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AN OPERATIONALLY INTEGRATED APPROACH TO THE SNS 2.8 MW POWER UPGRADE*

J. Galambos†, on behalf of the PPU team, SNS, Oak Ridge TN, USA

Abstract

The Spallation Neutron Source (SNS) accelerator consist of a 1 GeV H^- linac and an accumulator ring producing a 1.4 MW pulsed proton beam which drives a spallation neutron source [1]. The Proton Power Upgrade pro-ject will double the power capability from 1.4 to 2.8 MW by increasing the linac beam energy 30% and the beam current about 50%. Equipment upgrades include new superconducting RF cryomodules and supporting RF equipment, upgraded ring equipment, and upgraded high power target systems. An important aspect of the up-grade is a gradual power ramp-up starting in 2022 in which new equipment is installed during maintenance outages as it arrives, and used in subsequent run periods.

INTRODUCTION

The SNS is a neutron scattering materials science user facility that has been operating since 2006. The neutron flux used to study material structures and properties is proportional to the proton beam power, the history of which is shown in Fig. 1. Beam power has been operating stably at the design level of 1.4 MW since 2018, and SNS has been embarked on a Proton Power Upgrade (PPU) project since 2017 [2, 3]. This project aims to double the beam power capability by increasing the beam energy by 30% and increasing the average beam current by 50%. Of the post-upgrade 2.8 MW proton beam power capability, 2 MW will be provided to the existing First Target Station (STS) at SNS, and additional power will be available to power a new Second Target Station [4], which is a separate ongoing project. The PPU project received approval for long lead procurements in the areas of superconducting cryomodules, RF equipment and RF service building upgrades in the fall of 2019. In fall 2020 the project baseline and the start of construction was approved.

A major consideration of high-power proton accelerators is beam loss, which is discussed in section 2, along with some discussion on operational experience that guides the upgrade. The progress of different PPU technical systems is discussed in section 3. The coordination of the upgrade equipment installation and use with ongoing operations resulting in a gradual power ramp-up is discussed in section 4.

OPERATIONAL EXPERIENCE

As indicated in Fig. 1, SNS has been operating stably at 1.4 MW for 3 years. Accelerator availability of over 90% and over 4500 operational hours per year have been sustained over this period. The operational experience garnered since 2006 guides the PPU upgrade choices for 2.8 MW operation [2, 3]. In addition to the equipment needed to provide the higher power, PPU will provide additional beam instrumentation and control in the injection dump area, which is presently has limited diagnostics.

Beam loss was a major consideration in the design of SNS. Beam loss was expected to be less than 1 W/m [5] (or $<10^{-6}$ fractional loss for much of the facility) and this is the case. This level of beam loss is beyond what simulation tools accurately predict. But it is possible to scale anticipated post-upgrade beam loss from present observed beam loss levels at ~1 MW operation. This was done for the various sections of the SNS accelerator in Ref. [2], and the increase in beam loss and subsequent activation levels is expected to be smaller about a factor of 2 from presently observed residual activation levels. This increase can be accommodated without major impact on machine operations.

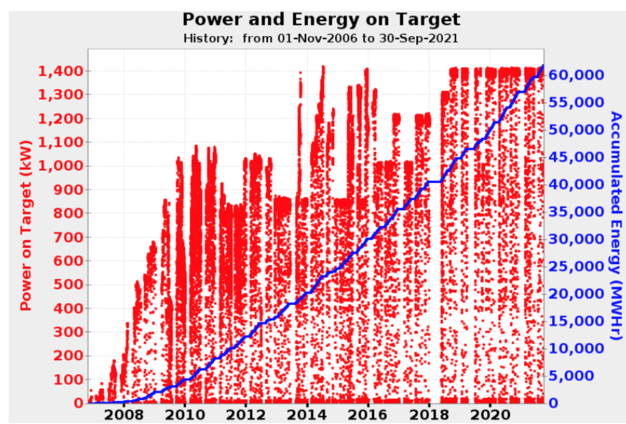

Figure 1: SNS Beam power history.

UPGRADE STATUS

Superconducting Linac

Seven new cryomodules will be installed in existing slots in the SNS high energy end of the linac [6]. Over the past year the superconducting RF cavities have been supplied by the vendor and cryomodule production is ramping up at the partner lab, JLab. Equipment procurements are largely in hand, cavities have been jacketed and qualified for the first 3 cryomodule strings, and the first cryomodule cold mass is nearing final assembly. (see Fig. 2). In addition, an 8th spare cryomodule has been added to the project scope. The cryomodule production is on schedule for delivery of the initial 2 cryomodules in April 2022.

