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H ION SOURCE SCALING STUDIES AT LBL

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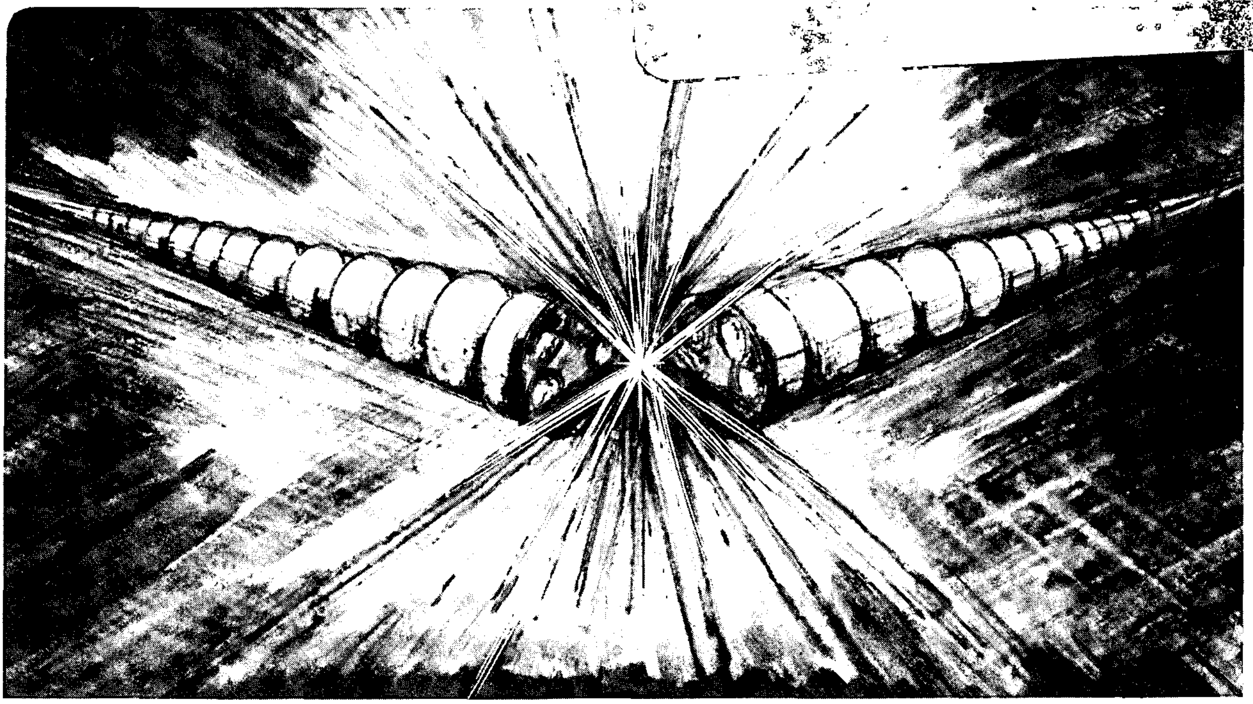
October 1986



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DISCLAIMER

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H^- Ion Source Scaling Studies at LBL*

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ABSTRACT

Four experiments are reported: 1) Constant arc voltage operation was compared with constant arc current operation over a similar range of plasma density. The higher arc voltage required in the constant arc current operation produced more H^-, but it was at the expense of an even larger increase in the accelerated electron current. 2) A comparison of different magnetic filter locations showed the highest accelerated H^- and the lowest e^- content at the closest filter location. 3) Beam-forming electrode aperture comparison for round apertures from 2mm to 10mm diameters and a 11x27mm oval slot showed a decreasing H^- and e^- with increasing aperture area. 4) Increasing accelerator voltage produced an increasing plasma potential and electron temperature and decreasing electron density in the exit chamber of the plasma source.

INTRODUCTION

In our H^- ion source scaling studies we have observed that many parameters affect the production and/or delivery of volume-produced H^- ions to the accelerator: gas pressure, location of filaments, arc current, arc voltage, aperture size, filter location, filter strength, type of electron feed or heater, the relative potential of the filter rods, the relative potential of the beam-forming electrode (Grid 1), and the size of the plasma chamber. One experiment reported here compared the accelerated H^- and e^- yields over a range of main chamber plasma density (a two chamber system) for two styles of operation... constant current vs. constant voltage. This experiment was a more methodical version of earlier unreported work that showed pessimistic results for high arc voltage operation. Reports from Stevens and York[1] at LANL prompted us to extend the earlier work to higher voltages. We also wanted to display a comparison in a more device-independent manner. We chose "J^+_{bucket}" (the main chamber saturated +ion current density) as an appropriate independent variable that "measured" the main chamber "excitation" level.

In the second experiment we extended the low density work of Leung,

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et al.[2] to higher density. We compared the H⁻ and e⁻ yields (over the range of our power supplies) at three filter locations relative to Grid 1. Data from this experiment has also been used for calibration of Hiskes' model of H⁻ production and is presented elsewhere in this conference.[3]

A new beam-forming electrode was installed which gave a new accelerator gap spacing and permitted delivery of the total beam at higher current densities. The design also allowed changing the aperture size of the beam- forming electrode without venting the system.

The fourth parameter we investigated was the effect of the accelerator extraction voltage on the plasma potential and electron density and temperature in the exit chamber of the ion source.

