THE SNS POWER RAMPUP *

J. Galambos, on behalf of the SNS Staff, SNS, Oak Ridge TN, USA,

Abstract

Since the start of neutron production in October of 2006, the average SNS proton beam power level has increased from ~ 5 kW to over 500 kW. This increase has been realized by increases in the beam current, pulse length and repetition rate. A major concern in the power ramp up has been minimization of uncontrolled beam loss. The beam loss levels, and operational experience with residual activation will be discussed. Also the operational beam availability is discussed.

INTRODUCTION

The Spallation Neutron Source (SNS) is a pulsed spallation neutron source. It has experienced a rapid increase in operational beam power from a few kW to over 500 kW, since initial neutron production began in Oct. 2006 [1-5]. In this paper we discuss some operational experience aspects during this exciting period. The power increase has been accomplished by increases in the beam current, pulse length and repetition rate. During this period beam loss fraction has been reduced, resulting in manageable residual activation of the machine. Related to machine activation, activities aimed at understanding the nature of the beam loss are addressed here as well as machine availability and some equipment issues.

BEAM LOSS / MACHINE ACTIVATION CONCERNS

As a high power proton beam facility, beam loss is a major concern at SNS. The SNS was designed with an allowance of about 1 W/m of uncontrolled beam loss, which is expected to result in a level of residual activation acceptable for hands on maintenance. Two areas at SNS are the primary focus of beam loss reduction: a) in the warm sections between the Superconducting linac (SCL) cryomodules, and b) in the Ring Injection area.

Fractional Beam Loss

SNS has observed a higher than expected beam loss in the Superconducting Linac region (SCL). No significant losses were expected in this region as the aperture is quite large. The loss is sensitive to upstream warm linac RF settings and insensitive to ~10% adjustments to the SCL entrance matching quadrupoles. The magnitude of the beam loss results in residual activation levels of 10-60 mrem/hr at 30 cm 1 day after the end of neutron production, which is below the level expected for 1 W/m beam loss. At the present operational power level 1 W/m represents < 2×10^{-6} fractional beam loss per meter. Beam measurements at this level are difficult to make, as Beam Current Monitors (BCM) - or current transformers - are accurate to only ~ 1%. Beam loss monitors (BLM) are the most sensitive instrument for measurements of very low fractional loss from high intensity beams. We have attempted to calibrate the BLM response by controlled spills of small known amounts of beam. However these calibrations result in factors of $\pm$ 3 differences from BLM to BLM in the lower energy part of the SCL and in factors of $\pm$ 2 uncertainty in the higher energy part of the SCL. On average though, the loss fractions measured using these calibrations are consistent with the 2×10^{-6} fractional beam loss per SCL warm section (1.6 m long) estimated from the residual radiation levels

The Ring injection area is expected to be the highest beam loss area in the accelerator, because of the unavoidable loss associated with the beam passage through the stripping foil. We calibrate the BLM readings in this area by inserting a thick foil which causes a measureable reduction (with a BCM) of a known small amount of beam (see Fig.1). Comparing the nearby BLM readings with the measured beam loss gives a calibration of BLM reading to lost beam charge. With this method we estimate < 5×10^{-4} beam loss in the vicinity of the injection stripper foil. This is consistent with the design expectation of 10^{-3} fractional beam loss near the stripper foil.

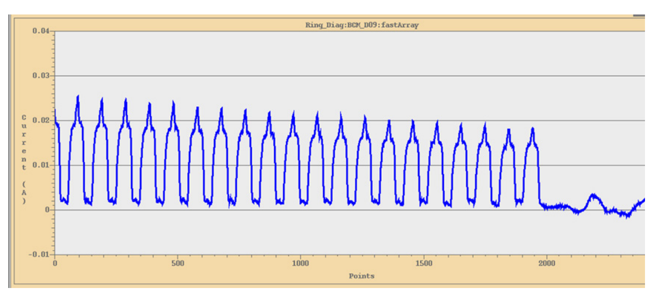

Figure 1. Ring beam current for the last few turns in the ring when passing through a thick foil, causing measureable loss of a small amount of charge.

