ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO19

PROGRESS ON THE PROTON POWER UPGRADE PROJECT AT THE SPALLATION NEUTRON SOURCE*

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

Abstract

The Proton Power Upgrade Project at the Spallation Neutron Source at Oak Ridge National Laboratory will increase the proton beam power capability from 1.4 to 2.8 MW. Upon completion of the project, 2 MW of beam power will be available for neutron production at the existing first target station with the remaining beam power available for the future second target station. The project will install seven superconducting radiofrequency (RF) cryomodules and supporting RF power systems and ancillaries to increase the beam energy to 1.3 GeV. The injection and extraction region of the accumulator ring will be 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. Equipment is being received from vendors and partner laboratories, and installation is underway with three major installation outages planned in 2022-2024. The project is planned to be completed in 2025.

INTRODUCTION

The SNS accelerator routinely delivers a 1.4 MW proton beam to a liquid mercury spallation target to provide neutrons to 19 instruments [1]. The existing Linac produces a 1 ms pulse train of H^- ions at a repetition rate of 60 Hz. The H^- ions are stripped of their electrons as they enter the accumulator ring, which compresses the proton beam to a sub-microsecond pulse that is extracted and sent to the target 60 times per second. The Linac presently provides a beam energy of 1.0 GeV that will be increased to 1.3 GeV through the addition of 28 superconducting cavities contained in 7 cryomodules. The Linac H^- current will be increased from 26 to 38 mA, which will increase beam loading throughout the Linac. Three Drift Tube Linac (DTL) radiofrequency (RF) stations will be upgraded to provide needed additional power by means of new higher-rated klystrons. Otherwise, the existing Linac can accelerate the increased H^- current.

The mercury target and supporting utilities in the existing First Target Station (FTS) are being upgraded to accept 2 MW of proton beam power, and the remaining beam power will drive the future Second Target Station (STS) that is being constructed as a separate project. The 2 MW beam delivered to the FTS will improve performance across the entire existing and future instrument suite, and the future STS will provide a wholly new capability in the form of a transformative new source optimized to produce the world's highest peak brightness of cold neutrons.

SUPERCONDUCTING LINAC

Eight cryomodules are being produced by Thomas Jefferson National Accelerator Facility (TJNAF). Three cryomodules have been delivered to SNS and exceeded performance requirements during RF testing at 2 K. Delivery of the 4th cryomodule is planned in Sep. 2022, and the final cryomodule is due for delivery in Aug. 2023. The first two cryomodules (Fig. 1) will be installed in Aug.-Sep. 2022.

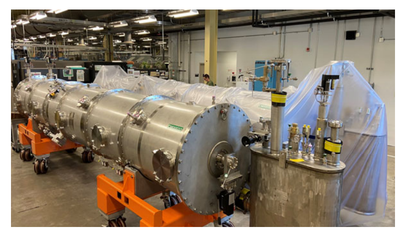

Figure 1: The first two cryomodules staged for installation in the front-end building.

The superconducting cavities were received from industry ready for vertical testing. Roughly 50% of the cavities required additional high pressure rinsing to eliminate field emission [2]. The helium vessels were attached at TJNAF [3], and then the cavities were again vertically tested to qualify for cryomodule cavity string assembly. It has been challenging to qualify the tanked cavities, and numerous cleaning cycles have been needed in many cases. A few cavities have required light buffered chemical polishing (BCP) to meet performance requirements.

Fundamental power couplers were RF tested at SNS and delivered to TJNAF ready for installation. U-tubes for connecting the cryomodules to existing cryogenic distribution lines are being fabricated by industry.

RADIO FREQUENCY SYSTEMS

Twenty-eight new 700 kW, 805 MHz klystrons are being installed to power the 28 superconducting RF cavities. The RF systems are largely the same as the existing RF systems with some improvements based on operations experience since the SNS construction was completed in 2006. Three new alternate-topology high voltage converter modulators will power 9, 9, and 10 klystrons. The modulators have been received, and the first unit has been installed in the

*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

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO19

klystron gallery (Fig. 2). Another unit has been tested at full voltage and duty factor on the test stand at SNS.

The RF transmitters have begun to arrive, and the first units are being installed with acceptance testing to begin in late Aug. 2022. The new low-level RF control system [4] has been tested extensively on the existing Linac and has been operating full time for several months supporting operations. The first 8 systems are being installed and tested to support operation of the first 2 cryomodules later this year.

