Report of the Second Spallation Neutron Source Accelerator Advisory Committee Meeting

SNS Accelerator Advisory Committee

March 19, 2009

Contents

1 Executive Summary

This was the second meeting of the SNS Accelerator Advisory Committee. All but one of the committee members were in attendance. During the two day meeting, the committee heard reports on the progress made since last year's meeting, the plan to ramp-up the beam power to the design level, and plans for future upgrades to 3 MW. This executive summary provides a brief overview of the report. Any recommendations noted in the executive summary are also repeated in the body of the report.

1.1 Current operations and the ramp-up plan

The SNS is currently averaging a beam power of > 650 kW and 80% availability (FY2009 to date), which is a significant improvement over FY08. The target date for achievement of the design performance (1.4 MW, 90% availability, 5000 hours/year) is now October 2010, which is a delay of one year from last year.

The energy goal for FY09 (1 GeV) is based on a full complement of cryomodules, with enhanced performance of the high-β cavities from in-situ plasma processing. Plasma processing has demonstrated a gradient increase of 2-3 MV/m, although further R&D is required for optimization.

Ion source performance (now 38 mA, with significantly reduced downtime) is substantially improved over last year. This is sufficient to support 1.4 MW operation.

The main linac modulators remain the primary performance limitation. These systems are the primary downtime contributor. In addition, they limit the beam pulse length.

1.2 Reliability and availability

Higher reliability and availability has become one of the highest priority goals for the user program. Availability is to be increased to 95% over a period of years following achievement of the design power goal.

The committee is concerned that the 95% goal is very aggressive, and that advertising this number without sufficient understanding of the underlying strategy is sowing the seeds of a future expectations management problem with the users. To develop a strategy for achieving the availability goal, the committee recommends that SNS develop a bottoms-up reliability model that includes MTBF and MTTR of individual components, based on reasonable extrapolation from current performance, redundancy of subsystem components, and a preventative maintenance strategy.

1.3 Ion Source, LEBT, RFQ

The ion source has demonstrated the ability to produce 38 mA using 48 kW of 2-MHz rf power. The 2-MHz RF system appears to be the largest availability risk in this system. Procurement of a solid-state replacement amplifier is planned.

The RFQ has experienced a second detuning event (250 kHz frequency shift), apparently caused by accidentally applied over-pressure in cooling water circuits. The committee considers it mandatory to prepare a new and improved RFQ to replace the present one. The time from design to installation could easily take 2-3 years. If SNS management is concerned about being without a viable spare for too long, they may consider building a carbon copy of the existing device. However, there will be problems with the copper-Glidcop brazes, and it will still take 12-18 months in any case. The committee suggests that it might be quite helpful to hold a specific review by experts.

1.4 Normal-conducting linac

The normal-conducting linac has now reached nominal specifications, except for duty factor (4% instead of 6%) and longitudinal emittance. Growth of the longitudinal core emittance to a factor of 1.2 - 2.3 over the design value remains unexplained. This should be addressed even though it does not directly impact on beam loss, because something rather basic may be missed.

1.5 High Voltage Converter Modulators (HVCM)

The HVCM is the principal contributor to downtime of SNS operations. Great strides have been made in reducing the HVCM failures, but integrated-gate bipolar transistor (IGBT) faults continue to cause unacceptable downtime.

The committee recommends that

- a technical investigation of the premature capacitor failures be carried out to determine the probable fault mechanism(s);
- the development of the HVCM control system be accelerated to increase the detection and control of the IGBT's;
- the HVCM Test stand be expedited, so that the new IGBTs and their drivers can be tested for a sufficient time to insure their operation before acceptance and installation in the operating HVCM's; amd
- the development of a Energy Storage Capacitor protection system be expedited to prevent explosions of the IGBT's under IGBT fault conditions.

1.6 RF and other pulsed power systems

In general, high-power RF systems and pulsed power supply systems, being associated with discharging or arcing problems, are two major accelerator components, of which special care should be taken for reliability and availability issues.

Diagnostic systems for the klystrons, the thyratrons, and others, incorporating very sophisticated control systems, should be developed on the basis of data accumulated throughout their operation and testing. A very efficient scenario of spare replacement for these components is required for reducing down time.

The Committee recommends an increase in the number of RF test stands to at least three (e.g., two for 2 different RF frequencies and one for HVCM).

1.7 SC Linac cryomodules

The lab has demonstrated the capability to repair a complete cryomodule, and has made three in-situ repairs of cavities.

There has been a proof of principle demonstration of in-situ plasma processing. Further intensive R&D is required to determine the best operating conditions. The present activities of the SRF group need to be focused on activities which validate this technology.

The SRF group is gearing up to assemble the first spare cryomodule. They will be relying on cavity processing at JLab. For the 1.3 GeV energy upgrade, the lab is planning assembly and testing of 9 additional crymodules, with cavity processing (electropolishing) at JLab. It is important to be sure that these efforts are getting due attention and care at JLab, in view of competing demands on their resources. Processing at industrial facilities should also be explored.

Currently, the SRF group is a matrixed organization in RAD and NFDD, with few full time people devoted to these efforts. The committee recommends a re-examination of the matrixed organization of this effort, and consideration of the formation of a specific SRF group within RAD.

1.8 HEBT/Ring/RTBT

The ring is keeping up with all the beam power available from linac.

The foil mechanical system has had problems, and a new design is being implemented. Diamond foils are successful at present and will probably work to 1.4 MW, based on experience at SNS and PSR. However, operation at 3 MW will be more problematic for a diamond foil. For this power level, Hybrid Boron Carbon foils show promise. The committee endorses the ongoing laser stripper study as exciting research, and a potentially critical ingredient in the 3 MW upgrade.

Significant beam loss in the ring down stream of the stripper foil is not fully understood. Improvements to simulation of injection painting are needed to help understand this issue.

The committee recommends a system to ensure that the beam spot on target does not get too small.

1.9 Target Facilities and target R&D

The 3 major failures incurred so far that caused noticeable down time are in the regime of normal start-up difficulties, not fundamental problems. There is a program in place for identification of possible weak spots and minimizing their potential effects (redundant components, spare parts, etc.)

A view screen system is being developed for the target window, to improve determination of the beam profile on target. The committee recommends implementation of this view screen coating on the next target, and changing to a proton beam window plug which accommodates the screen viewing system.

Development of a system to mitigate the effects of pressure waves is a difficult enterprise but makes reasonably good progress. A concept ready for implementation is not expected in the near future. The committee feels that it is important, based on progress made in the past, to establish a resource loaded work plan for a target with pressure wave mitgation, with well defined decision milestones.

Development of an optional alternative target system (rotating target) for the Second Target Station (STS) is prudent, but if STS is a long pulse 1MW facility, as presently envisaged, a Hg target would, in all likelihood, be a viable solution also, and might allow synergies with the existing system (spare parts, etc).

1.10 Target Utilization and Post-Irradiation Examination (PIE)

A careful approach to utilization of the first target being followed. The target is planned to be removed this summer, even if is has not yet failed.

The committee would prefer to see the target run to failure, since so much critical information would be provided by examination of the mode of failure. If taken out earlier, we recommend limited PIE, for the following reasons:

- PIE can still yield important information, in particular on the state of the water shroud, which is practically not affected by the pressure in the mercury.
- Optical inspection of the inner mercury vessel might also provide valuable insight with respect to the degree of damage.

- Mechanical impact testing of the mercury vessel might be done without too much effort in the service bay.

1.11 General beam dynamics and accelerator R&D

Beam loss in the superconducting linac (SCL) is not well understood. Although the level of loss is not an obstacle for reaching nominal performance, it deserves careful monitoring. Simulation alone is clearly not sufficient to resolve the SCL beam loss issue. Help will be needed from more diagnostics with specific aims.

Simulation efforts for the ring should continue. New ingredients should include, in approximate priority ordering, ring collimation, painting (in conjunction with dedicated painting experiments), extraction loss, space charge, and e-p instability.

Simulating extraction loss with LEBT/MEBT choppers is an area where one can benchmark simulations. Although it is difficult since the loss is small, the committee encourages clever ideas here.

A number of potential accelerator physics R&D issues to reach 3 MW were identified. The Committee recommends an initial emphasis on the e-p instability, the feedback system, and laser stripping.

1.12 Control System and Beam instrumentation

FY08 showed continued progress in the control system. A recent rash of PLC failures (all on cryo systems) was caused by Allen Bradley manufacturing problems. The system also experienced PLC-IOC communications problems on cryo systems.

The SNS accelerators are equipped with an extensive and very complete beam instrumentation inventory. SNS management has a clear analysis of the role and importance of every device. However, most instruments have to be improved to completely fulfill their role.

2 Introduction

2.1 Committee Membership and Charge

This was the second meeting of the SNS Accelerator Advisory Committee. The committee membership is given in Sec. 22. At this meeting, all members of the committee were in attendance except Andrew Hutton.

The Charter for the Committee is presented in Sec. 21. The specific charge for this first meeting was:

1. Assess the performance of the SNS accelerator complex to date.
2. Assess and provide advice on the plans for ramping-up the performance of the SNS accelerator complex to the baseline level (1.4 MW, > 90% availability, 5000 hours operation/year). Evaluate the risks to the plan and the mitigating actions aimed at addressing those risks.
3. Assess the longer-term plans for improving the availability of the accelerator complex.
4. Assess the progress in R&D for the Power Upgrade Project.

Following the agenda outlined in Sec. 23, the committee heard two days of presentations assessing the current status of the SNS accelerator systems, plans for the ramp-up to the baseline level, and plans for further upgrades. The committee was also given the opportunity to tour many of the SNS facilities.

2.2 General remarks

The committee thanks the SNS staff in both the RAD and NFDD for the excellent quality exhibited in the presentations, and generally for the warm hospitality provided during the review.

The committee congratulates the SNS staff on the progress that has been made since last year in bringing the beam power to its current point (700 kW), which is half of the design goal. At the same time, the SNS staff have been providing useful neutron beams with 80% availability to SNS users engaged in pioneering experiments, and planning for upgrades. Improving accelerator performance while maintaining good reliability is a challenging task, and the staff is to be commended for its successful efforts to maintain a good balance between these sometimes competing objectives.

The committee appreciates the attention which the SNS management have paid to last year's AAC comments and recommendations. All of the committee's comments and recommendations from last year were addressed, and a number of the recommendations were implemented.

The committee was pleased to hear of the neutron instrument deployment which took place in the last year and encourages accelerated instrument deployment in future years to fully utilize the neutron flux provided by the accelerator.

In the following sections of this report, the committee's detailed assessment of the performance of the complex is presented, together with advice on future plans. The final section gives answers to a number of specific questions addressed to the committee.

3 Operations

3.1 Findings

During FY09 to date, the SNS facility is averaging > 650 kW on target with 80% availablity. This represents a substantial improvement over FY08 (~ 300 kW at the time of last years AAC meeting, and 72% availability averaged over the year). SNS has met its formal MW-hours goals in each of the last two years.

The facility is currently operating at a beam energy of 870 MeV with a 38 mA peak current and a 0.6 msec linac pulse length, at 60 Hz repetition rate. All twenty-three cryomodules are now installed, following the first successful repair of a cryomodule (CM19) by SNS staff. In addition, in-situ repairs have been made to several cavities leaving 80 installed cavities operational for the upcoming run. These improvements should support operations at 930 MeV.

Ion source performance has significantly improved over the last year, both in terms of beam current (now 38 mA) and greatly reduced downtime. The current performance is sufficient to support 1.4 MW operations.

The primary performance limitation over the last year has been related to the modulators. The modulators have limited both facility reliability and peak performance. Catastrophic failure of capacitors and IGBT failures have been the primary causes. All capacitors are in the process of being replaced with longer lifetime specified components from multiple manufacturers. In addition, an eighth modulator has been added to provide more power to support higher energy operations.

Losses within the linac are not impacting performance, but are also not completely understood. Improved modeling of losses and residual activation is required. It is also anticipated that some new information will be required to guide the improved modeling.

Significant reliability improvements over the last year are based on systematic analyses of failures and performance shortfalls in all systems. The general strategy has been to go after the biggest downtime contributors first.

A good preventive maintenance program can significantly improve performance and availability. Such a program is being implemented, but still has a ways to go especially for accelerator components that contribute the most to downtime. Manufacturer's recommendations are being generally followed for conventional facilities, but the operations team needs to develop suitable criteria and procedures for the more specialized accelerator components that have been designed by accelerator scientists and engineers.

3.2 Comments and recommendation

It is unclear that there exists a larger strategy for reliability improvements that analyzes downtime and provides a structure for the associated Accelerator Improvement Projects (AIPs). A RAMI (reliability, availability, maintainability and inspection) modeling effort is underway and is judged by the mangers to be a good investment for improving availability. Most participants agree that it needs more development and validation, and in this committee concurs.

The committee sees the preventive maintenance program as an important part of an availability/reliability strategy based on assessment of downtime probabilities and impacts. The committee notes that accelerator development time seems to be a good part of operations contingency, and therefore there is less beam study time than shown in the schedule. Nevertheless, accelerator physicists seem to have had adequate amounts of beam study time but with less predictability as to when they will get it. Efficiency in planning and preparation for these activities would be helped by a more predictable schedule.

The committee recommends that RAD undertake an "operational vulnerability analysis" to identify possible failures or incidents that could compromise operations for a significant period. Prepare a strategy based on assessment of probabilities and impacts.

4 Ramp up Plan

4.1 Findings

The goal of the ramp up plan is to meet the SNS full operational goals by October 2010. These goals are: 1.4 MW operations with 90% availability, and 5000 hours of operation per year. The strategy is to concentrate resources on availability first and the power increase second. Availability improvements are based on an extensive set of AIPs. As noted above, it is unclear to the committee how the AIPs have been organized in the context of achieving at least 90% reliability.

The power goal appears to be based on making everything work as originally planned. It is based on operating the facility at 960 MeV, with a 38 mA peak current, a 0.95 ms pulse length, and a 60 Hz repetition rate. 38 mA and 60 Hz have already been achieved. The energy upgrade requires the full complement of SNS cyromodules, with enhanced performance from in-situ plasma processing, and the full complement of modulators, operating at design specification, to produce the desired beam energy.

For operations on a longer time scale, the SNS has established a task force to perform an assessment of the resources (cost, schedule, manpower, etc.) required to reach 95% availability.

4.2 Comments and Recommendations

The committee notes that no reliable extrapolation of losses, and accompanying residual activation, into the operational realm of 1.4 MW currently exists.

The committee regards the 95% availability strategy as a top down exercise. We are concerned that the 95% goal is very aggressive, and that premature advertising of this number without sufficient understanding of the underlying strategy is sowing the seeds of a future expectations management problem with the users. Specific suggestions and recommendations are given in Section 19.3.

The committee recommends that SNS complete the planned spare high-β cryomodule as soon as possible, and consider utilization of this spare to enhance operating energy margin via continuous swapping of spare with lower performing CM's

5 Ion Source and LEBT

5.1 Findings

The ion source is now supporting three uninterrupted weeks of operation at 4% duty factor and routinely delivering 38 mA beam through the MEBT. A multitude of technical and operational modifications has resulted in this significant improvement in performance. The internal rf antennas still fail about 1 out of 7 times on average, with no warning in terms of reduced performance. Spectroscopic diagnostics do not give any useful sign for impending failure either, indicating that failure occurs quite rapidly (possibly within seconds) once the porcelain coating is perforated. At this point, the 2-MHz rf system appears to be the largest risk for achieving high availability, and the procurement of a solid-state amplifier is being pursued.

The development of an ion source with external rf antenna has resulted in excellent test performance, and one such source was being made ready for beam production after the end of the review. 35 mA at 5% duty factor has been achieved at the end of the MEBT with such a source being administratively restricted in peak power. The Ion Source Group also intends to test a helicon-style saddle antenna with the same discharge chamber.

Further lines of development aim at directly utilizing a helicon discharge (now under development, intended to replace the present main discharge chamber) and examination of the performance of a Penning-style source developed at SUMY, Ukraine, but modified for cesiation.

With the extraction system, the importance of a fairly high electron-dump voltage was demonstrated; the main effect is the creation of a wider beam that is easier to focus by the second LEBT lens. An alternative extraction layout is being considered that provides electron dumping at a modest energy downstream of the extractor electrode; this system promises to yield lower emittances.

After conditioning, the LEBT only experiences about one arc per day which, again, is a remarkable improvement. To further reduce the danger of sparking and also in view of developing an injector with two sources, a magnetic LEBT configuration with two solenoids has been modeled. For this option, the LEBT chopper would be placed downstream of the second solenoid, close to the RFQ entrance. This type of LEBT has been proven in many similar installations around the world, but the loss of space-charge compensation by the rf fields in the RFQ structure needs to be carefully simulated. Another option, an electrostatic two-lens LEBT with the chopper placed between the lenses is being modeled as well. This design eliminates the need for splitting the second lens into four quadrants and allows applying the chopper waveforms from ground potential, with an expected major increase in reliability. It could be a short-term solution before a full magnetic LEBT has been assembled and beam-tested.

To ease the scheduling conflicts between source development and qualification for production runs, a second ion source test stand is being assembled.

Issues with the presently used LEBT chopper are addressed in Section 6.

5.1.1 Comments and recommendations

Long-term, the reliability of the internal rf antenna type is insufficient for nominal SNS operations. At present, the development line of the standard multi-cusp source with external rf antenna appears most attractive and should be pursued as the main development activity.

At this point it would be prudent to work towards viable final designs of two-solenoid and modified two-lens electrostatic LEBT's and also a modified extraction system with low-energy electron removal downstream of the extractor.

