SPALLATION NEUTRON SOURCE OPERATIONAL EXPERIENCE AT 1 MW*

J. Galambos, on behalf of the SNS team SNS-ORNL, Oak Ridge, TN, USA

Abstract

The Spallation Neutron Source (SNS) has been operating at the MW level for about one year. Experience in beam loss control and machine activation at this power level is presented. Also experience with machine protection systems is reviewed, which is critical at this power level. One of the most challenging operational aspects of high power operation has been attaining high availability, which is also discussed.

RAMP-UP HISTORY

The power ramp-up history for the SNS is shown in Fig. 1. Operation at the MW level has been routine for the past year. Initially the power increased quite rapidly, sometimes doubling over short periods. Careful residual activation measurements were performed during this ramp-up, both to understand the level of beam loss and to also provide a predictive basis for anticipating activation during the rampup. Generally the activation scales closely with beam loss monitor response. There were some cases of activation where beam loss was not detected, in which case, loss monitors were either added or moved closer to the beam pipe to increase sensitivity to loss detection. Throughout the beam ramp-up history to-date, the beam power has not been limited by excessive beam loss.

ACTIVATION HISTORY

Linac

Beam loss was not expected in the superconducting linac (SCL). However early in the power rampup, activation was detected, and subsequent movement of the loss monitors close to the beam-pipe confirmed beam loss. Over the first one to two years the beam loss and resultant activation increased roughly proportional to the beam power.

In 2009, a running mode of reduced transverse focusing resulted in lower beam loss per Coulomb of accelerated beam and the activation levels have stabilized. Figure 2a shows this progression of SCL activation, overlaid on the beam power history. The activation levels are measured about once a month during scheduled maintenance days, and are 30 cm from contact. There is variability in the time from beam shutoff. Typically the measurements are 1-2 days after neutron production ends, but beam study periods at lower power levels typically run until 1-2 hours before the measurements.

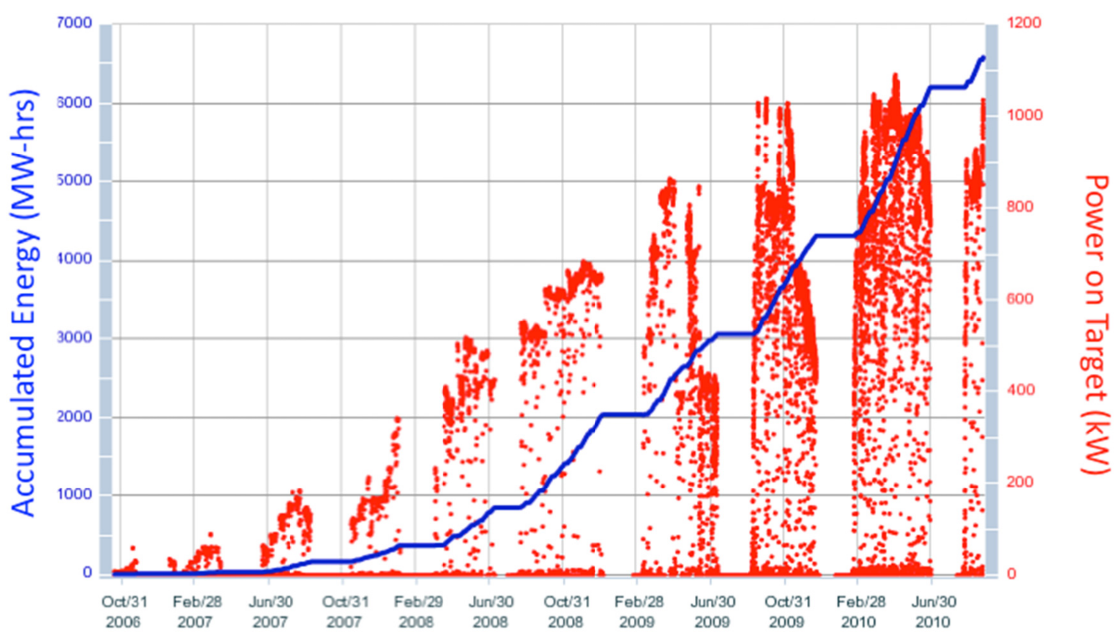

Figure 1: The history of the SNS power ramp-up to date.