Machine Activation

During dynamic periods of rapid increases in the operational beam power, understanding the expected residual activation levels is important. This is done primarily by scaling past observed activation levels with the amount of beam lost (as measured by BLMs). Figure 2 shows a comparison of the average residual activation along the SNS SCL and the integrated beam loss

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measurements for several run periods while the beam power was being ramped from 180 kW to 300 kW*. There is a general correlation of the activation levels and the measured accumulated beam loss prior to the activation readings. While there is more variation if comparing individual loss monitors and adjacent activation levels, the average over the entire SCL does show coincidence between integrated beam loss and resultant residual activation.

The SCL activation buildup shows saturation as we approach the end of extended run cycles (several months). Figure 3 shows the average SCL residual activation measured after 2 week run periods over the summer of 2007 and during the winter of 2008. For both of these run cycles the beam power was ramped up monotonically throughout the run cycle.

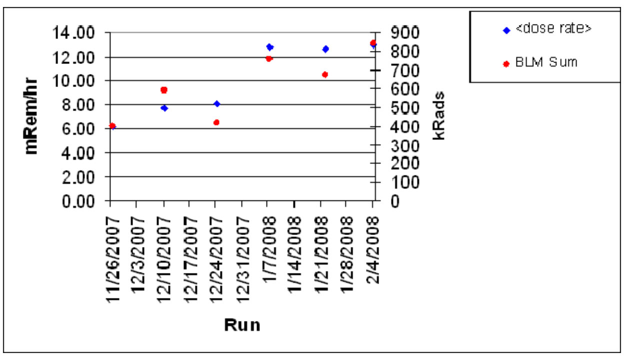

Fig. 2 Integrated BLM readings (red) summed over all SCL BLMs for several run periods and the average residual activation readings over the SCL warm sections (blue).

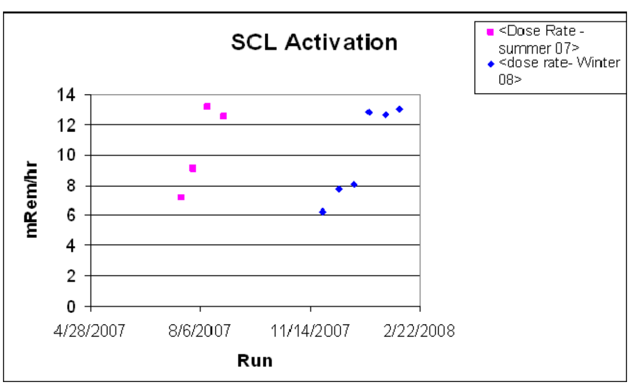

Figure 3. The average residual activation in the SCL warm sections after 2 week run periods two extended run cycles.

Another complicating factor regarding the residual activation is the rapid decay after the end of production runs. Figure 4 shows the residual activation decay for areas of the highest activation in the warm linac (CCL4) and in the SCL (SCL2-3). Data are shown in days after the end of neutron production for the last three run cycles.

* Note that all residual activations referenced here are measured at 30 cm.

The Fall 2007 decay period followed a power ramp-up to 180 kW, the Winter 2008 decay after power ramp-up to 330 kW and the Summer 2008 decay after a power ramp-up to 500 kW. The residual activation decays quite fast, indicating the need for consistent decay times for comparisons of activation levels. Also it is interesting that there is not an overall increase in the activation levels at the end of each decay period (i.e. at the start of the next run cycle), despite large increases in the operational beam power.

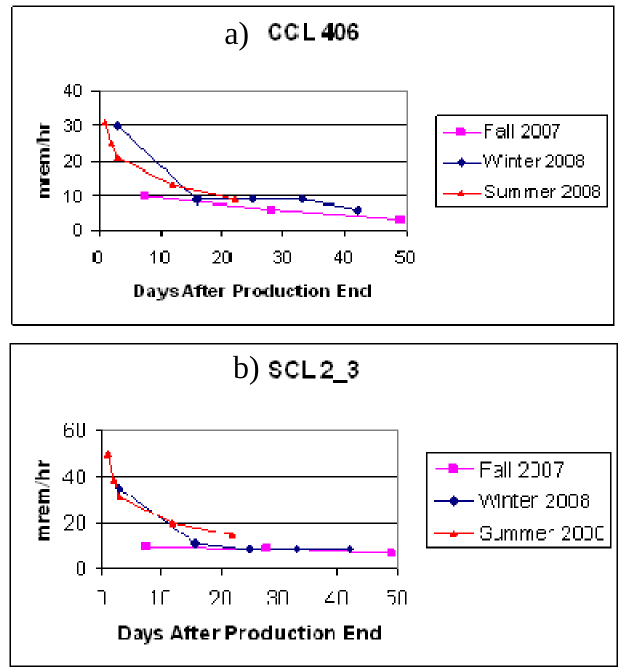

Figure 4. Residual activation decay after the end of the last three neutron production runs in the most activated region of the warm linac (CCL406) and the most activated region of the SCL (SCL 2-3).

