# IN-BEAM SNS RING COLLIMATION OPTIMISATION*

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*Abstract*

Hands-on maintenance of the Spallation Neutron Source (SNS) Accumulator Ring requires an uncontrolled beam loss of less than 1nA/m. A collimator system will be used to obtain this low uncontrolled beam loss. Some beam dynamics questions related to the collimators have been studied. Various factors are optimised with the given SNS ring lattice such as collimating tube length, location, number of collimators, aperture size of primary collimators and secondary collimators, and collimator material. The beam dynamics studies indicate that movable shielding may be necessary for a few hot places downstream of the primary collimators and also that secondary collimators could be designed according to their significantly less activation. These simulations indicate that with proper collimation the uncontrolled beam loss requirements of the SNS accumulator ring may be achievable.


## 1 INTRODUCTION

The Spallation Neutron Source (SNS) is the most powerful pulsed neutron source under construction [1]. With a repetition rate of 60 Hz, the SNS accelerates a proton beam up to 1 GeV with 1 MW initial beam power that is to be upgraded to 2 MW. SNS operation requires acceleration of intense beam for which space charge effects may play an appreciable role. It is understood that a certain level of beam loss is unavoidable during operation of the accumulator ring that comes from various sources such as halo generation due to the space charge force, magnet non-linearity, errors and harmonic modulations etc. Hands-on maintenance requires that uncontrolled beam loss should be less than 1 nA/m, which corresponds to 1 ppm of 1 MW beam power per meter. In order to meet the beam loss requirement, a special betatron collimator system is needed which can absorb halo protons and contain activation due to secondary particles.

Betatron and momentum collimation in circular accelerators has been studied [2-4]. Collimation in a linear collider was also studied [5]. A very effective collimator was designed at BNL [6] by using the LAHET Code System [7]. However, there remain a few questions that need to be answered with beam dynamics. These questions are as follows:

- What is the optimal length of the inner collimating tube of the collimators?
- What are the number and location of collimators?
- What should the aperture size of secondary collimators be with respect to that of the primary collimators to minimise the activation of downstream beam line components?
- On what components and what level of activation should be expected downstream from the collimators?
- What material should be used for the inner collimating tube?
- How much residual halo is anticipated from the collimators?

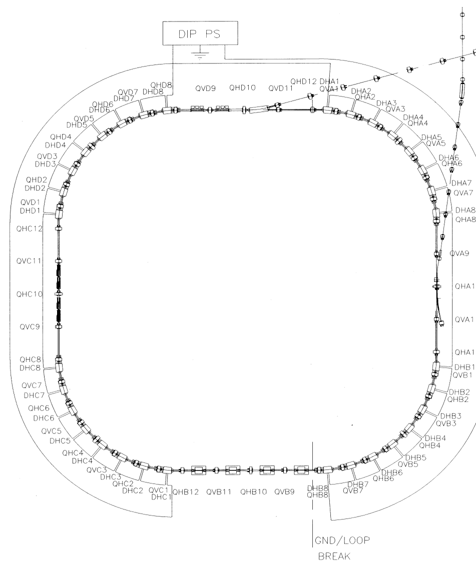


Figure 1: Layout of the SNS accumulator ring.

## 2 RESULTS

To answer these questions numerical simulation were performed with the ACCSIM H- injection code [8]. The x (y) bare tunes of the SNS accumulator ring lattice were set at 5.82 (5.80). With these tunes the numerical simulation of injection with space charge indicates that about 0.5% of the beam is generated as halo protons with emittance greater than 180 $\pi$ mm mad. The maximum number of particles that can be tracked is about 400,000, which is much too small to get statistically meaningful data to one part in a million. Consequently, from the 0.5% halo particles obtained from the numerical simulation with space charge, we constructed 100,000 halo particles and tracked them without space charge for the collimator simulation. However, due to other errors, we assume that about 1% of beam will appear as halo protons. The collimators are rectangular.

