The Second Target Station at the ORNL Spallation Neutron Source

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Abstract. After the Spallation Neutron Source (SNS) construction project was completed in June, 2006, development of plans to construct a second target station (STS) at SNS began. These plans have evolved to the establishment of a reference concept for a STS and associated neutron beam instruments, and the evaluation of the expected performance for this station, all of which have been documented in a White Paper. Based on this White Paper, the Department of Energy has approved development of a detailed conceptual design leading to a construction project for the STS. The STS reference design is based on pulse stealing from the 60 Hz SNS accelerator system, with one pulse of every three going to the STS and the other two going to the first target station. The STS would operate in long-proton-pulse mode with no pulse compression in the accumulator ring, and would be optimized for production of intense beams of cold neutrons. The reference concept for the STS and the estimated performance for this concept will be discussed

1. Introduction
The Spallation Neutron Source (SNS) facility at Oak Ridge National Laboratory (ORNL) became operational in the spring of 2006. The SNS is a short-pulse spallation source with a linac accelerating a beam of H ions to 1 GeV. This beam has a macro-pulse length of 1 ms which is chopped into a number of mini-pulses and injected into an accumulator ring where the mini-pulses are accumulated on top of one another. After the ring is fully loaded, the beam is extracted in a single turn to produce a ~700 ns proton pulse that impinges on a mercury target where the spallation process produces very intense short pulses of neutrons. Several moderators slow these neutrons to thermal or sub-thermal energies for use in neutron scattering experiments. This process repeats at a 60 Hz rate.

The SNS was designed and implemented such that the power of the facility could be upgraded with minimal disturbance, and the facility design and site layout facilitate provision of an additional target station to accommodate an expanding experimental instrument suite. A Power Upgrade Project (PUP) for the SNS is already underway, and a “white paper” has developed and evaluated a preliminary concept for a second target station (STS) at SNS. This concept, referred to as the “reference concept” will be described in this paper. This reference concept was optimized for the production of intense beams of cold neutrons, thus emphasizing areas of science for which the first target station was not fully optimized.
2. Reference concept

2.1. Reference concept for the accelerator system
In the STS reference concept the accelerator system operates in a “pulse-stealing” mode at 60 Hz with every third pulse going to the second target station (20 Hz second target station operation) and the remainder of the pulses going to the first (present) SNS target station (40 pulses per second in a “pseudo-60 Hz mode”). For the 20 pulses per second going to the second target station, the long proton pulse (~1 ms long) from the linac is sent directly to the second target station with no accumulation in the ring. This “long-pulse” operating mode enables the delivery of about 50% more power from the linac for the same pulse duration because the chopping of the proton beam necessary for storage and extraction in the ring can be eliminated, although acceleration of this additional beam power requires additional RF power to the linac. The use of long proton pulses also allows the use of a mercury target for the reference concept for the second target station even at the higher power per pulse, because spreading the proton pulse out over ~1 ms significantly diminishes any mercury cavitation effects.[1] The anticipated energy and beam current provided by the accelerator systems will permit operation in this mode with at least 1.3 MW of short pulses directed to the first target station and at least 1 MW of long pulses directed to the STS, using accelerator RF equipment upgrades consistent with the PUP.

2.2. Reference concept for the target building and target station
The reference concept for the second target station is similar to that of all recent spallation facilities—a horizontal proton beam colliding with a target located in the center of an iron and high-density-concrete shielding monolith. In the reference concept neutron beamlines arrayed on each side of the target shielding monolith are illuminated by moderators above and below a mercury target. A shielded target service bay used to replace the targets and contain the mercury cooling loop is located downstream of the proton beam. The target and associated shielding monolith are placed asymmetrically within the target building, so that the instruments on one side have more room to fit within the building while instruments on the other side will mostly be on longer beamlines that would not fit within the target building in any case.

The optimization studies for the STS reference concept led to the selection of two large pre-moderated supercritical para-hydrogen moderators, closely coupled in wing geometry to a mercury target similar to that at the first SNS target station. The cylindrical moderators are each 22 cm diameter and 14 cm tall, surrounded by water pre-moderators on all sides except where neutron beams are to be extracted, and embedded inside a beryllium reflector assembly. Figure 1 shows the STS reference concept target, moderators, and neutron beamlines inside the shielding.

2.3. Reference instrument suite
In order to better assess the full potential of the facility concept defined in the preceding sections, a set of neutron beam instruments has been selected as a reference or “straw man” instrument suite for STS. The specific instruments selected are based on concepts proposed and evaluated as part of the SNS Second Target Station Instrumentation Workshop. In some cases, the instrument designs proposed at the workshop have been modified to fit circumstances (e.g., the maximum beam length that fits on the site is ~130 m) and the performance reevaluated for the new parameters. Instruments selected for the STS reference instrument suite are those instruments proposed during the workshop that provide the greatest scientific payoff and benefit the most from the intense cold beams and low operating frequency at the STS.

2.4. Conventional facilities
Figure 2 shows the layout of the STS reference concept target building and instruments on the SNS site. The location of the target building is optimized to accommodate the longer beam lines appropriate for this type of facility.
3. Estimated performance

The neutronic performance of the STS reference target station and the associated performance of the reference suite of instruments were calculated for both the short-proton-pulse (~1 μs) and long-proton-pulse (~1 ms) operating modes. In the short-pulse option, the pulse shape is determined solely by the neutron moderation process. Shorter-wavelength neutrons are emitted in narrower and more peaked pulses, whereas long-wavelength neutrons need longer moderation times, resulting in wider pulses with less pronounced peaking. In the long-pulse option, the pulse shapes derive from a time-folding of the proton pulse shape and the short-pulse neutron pulse shapes.

Figure 3 shows the peak and time-averaged brightness calculated for the STS reference concept in both short-proton-pulse and long-proton-pulse modes. The time-averaged brightness is the important parameter for instruments that can use the full pulse width (i.e., the full pulse width provides adequate timing resolution), and the peak brightness is the most important parameter for instruments that need to chop the source neutron pulse to provide adequate resolution. One additional performance
difference between STS and the first target station is that STS would operate at 20 Hz, leaving a much longer period between pulses. This longer period gives access to a larger bandwidth.

The estimates show that in long-pulse mode, instruments on the STS that can take full advantage of both of these factors can perform more than an order of magnitude better than they would at the first target station, and on average the STS in long-pulse mode provides about an order-of-magnitude gain over the first target station for a broad class of important scientific applications. This improved performance makes it practical to tighten angular and/or energy resolution or to use other techniques to probe previously inaccessible ranges of parameters. It also makes it practical to consider the use of neutron beams focused to well below 100 microns in size, since the neutron intensity that will be available in such focused beams at STS will be enough to measure the very weak absorption or scattering produced by the relatively small number of sample atoms illuminated by such a beam.

![Figure 3. Peak and time-averaged moderator brightness calculated for the STS reference concept target-moderator system. For comparison, time-averaged cold-neutron brightness is also shown for the ILL cold source. Calculations are for 1 MW to the STS in long-pulse mode and 0.67 MW to the STS in short-pulse mode, reflecting the difference in the linac power in the two cases.](image)

4. Summary
A reference concept has been developed and evaluated for a second target station at the SNS. By focusing on and optimizing for the production of cold neutrons this new facility will provide much higher cold-neutron intensities than heretofore available on any pulsed neutron source. The evaluation shows that such a second target station will provide major new capabilities that significantly extend the types of scientific problems that can be fruitfully addressed with neutron scattering.

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References
[1] B. W. Riemer, private communication (2009).