Third SNS Accelerator Advisory Committee Meeting Feb 2-4, 2010

SNS Accelerator Advisory Committee

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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 last review:
  - beam power increase from ~0.6 to > 1 MW
  - beam availability increase from 72% (FY08) to ~85% (FY10 to date))

  while at the same time providing useful neutron beams to SNS users engaged in pioneering experiments.
- The committee appreciates the attention which the SNS management have paid to last year's AAC comments and recommendations.
- Availabilty was a major focus of this year's review and is highlighted in the responses from the AAC presented here.

Operations and ramp-up

- FY2009 operations met/exceeded commitments
  - 2165 MW-hours on neutron target, 3553 hours of neutron production, 4500 hours operations (total), 81% availability
- Significant improvement over FY08 (72% availability)
- FY2010: Operating up to 1 MW with 85% availability (to date)
  - Significant improvement over FY09
  - FY10 commitment: 3250 MW-hours neutron production with 85% availability
- Operating Strategy
  - Availability is higher priority than beam power
  - Plan is to maintain 1 MW with high availability for FY10
  - Modulator performance is a key to achieving this (recent reduction to ~700 kW due to duty factor limitations from continuing modulator issues)

Operations and ramp-up

- Availability Strategy: main issues
    - Modulators remain an issue of major concern
    - RF systems-ion source and MEBT-solutions identified
    - Controls (issues with MPS-solution implemented)
    - Foil failures (spring/summer) – appears resolved, but deserves continued attention
  - Systematically cataloging systems failures in all systems – priority on hitting biggest offenders.
  - There is not yet a larger strategy that analyzes downtime and provides a structure for the associated AIPs.
  - There is not yet a systematic analysis of incidents that could induce significant downtime, or a major reduction of performance over an extended period.

Operations and ramp-up

- Goal: 1.4 MW, 5300 MW-hours/year @ 90% availability
  - Achieve goal by October 2011 - delayed one year from last year, two years from two years ago.
  - Parameters remain the same as last year
  - Modulator is the key (pulse length and reliability), together with plasma processing for energy increase
  - losses/residual activation at 1.4 MW still uncertain

Ops/ramp up recommendations

- Establish a fall-back set of specific parameters (lower power, higher availability) in case there are issues meeting the plan for operations at 1 MW in FY2010
- Continue pursuit of “operational vulnerability analysis” suggested last year, and development of a bottoms-up, systemwide availability model.
- Retain focus on resolution of modulator issues.
- Complete the planned spare high beta cryomodule. Spare cryomodule should meet the requirements of PUP. Consider utilization of this spare to enhance operating energy margin via continuous swapping of spare with lower performing CM.
- Continue to purse beam loss experimentation and simulation to support extrapolations to 1.4 MW operations.

95% availability planning

- Findings:
  - A top-down plan was presented for reaching 90% and then 95% availability
  - It was stressed that 95% is a goal not a commitment
  - The plan is based on recent operational experience at SNS
  - Major causes of downtime have been identified
  - A Configuration Control Board has been established and has started to function
- Comments:
  - The plan is a work in progress – it is expected that a bottoms-up plan will be fleshed out by the next Review
  - The committee strongly supports the approach that was outlined and encourages its rapid implementation.
  - 95% availability will not be reached unless the modulator problems are resolved by an aggressive, funded project.

Ion Source and LEBT

- **Significant progress achieved with original ion source and LEBT**
  38 mA routinely delivered to MEBT, compatible with 1.4 MW for SNS
  Downtime decreased by factor of 4 from 2007
    Major offender is 2-MHz amplifier: solution identified
- **Deepened understanding of cesium management**
  Only one cesiation needed for four weeks
- **LEBT sparking expected to be down to one per day**
- **Development of alternate source still necessary**
  Increased availability requirements and current upgrade
- **LEBT development still necessary**
  Recommendation: Bring LEBT chopper back to <40 ns rise/fall time

Warm linac including RFQ

- The RFQ issue (the resonance frequency shift) looks mitigated by protecting the RFQ from overpressurizing. The committee nevertheless encourages rapid procurement of a spare RFQ.
- The other efforts, including the H2-flow reduction, were effective for improving its reliability.
- The further efforts under investigation are endorsed by the Committee:
  - Smaller aperture at the entrance of RFQ
  - The gate valve between LEBT and RFQ.
  - Minimize gas flow from ion source to RFQ.
- MEBT stripline chopper has been implemented and shows increased efficiency
- DTL6 frequency control and input window have been improved.

