

# DOUBLING THE SNS H<sup>-</sup> BEAM CURRENT WITH THE BASELINE LBNL H<sup>-</sup> ION SOURCE

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## Abstract

Over the past year the performance of the LBNL H<sup>-</sup> source has been improved to routinely produce 36 mA when averaged over 0.8 ms long pulses at 60 Hz, measured near the RFQ output of the Spallation Neutron Source accelerator. This is up from 25-30 mA during early 2008, and up from 10-20 mA during 2007. A 3-week source cycle utilized a RFQ output beam current of 38 mA, which is the design value for producing neutrons with a proton beam power between 1 and 1.4 MW. In one case, after 12 days of 4% duty factor operation, 56 mA RFQ output were demonstrated with ~60 kW of 2 MHz. This is close to the 59 mA required for 3 MW operations.

## INTRODUCTION

Lawrence Berkeley National Laboratory (LBNL) developed the SNS baseline ion source and LEBT, shown schematically in Fig.1, as a part of the SNS Frontend [1].

Typically 250 W from a 600 W, 13 MHz amplifier generate continuous low power plasma. The high current beam pulses are generated by superimposing 30-70 kW from a pulsed 80 kW, 2 MHz amplifier.

The two-lens electrostatic LEBT is 12 cm long and focuses the beam into the RFQ with the required Twiss parameters  $\alpha = 1.79$  and  $\beta = 0.0725$  mm/mrad. The LEBT's compactness prohibits any beam characterization before it is accelerated to 2.5 MeV by the RFQ. The first beam current monitor is located near the exit of the RFQ.

With ~0.1 ms pulse length during the 2006 production run, the source significantly exceeded the required 20 mA MEBT beam current. When the pulse length was increased to ~0.25 ms during production run 2007-1, the MEBT beam current marginally met the 20 mA requirement despite raising the RF power.

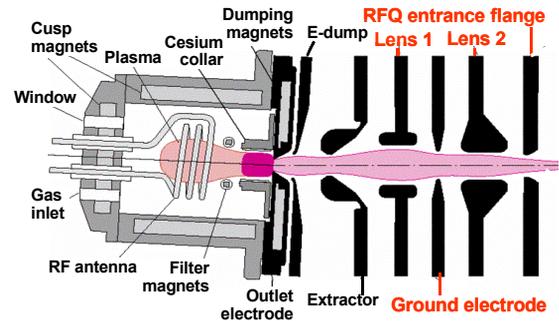


Figure 1: SNS baseline ion source and LEBT.

Short beam pulses are optimized by tuning the RF for a rapid breakdown of the plasma, which is near the resonance without any plasma. The highest currents for long pulses are obtained by tuning the RF to the resonance which includes the inductive and resistive load of the high power plasma. However, this tune is drastically mismatched for the initial breakdown of the plasma, which can cause missing pulses or a complete cessation of the beam production. Mitigations include increasing the power of the RF amplifiers, increasing the hydrogen pressure, and/or a compromise tune [2]. A combination of those mitigations allowed for restoring the 20 mA during run 2007-3 to meet the beam current requirement. However, the 25, 30, 32, 35, and 38 mA beam current requirements of the subsequent production periods appeared out of reach.

## SOURCE MODIFICATIONS

Throughout the end of run 2007-3, the gap between the Cs collar outlet aperture and the source outlet shown in Fig 2a was ~3.2 mm rather than the ~1 mm shown in the

Table 1: Duty factor, Pulse length, MEBT beam current requirement and achievements for the SNS Production Runs.

Production Run	Duty factor	Pulse length	mA required	mA in MEBT	RF [kW]	%Availability	Comments
2006-1		~.1 ms	20	28-20	~70	99.9	1 ion source, 1 cesiation, raise collar temperature
2007-1	0.2	~.25ms	20	30-16	~70	99.98	1 ion source, 1 cesiation + 24h @115°C collar temperature
2007-2	0.8	~0.4ms	20	20-10	60-80	70.6	Arcing LEBT; antenna puncture after 37 days, start 2-week source cycles
2007-3	1.8	~0.5ms	20	13-20	80	97.2	Modified lens-2; e-target failures; tune for long pulses
2008-1	3.0	~0.6ms	25	25-30	35-50	99.65	modified Cs collar
2008-2	3.6	~0.6ms	25/30	25-37	uncal.	94.9	Beam on LEBT gate valve
2008-3 2009-1	4.0	0.69ms	32	32-38	48-55	99.22	Start 3-week source cycles, Ramp up e-dump
2009-2	5.0	0.8 ms	35	36	~50		
2010-1	5.6	0.9 ms	38				
2010-2	6.2	1.0 ms	38				

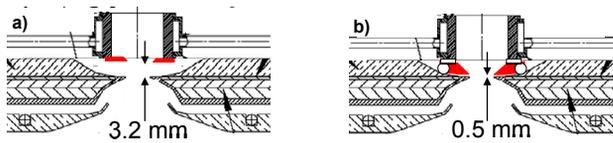


Figure 2: Original (a) and modified (b) Cs collar outlet.

