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COMPLETION OF THE PROTON POWER UPGRADE PROJECT AT THE SPALLATION NEUTRON SOURCE*

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Abstract

The Proton Power Upgrade (PPU) project at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) has completed the installation and testing of all project scope required to meet threshold key performance parameters (KPPs), supported beam commissioning in June 2024, and transitioned to operations in July 2024. Increasing the beam energy from 1.0 to 1.3 GeV required the installation of seven additional cryomodules in the SNS Linac along with supporting RF systems. The accumulator ring injection and extraction regions were upgraded, a 2 MW mercury target was developed, and ancillary target systems were upgraded to support high-flow gas injection, mercury off-gas treatment, and ortho-para fraction control in the cryogenic moderator hydrogen loop. Three of four threshold KPPs have been demonstrated, and the project is planning for its final review in early 2025. Beam power on the first target station (FTS) will be ramped up to 2 MW over the next two years. Completion of the PPU project supports increased scientific capability at the FTS and will support operation of the second target station (STS) upon its completion. Lessons learned will be documented and a project closeout report will be written prior to the final closeout of the project.

INTRODUCTION

The PPU project has been underway for more than six years since establishing the conceptual design and cost range (Critical Decison-1, CD-1) as depicted in Fig. 1. The upgrade increases the accelerator beam power capability from 1.4 to 2.8 MW, provides a 2-MW-capable mercury target for the first target station, and constructs a tunnel extension for future connection to the second target station. The detailed technical scope has been described previously [1], and the project status will be presented in an invited talk at this conference [2]. The long installation outage began in August 2023 and concluded in April 2024. All remaining PPU technical components required for threshold KPP demonstration were installed and tested during this outage. An external accelerator readiness review was conducted in May 2024, and authorization for beam commissioning and routine operations was granted in early June. Beam commissioning commenced June 7th and was completed in less than one month. Neutron production for the user program resumed July 11th as planned at 1.3 GeV and 1.7 MW. Three project threshold KPPs related to beam parameters have been achieved. Demonstration of the fourth KPP, for target lifetime, is progressing and expected to be achieved in October 2024.

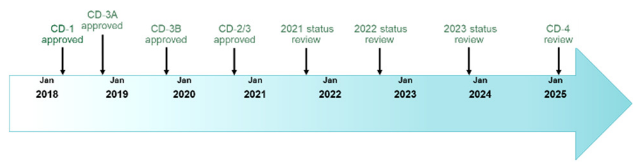

Figure 1: The PPU project execution spans seven years from CD-1 approval to CD-4 project completion review.

BEAM COMMISSIONING

PPU beam commissioning commenced June 7th, 2024, and proceeded quickly as shown in the timeline (Fig. 2). First up was commissioning of the Linac with seven new PPU cryomodules. Tune-up of the SNS Linac is a well understood process, and 1.33 GeV low-duty-factor beam was delivered to the Linac injection dump within a few hours. Accumulator ring commissioning began June 8th at 1.05 GeV for comparison with accelerator performance during the final run prior to the long outage. After successfully delivering low-duty-factor 1.05 GeV beam to the ring extraction dump, the energy was increased to 1.3 GeV, and full-energy beam was delivered to the extraction dump on June 11th.

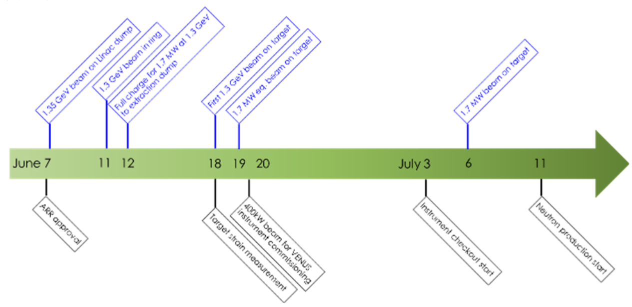

Figure 2: PPU beam commissioning was accomplished in approximately one month from start to neutron production.

1.7-MW-equivalent charge (22uC) at 1.3 GeV was circulated in the ring and sent to the extraction dump on June 12th at low duty factor. Tuning for low beam loss throughout the accelerator proceeded for several days, and

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beam was delivered to the target June 18-19th in support of the target strain measurements that are performed at the start of service for every target.

