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Author(s): Andy Arvin, Edwin Chacon-Golcher, Ernest G. Geros, Edward G. Jacobson, Bruce J. Meyer, Peter Naffziger, Gary Rouleau, Stuart C. Schaller, Joseph D. Sherman, James E. Stelzer, and Thomas J. Zaugg

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Development of a 25-mA, 12% Duty Factor (df) H^- Source for LANSCE*

J. Sherman, A. Arvin, E. Geros, E. Chacon-Golcher, E. Jacobson, B. Meyer, P. Naffziger, G. Rouleau, S. Schaller, J. Stelzer, and T. Zaugg.
Los Alamos National Lab, Los Alamos, NM87545, USA.

Abstract

Present operations at the Los Alamos Neutron Science Center (LANSCE) accelerator use a surface conversion source to provide 80-keV, 16 to 18-mA H^- beams with typical lab emittance of 7(πcm-mrad). Operational flexibility of the 800-MeV linac, proton storage ring, and other experimental facilities will be increased by a higher current H^- source. The present goal is to achieve a 25 mA H^- surface converter source with modest (20%) emittance increase without sacrificing the present LANSCE production source 12% df and 28-day lifetime. The LANSCE 80-kV ion source test stand (ISTS) has been brought into reliable 24-hour per day operation with computer control and modern electronics. A fourth production source has been fabricated, and is now operating on the ISTS. H^- currents up to 25 mA have been observed with 8-9 (πcm-mrad) lab emittances. An experimental study of surface converter geometries and electron filters at the emitter electrode are planned to optimize source current and emittance.

Introduction

The development of a new LANSCE H^- injector is being pursued for two principal reasons. First, the 16-18-mA H^- production source presents limits to 800 MeV linac and experimental facilities operations[1]. Forty mA H^- sources previously developed for LANSCE were accompanied by an undesired emittance growth[2,3]. Sources with these larger emittances were studied in the LANSCE 750-keV H^- injector (injector B) with the conclusion that significant changes in these beam lines would have to be made to accommodate the larger emittance beams[4]. Second, electronics in the present injector B dome are not compatible with planned control system upgrades at LANSCE. An intermediate goal of 25 mA H^- source with smaller emittance growth compatible with linac operations has been established. Design studies and first experimental results have been completed indicating that this H^- current goal is achievable with minimal (20%) emittance growth. This paper addresses some details on the new electronics for 24 hour/day operation, and experimental progress on the 25-mA H^- surface converter source.

Upgraded Injector Electronics and Control System

The new LANSCE H^- ion source test stand (ISTS) electronics and control system has been modified to study upgrades on the present two-filament LANSCE production source in 24 hours/day operations mode. This is a complex electro-mechanical device where approximately half the equipment resides in an 80-kV isolated power rack and the remaining equipment is in local ground racks. The ISTS hardware is summarized in ref. [5], and is a nearly exact replication of the 80 keV injector B system. Table 1 summarizes the description, specification, and function of the principal equipment located in the 80-kV racks. Figure 1 shows the 80-kV isolated equipment rack.

Table 1. Summary of the 80-kV isolated power equipment required to operate the ion source at 80 kV.

Description	Specification	Function
Filament power supplies (2)	20V / 150A	Emissive tungsten filaments
Converter power supply (1)	600V / 16A	Converter bias voltage
Repeller power supply (1)	33V / 33A	Improve e/H- ratio
Arc modulator	300V / 200A	Discharge current
Extractor electrode HVPS	45 kV / 6mA	Beam extraction potential
Analog light links	4, 1 MHz BW	Communication to ground
Hydrogen gas flow	0 – 5 sccm	Ion source gas throughput
Cesium oven	20 – 260 °C	Cs throughput
CAMAC crate	1-2 Hz scan, 16 bit resolution	Controls and diagnostics
Analog control modules(14)	12 bit resolution	Power supply setpoint
Binary control modules(14)		Power supply on/off

Details on the H^- source design and operation are found in ref [6]. The 80-kV system is controlled by fiber optic link from local ground by distribution through the 80-kV CAMAC crate. CAMAC distributes commands through a 12 bit resolution DAC board

Table 2. Summary of the ground-level equipment and controls for the 80-keV injector.