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- *Length of inner collimating tube*

When halo protons hit a collimator face, some of them are not absorbed and scattered back into the collimating tube with large transverse momentum. These protons are either removed at the later part of the collimating tube or scattered into the collimating tube again as shown in Fig. 2. Consequently, there are always scattered protons spewed out from the downstream end of a collimator. The vertical line and dots in Fig. 2 at 3.5 m represent these particles where a downstream quadrupole is located, and those protons that have larger transverse displacement than 100 mm at that point may activate the quadrupole. It is most effective to have a long inner collimating tube as possible in order to reduce the activation of the downstream quadrupole and beam pipe. Of course, a longer collimator is more expensive to build and space is limited. The simulations indicate that at least a 2-m or longer collimating tube is required.

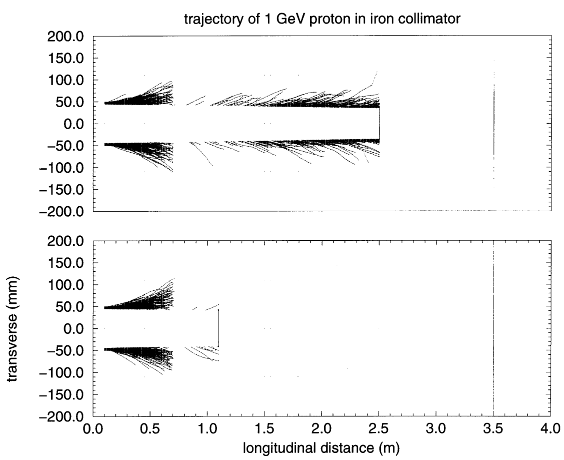


Figure 2: The trajectory of protons in the collimators. The length of the collimator is 2.4 m (upper plot) and 1.0 m (lower plot). The line at 3.5 m represents the scattered protons where a downstream quadrupole is located.

- *Number and location of collimators*

Due to the difference in phase advance between the x and y planes, and also due to the scattered protons from the downstream end of a collimator, it is necessary to place a collimator in every drift space. Consequently, four collimators are required to minimise the activation of downstream components. The Collimator-4 loss fractions are listed in Tables 1 and 2 and these fractions justify the need for a fourth collimator. Figure 2 shows that the scattered protons out of a collimator usually have large transverse momenta and reach the beam pipe aperture quickly. To minimise the activation of downstream quadrupoles from these scattered protons, the distance between a collimator and the following quadrupole should be minimised. The minimum distance is set at 1.0 m to reserve space for maintenance and installation.

- *Aperture size of secondary collimators*

The aperture of the primary collimators is set to $180\pi$ mm mrad. The aperture of secondary collimators should be set large enough to avoid direct interception of halo protons and yet be small enough to intercept the scattered protons from the upstream primary collimators. Numerical simulations with space charge indicate that the aperture of the secondary collimators, as shown in Fig.3, should be about $210\pi$ mm mrad for the 2 MW SNS ring.

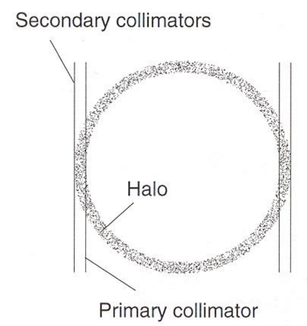


Figure 3: Schematic drawing of the aperture of primary and secondary collimators.

Table 1: Loss fractions verse collimator configurations.

| | Case 1 | Case 2 |
|---|---|---|
| Collimator 1 | 57.94 % | 88.30 % |
| QD | 0.30 % | 0.46 % |
| Pipe 2 | 1.40 % | 2.61 % |
| Collimator 2 | 35.24 % | 6.60 % |
| QF | 0.19 % | 0.03 % |
| Pipe 3 | 1.40 % | 0.08 % |
| Collimator 3 | 2.71 % | 1.03 % |
| QD | 0.01 % | 0.01 % |
| Pipe 4 | 0.04 % | 0.01 % |
| Collimator 4 | 0.47 % | 0.20 % |
| QF | 0. % | 0. % |
| Pipe 5 | 0.01 % | 0.01 % |
| Pipe 6 | 0.02 % | 0.01 % |
| Pipe 7 | 0.02 % | 0.02 % |
| Pipe 8 | 0.05 % | 0.04 % |
| Pipe 9 | 0.01 % | 0. % |
| Pipe 10 | 0. % | 0. % |
| Pipe 11 | 0.05 % | 0.02 % |
| Pipe 12 | 0.10 % | 0.06 % |
| Pipe 13 | 0.01 % | 0.01 % |
| Pipe 14 | 0. % | 0. % |
| Sum of Pipes 5 to 14 | 0.27 % | 0.17 % |

Clearly Collimator 1 should be primary and Collimators 3 and 4 secondary. Table 1 lists loss fractions at each component if Collimator 2 is primary (Case 1) or if Collimator 2 is secondary (Case 2). When Collimator 2 is an additional primary collimator (Case 1), the scraping of halo particles is faster and the load of Collimator 1 is reduced. However, the summed activation level of downstream components is less if Collimator 2 is secondary (Case 2).

