PROGRESS TOWARDS THE COMPLETION OF THE PROTON POWER UPGRADE PROJECT*

M. Champion†, M. Connell, N. Evans, J. Galambos, M. Howell, G. Johns, S. Kim, J. Moss, G. Stephens, K. White, Oak Ridge National Laboratory, Oak Ridge, USA
E. Daly, Thomas Jefferson National Accelerator Facility, Newport News, USA
D.J. Harding, Fermi National Accelerator Laboratory, Batavia, USA

Abstract

The Proton Power Upgrade project at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory will increase the proton beam power capability from 1.4 to 2.8 MW. Upon completion in early 2025, 2 MW of beam power will be available for neutron production at the existing first target station (FTS) with the remaining beam power available for the future second target station (STS). The project has installed seven superconducting radiofrequency (RF) cryomodules and supporting RF power systems to increase the beam energy by 30% to 1.3 GeV, and the beam current will be increased by 50%. The injection and extraction region of the accumulator ring are being upgraded, and a new 2 MW mercury target has been developed along with supporting equipment for high-flow gas injection to mitigate cavitation and fatigue stress. The first four cryomodules and supporting systems were commissioned in 2022-2023 and supported neutron production at 1.05 GeV, 1.7 MW with high reliability. The first-article 2 MW target was operated successfully for approximately 4400 MW-Hours over two run periods. The long outage began in August 2023 for installation of the remaining technical equipment and construction of the Ring-to-Target Beam Transport tunnel stub that will enable connection to the STS without interrupting operation of the FTS. The upgrade is proceeding on-schedule and on-budget, and resumption of neutron production for the user program is planned for July 2024.

INTRODUCTION

The Proton Power Upgrade (PPU) project [1] at the SNS received approval to begin construction in October 2020 (Critical Decision-3, CD-3). This followed two phases of long-lead procurements, CD-3A in October 2018, and CD-3B in September 2019. These long-lead procurements included superconducting RF cavities, fundamental RF power couplers, cryomodules, RF systems, and conventional facilities build-out of the existing klystron gallery.

The PPU technical systems have been installed over three outages:

FY22c: August – November 2022
- Install Test Target #2
- Install cryomodules 1 and 2
- Install Beam Power Limit System components
- Complete installation and integrated testing of RF systems
- Enabled 1.05 GeV, 1.55 MW operations

FY23a: March – June 2023
- Install cryomodules 3 and 4
- Complete installation and integrated testing of RF systems
- Enabled 1.05 GeV, 1.7 MW operations

FY24a: August 2023 – June 2024
- Install cryomodules 5, 6 and 7
- Complete installation and integrated testing of RF systems
- Install 2 MW production target
- Install ring upgrade equipment
- Install first target station upgrades for high-flow gas injection
- Construct Ring-to-Target Beam Transport (RTBT) tunnel stub
- Enables 1.3 GeV, 2 MW operations

Following each outage, newly installed PPU equipment was brought into service to verify performance and enable a phased ramp-up of the proton beam power on target. The experience gained in each outage and subsequent operating period was beneficial for planning the future outages and mitigating technical challenges.

The long installation outage began in August 2023 and will conclude with beam commissioning in June 2024 prior to resumption of neutron production for the user program in July 2024. The installation of PPU equipment is complete, and the accelerator readiness review required to gain permission for beam commissioning and operations is planned for May 2024.

SUPERCONDUCTING LINAC

The PPU project partnered with Thomas Jefferson National Accelerator Facility (TJNAF) to produce eight cryomodules (4 cavities each). The cavities operate at

* ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy. This research was supported by the DOE Office of Science, Basic Energy Science, Scientific User Facilities.

† championms@ornl.gov

805 MHz with a specified gradient of 16 MV/m. Seven cryomodules are installed in the SNS Linac (Fig. 1). They have been cooled to 2 K, RF conditioned, and achieved performance requirements [2,3]. The eighth cryomodule is a spare.

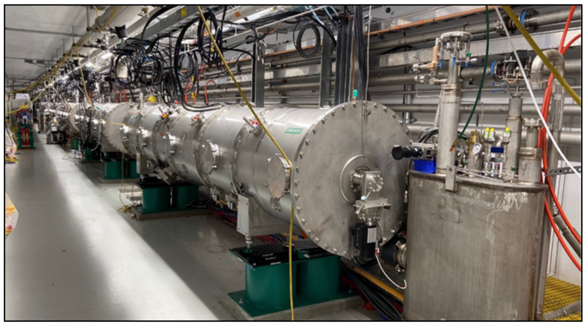

Figure 1: New cryomodules installed in the SNS Linac.

