First SNS Accelerator Advisory Committee Meeting Jan 22-24, 2008

SNS Accelerator Advisory Committee

General remarks

- The committee would like to thank the SNS staff for the warm hospitality provided during the review, and the excellent presentations.
- The committee congratulates the staff on the progress it has made since the end of the construction project in bringing the beam power to its current point (which makes the SNS the world’s highest power spallation neutron source), while at the same time providing useful neutron beams to SNS users engaged in pioneering experiments.

Congratulations! Challenges!

- 233KW and 60 Hz@ 840MeV, pulse length 270microsec.
- ~85% availability
- 300 kW (@60 Hz) achieved in beam study period on 1/24/08
- Achieved FY07 ~160 MW-hr, goal ~120
- Major down time areas in FY07
  - Ion source, LEBT electrodes
  - Modulator
  - Cryogenic moderator Heat exchanger
- Goal by end FY08
  - 950KW, 887MW-hr in FY08 (internal MW-hr goal 20% greater)
  - Falling behind at present in accumulated energy> need for 60Hz operation
- Goal by end FY09
  - 1.4 MW, 5000hr/y tot op, >90% availability

Challenges

- Steep ramp up this year
- Ion Source current
- Converter Modulator availability at 60Hz, high duty factor, Hi Voltage
- SRF hi beta cavity gradient
- Beam loss management, understanding, & reduction
- Target beam density restrictions

- Large number of AIP projects to address deficiencies and limitations

Ion Source and LEBT

- Ion Source and LEBT supported SNS commissioning well
  - Reduced requirements
  - Many detailed technical problems successfully tackled
    - Antenna lifetime
    - LEBT overheating and sparking
    - Protection of LEBT chopper switches
    - Cesium management and collar design
- Routinely delivering ~30 mA / 700 μs / 60 Hz over 2 weeks with high availability, compared to 38 mA / 1000 μs /60 Hz over 3 weeks nominal
- Lately achieved encouraging demonstration-quality results
  - 38 mA / 700 μs / 60 Hz
- Should again investigate emission spectroscopy technique as cesiation indicator
- New electron dumping scheme in LEBT promises to eliminate beam orbit fluctuations, heating of first lens
  - Not presented during review, but information handed out

Ion Source and LEBT

- New LEBT design with solenoid focusing looks promising
  - Need to further investigate chopper layout
  - Address issues of time-varying space-charge compensation under influence of chopper and RFQ fields
  - Potential issue with beam instabilities
- New source development progressing along two lines
  - RF driven discharge with external antenna
    - Good results with AlN discharge vessel
  - Helicon driven discharge
    - Significant boost in plasma density
- Second test stand and addition of one person to group will be very helpful
- SNS power ramp-up plan calls for reaching 38 mA beam current at 60 Hz / 1000 μs in Sept. 2008
  - Programmatic pressure might lead to accepting less-than-ideal technical concept for future ion source

Is the Ion Source Progress sufficient and appropriately directed to reach 1.4 MW?

- In spite of many technical improvements, Ion Source and LEBT performance overall is still marginal, measured at nominal parameters
  - Routinely delivering ~30 mA / 700 μs / 60 Hz over 2 weeks with high availability, compared to 38 mA / 1000 μs / 60 Hz over 3 weeks nominal
- Lately achieved encouraging demonstration-quality results
  - 38 mA / 700 μs / 60 Hz
- Many promising avenues for improvements of Ion Source and LEBT
  - Standard source
    - Improvements of cesium management
  - Source with external antenna
  - Helicon driven source
  - Improved electrostatic LEBT
    - Modification of electron dumping mechanism
  - Solenoid-focused LEBT
- May need more time than Sept. 08 to arrive a production grade solutions
- Should not be pressured to discard any of the available options prematurely

Front End and RT Linac

- RFQ suffering from poorly balanced power distribution
  - Limited to 3% duty factor
  - New distribution system has been designed, should be implemented as soon as possible
- Several MEBT problems
  - MEBT chopper not functional
    - New design ideas should be finalized and implemented
  - Power delivered by two amplifiers has to be increased
    - Presented design ideas appear reasonable
  - Concern whether MEBT chopper target can handle increased beam load resulting from slowed-down LEBT chopper
- No significant issues with DTL and CCL
  - Gate-valve overheating problems appears to be well in hand