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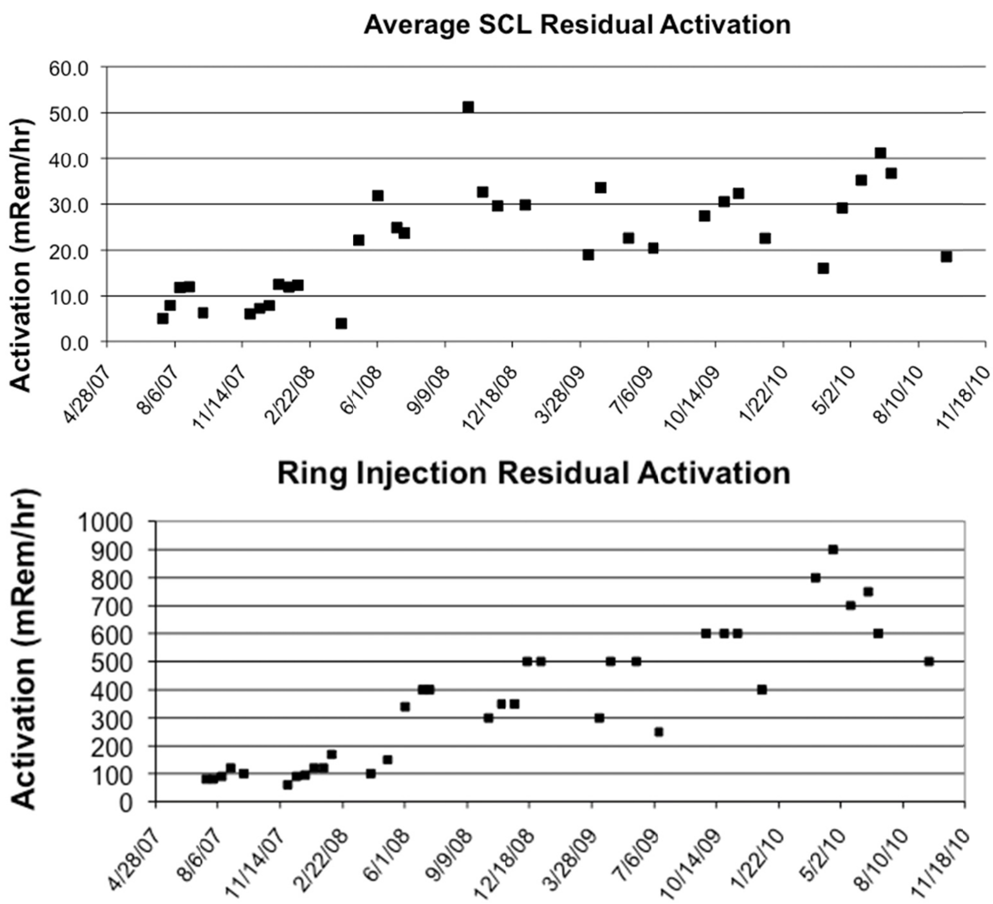
The SCL activation levels are the average of the maximum detected activation in each of the warm sections between SCL cryomodules (activation is very low by the cryomodules). The activation is typically evenly distributed along the SCL warm sections. The warm linac sections show lower levels of activation, with a few hot spots of up to ~50 mRem/hr.

Activation in the transport lines and the majority of the Ring is quite low. There are localized hot spots of ~ 50-80 mRem/hr in the Ring and HEBT collimation sections, and at the Ring extraction septum, but these are expected areas of beam loss. The primary area of residual activation is in the Ring injection, in particular in the few meters just downstream from the stripper foil. The history of this activation is shown in Fig. 2b. It has increased in rough proportion to the beam power level. Also, the activation levels in this area are close to the predicted levels for beam loss from foil scattering of ~10^{-4}.

WORKER DOSE

Worker dose is the ultimate measure of the ability to perform hands on maintenance. Figure 3 shows a summary of the history of worker exposure at SNS. These data include all radiological doses, including activities related to neutron instruments and the Target as well as accelerator work. There was an initial increase in the worker dose with the beam power increase, but over the past three outages, the dose has stabilized. The initial decrease in the dose rate is a reflection of an increase in the total number of rad-worker hours worked, much being in relatively low activity areas. The highest annual individual dose has been 103 mRem this year. We expect increases in the worker dose as planned upgrades in more active areas occurs.



a)

b)

Figure 2: Residual activation at 30 cm following beam runs in a) the superconducting linac and b) the Ring injection area, over the power rampup to 1 MW.

