STATUS REPORT ON THE SPALLATION NEUTRON SOURCE (SNS) PROJECT*

Jose R. Alonso ORNL, Oak Ridge TN
for the SNS Collaboration

1 INTRODUCTION

A collaboration of five Department of Energy National Laboratories is designing the SNS, a 1 MW, upgradable to "significantly higher powers," pulsed spallation source to serve the neutron-scattering community. SNS will deliver 600 ns pulses of 1 GeV protons to a liquid mercury target at a 60 Hz rate. Responsibility for system components is as follows: LBNL will provide the front end, consisting of a high-brightness, 35 mA H- ion source, as well as transport structures and a 2.5-MeV RFQ accelerator; Los Alamos will provide linacs to bring the beam to the full energy of 1 GeV; Brookhaven will provide the accumulator ring to compress the linac beam into the sharp pulse delivered to the target, ≈1200 turns will be injected, storing $1x10^{14}$ protons, which are extracted in a single turn; Oak Ridge will provide the mercury target and all conventional facilities; and Argonne and Oak Ridge are coordinating the design and construction of 10 neutron-scattering instruments to be provided as the initial suite of experiment stations. The Conceptual Design Report (CDR) was reviewed by DOE in June 1997, and was accepted as the baseline design. Approval and funding for a construction start is expected for FY99, and beam for experimental programs is anticipated in 2005.

2 BACKGROUND

The SNS Collaboration was formed in late 1995, in response to a request by DOE that Oak Ridge National Laboratory conduct a two-year study of an optimized and upgradable 1 MW spallation neutron source. With ORNL leading a consortium of five laboratories, these studies have resulted in the design published in the SNS Conceptual Design Report, and now to the imminent start of a seven-year construction project. (The CDR is available at http://www.ornl.gov/~nsns/nsns.html.)

The CDR underwent an extensive DOE review in June 1997, the favorable outcome of which led to funding in FY98 to continue optimization studies for a potential construction start in FY99. Following another favorable review in June 1998, as well a strong support from within DOE (the SNS is DOE/ER's number one priority for new construction starts for FY99, and $157 M was requested in the President's FY99 budget for the first year of construction), and good support in Congress, it appears that the construction start this October is likely.

3 BASELINE DESIGN

Figure 1 shows schematically the layout of the SNS, and Table 1 lists its major parameters. A more complete list of parameters is collected in the formal Parameter List, and is also available on the above web-site under "Design

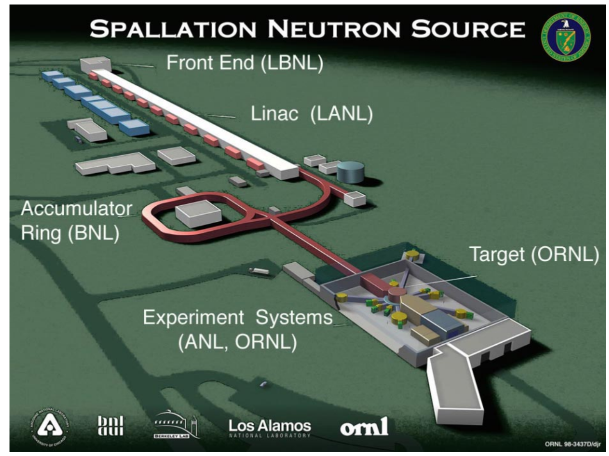

Figure 1: Schematic layout of the SNS.

Parameters." This Parameter List continues to evolve, with more details added as designs mature, and will eventually be the repository for all of the physics and engineering parameters for the completed facility. This list is one of the major mechanisms for controlling parameters and interfaces for five design teams spanning the North American continent.

Table 1: Baseline Design Parameters

Beam Power	1 MW
Beam Energy	1 GeV
Repetition Rate	60 Hz
Ion Source Current (peak)	35 mA
Source Emittance (rms, norm)	0.14π mm-mrad
Chopping Ratio	0.65
Linac Frequency, RFQ/DTL	402.5 MHz
Linac Frequency, CCDTL/CCL	805 MHz
Linac Beam Duty Cycle	5.8%
Linac Beam Pulse Length	0.974 ms
Linac Length (total, all structures)	503.6 m
Injected Turns	1158
Accumulator Ring Circumference	220.7 m
Ring Revolution Frequency	1.188 MHz
Particles Stored in Ring (ppp)	$1x10^{14}$
Extracted Pulse Length	591 ns
Target	Mercury
Beam Spot on Target	7 x 20 cm
Operating Temperature	80 - 110° C
Moderators, Ambient Temp	2 (water)
Moderators, Cryogenic	2 (Supercritical H_2)
Beam Ports	18
Uncontrolled Beam Loss (@1 GeV)	< 1nA/m

A comparison of the parameters in Table 1 with the similar table in our EPAC 96 report (TUP085G, 575) will show very little change, indicating the strength of the earlier Reference Design. In fact, the most significant changes have been the modification of the ring periodicity from three-fold to four-fold with a commensurate change in x/y tune from 3.82/3.78 to 5.82/5.80; and an increase in the HEBT achromatic bend from 60° to 90°, providing greater dispersion for momentum analysis of the linac beam.

