Spallation Neutron Source Project: Commissioning Results, First Operation Experience, and Upgrade Plans

Alexander Aleksandrov

Oak Ridge National Laboratory
Oak Ridge, USA
Nanoscale science and technology presents extraordinary opportunities.
Spallation-Evaporation Production of Neutrons

**Fission**
- chain reaction
- continuous flow
- 1 neutron/fission

**Spallation**
- no chain reaction
- pulsed operation
- 30 neutrons/proton
- Time resolved exp.
The Spallation Neutron Source

- The SNS began operation in 2006
- At 1.4 MW it will be ~7x ISIS, the world’s leading pulsed spallation source
- The peak neutron flux will be ~20-100x ILL
- SNS will be the world’s leading facility for neutron scattering
- It will be a short drive from HFIR, a reactor source with a flux comparable to the ILL

## The Spallation Neutron Source Partnership

### Funding Overview

<table>
<thead>
<tr>
<th>Description</th>
<th>Accelerator</th>
<th>Current Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Support</td>
<td>75.6</td>
<td>~177 M$</td>
</tr>
<tr>
<td>Front End Systems</td>
<td>20.8</td>
<td>~60 M$</td>
</tr>
<tr>
<td>Linac Systems</td>
<td>315.9</td>
<td>~113 M$</td>
</tr>
<tr>
<td>Ring &amp; Transfer System</td>
<td>142.0</td>
<td>20 M$</td>
</tr>
<tr>
<td>Target Systems</td>
<td>108.2</td>
<td></td>
</tr>
<tr>
<td>Instrument Systems</td>
<td>63.3</td>
<td></td>
</tr>
<tr>
<td>Conventional Facilities</td>
<td>378.9</td>
<td></td>
</tr>
<tr>
<td>Integrated Control System</td>
<td>59.7</td>
<td></td>
</tr>
<tr>
<td>BAC</td>
<td>1,164.4</td>
<td>~167 M$</td>
</tr>
<tr>
<td>Contingency</td>
<td>28.3</td>
<td></td>
</tr>
<tr>
<td>TEC</td>
<td>1,192.7</td>
<td>~106 M$</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>100.0</td>
<td>~106 M$</td>
</tr>
<tr>
<td>Pre-Operations</td>
<td>119.0</td>
<td>~106 M$</td>
</tr>
<tr>
<td>TPC</td>
<td>1,411.7</td>
<td>~106 M$</td>
</tr>
</tbody>
</table>

**Total Budget (BAC):** ~1,164.4 M$

### Construction Details

- **At peak:** ~500 People worked on the construction of the SNS accelerator.

### Location

- **Oak Ridge, TN**
  - Latitude: 35° 49' N
  - Longitude: 83° 59' W
Spring 1999
Spring 2000
Spring 2001
Spring 2002
Spring 2003
Spring 2006
SNS Accelerator Complex

Front-End:
Produce a 1-msec long, chopped, low-energy H- beam

LINAC:
Accelerate the beam to 1 GeV

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec
H- stripped to protons

Deliver beam to Target

Ion Source
2.5 MeV → 86.8 MeV → 186 MeV → 387 MeV → 1000 MeV
RFQ DTL CCL SRF, $\beta=0.61$ SRF, $\beta=0.81$

945 ns
Chopper system makes gaps
mini-pulse

1 ms macropulse

Current

1 ms
The SNS Target: 2-MW Design

- Cavitation-induced pitting is an issue.
- Options for mitigation:
  - **Materials, Geometry**
  - 25 kJ/pulse at 7x15cm beam size sets of transverse and longitudinal shock wave.
- Needs to be exchanged every 3 months

Pits on inner surface in this geometry
17 Instruments Now Formally Approved

- **Fundamental Physics to Engineering**
  - Backscattering Spectrometer – BL2
  - Disordered Materials Diffractometer – BL 1b
  - High-Pressure Diffractometer – BL 3
  - Magnetism Reflectometer – BL 4a
  - Liquids Reflectometer – BL 4b
  - Cold Neutron Chopper Spectrometer – BL 5
  - Small-Angle Neutron Scattering Diffractometer – BL 6
  - Engineering Diffractometer (VUCAN) – BL 9

