U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Project Assessment
Status Review Report on the

Proton Power Upgrade (PPU) Project

at Oak Ridge National Laboratory

September 2021

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Proton Power Upgrade (PPU) project, located at Oak Ridge National Laboratory (ORNL), was conducted remotely, due to the global COVID-19 pandemic, on September 14-17, 2021. The review was conducted by the Office of Project Assessment (OPA) at the request of Linda Horton, Associate Director of the Office of Science for Basic Energy Sciences (BES). Ethan Merrill, OPA chaired the review.

The purpose of this review was to assess the PPU project status and progress since the July 2020 DOE/SC CD-2/3 Review. The PPU project team provided well-developed and comprehensive status presentations, and overall, the Committee found that the project is continuing to make good progress in all areas.

Technical–Superconducting RF

Detailed cavity status is as follows: all 32 Research Instruments (RI) cavities have been received. Of these, 21 have been successfully tested bare but require additional cleaning. Eighteen of 21 have been jacketed and of the jacketed cavities, 11 have been qualified for assembly into cryomodule strings. Eight of the 11 jacketed cavities are now assembled in strings “1” and “2”, but those strings are not yet inserted into cryomodules. An ongoing high priority effort at Thomas Jefferson National Accelerator Facility (TJNAF) is the cleaning and testing of jacketed cavities for the remaining string assemblies.

The rate of bare and tanked cavity cleaning and testing at TJNAF has been higher than planned due to more field emission on RI received cavities than planned.

A total of 18 of 32 couplers have been delivered from the Spallation Neutron Source (SNS) to TJNAF. Six more will be delivered before the end of September 2021.

At the time of CD-2/3, the project had planned to have more than the required number of cryomodules on hand for each of the three outages. This is no longer likely and constitutes a slippage in schedule. The original delivery dates for the first five cryomodules was November 2021, February 2022, March 2022, May 2022, and July 2022. The present plan is now for the first two cryomodules to be delivered in February 2022 and April 2022, in time for the first outage.

The first and second module clean strings are assembled and ready for installation into space frames. One return end can, still at the vendor, is needed by early November 2021 to meet the schedule for installation in cryomodule 1. Neither end can for module 2 is in hand.

The superconducting linac (SCL) team made considerable progress since CD-2/3. Cryogenics and utilities are in good shape. Continuing progress on controls should be monitored to make sure these are ready for the outages.

The SCL technical approach remains prudently conservative, and the Committee continues to have confidence that systems will perform as planned.

An eighth cryomodule was added as a spare since CD-2/3 and is justified considering issues associated with aging SNS modules. It should be assumed that delivery for remaining SCL procurements may take longer than has historically been the case. Efforts to get these out the door early are encouraged.

The TJNAF PPU work is proceeding alongside TJNAF C100 and SLAC National Accelerator Laboratory (SLAC) Linac Coherent Light Source-II High Energy (LCLS-II-HE) work. The Electron Ion Collider (EIC) project will require effort from TJNAF PPU team members. While PPU is a high priority, work on the Continuous Electron Beam Accelerator Facility (CEBAF) accelerator remains the highest TJNAF priority. This could be more relevant as schedule pressures mount.

Learning curves associated with the new TJNAF PPU personnel (added since CD-2/3) may also add schedule pressures.

Monitoring of end can work through more frequent vendor interaction is prudent. TJNAF could also, in principle, fix end can issues in-house. The Committee suggested that the project may need to decide in the coming months that this, otherwise undesirable step, is advisable.

Cavity cleaning issues may be close to being resolved; however, this is not yet clear. The project team should quantitatively track progress over the next three to six months. Absent obvious improvement, the project should consider taking additional action, such as adding people resources to resolving the issue.

Overall trends on SCL work in the last year indicate that the possibility of additional schedule slippage is not small. The Committee suggested that the project explore ways to regain schedule contingency without sacrificing Quality Assurance (QA) and testing steps.

Technical–Target

A closed risk needs to be reopened due to recent fabrication challenges on the Proton Beam Window (PBW). All the remaining technical challenges on the test targets, the PPU targets, and associated systems are retired thanks to the extensive R&D program and the experience from operation.

High flow gas injection in the target to mitigate the target vessel fatigue and the cavitation damage is critical and necessary. Recent targets (T24, T25 and T26) operated at 1.4 MW show significant increase in lifetime with much less to no cavitation damage.

The Gas Liquid Separator (GLS) was removed from the Mercury Process System (MPS). The MPS still needs two new hardware to support higher gas injection increase (up to 20 SLPM): the Mercury Overflow Tank (OFT) design is near complete with the Final Design Review (FDR) planned in September 2021. The in-cell target gas supply hardware design is complete and the fabrication solicitation is in progress.

The Committee was very impressed with the excellent progress and the number of tasks accomplished since the CD-2/3 review in the various technical subprojects of First Target Station

(FTS). The project teams have overcome multiple challenges (loss/turnover of personal, COVID-19, change in scope) that reduce the schedule float, but they have completed a substantial number of tasks and the Committee judged that the early project completion is still possible.

The Committee urged the project teams to complete, as soon as possible, the design of the remaining tasks (Mercury OFT, Target Utilities, Hydrogen Refill System (HRS), ortho/para-hydrogen (o/p) H2 diagnostic, control) to raise any unknown issues and mitigate any further delay for the control completion.

Four new targets operated since the July 2020 review and accumulated nearly 7,000 hours of reliable 1.4 MW operation. Post Irradiation Examination (PIE) of recent targets shows less to no damage due to cavitation, providing high confidence in the reliability of target for 2 MW operation.

Systematic measurement of the strain level during operation confirms the efficiency of gas injection to mitigate the fatigue stress. The Committee encouraged the project team to continue this measurement with the future target including new gas injection feature (bubblers and nose gas injection) when higher gas rate and high power will be available.

The project team shows a robust strategy to implement the modifications of the PPU target in two steps (Test Target 1 only includes swirl bubblers, transition center baffle, and new jet-flow supply. Test Target 2 will have all the features of the 2 MW target). This will ensure a deep understanding of the effects of the modifications prior to the 2 MW operation. The Committee supported this strategy.

The R&D scope provided critical input to support design of the 2 MW target and for operation. This scope is complete but continuing R&D and keeping the Target Test Facility operational is strongly encouraged as it will be beneficial to support installation, commissioning, and future operation.

Assessing downstream impacts of an Inconel PBW to the FTS under PPU beam conditions are not part of project scope. Power may have to be limited until critical evaluations are completed by SNS operations. The Committee urged these evaluations to be started in a timely manner, and also that SNS operations give priority to develop an Aluminum Window design with more robust fabrication features. The long-term objective for FTS operation should remain with an Aluminum PBW.

Technical–RF

Since the CD-2/3 review, the project tested the first SCL klystron to 660 kW (the goal is 700 KW), the first article waveguide circulator (circulator failed the acceptance test), and the loads. Fabrication of all high-power radio frequency (HPRF) transmitters is underway.

The first article 3 MW klystron developed a crack on the fifth cavity during brazing and vacuum leak through the wall of first cavity. The first article circulator failed three times. Multiple issues have been encountered with the circulators. The vendor has not yet delivered a functional device.

Delay of the prototype 3 MW Drift Tube Linac (DTL) klystron will limit the time to manufacture the three production units to two years.

Manufacturing delays, primarily due to component suppliers, have had some impacts. The project team continues to work with vendors to optimize schedule and capture non-recoverable delays with Procurement Change Requests (PCR). However, the delays related to procurements are less than a few months on average in most cases.

The goal for the next twelve months is for the low-level RF (LLRF) team to continue system testing and feature advancements, gain operation experience with PPU LLRF systems, receive, test, and integrate LLRF subassemblies, complete Phase-1 installation and initiate installation of the Phase-2 systems.

The RF team made excellent progress with substantial achievements after the July 2020 review under difficult and unpredictable circumstances imposed by COVID-19. The technical maturity of all RF systems is high. Overall, a good portion of the RF systems, subsystems, and components have already been prototyped and tested. The RF team is still on schedule to meet high-level PPU milestones with near-term focus on receipt and testing of equipment needed for Phase-1 installation.

The project encountered several vendor quality and non-conformance issues (700 kW klystrons, 3 MW klystron, waveguide circulators failure, and loads coolant leaks) that required rework, thus causing schedule delays. This should be closely monitored and tracked to avoid further delays, with particular emphasis on circulators.

Large quantities of RF components and modulator hardware are planned for delivery within the next 12 months. This is a major labor resource and schedule challenge to the project team for installation, test, and commissioning activities. It requires careful detailed planning, coordination, communication, and management support to ensure successful execution.

The Committee was concerned that delay in prototype 3 MW DTL klystron will limit the time to manufacture the three production units to two years. This needs a close follow-up.

Managing LLRF collaboration with LBNL continues to be a challenge because of COVID-19 travel restrictions. This resulted in one-year contract extension with LBNL. The project team is highly encouraged to maximize virtual meetings with LBNL staff to take full advantage of remote hardware/firmware/software testing and verification at LBNL as much as possible. Due diligence is needed to stay the course.

Technical–Ring-Accelerator

Ring systems (Estimate at Completion (EAC) $22.4 million) is 45% complete. Costs have increased by 15%, half of which is due to a scope change in the Beam Power Limiting System (BPLS). The BPLS FDR is scheduled for February 2022. The ring systems schedule is still on track for the power ramp-up.

Overall, the project team has made very good progress in all ring systems. Even with some delays, the project is on track to accommodate the power ramp-up beginning in CY 2023.

The Committee noted that the Injection Dump Imaging System is now 63% complete and is progressing smoothly. Similarly, the ring utilities are progressing well. In ring controls, several of the work packages are based on existing systems and technologies, thus no issues were noted. The BPLS challenges are understood and being addressed. The Committee noted and commended the new BPLS team lead.

The production of the injection chicane dipoles and the septum is closely coordinated with FNAL but still requires attention from the project office. Personnel resources at FNAL appear to be largely isolated from competing activities. The Committee noted that two new hires at FNAL should be on board in December 2021, in time for the fabrication start (November 2021).

Outstanding orders (e.g., pumps) may be affected by increased commodity prices or supply chain disruptions.

The time between the BPLS FDR (February 2022) and planned Accelerator Readiness Review (ARR, September 2022), which requires completed installation of all hardware, is short enough to require continuous management attention.

There is one high risk (red) item for the ring systems in the PPU project Risk Registry: magnet fabrication at FNAL. Mitigation plans are established and are being followed. Specifically, there are frequent communications between SNS and FNAL. FNAL is hiring two new technical staff by December 2021 to increase the effort at a critical magnet fabrication moment.

Following the July 2020 review recommendation, the “BPLS redesign” was added to the Risk Registry (yellow). There is a new team lead in this area and it looks like this area is under control and is substantially improved compared to 2020. A mitigation plan for administrative controls was established that will allow the project to ramp up to 1.55 MW, giving BPLS approximately one year of float before it must be ready for operation.

Ring vacuum chamber and foil changers design and fabrication remains a concern (yellow) because of a loss of two key personnel in this area. As a result, the designs are still being finalized and the procurement schedule will be very tight. Overall, this could affect the long outage activities planning. The project team should pay close attention to this risk item and elevate, if needed.

Removal and installation of injection region equipment will be in a high-radiation area of the ring. Residual activation decay after beam shutdown is well known but is still being monitored for any additional impact. The ring team is planning some improvements to the injection region to reduce the time spent working in that area. The project should pay attention to this item as it requires tight communications with SNS operations.

Conventional Facilities

Accomplishments to date are consistent with the project baseline with the design, budget, schedule, contingency plans, and a very qualified staff in place to successfully manage Ring to Target Beam Transport (RTBT) construction.

The plan to tie into the existing tunnel beam line is well planned, schedule is challenging but planning measures in place to meet schedule. Inclement weather mitigation measures are in place.

Project team accomplishments to date and planning for future RTBT project have been very good. There are challenges to construct the RTBT tunnel during inclement weather, but the project has benefitted from a later start date (February 2023 in lieu of December 2022) to start the excavation work.

The tunnel excavation plan is well thought out and consideration to mitigate potential weather impacts have been addressed; as an example, placement of shotcrete on the 1½: 1 excavation slope to better control rainfall.

The geotechnical design plan has considered site conditions, which will benefit the future design build shoring subcontractor. The construction sequence is well thought out and planned, including the sequence to apply waterproofing material to the tunnel and the installation of a liner beneath the top portion of the soil backfill, as well as the plan to cut access points into the existing beam line tunnel.

The project team has updated the RTBT estimates after the Klystron Galley project, due to anticipated increased cost due to busy construction market.

The project schedule includes six months to perform RTBT work, which contains a conservative amount of inclement weather days (36 workdays). The new RTBT construction start date of February 2023 to start excavation, in lieu of December 2022, will help the project by avoiding inclement weather.

