects to have FOAK aspects unless it is the same design, at the same site, with the same project participants.**
- **FOAK aspects result in inefficiencies and unexpected challenges in the design and construction of new nuclear plants.**

<u>Lessons Learned</u>: 3.2.1 Recognizing what FOAK Is (3 items)

- **For the learning curve analogy to apply as much of the design and construction as possible must be identical to the previous experience of the leadership team and workforce.**
- **Any difference in experience or in execution details represent a FOAK risk that needs to be accounted for in planning the project.**
- **The contingencies included in the baseline must recognize that unless the companies involved have worked together to build an identical power plant, there are FOAK risks inherent in the process.**

<u>Lessons Learned</u>: 3.2.2 Experience of Stakeholders (5 items)

- **Management of the stakeholder activities during an NNP project is a major issue.**
- **Lack of experience with a nuclear design and construction project is an even more daunting handicap. Unless the stakeholders are all familiar with the details of a nuclear project, the risks of delays and intervention are high.**
- **Experience with only large non-nuclear industrial projects is insufficient for approaching a nuclear construction project. It must be augmented with keen nuclear lessons and practices.**
- **The interfaces, record keeping and need for rigorous conformance to design requirements for a nuclear plant are inadequately appreciated in other industrial applications.**
- **The openness and interactive nature of the safety conscious work environment is unusual in many industries and represents a new corporate culture for many.**

<u>Lessons Learned</u>: 3.2.3 Design Maturity and Details Required for Construction (7 items)

- **Design maturity to support construction consists of a design that is complete including all vendor design submittals incorporated in detail and thoroughly planned for construction.**
  - **To achieve this design maturity, essentially all procurement activities need to be completed prior to the start of construction.**
- **Constructing a nuclear plant consists of a highly complex, interrelated set of activities that must be executed in order and in accordance with the design.**
- **A completed design by itself is not adequate.**
- **NPP projects do not have detailed, released-for-construction drawings until they have assimilated the millions of vendor technical submittal elements into released for construction installation drawings.**
- **The design effort must be focused on constructability, and to the extent possible must identify and resolve all construction issues prior to their release for construction.**
- **New nuclear plants in the U.S. must apply the lessons learned and practices that recognize the need to have a design completed through ITAAC (Inspections, Tests, Analyses, and Acceptance Criteria) incorporated into the design and planned into the work packages before starting construction.**

<u>Lessons Learned</u>: 3.2.4 Realistic Cost and Schedule Baselines (6 items)

- **History shows that new nuclear FOAK projects generally do not reflect the lessons and parameters indicated in public domain cost, schedule, and risk management guidance documents and standards.**
- **Lack of nuclear construction experience creates blind spots and results in pressure on the project that leads to the need to find a way to minimize the project cost estimate and financial baseline.**
  - **NNP project stakeholders must observe these lessons and apply rigorous risk and estimate accuracy evaluations that reflect practices that recognize FOAK and the level of project design maturity.**
  - **These pressures result in unrealistic schedules, unworkable contracts and cost saving steps that doom project performance.**
- **NNP projects need to take advantage of the tools and practices developed for characterizing cost estimates and schedules.**
- **Developers and owners of NNP projects must utilize available industry guidance sources, recognize the uncertainties and risks in FOAK estimates/schedules, and adopt risk and opportunity management strategies to be applied for future Nth of a kind projects.**

<u>Lessons Learned</u>: 3.3 Project Management Involves Art and Science (4 items)

- **The integrated project team ensures accountability, communication, leadership, ownership, and clear direction.**
- **Each of these behaviors are commonalities associated with the three project management key elements covering people, processes, and tools.**
- **Large complex NNP projects involve an enormity of science-based tools providing a huge amount of data, process flows, and system information to facilitate the project leader in decision-making.**
- **Care must be taken to ensure the leader and project management staff do not become data clerks maintaining too much detail that provides too little value.**

Lessons Learned: 3.3.1 Integrated Project Schedule, Owner Control, and Simplified Reporting Systems (13 items)

- **A project management office (PMO) should be established with collocated members from the integrated project team (IPT).**
  - **A project management operation center should be established where updated real time information regarding the overall status of the project is always available.**
  - **The PMO project management operations center should be maintained by a dedicated owner-controlled staff.**
- **A key element for a FOAK NNP project is the integrated project schedule (IPS).**
- **The IPS is the basis for executing and managing all project activities of the owner, EPC contractor, and OEM suppliers in an open transparent manner to provide visible stakeholder accountability.**
- **In simple terms, data has overwhelmed most NNP projects.**
- **The onset of new improved systems to generate reams of data is beneficial and detrimental at the same time.**
- **The benefit is the ability to track millions of bits of data.**
- **The detrimental part is that much of the data is non-essential and the additional resources are burdensome and costly.**
- **Most of the data is historical and of little benefit for forward looking decision making.**
  - **Past performance is not necessarily indicative of future progress.**
- **The digital computer era allows complexity to flourish …. Beware of bits and bytes (B^3).**
- **Stakeholders must be cautious and maintain a balance with complexity and simplicity.**

Lessons Learned: 3.3.2 Rigorous Configuration Management and Design Change Control (4 items)

