Case Studies and Insights from Past Successful FOAK Projects

Summary level (4 to 5 page) case studies were developed for the 10 completed and successful large FOAK projects identified below. These construction projects include commercial nuclear power plants, nuclear facility decontamination and decommissioning (D&D), municipal infrastructure, and a government science facility. Project execution periods spanned over 40 years from the 1970's to the present.

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 Decontamination & Decommissioning (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. Columbia Generating Station (WPPSS 2)
10. Barakah Nuclear Power Station Units 1 to 4

These large FOAK projects all dealt with similar challenges involving enormous scope, new technologies, complicated interfaces, changing regulatory requirements, and numerous project stakeholder organizations. The top two common factors that led to success that facilitated overall positive performance in all areas involved a utility/owner-led integrated project team approach, reinforced with passionate leadership and extreme accountability by management of all stakeholder organizations.

1. River Bend Nuclear Power Station Unit 1
Gulf States Utilities (Entergy)
1979 to 1985

4.1 River Bend Nuclear Power Station Unit 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.

Insights on Keys to Success and What Went Well

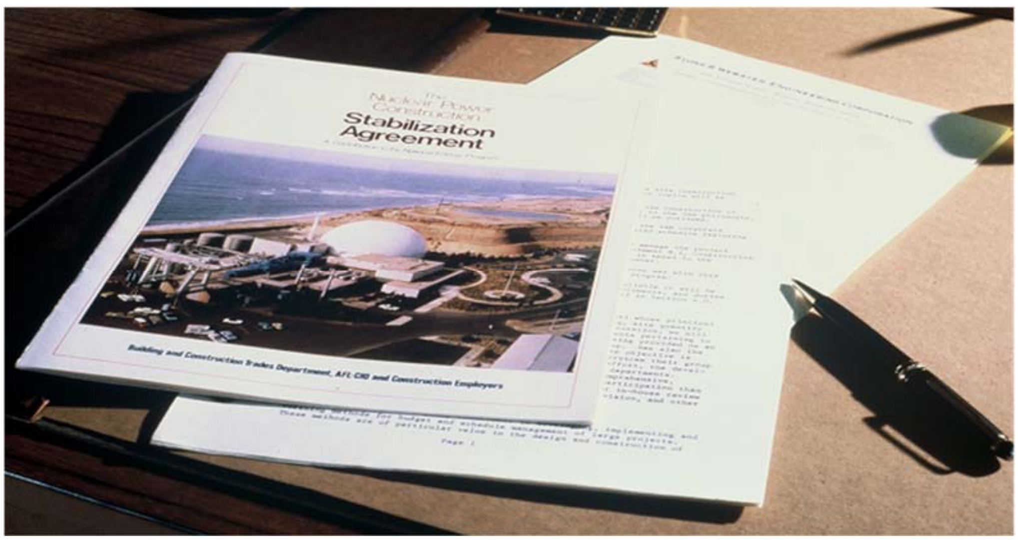
Project Management Leadership and Integrated Project Team Approach – Large and complex projects can easily evolve into unwieldy administrative organizations where responsibilities become shared or unclear. GSU and SWEC corporate and project leadership were committed to an integrated team approach. This 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 died in 1997 and 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 US 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 US 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 4.2.**

Exhibit 4.2, 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** from 1978 outlining parameters of the NPCSA, **Reference 20** from 2013 outlining the Alternating 4/10s shiftwork approach, and **Reference 24** from 2017 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 first-of-a-kind (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.