- **Chemistry to “Genomes to Life”**
  - Wide-Angle Chopper Spectrometer (ARCS) – BL 18
  - High-Resolution Chopper Spectrometer (SEQ) – BL 17
  - Neutron Spin Echo – BL 15
  - Hybrid Spectrometer (HYSSPEC) – BL 14B
  - Single-Crystal Diffractometer – BL 12
  - Powder Diffractometer (POWDEN) – BL 11a
  - Areas for User and Instrument Support

**Contact Information**

Backscattering Spectrometer – BL2
Em Hensley
(830)995-5371 - shenley@anl.gov

Disordered Materials Diffractometer – BL 1b
Mike Zilges
(630)252-6462 - mzkilges@anl.gov

High-Pressure Diffractometer – BL 3
Chris Turk
(630)252-4011 - ckturk@anl.gov

Magnetism Reflectometer – BL 4a
Park Knoll
(630)252-7480 - pknoll@anl.gov

Liquids Reflectometer – BL 4b
John Acker
(630)252-4168 - jacker@anl.gov

Cold Neutron Chopper Spectrometer – BL 5
Georg Effers
(630)252-3311 - geffers@anl.gov

Small-Angle Neutron Scattering Diffractometer – BL 6
Jinli Jiao
(630)252-4011 - jji@anl.gov

Engineering Diffractometer (VUCAN) – BL 9
Jun-Li Wang
(630)252-6462 - wjili@anl.gov

Wide-Angle Chopper Spectrometer (ARCS) – BL 18
Doug Abernathy
(630)252-9732 - daubern@anl.gov

High-Resolution Chopper Spectrometer (SEQ) – BL 17
Greene Cremer
(630)252-9900 - gcremer@anl.gov

Neutron Spin Echo – BL 15
Ufer Richter
+9-062417-81-30887771 - drichter@bevatron.de

Hybrid Spectrometer (HYSSPEC) – BL 14B
Stevie Shapiro
(630)252-3322 - stshapiro@anl.gov

Fundamental Physics Beam Line – BL 13
Geoffrey Greene
(630)252-0333 - ggreeneg@anl.gov

Single-Crystal Diffractometer – BL 12
Christine Hoffmann
(630)252-1890 - chhoffmann@anl.gov

Powder Diffractometer (POWDEN) – BL 11a
Robert Hedges
(630)252-3071 - rhedges@anl.gov
## The SNS Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic energy, $E_k$ [MeV]</td>
<td>1000</td>
</tr>
<tr>
<td>Beam power on target, $P_{\text{max}}$ [MW]</td>
<td>1.4</td>
</tr>
<tr>
<td>Chopper beam-on duty factor [%]</td>
<td>68</td>
</tr>
<tr>
<td>Linac beam macro pulse duty factor [%]</td>
<td>6.0</td>
</tr>
<tr>
<td>Average macropulse H- current [mA]</td>
<td>26</td>
</tr>
<tr>
<td>Peak Current from front end system</td>
<td>38</td>
</tr>
<tr>
<td>Linac average beam current [mA]</td>
<td>1.6</td>
</tr>
<tr>
<td>SRF cryo-module number (med-beta)</td>
<td>11</td>
</tr>
<tr>
<td>SRF cryo-module number (high-beta)</td>
<td>12</td>
</tr>
<tr>
<td>Number of SRF cavities</td>
<td>33+48</td>
</tr>
<tr>
<td>Peak gradient, $E_p$ ($\beta=0.61$ cavity) [MV/m]</td>
<td>27.5 (+/- 2.5)</td>
</tr>
<tr>
<td>Peak gradient, $E_p$ ($\beta=0.81$ cavity) [MV/m]</td>
<td>35 (+2.5/-7.5)</td>
</tr>
<tr>
<td>Ring injection time [ms] / turns</td>
<td>1.0 / 1060</td>
</tr>
<tr>
<td>Ring rf frequency [MHz]</td>
<td>1.058</td>
</tr>
<tr>
<td>Ring bunch intensity [$10^{14}$]</td>
<td>1.6</td>
</tr>
<tr>
<td>Ring space-charge tune spread, $\Delta Q_{sc}$</td>
<td>0.15</td>
</tr>
<tr>
<td>Pulse length on target [ns]</td>
<td>695</td>
</tr>
</tbody>
</table>
Front End (injector)

- 65 kV, 45 mA H- ion source
- Electrostatic LEBT with pre-chopper
- 2.5 MeV 402.5 MHZ RFQ
- 3.6 m long MEBT with chopper and beam diagnostics
402.5 MHz Drift Tube Linac (DTL)