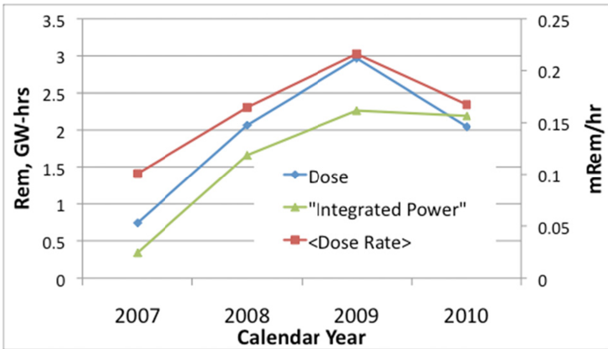


Figure 3: Collective worker dose (blue), average dose rate (red) and integrated beam power history (green).

MACHINE PROTECTION

A key concern with high power machine operation is machine protection. There are several components of the SNS Machine protection system [2]. These include a fast protection system, a slower system that protects against excessive machine activation, and a third set of controls to ensure adequate protection of the target.

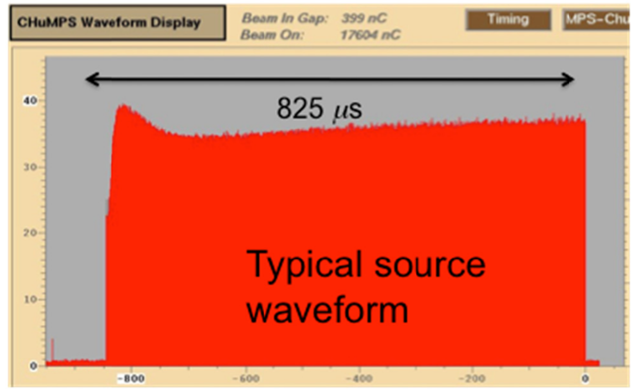
Fast Protection

There are inputs for fast protection beam shutoff from beam loss monitors, RF and magnet settings and insertion of intercepting devices under the wrong circumstances. For SNS this system is designed to turn the beam off within 20 µs from the detection of an errant condition. This protection layer is to prevent direct equipment damage from the beam (particularly vulnerable at lower beam energies). The beam loss monitors [3-4] and RF status are key components for this fast protection. This system is hardware based, and under careful configuration control. The loss monitor trip levels picked to be up to ten times higher than normal production beam levels (normal loss correspond to < 1 W/m). This large margin between the trip level and the typical operational level minimizes nuisance trips while still maintaining a quite safe operational envelope.

The components of the fast protection system were tested during beam commissioning period, but subsequently filters were added to reduce noise induced false trips. These had the effect of slowing down the overall shut-down time. Subsequent integrated testing showed quite large beam shutdown times. A careful campaign to remove the filters has restored the beam trip times to less than 20 µs, as indicated in Fig. 4.

Slow Beam Loss Limits

The beam loss trip limits for the fast protection hardware system described above works well to prevent direct machine damage from the beam. However, long term operation with 3-10 times higher than normal loss could allow excessive machine activation. A slower software integration system is used to control machine activation. This system provides an average beam loss over 10 seconds (600 pulses), and is much less prone to noise. Trip limits of only a few 10's of percent higher than the normal operational levels can be implemented without the nuisance trip problem of an occasional noisy pulse.



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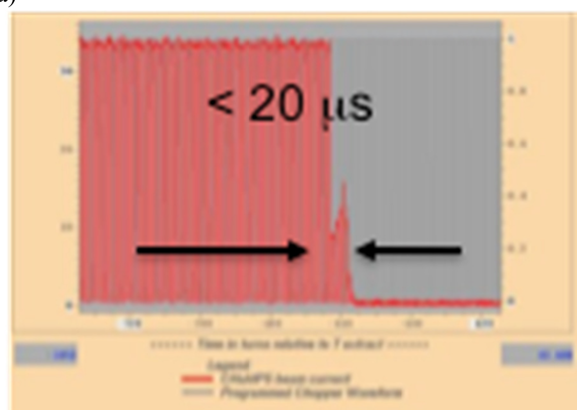

b)

Figure 4. a) A normal current waveform with an 825 ms beam width, b) zoom-in on the center of an errant pulse which had a sudden drop in current level causing excessive beam loss, which tripped the beam in < 20 µs.