6 Front End and normal-conducting linac

6.1 Findings

The good operational performance and the power increase of the SNS facility during the past year would not have been possible without a reliable operation of the warm linac. It has reached most of the nominal specifications, except for duty cycle and longitudinal emittance.

The issues quoted in the previous report of the AAC have been addressed and the results have been commented, during the present meeting:

- The number of RF couplers driving the RFQ has been successfully reduced from 8 to 2, removing the previous limitation to the duty factor,
- A demonstration has been made that the RFQ can operate and remain tuned at the nominal duty factor of 6% with a higher water flow,
- The rise and fall times of the LEBT chopper have been reduced from 120 to 75 ns, by connecting the damping resistors at a different location, with the main benefit that the average current during the pulse has increased in proportion to the change of the beam ON fraction (68% instead of 60%).
- The prototype of a new and simplified MEBT chopper has been tested during the last run. It performed as expected and helped reduce beam loss at the extraction septum of the accumulator ring. It remains, however, to be explained why the benefit is so marginal. An operational device is ready for installation in March 2009.
- The solution of driving the MEBT rebunchers from a single IOT-based amplifier has been investigated and finally abandoned, in favor of individual solid-state amplifiers. A first device has been ordered and will be available at the end of March 2009. No progress has been made in the analysis and cure of the breakdowns occurring in the rebunchers themselves.
- The heating observed on intertank gate valves in the DTL and CCL has been studied in more details. New valves have been designed which will soon be installed. The RF will be interlocked to prevent high power from being applied to the structures when the valves are closed.
- The beam losses in the CCL and the excessive longitudinal emittance of the beam delivered by the warm linac have been studied, but could not be explained or resolved.

In addition, the RFQ has suffered from a sudden change of tune, similar to the one encountered in 2003, but half as large. It seems related to an accidental overpressure in the water cooling system which has probably deformed the inner copper part of the structure. In a discussion after the review, it was mentioned that a systematic detuning effect was noted in proportion to the applied water pressure. Although the RFQ could be retuned and the field quality re-established, the present device is clearly a risk for the availability of the whole facility.

6.2 Comments and recommendations

It is mandatory to replace the present RFQ by a new one, designed, built and tested with all the care required to guarantee an optimum device, both from the RF and beam dynamics points of view. Beyond that statement, the advice of the committee concerning the RFQ is detailed in Section 19.1, answering a specific question of the SNS management.

The committee fully supports the rapid installation of the new MEBT chopper and recommends extensive beam studies to investigate the benefit for the whole facility.

The situation with the MEBT rebunchers is not satisfying and deserves more attention during the next 12 months. Bringing them to nominal performance is likely to influence the beam loss in the CCL and help contribute to a better understanding of longitudinal beam dynamics and emittance blow-up. The test and installation of the 20 kW solid state amplifiers should be accelerated and the rebunchers operated at high RF power and possibly modified to reach the nominal field.

The study of the beam losses and the search for the reason of the anomalous longitudinal emittance should continue to be actively pursued.

These recommendations basically fit with the plan presented by the SNS scientists, which the committee finds matched with the foreseen increase of performance to the nominal level during the next 2 years.

7 Superconducting linac cryomodules

7.1 Findings

The SC linac was operated very successfully in the energy range between 850 to 890 MeV. In the last runs the SC linac operated at 99% availability. In the downtime statistics of the SNS linac the superconducting systems are among the most reliable subsystems. The major operational achievements are:

- All 23 modules are installed in the tunnel, and 80 out of 81 cavities are operational.
- Several modules were successfully repaired in the tunnel (CM 10, CM 5 and CM 17) or outside (H1) and put back to operation.
- At 60 Hz operation, the gradient setting is determined by collective cavity limits (field emission) and available RF.

The committee is pleased to hear these excellent results which underline the competence of the SCRF group.

Improvements are planned for the near future:

- Upgrade of the HVCM system in order to increase the available RF power so that operation at 940 MeV, 1 ms and 26 mA will be possible (limited by field emission).
- Incorporation of DC bias at several input couplers to suppress multipacting.

The high-β cavities are operated 2 MV/m below specification. The performance is limited by field emission and resulting collective cavity effects. A cure of field emission is essential to operate at 1 GeV linac energy. As recommended at the last AAC meeting, intensive investigations were launched to investigate He processing as possible method to mitigate field emission.

A first attempt with helium processing (module H1) failed because of gradient limitations imposed by multipacting barriers at the higher order mode couplers. In a second test, plasma processing was applied to module H1. In contrast to Helium processing, this technology operates at very low RF fields, on the order of only several hundred volts. As a result, the field emission level was reduced by about a factor of 100. The analysis of released gases during warm up points to surface contamination by oil. Such pollution could be the explanation for the strong field emission in the high-β cavities. One well known reason for such contamination is a leaky seal at the high pressure pump of the clean water system.

RF plasma processing is a new technology in the field of SC cavities. The committee applauds the SRF group on this innovative work and the promising result. Detailed investigations should be started with highest priority to explore the parameter space of this new cleaning technology. There is hope that this cleaning method might even be applicable at room temperature.

The plans for the production of the first spare CM, and the 9 additional CM's for the energy upgrade to 1.3 GeV, were presented. The work relies on cavity processing (chemical cleaning, High Pressure Water rinsing and vertical cryo-testing) at JLab, and module assembly at SNS. JLab will be loaded in the next few years by the 12 GeV energy upgrade and additional cavity related work for ILC.

7.2 Comments and recommendations

- The committee recommends getting a firm commitment from Jlab for the SNS cavity fabrication tasks. Furthermore, SNS should explore the possibility of cavity chemical processing at existing industrial infrastructures. In the long term, it is recommended to establish a vertical test infrastructure for cavities at SNS.
- The committee acknowledges the professional and successful activity of the SRF group at SNS. In order to assure a long lasting implementation of this effort, the committee recommends the re-examination of the presently highly matrixed organization, and consideration of the formation of a specific group within RAD.
- In addition to the above mentioned activities, the SRF group investigates material properties and fabrication technologies for cavities, cryo-vessels and auxiliary components, in order to qualify superconducting accelerator modules for the high pressure vessel code (10CFR851). Similar activities are conducted at several laboratories worldwide, e.g. the recent module crash tests at DESY. It is recommended to keep in close contact with these laboratories, in order to benefit from synergetic effects and avoid duplication of work.

8 Cryogenic systems

8.1 Findings

The committee was pleased to hear that in FY08, the cryogenics plant was operated at 99% availability. The committee congratulates the cryogenic staff on this outstanding performance.

In early 2009, trips occurred which were identified as component failures (due to PLC's with manufacturing problems from Allen Bradley), and also loss of communications in PLC/IOC hardware. This seems to be similar to the 2007 event, but this time without severe consequences. The cryogenics and controls engineers are working to ensure fail safe systems. In addition, the cryogenics group conducts formal failure mode analyses to identify other improvements.

In addition to operation of the cryogenic plant, the staff of this group was involved in building a cryo I&C lab in the CHL, improvement of relief valve performance, installation of a permanent vacuum system in the tunnel, maintenance of the cleanroom, repair of cryomodules, and the test of module H1 in the test cave. Future activities are to complete the return CHL-RF test line and to install a backup refrigerator which also will be used to cool the RF test cave.

9 HEBT/Ring/RTBT

9.1 Findings

In the past year, the HEBT/Ring/RTBT systems have been able to keep up with all the beam power delivered from the linac with good reliability and availability, while at the same time the staff worked on a number of needed improvements. The committee applauds this positive outcome.

The injection dump line beam losses have received a great deal of attention and the causes of the poor transmission to the dump are now reasonably well understood. The Idump beams losses and transmission problems are basically related to departures in the bend angles of two as-built injection chicane magnets from the combined design specifications for the injection system plus the Idump line. A multi-stage improvement program to correct the problems is underway. The losses have been significantly reduced by the improvements to date, which include an empirically-developed, compromise tune of the Idump line and the ring optics/closed orbit, along with other measures such as an increased septum magnet aperture and reduced secondary foil thickness.

There are large beam losses in the ring (downstream of the stripper foil) that are not completely understood. They may be related to the compromise tune for the ring and Idump line, to injected beam halos, to space charge effects, or to combinations thereof.

Matching the linac beam to the HEBT has been achieved but with higher beam losses at injection. This is a puzzle that needs to be understood. Momentum scraping in the HEBT (until the dump failed) was more effective at reducing Idump and ring losses than the transverse HEBT scrapers. The present state of models and simulations do not explain these observations in detail.

The HEBT momentum dump failed last year from excessive pressure in the cooling loop due to a combination of excessive beam power and unanticipated gas creation from the beam passing through the cooling water. A new dump design is underway and will have equipment overload protection and monitoring. The radiolysis/gas creation issue revealed in the dump failure is a new issue relevant for all collimator systems at SNS.

The committee is relieved to hear that the cause of the RTBT cross-plane coupling was found to be in the extraction septum and is being corrected with new shims in this magnet. These shims have been installed and their effect on improving the operation is expected in the next run.