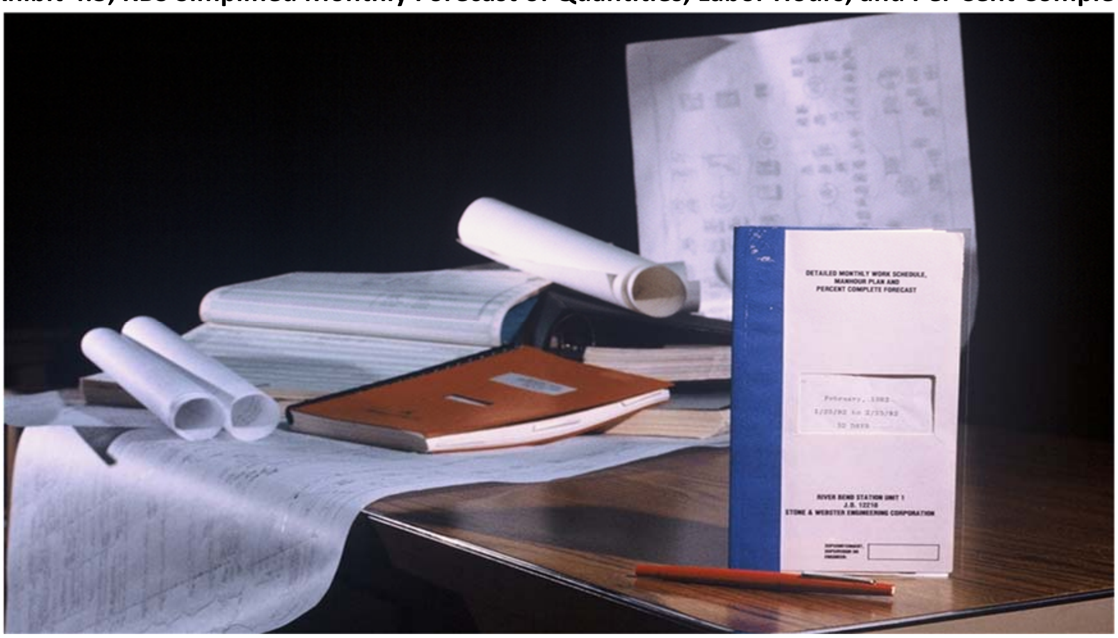
RBS success in this area was the result of measures taken by management to prevent the volume pf paperwork required to status the job from clouding individual accountability and confusing near-term weekly/daily work priorities. Supervisors responsible for daily work execution were not expected to digest 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.

Ken Aupperle, current High Bridge Associates senior vice president and NEI Task Team Lead, was the RBS on-site Superintendent of Cost and Scheduling. Ken sums up keeping things clear and simple as follows:

> *"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"*

For additional information and insights on this topic, see **Reference Document 4** from 1984 describing the construction management, planning and scheduling approach used at RBS. Also, **see Exhibit 4.3** of the RBS Simplified Monthly Forecast and Work Plan.

Exhibit 4.3, 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 per cent complete goals they must achieve in the near-term.**

2. St. Lucie Nuclear Power Station Unit 2
Florida Power & Light Company
1977 to 1982

4.2 St. Lucie Nuclear Power Station Unit 2

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 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, See **Exhibit 1**.

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.

Lessons and Insights on Keys to Success and What Went Well

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 4.4.**

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.