Description	**Specification**	**Function**
Beam-energy supply (regulator plus power supply)	+/- 2V/mA p-p at 80 kV	Monoenergetic beam energy
Solenoid magnet power (2)	20V/500A	Beam focus, transport
Steering magnet power (5)	+/-20V, +/-20A	Beam centroid control
Bending magnet power (1)		Suppress residual electrons before 670 kV column
Column electrode power supply	50 kV / 6 mA	Trap LEBT positive ions
Turbo pump controller	Balzers 2000 l/s	Pump source gas, $P_{LEBT} <$ $2X10^{-5}$ Torr
Cryopump controller	CryoTorr* 1000 l/s	Maintain $P_{LEBT} < 1 X 10^{-5}$ Torr
Ion pump controller	Varian	Maintain $P_{670kV} < 5 X10^{-6}$ Torr
CAMAC crate	1-2 Hz scan, 16 bit resolution	Controls and diagnostics
Analog control modules (10)	12 bit resolution	Power supply setpoint
Binary control modules (30)		Power supply on/off, Device activation (in/out, open closed)
Fiberplex fiber optics (5)	Timing distribution	Planned 670 kV dome communication

integrated into each power supply system. Table 2 summarizes the principal equipment located at the local ground potential. The beam-energy supply provides the extracted H^- ions with 80-keV energy for subsequent transport through the low-energy beam transport (LEBT) system. Two solenoid magnets provide beam focusing, and five steering

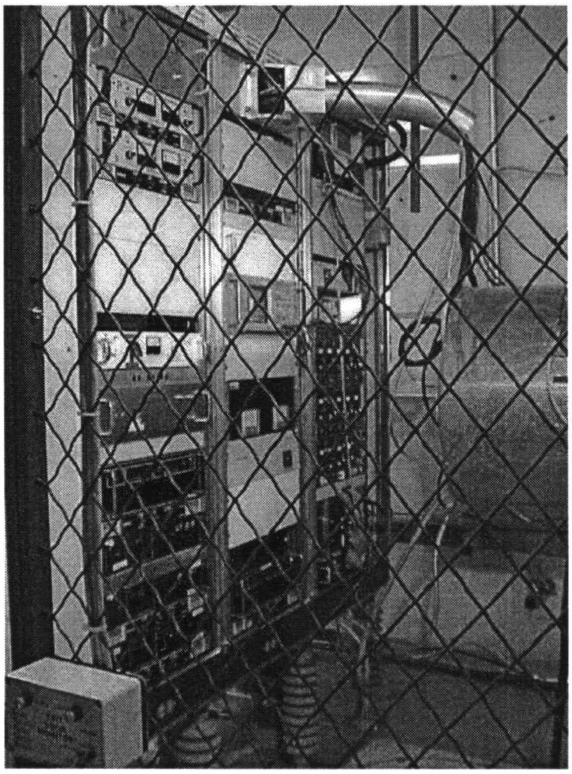

Figure 1. Photo of the ISTS 80-kV racks. The foreground box and fence are part of the ISTS safety systems.

magnets give beam centroid control. An additional function of the local ground equipment is device activation such as insertion of beam-line devices and control of vacuum pumps and valves.

25-mA H^- Surface Converter Source Development

A fourth version of the LANSCE production source has been fabricated for development purposes on the ISTS. Table 3 contains a summary comparison of the LANSCE production sources, and the best performance configuration to date of the development source. A design criterion followed here is to increase the H^- current without significant increase in discharge power. This accomplishes two objectives: first, the 28-day lifetime should be maintained; and, second, the beam emittance growth with discharge power increase[3] may be minimized. The initial production source modification involved a 20% increase in the emission (Pierce) aperture radius, r_P, from 0.5 to 0.6cm, and the repeller radius r_{rep} was increased from 0.64 to 0.86 cm to eliminate aperturing of the 260eV H^- beam at this location. See Fig. 2 for source component description. Assuming a uniform H^- beam illumination of the repeller/Pierce assembly, this step would give 25-mA H^- current with 20% emittance increase on the 80-keV beam.