9.2 Comments and recommendations

More work is needed to increase the transmission of the injection dump line, simplify its tuning and enable recovery of the design optics and closed orbit in the ring. In addition, improved diagnostics for determining the beam position at the injection line beam dump are needed to speed up steering of the beam onto the dump. The committee concurs that it is important to finish fixing the Idump line as soon as possible, so that the ring and HEBT may operate with the design optics instead of the compromise tune.

Improvements to the simulation of injection painting are needed to better reproduce measured ring beam transverse profiles and might also help to better understand ring losses.

A view screen system is being developed for the target window to improve the determination of the beam profile on target. The committee recommends high priority for its development, along with control system augmentations to ensure that the beam spot on target does not get too small and damage the target.

10 Stripper foil development

10.1 Findings

The corrugated, nanocrystalline diamond foils have been very successful at the present beam power and have experienced no catastrophic failures in production mode. However, the foil mechanical system has had jamming problems and an improved design is being implemented.

Curling of the diamond foils has been observed in SNS as well as PSR operations, and in tests at KEK. It may constitute a practical failure mode at higher operating temperatures. New corrugation patterns are being studied at SNS for mitigation of the curling problem.

The Hybrid Boron mixed Carbon (HBC) foil developed at KEK shows promise of longer life time, higher operating temperatures and little curling as compared with graphite or diamond foils. This has been borne out in tests at KEK and operating experience at PSR. The SNS team plans to grow HBC-like foils using the same growth reactor as used for diamond foils. These may be sufficient for 3 MW operation, but it is premature to make a definite conclusion.

A 30 keV electron beam test stand has been assembled at SNS and will be used for foil lifetime testing of various materials such as various diamond foils, HBC foils, etc.

10.2 Comments and recommendations

The diamond foils will probably work to 1.4 MW based on the experience at SNS and the LANL PSR. Operation at 3 MW is more problematic since the maximum operating temperature has not been determined but could be in the neighborhood of 2600 K. In fact, the present operating temperature of the diamond foils is also not known. It should be possible to measure foil temperatures with commercial optical pyrometers looking at the light emitted from the foil. We would recommend consideration of such a capability.

Foil temperatures can be calculated if the foil emissivity is known along with the spatial and temporal distributions of power deposition. Calculations were shown for 2 MW of beam power that indicate a maximum temperature of $\sim$ 2350 K for a 220 μgram/cm^2 carbon foil thickness and $\sim$ 2580 K for a 400 μgram/cm^2 thickness. Graphitization was expected to be significant at $\sim$ 1800 K and rapid evaporation expected to commence around $\sim$ 2300 K. Thermionic emission can also be a problem at higher temperatures of $\sim$ 2200 K or so. We would recommend additional calculations/simulations of foil temperatures at higher beam power, especially at 3 MW, as well as calculations of thermionic emission thresholds at the higher beam power.

The committee concurs that the development of the 30 keV electron beam test stand is a prudent investment to aid the development of foils for higher power operation.

More applicable short-term tests of the most promising foils can be tried at PSR or SNS with special beam conditions (highest accumulated charge, smaller stored beam size, foil moved further into the stored beam, etc.) that give high foil hits/proton, hence high instantaneous power-deposition rates. These would be done at low rep rate for durations commensurate with beam study time. One goal would be to determine the peak power-deposition rate (and temperature) that causes foil failure in a short period of time, of order 1-2 hours. The committee recommends consideration of such tests for the power upgrade activities. Also see Section 19.6.

11 Target Facilities

11.1 Findings

Considering that the mercury target as implemented on SNS is a first in the world and as such is highly innovative, the development team should be commended for the smooth and relatively trouble free commissioning and early operation. This part of the project is generally in good shape; there is one AIP remaining, which is the provision of the remote handling tooling of the Proton Beam Window plug. Completing this AIP should be of high priority, because it is necessary in order to implement important improvements to the target protection system (a fluorescent layer on the target nose for online observation of the beam profile) as discussed below .

The three noteworthy difficulties encountered during the start-up phase that contributed to unavailability if the facility (wrong orientation of a heat exchanger in the moderator cooling system, failure of a seal in the mercury pump, leak in an oil-filter) are all in the regime of normal start-up troubles and are not fundamental design problems. In all cases the team has shown great competence in dealing with the problems and has introduced modifications that should improve the reliability of the components. In addition, a comprehensive systems evaluation has been initiated to identify potential vulnerabilities and to develop indicators for predictive maintenance in order to meet the 1% unavailability budget allocated in view of the (ambitious!) 90% availability goal of the whole facility. This will also have to include keeping spare parts in stock and adding redundancy to certain subsystems. The cost is under evaluation in order to create a basis for the necessary management decision on the required budget.

The committee also commends the SNS Team for successfully fixing a glitch in the lower cryogenic moderator which prevented it from being adequately cooled even at relatively low beam power. The solution applied (fitting a spring through the moderator inlet pipe and locking it in position at its last bend) is ingenious and required a lot of skill and preparation.

In an effort to prevent the potentially most damaging malfunction, namely an uncontrolled narrowing of the beam profile on the target, the team is developing a method to deploy a fluorescent layer of alpha-alumina on the target nose which can be viewed via an optical system in the (new) proton beam window plug. Initial tests have shown promising results, but the method of depositing the material without introducing too much heat is still under development.

11.2 Comments and recommendations

The committee fully supports the comprehensive approach taken to meet the imposed availability goal as presented by the Target Systems Team and could not identify additional measures to be taken at this point in time.

Although the expectation is that the fix of the lower cryogenic moderator will alleviate the problem for the medium term future, it remains to be seen to what beam power, and whether the spring will last or break from vibrations and fatigue at the low temperatures. In any case, it would be prudent to accelerate the manufacturing of the spare reflector plug, for which a contract has recently been awarded.

Concerning the approach taken in the utilization of the present target, namely running it until it fails in the current beam period or taking it out at the end even if still intact, the committee feels that it would be preferable to run the target to the physical end of its service life in any case and to do post irradiation examination as quickly as possible. (See also Section 19.7). In particular with respect to the gas curtain mitigation method, it is essential to know where damage actually occurred, and to what extent. In this context, the method of removing mercury from the vessel wall must be carefully evaluated, because wetting may occur, and it is difficult to remove the mercury from the wall surface, in particular, from a rough surface due to pitting, etc.

The committee recommends considering laser surface treatment as a potential method for the target coating process. The heat-affected surface layer is very shallow and very limited in area. If the development of the system is successful, it should be incorporated in the automatic target protection system as soon as possible, which means that the exchange of the proton beam window should happen at the same time as the target exchange.

12 Target development

12.1 Findings

As the beam power on SNS increases towards its design value, protecting the mercury target container against the deleterious effects of pressure waves resulting from the pulsed power input becomes increasingly more important. Two promising methods have been identified and are being followed up in close collaboration with the target group at the Japanese JSNS facility:

- establishing a gas curtain near the regions in danger of suffering from cavitation erosion, and
- mitigating the build-up of pressure and the occurrence of cavitation by introducing a suitable amount of gas bubbles of the right size-distribution (up to 100 μm in diameter) in the target volume.

Both methods are pursued in a large collaboration with industry and research groups and good progress has been made on both fronts. In this context the availability of the Target Test Facility (TTF) at ORNL is a great asset, and the committee was pleased to learn that plans are in place to make extensive use of it in the near future. Unfortunately evaluation of data taken in the past, in particular in in-beam experiments at Los Alamos is slower than expected. Theses data might yield important clues for the next steps.

The committee was informed about LDRD-funded studies towards a rotating solid target capable of handling a beam power of 3 MW as an optional alternative target system for a second target station (STS) for SNS. The idea looks very promising, and good progress is being made in working out the overall concept.

12.2 Comments and recommendations

Regarding the development of target mitigation methods, the committee feels that the time has now come to establish a formal planning on the way forward, with well defined decision milestones and target dates for expected results on the various topics under investigation. This should enable the team to focus efforts and to make sure that the progress keeps pace with the power upgrade of the facility. Failing to do so may limit the power at which SNS can be run in order to avoid excessive down times and cost from target change-outs. SNS plans to limit the number of targets used per year to four, which seems like a large number considering the fact that SINQ uses its targets routinely for two years at a beam power of nearly 1 MW (albeit in cw operation). This indicates the scope of savings possible by a successful mitigation of the effect of pressure waves.

For the STS, studying a rotating target as an alternative to a Hg target is prudent. However, if STS is a long pulse 1MW facility as presently envisaged, a Hg target would, in all likelihood, be a viable solution too and might allow synergies with the existing system (spare parts, etc.)

13 General beam dynamics and accelerator R&D

13.1 Findings

- Many innovative studies led to good progress in this area during the past year. Given the demanding task, more is needed.