Target Protection

A key facet of high power beam operation is careful management of the beam parameters at the Target. At SNS a considerable set of protective measures are employed to ensure operation within the design envelope on the Target. Key concerns are keeping the beam centered on the Target, ensuring the peak beam power density remains below a tolerable limit, and ensuring the beam size (and halo) remains below specified limits. The state of these parameters are measured and documented during the tune-up prior to each production run. During the subsequent operation, parameters are monitored to ensure the documented setup does not deviate beyond acceptable bounds [5]. All magnets affecting the beam size (painting in the Ring, and focusing in the transport leading to the Target) are kept within specified tolerances (exceeding read-back noise fluctuations). Loss monitors along the transport line leading to Target are kept within a few 10s of percent of the tune-up values. Thermocouples that intercept the outer edges of beam halo just upstream from the Target are continuously monitored to ensure a symmetric distribution of the beam leading to the Target (i.e. preventing beam deviation from the Target center). Finally a Harp is continuously inserted in the transport line to monitor the beam distribution and peak density. A new direct phosphor imaging system of the beam on the Target is under development [6-7].

AVAILABILITY

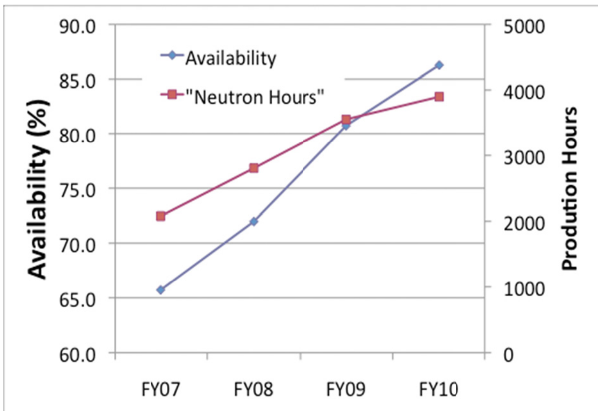

Figure 5: Machine availability and neutron production hour progress since the start of beam operations.

Beam availability (= time the beam is on / promised beam on time) is a key metric for a neutron source. Increasing he availability has been the primary focus of attention the past 1-2 years. Figure 5 shows the progress (2010 data is through July) While there has been steady progress, achieving > 90% availability has proved quite challenging. Figure 6 shows the progress in reducing trips as a function of trip duration. Reducing the long outage trips has the largest impact on availability, and this area has improved. Reducing long outages still offers more room for improvement. The 2010 data is through July.

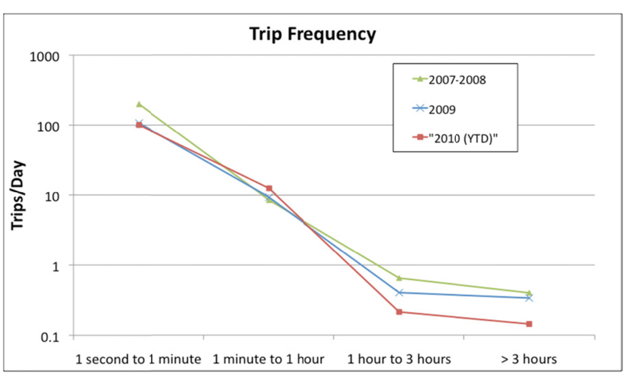

Figure 6: Trip frequency vs. outage length.

SUMMARY

SNS is completing the power increase to 1 MW operation. The beam loss and activation levels are generally within expected levels, except the SCL – where no beam loss was predicted. Workforce dose is not excessive and beam loss is not a limitation on operational power yet. Operation at 1 MW power levels requires careful vigilance for machine protection, with redundant and multi-level layers of protection. Beam availability is quite challenging and approaching 90% availability is quite difficult.

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