RADIOFREQUENCY SYSTEMS

Twenty-eight RF stations were installed to power the 28 cavities in the PPU cryomodules. Each station features an 805-MHz, 700-kW peak-power klystron operating at a duty factor of approximately 8% (Fig. 2). Three high-voltage converter modulators and five transmitters support the operation of the klystrons. A new low-level RF control system was developed and includes the hardware capabilities needed to support operation of both target stations in the future [4].

Figure 2: RF systems to power the new cryomodules.

Three of the Drift Tube Linac (DTL) RF stations are being upgraded from 2.5 MW to 3.0 MW klystrons, which required a concomitant upgrade of their high-voltage converter modulators [5]. The upgrade was designed so that any of the existing and new DTL klystrons can be used in any position of the seven RF stations that serve the Radio Frequency Quadrupole (RFQ) and DTL. These klystrons operate at 402.5 MHz.

RING SYSTEMS

Most magnets and power supplies installed during the construction of SNS were designed to support a 1.3 GeV proton beam. However, the ring injection and extraction regions required upgrades to support the increased beam energy. Fourteen pulsed extraction kicker magnets are used to extract the beam from the accumulator ring and direct it towards the first target station (FTS). The pulse forming networks and charging power supplies were upgraded to increase the voltage to the magnets to accommodate the 1.3 GeV beam.

The PPU project partnered with Fermi National Accelerator Laboratory (Fermilab) for the design [6] and fabrication of four new magnets: three chicane dipole magnets (including one spare) and one injection dump dipole magnet (including a spare coil). The injection dump dipole and two chicane magnets have been installed as shown in Figure 3. Additionally, a new quadrupole magnet was installed in the injection dump beamline to enable improved control of the waste beam on the injection dump. An injection dump imaging system was developed and installed along with a new phosphor-coated beam window for imaging of the waste beam.

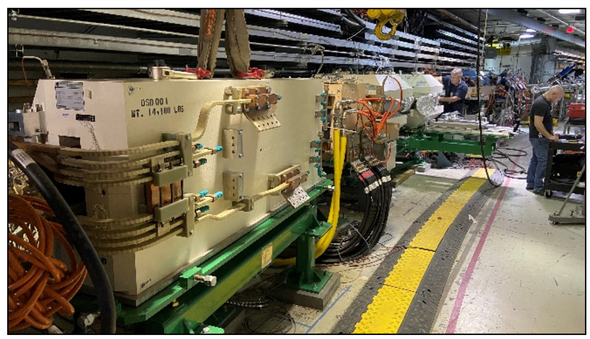

Figure 3: New ring injection region magnets.

A new primary foil stripper and electron catcher were installed. The diamond foil is used to strip electrons from the incoming H- beam from the Linac. A two-dimensional pyrometer system was developed to monitor foil temperature distributions and enable optimized foil conditioning in the future.

Ring deionized-water cooling systems were upgraded due to increased heat load, and a beam power limit system (BPLS) was developed to limit the beam power on FTS to 2 MW. The remaining beam power capability provided by the PPU project will be available for the future second target station (STS).

FIRST TARGET STATION

The FTS project scope included:

- 2 MW target R&D, design, and fabrication
- High-flow helium gas injection and recirculation
- Installation of a mercury overflow tank to increase head space in the mercury loop

- Modifications to the mercury off-gas treatment system (MOTS) to accommodate operation at 2 MW beam power on target
- Installation of an ortho-para conversion system and a new hydrogen refill system for the hydrogen moderator
- Analyses in support of the stated scope

The 2 MW target design has been validated through sustained high-power operation at 1.7 MW in 2023. The first production 2 MW target (Fig. 4) was installed during the long outage and will be used for a target lifetime demonstration (1250 hours at 1.7 MW) and routine neutron production beginning in July 2024. The new gas injection system will provide up to 20 standard liters per minute of helium gas to the body and nose gas injectors (10 each). The overflow tank will ensure mercury level limits are not challenged due to the high gas flow.

