Title

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Journal

Review of scientific instruments, 61(1)

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Publication Date

2017-12-04

LBL-27421

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Accelerator & