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Spallation Neutron Source
Proton Power Upgrade (PPU) Project

Lessons Learned for CD-4

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

Spallation Neutron Source - Proton Power Upgrade
Lessons Learned for CD-4

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Spallation Neutron Source - Proton Power Upgrade
Lessons Learned for CD-4

Project Title: Spallation Neutron Source (SNS) Proton Power Upgrade (PPU) Project

Project Location: Oak Ridge National Laboratory

Description of Project:

The SNS PPU project goals were to design, build, install and test the equipment necessary to double the accelerator power from 1.4 MW to 2.8 MW and to deliver a 2.0 MW qualified target. PPU also included the provision of a stub-out in the SNS accumulator-ring-to-target tunnel to facilitate a rapid connection to a new proton beamline for the Second Target Station (STS) project. The power capability was doubled by increasing the proton beam energy by 33% and the peak beam current by 50%, relative to pre-PPU accelerator performance. The project also included modifications to some buildings and services.

The PPU project accomplished the energy upgrade by fabricating and installing new superconducting radiofrequency (RF) cryomodules, with supporting RF equipment, in the existing linac tunnel and klystron gallery, respectively. The High Voltage Converter Modulators (HVCM) and klystrons for some of the existing installed RF equipment were upgraded to handle the higher beam current. The increased beam power of 2 MW on the First Target Station (FTS) was enabled by the addition of a new high-volume gas injection system for pressure pulse and cavitation mitigation in the mercury target and a redesigned mercury target vessel.

Project TPC: $271.6M

Introduction

This lessons-learned document presents three key successes on page 2, three key potential improvements on page 3, and numerous secondary successes and potential improvements beginning on page 5. These are lessons learned since CD-2/3 approval in October 2020. The lessons learned are not ordered by priority.

The PPU project partnered with Jefferson Lab for production of the superconducting radiofrequency cryomodules. The Jefferson Lab team produced a separate lessons learned document regarding their scope of work. This document is available in the ORNL Enterprise Document & Records Management (EDRM) system with document number P02030000-LLN10000.

Lessons Learned - Successes

Lessons Learned—Successes	Description, Impacts, and Solutions
Financial incentives for on-time completion	• Use financial incentives for early completion of conventional facilities construction projects, particularly when operations or other activities would be impacted by delays. • The project was concerned that the construction of the Ring-to-Target Beam Transport (RTBT) tunnel extension would delay the end date of the PPU long installation outage and the resumption of neutron production for the user program. • The request for bids included a request that the bidders propose a financial incentive for early completion. Bids were received with proposed financial incentives ranging from 5 to 10 percent of the total contract price. The best value bid was selected, and the construction was performed without causing delay to completion of the long installation outage.
Frequent engagement with vendors and partner laboratories	• Engage frequently with vendors and partner laboratories to ensure technical success and on-time completion. • Significant supply chain problems were encountered, including long lead times, vendor unresponsiveness, and lack of vendor technical expertise or quality control. • It was essential with a few vendors to visit frequently and help them to succeed. In some cases, the project loaned equipment or provided government furnished equipment (GFE) to keep the vendors on track. In a few cases, the project took delivery of parts and self-performed final assembly to maintain schedule with concomitant contract modifications. Welding expertise was in short supply at one vendor that has historically performed well. • The project made frequent visits to the partner labs to maintain good communications, to emphasize the importance of the partner lab contributions, and to verify performance requirements were being achieved.
PEMP notable outcomes	• Work with the Integrated Project Team (IPT) to recommend Performance Evaluation and Measurement Plan (PEMP) notable outcomes to the partner laboratories for successful on-time performance. • The partner labs have competing priorities that may pull away resources needed for on-time completion of the contracted scope of work. It can be difficult to effectively impress upon partner lab management the imperative of meeting project schedules. • Utilization of PEMP notable outcomes ensured partner lab management assigned the necessary resources and priority so that the work could be performed as scheduled.