Environment, Safety and Health, and Quality Assurance

Integrated Safety Management (ISM) is well established in the project and is being flowed down to lower, tiered subcontractors through the ORNL Chestnut Ridge Project Safety and Health Plan.

ESH&Q personnel are well experienced and integrated into the project to provide support for project document reviews and field inspections.

The project completed the construction of Klystron Gallery and RATS building with 60,000 man-hours without any recordable injuries, which is commendable.

Construction oversight and safety is well managed with the hire of a full-time Construction Field Representative that has safety experience and still utilizing the ORNL Safety Services Representative at 40% time for construction oversight and safety review.

The unreviewed safety issues (USIs) process is being utilized throughout the project as the designs have been finalized with the majority of the USI's incorporated directly to the Hazard Analysis Report (HAR). The additional scope of the RTBT stub and any future USIs will be incorporated directly into Safety Analysis Document (SAD) revisions.

The project has an optimistic view of timing between an Internal Readiness Review and Accelerator Readiness Review (IRR/ARR) to resolve any comments resulting from the IRR.

The SNS facility will develop a detailed, As Low As Reasonably Achievable (ALARA) plan to be set in place for Injection Region Magnet Installation based on ORNL Standards Based Management Systems (SBMS).

The project recognizes and is planning for high radiation activation component removal and replacement that includes removal of higher activation magnets and replacing them using the SBMS processes to assure ALARA is achieved.

The project completed a thorough Oxygen Deficiency Hazard (ODH) analysis that encompasses the additional PPU cryomodules using conservative factors in the analysis. A review of the location of the monitors shows thoughtful placement for effective coverage.

The project QA program has been operating well throughout the project and gets involved at the design phase with the development of the Acceptance Criteria List (ACL) using the graded approach early in the process.

TJNAF's Supplemental QA Plan (SQAP), in place between TJNAF and SNS, is a notable practice that clearly identifies processes and responsibilities for joint execution of the QA programs. TJNAF QA coordination has been very successful and directly addressed the shipping issues from the past to resolve them.

Cost and Schedule

Since CD-2/3 authorization the project has moved from 25% to 57% complete. The forecasted early completion date slipped by three weeks. A total of 14% or $14 million of procurements remain out of $106 million planned. The project has 28 Control Account Managers (CAMs) and 294 control accounts. Contingency, as a function of remaining scope, has increased since CD-2/3 authorization.

The project developed a Contingency Management Plan that outlines the strategy to allocate available contingency. This will become important as the project nears completion and entertains authorizing scope utilizing contingency.

Project Management

Monthly coordination meetings assure the proper allocation of resources across project and operations, with considerable autonomy left to line managers. The project team has been underutilizing resources by 10% and, so far, has not experienced conflicts with operations. This is also due to a one-year look-ahead plan.

PPU is collaborating with TJNAF to design, procure, assemble, low-power test, and ship eight PPU high-β cryomodules (the eighth added to scope in April 2021). There is a longstanding positive relationship between TJNAF and SNS and the collaboration is working well. The TJNAF team has applied lessons from previous experience to improve cryomodule production.

PPU is collaborating with FNAL to design and provide new injection magnets. Magnet design is complete. A high risk is identified in the project Risk Registry regarding competing projects and resource issues at FNAL. The mitigation is defined and being implemented. The FNAL team is adding additional staff to support the PPU schedule.

The Klystron Gallery buildout is complete, and lessons learned will be applied to the RTBT stub procurement.

Transition to Operations planning is progressing. The SNS operations five-year plan now includes a duration for the PPU readiness review and beam tuning. A beam commissioning leader has been assigned and the beam commissioning plan has been revised—the plan will be adjusted as progress evolves.

The PPU management team is very experienced, and the project is being managed well.

The project team should consider adding information to the spreadsheet for Contingency Management items to clarify if the item is procurement only (no installation) of an existing design and if the "Time to Acquire" shown in the spreadsheet is for a new procurement or if it is to exercise an option to an existing procurement.

The Committee suggested establishing a formal decision-making approach, with clear delineation of authority, to determine resource allocation between the project and operations. The coexistence of project management and line management/operations functions within the same person provide an undeniable advantage of simplifying expediting actions; it also creates the risk of impacting the project schedule without the project having a chance to act in a timely manner.

The nature of the certification schedule for Safety Systems, coming at the very end of the project, is such that it is often "under siege" by groups who need access to the premises while the safety systems test is in progress. Consider "protecting" such schedule by appointing one person who is responsible for orchestrating access to the facilities from other system.

Key Recommendations

- Document an acceptable back-up plan if further slippage in the cryomodule delivery schedule jeopardizes the baseline (2-3-2) installation plan. Complete this by October 2021, before a planned delivery for cryomodule end cans.
- Finalize HPRF circulators procurement award by the end of October 2021.
- The Committee supported and was in general agreement with the controls team to switch from the planned Versa Module European (VME) hardware to the Micro Telecommunications Computing Architecture (μTCA) hardware to address VME obsolescence and a path to controls system modernization with robust and more reliable μTCA platform. Even though the project team has estimated the engineering effort and costs are minimal for the conversion, the Committee judged that the numbers are unrealistic and should be scrubbed including any work that may need to be subcontracted. Given all the work that still needs to be done on controls, and ongoing uncertainties due to the pandemic, the Committee recommended it is more prudent at this time to stay

focused on VME and use project contingency to develop µTCA for the linac after the VME is fully commissioned.

- Perform a near critical path analysis of the entire RF systems to identify system and subsystem components that could put the PPU project critical path at risk. The Level 3 RF Systems CAMs should track delivery of the critical or near-critical path components and identify and develop specific plans to mitigate project schedule delays by the end of CY 2021.
- The Committee judged that the RF Controls need labor contingency on the order of 40%, which is currently at 20%. The project team should do a labor contingency scrub by January-February 2022.
- The LLRF team should look at taking advantage of the latest interactive communications technology to facilitate the online collaboration and development effort between the staff at Lawrence Berkeley National Laboratory and ORNL. Prepare a plan for evaluation by the end of October 2021.
- Work with DOE to finalize the language in the draft revision to the Contingency Management Plan. If items permitted to be delivered after CD-4 have any constraints, the plan should include this information.

CONTENTS

1. INTRODUCTION

The Proton Power Upgrade (PPU) is a U.S. Department of Energy (DOE) project at Oak Ridge National Laboratory (ORNL) to upgrade the Spallation Neutron Source (SNS) to maintain leadership among domestic and international neutron scattering facilities. SNS currently serves over 850 unique users annually from national laboratories, domestic and international universities, and industry. SNS provides the most intense pulsed neutron beams in the world for scientific and industrial research and development.

Neutrons for materials research can be generated by two different types of facilities. One utilizes a fission research reactor such as the High Flux Isotope Reactor (HFIR), and the other (SNS) utilizes an accelerator to produce high energy protons that in turn strike a heavy metal (liquid mercury) target producing neutrons by a spallation process. Both neutron scattering facilities in the Office of Basic Energy Sciences (BES) portfolio, HFIR and SNS, are sited at ORNL and address one of the DOE's key research areas—the use of neutrons and sophisticated instrumentation to probe materials.

The SNS was completed and approved for operations on June 5, 2006. It was designed and constructed to accommodate future upgrades. The SNS Second Target Station (STS) Mission Need Statement (MNS), approved in October 2008, described the "need to upgrade the SNS to provide higher beam power and a second target station."

The PPU project will design, build, install, and test the equipment necessary to double the accelerator power from 1.4 MW to 2.8 MW, upgrade the existing SNS target system to accommodate beam power up to 2 MW at the existing First Target Station (FTS), and deliver a 2 MW qualified target. PPU also includes the provision for a stub-out in the SNS transport line to the FTS to facilitate rapid connection to a new proton beamline for STS. The project also includes modifications to the Klystron Gallery and infrastructure.

PPU will accomplish the energy upgrade by fabricating and installing seven new superconducting radio frequency (SRF) cryomodules with supporting RF equipment in the existing linac tunnel and Klystron Gallery. The high-voltage convertor modulators and klystrons for some of the existing RF equipment will be upgraded to handle the higher beam current. The pulse accumulator ring will be upgraded with modifications to the injection and extraction areas. The FTS mercury target has been upgraded with a new high-volume helium gas injection system for pressure pulse mitigation in the mercury target. A redesigned mercury target vessel and other design and operational improvements will enable robust operation of the FTS at the threshold power of 1.7 MW and the eventual objective power of 2 MW. The FTS operating at 2 MW and 60 Hz will receive 33 kJ of energy per pulse. Additional upgrades will be needed for the future STS project to operate the FTS reliably at 2 MW and 45 Hz, when it receives 44 kJ per pulse, which is an increase of 33 percent.

On April 5, 2017, Dr. J. Stephen Binkley, Acting Director, Office of Science and the Project Management Executive, approved the path to Critical Decision-1 (CD-1), Approve Alternative Selection and Cost Range, for PPU, which is based on the 2008 STS MNS and CD-0, Approve Mission Need, determining that a separate CD-0 for PPU was not necessary. CD-1 was approved on April 4, 2018, by Dr. J. Stephen Binkley. The CD-3A, Approve Long Lead Procurements, for $10.505 million of procurements was also approved by Dr. Binkley on October 5, 2018. The CD-3B for an additional $53.43 million of long lead procurements was approved by Dr. Chris Fall on September 3, 2019. The combined CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, was obtained on October 6, 2020, establishing the Total Project Cost (TPC) at $271.6 million, including 40% contingency on work to go, and the CD-4, Approve Project Completion, date of July 2028, which includes 42 months of schedule contingency.

Charge to the DOE Review Committee

In a June 7, 2021, memorandum (see Appendix A), Dr. Linda Horton, Associate Director of Science for Basic Energy Sciences (BES), requested that Kurt Fisher, Director, Office of Project Assessment (OPA), organize and remotely conduct an independent project review on September 14-17, 2021, to assess the project's status and progress since the July 2020 DOE/SC CD-2/3 review.

Membership of the Committee

OPA assembled a Review Committee composed of members (see Appendix B) selected based on their independence from the project, as well as for their technical and management expertise, and experience with building large and complex scientific research facilities. The Committee was organized into eight subcommittees, each assigned to evaluate a particular aspect of the project corresponding to the subcommittee members' areas of expertise. Observers from the Office of Science (SC) and the Oak Ridge Site Office (OSO) also attended.

The Review Process

The review was conducted remotely on September 14-17, 2021. Representatives from the PPU Project Team, OSO, and OPA jointly developed the meeting agenda (see Appendix C) with BES concurrence. PPU project personnel provided information to the Committee in advance of the review and Committee members submitted questions and received responses prior to the review. Final results of the review are contained in this report, which the Committee individually authored and collectively reviewed.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Superconducting RF

2.1.1 Findings

The Committee was briefed on the project status in plenary talks and breakout sessions. The plan continues to be that PPU will double the present SNS beam power capability from 1.4-2.8 MW with 30 percent of the beam power increase from an increase in beam energy and 50 percent from an increase in beam current.

The PPU superconducting linac (SCL) work has proceeded throughout the COVID-19 pandemic. Thomas Jefferson National Accelerator Facility (TJNAF) was largely shut down for the early period of the pandemic but restarted PPU activities in June 2020. PPU activity at TJNAF will continue alongside work on TJNAF C100 and the SLAC National Accelerator Laboratory (SLAC) Linac Coherent Light Source-II High Energy (LCLS-II-HE) work. The Electron Ion Collider (EIC) project at Brookhaven National Laboratory may also require attention from some TJNAF PPU staff. While SNS PPU is a high priority at TJNAF, required work on the TJNAF Continuous Electron Beam Accelerator Facility (CEBAF) accelerator is the highest laboratory priority.

Many of the PPU managers at SNS were present at the original SNS installation. John Mammosser has taken on the additional role of integration manager since the July 2020 CD-2/3 review. At TJNAF, there have been five changes in the management team working on SNS PPU since the time of CD-2/3. In addition, many new engineers and technical staff have been added to the cryomodule assembly team.

The SCL scope increased by $3.6 million since CD-2/3. The majority of the increase, $3.1 million, is due to the addition of an eighth cryomodule. The primary justification is that the existing SCL modules are aging and that a swappable spare is prudent. The project team justified this, in part, by citing helium leaks observed during the past year in original SNS modules. The cost of the spare module is taken as a charge against project contingency and will add about 30 days to the period of performance for module assembly at TJNAF.

Long lead procurements initiated under the CD-3A/B scope are now 92% complete. The receipt and installation activities for the new cryomodules remain on or near the project critical path. New cryomodule installation at the SNS is still required to coincide with three planned maintenance outages during the period from FY 2022 to FY 2024. TJNAF remains largely responsible for meeting this schedule. TJNAF does have other significant and overlapping commitments including work on the CEBAF cryomodules and new cryomodules for LCLS-II-HE. There has been approximately three months of schedule slippage since CD-2/3 in PPU cryomodule assembly at TJNAF.