- DTL accelerates beam to 87 MeV

- System includes 210 drift tubes in six separate tanks (37m total length)

- Inside drift tubes: permanent magnet quadrupoles, electromagnetic dipole correctors, strip-line beam position monitors (BPM)
Drift Tube Linac in the tunnel
805 MHz Coupled-Cavity Linac (side coupled)

• CCL accelerates beam to 187 MeV

• System consists of 48 accelerating segments, 48 quadrupoles, 32 steering magnets and diagnostics (55 m total length)
Coupled-Cavity Linac in the tunnel
805MHz Super Conducting RF Linac (SCL)

- SCL accelerates beam from 187 to 1000 MeV
- 81 6-cell superconducting cavities in 23 cryo-modules (157m)
- Cavities are operated at 2.1K or 4.2K
- Two cavities geometries are used to cover broad range in particle velocities

Cavities are assembled into strings

Medium beta cavity

High beta cavity
Superconducting Cavity Performance

Medium Beta

High Beta

A. Aleksandrov

RuPAC 2006

Sept. 10 – 14, 2006 Novosibirsk
Super Conducting Linac in the Tunnel
High-Power RF Systems

- Compact High Voltage Converter Modulators using solid state devices (IGBT)
- High-Power RF System: klystrons, waveguides, circulators
  - 7 402.5 MHz 2.5 MW klystrons
  - 4 CCL 5 MW Klystrons
  - 81 SCL 550 kW klystrons
Digital Low Level RF system

Cavity field and phase droop with feedback alone (left) and feedback + feedforward (right) beam loading compensation.

Phase width of the bunch along the pulse with feedback alone (left) and feedback + feedforward (right)
SNS Central Helium Liquefying Facility

- Cold box specifications are:
- 8300 Watts on the shield
- 2400 Watts @ 2.1 Kelvin
- 15g/s Liquefaction
The SNS Accumulator Ring

Circumference     248 m
Energy       1 GeV
Revolution period      1 μs
Number of turns 1060
Final Intensity 1.5x10^{14}
Peak Current 52 A
Number of magnets >300
(bend and focusing)
Ring Installation Progress
SNS Liquid Mercury Target
SNS Remote Handling Manipulators
Commissioning Timeline

- 2002: Front-End
- 2003: DTL Tank 1
- 2004: DTL/CCL, DTL Tanks 1-3
- 2005: SCL, Ring
- 2006: Target
5x10^{13}/pulse Protons Delivered to the Target

Ring Beam Current Monitor

Beam on Target View Screen

Final RTBT Beam Current Monitor
1st “Production Run”
# The SNS Power Upgrade Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic energy, $E_k$ [MeV]</td>
<td>1000</td>
<td>1300</td>
</tr>
<tr>
<td>Beam power on target, $P_{\text{max}}$ [MW]</td>
<td>1.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Chopper beam-on duty factor [%]</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>Linac beam macro pulse duty factor [%]</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Average macropulse H- current [mA]</td>
<td>26</td>
<td>42</td>
</tr>
<tr>
<td>Peak Current from front end system</td>
<td>38</td>
<td>59</td>
</tr>
<tr>
<td>Linac average beam current [mA]</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>SRF cryo-module number (med-beta)</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>SRF cryo-module number (high-beta)</td>
<td>12</td>
<td>12 + 8 (+1 reserve)</td>
</tr>
<tr>
<td>Number of SRF cavities</td>
<td>33+48</td>
<td>33+80 (+4 reserve)</td>
</tr>
<tr>
<td>Peak gradient, $E_p$ ($\beta$=0.61 cavity) [MV/m]</td>
<td>27.5 (+/- 2.5)</td>
<td>27.5 (+/- 2.5)</td>
</tr>
<tr>
<td>Peak gradient, $E_p$ ($\beta$=0.81 cavity) [MV/m]</td>
<td>35 (+2.5/-7.5)</td>
<td>31</td>
</tr>
<tr>
<td>Ring injection time [ms] / turns</td>
<td>1.0 / 1060</td>
<td>1.0 / 1100</td>
</tr>
<tr>
<td>Ring rf frequency [MHz]</td>
<td>1.058</td>
<td>1.098</td>
</tr>
<tr>
<td>Ring bunch intensity [$10^{14}$]</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>Ring space-charge tune spread, $\Delta Q_{sc}$</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Pulse length on target [ns]</td>
<td>695</td>
<td>691</td>
</tr>
</tbody>
</table>