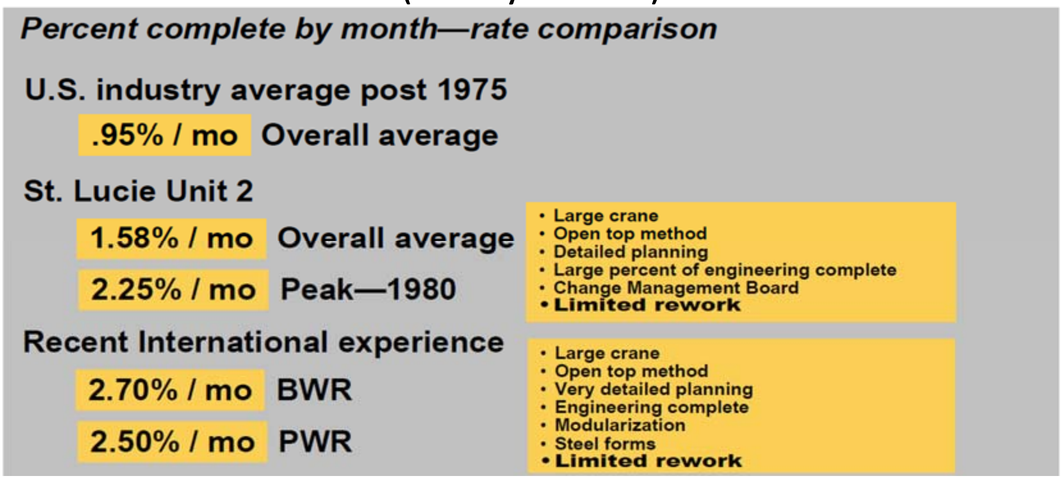
<u>Change Control Review Board -</u> Early in the initiation of the overall St. Lucie project for both units it was recognized by project management from both companies that continual increases in the scope of the project would make it impossible to routinely achieve milestone dates. It was decided to 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.

<u>Accelerated FSAR Preparation and Review Cycle by the NRC -</u> 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

<u>Engineering, Licensing, and Critical Materials Procurement Completion while Construction Delayed -</u> 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 4.4** 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 4.4, 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.

3. Palo Verde Nuclear Power Station Units 1, 2, and 3
Arizona Public Service Company
1977 to 1987

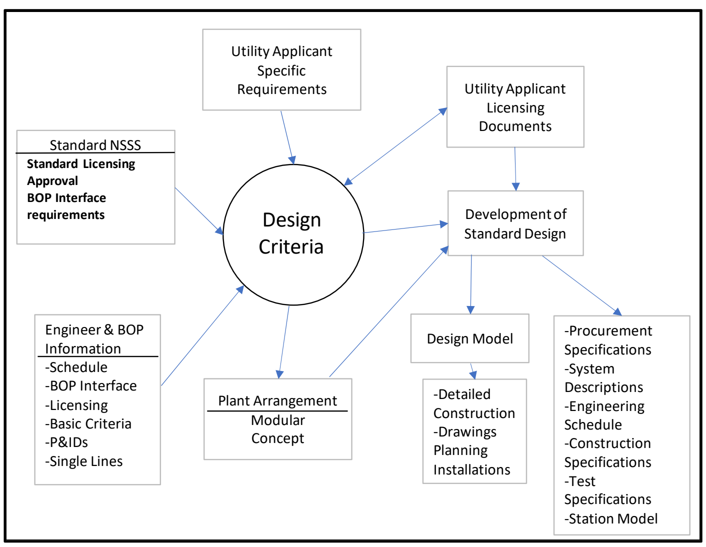
4.3 Palo Verde Nuclear Generating Station - Units 1, 2, and 3

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 4.5** 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 4.5, 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.

Insights on Keys to Success and What Went Well

Project Management Leadership and Integrated Project Team Approach – 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 first-of-a-kind (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. 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. Watts Bar Nuclear Power Station Unit 2

Tennessee Valley Authority

1977 to 1987 (Units 1&2) & 2012 to 2016 (Unit 2 Completion)

4.4 Watts Bar Unit 2

Background

In 1973 the Tennessee Valley Authority (TVA) began construction on two Westinghouse, 1170 Megawatt electric (MWe) pressurized water reactor. These units were constructed at the TVA Watts Bar Site. Construction was stopped on both units in 1985 with the civil structural construction having been basically completed. WBN 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 WBN 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 first-of-a-kind (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.

Insights on Keys to Success and What Went Well

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

<u>Project Planning, Estimating, and Scheduling -</u> 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 WBN 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).

<u>Community Relations -</u> 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. Welldefined 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.**

5. Rocky Flats Decontamination & Decommissioning
U.S. Department of Energy
1992 to 2006

4.5 Rocky Flats Decontamination & Decommissioning (D&D)

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.