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† jdg@ornl.gov

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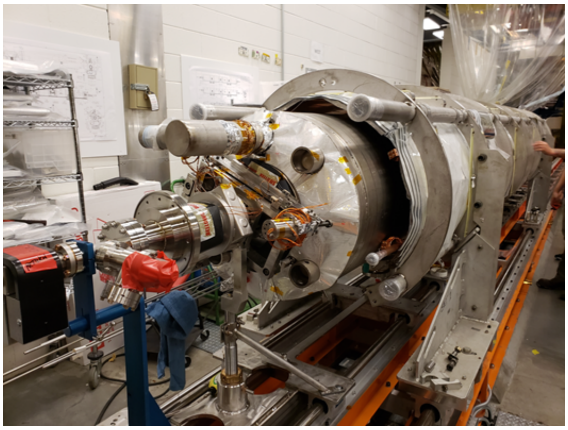

Figure 2: Initial PPU cryomodule cold mass.

RF Upgrades

The primary RF scope is the addition of new equipment to power the 7 new cryomodules. This includes transmitters, high voltage converter modulators and klystrons. These are all incremental extensions of existing technology implementations at use in SNS, with no fundamentally new developments. Because of this the RF equipment was well positioned for early long lead time procurement in 2019. Figure 3 shows a new klystron for the superconducting linac section delivered to SNS. Upgrades are also being made on the lower energy DTL RF systems to accommodate the higher beam loading post-PPU [7]. Also, the new LLRF systems will accommodate dual pulse flavors to support future interleaving of beam to the STS [8].

Figure 3: New RF klystron at SNS.

Ring Systems

The primary Ring system upgrades are upgraded injection and extraction magnet systems, and new diagnostics and control elements in the ring injection dump line. Two new chicane magnets and a new septum magnet are being provided for the injection region. We are partnering with FNAL for the design and fabrication of these critical upgrade elements. Figure 4 shows the final design for the chicane magnets. Also, a safety credited system to prevent exceeding the target power limit is being provided in the beam transport line upstream of the target [9].

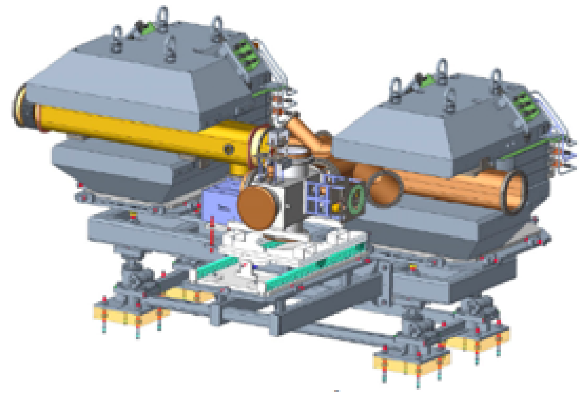

Figure 4: New ring injection chicane design.

Target System Upgrades

The primary target upgrade is a new target vessel with structure designed to handle the increased loads associated with higher beam intensity [10]. A major demonstrated operational target damage mitigation technique is gas injection to the flowing liquid mercury target material. PPU will provide for increased gas injection capability, new gas bubble generation techniques [11], and more complete gas coverage throughout the target vessel [12, 13]. These target upgrades will be implemented through a series of 2 incremental test targets. Other system upgrades include improvements in the mercury offgas treatment systems and providing a new orthopara hydrogen conversion system for the cryogenic moderator. Figure 5 shows the initial test target ready for installation, with the new gas bubble injection system.

Figure 5: First PPU test target ready for installation.

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Figure 6: Klystron gallery installed cooling systems.

Civil Construction

Construction is complete on the klystron gallery service building alongside the linac that houses the RF equipment powering the new cryomodules. Construction included adding a new pump room, installing HVAC equipment, cooling pipes installation and cable tray installation. Figure 6 shows the klystron gallery in August. Equipment installation activities are ongoing. In addition to the klystron gallery upgrades, a stub will be added to the transport line from the ring to the first target station.

POWER RAMP-UP PLAN

PPU will implement the remaining upgrade tasks in coordination with SNS operations. Typically, the SNS operation cycle includes 2-3 extended maintenance outages per year, of ~2-month duration each. PPU will take advantage of these outages for equipment installation in tunnels, electrical tie-ins, shielding modifications etc. Other PPU activities can take place during operation, such as equipment installation in the klystron gallery. Operations has its own sets of constraints on machine maintenance and upgrades. Also considered in PPU planning is the outage schedule for the sister neutron source at ORNL, at the High Flux Isotope Reactor (HFIR). Expected vendor delivery dates for equipment also are an element for outage scheduling. Finally, input was also solicited from the SNS government sponsor. The outage durations include the time required for restart approval with the newly installed equipment. All these impacts were considered in adopting the overall power ramp up schedule shown in Fig. 7. The red bars indicate extended maintenance periods, and the white bars indicate operational run periods. Some PPU project high-level activities in these periods are also indicated. There is one longer than usual (10 month) outage in 2023. Together, the interleaving of outage periods for equipment installation and run periods where the newly installed equipment is used constitutes the planned gradual power ramp-up. This will occur between 2022 and 2024.