EXPERIMENTAL SETUP

Fig.1 is a schematic of LBL's TS-1 facility. The plasma chamber (22x22x22 cm, cubic) was a standard longitudinal multi-cusp magnetic bucket (1.3x1.9x22 cm, SmCo, 4 cm- spaced side-wall cusps parallel to the beam direction). It was divided into two chambers by four magnetic rods

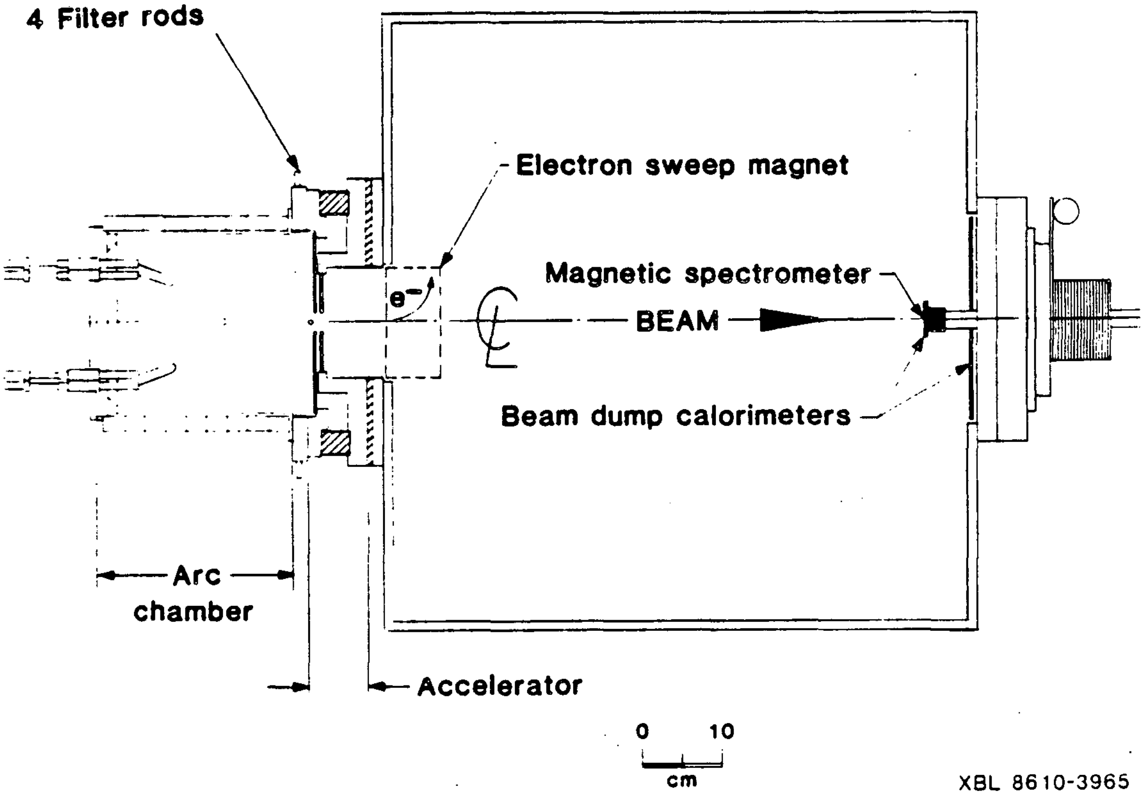

Fig. 1 Schematic view of LBL's Test Stand-1 facility.

(4.7x4.7x300mm SaCo with 6.4cm spacing) (Fig. 2) that were inserted into the bucket at either of three planes(2.5, 6.9, 11.3 cm) upstream from Grid 1 extraction plane. The peak filter field is 90 Gauss; and the peak Grid 2 field is 350 Gauss (Fig. 3). The filter thickness is 300 G-cm (Fig. 4). Eight 1.5mm diam. filaments injected up to 200 amperes of ionizing electrons into the main (hot) chamber at energies up to 200eV.

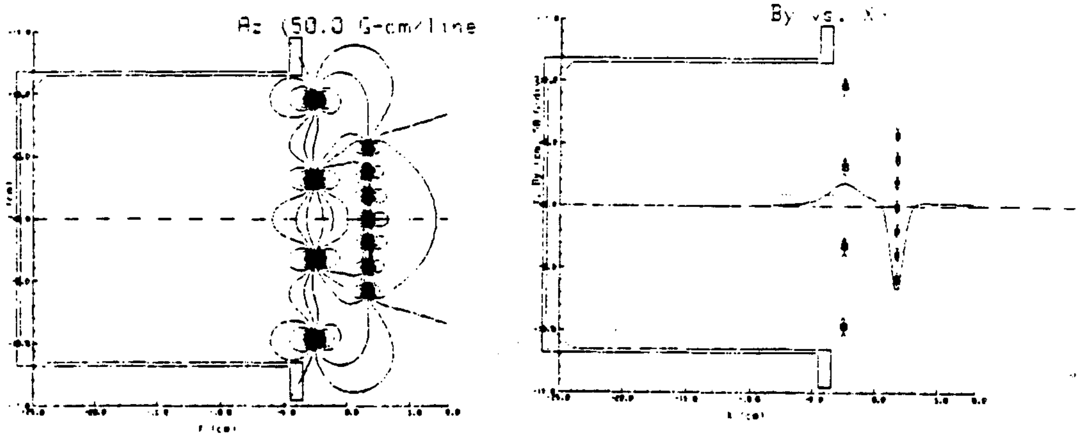

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Fig. 2 Magnetic structure: 4 filter rods @ 2.5cm up-stream from the beam-forming electrode; 7 Grid #2 magnets interact.

