October 21, 2003

Report of the Accelerator Systems Advisory Committee Of the Spallation Neutron Source September 2003 Meeting

Introduction

The ninth meeting of the Accelerator Systems Advisory Committee (ASAC) for the Spallation Neutron Source was held on September 22 - 24, 2003 at the SNS Office in Oak Ridge, Tennessee. The committee membership is: M. Allen (SLAC), D. Boussard (CERN), D. Finley (Fermilab), M. Harrison (BNL), R. Jameson (LANL), R. Kustom (ANL), W. McDowell (ANL), G. McMichael (ANL), D. Proch (DESY), G. Rees (RAL), P. Schmor (TRIUMF), R. Siemann (SLAC, Chair), and F. Zimmermann (CERN). M. Allen, D. Boussard and M. Harrison were unable to attend the meeting. R. Kustom (ANL) joined the committee for this meeting.

Charge to Committee

1) Provide an overall assessment of the physics and technical progress on the project. Does the committee see any serious problem areas?
2) Provide a detailed assessment on hardware installation and recommendations for improvements and increased efficiency within the constraints of funding and schedules?
3) Provide a detailed assessment on beam commissioning and recommendations for improvements and increased efficiency within the constraints of funding and schedules?
4) Comment on installation and commissioning scope, costs and schedule risks and resource allocation to mitigate these risks.

General Assessment

There has been impressive progress in the last six months since the ASAC meeting in March. This extends throughout the SNS project. We saw much progress in the construction and installation of the accelerator components during the tour. Early commissioning is off to a good start, and the accelerator teams at ORNL and the partner laboratories are functioning well. There is more detail about the progress in comments that follow.

Two of the critical areas of concern at the March ASAC meeting were the Drift Tube Linac (DTL) and High Voltage Converter Modulator (HVCM). There has been significant progress with both.

- DTL Tanks 1 and 3 have been processed to full power, and beam has been accelerated with Tank 1. A 1 msec long, 20 mA beam was accelerated while the ASAC meeting was taking place.
- SNS engineers worked closely with the HVCM manufacturer to improve the quality control, design and testing. As a result of the improvements all of the HVCM's have passed the acceptance tests and almost all of them have arrived at ORNL.

The SNS management has developed an End Game Plan that better matches the expected funding profile. This has led to *i)* slowing down some of the installation and *ii)* a commissioning schedule that has completion in March 2006. This is three months later than had been planned and three months earlier than the Project Execution Plan date of June 2006. SNS management has reviewed the pros and cons of changing the completion date and is convinced that this action is necessary. It is critical that the accelerator team not relax its effort because of this schedule shift. The present momentum and drive must be maintained to avoid any further delays.

There are some issues that could make the next commissioning steps difficult to achieve on the Integrated Project Schedule. These are: Drift Tube delivery, Coupled Cavity Linac tuning and delivery, performance and delivery of the 5 MW, 805 MHz klystrons, production of high

Proposed Integrated Project Schedule Commissioning Dates

Drift Tube Linac (DTL) Tank 1 (Diagnostic plate)	8/21/2003 – 10/17/2003
DTL Tanks 2 – 3	1/26/2004 – 4/1/2004
DTL Tanks 4 – 6 and Cavity Coupled Linac (CCL) Modules 1 – 3	5/17/2004 – 8/18/2004
CCL Module 4, Superconducting Linac	3/11/2005 – 5/31/2005
High Energy Beam Transport, Ring Target Beam Transport	7/6/2005 – 11/18/2005
RTBT to Target	2/1/2006 – 2/28/2006

beta modules of the superconducting linac, and the failure of the 1 MW klystron (needed for the superconducting cavities) at Jefferson Lab. In addition, the SNS project staffing remains lean, and in one area, the SNS RF group, there is a clear need at the present time for additional staff to meet schedule and performance goals.

There are several recommendations in the report that are highlighted here because of their importance.

- It is urgent for superconducting cavity production that the high power RF system at Jefferson Lab be repaired.
- The staffing of the SNS RF group needs to be increased.
- There should be sufficient budget for consulting from LANL to keep key staff actively involved in RF testing and development.