David Del Vecchio, currently a Vice President at High Bridge, was a Senior Project Manager on the RFETS Leadership team. He is one of a few leaders who remained on the project from the start in 1995 to its finish in 2005. In his own words, David recalls:

> *"As I reflect 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"*

Insights on Keys to Success and What Went Well

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.

Rocky Flats - Summary of Keys to Success and What Went Well

- **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.**

6. Steam Generator Replacement (SGR) and Refurbishment Projects
Various U.S. Utility Owners
1979 to 2015

4.6 Selected Steam Generator Replacement (SGR) and Refurbishment Projects

Background

Steam Generator Replacements (SGRs) were performed in Japan and in France before the large wave of US 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 SGR's 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.

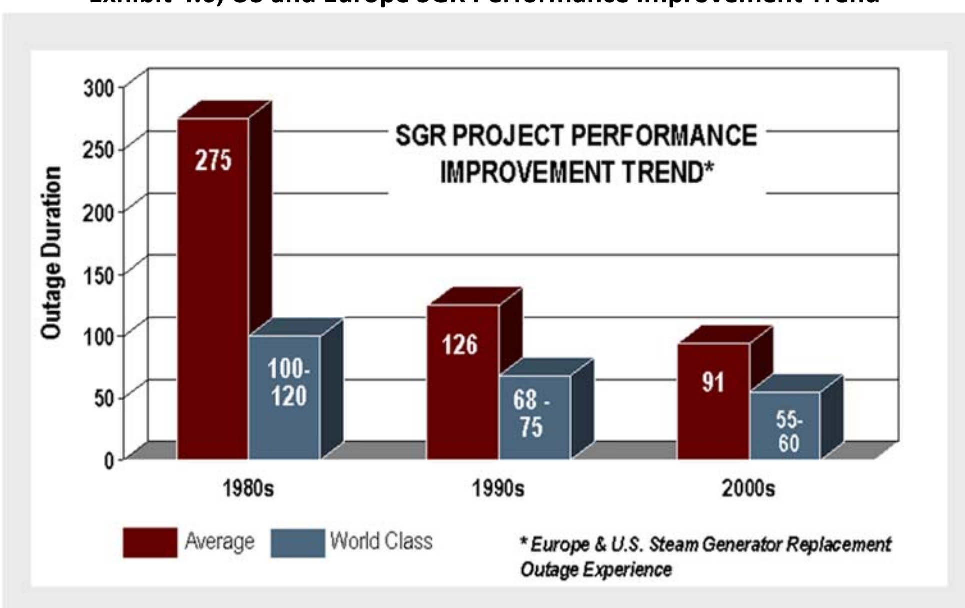
Overall, the US industry has performed 58 SGR projects over a 35-year period from 1979 to 2015. The first US SGR project was in 1979 for Surry Unit 2 with an outage duration of 560 days. All SGR outage durations performed prior to 1985 (seven total) were over 210 days in duration. The first US SGR performed 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 US being Watts Bar Unit 2 scheduled for 2023. This may be the end of US SGR projects except for the possibility of second SGR projects on units that are granted operating life extensions.

The US 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 4.6** 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 US record outage duration was 55 days achieved by Bechtel at Comanche Peak Unit 2.

Exhibit 4.6, US and Europe SGR Performance Improvement Trend[1]



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

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.

Insights on Keys to Success and What Went Well

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 SGR's 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.
- 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.

- LL 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. US SGR's 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 SGR's.

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 SGR's.**

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.

<u>Callaway SGR</u>

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

<u>Diablo Canyon Unit 1</u>

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.,

7. Spallation Neutron Source (SNS) Accelerator Project
U.S. Department of Energy
1999 to 2006

4.7 Spallation Neutron Source (SNS) Accelerator Project

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 4.7** provides a basic layout arrangement of the SNS facility indicating the responsibilities for the six national laboratories involved with the project.

Exhibit 4.7, 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.