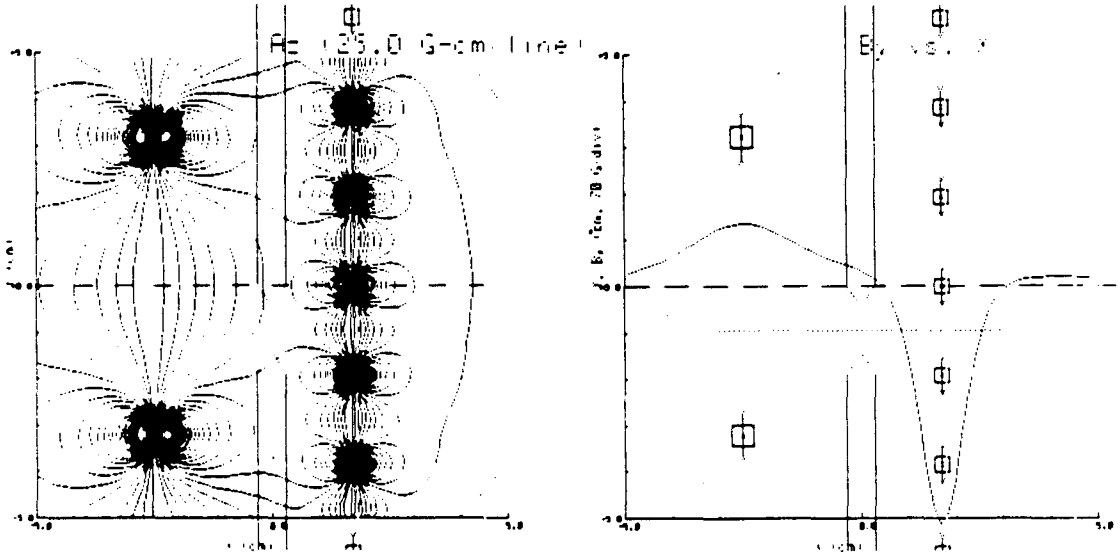

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Fig. 3 Magnetic structure near the beam-forming electrode.

The arc/filament power supply system could be operated with either constant current or constant voltage. The hydrogen gas flow for all

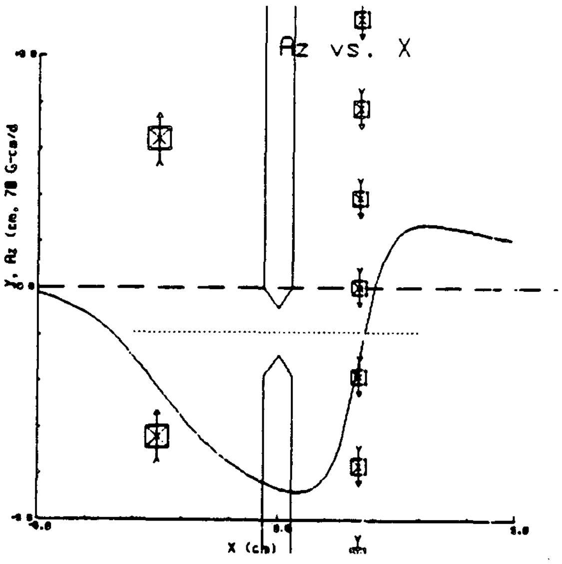

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Fig. 4 Vector potential near the beam-forming electrode.

experiments was the previously determined optimum which gave a cold (arc-off) chamber pressure of 10 mtorr. One water-cooled cylinder-probe monitored the center of the main plasma chamber; and a cup probe (for good low-density saturation characteristics) monitored the exit (low temperture) chamber 8mm upstream from the beam-forming electrode's mid-plane,and 5mm off the aperture's center-line. One of the probes was routinely swept (usually the one in the exit chamber) to ascertain the dependence of the plasma potential (V_p), the electron temperture (T_e), and the electron density (N_e) upon the parameter under investigation. These probe characteristics for the main chamber, when the filter location was at 2.5 cm, are shown in Fig.5.

For the first two experiments we had a one gap accelerator (Fig. 6) with one aperture exposed (10x25 mm, rectagular) that had an experimentally determined overdense (Grid 2 clipping) limit of $J/V^{1.5}$=45 nano-pervs/ 2.5 cm^2 hole. No magnets were installed in the beam-forming electrode ($B_{Grid\ 1}$=0)(Fig. 3), so as to reduce any impediment to H^- or e^- flow toward the accelerator hole. For the last two experiments, the filter location was 1.7cm upstream from Grid 1 and the Grid 1 aperture (11x27 mm,oval) had a movable aperture mask (2 mm to 10 mm diameter, round) (Fig.7). The cup probe was located 6 mm upstream from the beam-forming electrode's mid-plane,and 5 mm off the aperture's center-line.Accelerated electrons were deflected twice: once by the B-field from magnets in the 2nd electrode (Grid 2), and dumped mostly onto Grid 2, and again by an auxiliary B-field 10% of the way to the beam dumps.

