The Fundamental Neutron Physics Beamline at the Spallation Neutron Source

Update

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The Spallation Neutron Source at ORNL
www.sns.gov
Drift Tube Linac

- System includes 210 drift tubes, transverse focusing via PM quads, 24 dipole correctors, and associated beam diagnostics
Coupled-Cavity Linac

- System consists of 48 accelerating segments, 48 quadrupoles, 32 steering magnets and diagnostics
Superconducting Linac

- 11 Medium - $\beta$ cryomodules
- 12 High - $\beta$ cryomodules
- Cavities exceed gradient specifications
Target, Reflectors, and Moderators

- Cryogenic $H_2$ moderators
- Be reflector
- Mercury target
- Steel reflector
- Proton Beam
- Ambient $H_2O$ moderator
Target-Moderator System

Protons
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton beam power on target</td>
<td>1.4 MW</td>
</tr>
<tr>
<td>Proton beam kinetic energy on target</td>
<td>1.0 GeV</td>
</tr>
<tr>
<td>Average beam current on target</td>
<td>1.4 mA</td>
</tr>
<tr>
<td>Pulse repetition rate</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Protons per pulse on target</td>
<td>$1.5 \times 10^{14}$ protons</td>
</tr>
<tr>
<td>Charge per pulse on target</td>
<td>24 μC</td>
</tr>
<tr>
<td>Energy per pulse on target</td>
<td>24 kJ</td>
</tr>
<tr>
<td>Proton pulse length on target</td>
<td>695 ns</td>
</tr>
<tr>
<td>Ion type (Front end, Linac, HEBT)</td>
<td>H minus</td>
</tr>
<tr>
<td>Average linac macropulse H- current</td>
<td>26 mA</td>
</tr>
<tr>
<td>Linac beam macropulse duty factor</td>
<td>6 %</td>
</tr>
<tr>
<td>Front end length</td>
<td>7.5 m</td>
</tr>
<tr>
<td>Linac length</td>
<td>331 m</td>
</tr>
<tr>
<td>HEBT length</td>
<td>170 m</td>
</tr>
<tr>
<td>Ring circumference</td>
<td>248 m</td>
</tr>
<tr>
<td>RTBT length</td>
<td>150 m</td>
</tr>
<tr>
<td>Ion type (Ring, RTBT, Target)</td>
<td>proton</td>
</tr>
<tr>
<td>Ring filling time</td>
<td>1.0 ms</td>
</tr>
<tr>
<td>Ring revolution frequency</td>
<td>1.058 MHz</td>
</tr>
<tr>
<td>Number of injected turns</td>
<td>1060</td>
</tr>
<tr>
<td>Ring filling fraction</td>
<td>68 %</td>
</tr>
<tr>
<td>Ring extraction beam gap</td>
<td>250 ns</td>
</tr>
<tr>
<td>Maximum uncontrolled beam loss</td>
<td>1 W/m</td>
</tr>
<tr>
<td>Target material</td>
<td>Hg</td>
</tr>
<tr>
<td>Number of ambient / cold moderators</td>
<td>1/3</td>
</tr>
<tr>
<td>Number of neutron beam shutters</td>
<td>18</td>
</tr>
<tr>
<td>Initial number of instruments</td>
<td>5</td>
</tr>
</tbody>
</table>
Originally Projected SNS Operational Ramp-Up

Source: SNS Project

First SNS beam on target – April 2006
Originally Projected SNS Operational Ramp-Up

Source: SNS Project

SNS ran at ≥500kW during 2nd half of FY2008

SNS is the Highest Power Pulsed Neutron Source in the World.
One Beamline has been allocated for Nuclear Physics

11A - Powder Diffractometer
12 - Single Crystal Diffractometer
13 - Fundamental Neutron Physics
14B - Hybrid Spectrometer
15 – Spin Echo
17 - High Resolution Chopper Spectrometer
18 - Wide Angle Chopper Spectrometer
1B - Disordered Mat'l's
2 - Backscattering Spectrometer
3 - High Pressure Diffractometer
4A - Magnetism Reflectometer
4B - Liquids Reflectometer
5 - Cold Neutron Chopper Spectrometer
6 - SANS
7 - Engineering Diffractometer
**Brief FNPB Project History**

1989-2002 Three successive NSAC Long Range Plans identify research with Cold and Ultracold Neutrons as important opportunities.