- **Configuration management and design change control are the processes used to resolve discrepancies and to document the as-built configuration of the plant.**
- **A central configuration management design authority is essential to monitor the performance of procurement and construction activities to ensure no unexamined deviations are permitted.**
- **Accurate configuration management is essential and mandated by regulatory requirements to receive approval for operation.**
- **The 10 CFR 52 combined license approval process requires a rigorous ITAAC (Inspections, Test, Analyses, and Acceptance Criteria) plan. If 10 CFR 50 makes more sense for a project, a vigorous Regulatory Outreach Program is required to inform the NRC staff.**

<u>Lessons Learned</u>: 3.3.3 Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue (6 items)

- **NNP arrangements and redundant engineered safety systems result in significant bulk quantities and congested workspaces that create limits on the pace of construction installation that drive schedule duration and overall costs.**
- **As all deployments of SMR and microreactor designs have FOAK risk and may have construction quantity and congestion issues, the labor and schedule efficiencies for NNP construction are as critical as with LLWR designs to achieve required economic capital cost performance expectations.**
- **The primary need for utilizing a combination of overtime, extended work weeks, and multiple shifts in the past has been to improve cost/schedule labor efficiency and reduce schedule durations and related costs.**
- **Numerous comprehensive industry studies indicate a productivity loss of about 30% will be experienced when working more than 40 hours/week using a single shift of 5 workdays at 10 hours per day and 50 hours/week for an extended period of 12 weeks or more.**
- **The Nuclear Power Construction Stabilization Agreement (NPCSA) from the late 1970's (Reference 1) evaluated the Alternating 4/10's Shift Work Approach as a better work week and shift schedule approach to mitigate these productivity/fatigue/continuity losses and accelerate schedules with higher confidence and reduced risks.**
- **Both 10 CFR 50 and 10 CFR 52 are available to the owner to implement their NNP. Both have positives and negatives that must be considered and carefully reviewed for the most appropriate approach prior to implementing their NNP program.**

<u>Lessons Learned</u>: 3.3.4 Modularization Potential Benefits and Drawbacks (4 items)

- **Gaining the cost and schedule efficiencies from a construction modularization approach have been proven with NNP projects in Japan, South Korea, France, and other markets where Nth of a kind replication and rigid standardization have been achieved.**
- **Sub-assembly techniques coupled with stick-built and over the top construction practices can result in equal of more improved cost and schedule performance compared to modularization.**
- **Benefits for construction cost and schedule efficiency using modularization techniques require complete detailed released for construction detailed design maturity.**
- **SMR and microreactor modularization cost and schedule benefit expectations should be adjusted to recognize that the FOAK status and relative immaturity of the technology design concepts involved will limit initial economic benefits.**

<u>Lessons Learned</u>: 3.3.5 Managing Project Internal and External Stakeholders (4 items)

- **Project leadership must focus on any individual or group that may affect or be affected by a decision, activity, or outcome of the project.**
- **The NRC approval process for NNP projects is very open allowing for any individual stakeholder to exercise the safety and environmental mission of the regulators.**
- **To successfully complete a nuclear design and construction project the project leadership team needs an active Stakeholder Management Program to address all stakeholder concerns.**
- **A rigorous stakeholder management plan contains four key components including (1) Identify stakeholders, (2) Prioritize stakeholders, (3) Establish a communication management plan, and (4) Proactively engage stakeholders.**

APPENDIX B SUMMARY OF IMPLEMENTATION GUIDE CONTENT

Implementation Guide 1 (Reference 38)	
Best Practice #	**Description**
	Design Maturity and Details Required for Construction
1	Ensure that the design is complete including all vendor design submittals and thoroughly planned for construction prior to field deployment.
2	Identify that all the design and constructability issues have been resolved.
3	Confirm the design is released for construction without any holds.
4	Verify all the procurement has been finalized to support construction.
5	Validate the ITAAC process (as applicable) has been fully integrated into the design prior to commencing construction activities.
	Realistic Cost and Schedule Baselines
6	Validate that the cost and schedule baselines reflect the lessons and guidance parameters learned from previous projects.
7	Ensure the NNP project stakeholders have applied rigorous risk and estimate accuracy evaluations that recognize FOAK and project maturity.
8	Recognize the existing industry limitations in determining management reserve and contingency guidance for NNP project cost estimating.

IG 01 Executive Summary

New Nuclear Power (NNP) projects, including small modular reactor (SMR) projects have a long lifecycle with multiple steps prior to authorization and construction; these steps include the early conceptual design through final design, licensing, procurement, fabrication, estimating, scheduling, and detailed construction planning. Timelines for First of a Kind (FOAK) NNP projects are lengthy and uncertain, and FOAK elements add to the overall risk and uncertainty. A well-structured Phase Gate process is advocated for planning a project as design maturity progresses (i.e., clarity on the details of the scope and project definition) with an increasing confidence in the reliability of project cost estimates and schedules as each Phase Gate is reached. Sufficient investment is required to support the early Phase Gates to fund development of scope to develop a credible high-quality estimate to support the start of construction.

Relevant Best Practices and Lessons Learned from NEI 20-08, “Strategic Project Management Lessons Learned and Best Practices for New Nuclear Power Construction,” are addressed in Section 2 and Appendix D with recommendations for implementation. In this guide, these practices are laid out with a focus on the linkage between design maturity as an essential determinant of schedule and cost accuracy, uncertainty, and risk as a project is developed and executed.