One physics constraint on the assumption of uniform H^- current density at the emission aperture is the transverse sputter energy of the H^- ions as they leave the converter surface. This effect has been modeled in the PBGUNS code[7]. For

Table 3. Comparison of the LANSCE production and development sources.

	Parameter	Production Source	Development Source
1	r_P (cm)	0.50	0.60
2	r_{rep} (cm)	0.64	0.86
3	r_{cnv} (cm)	1.9	1.9
4	ρ_{cnv} (cm)	12.5	12.5
5	Admittance (cm-mrad)	304	379
6	B_c (kG)	2.0	3.4
7	I_{H^-}, Electron repeller	Line cusp	Line cusp
8	Discharge power (kW)	8	7.6
9	$(I_{H^-})_{max}$ (mA)	18	25
10	e/H^-	3.0	5.9
11	Electron repeller (for ε_l)	Line cusp	PM solenoid
12	ε_l (πcm-mrad), measured	7	8-9*

*$(I_{H^-})_{max}$ = 20mA.

comparison purposes, Fig. 2 shows 260eV H^- ion trajectories from the converter to the Pierce aperture for (A) the production, and (B) the development sources. Both calculations use a 12eV sputter energy, a converter radius r_{cnv} = 1.9cm, a converter curvature radius ρ_{cnv} =12.5cm, and a H^- converter current I_{H^-cnv} = 18mA. Figure 2(A)

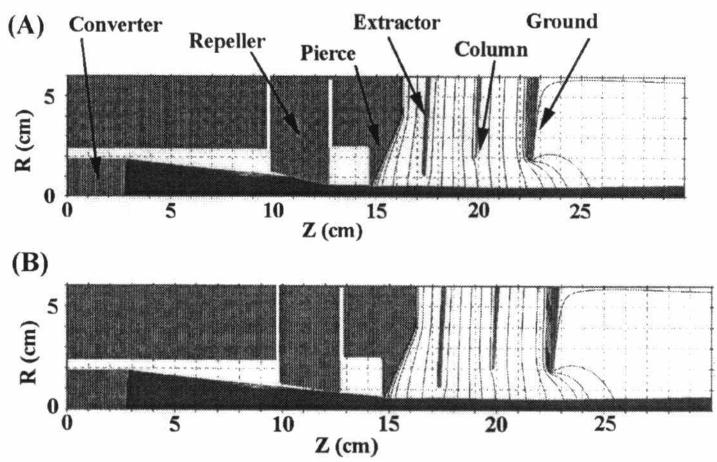

Figure 2. PBGUNS electrode, trajectory, and equipotential plot for the production source (A) , and the development source (B).

shows some 260eV beam interception on the unmodified source, while most of the H^- beam passes through the repeller/Pierce electrode assembly in (B). The converter surface area is calculated by $A_{cnv} = 2\pi\rho_{cnv}(\rho_{cnv}-l) = 11.4cm^2$ where $l = (\rho_{cnv}^2 - r_{cnv}^2)^{1/2}$.