Nov 1999 DOE begins construction of SNS
April 2002 Proposal for a nuclear physics beamline submitted to SNS
April 2002 Proposal for funding submitted to DOE NP.
Oct 2002 SNS Science Advisory Subcommittee (Peoples) Review
March 2003 Formal Allocation of Beamline by SNS for FNPB.
April 2003 NSAC Sub-Committee (Tribble)
May 2003 NSAC Sub-Committee recommends construction of Fundamental Neutron Physics beamline at the SNS.
Aug 2003 DOE Issues Critical Decision 0 (Mission Need)
Nov 2003 DOE NP project review
Dec 2003 DOE Issues Critical Decision 1 (Cost Range)
May 2004 Preliminary Design Review
Aug 2004 DOE Issues Critical Decision 3a (Long lead Procurement).
Feb 2004-8 Annual DOE Project Review
April 2006 Completion of SNS Construction Project.
Dec 2007 NSAC Long Range Plan reiterates interest in Fundamental Symmetries…

Sept 2008 Completion of “Cold Beamline” (projected)
June 2010 Completion of “UCN Beamline” (baseline)

Red indicates substantive review
The DOE-NP Investment in the FNPB is “Heavily Leveraged”

The FNPB M.I.E. is a $9.2M DOE construction project.

DOE Basic Energy Sciences invested $1.4G for the construction of the SNS.

DOE Basic Energy Sciences pays for the operation of the accelerator and the neutron production target ~$120M/y

Averaged over a period of 10-15 years and over 15-20 beamlines, this represents an investment of >$100M (≥$10M/y) by BES for nuclear physics at the SNS.
FNPB Project includes only the Neutron Beam Facility

The Fundamental Neutron Physics Beam M.I.E. includes only the construction of the neutron beams and the infrastructure that allows the installation of experiments.

Funding for experiments is done independently of the Beamline Construction Project.

Individual experiments are selected by a proposal driven, peer review process operated by ORNL Physics Division under the auspices of the SNS.

The FNPB has its own Proposal Review and Advisory Committee* to advise Physics Division and SNS Management on programmatic issues.

*B. Filippone, J. Nico, M. Ramsey-Musolf, A. Steyerl, R. Tribble (chair), F. Wietfeldt
SNS Fundamental Neutron Physics Program

1. Accurate measurement of parameters that describe the beta decay of the free neutron (i.e. Lifetime, Decay Correlations)
   - Universality of the Weak Interaction (Unitarity of CKM Matrix)
   - Extensions to the Standard Model (RH currents, new couplings, ...)
   - Big Bang Nucleosynthesis and Cosmic Elemental Abundances
   - Stellar Astrophysics
   - ...

2. Precision measurement of parity violation in the interaction low energy neutrons with “simple” nuclear systems (i.e. n-p, n-d, n-α)
   - Quark-Quark Weak Interaction
   - QCD in the strongly interacting limit

3. Search for a non-zero permanent neutron electric dipole moment
   - Origin of CP and T violation
   - Cosmic Baryon Asymmetry
   - ....
Two Classes of Fundamental Experiments

1. Cold Neutron, Broad Band (beta decay, hadronic weak studies)
   Optimal Beam:
   - Large X-section (10x12 cm²),
   - Large Divergence (> m=3 supermirror)
   - Broad Wavelength Band (short flight path ~15m)

2. Monochromatic Beam at 8.9Å for Ultra Cold Neutrons (EDM)
   Optimal Beam:
   - Large X-section (~10x12 cm²),
   - Large Divergence (> m=3 supermirror)
   - Long Flight Path (~40m)
   - Low Background Experimental Area
The FNPB has two independent neutron beamlines

"Cold" Beam - Intense "white" beam

"Ultra-Cold" Beam - Monochromatic 8.9Å
FNPB Cold Beam experimental Area
FNPB Ultra Cold Beam External Building
Ten proposals have been received and reviewed

FNPB Beamline Characterization and Commissioning
(SNS, ORNL, LANL, IUCF, NCSU,...)

Determination of $\tau_n$ Lifetime Using Magnetically Trapped UCN
(Harvard, NIST, NC State)

Measurement of “a” & “b” Correlations in Neutron Beta Decay
(U of Va., ORNL, LANL, Indiana, UNH, Tennessee...)

Measurement of “a,b,B,A” Correlations in Neutron Beta Decay
(LANL, Indiana, Michigan, NIST, ORNL, UNH, Tennessee...)

Measurement of “A+B” Correlation in Neutron Beta Decay
(Michigan, Indiana, NIST, ORNL, UNH,...)