Upon completion of the target strain measurements, the beam power on target was ramped up to 400 kW at 1.3 GeV (60 Hz) for radiation surveys. Once completed, the ramp up to 1.7 MW commenced. Unfortunately, the electron catcher at the primary stripping foil in the ring injection region failed on June 22nd due to overheating caused by inadequate water flow (Fig. 3). PPU and Operations staff worked diligently to diagnose the failure and implement repairs, and the electron catcher was returned to service on July 3rd. The beam power on target was then ramped up to 1.7 MW at 1.3 GeV to support neutron instrument checkout (Fig. 4), and neutron production for the user program began July 11th as planned.

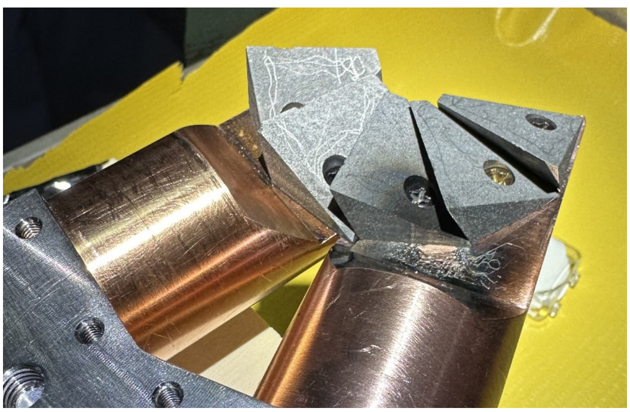

Figure 3: Electron catcher with signs of overheating.

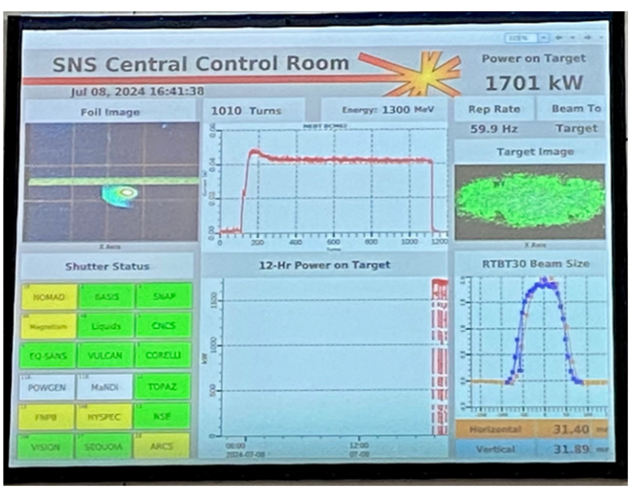

Figure 4: Beam on target at 1.7 MW and 1.3 GeV on July 8, 2024, during neutron instrument checkout.

CHALLENGES

Pandemic

The project encountered and mitigated numerous challenges throughout its execution, with the least expected and most severe being the COVID-19 pandemic that began in March 2020. The project was not yet baselined but was executing long-lead procurements under CD-3A and CD-3B authorizations. ORNL maintained operations throughout the pandemic, but many staff member worked from home, which limited the direct communication that is essential for executing a project. The Department of Energy (DOE) CD-2/3 baseline independent project review and independent cost review were both conducted remotely in July 2020, as was the DOE status independent project review in September 2021.

Fallout from the pandemic included supply chain problems, particularly in controls electronics. The project benefited greatly by placing long lead procurements before the pandemic. Further, baselining during the pandemic allowed for the incorporation of additional cost and schedule contingency to mitigate pandemic related risks.

Vendor performance suffered from the pandemic due to loss of experienced vendor personnel, and the project had to work closely with several vendors to meet technical performance and schedule requirements.

Technical

In addition to the electron catcher failure during beam commissioning that was described above, highlights of technical challenges include the following:

- Achievement of the required performance on the last few superconducting cavities required numerous cycles of high pressure rinsing and, in a few cases, buffered chemical polishing. All 32 cavities ultimately met performance requirements and were installed in cryomodules
- Several cavity tuners had to be repaired in the Linac tunnel due to incorrect materials that led to galling of a lead screw
- A few klystrons were removed from service due to excessive cathode arcing. These are being investigated by the vendor
- A silicon-controlled rectifier (SCR) power supply that drives the high-voltage converter modulator failed due to an arc discharge event that destroyed the unit
- A truck accident damaged a 13.8 kV transformer and SCR power supply. These components of the high-voltage converter modulator system that had to be returned to the vendor for repair
- Damaged optical viewports in the ortho-para conversion vessel were discovered during installation of the vessel and had to be replaced
- The baseline plan for increasing the extraction kicker voltage was abandoned due to reliability issues and was replaced with a dual power supply solution
- Development of the beam power limit system, a credited control for limiting beam power on the first target station to 2 MW, was more complex than expected due to rigorous documentation, calibration, and safety certification requirements
- Controls completion was challenging due to evolving requirements
- Helium gas accumulation in the target mercury loop was greater than anticipated