Insights on Keys to Success and What Went Well

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:

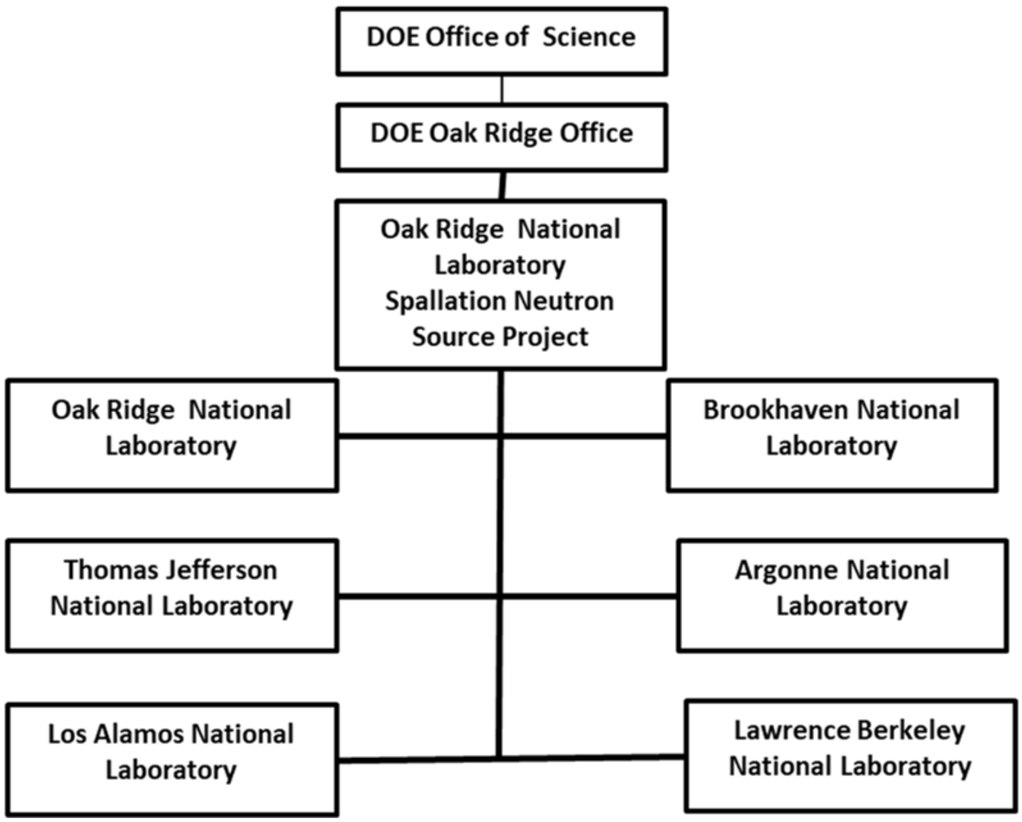
1. An integrated partnership of the DOE customer, and its federal representatives in the field, with the IPT of technical experts from the partner laboratories' managing contractors and a large AE/CM joint venture;
2. Integrated, electronically adaptable management information systems developed by the 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 4.8**.

Exhibit 4.8, 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.

<u>Multi-laboratory partnerships with clear responsibilities and centralized budget authority can be successfully used for new, big-scale projects -</u> 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.

<u>Many project management tools and processes are needed to manage project performance, but processes alone are not sufficient to effectively manage project performance -</u> 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 and currently High Bridge vice president
- 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

Spallation Neutron Source Project - Summary of Keys to Success and What Went Well

- **A clear mission-need and program support from the top are imperative.**
- **Project Management Leadership and Integrated Team Approach are vital.**
- **Multi-laboratory partnerships with clear responsibilities and centralized budget authority can be successfully used for new, big-scale projects.**
- **Many project management tools and processes are needed to manage project performance, but processes alone are not adequate to effectively manage project performance.**
- **Planning for commissioning and operations should take place early.**
- **Innovative HR programs are key for successful recruiting and retention of staff.**
- **Safety requires the unrelenting attention and commitment of management and labor.**

8. 2012 London Olympics Infrastructure and Facilities
The Olympic Delivery Authority (ODA)
2006 to 2012

4.8 2012 London Olympics Infrastructure and Facilities Project

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.[2] 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). [3]

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.

