Background

- SNS First Target Station (FTS) is a 60 Hz, 1.4 MW short-pulsed neutron source (baseline design parameters)

- An SNS Second Target Station (STS) had been planned from the beginning
  - Lower repetition rate to complement FTS

- Two design studies
  - 2002 – Jack Carpenter – a short-pulse Long Wavelength Target Station
    - 2 MW SNS, 1/6 pulses diverted to STS (10 Hz)
  - 2007 – Kent Crawford – long-pulse STS
    - 2.33 MW SNS, 1/3 pulses diverted to STS (20 Hz)
    - Speculated that perhaps 50% per pulse gain could come from eliminating chopping (required for injection into the ring for short-pulse operation)

- Mission Need Statement for STS (CD0) approved in 2009
  - Double the accelerator baseline power
  - Long-wavelength, cold neutron emphasis (long length scales, slow dynamics)

- SNS is no longer a “greenfield” site
  - Site geometry restricts maximum instrument length to ≈120 m
  - SNS has an accumulator ring
SNS Accelerator Complex

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

- 2.5 MeV
- 1000 MeV
- 1300 MeV

Accumulator Ring: Compress 1 msec long pulse to 700 nsec

- 1 ms macropulse

Chopper system makes gaps

mini-pulse

STS

Spallation Target

1 GeV LINAC (STS- 1.3 GeV)
Site Geometry
STS and Site Geometry
Neutron scattering facilities at Oak Ridge National Laboratory

High Flux Isotope Reactor:
Intense steady-state neutron flux and a high-brightness cold neutron source

Spallation Neutron Source:
World’s most powerful accelerator-based neutron source

U.S. Department of Energy investments have provided forefront capabilities

Power and Energy on Target
History: from 01-Nov-2006 to 09-Oct-2013

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<th>Year</th>
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<th>Accumulated Energy (MWh)</th>
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Approach to STS

• Explore concepts for a short-pulse STS
  – Proton Beam Profile
  – Target
  – Moderator
  – Highest Brightness

• Compare instrument performance between SP-STS and LP-STS
Three credible target concepts for STS for 300 – 500 kW 10 Hz SP beam

• Stationary tungsten plate target
  – Water-cooled
  – Good radiation lifetime

• Rotating tungsten target
  – Water-cooled, minimal in spallation zone gives brightness advantage
  – 20+ year radiation lifetime
  – Waste shipping and handling tbd.

• Mercury target
  – Established technology
  – Good radiation lifetime
  – Pulse issues (cavitation)
Edge-cooled, solid tungsten rod (Ta clad) concept was studied for SP STS

- Maximum tolerable power for a compact, edge-cooled cylindrical target, based on ISIS-TS2 design (32 kW)
  - Couples well to compact moderators
    - optimized for peak brightness
  - Steady state power limit is no more than 150 kW based on temperature and thermal stress
    - Would require water to be pressurized 3+ bar
  - Pulse / thermal shock effects may be more limiting
    - This was not investigated
The nature of the problem: Find a configuration of target, moderator and reflector to give prime neutron performance
Physics Driver

• Make the neutron production zone as small as reasonably possible
  – High target material density
  – Small proton beam footprint

• Position moderator as close as possible at the peak neutron production zone

• Have moderators with high slowing-down power
  – Hydrogen H with mass A=1 is performing best because it is very close in mass to the neutron’s (billiard ball effect)
  – Material with high hydrogen density: CH₄, H₂O, H₂, NH₃ ...
  – Material very radiation resistant due to proximity to target
  – Material that can transfer deposited nuclear heating
  – Low neutron absorption

• Have a good neutron reflector around moderator
Our Choices

- Proton beam 1.3 GeV with 30 cm$^2$ cross sectional area
- Stationary tungsten target ~40 cm$^2$ cross sectional area (density 19.3 g/cc)
- Para-hydrogen moderator $T=20$ K
- Ambient water pre-moderator (for coupled moderators only?)
- Beryllium metal reflector
What is prime neutron performance?