3.1 Front End

LBNL's design and R&D activities have made significant progress. A prototype volume H^- source has demonstrated the required 35 mA at 6% duty factor without use of Cs. The technique for addition of the appropriate amount of Cs seeding will be developed, allowing the required current to be achieved with about one-third of the power in the source, contributing to significant lifetime extension. A preliminary design for the electrostatic LEBT design, only 11 cm in length, has been completed, based on a similar design that has operated successfully at LBNL for positive ions. A cold model of the first section of the 2.5 MeV RFQ has been completed and is undergoing measurements; first results verify the excellent field-stabilization characteristics of the KEK pi-mode stabilizing rod concept. Pulsing supplies for prechopping in both the source and the LEBT have been successfully tested.

3.2 Linac

LANL has made good progress in physics and engineering design for the linac structures. Careful attention has been paid to smooth FODO lattice transverse matching between the DTL (2.5 to 20 MeV), CCDTL (20 to 93 MeV) and CCL (93 MeV to 1 GeV) structures, with close matching of lattice periods between the various structures. Periodicity is 8 $\beta\lambda$ for the DTL and 12 $\beta\lambda$ for the CCDTL and CCL. CCDTL segments contain two 3/2 $\beta\lambda$ cells, while the CCL is divided into two parts, the first part, to 165 MeV, contains eight cells per segment; the higher energy part has 10 cells per segment. This arrangement allows ample room in the spaces between segments for the quadrupole, plus appropriate diagnostics, correctors and vacuum interfaces. Focusing in the DTL is accomplished with permanent magnet quadrupoles arranged in a FFDD configuration to more closely match the periodicity of the following structures. Smooth matching is extremely important to mitigate halo growth. In addition, very large apertures are provided to contain any beam-radius growth. The aperture to rms beam radius is over a factor of 10 at the higher energies.

RF power is provided by 56 2.5-MW klystrons, delivering a conservative 2.02 MV/m real-estate accelerating gradient. E_oT in the cavities averages 2.7 MV/m. A novel pulsed HV power supply concept based on IGBT technology is being considered, which has the potential for significant savings in component costs for the RF system by combining the HV supply, capacitor bank, crowbar system and modulator into a single pulsed supply, as well as improved performance and reliability. An R&D program to develop these designs is beginning.

3.3 Ring

BNL has designed a new ring lattice with four-fold symmetry that provides a region in tune-space, far from structure resonances. It also provides an additional straight section, which will be used exclusively for collimation. These collimators will provide the principal aperture restriction for the ring in a place where little hands-on maintenance will be required and should limit beam losses in other areas of the ring with more critical requirements for personnel access. The collimators are carefully designed with graded low-Z and high-Z materials, and materials with good neutron-absorbing properties. On average, protons penetrate deeply inside the 3-meter long structures before reacting, and neutrons are largely contained inside the structure. This minimizes activation of external components. Calculations indicate that only 1 neutron emerges from the collimator for every 100 entering proton.

The injection region has been carefully optimized to prevent beam losses. By placing the stripping foil in the falling fringe-field of the combining dipole, halo in the ring due to Lorentz stripping of excited neutral hydrogens will be avoided. This development, a joint effort between BNL and ORNL, is reported at this conference (Galambos, et al). A tracking code has been developed by the ORNL group to model the injection process with proper accounting for space charge buildup in the ring, to optimize the stacking algorithms for proper beam distributions and minimal emittance and halo growth. This tracking code is also reported at this conference (Holmes et al). The beam distribution in the ring is a dominant factor in the power density deposited on the target, a tightly regulated parameter for the overall design. One notable result from the tracking simulations has been verification that the FODO lattice of the SNS ring produces less halo for high intensity beams than a doublet lattice ring.

The ring RF will be a dual harmonic system, with a peak amplitude of 40 kV net per turn in the first harmonic and 20 kV in the second harmonic. This very high voltage, more what one would expect of a rapid-cycling accelerator than an accumulator ring, is nonetheless necessary to prevent migration of protons into the gap. Cleanliness (to better than 1 part in 10^4) of the 250 ns gap is necessary both for prevention of losses during the rising of the extraction kicker, and to prevent buildup of electrons in the very deep potential well of the beam. This mechanism is considered a potential cause of the observed instability in the Los Alamos PSR ring.