Cavities production at Research Instruments (RI) was indicated to have been a technical success, though delivery was approximately three months later than originally planned. This is the major reason for the cryomodule assembly slippage so far. Cavity quality, however, appears to be good. PPU should be commended for taking the time to work with an experienced European scientist who performed vendor Quality Assurance visits on behalf of the SNS. Testing of RI cavities at TJNAF both before and after helium jacketing is well along and ongoing.

The cavity status is as follows: all 32 RI cavities have been received. Of these, 21 have been successfully tested bare. Eighteen of 21 have been jacketed and of the jacketed cavities, 11 have been qualified for assembly into cryomodule strings. Eight of the 11 jacketed cavities are now assembled in strings "1" and "2", but those strings are not yet inserted into cryomodules. An ongoing high priority effort at TJNAF is the cleaning and testing jacketed cavities for the remaining string assemblies. The total number and rate of bare and tanked cavity testing at TJNAF has been higher than planned due to more field emission on received RI cavities than planned.

A total of 18 out of 32 couplers have been delivered from the SNS to TJNAF. Six more will be delivered before the end of September 2021. Processing is ongoing at the SNS for the remaining couplers. As discussed in previous reviews, the new PPU coupler probe is slightly thicker and shorter than for the existing SNS couplers, but couplers are otherwise similar as for the existing SNS. RF couplers continue to be conditioned at 700 kW in traveling wave and 600 kW in standing wave. No remaining technical issues were identified in this area.

The PPU team is using the present time to complete preparatory tunnel work. Module stands have been installed into the tunnel for all seven new modules. Smaller tasks such as installing walking grating to prepare for making cryogenic connections is ongoing.

The following findings relate to the PPU schedule. At the time of CD-2/3 the project had planned to have more than the required number of cryomodules on hand for each of the three outages. This is no longer likely and constitutes a slippage in schedule. Original deliveries for the first five cryomodules were in November 2021, February 2022, March 2022, May 2022, and July 2022. The present plan is now for the first two cryomodules to be delivered in February 2022 and April 2022, just in time for the first outage. The three-month delay is due mostly to cavities arriving from the vendor later than originally planned.

The detailed status of the module assembly at TJNAF is as follows: the first and second cryomodule clean strings are assembled and ready for installation into space frames. A return end can, still at TJNAF and being prepared for return to the vendor for re-work, is needed back by early November 2021 in order to meet the schedule for cryomodule 1. Neither supply nor return end cans for cryomodule 2 are delivered to TJNAF. The jacketed cavities for the third cryomodule are fabricated, but not enough of these are clean and tested to proceed with assembly of the third string. This cleaning and assembly work is indicated to be a couple of months behind schedule.

The major item of scope for PPU cryogenics is the new U-tubes. Bayonets are designed and are essentially fixed length. An experienced vendor is identified. After the installation of seven of the new cryomodules into the SNS SCL, there is a planned 40% excess capacity in cryogenic cooling. Controls and utilities are moderately sized efforts but do plan many of the procurements in these areas for FY 2022.

The shipping fixture that will be used to move finished modules from TJNAF to the SNS has received needed modification to accommodate the new end cans. The fixture has been extensively tested in a realistic shipping tests with a dummy cryomodule. Measured bouncing during testing were within expectations and the PPU team expects the transport system to perform well.

Thirteen low- to medium-level risks are tracked by the project. None are identified as high-level for SCL systems. Risks include issues of TJNAF priorities with respect to other work, schedule slippage on cryomodule delivery and cavity underperformance in terms of gradient. PPU cryomodules delivered to the SNS from TJNAF will undergo extensive cold testing up to the operating gradients at the SNS both before and after installation into the tunnel.

2.1.2 Comments

Overall, the SCL systems have made considerable progress since CD-2/3 despite the challenges presented during 'unusual times'. SCL cryogenics and utilities work for PPU appears to be on track to support the module installation. PPU controls needed for new cryomodule operation are close to the critical path and it would be unfortunate if these impacted turn-on of the cryomodules. The overall PPU SCL system remains prudently conservative and the Committee continued to have good confidence that systems will perform as planned. The plan is to ramp the newly installed cryomodules to full operating gradient after each of the three outages. This might be challenging since all systems need to be functional, but it is nonetheless a good goal.

PPU managers continue to bring considerable experience from the original SNS installation. This reduces the likelihood of loss of institutional knowledge and is important for complex cavity and cryomodule systems. The SCL team at the SNS, has sufficient workforce and expertise to carry out the installation work plan. However, the SCL group is and will continue to be lean and the loss of any key manager or technical staff could have a significant negative impact. The Committee noted that there have been changes and an overall increase in accelerator staff at TJNAF in the last year and it is natural to expect this could have negative technical or schedule impacts for PPU. While it does not appear that staffing issues are the cause for the present three-month delay in module assembly, the learning curve associated with new staff could compound schedule pressures.

As noted in the CD-2/3 report, the TJNAF/SNS/PPU team have good tools in place for tracking vendor hardware and most of the hardware needed to perform cryomodule assembly is in hand, but key pieces are still with industrial partners. The Committee could not comment regarding procurement of smaller components that are needed to keep the module assembly on track (stainless bellows) might be purchased from alternate vendors, or even from two vendors simultaneously, if the cost/benefit is reasonable. It should be assumed that delivery for remaining SCL procurements may take longer than has historically been the case. Efforts to get these out the door early are encouraged.

Because all 32 new cavities are needed to fill the eight cryomodules, and to date 21 have been cold tested, there remains some risk to the baseline plan until all of these cavities are fully tested. If a cavity underperforms after testing, there is a reasonable backup plan to redo chemistry at TJNAF. Other backup possibilities to reuse pre-production or original SNS cavities are less than optimal, but not unreasonable.

The Committee noted at CD-2/3 that some of the larger procurements would require or benefit from close interaction with their respective vendors, particularly if vendors are new. The Committee also noted that oversight is more difficult with restricted travel. These issues likely underlie some of the problems with the cryogenic end can delivery. The Committee concurred with the SNS/TJNAF/PPU team that the present end can re-work and fabrication of the rest of the production units will benefit from increased and regular communication with the vendor and, if possible, with increased project presence at the vendor site. The Committee supported PPU efforts in that area. TJNAF could also, in principle, fix end can issues in-house. The Committee suggested that the project team may need to decide in the coming months if this otherwise undesirable step becomes advisable.

Cavity cleaning issues may be close to being resolved; however, this is not yet clear. The project should quantitatively track progress over the next three to six months. Absent obvious improvement, the project should consider taking additional action, such as adding people resources to resolving the issue.

SCL cost and schedule are not impacted significantly due to COVID-19. However, the float in the schedule for cryomodule delivery still present at CD-2/3 has largely disappeared due to the three-month delay in delivery of cavities from the vendor and issues with module end can delivery and cavity cleaning described in the findings above. Trends over the last year indicate that the likelihood of additional schedule slippage is not small and the Committee suggested that the project explore ways to regain schedule contingency without sacrificing rigorous Quality Assurance and test steps. This comment was intended especially with respect to cryomodule delivery and testing prior to the first two planned outages.

2.1.3 Recommendation

1. Document an acceptable back-up plan in the event that further slippage in the cryomodule delivery schedule jeopardizes the baseline (2-3-2) installation plan. Complete by October 2021, before a planned delivery for cryomodule end cans.

2.2 Target

2.2.1 Findings

The scope of the First Target Station (FTS) systems is to reliably operate the FTS at 2 MW with 1.3 GeV proton pulses delivered at 60 Hz with an extended lifetime to 60 years, as well as assure consistent neutron pulses with LH2 moderator catalysts and diagnostic.

The scope of the target systems is to provide a FTS that sustain high beam power and higher beam energy. The FTS includes the 2 MW target (P.5.9), the Mercury Process Systems (MPS, P.5.3), the Moderator Cryogenic Systems (MCS, P.5.4) the Vessel and Shielding System (P.5.5), the Target Utility Systems (P.5.6), the Instrument System (P.5.7), the Mercury Off-gas Treatment Systems (MOTS, P.5.8), the Safety, Controls and Operations (P.5.10); as well as the Neutronics (P.5.2) and the Gas Injection Developments (P.5.11) to support the evaluations and the development of the above systems.

Most of FTS (except the target module) were initially designed for 2 MW with 1.0 GeV protons. Only the target module needs new design inside the Monolith and it is a replaceable system. All the other hardware inside the Monolith (replaceable or permanent ones) are ready for PPU operation and extended lifetime of 60 years. Gas injection increase and beam energy increase imply some work on other subsystem outside of the Monolith. They were evaluated and addressed in the PPU FTS system.

All scopes (except P.5.4) are essential for meeting the Key Performance Parameters (KPPs) and need to be installed, tested, and ready by the middle of the extended outage in FY 2023. A mini-Accelerator Readiness Review (ARR) will be conducted to authorize integrated testing/ commissioning of target/mercury/gas systems without beam during this extended outage.

The remaining neutronics scope (P.5.2; mainly measurement activity) is transferred to the management scope P5.1 and to P.8.1 Commissioning.

The scopes of the Vessel and Shielding System (P.5.5) and Instrument System (P.5.7) were completed at the CD-2/3 review and were not presented at this DOE/SC Status review.

P.5.9 – 2 MW target and P.5.11 – Gas Injection Development

The design of the test target and the PPU target is based on a 10+ operational experiment and extensive R&D program.

Higher power levels for the project requires a higher helium gas injection flow-rate for the mercury target to mitigate target damage and fatigue.

Recent targets (T24, T25 and T26) operated at 1.4 MW show significant increase in lifetime with much less to no cavitation damage.

The gas injection was extensively supported by advanced simulations and by R&D, including a scale-1 mockup running with water and mercury. Experimental data match well with simulations providing a deep understanding of the phenomenon inside the target and the needed information for the gas injection implementation in FTS.

Systematic measurement during operation validates the gas injection to reduce the strain level in target.

Communication with the manufacturing company is strong and well-developed, leading to target fabrication success.

The strategy to run 2 test targets before the long outage will demonstrate new target features with potentially higher beam power. The test target 1 will have the new swirl bubblers to improve gas injection and will run at 1.4 MW and 1 GeV (same parameter than current operation). The test target 2 will have all the features of the PPU production target (swirl bubblers and nose gas injection) with a beam power ramp up to 1.5 MW and 1.1 GeV.

P.5.3 – Mercury Process Systems

Modification to the mercury process loop are needed to mitigate the potential of liquid mercury escaping the service bay under a hypothesized accident scenario. The Gas Liquid Separator (GLS) was removed from the MPS. The MPS still needs two new hardware to support higher gas injection increase (up to 20 SLPM): the Mercury Overflow Tank (OFT) design is near complete with the Final Design Review (FDR) planned in September 2021 and the in-cell target gas supply hardware design is complete and the fabrication solicitation is in progress.

P.5.4 – Moderator Cryogenic Systems

The 2 MW readiness of the Moderator Cryogenic System is not a scope of the PPU project. Project upgrades are not essential to meet project KPPs, but it will assure consistent cold neutron pulses regardless of beam power or time since H2 loading. The Hydrogen Refill System (HRS) needs to be upgraded to support the increase of H2 loop volumes.

The para-hydrogen fraction will be maintained above 99% with addition of ferrous oxide catalyst beds. The catalyst retention elements in the converter assembly are a credited control.

In-situ monitoring of ortho/para-hydrogen (o/p) fraction will be accomplished by Raman spectroscopy through sapphire windows. Extensive tests have been performed on sapphire windows for the Raman spectroscopy system to ensure safe operation under the operational conditions.

The design team is taking the advantage of the strong collaboration with J-PARC and his experience with the catalyst system.

P.5.6 – Target Utility Systems

The Target Utility Systems require some upgrade for increased beam energy from 1.0 to 1.3 GeV; and for increased flow-rate gas injection. Design and analyses of the gas injection upgrade are complete, and procurement is on progress.

The Gas Recirculation (GR) design is near complete with expected FDR during fall 2021 and installation to beginning during winter 2021.

P.5.8 – Mercury Off-Gas Systems

The MOTS are progressing well but requires an upgrade for increased flow-rate gas injection and modification with additional delay beds, cold traps, and associated shielding. The cold trap may encounter a plug or freeze event during operation, so a second cold trap is needed for operational redundancy as a backup unit.

P.5.10 – Safety, Controls and Operations

The Control System requires modification to support additional hardware for target control integration. It is based on existing EPICS architecture, which is scalable and extensible. Target

Control System progress has been delayed because the predecessors have been delayed but additional resources are working to recover the schedule. The safety scope includes the development of accelerator safety documentations to support FTS upgrades associated with PPU. FTS safety analysis is complete.

2.2.2 Comments

The Committee was very impressed with the excellent progress and the number of tasks accomplished since the July 2020 CD-2/3 review in the various technical subprojects of FTS.