LBNL assembly drawing. Recognizing the inefficiency triggered 13 ion source tests with different configurations within 5 weeks. These tests championed replacing the 1-mm thick stainless steel Cs collar outlet aperture with 4-mm thick, Molybdenum outlet aperture, featuring a 40° internal taper and ceramic balls, which centre the aperture and leave a ~0.5 mm gap. This change has roughly increased the beam current output by 50%, while allowing a reduction of the RF power.

Additional modifications were needed to reduce variations of the performance. For example, when being heated, the original Cs collar moved axially for several mm, where the direction depended on slight, uncontrolled misalignments. Another example is the uncontrolled position of the Cs cartridges, which are 1.8 mm shorter than their slots. Recognizing the problem triggered the insertion of compression springs to consistently deliver most of the Cs to the Cs collar outlet aperture, rather than into the plasma chamber.

### CONDITIONING AND CESIATION

To minimize Cs-induced arcing in the ultra-compact LEBT and the nearby RFQ, LBNL introduced 8 Cs<sub>2</sub>CrO<sub>4</sub> cartridges [3], which together contain <30 mg Cs. They are contained in the Cs collar shown in Fig. 2. The Cs collar is surrounded by an air channel, which allows for controlling its temperature between ~30 and ~400°C by heating compressed air.

Releasing Cs in atomic form requires the activation of the getter St101 [4], which requires temperatures >500°C. That is achieved by heating the collar with the plasma after switching off the compressed air.

A 2004 study incorrectly concluded that at elevated temperatures the getter would be consumed by the residual gases [5], and recommended to condition the source as cold as possible before raising the temperature to ~550°C for releasing Cs [6]. Three years of fairly erratic results triggered follow-up studies, which indicated that cold conditioning causes the getter to react for the first 20-100 minutes with surface contaminants before starting to reduce the Cs chromate. Obviously the large surface area of this powdery mixture needs to be degassed before being heated to the reaction temperature. Degassing can be accomplished with much extended conditioning at low temperature as it was done in the 2004 study, or with a much compressed conditioning at elevated temperatures, which was introduced on the Frontend after the recent follow-up studies.

Until 2008, on the Frontend the source conditioning at 6% was limited to 30 minutes to preserve source lifetime. Unknowingly this caused the initially poor persistence of the beam current seen in Fig. 3. After a certain number of

### Sources and Injectors

#### T01 - Proton and Ion Sources

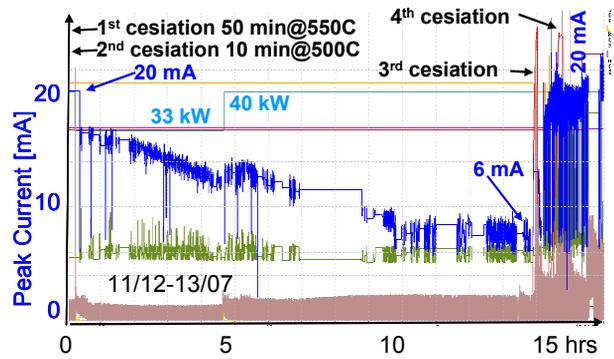


Figure 3: The MEBT peak current (blue) following the ion source change on 11/12/07.

hours, a follow up cesiation would then yield nearly perfect persistence.

In 2008, when the 6% conditioning time was gradually increased to 2.5 hours, the initially poor persistence disappeared. It appears that Cs deposited on inadequately sputter cleaned surfaces is sputter away with the remaining surface contaminants, where as Cs deposited on a sufficiently cleaned surface sticks extremely well.

These two lessons learned are combined in our conditioning and cesiation procedure illustrated in Fig. 4. It shows the “purple” Cs collar temperature to gradually rise to ~130°C, initially by the heated compressed air and rapidly assisted by the rapidly increasing “red” pulse length of the “green” 2 MHz RF power. The efficient degassing is indicated by the rapidly decaying “pink” partial pressure of water. After ~90 minutes, the temperature is ramped up to ~350°C, giving a final degassing boost as seen in the slow-down of the water pump down. The Cs collar temperature is then raised to 550°C where it is kept by adjusting the pulse length. Cs starts immediately to be released, which changes the plasma conditions, which require lowering the “black” matching capacitance. Once the “blue” MEBT beam current can be measured, the system is tuned, its RF power response explored, before being set to the desired 38 mA.



Figure 4: H<sub>2</sub>O partial pressure (pink), Cs Collar temperature (purple), 2 MHz power (green), matching capacitance (black), antenna current (brown), pulse length (red), and maximum beam current (blue) during the conditioning, cesiation, and tune up of a source.

