The SNS Linac and Storage Ring: Challenges and Progress Towards Meeting Them

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Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37830, USA
More than 31 SNS Presentations in this conference

THPLE020 - Algorithms for the SNS MEBT Commissioning*
WEPR1117 - An Improved Impedance Model of Metallic Coatings
THPLE013 - Upgrading the SNS Compressor Ring to 3 MW
THPLE023 - Finite Element Analysis And Frequency Shift Studies for The Bridge Coupler of The Coupled Cavity Linear Accelerator of The Spallation Neutron Source
THPDO016 - High Power RF Tests on Fundamental Power Couplers for the SNS Project
TUPLE101 - High Level RF for the SNS Ring
WEPR1036 - Measurements of the coupling impedance of the SNS extraction kickers
THPLE016 - Proton Beam Halo Intercept Design in the SNS HEBT Line
TUPDO037 - A Narrow Quadrupole for the SNS Accumulator Ring
THPLE017 - SNS Beam in Gap Cleaning and Collimation, S. Cousineau
THPLE021 - Spallation Neutron Source Application Programming Environment,
WEPR057 - Exploring Transverse Beam Stability in the SNS in the Presence of Space Charge
TUPLE068 - SNS Extraction Kicker System and First Article BPFN Test
TUPDO008 - Series Production of Accelerator Cavities for the Spallation Neutron Source
THPLE011 - Accelerator Physics Model of Expected Beam Loss along the SNS Facility
WEPR037 - Coupling Correction for the SNS Accumulator Ring
THPDO025 - Input Coupling and Higher-Order Mode Analysis of Superconducting Axisymmetric Cavities for the Rare Isotope Accelerator
TUPDO039 - Elimination of Digitizing Errors in a Rotating Coil Mapper
TUPDO038 - Characterization of a SNS Transfer Line Dipole
WEPR061 - Application of UAL-Based Correction Schemes to the SNS Accumulator Ring
WEPR055 - The SNS Ring Dipole Magnetic Field Quality
THPLE012 - Commissioning of the SNS Front-End Systems at Berkeley Lab
THR1079 - Progress in Laser Beam Profile Monitor Development
TUXGB001 - State of the Art of Multicell SC Cavities and Perspectives
THPLE019 - Enhancing Surface Ionization and Beam Formation in Volume-type H-Ion Sources
TUPLE119 - Development of 805-MHz Pulsed Klystrons for SNS
WEPDO006 - Simulation Results for the Electron Cloud at the PSR and SNS
THPRI071 - Tune Measurement in the SNS Ring
MOUPLE107 - 1.12 MVA Peak Two Quadrant Pulse Switch Mode Power Supply for SNS Injection Bump Magnet
THPDO015 - Superconducting Prototype Cavities for the Spallation Neutron Source (SNS) Project
THPLE024 - Selected Aspects of the SNS Linac Performance
The Spallation Neutron Source Partnership

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SNS-ORNL Accelerator systems: ~137 M$

~500 People work on the construction of the SNS accelerator

Oak Ridge, TN 35° 49' N, 83° 59' W
Development of Neutron Science Facilities

SNS is the Forefront Facility for Future High Beam Power Accelerators

Highest Beam Power worldwide under construction

Stepping stone to next generation Spallation Sources

\[ P_{\text{beam}} = E_{[\text{eV}]} \cdot I_{[\text{A}]} \cdot T_{\text{pulse}}_{[\text{sec}]} \cdot f_{\text{rep}}_{[\text{Hz}]} \]

SNS : Goal is to achieve 1.4 \rightarrow 2 + + MW average power

• The SNS will begin operation in 2006
• At 1.4 MW it will be \sim 8x ISIS, the world’s leading pulsed spallation source
• The peak thermal neutron flux will be \sim 50-100x ILL

SNS Accelerator Systems Division
Instrument Layout

- Backscattering Spectrometer
- Magnetism & Liquids Reflectometers
- High Resolution Chopper Spectrometer
- Proposed Spin Echo Spectrometer and Fundamental Physics Instruments
- Powder Diffractometer
- Cold Neutron Chopper Spectrometer
- SANS
- Areas for User and Instrument Support

To be Built by SNS Project
To be Built by IDTs
Proposed by IDTs
The Transformation of Chestnut Ridge into a construction site: More than 600 kH without major Lost workday!!
Progress on the Construction Site