- Last year, it seemed that the problem of beam loss in linac was longitudinal. This year, it might be both longitudinal and transverse. This change results from a deeper understanding of the system. With both transverse and longitudinal aspects taken into account, we learned that the beam at the entrance to the SCL has the following distribution:

	Transverse	Longitudinal
Core	Wire scan Beam bump experiment ——— OK after correction	Profile measurement SCL acceptance experiment ——— emittance $\times(1.2 - 2.3)$
Tail	Laser stripping experiment Beam bump experiment ——— Tail $< 5 \times 10^{-6}$	SCL acceptance experiment ——— $40° \times 3$ MeV tail (uncalibrated)

Table 1:

- Lack of diagnostics was a major issue last year. Although much improved, it remains a serious issue this year. More upgrades are planned.
- Some of the diagnostics lack a calibration between BLM readings and beam loss at the 10^{-5} level.
- The level of loss in the superconducting linac (SCL) is not an obstacle for reaching nominal performance. However, it deserves careful monitoring because this small loss is unexplained. The beam loss pattern can be reproduced with artificial tails in the simulations. But the big mystery is that this beam loss was not reduced when the SCL acceptance was tripled. Multipole errors in the quadrupoles and dipoles do not explain the observed losses.
- A second mystery is the observed growth of longitudinal core emittance by a factor 1.2 to 2.3, with a slow run-to-run drift. This should be addressed even though it does not directly impact on beam loss, because something rather basic may have been missed (and it slowly drifts!) in the RFQ or CCL, and that must be tracked down.
- Some data on residual activation were presented with inconclusive results.
- Simulation alone is clearly not sufficient to resolve the beam loss issue. Help from more diagnostics with specific aims will be needed. A review of missing information would guide the study. To narrow down where longitudinal emittance growth occurs, for example, it might be useful to be able to measure the emittance at another location upstream of the SCL.
- The aperture limit in the injection region has improved, but remains severe and not fully understood. There are still hotspots in the dump line as well as in the ring. With added diagnostics and collimation in the HEBT, increased physical apertures at critical spots, and by improving beam steering around aperture limitations, injection beam loss should substantially improve. However, without knowing what is causing the beam loss, this is not assured. An effort has been initiated by the SNS team to produce a study plan. We encourage this effort.
- The HEBT momentum dump developed a cooling problem. The committee suggests trying to solve this problem as soon as possible (hopefully in 2009). Judicious application of the transverse and momentum collimators will yield useful information on the beam transverse/longitudinal tails. They can also be powerful controllers of the beam loss.
- Simulation efforts for the ring have made good progress and should be continued.
- Simulating extraction loss with the LEBT/MEBT choppers on and off is difficult because the level of loss is small. However, it remains a sensitive area where one can benchmark simulations, using the measured beam distribution in the SCL as input.

- A number of potential accelerator physics R&D items to reach 3 MW were identified and presented. As the beam intensity increases, issues considered in expected sequence are the e-p instability, feedback system, laser stripping, self-consistent space charge, barrier cavity, and large tune spread integrable optics.

13.2 Comments and Recommendations

- The committee strongly encourages the efforts to upgrade and improve diagnostics and wishes to re-emphasize the need to aim for 10^{-5} dynamic range for beam tail measurements.
- The committee suggests that efforts be made to provide a calibration of the BLM readings in terms of beam loss. Provide diagnostics to do this, if needed.
- The mystery of why SCL beam loss was not reduced when the SCL acceptance was tripled must be resolved.
- Regarding the BLM and activation studies, the committee suggests that at the present stage attention be paid mainly to BLM data. Activation data are useful but not critical. On the other hand, what constitutes the principal activated isotope in the SCL should still be identified.
- The committee suggests that new ingredients in ring simulation efforts should include, in approximate priority ordering, ring collimation, painting (in conjunction with dedicated painting experiments), extraction loss (see next item), space charge, and e-p instability.
- The committee suggests an effort be made to try to simulate extraction losses with the LEBT/MEBT choppers off. Some clever idea is needed here.
- The committee considers the items identified for study in connection with the 3 MW power upgrade to be interesting R&D, and endorses the list, with initial emphasis on e-p instability, feedback system, and laser stripping.
- On the e-p instability, it is suggested that dependence of this instability on the second harmonic RF and the chromaticity should be pursued to a conclusion. The effective SEY of the TiN coated surface should be determined. The committee also considers it important to identify the source(s) of the cloud electrons.
- On laser stripping, the committee encourages the test of mode locked laser stripping a 10 μsec beam soon. An elaborate quantum mechanical calculation of stripping efficiency is being done to optimize the stripping electric and magnetic fields. The Committee endorses the laser stripper study as exciting research, and a potentially critical ingredient in the 3 MW upgrade.

14 High Voltage Converter Modulators

14.1 Findings

The HVCM is the principal contributor to downtime of the SNS beam. There were a total of 560 hours of downtime in CY08, with 54 hours of nuisance trips, 19 capacitor failures and 58 IGBT failures. (86% availability in CY08).

Significant strides have been made in reducing the HVCM failures by replacing capacitors, cleaning up the insulation and improving voltage clearance in the HVCM Switch plate, with the result that only 16 IGBT's failed in first quarter of CY09, with one IGBT failure in the last beam run. However, IGBT faults and nuisance trips continue to cause an unacceptable amount of downtime.

The premature failures of the switch plate capacitors are not understood. The reputable manufacture of the capacitor rated the capacitor for 500,000 hours of life, yet 19 capacitors have failed at less than 20,000 hours. There is either a design/manufacturing error, such as poor impregnation, insufficient foil margin, or over temperature, or the HVCM operation has caused overvoltage, resulting in a reduction in lifetime.

The IGBT failures are most likely not related to the capacitor failures, since there have been twice as many incidents of IGBT failure than capacitor failure. It is not apparent that the last run period with one IGBT failure means that the cause of the faults has been addressed. It is also not very probable that the FIT (Failures in Time) rating of the IGBT's is an explanation of the IGBT failures. The FIT rating is based on time at voltage. There is a circuit on the switch plate which causes the voltages on the IGBT's to return to half of the total voltage during the time between pulses. The IGBT's are only at the high voltage with the present pulses for half the pulse length or $\sim$ 300 μs every 17000 μs ($\sim$ 2% of the time). Even with a FIT rate of 10,000 at the peak voltage and 168 IGBTs, the operation would result in a mean life to failure of all 14 units of $\sim$29,000 hours. With $\sim$19,000 hrs in CY08 there should have only been a maximum one failure instead of 58. The low voltage rating of 3300 V of the IGBT may be a factor in the failure, but not the FIT rate of the IGBT's.

14.2 Comments and Recommendations

To meet the availability and power requirements it is essential to put as much effort as practical into solving the remaining HVCM failure problems.

The failed capacitors should be examined by the manufacture and the probable fault mechanism determined to ensure the replacement capacitors do not have the same failure problem. The failure of a tank resonance capacitor within a short operating time, as well as the self healing energy storage capacitor showing signs of approaching their end of life, indicate that these capacitors should also be examined before they become the next significant failure problem.

The development of the HVCM control system should be accelerated to increase the detection and control of the IGBT's to reduce the probability of IGBT failures (Action ID: 1918, from the last AAC review). Some of the possible failures of the IGBT's which are not presently incorporated in the control, such as preventing triggering of the IGBT at the wrong time (Shoot-thru condition) and over current/overvoltage, are incorporated and have been tested in the new SLAC designed gate drivers. Even saturation of the core in simulated tests did not result in an IGBT failure. These new gate drive circuits should be tested in the HVCM and incorporated as soon as possible. Without understanding the root causes of the capacitor and IGBT failures, the operational approach of increasing the pulse width and/or increasing the peak power without the improved protection controls will most likely result in an unacceptable increase in failure rate of the HVCM.

The new HVCM Test stand should be accelerated, so that the new IGBT's and drivers can be tested for a sufficient time to insure there operation and improved availability before installation in the operating HVCM. The HVCM test stand should not be used for other purposes until the failure rate of the HVCM are understood and fixed.

The development of the Energy Storage protection system should be expedited to prevent explosions of the IGBT under IGBT fault conditions (Action ID: 1922, from the last AAC review). When it can be avoided, it is unacceptable to have flying projectiles under frequent fault conditions.

The separation of the HVCM development engineering group from the daily operation and maintenance of the HVCM is necessary to increase their attention to the problem. However, being in a separate department during this critical time of improving availability, could limit their access to the actual failure conditions and technicians needed to resolve the availability problems.

15 RF systems

15.1 Findings

There are a number of RF systems in the SNS accelerator complex: the warm linac RF, the superconducting linac RF, the ring RF, the ion source RF, the MEBT rebuncher system, and their low level RF controls.

Warm linac RF Last year it was demonstrated that an average beam current of 24 mA, which is nearly full design intensity, could be accelerated in the warm linac. In this case, the klystrons were in operation with their voltage below the design level.

Superconducting linac RF The superconducting linac RF system runs out of power at high beam current, since the klystrons have been operated below the design voltage of 75 kV, in order to extend the life of the HVCM. An extra modulator has been added here to allow the design voltage to be achieved.