The Ring injection area activation is shown in Figure 5, for the same run periods as described for the SCL cases shown in Figure 3. It is interesting that in this case, there is a monotonic increase in the Ring activation levels throughout the run period – as one would expect. The saturation observed in the SCL (see Figure 3) is not seen here. Figure 6 shows the decay of the activation in several areas of the Ring following the last three production runs (see the conditions described for Figure 4). There is a significant decay in the activation levels, although not as rapid as for the linac cases. There is also a slight overall buildup in activation from one cycle to the next for the Ring injection region. The Ring collimation area shows a large jump for the last run, as Ring collimation was used for the first time during this run cycle, and the Ring extraction shows a large improvement for the last run period (despite higher beam powers) due to improved linac chopping quality of the injected beam gap.

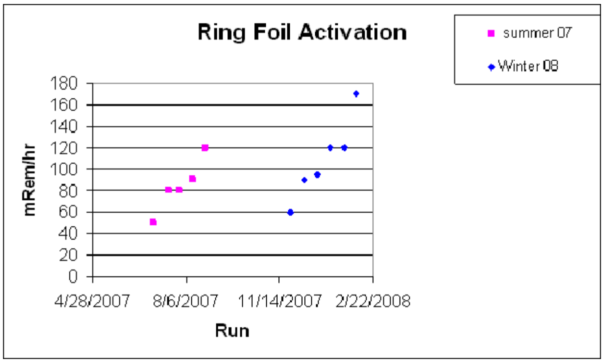

Figure 5. Average Ring Injection area residual activation after 2 week run periods for two extended run cycles.

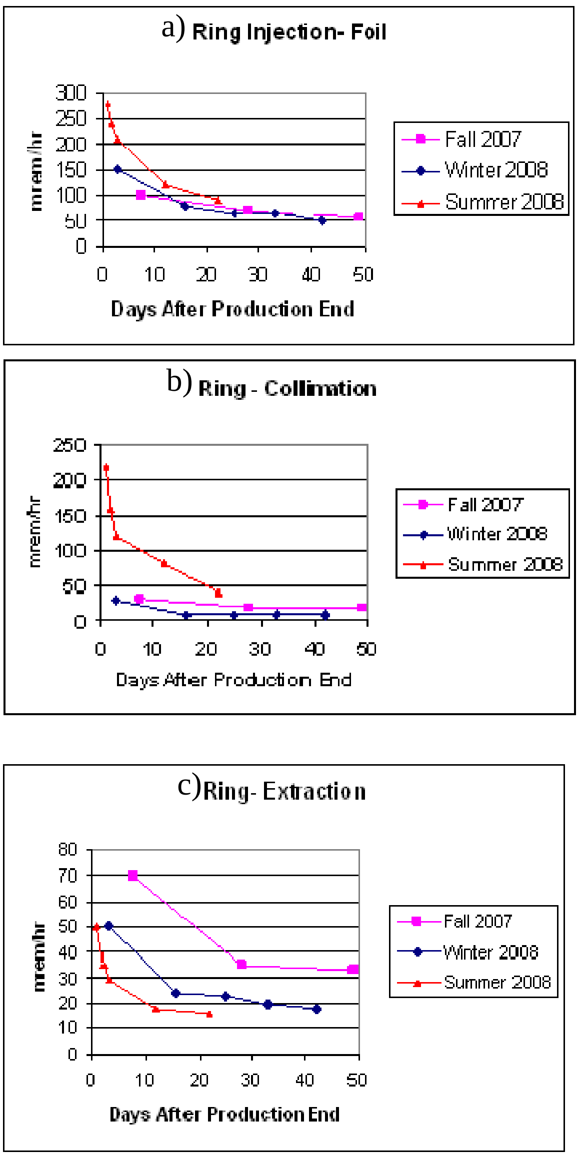

Figure 6. Residual activation decay after the end of the last three neutron production run cycles in the Ring a) Injection area, b) collimation area and c) extraction area.