Front End Building to Linac
Accelerator Infrastructure

- Klystron Building
- Power and Cooling Utilities
- Linac
- RF Feeds
Linac Tunnel

March 13, '02
Light at the end of the tunnel and through the side penetrations

March 13, ’02
First inserts in installation before the Klystron Building is finished
## High Level Baseline Parameters for the SNS

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<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
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<tr>
<td>Proton beam energy on target</td>
<td>1.0 GeV</td>
<td>SC linac output energy</td>
</tr>
<tr>
<td>Proton beam current on target</td>
<td>1.4 mA</td>
<td>HEBT length</td>
</tr>
<tr>
<td>Power on target</td>
<td>1.4 MW</td>
<td>Accumulator ring circ.</td>
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<tr>
<td>Pulse repetition rate</td>
<td>60 Hz</td>
<td>Ring fill time</td>
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<tr>
<td>Beam macropulse duty factor</td>
<td>6.0 %</td>
<td>Ring beam extraction gap</td>
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<tr>
<td>Ave. current in macro-pulse</td>
<td>26 mA</td>
<td>RF systems</td>
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<tr>
<td>H⁺ peak current front end</td>
<td>38 mA</td>
<td>RTBT length</td>
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<tr>
<td>Chopper beam-on duty factor</td>
<td>68 %</td>
<td>Protons per pulse on target</td>
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<tr>
<td>RFQ output energy</td>
<td>2.5 MeV</td>
<td>Proton pulse width on target</td>
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<tr>
<td>FE + Linac length</td>
<td>335 m</td>
<td>Target material</td>
</tr>
<tr>
<td>DTL output energy</td>
<td>87 MeV</td>
<td></td>
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<tr>
<td>CCL output energy</td>
<td>185 MeV</td>
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**AP Issue:** Minimize losses along the accelerator chain !!!!

→ 1 Watt per meter (or 1 nA) apart from collimators
Primary Concern: **Uncontrolled Beam Loss**

- Hands-on maintenance: no more than 100 mrem/hour residual activation (4 h cool down, 30 cm from surface)
- 1 Watt/m uncontrolled beam loss for linac & ring
- Less than $10^{-6}$ fractional beam loss per tunnel meter at 1 GeV; $10^{-4}$ loss for ring

Uncontrolled loss during normal operation
SNS Project Commissioning Schedule

- Installation, Testing and Commissioning will happen at the same time

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**Safety Documentation**
- Submit PSAR
  - PSAR Approved
- PSAR Fire
- PSAR Mercury
- PSAR Annual Addendum
- PSAD Approved
- PFSAD Plan of Action

**Accelerator Commissioning**
- Submit PSAR Update
- FSAD FE-Linac CASE
- FSAD Ring-Target CASE Ring-XDump
- Commissioning Program Plan

**Low-Power Operations**

**Accelerator Facility**
- Submit FSAR
- FSAR Approved
- TSRs Approved
- Low-Power Operations

**High-Power Operations**
- FSAR Updated
- TSRs Full Power
- ASE Full-Power Operations

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3 kW

**FY01**
- Front End-DTL ARR
- FE
- DTL
- CCL-SCL ARR
- CCL
- SCL
- HEBT-Ring XDump ARR
- RTBT-Target and Instruments ARR
- Operational ARR

**FY02**

**FY03**

**FY04**

**FY05**

**FY06**

**FY07**
- Low-Power Operations
- Target ORR

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SNS Accelerator Systems Division

Oak Ridge
Layout of Linac RF with NC and SRF Modules

- **RFQ** (1) 2.5 MeV
- **DTL** (6)
- **CCL** (4)

- **2.5 MeV**
- **86.8 MeV**

- **186 MeV** SRF, $\beta=0.61$ (33) from **CCL**
- **379 MeV** SRF, $\beta=0.81$ (48 cavities, all powered)
- **1000 MeV** HEBT (2)

**SNS Accelerator Systems Division**

- **402.5 MHz, 2.5 MW klystron** 3 Transmitter 3 Modulators
- **805 MHz, 5 MW klystron** 4 Transmitter 4 Modulators
- **805 MHz, 0.55 MW klystron** 16 Transmitter 8 Modulators
LBNL: The SNS Front End Systems