Ring RF The ring RF was successfully operated at 1.3×10^{14} protons per pulse with two fundamental mode cavities at 14 kV and 16 kV, and the second harmonic cavity at 14 kV. A small amount of dynamic cavity tuning on each cavity was employed, but nothing special was required for this beam intensity. On the other hand, the ring Low Level RF controls are not adequate at present: for example, the system doesn't display the beam pulse. The RF personnel had to be kept on-shift during development sessions, when changes in the RF parameters might be required . An improved ring LLRF system is under development, utilizing much of the Linac LLRF hardware and software.

Ion Source RF The ion source RF comprises a 2-MHz, 80-kW power amplifier and matching network. Since the existing amplifiers have reliability problems, candidate replacement amplifiers have been identified. A High Voltage isolation transformer is being developed, which would allow a solid state amplifier to operate at ground potential. In the future, a dynamic tuning capability will be preferable, since the plasma loading changes the matching network tuning.

MEBT rebuncher The MEBT rebuncher amplifier problems resulted in 140 hours of down time last year. The amplifiers can not provide the required power, since arcing occurs in the power supplies and output cavities. The high current surges during arc conditioning tripped and destroyed AC circuit breakers. In order to keep from damaging breakers, fast fuses were added. However, these amplifiers should be replaced to ultimately cure these problems. The existing amplifiers must continue running until the new improved amplifiers are available. The present system will be replaced with Solid State Amplifier Capacitor Charging Supplies, which can withstand an arc condition and will not blow fuses.

The original replacement plan called for a single, IOT Based, amplifier with Phase and Amplitude control accomplished by High Level Vector Modulators, However, the original plan ran into several problems, so the present candidate is a Solid State amplifier. After some operational experience of the first solid state amplifier, a decision will be made to purchase the remaining one.

15.2 Comments and recommendations

In general, high-power RF systems and pulsed power supply systems, being associated with discharging or arcing problems, are two major accelerator components, for which special care should be taken for reliability and availability issues. If the goal of the neutron availability is 95%, strong efforts should be devoted to these systems.

The down time budget of 38 hours per 5000 yearly operating hours (99.24% availability) given to the RF system is unreasonably small from this viewpoint. In order to realize this challenging goal (even if the down time budget is increased by a factor of four or so), any symptom for degradation in the performance of the RF systems should not be overlooked. Components which show symptoms could be replaced during the scheduled maintenance times. For this purpose, diagnostic systems for the klystrons, the thyratrons, and others, incorporating very sophisticated control systems, should be developed on the basis of data accumulated throughout their operation and testing.

The committee, thus, recommends increasing the number of RF test stands to at least three (for example, two for two different RF frequencies, and one for HVCM). In addition, an efficient scenario of spare replacement for these components is required to reducing down time.

The warm linac experienced a condition in which heavy window arcing was sustained at the input to the warm RF cavities. In future, the RF windows should be replaced, for example, by KEK/Toshiba type windows, which have been successfully operating with superconducting cavities.

The committee endorses the MEBT rebuncher RF strategy as a reasonable one on the basis of the experience obtained so far.

16 Other electrical systems

16.1 Findings

DC Power Supplies So far, DC power supplies have been mostly trouble free, as usual. However, the electrical system group argued that for realizing an availability of 95 %, they need either a very large MTBF ($\sim$ 100 years) or some redundancy, since there are a large number of DC supplies at SNS: 114 unipolar power supplies and 360 bipolar corrector power supplies. In addition, there are 8 slow-pulsed injector power supplies. With the addition of about 40 correctors for redundancy, the MTBF requirement for the remaining supplies can be reduced to 10 years.

Pulsed Power Supplies for Extraction Kicker The high-power pulsed power supply system, together with the RF system, detailed in previous section, are the two major systems critical for improvement of availability and reliability.

For example, when the repetition rate was increased from 30 Hz to 60 Hz, the failure rate of thyratrons used for the extraction kickers drastically increased. Failures caused long down times, although spares were available. The degraded thyratrons should be replaced during scheduled maintenance time. Although the triggering circuit has a design flaw, giving rise to timing jump and probably shortening the lifetime of thyratrons, the problem has been now solved by higher voltage rated capacitors.

The down time of the pulsed power supplies of 3.4% in FY08 was improved to 1.5% in FY09, which will be further reduced by the above remedies. However, the MTBF of the thyratron controlled PFN kicker power supplies is hard to improve better than 10,000 hours. It is proposed to construct spare power supply/magnet systems, which can be immediately switched in at the failure to meet the 95% availability goals. The data taking of the varying parameters of the thyratrons is very important in order to decide when and which thyratron should be replaced by a spare during the maintenance time. It is also proposed to air-condition the room in which the PFNs are located.

Pulsed Chopper Supplies There are two chopper systems: a LEBT chopper and a MEBT chopper. The LEBT chopper system comprises 4 bipolar 2.5 kV LEBT channels, each of which floats on a 60 kV LEBT lens element. Because of the float, the choppers are vulnerable to being damaged by sparking. The downtime due to extensive and persistent LEBT sparking was drastically improved from 245 hours in FY07 to 50 hours in FY08, but the improvement in FY09 was modest, to 30.5 hours. A redesigned system is planned to be installed this summer, but the vulnerability to spark damage will remain to some degree. It is proposed that two spare LEBT amplifiers be installed with remote high voltage switches so that a damaged channel could be switched out remotely.

The recently installed MEBT choppers, comprising two unipolar channels (positive and negative), have been fairly reliable, probably because these are not floated on high voltage. However, it is also proposed to install two spare channels upgraded to the same specifications as the working channel.

AC Systems and Cabling The 48 hours of downtime in FY08 are due to two issues: a 13 kV switch failure, and small voltage transients. Since the switch failure was due to an incorrect heater circuit, it has been checked that all substations have operating heaters.The voltage transients, which are typically 20-30% and last for 5-7 cycles (80-120 ms) , happen 2 or 3 times per year, arising from lightning strikes, etc. on the external TVA grid. Some equipment is very sensitive to these transients and can lead to long downtimes.

CHL is most sensitive system. Also, some systems can not be turned off without risking damage to rf cavities. This prevents scheduled maintenance on some electrical systems. It is proposed to install Uninterruptible Power Systems (UPS) on most sensitive equipment and provide duplicate feeders and substations on systems that cannot be turned off.

16.2 Comments and recommendations

It is a reasonable choice to reduce the MTBF to a practical level by having a modest amount of redundancy in the DC power supply system. The committee concurs with this proposal.

In general, the issues with respect to the pulsed power supplies are well addressed on the basis of operational experience, and possible remedies for improving the availability have been proposed. Since every possible effort should be taken if it can be effective, the committee endorses these proposals.

Regarding the proposed installation of UPS systems on some CHL equiment: Although the committee agrees with the necessity of this kind of system for 95% availability, the committee suggests that the group investigate further the possibility of other systems to protect against a few-cycle power loss, including a motor generator system.

17 Control systems

17.1 Findings

The controls system presentation showed good improvements achieved over the past year, and the results exceeded the group's own expectations. A competent, systematic approach to addressing issues is evident from the presentation, and the controls group was able to take advantage of numerous AIP projects. Fairly new is the utilization of the "Availability Index" system, a formal approach to prioritizing tasks.

Recently, a rash of PLC failures occurred, and all of these incidents affected the cryo systems. The cause was identified as manufacturing problems on the part of the vendor, Allen Bradley, and the controls group is now working closely with Allen Bradley to resolve these issues.

Again with the cryo systems, IOC problems and PLC-IOC communications problems were experienced; cryogenics and controls engineers have together identified control system improvements that will ensure a fail-safe state of the hardware. The cryo group is going to conduct formal Failure Mode Analysis procedures together with controls group, to identify other improvements.

The controls group will conduct code reviews for other critical areas as well, and strive to ensure that proper error checking and exception handling will be based on Failure Mode Analyses.

The controls group now maintains three "warm-standby" servers that contain the systems data base. Each of them maintain mirrored copies of critical file banks and is able to take over tasks when one of them drops out, providing significant and very useful redundancy of service.

The implementation of clustered Oracle servers eliminates the dependence of accelerator controls on the ORNL-IT network and machines with respect to utilizing the Relational Data Base.

The group established viewing capability of the Personnel Protection System through EPICS. This connection does not enable active control of the PPS, which would defeat important safety rules, but helps Operations personnel with trouble shooting. A new Archiver and Alarm Handler (BEAST) was written under Control System Studio (CSS), an open-source software mostly developed by SNS and DESY. It includes version control for the core software and is very user-friendly; for example, users can write enhancements, annotate graphs, and then send the file to the Electronic Logbook utility. The Archiver functions provide a careful assessment of off-normal data before an actual alarm condition is issued.