Figure 7 shows a comparison of the measured activation levels for several parts of the accelerator following the end of the summer 2008 neutron production run cycle, normalized to their starting values. The more rapid decay of the SCL activation levels compared to the Ring is evident This faster than expected decay in the SCL is not explained by the lower beam energy in the linac [6]. Possibly there are some impurities in the steel used in the SCL warm sections, with short lived half-lives.

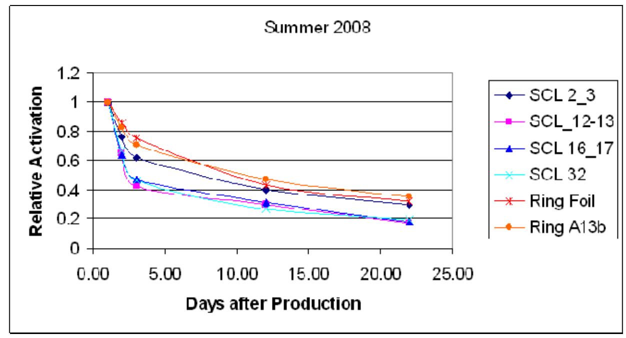

Figure 7. Normalized activation following the Summer 2008 neutron production run cycle for several parts of the accelerator

Table 1 shows some activation levels at various beam loss spots about 24 hours after production ended and at 30 cm. Most of the machine is effectively loss free and has much lower activation levels than shown in this table.

Table 1 Residual activation levels at beam loss locations, 24 hours after beam shutdown following a 500 kW run for 2 weeks and at 30 cm.

Location	Activation (mrem/hr)
Linac	10-60
HEBT collimation	100
Ring Injection	100-400
Ring injection dump line	100
Ring Collimation	200-250
Ring Extraction	50
Most other areas	< 1-2

Worker Dose

For the entire SNS radiation worker work force, the collective dose for 2008 (year to date) is 1600 mrem. The maximum individual dose (year to date) is 100 mrem. The annual limit for a Rad worker is 400 mrem for SNS (which includes a factor 1.5 margin on ORNL laboratory guidelines and a ~ factor of 3 margin on the governmental regulatory limits). This dose rate is similar to that accumulated over 2007 (for which the beam power level was much lower).

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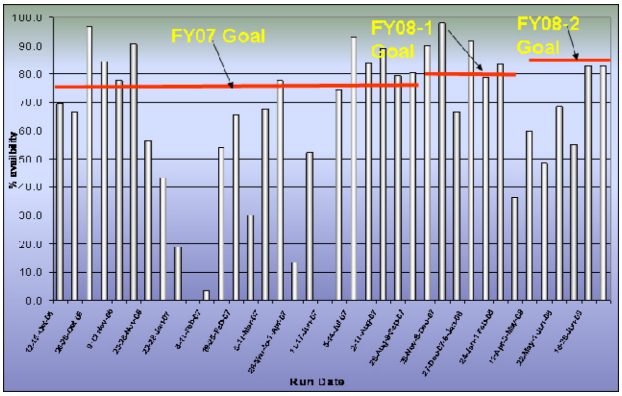