The project teams have overcome multiple challenges (loss/turnover of personal, COVID-19, change in scope) that reduce the schedule float, but they have completed a substantial number of tasks and the Committee judged that the early project completion is still possible.

Even if the Moderator Cryogenic System is making reasonable progress, it is the scope the most impacted by the loss of key personal (the Control Account Manager (CAM) and key subcontractor). The engineering is now under the responsibility of the Research Accelerator Division (RAD) cryogenic group with some new hiring coming in the next few months. The Committee encouraged P.5 Level 2 and 3 managers to continue pushing the use of available resource in-house and through subcontractors, when possible, as well as the new hiring to support FTS. The P5 Level 2 manager should also continue to develop good communication with RAD cryogenic group to keep a high priority and strong support on the numerous remaining CMS tasks as they have also duties with operation.

P.5 is supported by experienced and knowledgeable teams. New hiring will be beneficial for the project and will compensate the loss of several key persons that delay several scopes.

The Committee urged the project teams to complete, as soon as possible, the design of the remaining tasks (Mercury OFT, Target Utilities, HRS, o/p H2 diagnostic, control) to raise any unknown issues and mitigate any further delay for the control completion.

P5 teams continue to develop a strong relationship between PPU and operation to coordinate activities during the installation and a five-year operational plan was issued in conjunction with PPU. The Committee encouraged the project teams to regularly review this five-year plan for each scope to adjust and coordinate the installation and upgrade of the different FTS systems.

The current Proton Beam Window (PBW), made of Inconel, will reach it administrative radiation limit in late 2022 and it must be replaced. PPU FTS systems evaluations and designs are based upon an aluminum PBW. A risk for this assumption was retired a few months ago but recently, fabrication of both aluminum PBWs experienced critical manufacturing issues and an Inconel window replacement may have to be in service at the start of the PPU operation. Assessing downstream impacts of an Inconel PBW to the FTS under PPU beam conditions are not part of project scope. Power may have to be limited until critical evaluations are completed by SNS operations. The Committee urged these evaluations to be started in a timely manner. The Committee also urged SNS operations to give priority to develop an aluminum PBW design with more robust fabrication features. The long-term objective for FTS operation should remain with an Aluminum PBW.

P.5.9 – 2 MW target and P.5.11 – Gas Injection Development

The team members of the project are also part of operation team. It is understood that all progress and development from PPU project will be greatly beneficial for operation and vice versa. All the following statements are related to this comment:

- Four new targets have operated since the July 2020 CD-2/3 review and accumulated nearly 7,000 hours of reliable 1.4 MW operation. One target developed a leak, but the cause was identified as a crack initiation on an internal sharp corner. Design modifications are already implemented in target under fabrication. The Post Irradiation Examination (PIE) of recent targets shows less to no damage due to cavitation, providing high confidence in the reliability of target for 2 MW operation.
- Systematic measurement of the strain level during operation confirms the efficiency of gas injection to mitigate the fatigue stress. The Committee encouraged the project team to continue this measurement with the future target including new gas injection feature (bubblers and nose gas injection) when a higher gas rate and high power will be available.
- The project team continues to improve the procedures and to train personal to speed the change of targets. This effort will help for future operation, as well as during the installation process.
- The project teams should also continue to keep the good practice of performing systematic PIE of every targets to identify any damage or leak initiation and evaluate the effect of new/modified design on fatigue and cavitation mitigation.
- The Committee supported the operations of the two test targets before the extended outage—this successful fabrication has already provided good training for future fabrication of the three PPU targets.
- The project team shows a robust strategy to implement the modifications of the PPU target in two steps (Test Target 1 only includes swirl bubblers, transition center baffle and new jet-flow supply. Test Target 2 will have all the features of the 2 MW target). This will ensure a deep understanding of the effects of the modifications prior to the 2 MW operation. The Committee supported this strategy.

Even if attempts have been made, multiple sourcing for target production should continue to be pursued in order to avoid relying on single source expertise.

The R&D scope provided critical input to support design of the 2 MW target and for operation. This scope is complete but continuing R&D and keeping the Target Test Facilities (TTF) to be operational is strongly encouraged as it will be beneficial to support installation, commissioning, and future operation.

P.5.3 – Mercury Process Systems

The Committee endorsed the suppression of the GLS from the MPS. The GLS is not credited in the hazard analysis approach, so its removal from the PPU project scope will not impact the safety basis. The additional benefits of installing the GLS system no longer seem worth the operational risk of installation and post-installation complications that are associated with the GLS.

P.5.8 – Mercury Off-Gas Systems

The final installation activity of the MOTS is the upgrade of the existing cold trap that will serve as a back-up unit. This is planned in FY 2024 (after the extended outage when the new, primary cold trap will already be in service), allowing a longer radioactive decay downtime for modification of the backup.

Thanks to the early delivery of the delay beds from the supplier, they were already installed during summer 2021. The Committee appreciated the effort to install equipment as soon as they are available to mitigate schedule delay.

The Committee commended the addition of the Molecular Sieve to keep the dry environment for full efficiency and protection of the carbon absorber and lead to a better performance of MOTS.

The Committee appreciated the effort from the project team to develop the 3D model of the existing MOTS equipment room, reducing greatly the risk of interference with new equipment in this compact area.

P.5.10 – Safety, Controls, and Operations

A safety committee review of the Molecular Sieve Design (January 2021) shows concerns that force significant modifications on the shielding design. The new design is in place and reduces the source term values by 50%. Despite of the delay, there is enough float in the schedule for the installation during the extended outage in FY 2023.

The FTS safety analysis is complete including the safety aspect from new equipment or features (new gas injector design, o/p converter, impact of beam energy increase on existing facility), and no significant changes are expected during the implementation in the Final Safety Assessment Document—Neutron Facilities (FSAD-NF) before final approval.

2.2.3 Recommendations

None.

2.3 RF

RF Systems include Management and System Integration (P.3.1), SCL high-power radio frequency (HPRF; P.3.2), nonconducting linac (NCL) HPRF (P3.3), LLRF (P.3.4), Existing Linac Modulators (P.3.5), New Linac Modulators (P.3.6), Utilities (P.3.7), RF Controls (P.3.8), and Global Controls (P.3.9). The RF team has made considerable progress since CD-2/3 and worked effectively to address several vendor-related schedule delays and Quality Assurance issues, as well as overcoming multiple challenges last year due to pandemic. All final designs are complete. The RF team continues to focus on receiving, installing, testing, and commissioning rf hardware. Availability of resources including skilled workers is a concern and needs to be sorted out working closely with the PPU management and the SNS Directorate. This is critical as the team prepares for major and intense onsite installation and commissioning of RF equipment in the next 12 months. Pandemic uncertainty requires constant vigilance, close monitoring, and regular follow-ups to identify and mitigate problems early on.

2.3.1 Findings

On-going COVID-19-related delays to procurements have moved RF systems including several subsystems to near critical path. The project team is taking proper actions to mitigate issues related to the SCL klystrons, 3 MW DTL klystron, RF transmitter, Alternative Topology High Voltage Converter Modulators (AT-HVCM), low level RF (LLRF), and controls.

RF systems procurements are currently on track for power ramp-up.

Decision on the circulator procurement is imminent.

Critical PPU staff were permitted onsite throughout COVID-19.

Final design reviews have been completed for all RF systems.

All installation activities follow the Neutron Science Directorate five-year plan. Key RF systems installation dates are defined.

The project had to extend its current LLRF system support contract to LBNL due to COVID-19 travel restrictions.

Since the CD-2/3 review, the project tested the first SCL klystron to 660 kW (the goal is 700 KW), tested first article waveguide circulator (circulator failed the acceptance test) and the loads. Fabrication of all HPRF transmitters is underway.

RF transmitters encountered delays due to a supply-chain bottleneck.

No high risks are identified. Key risk categories have been analyzed and include vendor risks and equipment vulnerabilities.

Only six, from the first batch of 12, SCL klystrons have been received (total is 28). Three units failed due to fabrication issues. The first article 3 MW klystron developed a crack on the 5th cavity during brazing and vacuum leak through the wall of the 1st cavity. The first article circulator failed three times. Multiple issues have been encountered with the circulators. The vendor has not yet delivered a functional device.

A delay of the prototype 3 MW DTL klystron will limit the time needed to manufacture the three production units to two years.

All waveguide loads (due to Quality Assurance issues) returned to the manufacturer to re-work the relief valves.

Three AT-HVCMs are being procured for the new cryomodules. Delays in production of SCL-Mod30 puts it near critical path for Phase-1 installation.

Upgraded prototype radio frequency quadrupole (RFQ)/DTL HVCM did not meet all performance requirements. It will be retrofitted by adding a series inductor or modification of the transformer. Both fixes are being investigated.

Upgrading existing three modulators for RFQ and DTLs to support a 25% power margin.

Utilities upgrade scope includes new cooling water and electrical distribution for the new RF sources and cooling water system upgrades to the existing nonconducting linac system.

An upgrade to the existing three modulators for RFQ and DTLs will support a 25% power margin. A prototype was fabricated and tested at full power for the DTL configuration.

The project is waiting 3 MW klystrons for the RFQ configuration test.

Testing with a resistive load, and circuit modeling indicate that a transformer does not meet specifications and will prevent full-peak power for the RFQ-Mod1.

The prototype pulse transformer had a leakage inductance that was less than optimal, preventing full power into the worst-case klystron configuration for RFQ-Mod1. The solution includes adding a 1.2 µH choke in series with the transformer primaries or design new secondary winding baskets with the optimal leakage inductance. Both options are being pursued. Electrical design of new transformer secondary baskets and an optional series choke is complete. The project team can test at full peak power into resistive load but not with 3 MW klystrons. This is a nice to do but not essential for PPU.

Since the last week of May, full power testing with two 2.5 MW klystrons running with prototype HVCM has occurred. There have been multiple trips caused by klystron arcing and cooling faults, without a single internal fault.

Supply-chain delays of controls components may impact system availability for Phase-1 installation. This can be mitigated by using units that are currently at SNS for the initial Phase-1 testing. This primarily is related to the field programmable gate array (FPGA) boards.

Alpha Omega Power Technologies (AOPT) was awarded first article AT-HVCM in April 2020 with options exercised after the CD-2/3 approval. A procurement was awarded to Dynapower for two additional power transformers and SCR units in December 2020 to ensure there is interchangeability with the existing equipment.

Manufacturing delays, primarily due to component suppliers have had some impacts. The project team continues to work with vendors to optimize the schedule and capture unrecoverable delays with project PCRs. However, the average overall delays of procurements are less than a few months in most cases.

The 805 MHz RF driveline is complete to the end of the linac tunnel but requires the original unused portions to be temperature compensated.

The FDR of the existing linac modulators was completed in September 2020. Recommendations have been addressed and closed.

Production windings are scheduled to be delivered on March 24, 2022. There is no impact on modulator installation. Cost impact of design and testing new windings is approximately $100k.

Heavy technician labor support is a challenge for the new Electrical Power Conversion Group.

The goal for the next twelve months is for the LLRF team to continue system testing and feature advancements, gain operation experience with PPU LLRF systems, receive, test, and integrate LLRF subassemblies, complete Phase-1 installation and initiate installation of Phase-2 systems.

Controls made good progress and key accomplishments in several areas since CD-2/3 review including documentation, software development and configuration, software interlocks, supporting cavity testing in the linac, linac/SCL timing/MPS, protection system, networking, and computing infrastructure.

The controls team developed installation plans covering racks, cabling, MPS, timing and network hardware, and PPS interface.

Controls has enough Micro Telecommunications Computing Architecture (μTCA) crate processors to cover the first two cryomodule zones for LLRF.

MPS Fast Protect System (FPS) is based on a new design that is being developed through an Accelerator Improvement Project.

Delay of MicroTCA Processor Cards for LLRF is a risk (delayed four months). The project team; however, can still achieve the installation schedule.

Controls is considering switching from Versa Module European (VME)-based input/output controls to μTCA.

Some types of FPGA deliveries are now stretched out to 52 weeks.

2.3.2 Comments

The RF team made excellent progress with substantial achievements since the July 2020 DOE/SC CD-2/3 review under difficult and unpredictable circumstances imposed by COVID-19.

Presentations by the team members were thorough, focused, consistent, and very informative. The Committee appreciated the project team availability to answer questions and provide additional information.

The technical maturity of all RF systems is high. Overall, a good portion of the RF systems, subsystems, and components have already been prototyped and tested.

The level of RF systems documentations and system/subsystem drawings are at a mature level.

The project team has done a very good job conducting onsite acceptance tests as much as possible during last year, with limited onsite access imposed by ORNL due to COVID-19. The Committee encouraged the project team to continue safe and timely onsite acceptance tests of the RF components as they arrive from the vendors.

With ongoing travel restrictions, regularly scheduled virtual meetings and frequent communication with the vendors are essential and critical to prevent any additional schedule delays and to be able to flag and address any non-performance and non-compliance issues early.