As one of many General Plan items, the group intends to establish software configuration control and urgently needs a QA manager. They also lost the two original authors of that software due to retirement but will get one back as a contractor

17.2 Comments

The major challenges for the Controls Group relate to attracting and retaining a proper skills mix across the staff and a general need for more resources to tackle all manifest issues. This latter condition is being experienced by many other SNS organizations.

18 Beam instrumentation

18.1 Findings

The SNS accelerators are equipped with an extensive and fairly complete suite of beam instrumentation systems, covering priorities related to regular/safe exploitation, setting-up and tune of the accelerators, needs of expert beam physicists and special studies.

Following last year's recommendation of the AAC to improve beam diagnostics for a better understanding of beam dynamics in the linac, three additional Bunch Shape Monitors have been added.

However, most instruments deserve improvements to properly fulfill their role:

- the BLM system, to improve reliability,
- the Beam Position and Phase measurement system to increase user friendliness,
- the transverse beam profile devices, to upgrade halo measurement,
- the longitudinal beam profile devices, mostly to upgrade their user friendliness and hence their usability.

18.2 Comments and recommendations

The committee underlines that progress towards higher beam power and availability depends upon an in-depth understanding of beam behavior, which can only be obtained with high quality and user-friendly beam instrumentation. The improvements presently undertaken are hence strongly encouraged, and their ranking in terms of priority is felt appropriate.

More specifically, the committee highlights the importance of being able to measure tails and halo in all phase planes for reaching the planned objectives:

- In the longitudinal phase plane, the Bunch Shape Monitors have proven their very large dynamic range: the development of the software required to facilitate their use is highly recommended.
- In the transverse phase plane, the Laser Wire Scanners are remarkable instruments capable of monitoring transverse beam evolution along the linac and during the pulse. It is regrettable that they cannot presently be used to their full potential, mostly because of stability problems. The committee urges the implementation of the improvements proposed by the beam instrumentation specialists.
- The only possibility to measure transverse beam halo down to the 10^{-5} level is with the HEBT beam scraper. Transforming this scraper into a fully functional halo monitor is essential to help understand the process of halo formation and minimization.

In the accumulator ring, the committee is favorably impressed by the preliminary results obtained with the electron scanner and encourages its further development.

19 Answers to questions posed to the committee

19.1 Do you have any specific recommendations for RFQ spare acquisition strategy? Choices include a carbon-copy, an RFQ with revised mechanical design but the same beam dynamics design, or a fresh design altogether.

19.1.1 Findings

The strongest hypothesis for the failure mode is based on the observation of a significant pressure rise in the main cooling-water circuit when the second failure occurred. A discussion with the SNS Engineering Group Leader held a day after the review further revealed that a detuning effect proportional to this water pressure was recently observed.

A reasonable explanation for the underlying mechanism is the partial separation of the copper and Glidcop components in at least one quadrant of one of the four RFQ modules over a significant length of the structure. Such separations had been revealed during the fabrication at LBNL by ultrasound diagnostics, especially with Module 1, and had required re-brazing of two modules. Due to the fairly ambiguous nature of the ultrasound diagnostic, it could very well be that there still exist more such local separations at present, subjecting the soft-copper inner part of a module at those locations to plastic deformation when the water pressure rises significantly beyond nominal values. The recommendations below are based on this hypothesis.

Note that the water channels are cut into the (inner) soft-copper components but have no connections to the vacuum inside the cavity. Water leaks detected at the outside of the RFQ would indicate major copper/Glidcop braze failures, but failures could very well be present without any exterior sign, possibly causing a partial by-pass between water channels.

LBNL's design strategy for building copper cavities with Glidcop strongbacks was based on the assumed danger of material creep under the weight of a pure soft-copper cavity. This danger could be averted by using a stainless-steel strong back around the cavity. Secondary advantages were the ability to cover the cooling channels with the brazed Glidcop material and also to provide a stronger backing material for bolting down all attached flanges (which are sealed to the soft copper) and to connect the modules to each other. The cooling channel issue can be resolved by covering the channels with brazed copper sheet material or by inserting a flat gasket, and support for bolts can be provided by stiffer backing flanges, similar to the CW LEDA RFQ at Los Alamos.

19.1.2 Comments and Recommendations

It is mandatory to procure a new and improved RFQ to replace the present one. The committee judges that a mere carbon copy of the existing RFQ would carry the same risk of major failure as the existing one.

The new device should be built with all the care and attention it takes to guarantee optimum performance, both from the RF/structural and beam dynamics points of view. Technological approaches should be fully validated through a sequence of design reviews by recognized experts in the field. The device needs to be extensively tested and fully characterized with beam, measuring all beam characteristics at its exit.

The general mechanical layout should be kept:

- Consisting of four modules with pi-mode stabilizers
- Four vanes with cooling channels near vane tips for dynamic tuning
- Transverse cavity and (unmodulated) vane shapes.

A new mechanical design should be created, with interconnected steel strong backs attached to each quadrant of every module to support the weight and with other engineered solutions for flanges.

The time for the replacement project could easily amount to 2-3 years. While the mechanical design work is proceeding, the beam dynamics should be revisited using modern codes. The resulting, optimized vane tip modulations can be applied at the end of each quadrant's fabrication process.

19.2 Are there other experiments or simulations we should attempt in order to understand the SCL losses?

19.2.1 Comments and recommendations

- Continue the development and upgrade of diagnostics. Aim for 10^5 dynamic range.
- Try to calibrate between BLM readings and beam loss. Provide diagnostics if needed.
- Resolve the mystery of beam loss not reduced when SCL acceptance was tripled.
- Resolve the mystery of the growth of longitudinal emittance.
- Review the missing information on beam loss and design diagnostics accordingly. Example: perhaps measure longitudinal emittance at another upstream location.
- Solve the HEBT momentum dump problem, so as to apply both transverse and momentum collimations, as soon as possible.
- Add to ring simulation: ring collimation, painting, extraction loss, space charge, and e-p instability.

19.3 Do you have specific suggestions regarding the 95% availability strategy?

19.3.1 Comments and recommendations

We offer the following suggestions:

- The 95% plan needs to be supported by lower level budgets for mean time between failures and mean time to repair (MTBF, MTTR) and examination of correlated failures.
- The plan needs to incorporate current experience.
- We suggest looking at modeling (via Monte Carlo) that was done for ILC. This modeling incorporated MTBF, MTTR, preventive maintenance, and component redundancy.
- Make clear to user community that 95% is a preliminary goal, not a commitment.

The committee recommends that SNS develop a reliability model that includes MTBF and MTTR of individual components, based on reasonable extrapolation from current performance, redundancy of subsystem components, and a preventive maintenance strategy to support availability goals.

19.4 Is the modulator improvement plan and operational approach reasonable?

19.4.1 Comments and recommendations

The committee is concerned that the general approach to the modulator improvement may not be consistent with the operational and availability schedule.

The committee judges that the work necessary to reduce the failures in the HVCM, although started, is not proceeding at the rate needed to provide for the availability requirements outlined in the power ramp-up plan.

The prototype IGBT and IGBT drivers modifications are available, but there is no test stand available to test the units for a suitable amount of time to insure performance.

The operational approach of increasing the pulse width and/or increasing the peak power without the improved protection controls will probably result in a unacceptable increase in failure rate of the IGBT.

The committee recommends:

- a technical investigation of the premature capacitor failures be carried out to determine the probable fault mechanism;
- the development of the HVCM control system be accelerated to increase the detection and control of the IGBT to reduce the probability of IGBT failures;
- the HVCM Test stand be expedited, so that the new IGBT's and their drivers can be tested for a sufficient time to insure their operation before acceptance and installation in the operating HVCM.
- the development of a Energy Storage Capacitor protection system be expedited to prevent explosions of the IGBT under IGBT fault conditions.

19.5 Are the plans for cavities and cryomodules reasonable for achieving 1 GeV output energy?

19.5.1 Findings

At present 80 cavities are installed in the linac. With the planned upgrade of the HVCM system, the available RF power will increase. This will allow operation at 940 MeV (1 ms, 26 mA). The voltage limit is determined by collective cavity effects, driven by field emission. Without installation of more modules and some overhead in voltage, this would require operation of the high-β cavities at the design gradient, i.e. about 2 MV/m higher than presently possible.

There are only two in situ cleaning methods known: High peak power processing and He (or plasma) conditioning. The first one requires short high power pulses and a change of the input coupler adjustment. This technology will interfere with the operation of the linac and has risk of damaging the coupler. Therefore it is not applicable.

19.5.2 Comments and recommendations

The new method of plasma conditioning is promising. But intensive R&D is required to determine the best operating conditions. This activity should get high priority in the SRF group and might need additional manpower support.

19.6 Is the foil development program sufficient to reach 3 MW design beam power? Are there other approaches that you recommend?