NEI provides this guidance and recommends its use for sanctioning NNP projects. Phase Gates allow for coordinating design maturity with cost and schedule development accuracy during the pre-execution project planning stage. This guidance is based on successful methods used in large capital project development as adapted to the nuclear industry. Embracing the Phase Gate process for estimating the cost, schedule, and risks is a measured approach that increases confidence in the NNP project development process from the initial concept through to project close-out. Appendix C summarizes the elements of a NNP project Phase Gate process across the project lifecycle.

Phase Gates provide investors, executives, stakeholders, and the project team with a road map of objective measures for understanding, controlling, and overseeing a complex, lengthy process, including:

- Achievable and well-timed thresholds for the NNP project to meet in order to secure funding and advance project cost and schedule development
- An established methodology for understanding and addressing uncertainty
- Clear, objective criteria for measuring performance and supporting prudent decision-making

A Phase Gate process anticipates the progressive elaboration of the project's maturity over time as more scope is known, design thresholds are met, planning advances, and uncertainties are reduced. Performance is tracked in early stages by a Preliminary Baseline, which is the estimate of schedule and cost for the project before certain construction and procurement work is sanctioned. Assuming the requirements are met, ultimately a Control Baseline Budget and Control Baseline Schedule are issued at final notice to proceed (FNTP) that becomes the basis for all cost and schedule reporting.

Implementation Guide 2 (Reference 39)	
Best Practice #	**Description**
	Organization Challenges are Tougher than Technical Issues
9	Establish an integrated organization that facilitates teamwork and open communications.
10	Develop an organization training Plan.
11	Identify and develop the integration plan interfaces and transitions.
12	Engage industrial psychologists to assist in conducting project team building and training, and independent assessments of project team members.
	Collaborative Instead of Confrontational Contracting Strategies
13	Create a fair and flexible contracting framework that recognizes the status of design and licensing maturity.
14	Establish a “hybrid” contracting strategy plan that aligns incentives.
15	Embrace a collaborative vs. confrontational contracting approach.
16	Define contractual target cost terms.
17	Establish meaningful schedule milestones that incentivize meeting or beating schedule dates.
	Aggressive Risk and Opportunity Management Instead of Risk Shedding Approach
18	Develop an integrated risk identification and management program led by the owner.
19	Avoid re-assigning the project risk to primary contractors.

IG 02 Executive Summary

New Nuclear Power (NNP) projects, including small modular reactor (SMR) projects will have a long lifecycle with multiple steps prior to authorization and construction. The construction of a nuclear power plant, whether First of a Kind (FOAK) or Nth of a Kind (NOAK) is subject to relatively long project schedules and uncertainty, and FOAK construction has additional elements that add to the overall risk. The key to long term economic competitiveness with respect to the deployment of nuclear power plants is making both the design and project execution highly standardized reducing both the project schedule and risk. NEI 20-08, “Strategic Project Management Lessons Learned & Best Practices for New Nuclear Power Construction,” identifies 14 areas of construction best practices, with a total of 59 key construction best practices, that have been critical in the successful execution of large complex projects. Implementation guides (IG) are developed to explain how these best practices can be incorporated into actual new nuclear projects. This IG 02 discusses how to develop contract strategy and collaborative approaches to project delivery and execution together with an aggressive risk management plan to support project success. This approach aligns the objectives of project stakeholders while actively managing risk thereby increasing confidence in the ability to deliver the project to cost and schedule.

Relevant Best Practices and Lessons Learned from NEI 20-08 are addressed in Section 2 and Appendix D with recommendations for implementation. In this guide, these practices are laid out with a focus on organizational structure, approach to contracting and aggressive risk management to ensure a project can be managed to cost and schedule while continuing to reduce uncertainty as a project is executed. While the lessons learned used to develop this guidance come from experience with existing reactors and other sources as noted, this guidance can be applied to both small modular reactors (SMRs) and conventional large light water reactors. All entities using the information in this implementation guide should evaluate these best practices for their own purposes.

The success of any project, in particular a FOAK NNP, will be highly dependent upon the level of transparency, trust, collaboration and integration the project team achieves. Thoughtful consideration should be given to the organizational design that is best suited to enable and deliver this culture. The selection of the project delivery model depends on the intersection of the entity's core competencies and risk tolerance. Collaboration through use of an Integrated Project Delivery (IPD) model or through another "One-Team" approach aligns the objectives of all key project participants towards project success. This type of model establishes a culture of equality on the project by having the parties equally represented on the Steering Committee and Leadership Teams that oversee the delivery of the project. Regardless of the specific contract model, the project's culture must be developed and fostered from the top down and tested frequently throughout the lifecycle of the project to ensure it remains intact.

The contract model employed must also reflect the desired culture that is intended through the organizational design (ingrained nuclear construction, quality, and safety culture mentality). This is addressed in IG 03, "Extreme Ownership, Experience of Stakeholders, Owner Led Integrated Project Team, and Ingrained Nuclear Construction Quality and Safety Culture Mentality"). Focus should be given to remove standard rigid clauses and reduce the inherent tensions created through clauses that appear punitive or seek to transfer unreasonable risks given the lack of maturity in scope definition. The contract should be phased to match the gating and sanctioning process that is used to approve the project. This will reduce the level of risk and associated contingency by only having the partners commit and monitored against a cost and schedule baseline that is established based on a much higher level of scope definition (estimating a cost and schedule baseline is addressed in IG 01, "Design Completion and Reliability of Schedule and Cost Estimations to Support Construction Decisions"). Prior to engaging the market to secure the project partners, the Owner should establish a set of "Principles" and "Key Terms" that it believes aligns to the project goals and will establish the culture that is required for success.