Two beam dumps intercepted the beam: a small, mobile one (6x9cm) contained magnets and two collecting cups which permitted the simultaneous measurment of the H^- and e^- beam profiles; a large one was intended to catch highly divergent (±160 x ±350 m-radians) beams accelerated under a wide range of non-optimum conditions. Hence, only at the lowest currents, and (with inadequate voltage) at the highest currents would the dumps under-estimate the beam. A window, permitting visual beam observations from the side (the aperture's long direction and the beam

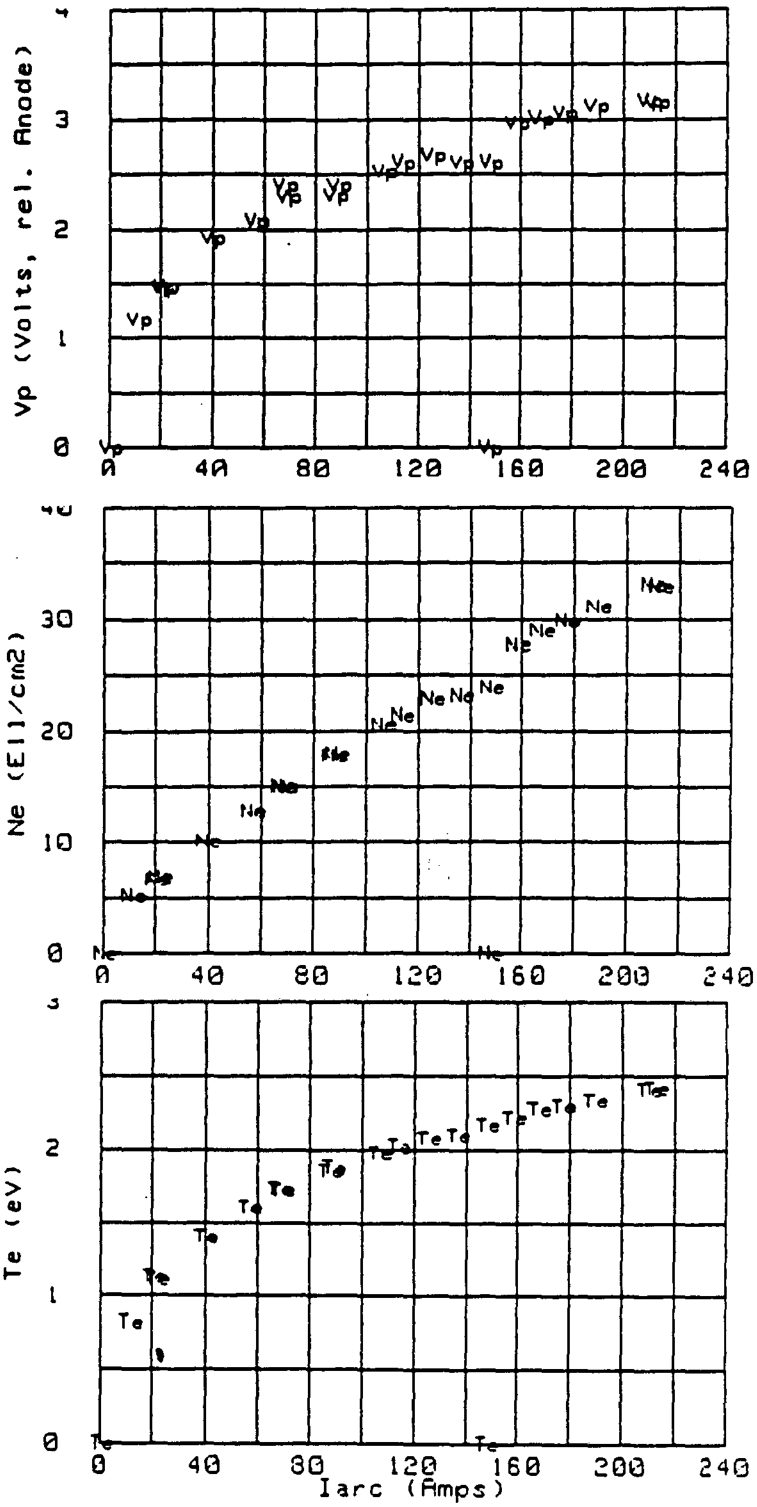

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Fig. 5 Main chamber plasma potential, electron density and temperture vs.. I_{arc} @ V_{arc}=100V, pressure=10mtorr (cold), filter rods @2.5cm.

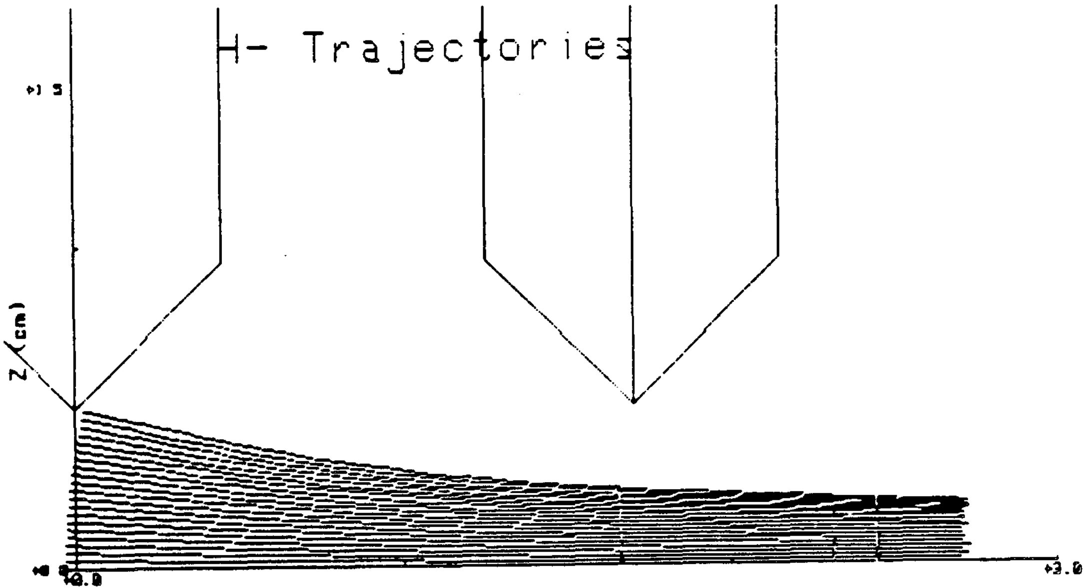

Fig. 6 H$^-$ trajectories in the round aperture approx.@ $J(H^-)=8$ mA/cm^2, $V_{accel}=6000$ V.