19.6.1 Findings

As noted in Section 10, the present nano-crystalline diamond foils are quite successful at present and will probably work to 1.4 MW, based on the experience with such foils at SNS and the LANL PSR. It is more problematic that they will work at 3 MW, since the maximum operating temperature with acceptable lifetime is still unknown. In addition, the foil lifetime is not known as a function of foil temperature (or beam power deposition) above present operating conditions. We do not know of an adequate model for extrapolation of present experience at 0.7 MW to the 3 MW goals. From simulations, one can estimate the power deposition in the foil at 3 MW, and hence the temperature (perhaps 2600 K or so), but as yet there is no applicable data on foil lifetimes at these temperatures.

19.6.2 Comments and recommendations

The Hybrid Boron mixed Carbon (HBC) foil developed at KEK shows promise of higher operating temperatures and longer life and its development along with development of other promising materials should be vigorously pursued for the power upgrade.

Studies of foil lifetimes and failure modes on the 30 keV electron beam test stand will provide some valuable insight and guidance for high power foil development of HBC and other foil materials. We would recommend that these studies be complimented with short-term tests of the most promising foils with proton beams at SNS (and/or PSR) using special high peak-power proton beam conditions (highest accumulated charge, smaller stored beam size, foil moved further into the stored beam, full ring RF voltage, etc) that give high foil hits/proton, hence high instantaneous power-deposition rates. These would be low rep rate experiments commensurate with beam study time allocations and, depending upon the maximum power deposition rates achievable in the experiments, could give results on short-term survivability at beam power deposition rates in excess of that needed for 3 MW. It would also be important to measure thermionic emission at high power and assess its impact on operations and the e-p instability.

Laser stripping injection, in the configuration tested at SNS, is a very attractive development that could eliminate the beam loss and foil lifetime problems associated with foil stripping. The committee recommends its continued development as a promising option for the power upgrade. All should be aware that this is a very different technology that has not yet been used for high power accelerators and may have unforeseen problems. Many practical implementation problems still need to be addressed, especially reliability and availability issues. For these reasons, the committee recommends that the stripper foil injection system be retained as an implementable backup if laser stripping is chosen for 3 MW.

19.7 If the first target module is removed intact during the summer 2009 shutdown (∼9 dpa) should we perform PIE on it, considering the PIE and waste handling costs, etc., or wait until the next target reaches its end of useful life?

19.7.1 Comments and recommendations

PIE of a target that has reached its end of service life can be expected to yield the most conclusive clues on the failure mechanism, which is why this would be the preferred option.

However, even if the target is taken out earlier, this removal is done for a reason (dpa-damage on the water shroud), and PIE should be carried out at least to an extent that allows one to judge whether the arguments for removal were valid, since the same arguments will be used again when targets with successful pressure wave effects mitigation are in operation. The current limits of 10 dpa may turn out to be unnecessarily low. The best way to assess this is by examination of a target in which dpa damage was the dominating damage mechanism. This is true for the first target.

20 Conclusion

The SNS team continues to make good progress towards the achievement of design performance, while simultaneously providing useful neutron beams to users.

There is a lot of work to do to achieve the ambitious performance and availability goals. Particular areas, such as the HVCM system, need more effort. Acquisition of a spare RFQ must be pursued vigorously. Nevertheless, the committee sees no show stoppers to achieving the 1.4 MW power goal, with 90% availability.

For the longer-term future, the R&D needed for the power upgrade to 3 MW and for the second target station has begun and is progressing well. A bottoms-up reliability model needs to be developed to understand what will be required to achieve 95% availability.

21 SNS Accelerator Advisory Committee Charter

- Committee Charge and Responsibilities

  The Accelerator Advisory Committee (AAC) will report to the Oak Ridge National Laboratory (ORNL) Associate Laboratory Director (ALD) for Neutron Sciences and will advise the Research Accelerator Division (RAD) and Neutron Facilities Development Division (NFDD) Directors on the operations and performance of the Spallation Neutron Source accelerator complex, which includes the target systems and the site conventional systems. The committee will assess and provide advice on accelerator performance, performance limitations, proposed improvements to overcome those limitations, operation of the facility, the on-going program of accelerator science and technology development, and plans for future upgrades to the accelerator complex.

- Committee Membership

  The Chair and Members of the committee will be appointed by the ALD for Neutron Sciences in consultation with the RAD and NFDD Directors. Members will be appointed to three-year terms with possible renewal by mutual consent.

- Operations

  The AAC will meet regularly, approximately once per year, but may be called upon at other times, via email or teleconference to address specific issues.

A specific charge for each meeting will be developed by the RAD and NFDD Directors, and transmitted to the committee in advance. The Chair, in consultation with the RAD and NFDD Directors, will set the meeting agenda.

A verbal report will be presented at the end of each meeting followed by a written report to the ALD for Neutron Sciences submitted within 4 weeks. The AAC will also be asked to provide an oral briefing to the Neutron Sciences Advisory Board which meets yearly.

22 Committee Membership

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SNS Accelerator Advisory Committee Meeting Agenda
February 24-26, 2009

Tuesday February 24, 2009

Length	Time Start	Time Stop	Talk	Speaker	Content
0:30	8:00	8:30	Executive Session		
0:30	8:30	9:00	SNS Overview	I. Anderson	Overview of SNS
0:40	9:00	9:40	Accelerator Systems Overview and Plans	S. Henderson	RAD, Accelerator System, Ramp Up Plan, Challenges and Progress
0:20	9:40	10:00	Break		
0:30	10:00	10:30	Neutron Facilities Development Overview and Plans	J. Haines	NFDD, Target Systems, Target Systems Challenges and Plans
0:20	10:30	10:50	SNS Science Overview	D. Myles	SNS Science Progress and User Program
0:25	10:50	11:15	SNS Operations Performance	G. Dodson	Performance plots, downtime results, Ops organization
0:40	11:15	11:55	Accelerator Physics Overview	J. Galambos	Ramp Up progress and challenges, beamloss overview, key AP topics
0:10	11:55	12:05	Discussion		
0:45	12:05	12:50	Lunch		
0:25	12:50	13:15	Accelerator Engineering Overview	G. Murdoch	Engineering challenges, AIP progress
0:40	13:15	13:55	Ion Source and LEBT Performance and Plans	M. Stockli	IS and LEBT Performance, limitations, challenges
0:30	13:55	14:25	Front-End and NC Linac Overview	A. Aleksandrov	Front-end performance, chopper systems, emittance, NC linac performance, losses, challenges, gate valve problem
0:20	14:25	14:45	Break		
0:35	14:45	15:20	Superconducting Linac Operations and Performance	S-H. Kim	SC Cavity and Cryomodule performance, testing program, understanding of limitations
0:35	15:20	15:55	Superconducting RF Activities and Plans	J. Mammosser	SRF Facilities, CM19 testing, path forward for spares, pressure vessel and Cryomodule repair
1:30	15:55	17:25	SNS Tours		Tunnels, Gallery, Experimental Hall
1:00	17:25	18:25	Executive Session		

Wednesday February 25, 2009

Length	Time Start	Time Stop	Talk	Speaker	Content
0:25	8:00	8:25	Linac Beam Dynamics Progress	Y. Zhang	Linac performance, matching, acceptance, SCL algorithms, output beam quality
0:40	8:25	9:05	Linac Modulator Performance and Upgrades	D. Anderson	Modulator performance, failure mode analysis, AIP progress, path to 8% duty
0:30	9:05	9:35	RF System Overview, Performance and Plans	T. Hardek	RF System overview, klystron performance and issues
0:20	9:35	9:55	Cryogenic System Performance and Plans	F. Casagrande	CHL Overview, 2K performance, plans for backup fridge and xfr line
0:20	9:55	10:15	Break		
0:20	10:15	10:35	Electrical Systems Performance	R. Cutler	Extraction Kickers, modulator operations (if needed), power supply systems, etc.
0:40	10:35	11:15	HEBT/Ring/RTBT Overview	M. Plum	Overview, challenges, Idmp situation, RTBT situation, RTBT/Target interface, foils, etc.
0:30	11:15	11:45	Ring Beam Dynamics Progress	J. Holmes	Lattice, tunes, collective effects, high intensity, collimation, etc.
0:15	11:45	12:00	Discussion		
0:45	12:00	12:45	Lunch		
0:40	12:45	13:25	Target Systems Performance and Plans	T. McManamy	Target Systems overview
0:40	13:25	14:05	Target R&D Program	B. Riemer	R&D progress on bubbles, gas wall, etc.
0:30	14:05	14:35	Controls System Performance and Plans	K. White	Controls systems overview, performance issues, challenges and plans
0:30	14:35	15:05	Beam Instrumentation Performance and Plans	A. Aleksandrov	BI systems overview, new systems under development
0:20	15:05	15:25	Break		
0:25	15:25	15:50	Foil Development Program	R. Shaw	Foil development progress, lifetime testing, plans
0:30	15:50	16:20	Accelerator R&D Activities	V. Danilov	laser-stripping, ORBIT code development, e-cloud simulation, etc.

Thursday February 26, 2009

Length	Time Start	Time Stop	Talk
3:00	8:00	11:00	Executive Session
1:00	11:00	12:00	Closeout