Front End System

It is now nearly one year since the initial commissioning began with the Front End systems. The initial beam commissioning indicated a number of systems that needed to be repaired and upgraded. Much of that work has now been completed. A reproducible ion source alignment system has been implemented. The redesigned high voltage insulators appear to have eliminated the down time due to high voltage breakdowns. The ion source performance has been improved. The longitudinal and transverse emittances have been shown to meet design specifications. Outstanding issues still requiring work include the LEBT chopper, the MEBT chopper, the buncher amplifiers, and the reliability of the MEBT quadrupole power supplies. Over all, the Front End systems appear nearly ready for CD-4 beam commissioning. Some additional ongoing activities will need to be completed to achieve 1 MW capability.

A LEBT is being added to the test stand to measure offline improvements that address thermal issues. The group should consider adding a diagnostics chamber to ensure that modifications do not impact ion source beam characteristics.

There are some concerns and lessons from the commissioning activities to date.

1) The Machine Protection System seems to be one factor that is preventing continuous operation. There are multiple false trips per shift with only two systems (the Front End and DTL tank #1) operational. The situation will become worse when the number of systems and inputs to the MPS increase by one or two orders of magnitude. The cause of false trips should be understood, and false trips need to be minimized.
2) Significant amounts of commissioning time have been used fixing problems (for example alignment). This should be expected for other SNS systems unless there is more preparation ahead of commissioning. Such preparation will be important if the tight commissioning schedule is to be met. In addition, maintaining systems during commissioning has placed significant demands on available manpower, and manpower

will have to be increased in critical areas. At the present time it is clear that the RF group is one such area. This is discussed more below.

Drift Tube Linac (DTL)

The DTL Recovery Program has brought the DTL back into technical performance, as verified by successful structure tuning for correct field distribution and high-power commissioning of DTL Tanks 1 and 3. The high-power commissioning for both proceeded quickly, and some tens of hours of operation at 30 Hz and full pulse width had been accumulated by the time of the ASAC meeting. The vacuum levels are better than specified, and they are showing the expected improvement with further conditioning.

It was encouraging to receive the news just prior to this ASAC meeting that DTL Tank 1 had been conditioned in only a few days and had accelerated first beam to 7.5 MeV. This followed the Accelerator Readiness Review that was held August 12-14, and DOE approval for operation on August 26. There has been steady progress since then, and a 1 msec long, 20 mA beam was accelerated while the ASAC meeting was taking place.

The fabrication of Tanks, 2, 4, 5 and 6 are under close management. The component delivery and tank assembly schedules are tight, but they are consistent with having the tanks ready for RF consistent with the IPS commissioning dates.

Coupled Cavity Linac (CCL)

The CCL is being fabricated by ACCEL Instruments GmbH based on a proven LANL design. Roughly one-quarter of the cavity segments and one-half of the bridge couplers have been fabricated. The first CCL module has been assembled and aligned at ACCEL. One-half of the module has been leak checked, and individual segments and bridge-coupler cells have been tuned.

A delay of about four months has occurred from the necessity to develop detailed structure, bridge coupler, and module-level tuning procedures for the vendor, and to repair minor problems. Engineers and physicists from LANL and ORNL have worked with ACCEL to develop tuning procedures, and the first module is scheduled for delivery in November 2003. The delivery of the last module is forecast for March 2004. These schedules have been folded into the planning for the commissioning schedule, but they have uncertainty associated with them given the delays and technical issues that have been encountered to date.

Superconducting Linac

Cavity preparation, vertical tests, module assembly and module testing are under intensive work at Jefferson Lab. Three medium-beta modules have been shipped to SNS, one additional one is under test, and three more are close to being tested. All remaining low-beta cavities are at Jefferson Lab. Vertical tests of first high-beta cavities have started.

Measurements on the first three cryomodules demonstrated that the cavity performance achieved in the vertical tests could be preserved in the module. Some cavities actually showed even higher gradients. This is explained by reduced thermal load for pulsed operation and has been observed in other laboratories also. The specified cavity gradient is met with some margin. For future acceptance tests of cryomodules it is highly recommended to incorporate the production model of low level RF control in order to simulate the cavity field shaping as close as possible to the accelerator conditions.