The general approach is to use new equipment as soon as it is available. In the target area, we will implement upgrades starting with the first test target in early 2022 that

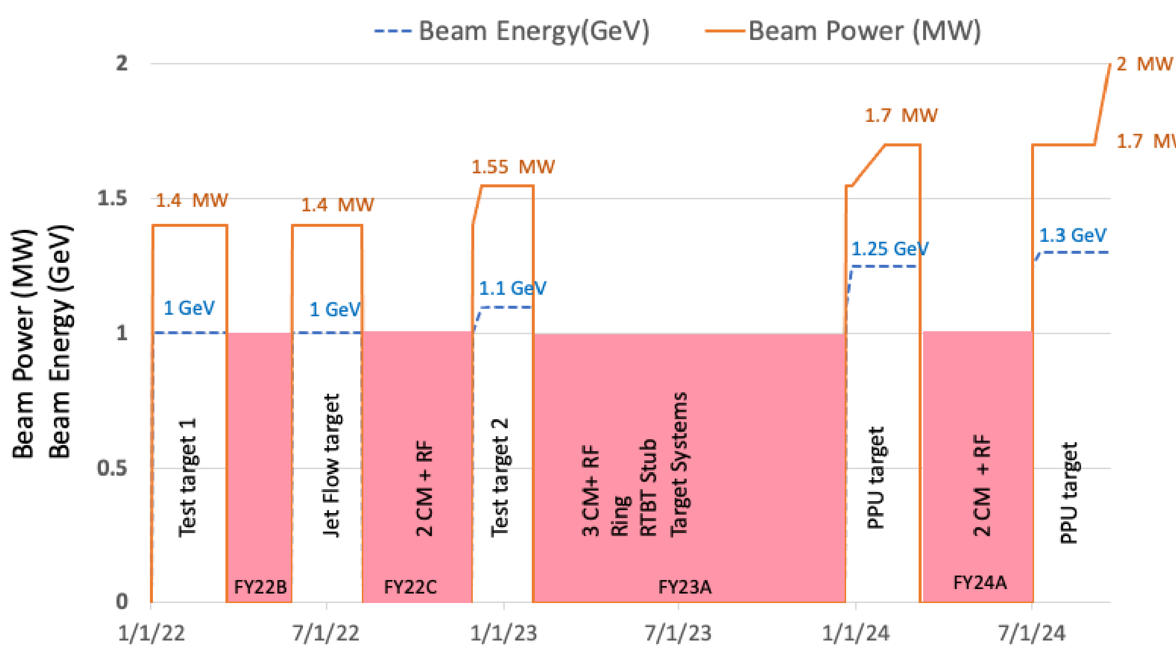

Figure 7: PPU gradual power ramp-up plan, indicating the expected beam energy and beam power increases. (CM+RF=cryomodule and supporting RF equipment installation).

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incorporates new gas bubbler injection technology and some of the new structural elements. The final target upgrades will be included in the long outage in 2023, after which higher flow and more complete target coverage gas injection will be possible.

A major component of the planned upgrade is to operate cryomodules starting in the run cycles following their installation. The first 2 cryomodules are planned for installation in mid 2022, and we will increase the beam energy and power by ~10% (to 1.1 GeV and 1.55 MW) coming out of this outage.

The following 10-month extended outage in 2023 is the primary installation period for PPU. Several activities require extended down time and it is important to have these proceed in parallel to minimize overall machine downtime. Two of these extended duration activities are the upgrade to the ring injection area and the addition of a stub in the tunnel from the ring to the existing target station. Including the stub during this period will avoid a future long outage to tie into the future second target station. Coming out of this extended outage in late 2023, 5 of the 7 PPU provided cryomodules should be installed and operation at 1.25 GeV and 1.7 MW is planned. Also, the final PPU target configuration should be operational coming out of this outage.

The maintenance period near the start of 2024 is planned to be close to the normal outrage length and the last 2 PPU cryomodules will be installed, after which the full capability to run at the full upgrade energy of 1.3 GeV and power of 2.8 MW will be complete. We plan to initially run at 1.7 MW for 1250 hours to meet a project completion threshold milestone, and then quickly ramp-up to the 2 MW capability of the existing target station. When the new STS is available additional proton beam power will be sent there.

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