## ELECTRON DUMP OPTIMIZATION

The dipole dumping magnets integrated into the source outlet aperture steers the co-extracted electrons to the side, where they impact on the electron dump [1], which is shown in Fig. 1 and at the bottom of Fig. 2. When tuning up sources, no significantly higher beam currents could be found with higher e-dump voltages. When operated at higher duty factors and voltages  $\geq 3$  kV, the e-dump would often arc against the source body. The arcing made the beam unstable and sometimes led to a short, which lowered the beam current by  $\sim 15\%$ . During summer 2008 the Vespel insulators were replaced with alumina and the hex socket head screws were replaced with low profile screws [7]. Field testing was completed during run 2009-1, by increasing the e-dump voltage by 1 kV for every 3-week source cycle until reaching 6.2 kV.

During a maintenance day, eight days after starting up the source, the two lenses were tuned to maximize the MEBT beam current for 5 different e-dump voltages, while the extractor was kept at ground. The results shown in Fig. 5 reveal that the MEBT beam current increases with e-dump voltage if the lenses are properly adjusted.

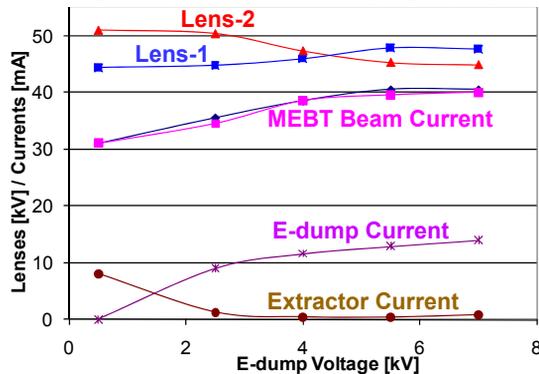


Figure 5: relative electron-load currents and lens voltages when optimized for the measured MEBT beam current vs. e-dump voltage.

The lens voltages suggest different modes for low and high e-dump voltages. The PBGUNS [8] calculations for the optimized 2.5 kV setting shows that the low e-dump voltage focuses the beam, which easily passes through the extractor as shown in Fig. 6.

Passing lens 1 as a rather small beam, the beam is large in lens 2, which increase the aberrations. At the entrance of the RFQ the beam meets the required Twiss parameters with a 3.8 mm diameter and a normalized emittance of  $0.159 \pi\text{-mm-mrad}$ .

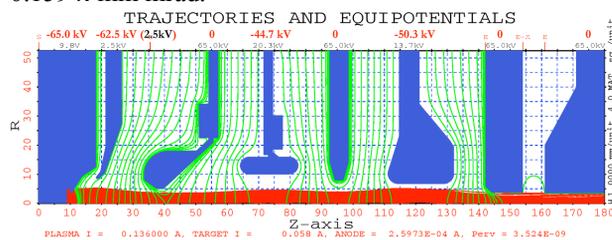


Figure 6: PBGUNS LEBT model for E-dump = 2.5 kV.

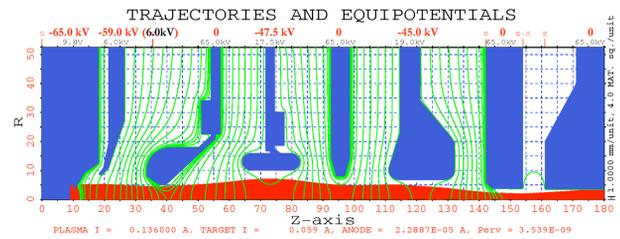


Figure 7: PBGUNS LEBT model for E-dump = 6 kV.

With 6 kV on the e-dump shown in Fig. 7, the beam is minimally focussed by the e-dump and barely clears the extractor. Lens 1 squeezes the large beam down, yielding a smaller beam in lens 2. At the entrance of the RFQ the beam meets the required Twiss parameters with a 3.2 mm diameter and a normalized emittance of  $0.146 \pi\text{-mm-mrad}$ .

The model calculations explain the higher beam currents found for higher e-dump voltages and show that the higher e-dump voltage significantly contributed to the 38 mA run, which was tuned up in Fig 4. 38 mA is the ultimate design current for 1.4 MW neutron productions. The higher e-dump voltage also contributed to the record 56 mA MEBT beam current shown in Fig. 8 and tuned up after a 12 day production run before replacing the source. This is close to the 59 mA, the ultimate design current for 3 MW neutron production.

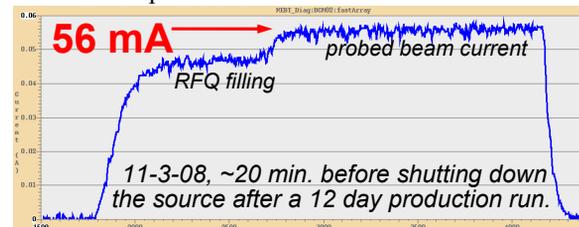


Figure 8: The  $50\mu\text{s}$  slice accelerated by the RFQ  $350 \mu\text{s}$  after the start of the  $690\mu\text{s}$  long ion source pulse at 60 Hz, yielding 56 mA beam from the RFQ.

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