It was quite unexpected, however, that on average every third cavity needs more than one preparation cycle (chemical etching, high pressure water cleaning and clean room assembly) to reach specified performance. There is suspicion that the water system and/or the assembly procedure are responsible for uncontrolled contamination of the cavity surface. ASAC endorses

the idea of calling in external experts for an investigation of this problem. This examination should not be restricted to examination of infrastructure and procedure only. It should also include analysis and interpretation of all available date for correlations that might hint at other reasons for the degradation.

This problem has resulted in requiring additional effort that is not acceptable with respect to costs and schedule. ASAC endorses the review of those aspects that is planned for mid-October.

Measurements of four high-beta electro-polished cavities show disappointing results with only one reaching specified performance. This could be due to the same unidentified contamination as mentioned for the low-beta chemical etched cavities. On the other hand the new installation for electropolishing still needs time for commissioning and establishing the optimum working parameters.

A 1 MW RF system is installed at Jefferson Lab for coupler conditioning and cryomodule testing. Technical problems mainly with the tubes resulted in reduced availability and finally the transmitter is no longer operational at this time. Coupler conditioning could possibly have to be moved to ORNL as a consequence. If that 1 MW RF system is not repaired, the only alternative for cryomodule testing would be after installation and cool down in the accelerator tunnel at SNS. Considering the low statistics of tested cryomodules it seems highly risky to accept this procedure. Furthermore the effort of a late repair of a cryomodule will be considerably higher than an immediate action at Jefferson Lab during the production period. Therefore we strongly recommend a fast repair of the high power RF system at Jefferson Lab.

Detailed calculations of heating at the end groups were presented. Temperature measurements near to the beam pipe of a cavity confirmed the predicted heating from the input coupler. It was concluded that under normal operation the heat conductivity of the end group material (after heat treatment this material has a RRR value of about 70) is sufficient to assure thermal stability.

Impressive progress has been made in installation of the refrigerator and distribution system. But there is a delay of thirty-two days of refrigerator, which puts this installation on critical path.

Linac RF Systems

The progress on the low level RF systems is impressive with operating prototypes showing the required performance, programmability, and interface to the control system. The low level RF Advisory Committee set up to monitor this activity has ended its supervision, and the construction of low level RF control systems should support the commissioning schedule. ASAC supports using a production model low level system at Jefferson Lab for use in cryomodule testing.

Progress on the HVCM is satisfactory with the improvements in quality control, design and testing. There are solutions for the problems that have been uncovered so far, and it appears that the basic design will eventually be able to meet the demands of the facility. More problems will undoubtedly be encountered as more operation time is logged. For example, some components are at or above their specified thermal operating limits.

The Los Alamos RF group continues to be well managed and on top of the numerous problems that have arisen in delivering the SNS complex high power RF system. In particular, they should be commended for their effort to reach the level of performance on the 5-MW, 805 MHz klystron that has been achieved.

The Thales performance on both the 550 kW and 5 MW tubes continues to be deficient. The first four Thales 550 kW tubes have failed to meet the acceptance tests. It appears the

design will not be able to achieve the required efficiency and cathode power specifications. CPI, which is the primary source for 550 kW tubes, has achieved excellent performance, and part of the Thales order has already been shifted to CPI.

The 5 MW Thales klystron is a much more serious problem. A tube has shown that it can produce 5 MW and 1.1 msec pulse length with smooth power transfer characteristic for a limited time before arcing developed in the output section. This problem of arcing in the output section may be solved with careful treatment of the flanges and conversion to allow SF6 pressurization. Gun arcing occurs, with rates from 1 – 2 up to 3 - 4 arcs per hour observed on the first tube (the specification is less than 2 arcs/24 hours). Fault protection in the HVCM handles the gun arcing problem without damage to the system, so this does not preclude operation. But, it would be disturbing during operations because of drop-out transients that must be handled by the resonance control system, etc.

In addition, the tube efficiency is ~52%, which is below the specified 55%. The loss in efficiency is important because if the required power output is achieved by increasing the drive, further strain would be placed on the HVCM. Alternatively, if the efficiency were improved by tuning methods, the usual procedure would be to place stubs in the output region, which could cause arcing to reappear there. These considerations emphasize that the RF system is a complex one with many interdependencies.