The Risk Management Plan lays out the process of defining how to conduct risk management activities for a project. Nuclear projects are larger, subject to a higher degree of regulation and are generally longer in duration than many other types of projects. A risk management plan starts with risk identification with risks being managed using both a qualitative approach to understand and address the risks, and a quantitative approach to calculate the appropriate contingency to cover the inevitable occurrence of some risks. Risks must be managed throughout the project. Active risk management on an ongoing basis is essential to project success.

Implementation Guide 3 (Reference 40)	
Best Practice #	**Description**
	Project Organization, Owner Led Integrated Project Team, and Best Athlete Approach
20	Develop a plan for the life of the project to: 1. Design it to build it, 2. Build it to test it, 3. Test it to operate it.
21	Create an organization with resources for an integrated and singular focus NNP project team.
22	Establish clear roles, responsibilities, and authorities within the project structure.
	Extreme Ownership and Leadership from the Top
23	Identify and empower an experienced, motivated and passionate project leader.
24	Define clear project mission and goals.
	Ingrained Nuclear Construction Quality and Safety Culture Mentality
25	Embrace a quality acceptance plan based on NUREG 1055 that includes ASME NQA -1 and other requirements.
26	Develop a resource plan with skilled craft labor and experienced supervisory personnel.
27	Establish a Safety Conscience Work Environment (SCWE) culture across all stakeholder organizations. SCWE attributes include: Leadership clearly committed to safety, Open and effective communication across organizations, Employees feel personally responsible for safety, Organization practices continuous improvement, Reporting systems are clearly defined and non-punitive, Actions demonstrate safety is valued over other priorities, Mutual trust fostered between employees and organization, Organization is fair and consistent in responding to safety concerns, Training and resources are available to support safety.
28	Establish a project mentality that includes: Personal accountability, Procedure compliance, Technical inquisitiveness (questioning attitude), The willingness to stop in the face of uncertainty.
	Experience of Stakeholders
29	Review internal and external stakeholders NNP project experience.
30	Ensure all stakeholders are entrenched with the details of the NNP project.
31	Create clear NNP project mission, goals, and accountabilities for all Stakeholders.
32	Ensure organizational structure has an adequate focus on document control integration and defines a clear structure to support the culture of a SCWE.
	Managing Project Internal and External Stakeholders
33	Develop a Stakeholder Management Program to address and control internal and external stakeholders that contains stakeholder identities, has prioritized the stakeholders, includes a communication management plan.
34	Proactively engage all stakeholders on an ongoing basis.

IG 03 Executive Summary

New Nuclear Power (NNP) projects, including small modular reactors (SMR), large light water reactors, heavy water reactors, or other advanced reactor projects have a long developmental lifecycle with multiple steps prior to authorization and construction. These steps include the early conceptual design through final design, licensing, procurement, fabrication, estimating, scheduling, and detailed construction planning. Timelines for First of a Kind (FOAK) NNP projects are lengthy and uncertain, and

FOAK elements add to the project's overall risk and uncertainty. Even for Nth of a Kind (NOAK) projects, NNP projects are complex with relatively long timelines. A key challenge for owners and developers of NNP projects will be maintaining focused leadership through a lengthy and challenging process.

NEI's Strategic Project Management Lessons Learned & Best Practices for New Nuclear Power Construction (NEI 20-08) identified critical components and key principles of effective project leadership. Through the series of Implementation Guides (IGs), NEI has provided guidance for senior management and executive leadership to build on the key lessons from past nuclear projects in the planning of the next wave of NNP projects to ensure these best practices are incorporated. Simply put, NEI 20-08 provides the "what" and these IGs are the "how."

Relevant Best Practices and Lessons Learned from NEI 20-08 are addressed in Section 2 and Appendix C with recommendations for implementation. While the lessons learned used to develop this guidance come from experience with existing reactors and other sources as noted, this guidance can be applied to SMRs, other advanced reactors, heavy water reactors, micro-reactors, or large light water reactors. All entities using the information in this implementation guide should evaluate these best practices for their own purposes.

As stated in NEI 20-08, from the review of the 59 best practices and 89 lessons learned, the need for Extreme Ownership and leadership from the top was identified as the most important success factor. Therefore, it will receive significant attention in this implementation guide. This IG 03 focuses on the people who will be needed to manage an NNP project and how to establish a durable accountability structure for planning and executing these projects. IG 03 focuses on the owner's role as acceptance and implementation of all lessons learned flow from Extreme Ownership and top-level Leadership, including:

- Defining and asserting the Owner's role throughout the project
- Ensuring the project's structure, including responsibilities and risk sharing, are aligned with the Owner's priorities
- Establishing a Project Leadership Team (PLT) that is empowered to deliver the project and is accountable for the results
- Utilizing the "Best Athlete" approach to develop an Integrated Project Team (IPT) that accounts for the Owner's role and the capabilities of the vendor partners (further discussed in IG 02 *"Organizational Challenges, Collaborative Contracting Strategies, and Aggressive Risk and Opportunity Management"*)
- Ensuring that the PLT and IPT have the processes, procedures, tools and resources needed to execute the work
- Ensuring the PLT and IPT have ingrained nuclear quality assurance and safety culture into their daily conduct of the work
- Ingrained Large Nuclear Construction, Quality, and Safety Culture and Mentality
- Experience of Stakeholders
- Managing external stakeholders and interested parties.