Figure 3 shows a summary of the PBGUNS simulations for $r_{rep} = 0.864cm$. The dependence of H^- converter current density ($j_{H^-cnv} = I_{H^-cnv}/A_{cnv}$) for a 12eV sputter energy on beam current (I_{H^-}) accelerated to 80 keV is shown. The parametric linear curves are for $r_P = 0.5$, 0.55, and 0.60cm. Since I_{H^-cnv} is unknown (a speculation on the true value of this current is made below), it is interesting to normalize the PBGUNS calculations to the 18mA production source prediction ($r_P = 0.5cm$). This gives $j_{H^-cnv} = 2.4mA/cm^2$. This normalization is extended to $r_P = 0.55$ and 0.60cm by the horizontal line shown in Fig. 3. It is asserted that this normalization condition imposed on the simulations would ensure discharge power is maintained at the level of the LANSCE production source, while giving 25mA H^- (see the intersection of the $2.4mA/cm^2$ line with the $r_P = 0.60cm$ prediction). Thus, this upgrade to 25mA should not be at the sacrifice of ion source lifetime. The simulations predict laboratory emittance at approximate 95% beam fraction of $\varepsilon_l = 7.6$ (πcm-mrad) for 18 mA(production source) to $\varepsilon_l = 9.3$ (πcm-mrad) for 25mA(development source), an emittance growth of 1.22. The 1rms normalized emittance (ε_{1rms}) is related to ε_l by $\varepsilon_{1rms} = \beta\varepsilon_l/7$ where β is the relativistic velocity. Emittance growth predicted by comparing the two sources admittance (cf Table 3) is 1.25. If the simulations contained in Fig. 3 are repeated for 6eV sputter energy, then the j_{H^-cnv} normalization decreases to $1.6mA/cm^2$. For the 6eV H^- sputter energy, all of the converter current passes through the repeller/Pierce assembly, and the three parametric curves for $r_p = 0.50$, 0.55, and 0.60cm collapse to a single line in the j_{H^-cnv} vs. I_{H^-} plot.

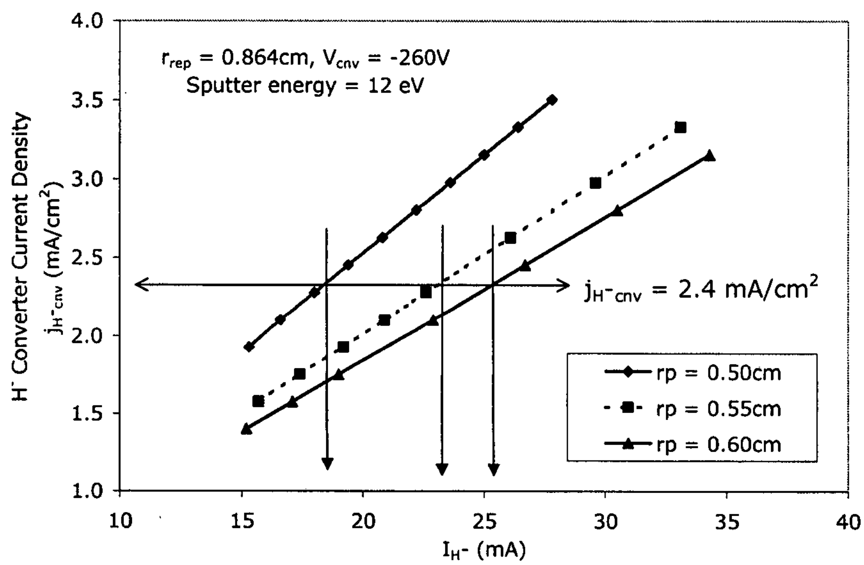

Figure 3. PBGUNS predictions for 80keV H^- current and j_{H^-cnv} at a H^- sputter energy of 12eV. These predictions show 25 mA H^- current may be obtained from the development source with $r_P = 0.60cm$ and $r_{rep} = 0.86cm$.

These results are shown in Fig. 4.