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- The ring injection dump beam window installation was complex due to unexpected corrosion and the necessity to perform the work with remote handling tooling
- Buss bar supports in the ring injection area had to be replaced due to radiation damage

DELIVERABLES STATUS

All baseline project scope has been received except for the following items with final deliveries expected in calendar year 2025. These items are not needed to support threshold KPP demonstration nor 2 MW operation of the first target station.

- Three 3 MW, 402.5 MHz klystrons that will be installed in the Drift Tube Linac to support operation at 2.8 MW after the second target station project is completed
- One spare SCR controller that drives the high-voltage converter modulators for the radiofrequency systems that support the PPU cryomodules

KEY PERFORMANCE PARAMETERS

The project must demonstrate the threshold KPPs shown in Fig. 5 to declare success. The project scope enables the objective KPPs, but these may be demonstrated following project completion.

- Beam power on target and beam energy were demonstrated and documented on July 11, 2024
- Stored beam intensity in the ring was demonstrated and documented July 16, 2024
- Target reliability lifetime without target failure is progressing and expected to be completed in mid-October 2024

Key Performance Parameter	Thresholds	Date Achieved	Objectives	Date Achieved
Beam power on target	1.7 MW at 1.25 GeV	11-Jul-24	2.0 MW at 1.3 GeV	post-PPU
Beam energy	1.25 GeV	11-Jul-24	1.3 GeV	11-Jul-24
Target reliability lifetime without target failure	1250 hours at 1.7 MW	Oct-24	1250 hours at 2.0 MW	post-PPU
Stored beam intensity in ring	≥ 1.6e14 protons at 1.25 GeV	16-Jul-24	≥ 2.24e14 protons at 1.3 GeV	post-PPU

Figure 5: PPU key performance parameters.

KEY LESSONS LEARNED

The project will formally document lessons learned in preparation for the CD-4 project closeout review. A preliminary list of the key lessons learned is presented here:

- Executing the upgrade in a phased manner allowed for early debugging of systems and supported early enhancement of neutron science productivity
- Partner with other laboratories to take advantage of existing expertise and facilities
- Utilize existing processes and personnel to the extent possible
- When upgrading an existing facility, staff the project team with people matrixed from operations since they are most knowledgeable of their technical systems and will be responsible for those systems in the future
- Execute procurements and upgrade tasks as early as possible to prevent pile-up later in the project
- Look ahead for developing problems and be ready with alternate plans to minimize schedule impacts. Use cost contingency to develop the alternatives and mitigate risk
- Seek long lead procurement authorization to proceed with procurement/construction of mature designs. Prepare procurement packages so that they're ready to go when authorization is received
- When travel to vendors is not possible, use local experts to conduct vendor surveillance. Use mobile phones to virtually witness vendor tests
- Maintain frequent contact with vendors, including vendor visits, to keep procurements on track
- Financial incentives for on-time completion should be considered for time-critical contracts, especially construction
- When using Building Information Modelling (BIM) to design a facility, include just enough detail to facilitate construction. Make sure the project team and vendor agree on the needed level of detail
- Maintain open and frequent communication with the federal project director and program manager
- The project management team should spend time in the field talking with people
- Ensure the project management team is available for informal discussions on project challenges and plans
- Project management should meet with each level 2 manager on a weekly or bi-weekly schedule to assess progress and discuss concerns
- Avoid overstaffing the project office

STATUS AND PLANS

The SNS is presently operating at 1.7 MW beam power on target in support of neutron production for the user program and to demonstrate the target reliability lifetime KPP. The next maintenance period will begin in late November 2024 with a duration of approximately two months. The only PPU work planned for this outage is the upgrade of two high-voltage converter modulators in the Drift Tube Linac to support eventual operation of the 3 MW klystrons.

The post-PPU power ramp up plan calls for a gradual increase in beam power on target and annual neutron production hours to 2 MW and 5000 hours, respectively, in fiscal year 2027. However, it may be possible to increase the beam power earlier, which would benefit the science productivity of the facility.

The project is preparing a closeout report, lessons learned, and other documentation as required to support a CD-4 project completion review in mid-January 2025.

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