Planning and executing an NNP project requires coordination of many corporate and functional groups or stakeholders. NEI 20-08 identifies, "*An owner-led Integrated Project Team (IPT) is the single most important element required for a successful NNP project. The majority of the FOAK projects successfully completed and current active NNP projects have adopted the owner led IPT approach*." Working collaboratively in an effective IPT, that is focused on project objectives can minimize counter-productive silos and improve communication, creating opportunities for a successful project. The Owner-led Integrated Project Team in Section 5 discusses the challenges and provides guidance for successfully evaluating and implementing an IPT.

Dealing with the various groups of stakeholders addresses the levels of experience and understanding of NNP project planning and executing considers the various stakeholder groups and their understanding of NNP projects. Guidance for identifying and creating an effective communication program to “manage” these groups is presented Section 7.6.

Creating an Ingrained Large Nuclear Construction, Quality, and Safety Culture and Mentality drives the behavior of all project participants to create a Safety Conscious Work Environment (SCWE). It is an expectation of the Nuclear Regulatory Commission (and other regulators) for new nuclear plants to have an SCWE focused on the unique concerns arising from ensuring reasonable assurance of adequate protection from nuclear hazards. The existing nuclear facilities throughout North America have this today. Section 7 draws from extensive experience at other facilities and offers guidance for establishing and sustaining an SCWE. Like any large project, an NNP presents numerous other concerns, like industrial safety and financial accountability. A leadership challenge is to police SCWE implementation to remain focused on nuclear safety and not be diluted by other safety and accountability concerns.

IG 03 is intended to be a desktop guide for senior management to identify how to ensure the Owner’s priorities for the NNP project are meaningfully asserted and effectively executed. With this goal in mind, IG 03 includes a series of checklists that identify specific actions the Owner’s senior management should take to ensure that the goals of Extreme Ownership are communicated and met. These actions are summarized in Appendix A of IG 03.

Implementation Guide 4 (Reference 41)	
Best Practice #	**Description**
	First of a Kind (FOAK) Project Parameters and Challenges
35	Identify the FOAK project elements that are essentially different in scope or in detail from previous stakeholder experience.
36	Develop strategies to mitigate the pitfalls from a lack of learnings.
37	Identify the transition phases and effectively address the interface challenges between the design, construction and testing activities.
	Recognizing What FOAK Is
38	Understand the details of the design, licensing mechanism, construction plan, workforce, contract terms, and stakeholders of the NNP project that differ from any previous NNP project experience.
39	Identify and address project participants' experience with the licensing requirements.
40	Ensure adequate contingencies are contained in the baseline to recognize the FOAK NNP project.
	Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue
41	Develop work schedules that are consistent with the available labor pool, address lessons learned for efficiency and fatigue, and meet project needs.
42	Evaluate available licensing processes to achieve maximum cost and schedule benefits.
	Modularization Potential Benefits and Drawbacks
43	Compare the efficiencies and benefits of modularization for applicability to those achieved with a stick-built approach.
44	Evaluate cost/benefit of modularization early in the front-end engineering and design phase for each new project site based on the transportation and logistics study for that site. Then ensure the design and procurement strategies are properly driven and matured per the modularization plan.

IG 04 Executive Summary

Adapting best practices and lessons learned [10] is key to predictable project execution, reducing cost and schedule risk, and achieving economic competitiveness for nuclear energy. NEI 20-08, "Strategic Project Management Lessons Learned & Best Practices for New Nuclear Power Construction," identifies 14 areas of construction best practices, with a total of 59 key construction best practices, that have been critical in the successful execution of large complex projects. Implementation guides (IG) are developed to explain how these best practices can be incorporated into new nuclear projects (NNP). The development and construction of nuclear power plants, whether First-of-a-Kind (FOAK) or Nth of a Kind (NOAK) may be subject to longer project schedules and need to account for uncertainty, and FOAK construction has additional elements that add to the overall risk.

The following are the high-level key insights, which provide discussion, guidance and recommendations concerning FOAK risks, construction shiftwork, and benefits and/or drawbacks of modularization. This

[10] While the lessons learned used to develop this guidance come from experience with existing reactors and other sources as noted, this guidance can be applied to SMRs, other advanced reactors, heavy water reactors, micro-reactors, or large light water reactors. All entities using the information in this implementation guide should evaluate these best practices for their own purposes.

guide is written primarily from the perspective of internal stakeholders[11] that are directly engaged in the new nuclear power project.

A "First-of-a-Kind" project is defined as the initial project that is materially different in design or deployment method from previous projects, including new technology, materials/components, or design/construction means and methods. FOAK can refer to a full project or key elements that are part of the scope. FOAK project issues and risks must be accounted for from the early planning phases through execution. Projects should factor the actions to resolve FOAK issues into the integrated project schedule and cost estimate with appropriate uncertainty factors. Addressing the risks posed by FOAK requires identifying FOAK and non-FOAK project elements, understanding and applying relevant lessons learned, preparing mitigation strategies, creating appropriate contingency and documenting lessons learned for future projects. More details for risk management can be found in IG 02 *"Organizational Challenges, Collaborative Contracting Strategies, and Aggressive Risk and Opportunity Management"*.