Front end and NC Linac + Linac beam dynamics

1. Most limitations in the Front end and nc linac hardware are identified and properly addressed:
   - The mechanism of breakdown of the LEBT chopper has been understood and mitigation measures have been taken,
   - The maximum duty factor of the RFQ will be brought up to 8 % by using 2 SCL-type RF windows instead of the present 8 RF coupling ports.
   - The amplifiers driving the rebunchers in the MEBT are being improved to deliver the nominal power of 20 kW.
   - A simplified version of the MEBT chopper is in preparation
   - Corrective measures are being designed for CCL gate valves heated by RF.

2. Large progress has been made in modelling the beam and tuning the accelerator, as illustrated by the noticeably reduced beam losses in the CCL after correction of the beam trajectory.

Front end and NC Linac + Linac beam dynamics

HOWEVER…

3. The accuracy of the tuning methods remains to be improved (e.g. discrepancy between measured and expected bunch phases along the CCL) – It could be related to ambiguities of interpretation of some measurements…

4. There are unknowns in the longitudinal phase plane: the longitudinal emittance is twice nominal and the presence of long tails is strongly suspected. => More large dynamic range bunch shape measurement devices are necessary.

5. The Twiss parameters of the RFQ in one plane seem different from theory: could the RFQ be also the culprit for the problems found in the longitudinal phase plane?

Front end and NC Linac + Linac beam dynamics

THEREFORE…

6. The hardware improvements planned during the next months in the front end and nc Linac together with the present quality of understanding of the full Linac easily allow for doubling the beam power (~ 500 kW) in operation.

7. Machine studies must be actively pursued to understand the longitudinal beam characteristics and correct or mitigate the losses in the SCL before regularly running at higher beam power. A better understanding and characterization of the RFQ is urgently needed.

8. Afterwards, the nc Linac and the beam dynamics in the whole Linac will not present any obvious bottleneck on the path of the PUP (3 MW).

- Accelerator Physics, HEBT/Ring/RTBT,
- Ring Beam Dynamics, Accelerator R&D Activities

Modeling

– Tunings of RFQ, DTL, CCL, SCL were done by detailed fitting of beam behavior to what is expected from the computer model that took into account of space charge. Tuning procedure has regularly progressed and is rather successful:
    - Beam-based orbit correction was successful in CCL
    - Measured SCL longitudinal acceptance agreed very well with simulation.
    - Tuning time steadily improved so turn-on time is no longer a problem.
    - Some questions remains to be answered before safely considering operation at the highest power level.

– Optics in the RTBT line has encountered some apparent discrepancies (e.g. power density and beam positions between the target and the proton beam window). This should not be an unsurmountable problem. Resolution of this problem will require understanding of RTBT optics including coupling. With some priority given to the problem and some dedicated time, it should be resolved in time. Additional diagnostics and correction elements might/should be considered.

– Ring linear lattice looks reasonable. X-Y coupling measured and corrected to reasonable level. Should
  - try to identify source of the coupling
  - include space charge as beam intensity increases
  - The discrepancy of betaY at some ring locations seems not a serious problem. However, its origin should be traced.
  - Collimation losses were measured and compared with simulation; should continue it as an important benchmarking effort.

– A single-minipulse technique has been developed to measure the macropulse beam distribution in the RTBT. It was applied to address the coupling problem. It was convincingly found that coupling in RTBT comes from skew quad in the extraction septum as calculated in a 3D magnet code. When included, the coupling in the RTBT line is well explained by the ORBIT model.

– In general, modeling of the ring is in better shape than that of the linac and transport lines. It is troubling that the linac longitudinal dynamics is not understood well enough to evaluate the beam centroid and/or rms values. The cause for the measured longitudinal emittance which is twice the expected value is unexplained. Transverse matching HEBT-ring-RTBT also seems to need some study. More priority should be given to modeling, including halo/tail, for the linac and transport lines.