Linac Beam Dynamics

- The SNS linac (and J-PARC linac also) have successfully reduced the beam loss down to a level of 10^{-3}.
- This beam loss level is sufficiently low for the presently required performance.
- Further effort to theoretically understand the presently achieved low beam loss is a good idea, since the effort is required for upgrading the machine performance to a several-MW level in (near) future. The effort is exemplified by finding the weak 60-degree resonance.
- However, the presently available computer simulation codes like XAL, PARMILA and IMPACT (the latter may be OK, but needs impractically long computation times) looks insufficient for predicting the beam loss below the 10^{-3} level.
- The efforts to theoretically understand the beam behavior are strongly encouraged by the Committee for the above reason.
  - Study observed off-normal loss events in the SNS machine and provide feedback to operations.
  - This should include the developments/improvements of the simulation codes together with their benchmarking by the real machines.

RF systems-availability

- If the availability is to be improved to maximize the scientific output of the facility, both the downtime and the event rate (for example, trip rate) also should be minimized. (Of course, the latter also contributes to minimization of the down time.)
- The trip rate (and the downtime) of the high-power RF and pulsed components can be improved by increasing the maximum peak power and duty factor ratings, say by 20 or 30 %, to achieve an availability of > 99%.
- Of course, the sufficient number of spares and its replacement scenario decreases the downtime. The presently proposed efforts will be effective for this purpose.

Modulator development and upgrade plans

- **Accomplishments**

1. Formation of HVCM Development Group
2. Completion of dedicated HVCM test stand for development
3. Improvement of HVCM availability by IGBT timing adjustment
4. Replacement of 4kV capacitors with new pretested self healing capacitors
5. Development of a new IGBT driver circuit
6. Development of new control specifications
7. Development project for the energy storage cap bank fast disconnect switch
8. Replacement of SCR supply connectors

Modulator development and upgrade plans

- **HVCM Availability Findings**

1. The HVCM is **the major contributor** to the SNS Accelerator down time so it needs more work to meet availability goal.
2. The 4kV Capacitor failures are not completely understood so it is not clear if the failure problem is solved by their replacement
3. The warm section HVCM resonance capacitors were all replaced, although the cause of their failures is not totally understood.
4. The IGBT failures are not understood, so their availability is uncertain
5. IGBT over voltages are generated by their diode snap off during IGBT pulse termination. May cause IGBT failures

1. The cause of the droop compensation failures is not understood

Modulator development and upgrade plans

- **Recommendations for Immediate Action**

1. Implement snubbers or equivalent devices across the IGBT to reduce the overvoltage due to diode snap off.
2. Procure, test, and replace all of the resonance capacitors for warm section modulators, and monitor all resonance capacitors
3. Implement new IGBT driver circuit to improve the monitoring and protect the IGBTs from “shoot thru” pulsing
4. Implement the energy storage cap bank fast disconnect switch to improve failure diagnostics and prevent explosive faults under IGBT/capacitor failure
5. Proceed with procurement of the new control driver to provide improved monitoring and control

Modulator development and upgrade plans

- ## Longer Term Recommendations

1. Continue evaluating the IGBT failure problem

2. Develop a new modulator Topology using series connected output rectifiers to reduce voltage stress on high voltage components

1. Reduce ground loops and develop damping from energy storage capacitor bank

2. Develop automatic methods to insure minimum power loss in IGBTs

3. Study automatic core saturation and output voltage droop compensation techniques to reduce the RF requirements and adjustment requirements

Progress SNS SRF

- SCL supported neutron production at 1 MW and 930 MeV with 80 out of 81 cavities
- Beam loss resulted in cavity trips
  - Two cavities (5a and 6c) lost performance after beam loss.
- SNS has made good progress in understanding FE limitation in High Beta cavities. Mitigation strategies still unclear.
- New facilities & components
  - RFTF is considerably upgraded
  - Infrastructure for plasma cleaning R&D is established
  - Major improvements of the PUP cryomodule were worked out

SRF: Recommendations to reach the SNS baseline design level

- Immediate term activity
  - Continue RF processing of cavities 5a and 6c to try to recover the original performance. **The result will be decisive for further actions.**
  - Install temperature sensors on all input couplers (water cooling)
- Near term activities
  - Assemble and exchange spare module (after replacing poor performing cavity so that module meets PUP spec)
  - Finalize and implement “in situ” plasma cleaning technology
- Medium term activities
  - Any new cryomodules (spares or for PUP) should use newly fabricated SRF cavities built and processed using J. Mammosser`s recipe.
  -