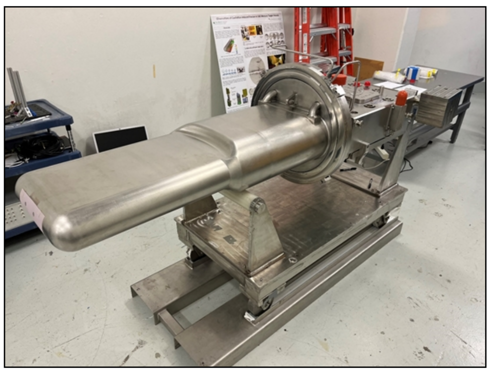

Figure 4: First production 2 MW target at SNS.

The MOTS system upgrades ensure that site emissions of activated spallation gases are minimal and well below requirements when operating the facility at 2 MW. The ortho-para conversion system will provide for >99% para hydrogen in the cryogenic moderator to maximize performance of the neutron instruments.

CONVENTIONAL FACILITIES

Conventional Facilities scope included: buildout of the existing klystron gallery to support the new RF systems; construction of a new alcove to house a deionized water system to provide cooling for the RF systems; and construction of the Ring-to-Target Beam Transport (RTBT) tunnel stub to facilitate connection to the future STS without impacting operation of the FTS during STS construction (Fig. 5).

The stub was constructed over approximately seven months, beginning in mid-August 2023. Beamline and personnel openings were cut into the existing RTBT tunnel. Upon completion of the construction, a temporary concrete-block shield wall was erected to provide radiological protection for workers at the downstream end of the stub where connection to a future Ring-to-Second-Target (RTST) tunnel will be performed by the STS project.

CONTROLS

The controls and instrumentation designs build upon established SNS technologies and methodologies and support deployment of the PPU project scope described above. The controls scope of work was embedded throughout the project and reported up through the responsible level 2 manager for each technical area. In retrospect, it may have been preferable to establish Controls as a separate level 2 topic within the work breakdown structure to more efficiently manage the Controls scope of work and ensure uniformity of approach.

Figure 5: RTBT tunnel stub for connection to the STS.

STATUS AND PLANS

The PPU project has completed installation of all scope needed to demonstrate threshold key performance parameters (KPPs) and enable future achievement of the objective KPPs. The threshold KPPs are the minimum key parameters that must be achieved to declare project success, whereas the objective KPPs are the operational goals that will be achieved by SNS Operations following PPU project completion. The formal accelerator readiness review is planned for May 2024, and commencement of beam commissioning is planned in June 2024 after pre-start action items are addressed and closed. Threshold KPPs will be demonstrated during the summer of 2024, and neutron production for the user program will resume in July 2024. The project plans to conduct a CD-4 project completion independent project review in December 2024.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank all PPU staff members and others from ORNL and partner laboratories for their support in executing the PPU project.

REFERENCES

[1] M. Champion *et al.*, "Progress on the Proton Power Upgrade at the Spallation Neutron Source," in *Proc. LINAC'22*, Liverpool, UK, Sep. 2022, pp. 390-393. doi:10.18429/JACoW-LINAC2022-TUPOJO19

[2] J. Mammosser *et al.*, "Proton Power Upgrade Project Progress and Plans at the Spallation Neutron Source in Oak Ridge Tennessee," in *Proc. SRF'23*, Grand Rapids, USA, Jun. 2023, pp. 25-29. doi:10.18429/JACoW-SRF2023-MOIXA03

[3] P. Dhakal *et al*., "Cavity Qualification and Production Update for SNS-PPU Cryomodules at Jefferson Lab," in *Proc. LINAC'22*, Liverpool, UK, Sep. 2022, pp. 387-389. doi:10.18429/JACoW-LINAC2022-TUPOJO18

[4] M. Crofford et al., "Spallation Neutron Source Proton Power Upgrade Low-Level RF Control System Development," in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 3363-3366. doi:10.18429/JACoW-IPAC2021-WEPAB299

[5] J. Moss *et al*., "The Spallation Neutron Source Normal Conducting Linac RF System Design for the Proton Power Upgrade Project," in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 4383-4386. doi:10.18429/JACoW-IPAC2021-THPAB296

[6] V. Kashikhin *et al*., "Magnetic Designs of New First Target Beamline Magnets for the ORNL SNS Upgrade," in *IEEE Transactions on Applied Superconductivity*, vol. 32, no. 6, pp. 1-4, Sept. 2022, Art no. 4001604. doi:10.1109/TASC.2022.3153439