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.[4] 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,

[2] "London Olympics exceed initial budget by £6.50bn," by Alex Hern, BBC News, Feb. 1, 2007

[3] APM Project Management Awards, Winner's Case Study, BNFL Award 2012, C

[4] "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

the ODA performed admirably to bring the complex of projects to a successful conclusion ahead of schedule and under budget.

Insights on Keys to Success and What Went Well

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. 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 Integrate 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.[5]

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

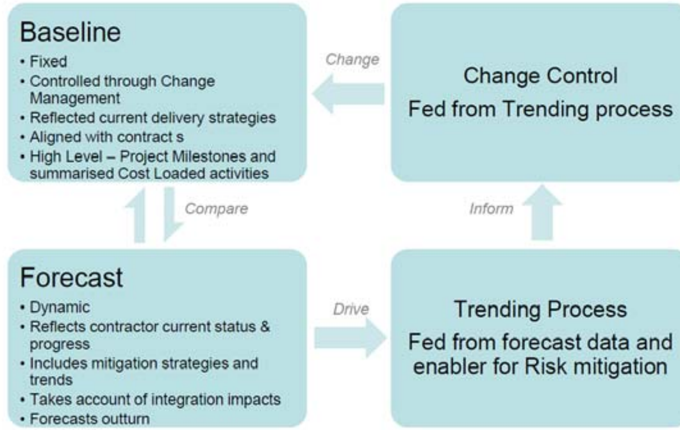
- Infrastructure and Venues work in parallel in a small area of land
- Key milestones for Infrastructure and Venues were driven from various project interfaces
- Design interfaces could lead to a project interface on site
- Principal Contractor methodology (site boundaries) and handovers of areas of 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
- 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.

[5] "Olympics Lessons Learned Event Presentation slides, Section 2: Project Controls," Energus, Lillyhall, Cumbria, Feb. 21, 2013



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.

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 were committed to its success. 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

Exhibit 4.9 - Infrastructure Work for the London Games

    - North London Line
    - Other Transport Capital Projects
- Athletes Village

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.[6]

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 resulted in Completing Venues 12-months Ahead of Schedule and Under Budget**
- **Design Reviews of Cross-Border Projects Ensured Consistent and Coordinated Designs**
- **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**

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

9. Columbia Generating Station
Washington Public Power Supply System (WPPSS 2)
1974 to 1984

4.9 Columbia Generating Station (WPPSS 2)

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 grow 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.

Insights on Keys to Success and What Went Well

While the WPPSS nuclear program initially did not follow many of the rules for managing mega-projects offered in this report, circumstances developed over time that enabled completion in observance of getting detailed design complete before resuming activities to complete the project. 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 along with their experience with nuclear plants, as were most of the rest of the nation's utilities in 1968. The WPPSS management team selected three different reactor designs which did not allow them to 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 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 aka WNP-2

Only WNP-2 survived this framework 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 not 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 ash. It suffered from labor walkouts of the pipe fitters in the 1975 – 1977 timeframe (which 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 (the Columbia Generating Station) was completed and went into commercial operation in 1984. Indeed, practices evolved during completion of WNP-2 that mirrored those recommended herein.

<u>Establishment of an Owner-Lead Team</u> – The WPPSS owner led 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 owner-licensee, the most important stakeholder. 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 and supported completion of construction with completed detailed design.

Another contributing factor was the way the project dealt with the numerous pipe fitter walkouts. Because of the piping problems a decision was made to continue forward with design but stopped installation of 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."*[7]

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.