Beam loss

- Beam loss is difficult problem, and it might get harder with higher beam intensities. Beam loss mechanism at a level of 1W/m demands a detailed understanding of the accelerator. The following efforts are needed:
  - updated sharpened simulation codes
  - dedicated machine time
  - associated diagnostics (how to use the data taken by 400 BLMs and activation measurements, new diagnostics, such as BLM's with microsecond-scale time resolution, scrapers to measure halo)

- Beam losses are localized at
  - Several locations in the SCL
  - Idmp line
  - Ring collimators
  - Extraction line

It is puzzling why the linac seems to cause more beam loss than the ring proper. On the other hand, it is comforting to know that the bulk of the accelerator system is more or less loss free. The understanding and correction of the imperfections has significantly progressed, as testified by the reduction of the activation per Coulomb which has dropped even as the beam power was increased from 30 kW to 200 kW. The factor of 3 reduction of beam loss per proton which is necessary in some locations for an acceptable operation at 1.4 MW can be reasonably expected during the next 18 months, with effort.

Beam loss (con't)

- \- Loss along SCL is found to be most likely to be longitudinal. But it is not clear where this longitudinal tail originates from and how it behaves down the linac. It is suggested that a focused effort be made to
  - design experiments to detect the tail even with crude accuracy. We suggest deploying additional bunch shape monitors with improved sensitivity. Developing additional large dynamic range diagnostic devices for bunch shape measurement would also be very beneficial.
  - model and simulate this, in particular to look for possible sources of the tail and avoid its generation, to find an efficient way to optimize the linac operation set points, or to find where there might be ways to collimate the tail.

Instabilities

- In general, instabilities not serious up to 1.1E14.
    - Ep instability was observed, qualitatively in agreement with simulation.
    - Observed instability beam spectrum peaked at 6 MHz due to extraction kicker impedance.
  - This is a relief! It is expected that instabilities is not going to be serious up to 1.4 MW. But should keep it in close attention when considering power upgrade to 3 MW:
    - The active damping system being developed as an AIP project is a prudent measure to address this risk.
    - Modeling efforts on the e-p instability using ORBIT with the electron cloud module are encouraged
    - Laser stripping with 90% efficiency has been demonstrated. Need mode lock the laser to save power. A clever idea of introducing D'=2.6 at the IP to compensate for Doppler broadening was invented.
    - A space-charge painting scheme is proposed theoretically. By going to diagonal tunes plus a solenoid, and by introducing a barrier rf bucket, space charge tune spread can in principle be much reduced. This exciting possibility should be pursued. In parallel, it should also be pursued the possibility of applying the 2nd harmonic rf to see if that suffices at 3 MW.

HVCM System

- The HVCM is responsible for a large portion of the present operations down time and potentially could limit the “ramping-up program” plans for high availability.

- Dave Anderson and his colleagues need to be commended for their efforts in replacing the transformer and filter inductor in the HVCM oil tank which reduced the failures in the tank thereby significantly reducing the time to repair of the modulators.

- A number of Acceleration Improvement Programs are underway which could have a significant impact on the reliability of the modulators.
  - higher voltage and current IGBTs
  - improved gate circuit
  - capacitor replacement
  - improved insulation

HVCM System

- Some of the present failures are undetermined and there relationship to repetition rate. There is an uncertainty if the modulator improvements well be implemented in time or will result in the reliability necessary for the “ramping-up” program.

- The modulator controls should be improved to intervene to avoid modulator problems without turning off the modulator to avoid unnecessary failures or shut downs.
  - control the saturation of the transformer
  - prevent IGBT triggers at the wrong time at the plate assembly
  - monitoring and adjust switching currents to reduce losses

- Steps should be taken to limit the energy delivered to a fault by the 200kJ capacitor banks, to eliminate the fires and/or explosions resulting from equipment failure.
  - Subdivide the capacitor bank into 6 section instead of 2
  - Insert IGBTs in series with the capacitor banks to limit discharge currents

- Improved diagnostics to monitor the switching losses should help in determining failure modes in the test stand

- Provide more engineering help to address the additional improvements

Is the modulator improvement plan and operational approach reasonable?

The modulator improvement plan is necessary but not sufficient.

The operation approach of operating at 60 PPS with a long pulse may give you more information about the modulator failure modes but without more diagnostics on the modulator it is unlikely.