General Forms of FOAK Risk

- FOAK Bias (Dunning-Kruger Effect)
    - Overconfidence and Underestimate Challenges
    - Poor Accounting for Contingencies
    - Learning Curve Trap
- Types of FOAK (Difference in Scope or Detail than prior experience)
    - New Technology (e.g., New Reactor Design)
    - New Components (e.g., New Pump)
    - New Approaches (e.g., Construction or Assembly Method)
    - New Partners
    - New Licensing Processes
- Workforce Proficiency
    - Lack of Experience in Project Team (e.g., Construction Management)
    - Lack of Recent Nuclear Construction Experience (e.g., Construction Labor)

Managing labor can be one of the most difficult challenges for new nuclear power (NNP) projects, based on the size, complexity and availability of skilled knowledgeable resources. Constructing a nuclear power plant involves careful coordination of trained craft workers on-site over extended periods of time. Craft retention and increasing efficiency should be prime goals for nuclear constructors. New nuclear power

[11] For our purposes, a "stakeholder" is any person or group that may be positively or negatively impacted by an NNP project. Stakeholders can be internal (directly or indirectly within the owner/contractor/supplier organization) or external (outside of the project organizations). Section 7.1 of IG #3 provided additional information about identifying stakeholders.

projects need to develop work schedules that balance the skills, capability and size of the available labor pool. Understanding lessons learned related to causes of inefficiency and fatigue should inform the labor strategy and shift patterns developed. The overall project schedule and budget should also identify the delivery of offsite modules to match the required erection sequencing.

Based on extensive research coupled with direct construction experience, a combined extended work week (beyond regular hours, i.e., 40hrs) and second shift program should be used prudently, only when necessary, to accelerate the schedule, implement critical path corrective action or alleviate congestion. Excessive use of extended work weeks and extra shifts can lead to loss of productivity and other unintended project costs. New nuclear power projects need to develop work schedules that balance the available labor pool, recognize lessons learned for efficiency and fatigue, and the overall project schedule and budget. A lightly manned second shift can complete clean-up and stage material to ensure the main shift is fully productive on critical path and near critical path tasks.

Reaching NOAK will require achieving benefits from repeatable processes, standardization, and modularization. The design for nuclear plants may consist of a combination of modules and stick-built construction techniques. Modularization has been a focus for most recent technology developers as they finalize their standard plant designs. Standard plant designs including modules and equipment skids constructed offsite can reduce overall completion times and provide significant schedule and economic savings when properly managed. Offsite modular construction in shop conditions can occur in parallel to on-site stick-built field construction activities, reduce labor congestion and improve labor productivity. Deliberate consideration on how modules will be designed, constructed, manufactured, and inspected will improve the success rate of deployment. Standardized designs for NNP projects will also allow for continuous improvement through application of lessons learned and repetitive work tasks.

Implementation Guide 5 (Reference 42)	
Best Practice #	**Description**
	Project Management Involves Art and Science
45	Ensure that the integrated project team organizing policies and procedures stress clear direction for roles, accountability, communication, leadership, and ownership.
46	Ensure that the Organization embodies good teamwork and communications integrated with a balanced risk management approach.
47	Develop PM tools consistent with the detail necessary to optimize stakeholder communication and management of the project.
	Integrated Project Schedule, Owner Control, and Simplified Reporting Systems
48	Establish a joint project management office (PMO), that includes the owner, OEM, and EPC contractor. The PMO addresses both the project controls and project management functions that includes the project management operations center and is maintained by a dedicated owner-controlled staff.
49	Collocate members of the integrated project team (IPT) organization with the PMO.
50	Develop an integrated project schedule (IPS).
51	Produce timely and transparent progress updates of the IPS.
52	Perform regular variance reporting from baseline and address and correct baseline variances.
53	Develop project management systems designed with simplicity and avoid complexity.
54	Data is forward looking and does not overwhelm ability to focus on critical information.
55	Nuclear plant outage mentality is focused for communications and transitional periods.
56	Stakeholders' performance systems maintain a balance with complexity and simplicity.
	Rigorous Configuration Management and Design Change Control
57	Establish and maintain configuration management and design change control plans.
58	Develop a central configuration management design authority.
59	Establish a rigorous inspections and test plan.

IG 05 Executive Summary

Adapting best practices and lessons learned is key to standardizing design and predictable project execution, reducing cost and schedule risk, and achieving economic competitiveness for nuclear energy. NEI 20-08, "Strategic Project Management Lessons Learned & Best Practices for New Nuclear Power Construction," identifies 14 areas of construction best practices, with a total of 59 key construction best practices, that have been critical in the successful execution of large complex projects. Implementation guides (IG) are developed to explain how these best practices can be incorporated into actual new nuclear projects (NNP). The development and construction of nuclear power plants, whether First-of-a-Kind (FOAK) or Nth of a Kind (NOAK) may be subject to relatively longer project schedules and need to account for uncertainty, and FOAK construction has additional elements that add to the overall risk.

This Implementation Guide, IG 05, discusses three areas of interest: schedule practices, team and data management, and configuration control. However, individual users of this IG should consider the guidance and apply it as appropriate for their specific projects. Additional detail on what information should be incorporated into the project plan and management systems is discussed in IG 01, "Design Completion and Reliability of Schedule and Cost Estimations to Support Construction Decisions."