Lessons Learned – Potential Improvements

Lessons Learned—Potential Improvements	Description, Impacts, and Solutions
Safe excavation	• Ensure excavation permitting process properly communicates requirements. • Ensure the construction field representative (CFR) or equivalent is fully cognizant of the requirements for excavation, especially for underground utilities and lockout-tagout requirements. • An underground electrical conduit was damaged during excavation in preparation for construction of the Ring-to-Target Beam Transport (RTBT) tunnel extension that will facilitate future connection to the second target station. • From the occurrence report: "On July 8, 2023, a subcontractor unintentionally contacted an electrical conduit at the Proton Power Upgrade construction site. The conduit contained electrical conductors (480-volt, three phase) which were controlled by a photocell for exterior lighting and de-energized at the time of contact. Work was being performed under an approved excavation/penetration permit. The electrical line had been identified using drawings and a utility location service. The line was required to be lock/tag/verified (LTV) per UT-Battelle's excavation procedure, but no LTV was performed. The Construction Field Representative was unaware of the LTV requirement. The conduit was potholed by hand to verify its location. During the subsequent excavation work, loose soil re-entered the pothole obstructing the spotter and operator's view of the conduit when the event occurred. The conduit was damaged, and the conductors were pulled from their connections inside a nearby junction box. No employees were shocked or injured." • A root cause analysis was performed, and a corrective action plan was developed. The plan included strengthening the work control process and ensuring the CFR has training on the excavation process.
Project spares	• Be sure to include all project spares necessary for meeting the key performance parameters when baselining the project. • Consider facility reliability following project completion in the determination of needed project spares. • Project spares are included in the baseline at CD-2. These are items that are needed to ensure successful completion of the project (CD-4). • It may be difficult to add spares later due to pressure to keep cost contingency in reserve. • Spares need to be ordered early enough so that they are available if needed and do not impact the schedule for the CD-4 review (in general, all equipment should be received before the CD-4 review).
Controls as a level 2 WBS element	• Include Controls as a separate level 2 activity in the work breakdown structure. • The Controls scope of work was distributed across the level 2 areas of the work breakdown structure (WBS), including Superconducting Linac Systems, Radio-Frequency Systems, Ring Systems, First Target Station Systems, and Conventional Facilities. • The Research Accelerator Division section head for control systems was designated as the Controls Integration Manager for the project and served as the Cost Account Manager (CAM) for all controls scope. • It would have been better to include all the controls work in a single level 2 section of the WBS because:

Lessons Learned—Potential Improvements	Description, Impacts, and Solutions
	- Earned value management and reporting would be more efficient. - Communications would be improved (sometimes the Controls Integration Manager was omitted from communications sent to the level 2 managers). - It would be easier to develop controls solutions consistently across the project sharing designs and technologies where feasible.

Lessons Learned - Other

Lessons Learned—Successes	Description, Impacts, and Solutions
Phased project execution	• Executing the upgrade in a phased manner allowed for early debugging of systems and supported early enhancement of neutron science productivity through a phased ramp-up of the beam power on target. • The project was executed in three phases. In each phase, a subset of the project scope was installed, after which the technical equipment was utilized by Operations to increase the beam power on target.
Partner laboratories	• Partner with other laboratories to take advantage of existing expertise and facilities. • This avoids building up expertise and facilities that will not be needed after the project is finished. • Fermilab designed and produced magnets. Jefferson Lab produced the superconducting radiofrequency cryomodules.
Processes and procedures	• Utilize existing processes and procedures to the extent possible. • This is particularly applicable to an upgrade of a mature facility. There is no need to reinvent processes and procedures that are familiar to the staff and adequately serve the facility and the project. Adding project-specific processes and procedures decreases efficiency and increases the risk of inconsistencies or confusion of when project vs. facility processes and procedures apply.
Matrixed staffing	• When upgrading an existing facility, staff the project team with people matrixed from operations since they are most knowledgeable of their technical systems and will be responsible for those systems in the future. • This approach minimizes costs and yields solutions that are optimal for future operations and maintenance.
Execute plans as early as possible	• Execute procurements and upgrade tasks as early as possible to prevent pile-up later in the project. • Early execution and working activities in parallel are essential to maintain project schedule because unexpected delays introduce risk to the project schedule.
Proactive development of backup plans	• Look ahead for developing problems and be ready with alternate plans to minimize schedule impacts. Be willing to use cost contingency to develop the alternatives and mitigate risk, especially when schedule is important to existing operations and users. • With this approach, when "plan A" fails, the existence of "plan B" minimized schedule impacts.
Long lead procurements	• Seek long lead procurement authorization to proceed with procurement/construction of mature designs. Prepare procurement packages so that they're ready to go when authorization is received. • This approach allowed the project to get many procurements placed in advance of the COVID-19 pandemic and minimized the supply chain issues that were a problem later.
Use local experts for vendor surveillance	• When travel to vendors is not possible, use local experts to conduct vendor surveillance. Use mobile phones to virtually witness vendor tests. • This approach proved successful and essential to maintain schedule and achieve technical success during the pandemic when travel was limited.
Communications with sponsor	• Maintain open and frequent communication with the federal project director, program manager, and the Integrated Project Team (IPT).