Additionally, 3 existing RF stations for the DTL will be upgraded to 3 MW klystrons [5]. This requires upgrades to the existing high voltage converter modulators. The first article modulator has undergone extensive testing, and the first article 3-MW klystron has been received and is being prepared for acceptance testing.

Figure 2: The first new high voltage converter modulator installed in the klystron gallery.

RING SYSTEMS

The accumulator ring upgrades include two chicane magnets and an injection dump septum magnet, designed and fabricated by Fermilab [6], that will replace existing injection region magnets. The first chicane magnet core (Fig. 3) has been received, and fabrication of the first winding set is nearing completion (Fig. 4). The next step is to pot the windings, and then the magnet will be assembled and prepared for field measurements at Fermilab.

The new injection dump window has been received, and the injection dump imaging system is complete. These components will be installed in 2023 and will enable viewing of the injection waste beam location and pattern on the injection dump. A new injection dump quadrupole is in fabrication at a vendor and will be installed during the long outage that begins in Aug. 2023, to enable finer control of the waste beam parameters.

The Beam Power Limit System [7] passed its final design review in early 2022, and the system has been installed and tested with beam recently. Precision calibrated current transformers will be installed in Sep. 2022, and the system will be credited for personnel protection prior to the neutron production run scheduled to begin in Dec. 2022. This system will prevent beam power above 2 MW on the mercury target.

An upgrade to the extraction kicker power supplies is planned to accommodate the increased beam energy. Two concepts are presently undergoing long-term testing: a resonant charging power supply and a dual power supply charging supply. A decision on the final configuration will be made later this year.

Figure 3: The first chicane magnet core at the vendor.

Figure 4: Taping of a chicane magnet winding (left) and the completed winding set (right).

FIRST TARGET STATION

The FTS Systems scope includes the 2 MW mercury target [8] along with a high-flow helium gas injection system, off-gas treatment, and upgrades to the moderator cryogenic system. PPU Test Target #1 was operated successfully for over 1,500 hours at 1.4 MW during the Jan.-Mar. 2022 neutron production period. This target demonstrated the effectiveness of the new swirl bubblers [9], which flowed helium at a steady rate, unlike the inlet orifice bubblers that exhibit declining gas flow rates. Post irradiation examination showed no observable cavitation damage. PPU Test Target #2 (Fig. 5) will be installed in Aug.-Sep. 2022 and will operate during two run periods in 2023 at beam energy up to 1.1 GeV and beam power up to 1.7 MW. This target is identical to the 2 MW production target but will operate without the helium gas injection for the target nose because the high-flow helium gas injection upgrades will not be completed until the long outage.

The mercury off-gas treatment system (MOTS) upgrades are making good progress – the delay bed and cryogenic cold trap installations are complete, and the copper-oxide beds have been relocated. Molecular sieves and iodine filters are in vendor production. Installation of gas injection and gas recirculation components is underway, and a mercury overflow tank is in fabrication at a vendor.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJ019

Figure 5: Test Target #2 at the vendor prior to shipping.

A catalyst converter assembly is in fabrication and will provide for control of the ortho-para fraction in the hydrogen moderator. Instrumentation for measurement of the ortho-para fraction is included. The added equipment will increase the volume of hydrogen in the cryogenic system, so a new higher-capacity hydrogen refill system will be installed.

CONVENTIONAL FACILITIES

The PPU project includes two conventional facilities activities: buildout of the existing high-energy end of the klystron gallery, which was completed in Apr. 2021 [10], and construction of a tunnel stub that penetrates the wall of the existing Ring-to-Target Beam Transport (RTBT) tunnel and will facilitate connection to the future STS without interrupting operation of the existing FTS.

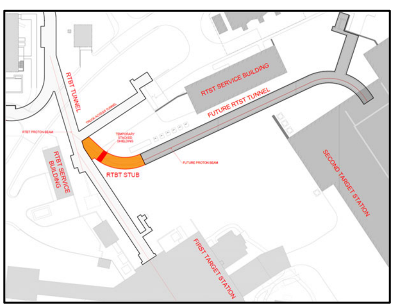

Figure 6: Plan view of the SNS site showing the existing RTBT tunnel, the planned RTBT stub, and the connection to the future Second Target Station.