It is apparent that there are serious development problems that must be overcome before this tube is acceptable for fully a functioning facility. Many problems seem to be quality related rather than fundamental, and it would seem reasonable to expect that these tubes can be made to work. At worse, they could be used for meeting CD-4 goals in their present state. Thales has given a delivery schedule for three more tubes by end of November 2003. There is a high risk of delivery slips and continuing technical problems with the next tubes.

LANL support for the SNS will be essentially finished by April 2004. Testing of the 5 MW klystrons will be moved to the ORNL/SNS test facility, and maintaining and upgrading the HVCM's will be shifted to ORNL. We recommend that there should be sufficient budget for consulting from LANL to allow key staff to remain actively involved in ongoing testing and development work.

The SNS RF group will need to simultaneously support supervision of installation of all high power RF components, conditioning of newly installed klystrons and cavities, operation and maintenance of upstream systems during commissioning, further development of the 5 MW klystron, troubleshoot future problems that are sure to arise with expanded operation and possibly condition production couplers for Jefferson Lab. There are only 2 engineers and 5 technicians assigned to accomplish these tasks with no plans to increase this number during the project. This staffing level puts the schedule and performance goals at high risk, and at least one more engineer and three to four more technicians are likely to be needed to meet the demands on this group.

Accumulator Ring

Many of the devices and parts of subsystems for the High Energy Beam Transport (HEBT), Ring, and Ring Target Beam Transport (RTBT) have been delivered to ORNL. Some of these were seen on a walking tour of the HEBT and Ring beam enclosures, but not the RTBT, which is still under construction. The facilities in these enclosures are apparently complete with cable trays, air handling, and lighting in place and in use.

Nearly all HEBT quadrupole magnets are stored along the HEBT beam line, but not installed in their final positions. A collimator is staged in the HEBT beam line, and its shielding is staged outside the beam enclosure. The ends of the beam pipes of these HEBT magnets are

covered with plastic caps. There are no vacuum pipes in place in the HEBT or the Ring, which is prudent at this point in the installation. Several pipes for the laser profile monitor system are staged at the end of the HEBT. The first Ring half-cell is installed on grouted stands, although it is not yet finally aligned. In addition, several Ring half-cells and other magnets are located along the beam line. Proper vacuum techniques are being used for the Ring elements to preserve the quality of the titanium nitride coated beam pipes while being stored in the beam enclosures, which have high humidity and dust.

The work on quick disconnects and remote removal of water and vacuum connections for ring components is being properly addressed. Magnet measurements, both at BNL and ORNL, are going at full pace and do not appear to be limiting the delivery of magnets at this time.

The HEBT Energy Correction and Energy Spreader Cavities are to be used to adjust the energy and energy spread provided by the linac to avoid Ring instabilities and consequent beam loss at high beam power. A calculation, which assumed a linac small energy spread and no HEBT cavities, indicates that the losses are expected to be about a factor of ten below the loss limit for operation at 1 MW. In addition, if needed there are ways to increase the linac energy spread without the cavities. ASAC endorses the conclusion that the HEBT cavities are not needed to achieve CD-4 goal of 10^{13} protons delivered to the target. In addition, the calculations presented to the committee indicate that they are not needed to be capable of 1 MW operation.

We encourage the beam physics team to calculate the effects of the field distributions in the injection chicane magnets. These magnets have field requirements appropriate for transporting stripped electrons to their absorber. However, there were no presentations on the effects of these same fields on circulating protons. This has similarities with the Fermilab Booster extraction dogleg which was found to limit the Booster aperture. The beam physics team should understand the Fermilab Booster and how that experience relates to the SNS.

At the next meeting we would like to hear a presentation about the beam transport from the end of the last magnet in the RTBT to the target. It should include the design considerations for transporting the proton beam to the target, for minimizing the radiation of the magnets from backsplash from the target, for specifying the limitation of magnetic fields in this region, and for required operational adjustments to the proton beam in achieving both the CD-4 goals as well as eventual high power operation.