Spallation Neutron Source - Proton Power Upgrade
Lessons Learned for CD-4

Lessons Learned—Successes	Description, Impacts, and Solutions
	• Transparency and trust are essential for good project execution. The project had monthly conference calls with the IPT to report progress (later bi-monthly), met with the program manager for a mid-month conference call, and met weekly with the federal project director.
Communications within the facility	• Communicate openly and frequently with the facility operations management and staff to keep everyone on the same page and to avoid conflicts between project plans and operations plans.
Management field presence	• The project management team should spend time in the field talking with people. • This provided for a stronger connection to the project team and gave the managers a better understanding of the progress and challenges. This served to keep the management team informed of technical challenges that could impact cost or schedule. • The project team noticed and appreciated that top management spent time in the field.
Management availability for discussions	• Ensure the project management team is available for informal discussions on project challenges and plans. • The project director and project manager had “open door” policies and encouraged team members to stop by whenever necessary to share concerns and discuss progress. Similarly, the level 2 managers were available to support their teams. • This approach was useful in identifying and mitigating challenges in project execution including the development of backup plans.
Frequent management meetings	• Project management should meet with each level 2 manager on a weekly or bi-weekly schedule to assess progress and discuss concerns. • The project director and project manager met with each level 2 manager on a bi-weekly basis. These meetings were quite useful in identifying challenges and developing mitigations including the development of backup plans. This format was more conducive to open and detailed discussion compared to the weekly project meeting.
Avoid overstaffing the project office	• The project took a lean approach to staffing the project office relative to other similarly sized projects. For example, the project did not have a chief engineer, chief scientist, or lead systems engineer. • The management team was experienced and capable of covering all the bases. The project director and technical director were accelerator physicists, and the project manager was an accelerator engineer. The entire management team including the level 2 managers was highly experienced in accelerator design, technology, and operations and had many years of experience at SNS. • This approach minimized project management costs and made it easier to keep the management team informed and integrated and is especially applicable to upgrades of a mature facility with project staff matrixed from operations.
Conduct shipping tests	• Conduct shipping tests for sensitive components that must be transported from the fabrication facility to the installation site. • Jefferson Lab and the PPU project team collaborated to conduct cryomodule shipping tests between Jefferson Lab and SNS. Initially, a cryomodule mockup was transported via truck to confirm expected shocks and vibrations were not exceeded. Later, the first production cryomodule was subjected to a shipping test between Jefferson Lab and SNS to validate the shipping methodology and to confirm no impacts on cryomodule integrity and performance.

Spallation Neutron Source - Proton Power Upgrade
Lessons Learned for CD-4

Lessons Learned—Successes	Description, Impacts, and Solutions
Contractor focused reviews	• Use contractor focused reviews instead of accelerator readiness reviews when feasible. • The project used contractor focused reviews after the first two phases of installation because the installed equipment was essentially the same as already installed and operating equipment (cryomodules and RF systems). The project also used a contractor focused review for authorizing the testing of the new gas injection system since no beam operations were planned. • The project conducted a single accelerator readiness review in May 2024 at the end of the long installation outage. It was essential to discuss this approach up front with the Oak Ridge Site Office to obtain concurrence. • This approach minimized the cost, effort, and schedule associated with conducting accelerator readiness reviews.
Dedicated procurement team	• Ensure a dedicated Procurement staff is in place to award contracts. • Having a dedicated Procurement Manager and staff was important to manage the large volume of procurements and ensure timely placement. • During the PPU Project a new ORNL Procurement system was deployed. The impact was less severe for PPU as procurements were monitored by one group. • Having a dedicated procurement closeout group has enabled de-obligations and closeout to proceed quickly and efficiently to release TEC funds.
Use of Procurement Readiness Reviews	• Utilizing Procurement Readiness Reviews following final design reviews ensured all documentation was complete, recommendations were addressed, and team members and project office concurred on readiness for orders to be placed.
DOE annual milestones	• Proposing annual milestones before the start of the fiscal year facilitates reaching agreement with the sponsor early in the fiscal year. • Developing completion criteria for each annual milestone ensured transparency with the customer regarding what constitutes completion. • Completion criteria was often referenced to remind the control account manager when success could be claimed.
Project closeout	• Follow best practice of reviewing open charge codes monthly compared to the project schedule and closing charges codes as work scope completes in a timely manner. This practice helps prevent inaccurate charges that require correction. • Monthly review of outstanding obligations to ensure completed work is de-obligated/closed out throughout the project is a best practice.
CD-4 Independent Project Review (IPR)	• Focus the review agenda, presentations, and supporting documentation on project completion. Ensure that Project Execution Plan and DOE Order 413.3B project completion criteria are fulfilled. This review differs substantially from previous IPRs and should be concise and focused. • A two-day review is sufficient for CD-4 (compared to three-day IPRs during project execution). • Update project documentation to reflect the latest status (e.g., hazard analysis report, transition to operations plan).
Anticipate repairs to existing systems	• Anticipate unplanned work during upgrade activities to repair ancillary components that are damaged due to radiation or general wear and tear. • In particular, be aware of radiation damage in non-metallic items such as cable insulation, hoses, and bus bar brackets.
Verify field conditions	• Facility documentation and drawings may not properly convey actual conditions due to "as built" variations and modifications following facility completion.