COVID-19 had some impacts on the RF systems schedule, causing noticeable procurements delays that have pushed RF systems to near critical path. Impacts have been mitigated and are manageable.

The project team is on schedule to meet high-level PPU milestones with near-term focus on receipt and testing of equipment needed for Phase-1 installation.

Recent schedule delay requests have resulted in several change requests with cost increases.

Finding and retaining staff and skilled workers (craft workers) continues to be challenging. This requires close monitoring of staff planning and making timely adjustments as the project goes forward. The project team should consider utilizing resources from other directorates when necessary. Succession planning is important for critical staff as the project approaches installation and commissioning phase.

Lack of available skilled labor has caused delays in the ramp-up of technical equipment installation.

Appropriate mitigation measures were taken to address failure of first article 3 MW klystron and three 700kW klystrons at the factory.

Several project change requests resulted in a roughly $700,000 change to the HPRF baseline.

The project encountered several vendor quality and non-conformance issues (700 kW klystrons, 3 MW klystron, and waveguide circulators failure and loads coolant leaks) that required rework thus causing schedule delays. This should be closely monitored and tracked to avoid further delays, with particular emphasis on circulators.

Software for the MPS upgrade is still in the design stage. This is being support by a separate Accelerator Improvement Project but is needed for PPU.

Large quantities of RF components and modulator hardware are planned for delivery within the next 12 months. This is a major labor resource and schedule challenge to the team for installation, test, and commissioning activities. It requires careful detailed planning, coordination, communication, and management support to ensure successful execution.

The Committee was concerned that a delay in the prototype 3 MW DTL klystron will limit the time to manufacture the three production units to two years. This needs a close follow-up.

The L3 transmitters are on track for delivery but are incurring subsupplier delays due to COVID-19. The L3 purchased all of the printed circuit boards (PCBs) early so there are no chip availability issues.

For P3.6, modulators: three new AT-HVCM will power twenty-eight 700 kW klystrons. The modulators will experience a three-month schedule impact due to COVID-19 delays—there is now a five-month window for AT-HVCM commissioning.

Inability to travel required ORNL to hire a local consultant to monitor modulator fabrication and assembly by the company in Albuquerque. This has worked very well for the project. The factory acceptance testing has been delayed by one month and is expected to be done in October-November 2021.

Managing the LLRF collaboration with LBNL continues to be a challenge because of COVID-19 travel restrictions. This resulted in a one-year contract extension with LBNL.

The project team is highly encouraged to maximize virtual meetings with LBNL staff to take full advantage of remote hardware/firmware/software testing and verification at LBNL as much as possible beyond the conventional virtual meeting apps that are currently being done. Due diligence is needed to stay the course.

The project team was encouraged to review the current LLRF activities and revise key milestones and resource availability to get a better handle on the delivery schedule.

The project team should focus on completing all aspects of software/firmware development and verification of their functionality with beam operation in mind. This goes beyond basic functionality tests and verifications. This should be a high priority.

The Committee encouraged the LLRF team to continue developing advanced features (bench and SCL23D) as needed and continue testing with beam as much as possible.

The adaptive beam controls have not yet been tested with beam. It was tested in laboratory with simulated beam.

Addressing the modulator installation and commissioning will be tricky from a resource perspective because of priority of operations vs PPU. There is a five-month window for AT-HVCM commissioning, and the project does not want to be stopping and starting this effort.

The electrical subject matter expert has delayed retirement through the end of the year. He is working with and mentoring a new hire to assume the role. Good succession planning was commended.

The Committee encouraged the LLRF team to continue developing advanced features (bench and SCL23D) as needed and continue testing with beam as much as possible.

The LLRF three-phase installation plan appears to be reasonable, but details are missing. For the Phase-1 LLRF installation, 16 AMC-532 FPGA boards can be borrowed from controls if board delivery is delayed. This is a good gap measure approach if needed.

The RF system utility installation activities must be closely coordinated with SNS operations if the October installation plan overlaps into the run schedule.

The MPS FPS is based on a new design under development through an Accelerator Improvement Project. It is a critical system for PPU. FPS is not in the advanced design stage. The controls team is looking into several alternative plans if this system is not available for the PPU accelerator commissioning. The project team is encouraged to make an effort to test the new design with SNS beam.

Good progress was made over the last 12 months. The RF team is still on schedule to meet high-level PPU milestones with near-term focus on receipt and testing of equipment needed for the Phase-1 installation.

The project team should continue to review and update documentation as needed as the project progresses, especially the Integrated Control documents (ICDs), installation, test, and commissioning plans.

All recommendations from past reviews have been addressed and closed.

The Committee was concerned that controls has much work yet to do. A shortage of integrated circuits (ICs) and PCBs have caused schedule delays. The project team has tried to move up procurements in the schedule. The project team lost a technician and an engineer, and was also affected by a COVID-19 quarantine.

Currently, controls has 20% contingency in resources. This is not likely enough given the amount of work left to do, potential supply chain issues, and uncertainties associated with the pandemic.

The Committee suggested that a possible solution is borrowing controls technicians from another laboratory for six to nine months.

The controls team is debating whether to switch to µTCA hardware (the future technology) or stick with the already planned and procured VME hardware.

2.3.3 Recommendations

2. Finalize HPRF circulators procurement award by the end of October 2021.

3. The Committee supported and was in general agreement with the controls team to switch from the planned VME hardware to the µTCA hardware to address VME obsolescence and a path to controls system modernization with robust and more reliable µTCA platform. Even though the project team has estimated the engineering effort and costs are minimal for the conversion, the Committee judged the numbers are unrealistic and should be scrubbed including any work that may need to be subcontracted. Given all the work that still needs to be done on controls, and ongoing uncertainties due to the pandemic, the Committee recommended it is more prudent at this time to stay focused on VME. Use project contingency to develop µTCA for linac after VME is fully commissioned.

4. Perform a near critical path analysis of the entire RF systems to identify system and subsystem components that could put the PPU project critical path at risk. The L3 RF Systems Control Account Managers (CAMs) should track delivery of the critical or near-critical path components and identify and develop specific plans to mitigate project schedule delays by the end of CY 2021.

5. The Committee judged that controls need labor contingency on the order of 40% which is currently at 20%. The project team should do a labor contingency scrub by January-February 2022.

6. The LLRF team should look at taking advantage of the latest interactive communications technology to facilitate the online collaboration and development effort between the staff at LBNL and ORNL. Prepare a plan for evaluation by the end of October 2021.

2.4 Ring-Accelerator Systems

2.4.1 Findings

The start of the injection dipole fabrication was delayed by three months, and the completion of the injection region vacuum chambers and foil changers design is still outstanding due to the loss of two key personnel. The ring systems schedule is still on track for the power ramp-up, with ring systems (Estimate at Completion or EAC, $22.4 million) 45% complete. There was a cost increase of 15%, half of which is due to a scope change in the Beam Power Limiting System (BPLS). The BPLS FDR is scheduled for February 2022.

2.4.2 Comments

Overall, there is a very good progress in all ring systems. Even with some delays, the ring systems are on track to accommodate the power ramp-up beginning in CY 2023.

In particular, the Committee noted that the Injection Dump Imaging System is now 63% complete and is progressing smoothly. Similarly, the ring utilities are progressing well. In ring controls, several of the work packages are based on existing systems and technologies, thus no issues were noted. The BPLS system is described above, and challenges are understood and being addressed. The Committee noted and commended the new BPLS team lead.

The production of the injection chicane dipoles and the septum is closely coordinated with FNAL but still requires attention from the project office. Personnel resources at FNAL appear to be largely isolated from competing activities. The Committee noted that two new hires at FNAL should be on board in December 2021, in time for the fabrication start (November 2021).

Outstanding orders (e.g., pumps) may be affected by increased commodity prices or supply chain disruptions.

The time between the BPLS FDR (February 2022) and planned ARRs (September 2022), which requires completed installation of all hardware, and is short enough to require continuous management attention.

2.4.3 Recommendations

None.

3. CONVENTIONAL FACILITIES

3.1 Findings

Despite the challenges faced early on during the Klystron Gallery project, due to COVID-19 impacts and limited bid participation, the project team overcame these obstacles with a good schedule and cost performance.

Klystron Gallery

The project is complete with a Schedule and Cost Performance Indices (SPI/CPI) of .99 and 97, respectively. The project scope was coordinated with a total of four different customers. A limited number (two) of firms bid the project. The subcontractor was unable to complete controls work, so ORNL completed it. The project team utilized frame mockup templates, which allowed MEP work to accurately proceed in the field while transmitter rack cooling carts were fabricated offsite in Knoxville, Tennessee. There were existing field conflicts encountered, due to a lack of scanning by the A/E during the design phase. A total of $283,000 in project change orders and a predominant contingency amount was for COVID-19 impacts.

Ring to Target Beam Transport

The Ring to Target Beam Transport (RTBT) project is very well thought out from a design and construction standpoint. Past ORNL project experience and very knowledgeable and experienced ORNL staff is the driving factor in this project being so well planned. Future potential project challenges have been analyzed and plans to address these issues have addressed from a design, schedule, and construction sequence standpoint.

The construction of the tunnel that will connect to existing tunnel(s) is scheduled to start February 2023.

Shoring design is sheet piling for a design build subcontractor to design and install.

The excavation is a 1½:1 slope with shotcrete applied to provide protection against rainfall.

There is a plan to have the contractor begin the submittal process for approval in September 2022.

The project has a dual path plan to manage work. This plan includes ORNL managing construction—concurrently they are pursuing DOE approval to utilize a CM/GC to manage and subcontract work.

A soil stockpile location was determined on site, but will change if the STS project starts earlier than planned.

A total of 36 workdays for inclement weather was incorporated into the project schedule.

The project schedule is a six-month duration (February 2023 to July 2023).

A liner to be installed just below the topsoil backfill surface will serve as an additional means of water proofing.

The estimates were updated to reflect the Klystron Gallery lessons learned and anticipate a tight labor market.

The project is carrying 47% in contingency for the RTBT stub and management WBS.

The existing soil stockpile adjacent to the site will be relocated by the STS project.

3.2 Comments

The project team's knowledge and consideration of project details has led to a very well-planned project prepared for success. The project has benefited from a later start date (February 2023 in lieu of December 2022) and has prepared a plan to complete this project in an expedient weather. The project schedule is sufficient to perform this work and the only comment for the project team was to consider working less than seven days a week (perhaps working no more than six days a week and/or two shifts if needed).

The project team accomplishments and planning for the future RTBT project have been very good. There are challenges to construct the RTBT tunnel during inclement weather, but the project has benefitted from a later start date (February 2023 in lieu of December 2022) to start of excavation work.

The tunnel excavation plan is well thought out and consideration to mitigate potential weather impacts have been addressed; as an example, placement of shotcrete on the 1½:1 excavation slope to better control rainfall.

The geotechnical design plan has considered site conditions, which will benefit the future design build shoring subcontractor. The construction sequence is well thought out and planned, including the sequence to apply waterproofing material to the tunnel and the installation of a liner beneath the top portion of the soil backfill, as well as the plan to cut access points into the existing beamline tunnel.

In the event the adjacent STS project receives early funding and starts work earlier (concurrent with RTBT work), the project team has planned for an alternate soil stockpile location.

Electrical outage shutdowns have been well planned.

The previous recommendation to perform outreach to improve contractor bid participation has been met with on-going project team outreach. With the east Tennessee construction market being so busy and workers being given incentives on other projects it will be a challenge to obtain workers on the RTBT project. The project team has a good strategy to leverage upcoming

STS work as an incentive to get contractors on site early for RTBT work to help improve chances to get the larger project and keep the work force employed for a longer duration.

The project team has updated RTBT estimates after the Klystron Galley project, due to anticipated increased cost due to a busy construction market.

The project schedule includes six months to perform RTBT work, which contains a conservative amount of inclement weather days (36 workdays).

The new construction start date of February 2023 to start excavation, in lieu of December 2022, will help the project by avoiding inclement weather.

The current work plan schedule considers working eight-hour days, seven days a week and other work schedule options have been considered such as ten-hour workdays. To avoid potential worker fatigue, the project should consider working no more than six days a week and/or two shifts if needed.

A top risk for the RTBT project is the potential for the STS project to receive early funding and thus their start date would move up and they would be performing work concurrently with the RTBT construction, which will create logistic challenges.

The STS project is moving approximately 1 million cubic yards of soil. In the event this work will be performed concurrent with RTBT the project team has a mitigation plan to locate the RTBT soil stockpile to another location on site.

The STS project will need to relocate or haul off a large existing stockpile of soil, located near the RTBT site, in order to provide adequate workspace for the RTBT and STS projects.

The project team is currently planning to manage RTBT project construction with in-house staff.

The STS project is also pursuing DOE approval to have a CM/GC manage construction work, but due to the time to obtain DOE approval this may not be a viable option. At some future point the project team will need to decide if a CM/GC delivery method is a valid option to complete the RTBT stub.