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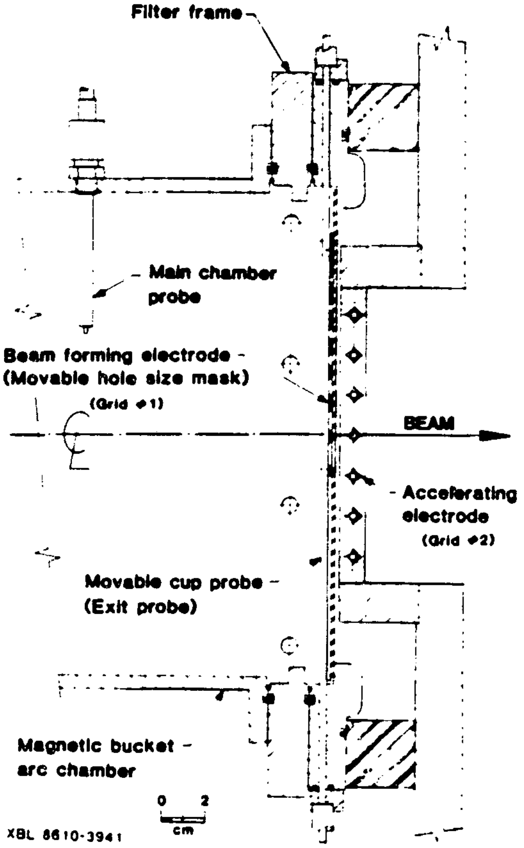

Fig. 7 Schematic view of arc chamber and accelerator, with movable aperture mask.

beam observations from the side (the aperture's long direction and the beam short direction), and the movable spectrometer could be used to determine the size of the beam.

The beam dumps were monitored calorimetrically and electrically (saturated +ion current). The more convenient electrical signal was calibrated against the water-flow calorimetry and found to be linear with beam current, but dependent upon accel voltage and dump chamber pressure. In this paper

$J(H^-)=$ (Heat power) $/V_{accel}/A_{hole}$;
and $J_e=I(\text{grid } 2)/A_{hole}$.

EXPERIMENTAL RESULTS

For the V_{arc}/I_{arc} comparison, the arc voltage was varied from 60-170 volts at two currents (50A,100A); and the current was varied from 0-200A at

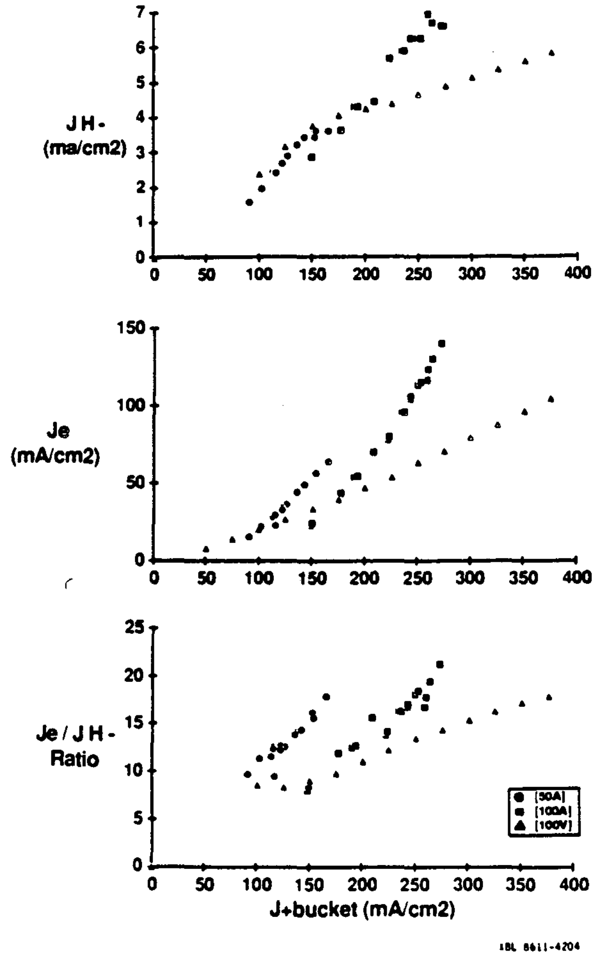

Fig. 8 I_{arc} vs. V_{arc} variation.

one voltage (100V). An 11kV accel voltage was used to avoid Grid 2 beam-clipping at the top end. At the low power end, all the $J(H^-)$ data overlaps (Fig. 8); But at high power, the high voltage (constant current) operation produced more H^-, avoiding the first knee characteristically observed with a variation in arc current. Unfortunately this increase came at the expense of more electrons and a higher e^-/H^- ratio than obtained with 100V operation.