The cause of the increase in failure resulting from the increase repetition rate of 60 PPS is apparently not understood. Is the problem increase corona, which results in voltage breakdown, overheating of components or something else? It is not clear. The improvement plan may make sufficient changes to eliminate the failures, or only reduce the problems. Without a complete understanding of the failure problem it is difficult to predict what will fix the failures. It would be prudent to implement even more changes even before the test stands or the present set of improvements is completed.

- Examples could be, controlling the transformer core saturation, locally interlocking the triggers to prevent any improper trigger, and monitoring and controlling the IGBT switching current to insure low switching losses throughout the pulse. Other items might be included like snubbers for the IGBTs to limit dV/dt or addition of over voltage protection on the IGBTs or transformer. Most of these ideas are already used in many other switching power supplies.
- With an “open loop” control system like the present modulator it is unclear what all can go wrong that could cause failures. With the magnitude of the problems with the modulator and the short time scale for the “ramping-up” program couples with the heavy maintenance program just to keep the modulator running, the modulators would benefit from more engineering help.

RF Systems

- **In general, it is plausible that a proton beam power of 230 kW became available for user's use in such a short time after the commission of all the accelerator components. The RF group correctly addressed the problems, and presented their possible remedies for some of them. If these problems are properly solved or mitigated, the Committee believes that there remain few issues regarding a 90 % availability with a designed beam power of 1.4 MW.**

- **Eight input couplers are installed to the RFQ, and the powers are very difficult to properly distribute among the eight couplers. In order to mitigate this problem, the RF group is going to install the two couplers, the windows of which will guide an RF power of 400 kW. The window has been widely used for the superconducting cavities in KEK and in SNS with a planned power transmission. The availability and reliability will be drastically improved by this replacement.**
- **However, the Committee's worry is regarding the reason for the difficult balancing. The PISL installed to the RFQ guarantees its field stability among the four quadrants. However, the RFQ is equipped with no stabilizing mechanism, regarding the longitudinal field. The Committee heard that the resonant frequency of the RFQ was suddenly changed a long time ago. This definitely indicates that the RFQ was mechanically deformed at that time. In this relation, the Committee notices that the beams accelerated by the RFQ have different TWISS parameters and longitudinal bunch shape from those designed. Since the RFQ is one of the most important accelerating components defining the emittances both transverse and longitudinal at the very front end, the Committee recommends the detailed thorough measurements of the field distribution of the RFQ again. Full understanding of the RFQ behavior is essential to guarantee the good beam quality and to minimize the beam loss, which are definitely required for a beam power of 1.4 MW and beyond.**

- **The RF power source did not provide the rebunchers with a necessary power. Also, the rebuncher cavities generate abnormally strong x rays, which indicates the strong field emission. It is planned that the RF power sources will be replaced by the better ones. Most likely causes for the strong x rays emitted from the rebuncher cavities at this field level is the surface quality. There are several options for drastically improving the surface quality, depending upon how it was deteriorated. The pure water rinsing, the baking, the Argon discharge and so forth should be considered for choosing the most appropriate method. The replacement by the newly fabricated cavities may be only a possible choice. The full performance of the rebunchers is anyway necessary for a beam power of 1.4 MW, since no compromise is allowed for minimizing the beam loss.**

RING RF

- **The set-up used for the ring RF set-up is minimum and apparently sufficient for intensity up to 1.1 E14 protons. It is not clear if this system is given enough attention. Serious consideration should be given to the improvement options to make sure that the 3 MW beam power goals can be met.**

SC linac, advances

- In average medium beta cavities operate at specified gradient
- Unscheduled down time by SC linac is minimal
- First experience with 60 Hz SC linac operation at 860 MeV -but only 250 usec (beam pulse)
- SC cavity linac is very forgiving for parameter tuning
- Adaptive feed forward control is in routine use
- SRF laboratory active: successful repair of cry-module CM19 (blanking HOM flange), individual cavity test up to 16 MV/m (at 4K)

SC linac, challenges

- Average of high beta SC modules is 2 MV/m below spec!!
- All high beta modules are limited by collective effects associated with field emission, end group heating
  - Remedy for end group heating
    - Short term: extended processing
    - Medium term: thermal anchor at end group; in situ cavity cleaning
  - HOM coupler problems will need to be continually addressed
- Operation of SC linac at full RF pulse length
- Demanding plan for module repair (CM12), cavity in situ cleaning and spare modules fabrication
  - Is the work prioritized and manageable? (see next pg.)