3.3 Recommendations

None.

4. ENVIRONMENT, SAFETY and HEALTH

4.1 Findings

The Environmental, Safety and Health (ESH) documentation and processes are mature and working well for project execution. The National Environmental Protection Agency (NEPA) Categorical Exclusion was approved back on January 23, 2017 and the project has not had any changes that would require NEPA updates. The Hazard Analysis Report (HAR) was completed and updated for CD-2/3, which included five Safety Evaluations and one Unreviewed Safety Issue Evaluation (USIE). The Construction Project Safety and Health Plan was completed in September 2019 for CD-2/3 and will remain in effect until the RTBT stub construction and commissioning is complete.

The project has continued to refine the design and plans for execution and completion of the project scope since CD-2/3 approval. A new USIE has been developed for the RTBT stub that will be incorporated into the operational Safety Analysis Document (SAD) and Accelerator Envelope (ASE) document with the five safety evaluations and one positive USIE from the HAR. An External Readiness Review (ERR) or ARR is required to be performed and approved as part of the transition to operations plan.

The Quality Assurance (QA) program continues to operate with full incorporation of QA processes from partner and supplier DOE facilities, respectively TJNAF and FNAL. In response to the complexity and criticality of the project, the project's QA team modified the QA program to become more effective and coordinated with partner DOE facilities. QA is involved in the procurement readiness reviews and does vendor qualifications including site visits and surveillance. QA processes have identified fourteen non-conformance reports (NCRs) to date and eleven NCRs have been closed. QA has developed a computerized asset tracking database and is being utilized for the project activities.

The emergence of the COVID-19 pandemic created additional health and safety challenges for the PPU project team during the DOE/SC CD-2/3 review in 2020. Implementation of COVID-19 protections and safety measures continues to be a challenge and has changed significantly since CD-2/3. COVID-19 protections continue to be part of the ESH charge questions for this review for PPU. COVID-19 precautions and safety measures have been presented through the ORNL Return to Normal On-site Operations (RTNOO) Playbook and COVID-19 mapping tool. These requirements and procedures are being flowed-down to lower-tiered subcontractors.

4.2 Comments

Integrated Safety Management (ISM) is well established in the project and is being flowed-down to lower, tiered subcontractors through the ORNL Chestnut Ridge Project Safety and Health Plan. ESH&Q personnel are well experienced and integrated into the project to provide support for project document review and field inspections. Construction oversight and safety is well managed. Since CD-2/3, the project hired a full-time Construction Field Representative who has safety experience and provided additional safety oversight. The project still utilized the ORNL ES&H Safety Services at 40% time for construction oversight and safety review. The attention to safety is most noticeable from the statistic that the project was able to complete the construction of the Klystron Gallery and RATS-II building upgrades with 60,000 man-hours and no recordable injuries. This accomplishment is very commendable.

The execution of the civil construction that has been completed thus far has been done during the height of the pandemic and demonstrates the effectiveness of the ES&H processes in place. ORNL has developed a notable approach to pandemic controls through the implementation of robust, COVID-19 precautions and safety measures through the ORNL RTNOO Playbook and COVID-19 mapping tool. The mapping tool monitors building density, and rates for testing, and vaccinations. ORNL has an 85% vaccination rate and is striving for 100% vaccinations of onsite workers by October 15, 2021. The COVID-19 precautions, safety measures, testing, and vaccination requirements are being flowed-down to lower, tiered subcontractors. ORNL procedures and policies for COVID-19 controls have been a tremendous accomplishment.

ORNL's USI process is being utilized throughout the project as the designs have been finalized with the majority of the USI's incorporated directly into the HAR. The project is working to finalize the designs of a few technical systems and in doing so have ESH staff participated in the designs. Additional scope of the RTBT stub USI, and any future USI's, will be incorporated directly into the SAD revisions. The project has a stepped schedule for revision of the SAD and ASE with the first revision scheduled for 2022. This first revision will encompass the addition of the beam current limiting system. During the long shutdown, the PPU project will incorporate the balance of the project scope changes into the second revision of the SAD and ASE. The project has a very optimistic view of timing between a planned Internal Readiness Review (IRR) and ARR. In the current plan, there is only two weeks between the IRR and ARR to resolve any comments and this may not be enough time to incorporate any necessary resolutions or changes.

The SNS facility will develop and implement a detailed, As Low As Reasonably Achievable (ALARA) plan based on ORNL's Standards Based Management Systems (SBMS) for the installation of the injection magnets. The project also recognizes the potential impact that high radiation area work will have on timing and worker dose, and thus is planning for removal and replacement of highly activated components contributing to the higher radiation field. Removal and replacement activities will also utilize ORNL's SBMS processes to assure ALARA is achieved.

A hydrogen filling station that is part of the project scope includes design that has been reviewed by the fire safety group at ORNL and electrical installation in the area will be compliant with Class 1 Division 2, group B requirements and also to IP65 or better.

The project has completed a thorough Oxygen Deficiency Hazard (ODH) analysis that encompasses the additional PPU cryomodules using conservative factors in the analysis. A review of the locations of the monitors shows thoughtful placement for effective coverage.

In response to COVID-19, the project upgraded air filtration on installed components during the Klystron Gallery construction that meets the American Society of Health and Air-Conditions (ASHRAE) guidance for pandemic controls.

The project QA program has been operating well through a Memorandum Purchase Order (MPO) agreement where FNAL's QA program was reviewed and accepted for fabrication activities. PPU QA is involved in the weekly FNAL meetings to ensure good coordination is being maintained.

The QA program has been executed in an effective and coordinated manner including a Supplemental QA Plan (SQAP) that was developed by TJNAF and approved by both Laboratories. There is good communication between TJNAF QA and SNS QA and the SQAP clearly identifies processes and responsibilities for joint execution of both QA programs. TJNAF QA coordination has been very successful and directly addressed the shipping issues from the past and resolved these issues. The standard and non-standard non-conformance reporting (NCR) processes are well developed and give consideration to the importance for both, TJNAF and SNS, involvement in NCR resolutions. TJNAF's data collection allows them to analyze data to review performance and NCRs for QA focusing. The SQAP included a lessons learned process with examples provided on the process outcomes using a lessons learned and a lessons applied process. This idea of documenting how lessons are applied from lessons learning is an example of a best practice.

In closing, the Committee would like to thank the project team for their assistance in providing responses to a myriad of queries and providing support documentation throughout this review.

4.3 Recommendations

None.

5. COST and SCHEDULE

PROJECT STATUS – As of July 2021		
Project Type	Line Item	
CD-1	Planned: 3QFY2017	Actual: April 2018
CD-3A	Planned: 2QFY2019	Actual: October 2018
CD-3B	Planned: 4QFY2019	Actual: September 2019
CD-2/3	Planned: 2QFY2020	Actual: October 2020
CD-4	Planned: 4QFY2028	Actual: TBD
TPC Percent Complete	Planned: 59%	Actual: 57%
TPC Cost to Date	$122.5M	
TPC Committed to Date	$34.1M	
TPC	$271.6M	
TEC	$202.5M	
Contingency Cost	$55.3M	59% to go
Contingency Schedule on CD-4	42 months	100% to go
CPI Cumulative	1.01	
SPI Cumulative	0.96	

PPU is highly integrated with ongoing operational experiments and other projects. The integration of these potential hindrances is reviewed and coordinated frequently.

Excellent progress has been made since the CD-2/3 award, from 25% to 57%.

The PPU project is heavily influenced by procurements and through July 2021. The project has awarded 86% of the planned procurements.

The Total Project Cost (TPC) has remained steady at $271.6 million, with contingency as a percentage of remaining scope growing from 47% to 53%.

The project developed a Contingency Management Plan to address use of contingency throughout the project lifecycle. PPU is forecasting available contingency that could be Baseline Changed into the Performance Measurement Baseline to project execution scope. Having an organized approach to evaluate potential scope, which is consistent with the PPU Mission Need Statement is beneficial. The Contingency Management Plan is in the signatory phase.

The project early finish has moved out slightly; however, the forecasted early finish is still in February 2025.

Project responses to COVID-19 has been proactive and minimized thus far. Continued management attention is warranted.

The detailed project schedule includes approximately 3,000 activities to go with 123 activities on the critical path. The schedule diagnostics shows approximately 42 months of favorable float. The schedule integration during science experiment outages is evident. The communication between the PPU Project and Operations is not limited to high level schedules, but also includes collaboration during the plan of the day (POD) meetings to discuss work in shared areas.

The PPU project institutes an organized approach to risk management and actively performs risk analysis. Residual risk is recognized and accounted for.

5.1 Findings

Schedule

The project's Early Finish forecast of February 12, 2025 is approximately 42 months ahead of the project planned date of July 31, 2028. The PPU execution schedule is integrated with SNS operations execution schedules in Primavera (P6). This integration is reviewed frequently, and project priorities are recognized.

The Acumen Fuse Schedule Quality is 87%. FY 2023 includes significant integration, which reduces the schedule quality score below 80 for that individual year.

A total of 123 activities are on the critical path. Several critical path activities associated with ring design for the Beam Limiting System were completed on September 9, 2021.

Since CD 2/3 authorization the project has moved from 25% to 57% complete. The forecasted completion date slipped three weeks.

The primary earned value method is percent complete and works to minimize level of effort as an earned value technique.

Approximately 400 activities are near the critical path (less than ten weeks of float). The project is maintaining 26 days of float against Outage #2 (Extended Outage).

The project has 28 CAMs and 294 control accounts.

Cost

The TPC remains $271.6 million. In May 2021, the Baseline at Completion was 216.7 million, and the Estimate at Completion was $218.2 million. The contingency (plus Management Reserve) remaining is $53.3 million (52% on work to go), the calculated risk exposure is $48.6 million. The contingency dropped from the $63 million identified during the CD-2/3 review.

The SPI/CPI is .98 and 1.01, respectively.

A total of 14% (or $14 million) of procurements remain out of $106 million planned.

The bottom-up Estimate to Complete (ETC) was performed during the CD-2/3 authorization phase. The bottom-up estimate is targeted to be performed once a year.

Table 5-1.

May 2021 ($k) ITEM	Cumulative to Date BCWS	BCWP	ACWP	BAC	EAC	ETC	% Complete	Status at CD2/3 IPR BAC	ETC	% Complete	Performed since CD2/3 Accomplished	Change in Estimate
P.01 - PPU Project Management	8,832	8,816	8,437	22,169	21,791	13,354	40%	22,083	17,970	19%	21%	87
P.02 - SCL Systems	9,241	8,875	8,444	24,082	23,652	15,208	37%	20,493	16,250	21%	16%	3,589
P.03 - RF Systems	19,180	19,596	19,532	43,696	44,098	24,567	45%	40,767	32,397	21%	24%	2,930
P.04 - Ring Systems	9,959	9,206	9,693	20,662	22,382	12,690	45%	18,019	13,698	24%	21%	2,643
P.05 - First Target Station Systems	17,584	16,463	17,031	34,544	35,119	18,088	48%	35,035	28,079	20%	28%	(491)
P.06 - Conventional Facilities	2,758	2,772	2,846	10,900	10,974	8,128	25%	10,983	8,656	21%	4%	(84)
P.07 - R&D	2,267	2,315	2,328	2,476	2,488	160	94%	2,409	186	92%	1%	67
P.08 - Pre-Ops	87	87	76	1,137	1,127	1,051	8%	1,126	1,094	3%	5%	11
P.09 - Pre-CD-1 Activities	7,250	7,250	7,250	7,250	7,250	0	100%	7,250	0	100%	0%	0
P.10 - Long Lead Procurements	43,007	40,108	39,554	49,785	49,346	9,793	81%	50,439	38,213	24%	56%	(654)
TOTAL	120,165	115,488	115,190	216,701	218,229	103,039	53%	208,605	156,544	25%	28%	8,096
		Mgmt Reserve		5,105	5,105			62,963				
		Contingency		49,762	48,233							
		TPC		271,567	271,567			271,567				

Table 5-2. Contract Performance Report

CONTRACT PERFORMANCE REPORT
FORMAT 1 - WORK BREAKDOWN STRUCTURE
PERFORMANCE DATA (WBS Level 2)

May 2021 ($k) ITEM	CURRENT PERIOD BCWS	BCWP	ACWP	VARIANCE SV	CV	CUMULATIVE TO DATE BCWS	BCWP	ACWP	VARIANCE SV	SPI	CV	CPI	AT COMPLETE BAC	EAC	VAC
P.01 - PPU Project Management	347	363	385	16	(22)	8,832	8,816	8,437	(16)	1.00	378	1.04	22,169	21,791	378
P.02 - SCL Systems	449	254	331	(194)	(77)	9,241	8,875	8,444	(366)	0.96	430	1.05	24,082	23,652	430
P.03 - RF Systems	685	928	952	244	(24)	19,180	19,596	19,532	416	1.02	64	1.00	43,696	44,098	(402)
P.04 - Ring Systems	539	271	327	(268)	(57)	9,959	9,206	9,693	(753)	0.92	(486)	0.95	20,662	22,382	(1,721)
P.05 - First Target Station Systems	566	668	1,249	101	(581)	17,584	16,463	17,031	(1,120)	0.94	(567)	0.97	34,544	35,119	(575)
P.06 - Conventional Facilities	22	55	57	33	(2)	2,758	2,772	2,846	13	1.00	(74)	0.97	10,900	10,974	(75)
P.07 - R&D	0	48	48	48	(0)	2,267	2,315	2,328	48	1.02	(13)	0.99	2,476	2,488	(12)
P.08 - Pre-Ops	4	4	3	0	2	87	87	76	0	1.00	10	1.14	1,137	1,127	10
P.09 - Pre-CD-1 Activities	0	0	0	0	0	7,250	7,250	7,250	0	1.00	0	1.00	7,250	7,250	0
P.10 - Long Lead Procurements	382	536	613	154	(76)	43,007	40,108	39,554	(2,899)	0.93	554	1.01	49,785	49,346	438
TOTAL	2,994	3,128	3,965	135	-837	120,165	115,488	115,190	-4,677	0.96	297	1.00	216,701	218,229	-1,529
									Management Reserve				5,105	5,105	
									Contingency				49,762	48,233	
									TPC				271,567	271,567	

Cumulative Thresholds:

- Red: CPI/SPI <0.85 or >+1.20 AND >$100k
- Yellow: CPI/SPI between 0.85-0.90 or 1.15-1.20 AND >$100k

Risk

Near-term and emerging risks are reviewed regularly. The risk analysis includes $16 million in potential COVID-19 exposure. A total of 80 threats and 16 opportunities have been retired—six threats and three opportunities have been realized. The PPU project institutes an organized approach to risk management and actively performs risk analysis. Residual risk is recognized and accounted for.