Measurement of Parity Violation in n-p Capture
(LANL, Indiana, Manitoba, ORNL, Kentucky, Tennessee...)

Measurement of Parity Violation in n-d Capture
(LANL, Indiana, Manitoba, NIST, Berkeley, ORNL,...)

Precise Measurement of Neutron Spin Rotation in $H_2$ and He
(Indiana, Washington, NIST, NC State, Indiana, ORNL,...)

Proton Asymmetry in n+3He capture
(Indiana, Washington, NIST, NC State, Indiana, ORNL,...)

New Search for an Electric Dipole Moment
(LANL, Caltech, Berkeley, ORNL, NC State, Illinois, MIT, BU...
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Measurement of “a,b,n” Correlations in Neutron Beta Decay
(Michigan, Indiana, ORNL, UNH)

Measurement of Parity Violation in n-d Capture
(LANL, Indiana, Manitoba, ORNL, Kentucky, Tennessee...)

Precise Measurement of Neutron Spin Rotation in $H_2$ and He
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New Search for an Electric Dipole Moment
(LANL, Caltech, Berkeley, ORNL, NC State, Illinois, MIT, BU...)

>100 Distinct Participants
>30 Different Institutions
Ten proposals have been received and reviewed

FNPB Beamline Characterization and Commissioning  
(SNS, ORNL, LANL, IUCF, NCSU,...)  
Approved

Determination of $\tau_n$ Lifetime Using Magnetically Trapped UCN  
(Harvard, NIST, NC State)  
Approved

Measurement of “a” & “b” Correlations in Neutron Beta Decay  
(U of Va., ORNL, LANL, Indiana, UNH, Tennessee...)  
Approved

Measurement of “a, b, B, A” Correlations in Neutron Beta Decay  
(LANL, Indiana, Michigan, NIST, ORNL, UNH, Tennessee...)  
Deferred

Measurement of “A+B” Correlation in Neutron Beta Decay  
(Michigan, Indiana, NIST, ORNL, UNH,...)  
Deferred

Measurement of Parity Violation in n-p Capture  
(LANL, Indiana, Manitoba, ORNL, Kentucky, Tennessee...)  
Beam Allocated

Measurement of Parity Violation in n-d Capture  
(LANL, Indiana, Manitoba, NIST, Berkeley, ORNL,...)  
Deferred

Precise Measurement of Neutron Spin Rotation in $H_2$ and He  
(Indiana, Washington, NIST, NC State, Indiana, ORNL,...)  
Deferred

Proton Asymmetry in $n+^3He$ capture  
(Indiana, Washington, NIST, NC State, Indiana, ORNL,...)  
Approved

New Search for an Electric Dipole Moment  
(LANL, Caltech, Berkeley, ORNL, NC State, Illinois, MIT, BU...)  
Approved UCN Beam
The NPDGamma Experiment
The $n+p \rightarrow d+\gamma$ completed data collection at LANSCE in 2006.

Polarizer, Field Coils, Spin Flipper, & Detector

Liquid $H_2$ Target

$H_2$ Safety System

$H_2$ Vent Stack
The NPDGamma Experiment

- Supermirror polarizer
- FNPB guide
- Magnetic Field Coils
- Magnetic Shielding
- H₂ Vent Line
- H₂ Manifold Enclosure
- Liquid H₂ Target
- CsI Detector Array
- Beam Stop
The NPDGamma Experiment – Vent System
The NPDGamma Experiment – Shield Roof and Mezzanine
The NPDGamma Experiment – Vent Line Routing
FNPB Construction
SNS Target “Monolith”
FNPB Neutron Guide (Shutter)
Insertion of Upstream Neutron Guide
SNS Experimental Hall
FNPB Chopper Housing #1
Shielding Seismic Tie-Downs
FNPB 1st Level Shielding
FNPB 2nd Level Shielding
FNPB Cold and Ultra Cold Beam Line Installed
FNPB Cold Neutron Beamline

Photo – Feb 2007
FNPB 3rd Level Shielding Installation
Shield Walls
Excavation of Magnet Pit
Magnet Pit Non-Magnetic Rebar
FNPB Magnet Pit
Anticipated Schedule

**Commissioning of FNPB Cold Guide**  
Sept  
2008

**1st beam to npdgamma**  
Spring  
2009

**Cold Beam Operation with LH2**  
Summer  
2009

**UCN (EDM) Building available**  
Late Summer  
2009
End of Presentation