Prioritizing R&D activities

- Scope of planning SRF activity in FY08-09 is very broad, and the committee feels that everything will not be able to be done, so the effort must be prioritized.
- Plasma (He) processing
  - Well established practice in earlier days
  - Can be done in situ without any changes other than controlled **GHe** inlet
  - 20 % increase of Eacc seems easy
- High power pulse processing
  - 30% + more increase of Eacc possible
  - Can be done in situ, but high power RF pulse required (x2)
- Internal cleaning by CO_2
  - High risk R&D
  - Cavity must be opened !!
- First priority should be given to He processing because of reasonable benefit at smallest effort. Forget about the other R&D activities, and bring CM12 back into operation soon.
- Second priority should be given to spare CM fabrication

Cryogenic system

- Reliable support of the SC linac operation at 4K and 2 K
- Limited service to the SRF laboratory, will be improved after decoupling from the SC linac circuit
- Very low loss of He inventory
- Good overall efficiency of 1.2 KW mains for 1 W at 2K.
- February 07 SCL event
  - loss of communication to the network
  - Local control system and interlocks allowed to continue operation without exceeding design specification of cryomodule
  - Only damage of several cavity tuner with design / installation out of specification
  - The cause of this event was identified as failure of network hardware with subsequent network traffic overload.
  - **Action should be taken to avoid similar failure in the future, e.g. avoiding network transmission of critical signals or drive the CHL into safe operating mode by the local control system if critical network data are missing.**

Target Systems- Response to Charge (1)

Performance to date

- With the exception of two major problems which have been corrected in the mean time the performance record of Target Systems is excellent. In the last reporting period (1-08) all subsystems have reached 100 % availability. This is strong proof of excellent planning as well as high quality of engineering and craftsmanship.

Congratulations!

Target Systems- Response to Charge (2)

Ramping-up the performance to 1.4 MW, >90% availability, 5000 hours operation/year.

- After the new mercury pump will have been installed in March 08, TS is essentially ready for operation at the design power level of 1.4 MW.
- 5000 h/y are currently thought to be achievable by using 4 target shells. Although this estimate suffers from a large uncertainty in the service life prediction of each individual target and the lack of reliable diagnostics for the peak beam intensity, it is probably realistic.
- > 90% reliability of the target systems are routinely achieved elsewhere (SINQ at PSI, 750 kW) and there is no reason to assume that SNS-TS should fall short of this goal unless target life turns out unexpectedly short.

Target Systems- Response to Charge (3)

Longer-term plans for upgrades

- Upgrade of TS to a beam power of >2 MW has been designed into the system as far as permanent installations are concerned. However, in order to meet the reliability (beam time) and availability goals, a solution to the cavitation erosion problem is mandatory. R&D work currently carried out towards such a solution has shown promising results but has still a long way to go before the problem can be considered as solved. Similarly, existing ideas towards a reliable peak beam current diagnostic and control system must be implemented.

Target Systems-Answers to Specific Questions (1)

Should we pursue Hg Pump alternatives?

- An alternative mercury pumping system has been developed for the ESS Project and has recently been implemented in the JSNS mercury loop. It employs a rotating permanent magnet to drive the mercury flow in a completely closed loop by EM-forces. This has clear advantages over an immersed impeller pump. The JSNS-system has been shown to work extremely smoothly and with high efficiency. Pursuing this line also for SNS is strongly recommended.

Target Systems-Answers to Specific Questions (2)

Is there the right balance in target damage mitigation work?

- Target damage mitigation work is currently based on four types of activities:
  (1) Investigation of the effect of different parameters by using out-of-beam techniques, notably the MIMTM-facility at JAEA and theoretical approaches. This work has been highly successful, but its portability to the real target operating conditions is not clear.
  (2) In-beam tests at WNR, which have so far generated important results but did not allow to establish conclusive correlations yet. They need to be continued with priority.
  (3) Development work towards controlled bubble size generation in mercury and associated diagnostics systems. Progress on this front seems to be rate limiting.

Target Systems-Answers to Specific Questions (3)

Is there the right balance in target damage mitigation work? (cntd.)

(4) Full size simulations on the TTF-loop, mainly directed towards establishing a method to generate and test the effect of a protective gas curtain at the target window.