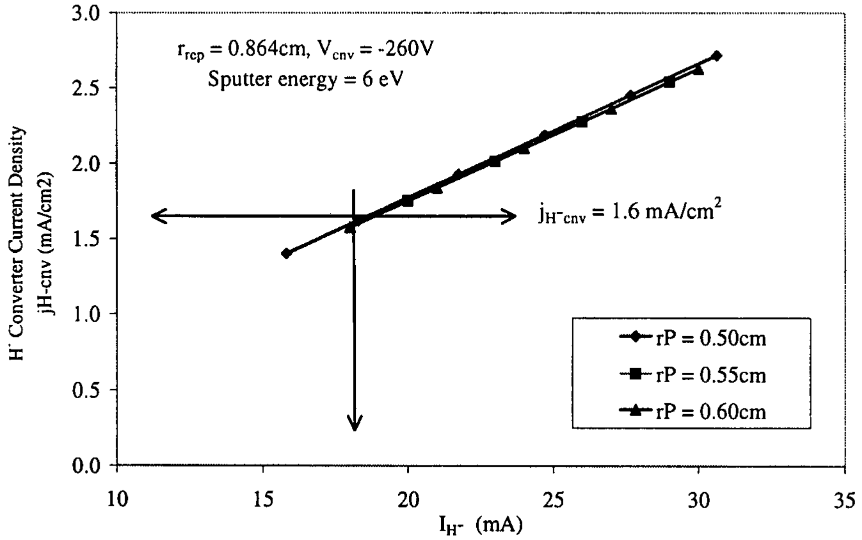

Figure 4. PBGUNS predictions for 80keV H^- current and j_{H^-cnv} at a H^- sputter energy of 6eV. For 6eV sputter energy, the internal component changes made in the development source would not lead to an increase in the H^- beam current, I_{H^-}.

In the early stages of development source operation, the discharge voltage V_d would operate in stable mode only for $V_d < -270V$. By comparison, production sources routinely operate at $V_d = -190V$. This behavior is attributed to the 3.4kG contact SmCo magnets used in the development source fabrication, as compared to the 2kG SmCo magnets used in the production sources (cf Table 3, sixth entry). Discharge voltage instabilities are a known phenomena in surface converter cusp-field sources[8]. The voltage instability was overcome by displacing 6 of the 10 line cusp radial magnets 6mm further out from source axis. This displacement gave a contact field of 1 kG on the inner source wall, about the same as the production sources. This change increases the

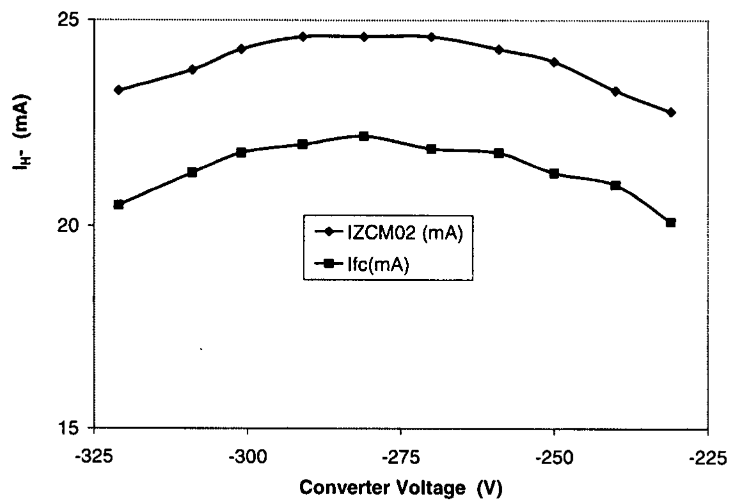

Fig. 5. Plot of the experimentally measured H^- currents from the development source.

anode area, and allows the plasma potential to remain positive over a broader V_d range. With this change, the development source operated with $V_d = -190V$. Several different magnetic repeller fields have been tested. With a line cusp repeller magnet, up to 25mA H^- current was obtained near the source exit beam current transformer, with 22mA being delivered to a Faraday cup at the end of the 80keV LEBT. The e/H^- ratio is 5.9, about double the production source. Figure 5 shows the maximum I_{H^-} with variation in the converter voltage. The discharge power, given by the product of $V_d = -195V$ and discharge current, was 7.6 kW.

The e/H^- = 6 is too great for 120 Hz LANSCE operations. In order to reduce the e/H^- ratio, a PM solenoid magnet with 500G on-axis field was installed in the repeller assembly. The e/H^- was reduced to 3.2, but I_{H^-} was also reduced to a maximum of 20mA. During the solenoid magnet test period, an emittance survey was conducted on the development source. At the ISTS emittance station 2, ε_l = 8-9 (πcm-mrad) was measured, depending on the horizontal or vertical emittance station. The experimental emittance results as function of the extraction voltage setting are shown in Fig. 6, and summarized in lines 11 and 12 of Table 3.

