Operational Experience of SNS at 1.4 MW and Upgrade Plans for Doubling the Beam Power

John Galambos
Director Proton Power Upgrade project
On behalf of the SNS staff

IPAC 2019
May 25, 2019, Melbourne Australia
Outline

- Spallation Neutron Source (SNS) introduction
- We are at the design 1.4 MW power level operation
- The Proton Power Upgrade (PPU) project
  - Double the accelerator power capability to 2.8 MW

Upgrades build on experience that paved the way to 1.4 MW operation
Spallation Neutron Source (SNS): A high intensity short pulse spallation neutron source

- Spallation: accelerator driven, protons
- High intensity neutron: MW power level accelerator
- Short pulse: ring
SNS overview: short pulse neutron source

The linac accelerates a 26 mA, ~1 msec long H⁺ beam

@ 60 Hz, this represents a 1.4 MW proton beam power

The accumulator ring compresses the pulse to ~700 nsec

186 MeV

~1000 MeV
The early operation years: 2007-2011 “Race to 1 MW”

- Ramp up as fast as possible, see what breaks and fix it
  - Limitations: high power RF, ion source, superconducting RF
Technology initiatives launched in the early years

**Ion source**
- World class high current and repeatable performance has been developed

**High voltage convertor modulators**
- Component and system robustness

**Superconducting RF**
- Cryomodule rework: remove un-necessary ancillary equipment (piezo tuners, HOMs)
- Equipment protection: fast beam turn-off with beam loss
- Improve performance: in-situ plasma processing
Intermediate years 2012-2016: “It’s the target stupid”

- Target failures limited beam power
  - 6 of 8 targets leaked during this period

Power limited by target
Target improvement campaign

Gas bubble injection into mercury target

Target instrumentation: strain gauges

Post Irradiation Examination

Improved design / fabrication oversight

80 RPM: 474 MPa
Gas bubble injection in targets demonstrates strain mitigation

Measurements show clear target vessel strain reductions with gas bubble injection

- Demonstrates strain reduction required for PPU 2 MW design
Gas bubble injection in targets demonstrates cavitation mitigation

Disc specimens are regularly taken from irradiated target nose regions

Operating in the service bay

- Vertical target
- Specimen cutter
- Disc specimen

Post irradiation core samples indicate clear reductions in cavitation damage

- Last target without gas
- First target with gas
  - Center
  - Edge

- Last 8 operational targets: no leaks
New RFQ provides beam current (power) headroom

Original RFQ had performance issues

• Original RFQ had performance issues
  – Sudden frequency shifts
  – Gradual field profile change
    • Transmission reduced ~ 20-30%

New RFQ installed in 2018

• Recovered 90% design transmission which provides power margin

Upstream view of the original SNS RFQ vanes

Installed new RFQ
2016-2019: “Systematic approach” to 1.4 MW design level

- New RFQ provides beam power headroom
- Gas injection mitigates target damage
  - No mercury leaks
- Developments in other accelerator systems provide a basis for reliable high power operation.

*SNS is operating at its design power of 1.4 MW*
Operation at 1.4 MW

- Trip frequency is not affected by beam power
  - Reliability dominated by infrequent but long outages

- Beam loss is proportional to beam power
  - Activation levels have never limited beam power

- Operational rhythm is much the same as before
SNS operation metric history

> 90% accelerator reliability

75%-95 % overall reliability (dominated by major failures)

Run 4000-5000 hrs/yr
SNS beam power summary

Power and Energy on Target
History: from 01-Nov-2006 to 27-Mar-2019

1.4 MW

Time to upgrade the SNS!
SNS Upgrade Plans

**Today**
- 24 instrument positions
- 19 instruments built

**First Target Station**
- 1.4 MW Accelerator

**Future**
- 24 instrument positions
- 21 instruments built

**First Target Station**
- 2.8 MW capable Accelerator

**Proton Power Upgrade (PPU)**
- 2 MW

**Second Target Station (STS)**
- 22 instrument slots,
  8 initial instruments

**STS Upgrade**
## PPU parameters

<table>
<thead>
<tr>
<th></th>
<th>SNS 1.4 MW</th>
<th>PPU full upgrade capability</th>
<th>PPU FTS 60 Hz operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton beam power capability (MW)</td>
<td>1.4</td>
<td>2.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Beam energy (GeV)</td>
<td>1.0</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>RFQ output peak beam current (mA)</td>
<td>33</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Average linac chopping fraction (%)</td>
<td>22</td>
<td>18</td>
<td>41</td>
</tr>
<tr>
<td>Average macropulse beam current (mA)</td>
<td>25</td>
<td>38</td>
<td>27</td>
</tr>
<tr>
<td>Energy per pulse (kJ)</td>
<td>23</td>
<td>47</td>
<td>33</td>
</tr>
<tr>
<td>Pulse repetition rate (Hz)</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Macro-pulse length (ms)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FTS decoupled moderator brightness/pulse (AU)</td>
<td>1</td>
<td>2.04</td>
<td>1.43</td>
</tr>
<tr>
<td>FTS coupled moderator brightness/pulse (AU)</td>
<td>1</td>
<td>2.16</td>
<td>1.51</td>
</tr>
</tbody>
</table>

### Observations
- **33% energy increase**
- **50% current increase: front end is good to go**
- **No change**
Superconducting linac (SCL): 7 new cryomodules

Cavities

• Cavities are presently being procured
  - Similar as existing cavities
  - 16 MV/m gradient, $Q_0 > 5 \times 10^9$

Cryomodules

• JLab is a PPU partner and is providing the cryomodules
  - Similar to existing SNS spare cryomodule

9 empty slots are available in the tunnel
Radio frequency upgrades

Upgrade some existing RF installations

- Tests done on existing systems
  - CCL and existing SCL RF systems: OK
  - DTL systems: upgrade from 2.5 to 3 MW

New equipment to power the new cryomodules

- High voltage convertor modulators use new topology
- Klystrons will be same as presently in use
Accumulator ring upgrades

Injection magnets

- Some chicane magnets need replacement

Extraction region

- Extraction kickers: upgrade existing power supplies rather than add new kickers

Partnering with FNAL

96% of magnets and power supplies are 1.3 GeV capable now
Target upgrades

New 2 MW mercury target vessel

- Enhanced structural design
- Enhanced gas bubble injection
  - 10x increase flow rate
- Gas wall in nose

Other target systems

- Recirculating injected He gas in service bay
- Ensuring 2MW capable systems
Conventional facility upgrades

Klystron gallery buildout

- Coupled CF / technical systems 3-D layout to facilitate installation

Tunnel stub to Second Target Station (STS)

- Facilitates seamless tie-in to STS
PPU is partnering with other laboratories

J-Lab is building the new superconducting cryomodules

- J-Lab built the original SNS cryomodules, has the resources and facilities for this task

FNAL: Ring magnet scope

FNAL chicane magnet design

LBNL: LLRF

PPU Overview March 19 2019
Power upgrade project timeline

- Aggressively pursuing “early procurements” to accelerate schedule
  - CD-3a, CD-3b
- Plan a power ramp-up starting in 2022
- Early finish in 2024
Summary

• SNS has reached its design operational power of 1.4 MW
  – Builds on many years of development
  – Target and RFQ improvements are most recent steps forward

• An accelerator upgrade project (PPU) is underway to double the power capability
  – Largely based on existing accelerator technology
  – Partnering with other labs to leverage fabrication capabilities
Thanks!

Questions ?