Ion Source
Multicusp, rf driven, cesium-enhanced
- Create beam of about 50 mA, 65 keV
- Dump extracted electrons at 5 keV

SNS Front End (Linac Injector)
Built and commissioned at LBNL Berkeley

Low-Energy Beam Transport (LEBT)
- Fully electrostatic
- 2 Lenses
- Beam into RFQ
- Precise into mini pulses
- Steer beam

Radio-Frequency Quadrupole (RFQ)
- 402.5 MHz
- 4-vane structure with π-mode stabilizers

Beam Transport (MEBT)
Front-End Systems Commissioned @ LBNL

• Ion source performance adequate for SNS early operations
  – 50 mA average pulse current achieved
  – Established lifetime exceeds 100 hrs
  – Expected to be much longer with latest antenna design: thicker coated antenna

• Feasibility of fully electrostatic LEBT proven
  – Good match of 40-mA beam into RFQ

• RFQ performs better than planned
  – More than 90% transmission at 40-mA current

• MEBT commissioning started on 4/4/2002
  – A maximum of 36 mA was achieved:
    \[ \varepsilon_{x,y} \approx 0.3 \pi \text{ mm mrad} \]
MEBT Collimation: Mitigate Halo when it develops!

- MEBT is the biggest contributor to halo formation ⇒ Collimate there!
  - Nonlinear space charge force due to large beam eccentricity (chopper box to anti-chopper box) is responsible for halo formation in MEBT
- Alternative MEBT optics and collimation at the chopper target box preempt halo formation, removing 97% of halo at CCL
- Beam loss potentially jeopardizes quadrupole performance if collimated in the DTL
Beam Loss Occurs Primarily at Structure Interfaces for Mismatched Beams

Does not yet include MEBT scraping!

10 Linacs, all errors + mismatch

- Pmin
- Pave
- Pmax
 LANL: Design, Accelerator Physics and Linac Components

- DTL is in full production
- First operation this summer

Tank 1+2 under Way At GSI: 04-16-02

Tuning DTL Tank #3

Here it goes …
CCL Construction is Underway

- Contract awarded
- Hot model operated at 130% of peak field and 190% average power

87 MeV Tuning of hot model
LANL: The RF Systems

1st + 2nd 402 MHz Klystron & Transmitter Delivered & Tested

~ 100 Klystron stations @ SNS

IGBT based HVCM with Nanocrystalline transformer cores

LLRF system

Klystron Oil tanks in production
JLab: The Superconducting Linac

- Emittance Growth and Halo Scraping
- SC cavities have large apertures and high field
  - Saves real estate, operational money, reduces beam loss (since most of it comes from gas stripping or aperture restrictions)

![Image of SC cavity]

![Graph showing emittance growth vs W (MeV)]

\[ \varepsilon_{\text{rms}}(\pi \text{ cm-mrad}) \]

\[ \varepsilon_x, \varepsilon_y, \varepsilon_z \]

\( \sim \) No \( \varepsilon \) growth
Varying $\beta$ In Cavity Fixed Geometry

- Distribution assumed as a result of cavity production for $\beta=0.61$ and $\beta=0.81$ cavities
- High $\beta$ cavities will be electropolished

- Surface Field: $E_{\text{max}}$
- On axis field: $E_0$
- Accelerating field: $E_0T$
  - Variation of $E_0T$ because of varying $\beta$ of particles

![Graph showing expected distribution and E vs. $\beta$]
Prototype Cavity Performance

High $\beta$ performance

$E_{\text{surf}} = 35$ MV/m

$Q_0$ vs. $E_{\text{acc}}$

- $T=1.99K$ 30’ RF & He Processing

Test #2

Old Design goal  New Design goal  VTA Performance goal

Performance of 6-cell, $\beta=0.81$ cavity, stiffening ring at 80 mm.
High Power Requirements:
25%-50% Power Reserve in high and medium $\beta$

Example: High $\beta$ cavities

Including 100 Hz Microphonics

522 kW max at cavity

Lorentz Force Detuning Limit

Without Piezo Tuner

With Piezo Tuner

1220 Hz

1120 Hz

470 Hz
Development of the SC RF Cryomodules

• Prototype cryomodule (3 x $\beta=0.61$) in test cave
• Piezo tuners: Development underway and in the baseline
• Tuner test ongoing
• Response @ 4 K
• Need 15 $\mu$m

Response: 60 Hz, 1800 N

![Graph showing response and displacement](image)
Production Cryomodule subassemblies

- Complete refrigeration system components and start refrigeration installation (ORNL)
- Complete prototype cryomodule testing
- Cryomodule production
  - Full cavity production
  - Start production cryomodule assembly
- Install electropolish cabinet

Schedule is tight!