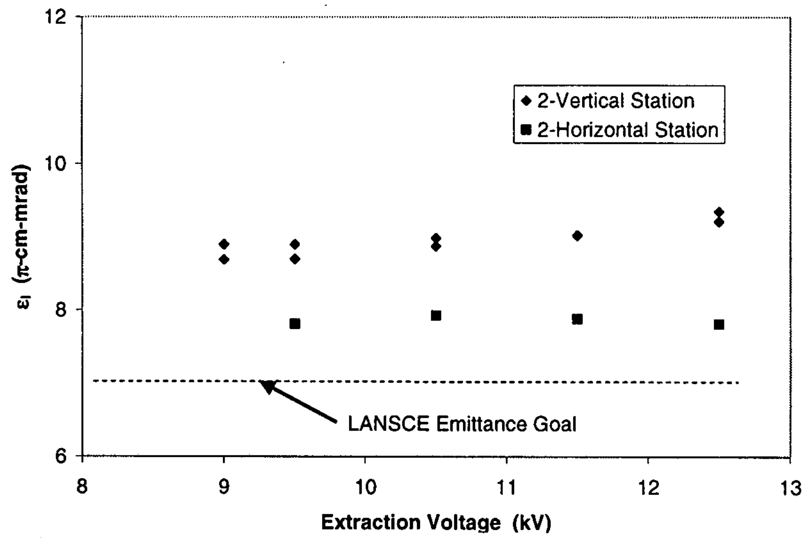

Figure 6. Plot of 95% beam fraction laboratory emittance for 19mA H^- beam from the development source.

Discussion

Generally, there has been good agreement between the development source measurements as compared with those properties extrapolated from the production source. The development source has achieved the 25-mA design H^- current for one repeller configuration (cf. line 9, Table 3). This was achieved by holding the discharge power to the same value as used in the production source (cf. line 8, Table 3). An unexpected result is the development source e/H^- ratio of 6 where we expected a ratio of 4.2. This may be accounted for by the higher contact magnetic cusp field magnets used in the development source (line 6, Table 3). Plasma leakage at a multicusp source wall[9] has been established to be proportional to $(B_c)^{-1}$. It is planned to reduce the development source's B_c to 2 kG (as in the production source) with the thought that the source electron current will be rebalanced so as to improve the e/H^- ratio. During experiments with a modified PM solenoid repeller magnet, emittance growths of 20% were found in the development source as predicted both by the admittance calculations and the PBGUNS code (cf. lines 5 and 12 of Table 3). The H^- beam current for these measurements was 20 mA.

Because the H^- current from the development source scaled as the repeller-Pierce area increase, the PBGUNS model for the higher sputter energy (12eV) seems to be confirmed (cf. Fig. 3). One can speculate as to other possible mechanisms that would lead to a spreading of the converter H^- beam and a uniform illumination of the repeller-Pierce apertures. Consider that this H^- surface converter source falls into the general category of cathodic surface plasma source (SPS) H^- production (cf. Fig. 1f in ref [10]). Further, total converter currents I_{cnv} in both the production and development sources are measured to be 4A. Secondary electron production coefficient $\gamma = I_e/I^+$ may vary from 1 to 7 while the secondary H^- production coefficient $K^- = I_{H^-}/I^+$ may vary from .1 to .7 in cesiated SPS[11]. Since $I_{cnv} = I^+ + I_e = 4A$, a prediction for possible I_{H^-cnv} may be made over the limits of the γ and K^- parameters. This prediction is shown in Fig. 7, and $(I_{H^-cnv})_{min} = 40$ mA is found at $\gamma = 7$, $K^- = 0.1$ while $(I_{H^-cnv})_{max} = 1000$mA is found for $\gamma = 1$, $K^- = 0.7$. For a well-cesiated molybdenum surface the parameters γ and K^- may be 7 and 0.7[11] which yields $I_{H^-cnv} = 300$ mA (cf. Fig. 7). This H^- converter current is a factor of ten greater than the PBGUNS sputter model presented in Figs. 3 and 4.