HEBT/RING/RTBT

- Notable Accomplishments in 2009
  - Reached design peak intensity of 1.55xE14 ppp with tolerable losses
- Main issue was rash of foil failures after May 3, 2009
- Several changes to foil system were made which were motivated by several plausible hypotheses and resulted in a foil arrangement that lasted for the last 3 month run period.
  - Not clear which changes were most responsible for the success
- Arcing from charging of the foil seems most likely root cause of foil failures. Charging has at least two sources:
  - secondary emission from protons passing through the foil and
  - reflection of convoy electrons from region of electron catcher
- New observations of hot spots and edge glow are rather puzzling and not well understood, although some plausible hypotheses have been put forward. The edge glow that persists for 1-2 seconds after beam is shut off is very mysterious.
  - Lack of clear understanding of these poses unknown risk factors to reaching reliable operation at the design intensity

HEBT/RING/RTBT continued

- The committee applauds the vigorous effort to understand and correct the foil system failures. We endorse the aggressive follow up program to develop better foils and further improve the foil mechanism
- The HEBT momentum scrapers proved very useful in past operations and a new HEBT momentum dump been designed and installation under way
- The e-p instability shows up well below the design intensity but can be controlled (just barely) at the design intensity with full RF voltage. Active damping (transverse feedback) has been shown to be effective for e-p and will provide a highly desirable additional margin of safety.
- The value of TiN coatings for stainless steel vacuum chambers has been questioned in the light of data obtained in the past few years. A systematic study to resolve this issue can be expensive. SNS has already made the investment in the hardware for TiN coating and will prudently continue to coat new chambers that are installed in the ring.

Foil development

- Development of reliable, long-life foils and foil system is a highly important goal for SNS, especially in light of the foil system failures in 2009
- While nano crystalline diamond foils have demonstrated many desirable properties, improved conductivity to significantly reduce the foil charging is highly desirable.
  - Development of more conductive foils via Boron doping is underway and thin metallic coatings are being considered
  - Development of HBC-like foils also an option under consideration
- The HBC foil developed at KEK has excellent lifetime in proton beams such as the LANL PSR and is expected to have good conductivity. It should be tested at SNS
- The committee strongly encourages a focus on development of higher conductivity foils with long time times
- The electron beam test stand is an essential tool for evaluation of foil developments

Ring Beam Dynamics

- Orbit Response Matrix (ORM) methods are used successfully to improve the ring lattice model but Model Independent Analysis (MIA) shows significant beta function beating in both planes
- The benchmarking program for ORBIT revealed problems with the painting waveforms, which have now been corrected. There are still some disagreements between measurements and simulations of transverse beam profiles at high intensity in the vertical plane for the painted beam. These are presently under study.
- Measured Losses at A13b are in reasonable agreement with simulations.
- Good agreement between simulations and measurements were obtained for the kicker-impedance-driven instability
- Simulations of the e-p instability for bunched beams is a work in progress
- It is the committee’s assessment that the progress on understanding and modeling of the ring optics and beam dynamics is progressing at a reasonable pace for the needs of the 1.4 MW goal.

Target Life Time Improvement

- Given the current limitations and uncertainties in target service life, the SNS has decided *not to count downtimes needed for target replacement against the availability contingent*

"Planned unscheduled Shut-downs"

- **Since these are likely to take the better part of two weeks each, this situation should prevail for as short a time as possible.**
- Once SNS arrives at a scheme where three to four targets are needed per year, (10 dpa-limit) the operating schedule should be adjusted to accommodate the target changes in the planned shutdowns.

Target Life Time Improvement

- In the quest to come to grips with the pitting erosion problem the collaboration with J-SNS has proven highly effective.

  This collaboration should be continued by all means

- Limited examination of Target 1 suggests that (shear) flow is an important parameter controlling pitting damage rate,causing maximum damage at the point of flow stagnation in the center of the proton beam window
- It is highly desirable to validate this conclusion by examining other regions of the shell(s).

Target Life Time Improvement

- The committee recommends trying the following measures on the next few targets:
  - (1) shift the stagnation point as far as possible from the window center by using different size orifices in the two inlet flow channels (near term option for the next target)
  - (2) try to mimic a cross flow configuration by introducing a guide baffle in one of the inlet channels to split the flow (It might be possible to insert a tube carrying the baffle plate in one of the targets currently on order for manufacturing before the front window is welded on.)
  - (3) In the medium time scale a target applying the gas wall idea developed during the R&D work may provide additional -and possibly ultimate- protection (requires target re-design and some additions on the target trolley).
- On the long run raising the dpa-limit should be a goal, based on PIE results of used targets.

PIE of spent targets must, therefore, be given high priority

Other Target System Improvement Plans

- **Leak detection system**: Dependable detection of a leak of mercury unto the interspace is important for saving the outer shell. The Committee supports the efforts of adding more diversity to this system
- **Target imaging system**: This has been a highly successful development adding important capability to analyse and control the beam on target. The performance is satisfactory at the present current level, but more development will certainly help for the future. The Committee supports this effort unanimously.
- **Development of a rotating target**: This option for STS holds a promise for significant extension of the target life time (up to 10 years). Ongoing work has been very successful so far, but more studies are needed to prepare a qualified decision, since this would introduce a new technology with its associated side effects on handling and waste disposal.