In the filter location experiment (V_{arc}=100V, 0<I_{arc}<200A, V_{accel}= 6 kV), some Grid 2 beam-clipping was observed as a rollover in $J(H^-)$ at the top end (Fig. 9). The closest filter delivered the highest H^- and the lowest e^- (consistent with the lower density results of Leung[2]). The data with the filter at 11.3cm was even more extreme, but was not plotted because the main chamber probe was part way into the filter and read ≈2x too low (indicating that the density falls going into the filter).

The aperture size scaling study (V_{arc}=100V,I_{arc}=75A, filter @ 1.7cm, V_{G1} @ anode, V_{accel}=12kV) indicated a factor of 1.25 decrease in $J(H^-)$ (calorimetrically) and 3x smaller accelerated electron current density as the aperture size was increased from 2 mm to 10 mm diam. (Fig. 10). The majority of the data clustered around $J(H^-)=7mA/cm^2$. The 3cm^2 (oval) aperture data showed a proportionately similar decrease (0.65 of the 2mm intensity). At another operating condition (higher H^-, lower e^-), the qualitative trend was the same. The plasma potential and electron temperature increased , and the electron density decreased in the exit chamber, with larger aperture diameters (Fig.11). Most of the changes were observed only for the largest apertures. The arc-only measurements were used for reference purposes.

The results of the V_{accel} study (V_{arc}=100V,I_{arc}=75A, filter @ 1.7cm, V_{G1} @ anode,D=8mm) showed that the density of the electrons in the exit chamber decreased as the accel voltage increased (Fig. 12). This was also observed for larger apertures. Most of the variation was observed between 0-2kV.

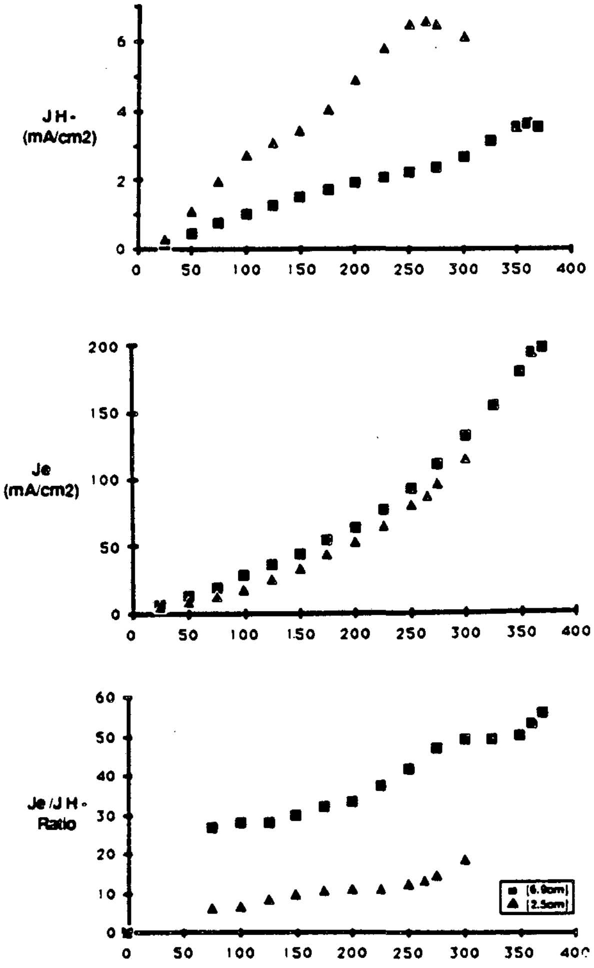

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Fig. 9 4-rod filter location: Optimum V_{G1}, pressure=10mtorr (cold), V_{accel}=6kV, B_{G1}≈0, slot #3 (2.5cm^2).

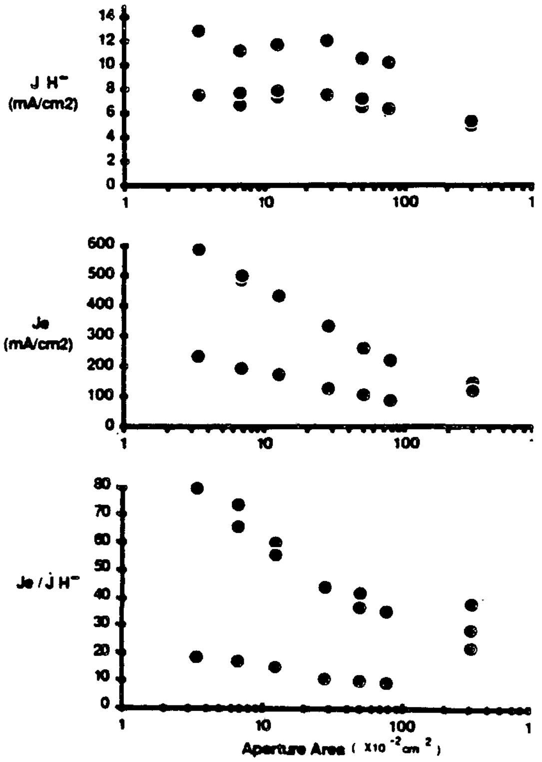

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Fig.10 Aperture area variation: Optimum V_{G1}, pressure=10mtorr (cold), 4-rod filter @ 1.7cm, V_{accel} =6-12kV, B_{G1}≈0, slot #3.