Spallation Neutron Source - Proton Power Upgrade
Lessons Learned for CD-4

Lessons Learned—Successes	Description, Impacts, and Solutions
	• Always confirm field conditions prior to executing design and installation activities to avoid surprises that may impact safety, cost, and schedule. • Locate rebar in walls via nondestructive techniques prior to cutting or drilling. • Locate underground utilities via nondestructive techniques prior to excavation.
Avoid electronics obsolescence	• Specify and procure electronic components, e.g., controls hardware, as late as possible to avoid obsolescence.

Spallation Neutron Source - Proton Power Upgrade
Lessons Learned for CD-4

Lessons Learned—Potential Improvements	Description, Impacts, and Solutions
Building Information Modelling level of detail	• When using Building Information Modelling (BIM) to design a facility, include just enough detail to facilitate construction. Make sure the project team and vendor agree on the needed level of detail. • Initially, the project engineers had different opinions on the desired level of detail. If agreement on the required level of detail had been made at the onset, cost and schedule would have been minimized without sacrificing design quality.
Database for project change requests	• It would be useful to have a database for project change requests (PCRs). As the number of PCRs increases, it becomes difficult to comb through them and answer questions such as: which PCRs were driven by risk realization, which PCRs increased the baseline, which PCRs decreased the baseline, which PCRs resulted in additional procurements, which PCRs were no-cost administrative changes, etc.
Annual assessment of OPC and TEC funding needs	• Annual evaluation of funding requests prior to fully funding a project is advised along with a careful consideration of funding needs at project end. • The PPU project completed with a surplus of OPC and TEC funding. OPC funding is preferred at project completion due to the ease with which it can be re-allocated (e.g., procurement of spares, transfer to operations)
Project priority for resources during installation outages	• Ensure needed labor resources are available to complete the planned work during the project installation outages. This requires close collaboration and planning with operations to develop agreement on outage priorities.
Legacy product specifications	• It is recommended to use up-to-date products where feasible. • The RTBT tunnel extension task specified a tunnel waterproofing product that was used during the SNS construction twenty years ago. This caused delays due to limited availability of the product, installation tools, and qualified installation vendors.
Design for sufficient operating margins	• Design all components and systems with sufficient margins so that the systems are controllable and are not operating at the limits of their capabilities. • The beam power on target limitation of the first target station is 2.0 MW, and it is desired to operate at 2.0 MW. This required complex design and calibration considerations in the development of a beam power limit system that prevents exceeding the 2.0 MW power limit.
Workforce training for wiring and cabling	• Ensure that personnel performing wiring and cable installation and terminations are adequately trained and supervised to minimize troubleshooting and rework. • A subcontractor performed much of this work, and there were reports of too many errors that needed rework. • Improved training and supervision may have yielded fewer errors.
Transportation incidents	• Consider the possibility of transportation incidents that may cause equipment damage. Utilize “white glove” transportation when appropriate. Acquire sufficient spares to mitigate the risk of transportation incidents. • High-voltage modulator equipment was damaged during shipment from the vendor due to a truck accident. Repair of this equipment caused schedule delays and cost increases.