Cold Moderator Operation and Development

- SNS has luckily avoided two potential down times because the respective incidents occurred during shut down periods:
- (1) Power outage on the CMS compressor controls.
  - A > 3-6 sec outage can cause a 3+ days downtime
  - **SNS should try to identify similarly critical systems and hook them up to uninterrupted emergency power supplies**
- (2) Degradation of the moderator refrigerator capacity due to contamination of the heat exchanger and adsorber was discovered and fixed during a shutdown. Regular regeneration during planned shut downs should be considered.
- Interesting ideas have been presented for **novel moderator concepts**. These should be pursued with an appropriate effort in the medium term. The proposed Moderator laboratory would be an important asset in this effort.

Component Replacement / Remote Handling

- Remotely handled replacement of two major components – the target and the proton beam window plug – was accomplished successfully, although some lessons can be learned:
  - Make sure all procedures are described precisely and in detail, including numerical values e.g. for the torques to be applied or dimensions to be checked.
  - As a backup, provide tooling that may be needed for fault recovery (but don't view them as a substitute for careful work).
- Efficient remote handling techniques become increasingly important as the source power continues to go up. In particular, the imminent core vessel insert replacement on BL 16 will be a challenge, which must be thought through in all details.
- An impending problem is disposal of radioactive or contaminated waste. It is important to make sure that pileup and disposal of stored components does not jeopardize source operation.

Controls and instrumentation

- Controls:
  - Very solid performance: No major problems experienced
  - Actual availability of control systems nearly matches 2010 goal.
  - Many MPS nodes did not trip beam in required 20 ms: measured 3 - 194 ms
    - MPS delay problem agressively attacked and repaired
  - LLRF load problems
    - Get better processor: MVME5500, will become standard after winter outage
  - Fixed radiation monitor failures (techical and administrative fixes)
- Instrumentation:
  - Existing Beam Instrumentation is capable of supporting machine tuning and production runs
  - Laser “wire” scanner
    - Nine stations served by one laser, using mirrors
    - Vibrations: mirror mount, now redesigned, much better performance
    - Reduced cross talk: eliminated diagonal wire
  - Implemented HEBT beam scraper to measure halo down to 10^{-5}
  - Ring profile monitor with electron beam improved. Still needs 100 keV e-beam.
  - Feedback damping system installed with analog processor
    - 800 W amplifier, 300 MHz band width
  - Main goal for FY 10 is to bring Beam Shape Monitor and MEBT emittance devices to user-friendly status

Accelerator Engineering

- The engineering group has now got into a rhythm of building projects while the accelerator is operating and installing during the downtime.
- All of the work appeared to be well designed, well executed and planned.
- Impressive quantity of work
- They are having to rework equipment that was not well engineered initially
  - E.g, replacing bolted vacuum chambers in high radiation areas
- No evidence that corners are being cut in the rework
- The work is aiming to repair those items that are causing downtime
- There seem to be few risks
- Suggest using dry nitrogen to cool the Injection Dump (not air) to avoid ozone and nitric acid production
- The priorities are well adapted to improving availability and continuing the performance ramp-up

PUP and CU AIP's

- PUP goal is an energy increase to 1.3 GeV, beam power to 1.8 MW
  - Scope
    - 9 cryomodules + rf power (36 klystrons, 4 modulators)
    - Ring: Upgrades to chicane magnets and injection/extraction kickers
  - PUP Project Plan
    - TPC = $90-96M
    - CD-1 January 2009, CD-2 January 2011, Construction period 2012-2015
- CU AIP Goal is 3 MW
  - 1.3 GeV, 42 mA average current (59 mA peak from RFQ)
  - Requires a second target station to utilize
  - Careful analysis required to determine how to provide the current capability in existing linac and requirements in the ring.
  - CU AIP Plan: ~$60M over 5 years
  - Issues
    - Consistent configuration between PUP and CU AIP (and STS)
    - CU AIP Funding availability
- Recommendation:
  - Produce an integrated (PUP, CUAIP and STS) plan in support of the PUP CD-2 review
  - Use new cavities in PUP cryomodules, not SNS spares.

Conclusion

- The committee would again like to thank the SNS staff for the warm hospitality provided during the review, and the excellent presentations.
- The committee looks forward to next year's visit to a > 1 MW facility operating with 88% availability, and to hearing a bottoms-up plan for 95% availability.