Established a Valid Baseline Construction Schedule - 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 validated real-world construction schedule at the outset of the project. Although the subject plant was an older version of the GE BWR, a fully validated construction schedule was available at the beginning of construction. Most of the assumptions were overcome by events, but the logic in the sequence were firm. At the time, schedules were produced manually with automated tools only becoming available near the end of construction. This made changes to the baseline extremely problematic. The approach to the labor upsets caused by strikes also served to preserve the logic 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.

Cost was the Final Determining Factor - 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 Generating 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

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

- Licensee involvement and leadership (WPPSS was directly involved in WNP-2 while it was not directly involved with WNP-1 or WNP-3)
- 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)

[7] Telephone interview conducted Nov. 7, 2019

- The benefit of an Integrated Project Team approach (where the failed WNP-1 and WNP-3 did not follow this approach)

The partial application of only some of the lessons learned contained in this report resulted in dramatically different results. The lesson of the WPPSS experience is that even in the face of daunting challenges, a nuclear project can succeed if deployed with the proper approach.

<u>Columbia Generating Station – 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**

10. Barakah Nuclear Power Station Units 1 to 4
Emirates Nuclear Energy Corporation
2009 to 2020

4.10 Barakah Nuclear Power Station Units 1 to 4

4.10 Barakah Nuclear Energy Plant, Unit 1

> *"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

4.10.1 Background - 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 will supply up to 25% of the UAE's electricity needs once fully operational, 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. Fuel load has successfully been completed and the unit is now undergoing the start-up process, which is anticipated to take a number of months. With the commencement of commercial operations, the UAE will benefit from clean 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 **Insights on Keys to Success and What Went Well**

4.10.2.1 **Development of a comprehensive national policy and subsequent adherence to its principles:** 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 four primary principles that provide the overarching direction for the life of the program:

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.

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). Since 2009, ENEC and its operating subsidiary Nawah have undergone 255 inspections, and more than 40 missions and peer reviews, from these and other bodies. All have been aimed at ensuring the highest international standards have been met throughout.

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.

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.

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.

4.10.2.2 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.

4.10.2.3 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. ENEC also submitted the Operating License Application (OLA) for the first two units on behalf of Nawah, the operator, with the submittal of the OLA for Units 3 and 4 by Nawah in 2017.

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, construction across the four units of the Barakah plant stands at 95% complete. Construction of the first unit was completed in March 2018 and Nawah received the Operating License for Unit 1 in February 2020. The team is now completing commissioning and testing as it prepares for operations.

4.10.2.4 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 will be responsible for operating and maintaining the four units at Barakah, making it the newest operator 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.

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.

4.10.2.5 Commencing local capacity building at the start of program inception: ENEC and Nawah are also using unique and innovative methods to develop the workforce that are 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.

To date, 30 talented UAE Nationals, including three 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. To date, a further 42 international nuclear professionals have been certified as SROs and ROs, with many more in the pipeline.

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.

4.10.2.6 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.

4.10.2.7 Active development of a local nuclear supply chain: ENEC works 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 hold regular Supplier Forums to ensure local companies are informed about upcoming opportunities and are educated on the steps required to register for the tendering process for the Barakah Nuclear Energy Plant.

More than 2000 UAE companies have been 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.

4.10.3 Emerging as a Leader in New Build Peaceful Nuclear Energy Development

The Barakah Nuclear Energy Plant is one of today's most advanced nuclear energy facilities and sets the bar for new nuclear construction and development around the world. The most recent milestone involved the successful completion of fuel loading at Unit 1, meaning that the UAE has officially become 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.

In the immediate term, ENEC and its operating subsidiary Nawah are focused on the safe and successful start-up and commercial operations of the first unit, as well as the subsequent units 2-4, which will benefit from the lessons learned from Unit 1. Going forwards, the UAE continues on its journey to operational excellence, generating clean baseload electricity for the Nation, and the continued development of the UAE Program in line with the highest national and international standards.