A well-formed, integrated project schedule is a powerful tool that can be used to manage and drive project behavior and performance. Early and continuing effort by the project owner to define clear requirements for the schedule is essential to efficiently develop and maintain an accurate and effective project schedule with a strong basis documented. Projects should develop rigorous Schedule Development and Schedule Management Plans that will allow the schedule to be successively developed through each of the major project phases, and updated throughout the project lifecycle. This implementation guide discusses key features of an integrated project schedule to enable effective planning, management, and communication of key project schedule milestones and performance indicators.

Beyond the project management tools, effective project management requires experience with balancing the human and technical aspects of the project. Developing an effective integrated project team (IPT, further discussed in IG 02, "Organizational Challenges, Collaborative Contracting Strategies, and Aggressive Risk and Opportunity Management") for an NNP project does not occur by simply following a procedure or checklist – but rather, by collaborating with teams that have the right experience and aligned motivations to execute the project. FOAK NNP projects will rely on past experiences, process, and culture; and will also need to be flexible and adaptable. As noted in IG 03, extreme ownership and leading from the top are essential parts of a successful NPP project. The Owner's Project Management Organization (PMO) must display ownership of the project and be at the forefront in leading the project's culture. Not just anyone can successfully lead an NNP project. An effective PMO is one that is efficient and focused on the right details enabling leadership, direction, and encouragement to the IPT using both interpersonal and data-driven tools. This implementation guide discusses the characteristics of a successful IPT and PMO pairing.

The management of an NNP project requires effective use of objective measurements. Developing a set of key performance indicators (KPIs, also discussed in IG 02) will enable the PMO to focus on key activities, quickly evaluate trends in performance, and identify successes and challenges throughout the project and efficiently provide timely direction to the IPT. Project leaders must be cautious and intentional in displaying information to ensure that the correct insights are consolidated from the vast amounts of data available for an NNP project. This requires them to be informed by key indicators that enable them to manage the work and personnel executing the project tasks. This implementation guide provides examples and best practices for developing KPIs, maintaining the underlying data that informs the project, and using that information to manage effectively.

Configuration management in essence is the process of ensuring the physical plant matches the paper plant and is essential for the success of nuclear construction projects and subsequent plant operations. Being able to demonstrate strong configuration management is a requirement throughout the licensing process and ongoing operations of the facility. The PMO must consider how to implement a process that provides appropriate structure and guidance for the IPT (while maintaining appropriate flexibility) throughout the project. This implementation guide provides best practices for developing and defining the configuration management program.

Specific relevant Best Practices and Lessons Learned from NEI 20-08 are addressed in Section 2 and Appendix C with recommendations for implementation.

APPENDIX C BEST PRACTICES RESPONSIBILITY MATRIX

Implementing Guide	Best Practice	Responsible			Best Practice Area
		Owner	OEM	EPC	
Implementation Guide 01 (Reference 38)	1. Ensure that the design is complete including all vendor design submittals and thoroughly planned for construction prior to field deployment.		X	X	Design Maturity and Details Required for Construction (Section 3.2.3)
	2. Identify that all the design and constructability issues been resolved.		X	X	
	3. Confirm the design released for construction without any holds.		X	X	
	4. Verify all the procurement has been finalized.	X		X	
	5. Validate the ITAAC process has been fully integrated into the design prior to commencing construction activities.		X	X	
	6. Validate the cost and schedule baselines reflect the lessons and guidance parameters learned from previous projects.	X	X	X	Realistic Cost and Schedule Baselines (Section 3.2.4)
	7. Ensure the NNP project stakeholders have applied rigorous risk and estimate accuracy evaluations that recognize FOAK and project maturity.	X	X	X	
	8. Recognize the existing industry limitations in determining management reserve and contingency guidance for NNP project cost estimating.	X	X	X	
Implementation Guide 02 (Reference 39)	9. Establish an integrated organization that facilitates teamwork and open communications.	X	X	X	Organizational Challenges are Tougher than Technical Issues (Section 3.1.2)
	10. Develop an organization training Plan.	X	X		
	11. Identify and develop the integration plan interfaces and transitions.	X	X	X	
	12. Engage industrial psychologists to assist in conducting project team building and training, and independent assessments of project team members.	X			
	13. Create a fair and flexible contracting framework that recognizes the status of design and licensing maturity.	X			Collaborative instead of Confrontational Contracting Strategies (Section 3.1.3)
	14. Establish a "hybrid" contracting strategy plan that aligns incentives.	X			
	15. Embrace a collaborative vs. confrontational contracting approach.	X			
	16. Define contractual target cost terms.	X			
	17. Establish meaningful schedule milestones that incentivize meeting or beating schedule dates.	X			
	18. Develop an integrated risk identification and management program led by the owner.	X	X	X	Aggressive Risk and Opportunity Management instead of Risk Shedding Approach (Section 3.1.4)
	19. Avoid re-assigning the project risk to primary contractors.	X			