In the Committee's view the work on the TTF loop is of high relevance and should be pursued with vigour both in relation to the gas curtain and the small bubble injection into the volume. To this end a system to generate pressure pulses in the mercury on the one hand and a damage potential diagnostics device on the other need to be implemented.

A workshop to be held on Jan 24-26 is expected to produce important clues on what the way forward should be.

Target Systems - Recommendations

1. Consider replacing the impeller pump in the mercury loop by a rotating magnet EM-pump.
2. Aggressively pursue damage mitigation work at the TTF-loop and WNR, if necessary even in the absence of a reliable bubble size diagnostic system.
3. Implement a permanent beam profile diagnostic system in front of the mercury target with high priority (example: VIMOS at SINQ) and incorporate it in the target protection system.
4. Rather than protecting Target 1 from excessive damage on the expense of neutron production, accept the possibility of its failure. If this occurs early, it should give a clue on restrictions to be imposed on the operation of Target 2.

Is the balance of Risk between Target and Accelerator (higher rep. rate) in this ramp-up phase appropriate?

- Given the current limited understanding about the conditions under which target failure occurs, operation at 60 Hz appears to be the mode in which power increases can continue to be made with the least risk to the target, and is probably also the mode which stresses the modulator the least (for a given power level).

Control System

- SNS has the largest operational EPICS control system in the world
  - Highly distributed
  - Connections to ORNL-IT and SNS test facilities
- Network saw biggest problem n 3/1/2007
  - Network switch was root cause
  - Second, unrelated, problem occurred shortly after first one
  - SNS Controls Group shares responsibility with ORNL networking
- Mitigation options presented
  - Need to monitor system to detect problems before impact spreads widely
  - Test and implement risk mitigation features
  - Introduce segmentation between major facility part
  - Provide backup for critical service
  - Capture diagnostic messages
- Data base does not have dedicated manager
  - Several people in charge
  - Infrastructure maintained by ORNL staff

Control System

- Alarm monitor needs to be improved
  - Originator has left ORNL
- Plans to develop new archiving system
  - No data mining tools
- Timing system to be refurbished under AIP
- Control System Studio
  - Infrastructure for developing applications
  - Java based
- Will ask SNS for network testing time
- Looking into new location for backup media
  - Fire danger
- Presented sound concept for installing software upgrades
  - Avoid interference with system operations

Beam Instrumentation

- Established collaborations with Russian laboratories
- Major concern with configuration control
  - Issue is recognized and being addressed
- Planning to complement instrument suite
  - Differential current measurements
  - Profile measurements in Ring
    - Student working on ionization profile monitors
  - Multiple x/y laser profile measurement stations in Linac
    - Results can be used to deduce emittance
  - Genuine emittance device near first HEBT bend
    - Using neutralized beam portions, 10 m base line to detector array
  - After pertinent experience with profile harp, implementing plan to eliminate miscommunication and wiring errors
  - New beam loss monitor can hold acquired data
    - Avoids flooding network with excessive data flow

Beam Instrumentation

- Investigating design of electron detector from stripper foil
    - For now going to utilize IR image of electron catcher

Power Upgrade Project

- The current concept of the power upgrade project implements the energy upgrade to 1.3 GeV as an MIE construction project (which has CD-0 approval), while the beam current and target upgrades will be executed as operations-supported R&D and AIP projects.
- The committee feels that the energy upgrade is a scientifically well-motivated extension of the accelerator’s capabilities, and provides a natural and well-timed continuation of the SRF component and facility development currently underway as part of the beam power ramp-up.
- The additional R&D required for the beam current and target upgrades will benefit current operations, as well as preparing for the power upgrade, by providing deeper understanding of key issues in the ion source, LEBT, ring, and target systems.
- The committee recognizes the risk associated with implementation of the beam current and target upgrades outside of a construction project. However, since these upgrades have a large R&D component, the increased flexibility inherent in this approach may be very helpful.

Summary

- Overall, no show stoppers to 1.4 MW power goal.
- But there is a lot of work to do, especially in achieving the ambitious performance and availability goals.
- The planned approach to reaching 3 MW appears credible: the energy upgrade should be straightforward. The beam current upgrade will be more challenging.