- Ideally: number of useful neutrons on sample at a particular instrument
- Reality: we only have a very rough idea about instruments to be built at STS
- Fall back metric:
  - neutron emission from moderator viewed area
  - peak intensity
  - long-wavelength
  - Brightness (n/cm²/s/eV/sr)
Coupled Moderator Performance

- Gains in time-integrated and peak brightness of a factor of 5 are possible for SP-STS compared to FTS on a per unit power basis for moderators with 10x10cm viewed area.
- Another factor of 2.4 can be gained in brightness by reducing the viewed area to 3x3cm.
Decoupled moderator performance

- A factor of 2.5 can be gained in peak brightness on a per unit power basis over FTS by improved coupling of target and moderator.
- By downsizing the viewed area from 10x10cm to 3x3 cm, another factor of 2 can be gained.
Instruments Performance on Short- or Long-Pulse STS

- Four instrument classes were considered
  - Broadband, low wavelength resolution instruments (SANS)
  - High wavelength resolution, broadband instruments (high-resolution powder diffractometer)
  - Narrowband, peak-flux driven instruments (cold neutron chopper spectrometer)
  - Small sample instruments (single crystal, high pressure diffractometers)

- The short-pulse option for STS offers significantly better performance for most instruments

ORNL Source Strengths

• HFIR
  – Highest time-averaged thermal flux – about 40 x that of SNS-first target station (SNS-FTS)
  – Highest time-averaged cold brightness – about 10 x that of SNS-FTS or SNS-second target station (SNS-STS)

• SNS-FTS (optimized for de-coupled moderators)
  – High peak-brightness @60 Hz
  – De-coupled moderators – sharp time pulses across broad wavelength band

• SNS-STS (optimized for cold neutrons and coupled moderators)
  – Highest cold-neutron peak brightness
  – 10 Hz – very broad wavelength band
Qualitative Analysis

- Instrument Case 1 – Performance depends on time-averaged source brightness integrated over wavelength band of interest
  - High integrated flux of cold neutrons (SANS) or limited wavelength band (TAS)

- Instrument Case 2 – Performance depends on peak source brightness
  - Good-excellent wavelength resolution and can effectively use a broad incident wavelength band (Powder and single-crystal diffraction)
  - Uses a broad scattered-wavelength band (chopper spectrometers)

- Instrument Case 3 – Performance depends on details of the science being addressed

- Note: Instruments of all types have been built on both continuous and pulsed sources

- Our Opportunity – Design and Position instruments at the optimum source to deliver the highest impact science

- Neutron Advisory Board – “Together, these three facilities can and will support the most potent and complete range of neutron beam facilities available in the world, now and in the foreseeable future.”
Semi-Quantitative Analysis – Elastic Instrument Optimization at ORNL Sources

• Performance depends on range of accessed momentum transfers, $Q$-resolution, and effective count rate.
  – $Q$-resolution is typically proportional to wavelength resolution as instrument geometry is matched to wavelength term.
  – Wavelength resolution -- $\delta \lambda / \lambda$ -- x-axis scaling of elastic instrument performance
  – Number of useful/needed resolution elements, $\delta \lambda / \lambda$, will be the y-axis of our map
    • Allows us to identify where time-of-flight gains are practical and useful
    • Example 1 – SANS
      – Typically required wavelength resolution -- $0.03 \leq \delta \lambda / \lambda \leq 0.20$
      – Data set can be obtained with 1 to a few wavelength resolution elements
    • Example 2 – Powder diffraction
      – Medium to high resolution instruments - $0.003 \geq \delta \lambda / \lambda \geq 0.0003$
      – Data set can usefully employ 100’s to 10000's of resolution elements

\[ \lambda_{\text{min}} \times \delta \lambda / \lambda \]

\[ \lambda_{\text{max}} \]

\[ \lambda_{\text{min}} \times \delta \lambda / \lambda \]

\[ \lambda_{\text{max}} \]
Instrument Performance Map

- Powder Diffraction
- Single Crystal Diffraction
- Strain Engineering Diffraction
- Reflectometry
- SANS/WANS
- Laue Pseudo-Laue
- SANS
- Radiography

Number of Useful Resolution Elements

$\delta \lambda / \lambda$
Time-of-flight gains and source comparison

• Time-of-flight gain is the number of resolution elements that can be collected in a single pulse of the source.
  - The break even point is when the time-of-flight gain times the time averaged flux of the pulsed source = time averaged flux of a continuous source

• Maximum possible time-of-flight gain is proportional to $\left(\frac{\delta \lambda}{\lambda}\right)^{-1}$
  - Requires that an instrument can be built at a length such that the required wavelength band can be obtained in a single pulse of the source (if multiple frames are required than tof-gain is reduced by that factor)
  - That this length corresponds to the required wavelength resolution, $\frac{\delta \lambda}{\lambda}$
Elastic Instrument/Source Performance Map
Inelastic Instruments

![Diagram showing the relationship between different inelastic resolution elements and energy resolution. The diagram includes labels for STS, FTS, FTS/STS, TOF Backscattering, Fermi Chopper Spectrometers, Reactor Backscattering, Cold TAS, Cold Neutron Chopper Spectrometers, Thermal TAS, and HFIR. The y-axis represents the number of useful resolution elements, and the x-axis represents the energy resolution (δE) in meV.]