The RTBT stub will connect to the existing RTBT tunnel at the intersection of the RTBT tunnel and the truck access tunnel as depicted in Fig. 6. The RTBT stub design was performed by an architecture/engineering firm in collaboration with SNS staff. A request for proposals will be issued in late 2022 with the goal to award a construction contract in Apr. 2023 so that construction can begin promptly when the PPU long outage begins in Aug. 2023. The primary challenge associated with this construction is the schedule: the stub construction must be complete within six months so that accelerator operations may resume as planned to support neutron production.

STATUS AND OUTLOOK

The PPU project received Department of Energy (DOE) Critical Decision 2 and 3 approvals in Oct. 2020. With these approvals, the cost and schedule baseline was established, and construction was authorized to proceed. The total project cost is $271.6M with early finish in 2025.

The PPU technical components will be installed during three primary installation outages. The first outage began in Aug. 2022. Two cryomodules will be installed, installation and testing of the supporting RF systems will be completed, and the remaining beam power limit system components and Test Target #2 will be installed. The second installation outage will begin in Mar. 2023, during which two more cryomodules will be installed, RF systems will be completed, and the ring injection dump imaging system will be installed. The long installation outage will begin in Aug. 2023, wherein the final three cryomodules will be installed, along with their supporting RF systems, the first production 2-MW target will be installed, accumulator ring and first target station components will be installed, and the RTBT stub will be constructed.

Newly installed equipment will be operated following each installation outage to support the power ramp-up plan shown in Fig. 7. The beam energy will be increased to 1.1 GeV following the first outage and will not be increased further until the new injection region magnets have been installed. After the long outage, the beam energy will be increased to 1.3 GeV, and a target lifetime demonstration at 1.7 MW beam power will be performed prior to the final ramp-up to 2 MW.

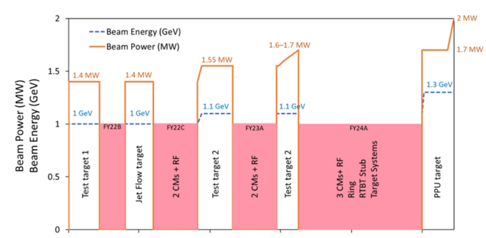

Figure 7: PPU power ramp-up plan. Proton beam power/energy will increase as components are installed and commissioned over the three installation outages.

The project has good cost and schedule performance metrics to date and has sufficient cost and schedule contingencies to complete the project within the cost and schedule baseline. The project placed many procurements early because designs were mature, and long lead procurements were approved by DOE (CD-3a, CD-3b). As a result, the project largely avoided supply chain and inflation impacts. Recent procurements show increased costs and delivery schedules, but the early finish in 2025 is not impacted. The largest remaining procurement is the construction contract for the RTBT stub construction.

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] J. Galambos, "Final Design Report Proton Power Upgrade," Oak Ridge National Laboratory, Rep. ORNL/TM-2020/1570-R0, June 2020.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO19

[2] P. Dhakal *et al*., "Cavity Qualification and Production Update for SNS-PPU Cryomodules at Jefferson Lab," presented at the LINAC'22, Liverpool, UK, Aug.-Sep. 2022, paper TUPOJO18, this conference.

[3] P. Dhakal *et al.*, "Development of Helium Vessel Welding Process for SNS PPU Cavities", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 1212-1213. doi:10.18429/JACoW-IPAC2021-MOPAB400

[4] M. T. 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. S. Moss, M. T. Crofford, S. W. Lee, M. E. Middendorf, and G. D. Toby, "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

[7] C. Deibele and K. Mahoney, "SNS Credited Beam Power Limit System Preliminary Design," presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, SP, Brazil, May 2021. doi:10.18429/JACoW-IPAC2021-TUPAB319

[8] D. E. Winder, "Evolution of the High-Power Spallation Neutron Mercury Target at the SNS", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 3735-3739. doi:10.18429/JACoW-IPAC2021-THXC03

[9] C. N. Barbier *et al.*, "Bubble Generation in the SNS 2 MW Mercury Target", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 3567-3570. doi:10.18429/JACoW-IPAC2021-WEPAB367

[10] M. S. Champion *et al.*, "Progress on the Proton Power Upgrade at the Spallation Neutron Source", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 1876-1879. doi:10.18429/JACoW-IPAC2021-TUPAB199