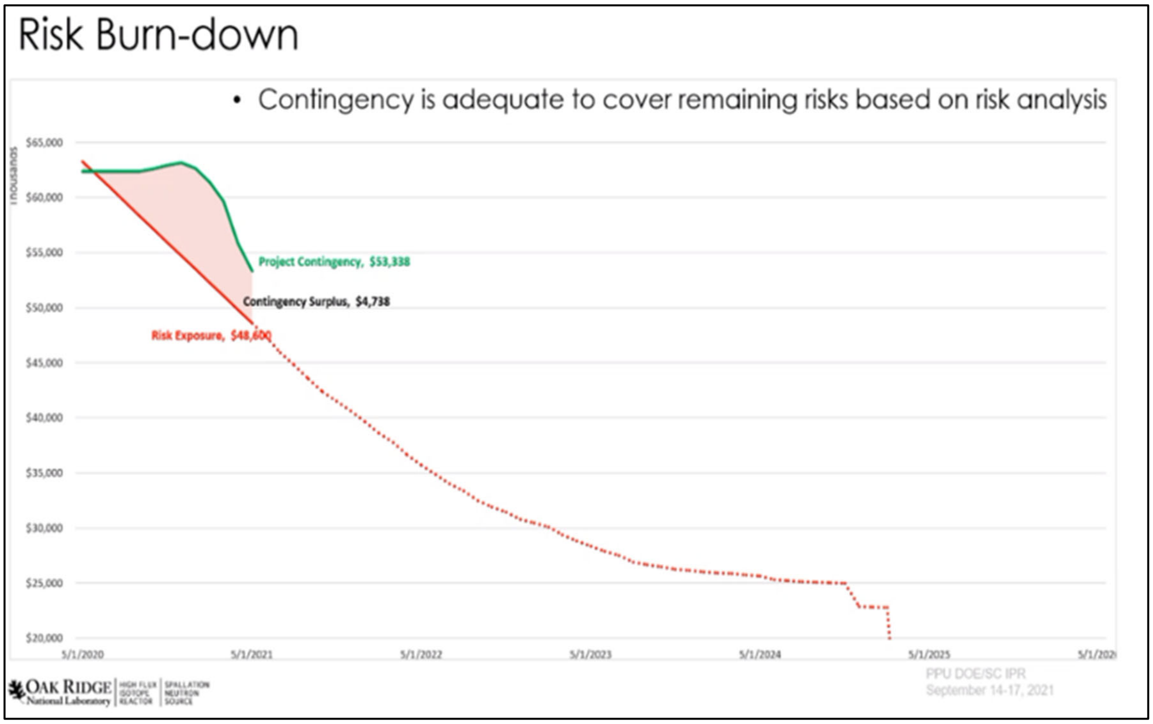

Figure 5-3. Risk Burn-Down

5.2 Comments

The project has four project controls analysts (PCA) dedicated to the project.

TJNAF provides many key fabrications and conducts a resource and technical management deep-dive monthly.

The project team feels the Oak Ridge Site Office support is very productive and transparent.

Near-term and emerging risks are reviewed regularly.

Contingency as a function of remaining scope has increased since CD-2/3 authorization.

PPU has written a "Contingency Management Plan," which outlines the strategy to allocate available contingency. This will become important as the project nears completion and entertains authorizing scope utilizing contingency.

Plan-of-the-Day meetings to discuss ongoing work in shared areas.

Impacts related to COVID-19 have been managed, minimizing project impacts.

Project Controls support is in good communication with SNS operations and other projects that may have integration points with the PPU schedule.

The WBS is deliverable based.

Monthly schedule status is updated by the PCAs and CAMs. Input is then QA checked.

TJNAF cost and schedule status is received monthly.

Baseline Change Requests (BCRs) and Project Change Requests (PCR) are performed on an as needed basis. A monthly log of changes is sent to the Federal Project Director.

Residual risks are maintained after a risk is retired.

The Project Controls team consists of four analysts dedicated to the project.

The project analysis tools are extensive and support numerical based decision making.

5.3 Recommendations

None.

6. PROJECT MANAGEMENT

6.1 Findings and Comments

The PPU management team is very experienced, and the project is being managed well. PPU plans are integrated in the "five-year" Neutron Sciences Directorate plan to ensure coordination of project work with operations. Resource planning for matrixed staff are coordinated on a yearly basis. Matrixed staffing peaks in FY 2022. A project change request was processed in June 2021 to align project staffing needs with ORNL resource availability. Monthly coordination meetings assure the proper allocation of resources across project and operations, with considerable autonomy left to line managers. The project has been underutilizing resources by 10% and, so far, has not experienced conflicts with operations. This is also due to a one-year look-ahead plan. Staffing levels are adequate, and the laboratory's size is such that risks related to talent bench depth are mitigated by access to other ORNL resources and to contractors for engineering work.

The coexistence of project management and line management/operations functions within the same person provide an undeniable advantage of simplifying and expediting actions; it also creates the risk of impacting the project schedule without the project having a chance to act in a timely manner. Clear lines of authority and communication of priorities will facilitate maintaining the project schedule. A densely populated critical path reflects a strategic choice of maintaining a healthy schedule pressure with a judicious management of float.

CD-3A procurements are 96% complete and CD-3B procurements are 78% complete. PPU/SNS procurements to date total $106 million (63% complete). TJNAF procurements to date total $9.85 million (98% complete), excluding the spare cryomodule. Maintaining equipment delivery schedules to support the operational long outage is a key milestone supporting achievement of the project early finish. There is a three-month notification period needed by operations to coordinate with users, if a change to the outage is needed.

To date, impacts due to COVID-19 have not been severe and have been handled well. The Project Director has identified some indications of potential issues due to COVID-19 related to cost increases and finding resources, these are being monitored. A mechanism exists which enables prompt communication and escalation of risks from Level 2 up to the project director, through monthly meetings. The Risk Registry includes project risks and operations risks, giving a complete perspective.

The Project Execution Plan (PEP) allows contingency to be used "to optimize the scientific capability or substantially improve the performance, reliability, or functionality within the overall facility design and mission need including spares acquisition". A Contingency Management Plan exists. There is a separate spreadsheet containing items that potentially could be included in the project scope. The draft revision to the plan added the following information: "…it is understood that contingency procurements can be completed and closed-out later, after CD-4 approval." The project management team determines scope and timeline of contingency spending as risks are retired. The management team has input from the Directorate management team to evaluate proposed scope. Use of contingency in this manner is subject to the approval of the Federal Project Director. Spending decisions related to these items are communicated to DOE/BES.

The project demonstrated a mature approach to lessons learned, by shifting the attention from compiling lessons to enabling the entire organization to learn, by incorporating those lessons into changes to practices and guidelines. This is an effective way to assure that lessons learned actually translate into actions, as opposed to long lists of warnings for the next project.

Transition to Operations planning is progressing. The SNS operations five-year plan now includes the duration for a PPU readiness review and beam tuning. A beam commissioning leader has been assigned and the beam commissioning plan has been revised. The plan will be adjusted as progress evolves. There are four main outages related to the approval process: FY 2022B, FY 2022C, FY 2023A, and FY 2024A. There is a three-phase approach to commissioning and operations approval. Each phase has common steps: equipment installation and checkout, documentation, personnel ready, and IRR. The first readiness reviews will be in October/November 2022. The readiness review plan has been updated in the PPU schedule.

6.2 Recommendation

7. Work with DOE to finalize the language in the draft revision to the Contingency Management Plan.   If items permitted to be delivered after CD-4 have any constraints, the plan should include this information.

Appendix A Charge Memo

Department of Energy
Office of Science
Washington, DC 20585

June 7, 2021

MEMORANDUM FOR: KURT FISHER
DIRECTOR, OFFICE OF PROJECT ASSESSMENT
OFFICE OF SCIENCE

Linda L Horton

Digitally signed by Linda L Horton
Date: 2021.06.07 06:55:26 -04'00'

FROM: LINDA L. HORTON
ASSOCIATE DIRECTOR OF SCIENCE
FOR BASIC ENERGY SCIENCES
OFFICE OF SCIENCE

SUBJECT: DEPARTMENT OF ENERGY REVIEW OF THE SPALLATION NEUTRON SOURCE (SNS) PROTON POWER UPGRADE (PPU) LINE ITEM CONSTRUCTION PROJECT

With this memo, the Office of Basic Energy Sciences (BES) requests that your office organize and conduct a virtual Independent Project Review (IPR) of the PPU project at the Oak Ridge National Laboratory on September 14-17, 2021. The purpose of this review is to assess project's status and progress since the CD-2/3 IPR in July 2020.

The PPU project Critical Decision-2 (CD-2) and CD-3 were approved on October 6, 2020, establishing the Total Project Cost of $271,567K, and the CD-4 date of July 31, 2028. The PPU project will double the accelerator power capability from 1.4 megawatts (MW) to 2.8 MW, providing increased proton beam power for the First Target Station to operate at up to 2.0 MW and sufficient added capacity for the future Second Target Station.

In carrying out this charge, the review committee should respond to the following questions:

1. Technical: Are the accomplishments to date and planned future activities consistent with the approved baseline plan? Are the technical challenges, including the test target performance issues, being properly addressed, and is the remaining design progressing per the baseline plan? Are major technical risks and interfaces well understood and being managed to mitigate related impacts?

2. Procurement: Are the phased procurement plans and associated contracts progressing satisfactorily to support the activities per the approved baseline? Are the procurements being effectively monitored to ascertain and react to supply chain issues and delays caused by material and labor shortages and the COVID-19 pandemic?

3. ES&H/QA: Are Environment, Safety, and Health and Quality Assurance (ES&H/QA) requirements and plans, including COVID-19 protections and safety measures, being properly implemented?

4. Cost and Schedule: Are the cost, schedule, and performance metrics being properly collected and reported? Are major cost and schedule assumptions, resource constraints, and project risks, as well as COVID-19 uncertainties being adequately addressed?

5. Management: Is the project being properly managed and staffed to successfully deliver the scope and Key Performance Parameters within the baseline cost and schedule? Are the external interfaces, in particular with the SNS operation and maintenance periods, identified and managed? Are the major project risks, including COVID-19, captured in the risk registry and are the mitigation plans reasonable and effective? Is there a contingency management plan for potential scope and capability enhancements? Is the planning for the transition to operation adequate for this stage of the project?

6. Recommendations: Have the CD-2/3 review recommendations been appropriately addressed, or on schedule for completion? Are there any outstanding recommendations from the prior DOE SC reviews?

Hannibal Joma, the PPU Program Manager, will serve as the BES point of contact for this review. We would appreciate receiving the committee's report **within 60 days** of the review conclusion.