ASAC was not presented a Ring diagnostics plan in sufficient detail to form an opinion on the readiness of these crucial systems, and we would like to see an appropriately detailed plan at the next meeting.

Accelerator Physics

A significant competency in accelerator physics has been built up at ORNL. This will ensure, in particular, a smooth transition in ring beam-dynamics studies from BNL to ORNL. Many links and collaborations have been established with outside groups and institutes that have enhanced the scope of accelerator physics studies. Important results include the development of diamond stripping foils, a novel concept for laser stripping, electron-cloud simulations, and an analytical treatment for space charge effects and related cures, in particular the generalization of the KV distribution to three dimensions.

Recent accelerator-physics studies have focused on practical forthcoming issues like commissioning, fault scenarios, and ring lattice tuning. We encourage the accelerator physics group to further pursue and extend this type of studies.

Most of the commissioning simulations so far are based on single-particle tracking. As an example, in a simulated optics measurement the betatron-phase advance around the ring was determined with a resolution of the order of a degree from multi-turn beam position monitor

data. There will be a loss in resolution incurred when the response of a more realistic beam is simulated, including longitudinal and transverse decoherence, space charge and impedance. Experience at the CERN SPS and at the PS booster indicates that with protons it is difficult to achieve the same resolution as with electron beams.

The instability threshold under the combined influence of impedance, space charge and lattice nonlinearities is an unresolved question in the worldwide accelerator physics community. Most of the stability estimates for the SNS rely on simulations with the UAL and ORBIT codes. The committee encourages further benchmarking of ORBIT against instability threshold observations at existing proton storage rings, for example the CERN PS. The BNL studies with UAL have partially been cross-checked with the ORBIT code. Conventionally, beam stability is discussed in terms of dispersion relations, stability diagrams and coherent tune shifts. These calculations can also take into account the effects of space charge and nonlinearities. It would be worthwhile to compare the predictions from such stability analyses with the numerical simulations. In addition, though ORBIT and UAL encompass a rich repository of modules, not all the possibly relevant physical phenomena have been, or can be, included. For example, the magnitude of the Laslett tune shift will depend on the magnetic boundary conditions, e.g., on the time-dependent penetration of the beam magnetic field through the chamber wall.

The simulations of electron-cloud build-up, which are being performed for the SNS, are state-of-the-art. Both the BNL/KEK PIC code and also the ORBIT code have reproduced the results from POSINST (M. Furman and M. Pivi). The study of the effects of a clearing electrode and its dependence on the clearing voltage has shed light on one promising countermeasure. In the longer term, the committee recommends that, as planned, the capacity be developed to simulate not only the electron build up, but also *i)* the consequent beam-electron interaction and its impact on beam stability and halo generation and *ii)* the interplay of the electron-cloud effect with space charge and conventional impedance.

The dedicated simulation program ORBIT is presently decoupled from the control-room modeling code. A more direct interface with the control system and extension of ORBIT to the linac should be considered. (An outstanding example of such an approach is the KEK B factory where the SAD code was not only used for the design of the accelerator, but also serves as the basis of the online model.). The development of integrated simulation tools covering the beam transport from the source to the target would facilitate a global modeling of SNS tuning, so that upstream systems can be optimized for minimum losses and highest beam quality on the target.

Controls

Good progress is being made, and there are no technical problem areas with the control system itself. The system is very mature and is providing services well ahead of commissioning needs. The Controls Group has installed eleven Servers, and seven Operator Interfaces in the Front End Control Room as well as having installed over 1200 cables. There are twenty-eight Input Output Crates, over eleven-hundred Operator Screens, thirty one thousand EPICS Records, thirty-seven Communication Room Racks, 26 network switches, a fiber backbone in the Front End-Linac-Klystron building with the remaining fiber being installed now. The Timing Master and the Machine Protection System master have been installed in the Front End Control Room, and 104 Rack assemblies are now in place.

The Personnel Protection System is being developed in phases. Phase 0.4 is now certified to run the Front End, DTL tank 1, and DTL tank 3. Phase 1, currently under construction, will support the entire Linac. All Programmable Logic Control racks have been installed, and over 50% of the field cabling and hardware is in place.