3.4 Target

Development of the mercury target concept by ORNL continues. Materials irradiation experiments are being conducted at different accelerator facilities to test the impact of radiation in addition to mercury on different containment materials, studying primarily wetability, embrittlement and ductility. Hydrogen and helium formation is known in spallation processes to be significantly greater than experienced in reactor environments, and can have an adverse effect on target component lifetimes. Various mercury loops are also being built to study thermal hydraulics, flow of mercury through the target head geometry, as well as leaching of materials, such as nickel, from the containing 316 SS vessel.

An international group, known as the ASTE collaboration (KEK, JAERI, PSI, Juelich, ORNL, BNL), is conducting tests on a mercury target at the AGS in Brookhaven. This experiment is aimed at measuring shock and stress experienced by the intense pulse expected from the SNS, and other planned spallation sources of similar power. The SNS pulse will deliver 17 kJ per pulse, at an instantaneous pulse power of around 30 GW, the shock pulse could be expected to have very deleterious effects on the containing vessel. Though at a significantly lower repetition rate, the instantaneous pulse of the 26 GeV proton beam at the AGS is comparable to that expected at the SNS. Strain gauges mounted on the mercury-containing cylinder have registered the pressure pulses from single AGS pulses, and show good agreement with predictions. Future phases of the ASTE experiments are expected to benchmark slow neutron spectra and yield with water moderators placed in close proximity to the mercury cylinder.

3.5 Instruments

Neutron scattering instrumentation will be the heart of the SNS. As a dedicated user facility for the materials-sciences community, of paramount importance will be the ability to measure the detailed interaction of the neutrons produced with the samples brought by the experimenters. While an extensive body of instruments exists today at the various operating spallation sources, it is well-understood that the fluxes from the SNS will be considerably higher than those for which the present-day instruments have been designed. Furthermore, it is expected that significant advances will be needed in neutron detectors, guides, neutron choppers and other elements of the instrumentation to make optimum use of the SNS beams. As a result, R&D efforts in all these areas are being planned.

ANL has primary responsibility for instrument development, in collaboration with ORNL. Instruments will be built by SNS neutron scientists at ANL and ORNL, with close contacts to the neutron-scattering community through appropriate oversight and advisory committees.

3.6 Controls

EPICS has been selected as the basis for the controls systems for all elements of the SNS. This system now has a proven track record, having been successfully implemented at CEBAF and APS as well as at numerous other smaller installations. Notable in this project is the need to tightly coordinate controls activities across all the laboratory boundaries. To this end a very active Integrated Controls Working Group has been formed, with LANL taking the lead, and with representatives from all the labs. This group has been working through architectures, naming conventions, interface definitions and general implementation strategies. This Working Group is serving as a cross-cutting model for interfacing in many other technical and managerial areas of the project.

4 SUMMARY

The design concepts for the SNS have reached a very high level of maturity in these past two years, to the point where the collaborative team is confident that technical risks in being able to achieve design performance are very low. In addition, the costs and schedules are quite well in hand. The total project cost and the seven-year construction schedule have been validated by two DOE review teams. In this past year the requisite project management tools have all been put in place; from the Project Office functions and staff to the cost-accounting and schedule tracking systems suitable for working across the full five-laboratory consortium. In summary, the team is in place, the baseline design is complete, and the overall project is ready for a construction start.

5 ACKNOWLEDGEMENTS

Leadership of the technical teams at the collaborating laboratories deserve recognition. The LBNL team is led by Roderich Keller, with Rick Gough, John Staples, Ka-Ngo Leung, Alex Rati and Ron Yourd contributing technical and managerial expertise. Leadership of the LANL linac team consists of Bob Hardekopf, Senior Team Leader, with principal groups led by Andy Jason, Mike Lynch and John Erickson. BNL's team is led by Bill Weng, with assistance from YY Lee, Andy Soukas and Joe Tuozzolo. Instrument science at ANL is led by Kent Crawford, with input from Jack Carpenter and Bruce Brown. The ORNL Target team is led by Tony Gabriel, with John Haines and Tom McManamy as assistants. The controls group is led by Dave Gurd from LANL. Accelerator physics at ORNL is led by Dave Olsen. The ORNL senior management team consists of Bill Appleton, ALD for SNS and Project Director, with John Cleaves, Thom Mason and Jose Alonso as Deputies for engineering, science and accelerators, respectively.

----

* This work is supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, of the US Department of Energy under Contract No. DE-AC05-96OR22464.