Figure 8. Beam availability for 2007-2008

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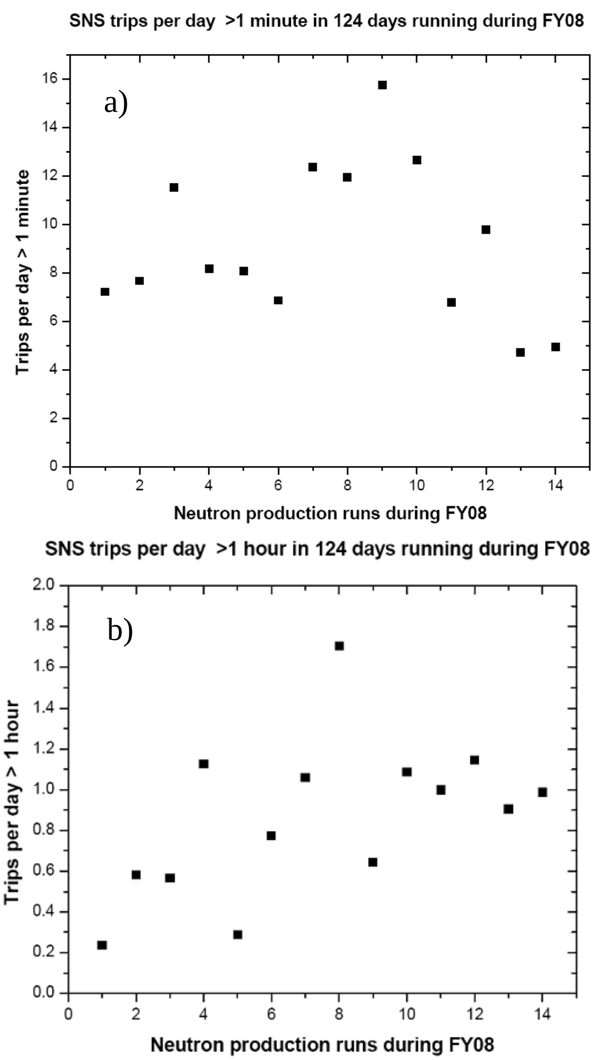

Figure 9. Trip frequency of duration a) > 1 minute, and b) > 1 hour

MACHINE AVAILABILITY

The beam availabilities (defined as the beam on time / scheduled beam time) for the first two years of neutron production are shown in Figure 8. The average availability for 2007 was 66% and for 2008 (to date) is 73%. A number of equipment improvement projects are underway to improve the availability. Key areas needing improvement are the RF High Voltage Convertor Modulators (HVCM), the Ion Source systems (including low energy chopping systems), and RF systems.

Figure 9 shows the beam trip frequency for outages greater than 1 minute and greater than one hour, for the run periods in 2008.

SUMMARY

To date the SNS has ramped the operational beam power to over 500 kW. Beam loss, associated machine activation and resultant worker doses are not excessive. The beam availability is not as high as hoped for, but has improved in 2008 compared to 2007.

ACKNOWLEDGEMENTS

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REFERENCES

[1] S. Henderson, “Spallation Neutron Source Progress, Challenges and Power Upgrade Paths”, Proceedings of EPAC08, Genoa, Italy, http://accelconf.web.cern.ch/AccelConf/e08/papers/thxg01.pdf .

[2] S. Henderson, Status of the Spalaltion Neutron Source:”Machine And Science”, Proceedings of PAC07, Albuquerque, New Mexico, USA, http://accelconf.web.cern.ch/AccelConf/p07/PAPERS/MOXKI03.PDF .

[3] S. Henderson, “Commissioning and Initial Operational Experience with the SNS 1 GeV Linac” , Proceedings of LINAC 2006, Knoxville, Tennessee USA, http://accelconf.web.cern.ch/AccelConf/l06/PAPERS/MO1002.PDF .

[4] A. Aleksandrov, S. Assadi, W. Blokland, P. Chu, S. Cousineau, V. Danilov, C. Deibele, J. Galambos, D. Jeon, S. Henderson, M. Plum, A. Shishlo, “SNS Warm Linac Commissioning Results”, Proceedings of EPAC 2006, Edinburgh, Scotland, http://accelconf.web.cern.ch/AccelConf/e06/PAPERS/MOPCH127.PDF .

[5] M.A. Plum, A.V. Aleksandrov, S. Assadi, W. Blokland, I. Campisi, C.P. Chu, S.M. Cousineau, V.V. Danilov, C. Deibele, G.W. Dodson, J. Galambos, M.

Giannella, S. Henderson, J.A. Holmes, D. Jeon, S. Kim, C. Long, T. Pelaia, T. Shea, A.P. Shishlo, Y. Zhang, "SNS Ring Commissioning Results", Proceedings of EPAC 2006, Edinburgh, Scotland, http://accelconf.web.cern.ch/AccelConf/e06/PAPERS/MOPCH131.PDF .

[6] I. Popova, "Residual Dose Rate Analysis for the SNS Accelerator Facility", these proceedings.