- *Downstream activation and collimator material*

Table 2 lists loss fractions for both iron and tungsten collimating tubes. The collimator configuration of Case 2 is used where Collimator 1 is the only primary collimator with aperture size $180\pi$ mm mrad and Collimators 2, 3

Table 2: Loss fractions verses collimator material.

| | Fe ( $\rho$ =7.87) | W ( $\rho$ =19.3) |
|---|---|---|
| Collimator 1 | 88.30 % | 95.41 % |
| QD | 0.46 % | 0.31 % |
| Pipe 2 | 2.61 % | 1.18 % |
| Collimator 2 | 6.60 % | 2.18 % |
| QF | 0.03 % | 0.01 % |
| Pipe 3 | 0.08 % | 0.04 % |
| Collimator 3 | 1.03 % | 0.28 % |
| QD | 0.01 % | 0. % |
| Pipe 4 | 0.01 % | 0. % |
| Collimator 4 | 0.20 % | 0.04 % |
| QF | 0. % | 0. % |
| Pipe 5 | 0.01 % | 0. % |
| Pipe 6 | 0.01 % | 0. % |
| Pipe 7 | 0.02 % | 0.01 % |
| Pipe 8 | 0.04 % | 0.02 % |
| Pipe 9 | 0. % | 0. % |
| Pipe 10 | 0. % | 0. % |
| Pipe 11 | 0.02 % | 0.01 % |
| Pipe 12 | 0.06 % | 0.02 % |
| Pipe 13 | 0.01 % | 0. % |
| Pipe 14 | 0. % | 0. % |
| Sum of Pipes 5 to 14 | 0.17 % | 0.06 % |

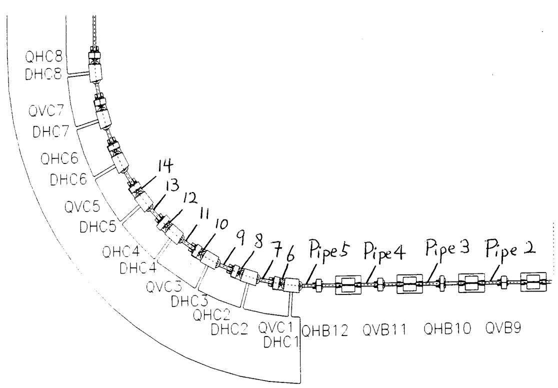


Figure 4: Beam line element labels used in Tables 1and 2 where the beam circulates in clockwise direction.

and 4 are secondary collimators with aperture size $210\pi$ mm mrad. Clearly dense material is more effective in removing halo particles and subsequently reducing downstream activation levels. However tungsten is very expensive. Calculations indicate that lead is very effective for scattering; however lead produces a lot of secondary neutrons.

## 3 CONCLUSION

The main problem in obtaining statistically accurate loss fractions is the limitations on computing power. In order to get a statistically meaningful accuracy down to 0.01%, at least 0.1 billion halo particles are necessary. From the 2D PIC code simulations, it is shown that about 0.5% of the beam appears as halo with emittance greater than $180\pi$ mm mrad. Therefore at least 20 billion macro particles would need to be injected and tracked in the SNS ring to do the simulations properly, which greatly surpasses current computing capability.

Nevertheless, these simplified initial numerical simulations indicate that the required uncontrolled beam loss of 1nA/m may be achievable with a properly designed collimation system. The simulations indicate that long collimating tubes made from heavy metal would be most effective. The collimators need to be located as close as possible to the next downstream quadrupole. Four collimators should be used, but the halo load on the last two collimators could be significantly less than on the first two. Movable shielding may be necessary for a few hot places downstream of the primary collimator. More detailed numerical simulations, including turn by turn halo growth from the space charge effect, need to be carried out.

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