Abstract
The Front-End Systems (FES) of the Spallation Neutron Source (SNS) project have been described in detail elsewhere [1]. They comprise an rf-driven H ion source, electrostatic LEBT, four-vane RFQ, and an elaborate MEBT. These systems are planned to be delivered to the SNS facility in Oak Ridge in June 2002. This paper discusses the latest design features, the status of development work, component fabrication and procurements, and experimental results with the first commissioned beamline elements.

1 INTRODUCTION
The Spallation Neutron Source (SNS) project [2] is presently in the third year of its construction phase. LBNL is building the front end (linac injector) with its main sub-systems consisting of ion source, low-energy beam-transport section (LEBT), RFQ accelerator, and medium-energy beam-transport section (MEBT). Some parts of the front end, i.e. the rf power system for the RFQ and the MEBT chopper structures with their power supplies, will be supplied by LANL; some diagnostic elements by BNL. The SNS Front-End project has been described in detail elsewhere with an ample collection of references [1], and the present paper emphasizes design changes and progress with construction. Some basic features, however, are presented here as well, to facilitate easier understanding and address recent changes in main SNS parameter values as they relate to the front end. A 3-dimensional CAD layout of the front-end beamline is shown in Figure 1, omitting all ancillary systems.

The SNS accelerator systems aim at delivering intense proton-beam pulses of less than 1-μs duration to the spallation target at 60-Hz repetition frequency and with an average beam power of 1.44 MW. The 1-ms long H macro pulses that are accelerated in the linac to 1-GeV energy have to be chopped into ‘mini pulses’ of 645-ns duration, with 300-ns pauses.

Chopping is performed in the front end by two separate chopper systems located in LEBT and MEBT, respectively. The LEBT chopper removes most of the beam power during the mini-pulse gaps, and the MEBT chopper reduces the rise and fall time of the transported beam.

The main requirements for the SNS Front-End Systems are listed in Table 1. The front end is being assembled and commissioned at the Integrated Testing Facility at LBNL before being shipped to ORNL in the summer of 2002.

![Figure 1. Layout of the SNS front-end beamline.](image-url)
2 ION SOURCE AND LEBT

The H\textsuperscript{-} ion source and LEBT are shown in Fig. 2. The source plasma is sustained by pulsed 2-MHz-rf power and confined by a multi-cusp magnet configuration. A magnetic dipole filter separates the main plasma from a smaller H\textsuperscript{-} production region (darker area in Fig. 2) where low-energy electrons help generating copious amounts of negative ions. A heated collar, equipped with eight cesium dispensers, surrounds this H\textsuperscript{-} production volume.

The outlet plate of the ion source contains another dipole-magnet configuration that creates a deflecting field across the extraction gap in order to separate extracted electrons from the ion beam and steer them towards a ‘dumping’ electrode biased at 5 kV with respect to the outlet plate. Because this dumping field steers the ion beam as well, the entire plasma generator is tilted at an adjustable angle of about 3° against the LEBT axis to compensate for this effect.

The LEBT structure has to serve five main purposes, i.e., beam formation, 2-parameter matching into the RFQ, steering in angle and transverse offset, pre-chopping, and gas pumping. A fully electrostatic system with two einzel lenses as focusing elements was chosen for the SNS LEBT. The second one of these lenses is split into four quadrants which can be biased with d.c. and pulsed voltages to provide angular steering as well as pre-chopping. The LEBT can also be offset against the RFQ axis.

The last LEBT electrode is part of the RFQ entrance wall, and on its upstream side it carries a diagnostic element made again from four insulated quadrants. During the pauses in between mini pulses, chopping voltages of ±2.5-kV amplitude and 300-ns duration are applied to opposing pairs of lens quadrants in a rotating pattern, directing the chopped beam alternatingly towards each of the four separation zones between the diagnostic-electrode quadrants. In this way, any parts of the beam that are not intercepted by the diagnostic electrode are prevented from hitting the RFQ vane tips whose accurate shapes could otherwise gradually be eroded by sputtering.

The LEBT-electrode shapes were optimized by simulating proton beams, using the 2-d positive-ion code IGUN \cite{3} in a novel way that allows introduction of finite ion temperatures into the calculation without experiencing unrealistic deformations of the plasma meniscus \cite{4}. Details of the beam-formation and electron-dumping processes were modeled \cite{5} using the 2-d code PBGUNS \cite{6} with actual H\textsuperscript{-} ion species input and handing the trajectory data over to the 3-d code SIMION \cite{7}. These simulations were helpful to determine the source tilt-angle and prove that no lateral axis offset was needed to obtain low emittances.