There are some open issues

- The electrical noise problem that has not been completely solved and some rework and rewiring (adding fiber optic cable) may be required.
- Computer security issues are being actively studied, and a paper has been written discussing these issues. Further studies on virus protection, security software updates, and vulnerabilities introduced by remote access are underway. Results will be reported to the ASAC during the next meeting.
- Some power line frequency changes appear to be faster than the present slew rate of the neutron choppers.
- The Controls Group has taken on some out-of-scope work particularly in the area of Cryogenics plant controls. This is a drain on resources.
- The Controls Group probably has too few people to support operations over the long run. Three of four people are handling the required work, and they may burn-out with the long hours, late nights and late calls.

Diagnostics

SNS diagnostics is a project-wide activity with coordination between and contributions from many of the partner laboratories. The SNS diagnostics effort is a successful one in several regards. First, instruments have been available and working well as needed to support commissioning. The DTL "D-plate", which is a complex set of instruments that was essential for DTL commissioning, is the most recent example. Second, new diagnostics have been designed and developed in response to accelerator physics requirements. Recently, a diagnostic box was developed for the 2.5 MeV beam in the MEBT. This system was taken from a concept to realization in a short period of six months.

There is now enough experience with the diagnostics systems that it would be good to compare the achieved performance with the requirements that came from accelerator physics considerations. In addition to hearing about this topic at the next meeting we would like to have a presentation about the detailed plans for Ring diagnostics.

Topics for the Next Meeting

We would like to hear presentations on the following at the next ASAC meeting.

1) The effects of the Ring injection chicane magnets on the circulating proton beam.
2) The status of the beam transport from the end of the last magnet in the RTBT to the target.
3) Computer security issues introduced by remote access to the controls.
4) Diagnostics – a comparison of achieved performance with accelerator physics requirements and the detailed plan for Ring diagnostics.

Agenda Spallation Neutron Source ASAC Review
September 22-24, 2003

Monday September 22

8:00	Closed Session	
8:30	Welcome, Charge and Project Status	T. Mason
9:00	SNS Accelerator Systems Overview	N. Holtkamp
9:45	ORNL ASD Resources, Installation and Progress	D. Olsen
10:30	Accelerator Physics Overview	S. Henderson
11:15	DTL Conditioning, Readiness and Operations	G. Dodson
11:45	DTL Commissioning Results and Plans	E. Tanke
1:15	Performance Update for Front-End Systems	S. Aleksandrov

1:40	Beam Diagnostics Experience and Update	T. Shea
2:05	Controls and Safety System Status	D. Gurd
2:30	Questions	
3:00	SNS Site Tour	
5:00	Closed Session	

Tuesday September 23

8:00	Closed Session	
8:30	Linac Overview and LANL Progress	D. Rej
9:00	DTL Recovery Status	J. Stovall
9:25	CCL Status	J, Stovall
9:50	Warm Linac Assembly, Installation and Integration	G. Johnson
10:30	High Power RF Components	D. Rees
10:55	HVCM Progress	D. Anderson
11:20	HPRF Installation, Testing and Commissioning	R. Fuja
11:55	LLRF Status and Results	M. Champion
1:20	Cold Linac Overview and Cavity and Cryomodule Production	C. Rode
1:55	SRF Cavity Thermal Issues	S. Kim
2:20	CHL and TL Installation, Progress and Commissioning	M. White
2:45	Cryomodule and Warm Section Installation	D. Stout
3:10	Questions and Closed Session	

Wednesday September 24

8:00	Closed Session	
8:30	Ring Overview and Progress	J. Wei
9:00	HEBT-Ring-RTBT Magnet, Kicker, Power Supply Test Results	D. Raparia
9:25	HEBT-Ring-RTBT Construction Engineering Issues	W. McGahern
9:45	ORNL Magnet Measurements	T. Hunter
10:20	HEBT-Ring-RTBT Installation Progress	M. Hechler
10.40	Activation Handling Plans	G. Murdoch
11:00	ORBIT Simulations and Results	J. Holmes
11:20	ORNL LDRD Laser H^- Stripping Experiment	S. Henderson
11:40	Closed Session	
1:30	Closeout	