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T. Russell, SC-32
R. Meneses, SC-32.3
L-A. Kiser, ORISE
P. Hudson, ORISE

Appendix B Review Committee

DOE/SC Status Review of the
Proton Power Upgrade (PPU) Project at ORNL
September 14-17, 2021

Ethan Merrill, DOE/SC/OPA, Chairperson

SC1 Superconducting RF	**SC2 Target**	**SC3 RF**	**SC4 Ring-Accelerator**
* Mike Kelly, ANL	* Frederique Pellemoine, FNAL	* Ali Nassiri, ANL	* Sergei Nagaitsev, FNAL
Jei Wei, MSU	Fernando Sordo, ESS-Bilbao	Mike Fazio, SLAC	Wolfram Fischer, BNL

SC5 Conventional Facilities	**SC6 Env, Safety and Health**	**SC7 Cost and Schedule**	**SC8 Project Management**
* Dave Dovichi, LBNL	* Joy Fleming, PPPL	* Jim Ferry, PNNL	* Lori Plummer, retired SLAC
	Mike Fries, ANL	Whitney Hughes, PNNL	Enzo Carrone, SLAC
	Jeff McGhee, ANL		Deb Grubbe, Retired DuPont

Observers

Linda Horton, DOE/BES	Thiyaga Thiyagarajan, DOE/BES
Hannibal Joma, DOE/BES	Wendy Cain, DOE/ORSO
Ed Stevens, DOE/BES	

LEGEND

SC Subcommittee
* Chairperson

Count: 18 (excluding observers)

Appendix C Review Agenda

DOE/SC Status Review of the
Proton Power Upgrade (PPU) Project at ORNL
September 14-17, 2021

<u>Tuesday, SEP 14, 2021</u>

07:00 (PST)	09:00 (CST)	10:00 (EST)	Executive Session....Ethan Merrill
07:45	09:45	10:45	ORNL Welcome....Thomas Zacharia
07:55	09:55	10:55	NScD Welcome....Ken Andersen
08:05	10:05	11:05	Jefferson Lab Perspective....Stuart Henderson
08:15	10:15	11:15	Project Overview....John Galambos
08:45	10:45	11:45	Project Management....Mark Champion
09:20	11:20	12:20	Lunch
10:00	12:00	1:00	Subcommittee Breakout Sessions

Session B1: Superconducting Linac
Session B2: First Target Station and R&D
Session B3: Radio-Frequency Systems
Session B4: Ring Systems
Session B5: Conventional Facilities
Session B6: ESH&Q
Session B7: Cost & Schedule
Session B8: Project Management

11:15	1:15	2:15	Executive Session....Ethan Merrill
12:00	2:00	3:00	Adjourn

<u>Wednesday, SEP 15, 2021</u>

07:00	09:00	10:00	Executive Session / Responses to homework
07:30	09:30	10:30	Subcommittee Breakout Sessions
09:30	11:30	12:30	Lunch
10:15	12:15	1:15	Subcommittee Breakout Sessions
11:00	1:00	2:00	Executive Session
12:00	2:00	3:00	Adjourn

<u>Thursday, SEP 16, 2021</u>

07:00	09:00	10:00	Executive Session
07:30	09:30	10:30	Subcommittee Breakout Sessions (as needed)
09:30	11:30	12:30	Lunch
10:15	12:15	1:15	Subcommittee Internal Sessions / report prep
11:00	1:00	2:00	Executive Session / Dry Run #1
12:00	2:00	3:00	Adjourn

<u>Friday, SEP 17, 2021</u>

07:00	09:00	10:00	Executive Session / Dry Run #2
09:00	11:00	12:00	Closeout Presentation
10:00	12:00	1:00	Adjourn

Appendix D PPU Cost Table

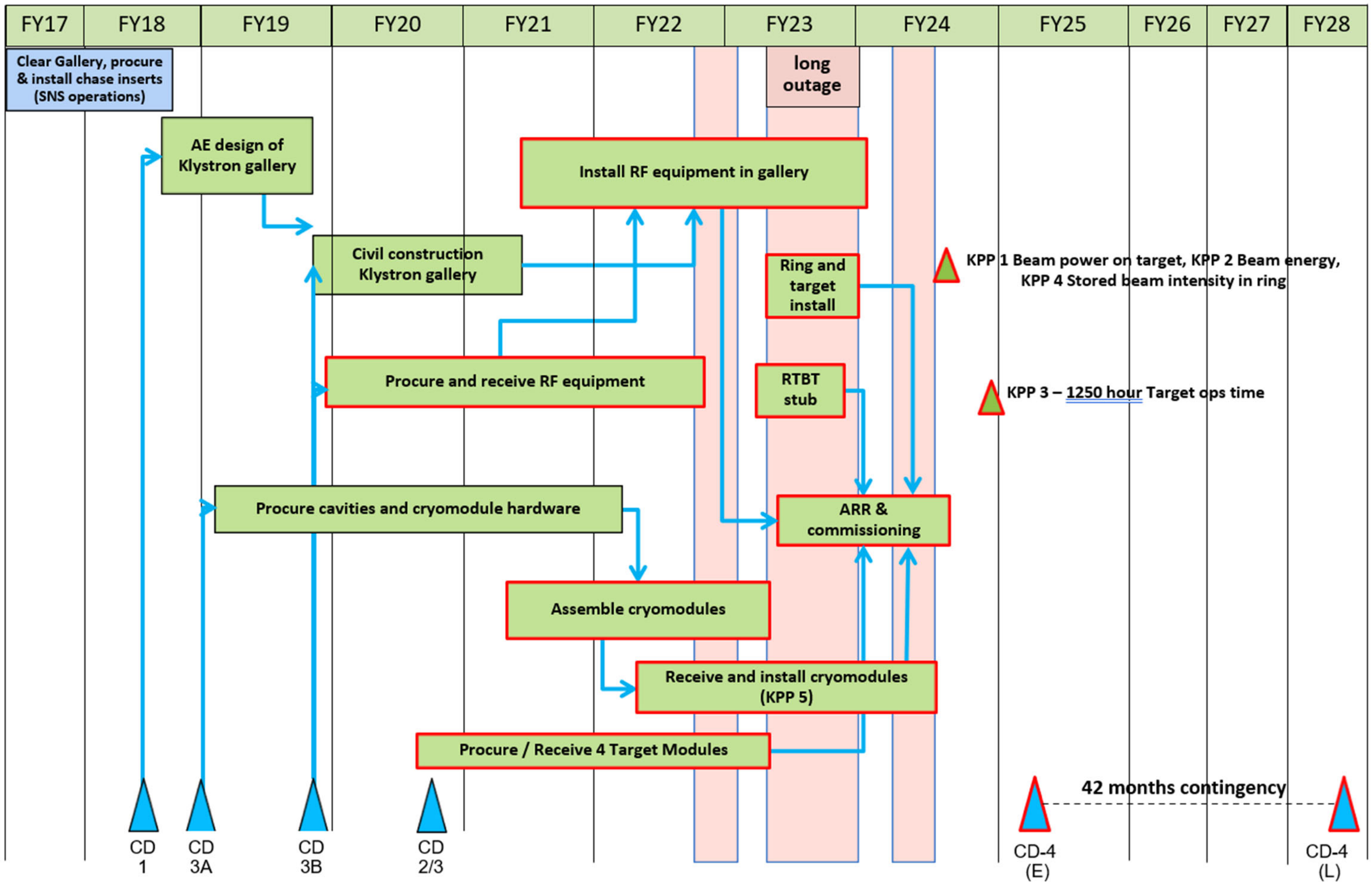
CONTRACT PERFORMANCE REPORT
FORMAT 1 - WORK BREAKDOWN STRUCTURE
PERFORMANCE DATA (WBS Level 2)

May 2021 ($k)	CURRENT PERIOD					CUMULATIVE TO DATE							AT COMPLETE		
	BCWS	BCWP	ACWP	VARIANCE		BCWS	BCWP	ACWP	VARIANCE				BAC	EAC	VAC
ITEM				SV	CV				SV	SPI	CV	CPI			
P.01 - PPU Project Management	347	363	385	16	(22)	8,832	8,816	8,437	(16)	1.00	378	1.04	22,169	21,791	378
P.02 - SCL Systems	449	254	331	(194)	(77)	9,241	8,875	8,444	(366)	0.96	430	1.05	24,082	23,652	430
P.03 - RF Systems	685	928	952	244	(24)	19,180	19,596	19,532	416	1.02	64	1.00	43,696	44,098	(402)
P.04 - Ring Systems	539	271	327	(268)	(57)	9,959	9,206	9,693	(753)	0.92	(486)	0.95	20,662	22,382	(1,721)
P.05 - First Target Station Systems	566	668	1,249	101	(581)	17,584	16,463	17,031	(1,120)	0.94	(567)	0.97	34,544	35,119	(575)
P.06 - Conventional Facilities	22	55	57	33	(2)	2,758	2,772	2,846	13	1.00	(74)	0.97	10,900	10,974	(75)
P.07 - R&D	0	48	48	48	(0)	2,267	2,315	2,328	48	1.02	(13)	0.99	2,476	2,488	(12)
P.08 - Pre-Ops	4	4	3	0	2	87	87	76	0	1.00	10	1.14	1,137	1,127	10
P.09 - Pre-CD-1 Activities	0	0	0	0	0	7,250	7,250	7,250	0	1.00	0	1.00	7,250	7,250	0
P.10 - Long Lead Procurements	382	536	613	154	(76)	43,007	40,108	39,554	(2,899)	0.93	554	1.01	49,785	49,346	438
TOTAL	**2,994**	**3,128**	**3,965**	**135**	**-837**	**120,165**	**115,488**	**115,190**	**-4,677**	**0.96**	**297**	**1.00**	**216,701**	**218,229**	**-1,529**
									Management Reserve				**5,105**	**5,105**	
									Contingency				**49,762**	**48,233**	
									TPC				**271,567**	**271,567**	

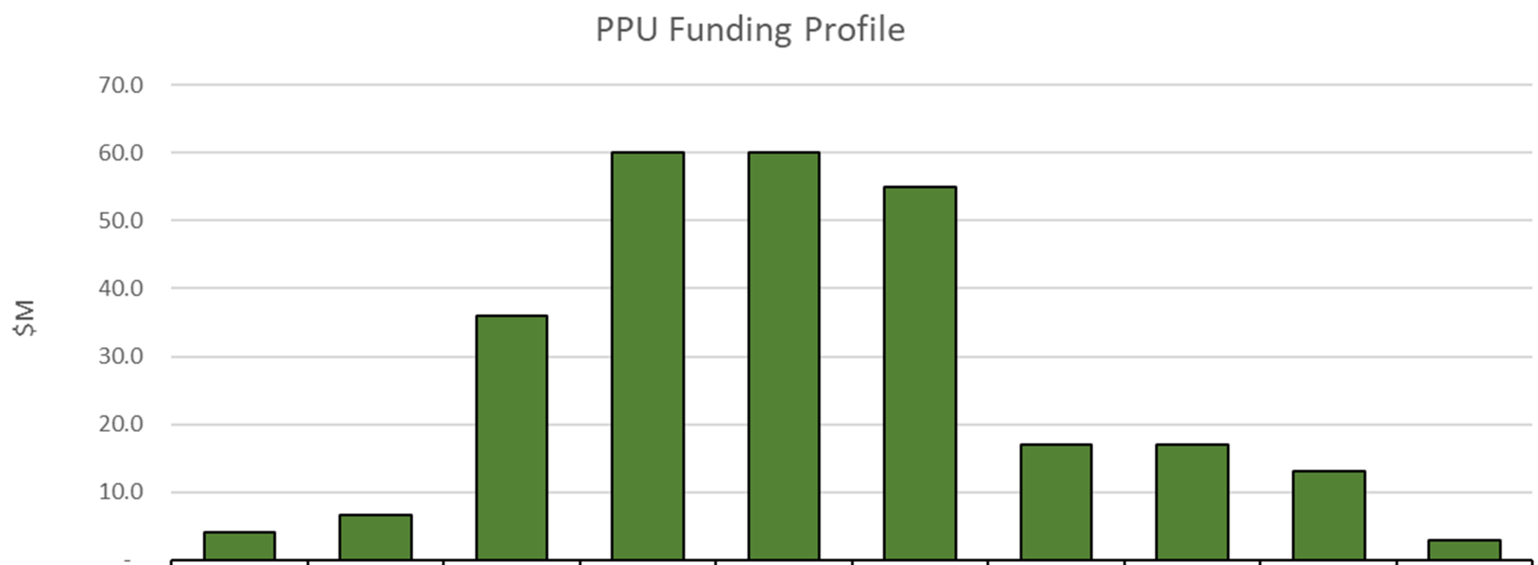
Cumulative Thresholds:

- Red: CPI/SPI <0.85 or >+1.20 AND >$100k
- Yellow: CPI/SPI between 0.85-0.90 or 1.15-1.20 AND >$100k

Appendix E PPU Schedule Chart



Appendix F PPU Funding Table



	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025
OPC	4.1	6.7	-	-	-	3.0	-	-	-	-
TEC	-	-	36.0	60.0	60.0	52.0	17.0	17.0	13.0	2.8
Funding Profile	4.1	6.7	36.0	60.0	60.0	55.0	17.0	17.0	13.0	2.8

Appendix G PPU Management Chart