The ion source and LEBT have been commissioned, and average beam pulse-currents of 50 mA have been obtained at 6% duty factor and transported through the LEBT. Our simulations predict transmission values >85% through the RFQ with the actual emittances measured by an Allison scanner and shown in Figure 3. Peak beam-current values up to 68 mA were measured at the beginning of the pulses.

![Figure 2: Schematic of the ion source and LEBT. Note that the actual filter and electron-dumping magnetic fields are oriented orthogonally to the illustration plane. The width of the ion beam is exaggerated in this schematic to emphasize the focusing action of the double-lens system.](image)

![Figure 3: Transverse emittances of a 50-ma beam, taken at the LEBT exit.](image)
sign are given elsewhere [Staples**]; efforts are under-
way to finalize the implementation of this scheme.

3 RFQ
The SNS RFQ is 3.72-m long overall and consists of
four modules built as composite structures with an outer
GlidCop shell and four oxygen-free copper vanes. Peak
surface fields reach 1.85 kilpatrick, and the total rf power
consumption is 800 kW during pulses. Water-cooled π-
mode stabilizers separate unwanted dipole modes from
the main quadrupole mode. Static frequency tuning is
achieved by 20 slug tuners per module, and dynamic tuned
by adjusting the temperature difference between vane
tips and the outer walls of the modules.

Figure 4 shows the assembled first module before the
final brazing operation. This module has now been com-
missioned, reaching the full rf gradient. The resonance
frequency with slug tuners at nominal positions is very
close to the design frequency of 402.5 MHz, and the field
flatness is better than ±1% peak-to-peak. The dynamic
tuning procedure involving regulation of the vane-to-wall
temperature difference was successfully tested with this
module. The other three modules are all in advanced
stages of fabrication; Module #2 has been conditioned to
full rf amplitude as well.

Figure 4: End-on view of the assembled RFQ Module #1
prior to the final brazing operation. The upstream ends
of the four vanes are seen at the center, with π-mode stabi-
lizers penetrating the vanes horizontally and vertically.

The first rf-accelerated SNS beam was achieved on the
first day after connecting RFQ Module #1 to the LEBT
tank. These experiments resulted in validating the struc-
ture modeling efforts and the LEBT-chopper design. As
an example, Figure 5 shows the simulated and measured
beam transmission values as a function of cavity excita-
tion. The mini-pulse rise and fall times generated by the
LEBT chopper amounted to 25 ns, twice as fast as had
been assumed for the design of the MEBT chopper target.

Figure 5: Simulated (red squares) and measured (green
crosses) transmission values of RFQ Module #1, normal-
ized to 100% maximum, for an input beam of 35-mA.

4 MEBT
The 3.67-m long Medium-Energy Beam Transport
(MEBT) structure shown in Figure 1 has three main func-
tions, i.e., matching the beam from the RFQ exit plane
into the MEBT chopper and its target, cleanup chopping,
and guiding the remaining particles into the Drift-Tube
Linac currently being built by LANL. Matching in both transverse and in the longitudinal direction is provided by
14 quadrupole magnets, arranged in three families, and
four rebuncher cavities. An anti-chopper will direct all
particles back on axis that were deflected by the chopper
during the rising and falling pulse flanks and not inter-
cepted by the target.

The MEBT will also contain diagnostic elements such
as beam-position monitors that will also gather phase in-
formation, profile monitors, and two fast current trans-
formers.

All MEBT elements are grouped on three rafts that can
be individually aligned. At present, most major beamline
components, including power supplies, have been fabricat-
ated and received at LBNL; power tests of the first re-
buncher cavity are scheduled for June 2001.

5 REFERENCES
Materials Research,” Paper MOAL04, these conference proceed-
ings, PAC ’01, Chicago, IL (2001)
[5] R. Welton at al., “Simulation of the ion source extraction and low-
energy beam transport systems for the Spallation Neutron Source,”
submitted to ICIS ’01, Oakland (2001).
Garland, TX 75042.
[7] D. Dahl, “SIMION 3D v.7.0,” Idaho National Engineering and
Environmental Laboratory Idaho Falls, ID 83415 (2000).