DISCUSSION

The higher H$^-$ observed in the high V_{arc} operation may support either of two arguments: 1) the more energetic primary electrons would likely increase the density of electrons that are energetically capable of vibrationally exciting molecules close enough to the filter to survive and

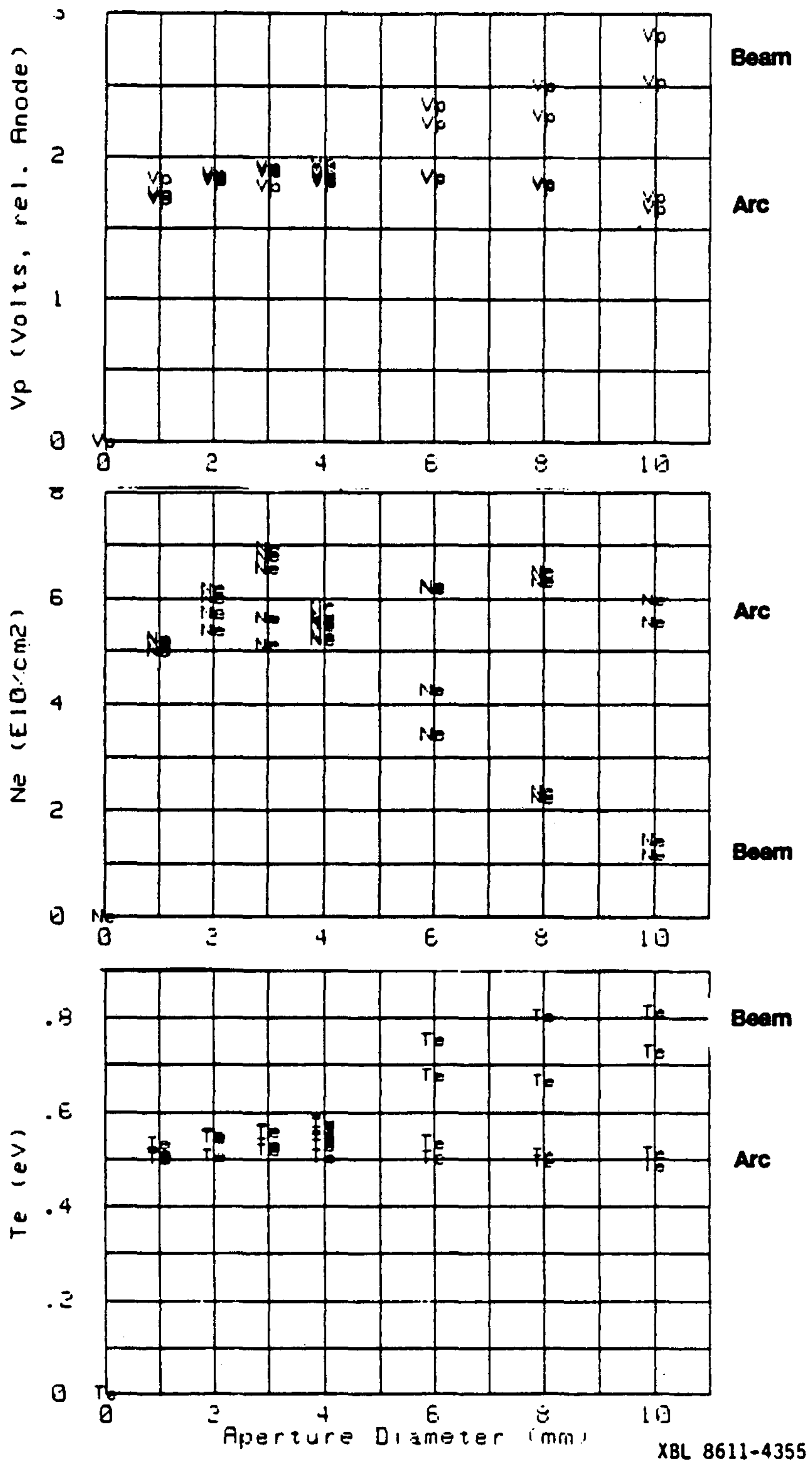

Fig. 11 Exit chamber plasma potential, electron density and temperature vs. aperture diameter @ V_{arc}=100V, I_{arc}=75A , pressure=10mtorr (cold), 4-rod filter @ 1.7cm, V_{G1}=0.