Implementing Guide	Best Practice	Responsible			Best Practice Area
		Owner	OEM	EPC	
Implementation Guide 03 (Reference 40)	20. Develop a plan for the life of the project to: 1. Design it to build it, 2. Build it to test it, 3. Test it to operate it.	X	X	X	Owner Led Integrated Project Team (Section 3.1)
	21. Create an organization with resources for an integrated and singular focus NNP project team.	X	X	X	
	22. Establish clear roles, responsibilities, and authorities within the project structure.	X	X	X	
	23. Identify and empower an experienced, motivated and passionate project leader.	X			Extreme Ownership and Leadership from the Top (Section 3.1.1)
	24. Define clear project mission and goals.	X			
	25. Embrace a quality acceptance plan based on NUREG 1055 that includes ASME NQA -1 and other requirements.	X	X	X	Ingrained Large Nuclear Construction, Quality, and Safety Culture and Mentality (Section 3.1.5)
	26. Develop a resource plan with skilled craft labor and experienced supervisory personnel.	X	X	X	
	27. Establish a Safety Conscience Work Environment (SCWE) culture across all stakeholder organizations. SCWE attributes include: Leadership clearly committed to safety, Open and effective communication across organizations, Employees feel personally responsible for safety, Organization practices continuous improvement, Reporting systems are clearly defined and non-punitive, Actions demonstrate safety is valued over other priorities, Mutual trust fostered between employees and organization, Organization is fair and consistent in responding to safety concerns, Training and resources are available to support safety.	X	X	X	
	28. Establish a project mentality that includes: Personal accountability, Procedure compliance, Technical inquisitiveness (questioning attitude), The willingness to stop in the face of uncertainty.	X	X	X	
	29. Review internal and external stakeholders NNP project experience.	X	X	X	Experience of Stakeholders (Section 3.2.2)
	30. Ensure all stakeholders are entrenched with the details of the NNP project.	X			
	31. Create clear NNP project mission, goals, and accountabilities for all Stakeholders.	X			
	32. Ensure organizational structure has an adequate focus on document control integration and defines a clear structure to support the culture of a SCWE.	X			
	33. Develop a Stakeholder Management Program to address and control internal and external stakeholders that contains stakeholder identities, has prioritized the stakeholders, includes a communication management plan.	X			Managing Project Internal and External Stakeholders (Section 3.3.5)
	34. Proactively engage all stakeholders on an ongoing basis.	X			

Implementing Guide	Best Practice	Responsible			Best Practice Area
		Owner	OEM	EPC	
Implementation Guide 04 (Reference 41)	35. Identify the FOAK project elements that are essentially different in scope or in detail from previous stakeholder experience.	X	X	X	FOAK Project Parameters and Challenges (Section 3.2)
	36. Develop strategies to mitigate the pitfalls from a lack of learnings.	X	X	X	
	37. Identify the transition phases and effectively address the interface challenges between the design, construction and testing activities.	X	X	X	
	38. Understand the details of the design, licensing mechanism, construction plan, workforce, contract terms, and stakeholders of the NNP project that differ from any previous NNP project experience	X	X	X	Recognizing what FOAK Is (Section 3.2.1)
	39. Identify and address project participants' experience with the licensing requirements.	X	X		
	40. Ensure adequate contingencies are contained in the baseline to recognize the FOAK NNP project.	X	X	X	
	41. Develop work schedules that are consistent with the available labor pool, address lessons learned for efficiency and fatigue, and meet project needs.	X	X	X	Labor Efficiency, Extended Workweeks, Shiftwork, and Fatigue (Section 3.3.3)
	42. Evaluate available licensing processes to achieve maximum cost and schedule benefits.	X	X		
	43. Compare the efficiencies and benefits of modularization for applicability to those achieved with a stick-built approach.	X	X	X	Modularization Potential Benefits and Drawbacks (Section 3.3.4)
	44. Evaluate cost/benefit of modularization early in the front-end engineering and design phase for each new project site based on the transportation and logistics study for that site. Then ensure the design and procurement strategies are properly driven and matured per the modularization plan.	X	X	X	
Implementation Guide 05 (Reference 42)	45. Ensure that the integrated project team organizing policies and procedures stress clear direction for roles, accountability, communication, leadership, and ownership.	X	X	X	Project Management Involves Art and Science (Section 3.3)
	46. Ensure that the Organization embodies good teamwork and communications integrated with a balanced risk management approach.	X	X	X	
	47. Develop PM tools consistent with the detail necessary to optimize stakeholder communication and management of the project.	X			
	48. Establish a joint project management office (PMO) that includes the owner, OEM and EPC contractor	X			Integrated Project Schedule, Owner Control, and Simplified Reporting System (Section 3.3.1)
	49. Collocate members of the integrated project team (IPT) organization with the PMO.	X	X	X	
	50. Develop an integrated project schedule (IPS).	X	X	X	
	51. Produce timely and transparent progress updates of the IPS.	X	X	X	
	52. Perform regular variance reporting from baseline and address and correct baseline variances.	X	X	X	
	53. Develop project management systems designed with simplicity and avoid complexity.	X			
	54. Data is forward looking and does not overwhelm ability to focus on critical information.	X			
	55. Nuclear plant outage mentality is focused for communications and transitional periods.	X			
	56. Stakeholders performance systems maintain a balance with complexity and simplicity.	X			
	57. Establish and maintain configuration management and design change control plans.	X	X		Rigorous Configuration Management and Design Change Control (Section 3.3.2)
	58. Develop a central configuration management design authority.	X	X		
	59. Establish a rigorous inspections and test plan.	X	X	X	