15 MV/m achieved in Prototype
BNL: Accumulator Ring and Transfer Lines

Totals:
235 Low Power Bipolar Supplies (< 5 kW)
24 Medium Power Bipolar Supplies (5-50 kW)
101 Medium Power Supplies (5-50 kW)
42 High Power Supplies (>50 kW)
22 Kicker Power Supplies

Nr of injected turns 1060
Ring revolution frequency MHz 1.058
Ring filling fraction % 68
Ring transverse emittance 99% \( \pi \text{mm mrad} \) 240
Ring transverse acceptance \( \pi \text{mm mrad} \) 480
Space charge Tune shift \( \Delta Q_{x,y} \) 0.15
Peak Current 52 A
HEBT / RTBT Length m 170 / 150
Ring Circumference m 248
RTBT transverse acceptance \( \pi \text{mm mrad} \) 480
Beam size on target (HxV) mm x mm 200x70

Several commissioning beam dumps
1% of the Reference Beam Misses the Injection Foil

- Some fraction of uncollimated beam will miss the foil
- 200 kW "injection beam dump" ($H^0,H^+$)

- Transverse Jitter at the Foil is a Function of Quad Vibrations & Increases the Effective Emittance
- This drives tolerance for mechanical design
Combined tune spread: various intensities

Tune Diagram during Accumulation

N=0.5*10^{14} – 263 turns
N=1.0*10^{14} – 526 turns
N=2.0*10^{14} – 1052 turns
Electron Cloud Coating, Clearing Electrodes, Studies

- Electron-cloud: a potential threat to full-intensity performance
- Floating-ground BPMs serve dual purpose as clearing electrodes
  - 42 BPM, each holding ~ +/- 1 kV
  - No change of design
- Clearing electrodes near injection foil assembly
- TiN coating fully in progress

Electrons behind bunch
Ring Progress – Vacuum, Coating, Handling

(Half-cell chamber welding)

(Titanium Nitride Coating)

(Half-cell lifting fixture)
Ring Progress – Magnet, Assembly, Measurements

- Half-cell trial assembly
- Ring dipole measurement
- Dipole assembly area
- Ring dipoles
Ring Progress –
RF, Injection, Extraction, Collimation

- RF system & dynamic tuning test
- Injection foil changer
- RTBT collimator
- Extraction kicker section
- Extraction kicker PFN oil fill
Controls Team: Scattered Effort over 5 Labs

- MPS, PPS, Timing… Everything under EPICS
- Support has been provided for Front End runs at Berkeley
- Global components are arriving. Timing and MPS components distributed among partner labs for testing and integration
- Linac Controls ready for DTL Installation
- Have been operating FES @ Berkeley from ORNL + data analysis → GAN
The Installation and Production of Components

- Design, construction, transport and installation
  - Transfer line installation
  - Chase insert installation on site
  - Buss bar production
Diagnostics: Scattered Effort over 5 Labs

LASER Profile Monitor:
The future device for high power beams
Survey and Alignment Group (6/7)

- Establish independent network on the site
- Verification of construction
- Establish Laser Tracker as prime tool to speed up installation and alignment
- Enable long-term survey
The SNS target: A 2 MW design

Cavitation is most recent issue!

Several routes out ...: Materials, Geometry, Mitigation

Pits on inner surface using cylindrical geometry
Summary

• With delivery of the Front End Systems to ORNL installation on the site has begun.
• The first of the 5 partnerlabs is transitioning out of the collaboration after delivery (LBNL).
• The Project is on track for commissioning of the target in December ’05.
• Major issues (at least the ones we know about) are addressed and solutions are identified

• My Assessment:

  It is a very fruitful, intellectually and technically challenging and certainly very productive collaboration. Thanks to the contributors !!!!