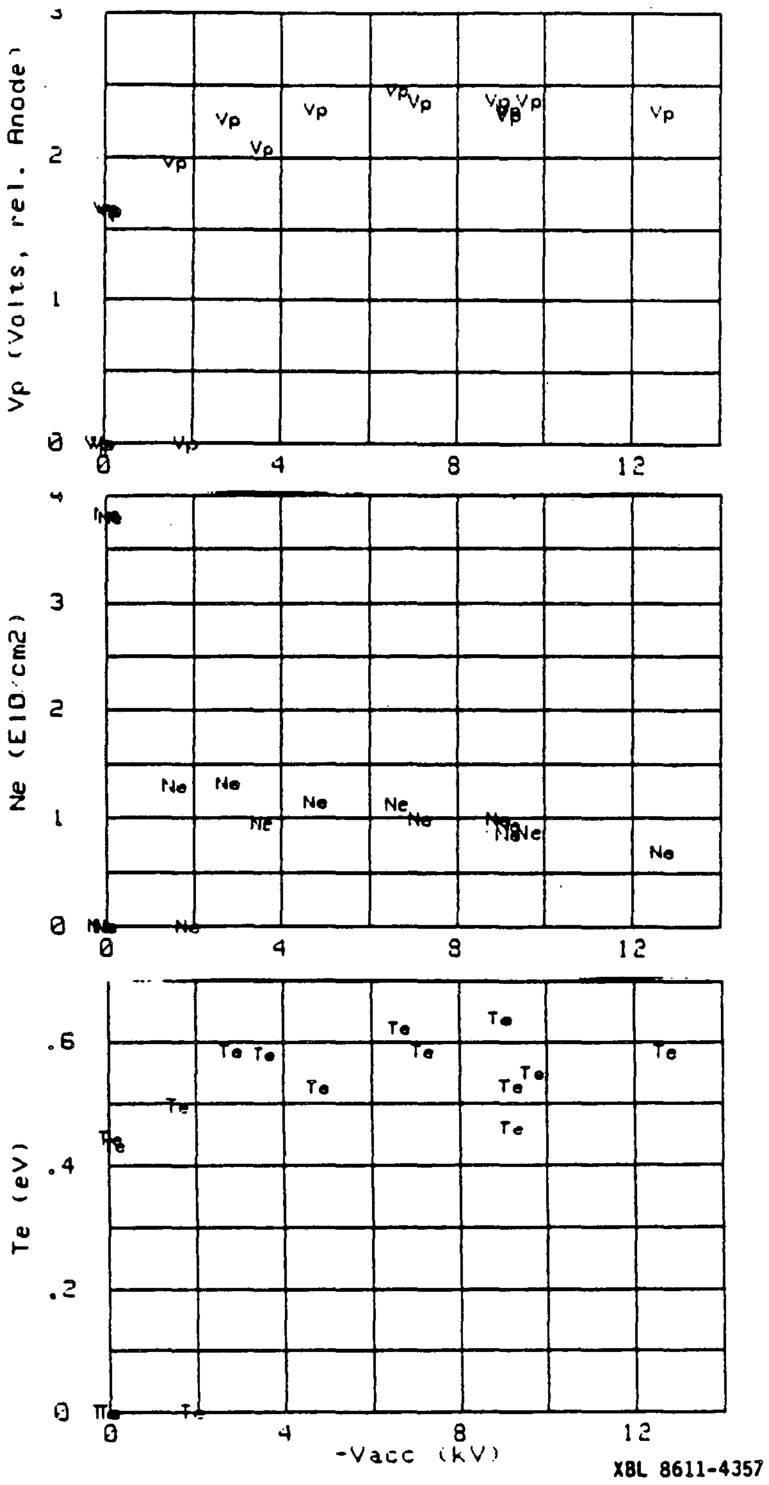

Fig. 12 Exit chamber plasma potential, electron density and temperature vs. V_{accel} @ V_{arc}=100V,I_{arc}=75A , pressure=10 mtorr (cold), 4-rod filter @ 1.7 cm, V_{G1}=0 .

produce extractable H^-. 2) The higher e^- density observed in the second chamber more efficiently utilizes the available molecules.

What is not so clear is why the exit electron density increased (relative to the first chamber density) with higher arc voltage. Perhaps the more energetic primary electrons decouple from the body of the electron distribution. This would result in a lower main chamber electron temperature and faster diffusion across the filter. Unfortunately, we did not measure the main chamber temperature. The exit temperature is always lower and increases more slowly with arc power, thus, we can not support this conjecture. It is also not clear as to the applicability of these results to more practical systems having stronger electron-control B-fields at the beam-forming electrode.

The second experiment produced results in realistic agreement with Hiskes' model (see Hiskes and Lietzke, this conference). According to that model, the vibrationally excited molecules from the edge of the main plasma volume do not survive well in the exit chamber (due to destruction by atomic hydrogen generated in the main chamber). The H^- ions are similarly fragile. As the filter, which controls the electron temperature transition, is moved upstream, the dominant source of the H^- moves away from the beam-forming electrode and less H^- is accelerated.

In the aperture size experiment, larger H^- and e^- currents were obtained with larger apertures, but, when normalized by their respective areas, lower current densities were observed. The dependence was more pronounced for the electrons and was opposite to earlier (unpublished) long slit data. The anomaly is unresolved.

The accelerated H^- was approximately correlated to a decrease in Ne at the exit probe (8mm upstream)(Fig.10, Fig.11). Noticeable changes began to appear for $D \leq 5$mm which implied that the plasma parameters were affected $L \leq 1.5$ diameters upstream. The reduction in H^- with increasing diameter is believed to be due to a partial depletion of cold electrons by acceleration through the aperture. The removal of cold electrons is possible ($B \approx 0$) and consistent with the observed increase in the exit plasma potential and electron temperature. Electron heating was precluded because the exit potential was smaller than the main chamber potential.

The last experiment indicated that these changes (Ne,Te,Vp) are relatively insensitive to the plasma sheath position which must move semi-qualitatively as $J \sim V^{1.5}/d^2$. Most of the dependence existed below 2kV. This was interpreted to mean that the scale length for upstream plasma perturbation greatly exceeded the distance of plasma boundary movement in this experiment (1-2mm).

CONCLUSIONS

Four experiments have been reported. They show that higher arc voltage operation generally yielded more H^- at the same main chamber density, but this increase occurred at the expense of higher e^-/H^- ratios. The closest filter plane (2.5cm from the beam-forming electrode) yielded the highest H^- output intensity and the lowest e^-/H^- ratio. The larger apertures delivered larger currents but had smaller H^- current densities; and they had smaller e^-/H^- ratios, contrary to previous slit experiments. Larger apertures also produced greater perturbations on the plasma immediately upstream from them, but only when some small accelerating voltage was applied. Most of the voltage dependence occurred when $V_{accel}<2kV$.

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