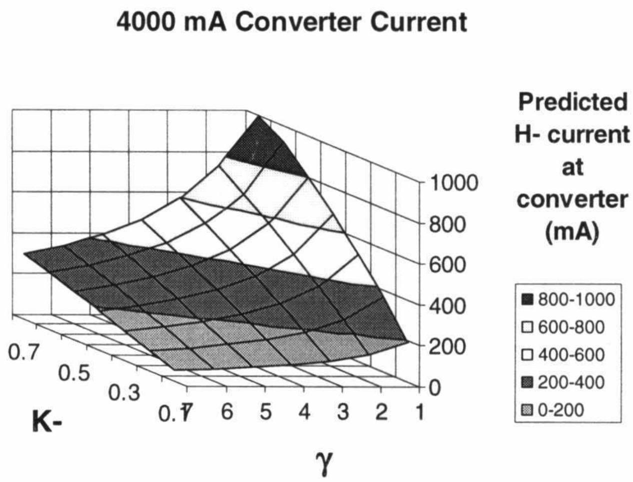

Fig. 7. Prediction for H^- converter current, I_{H^-cnv}, using the measured converter current, I_{cnv} of 4A, and published γ and K^- factors for SPS.

One possible cause of H^- converter beam expansion is incomplete neutralization of the converter beam space charge. An approximate plasma density of $1X10^{11}$ $(cm)^{-3}$ has been derived by using the converter as a floating probe. Using this plasma density and an electron temperature of 1eV, a converter plasma sheath thickness of 1.7 mm is derived[12]. A 2-D particle in cell (PIC) code is being developed at Los Alamos for application to ion source plasma problems[13]. A preliminary result from the PIC code simulation as applied to the LANSCE H^- surface conversion source is shown in Fig. 8. The plasma density in this simulation is $3X10^{10}$ $(cm)^{-3}$. The H^- beam is born on the plasma converter on the left of Fig. 8. The sheath region has formed approximately 3mm downstream from the converter. The 300eV H^- beam is indeed predicted to have a strong

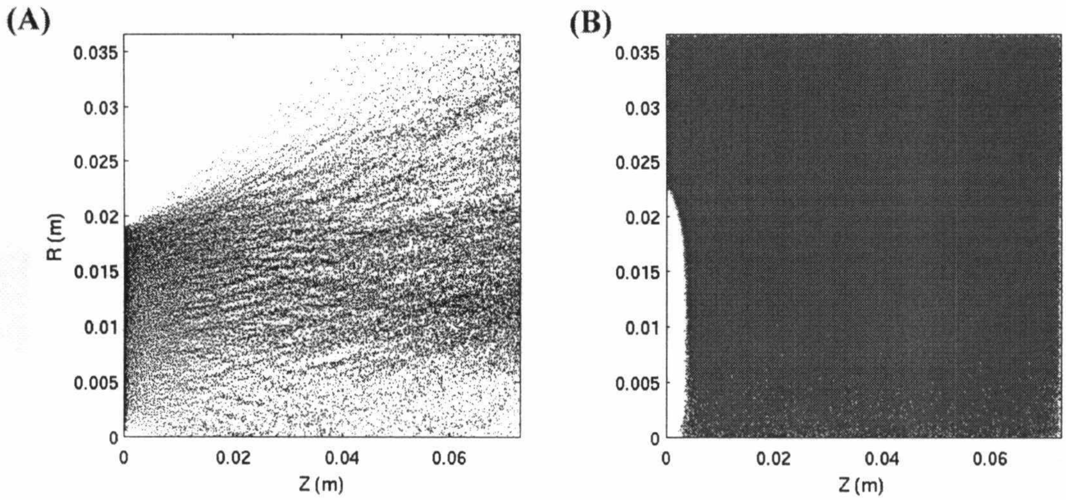

Fig. 8. Preliminary 2-D PIC code simulation for H^- beam being accelerated off the surface converter located on the left in Figs. 8(A) and (B). Fig. 8(B) shows the plasma electrons, and formation of the sheath at about 3 mm from the converter.

divergence at the converter from residual negative space-charge, and from a defocusing electric field at the converter edge. These sheath predictions are suggestive of further experimental work, such as addition of a heavy neutral gas to the plasma discharge to alter the converter sheath formation.

Acknowledgements

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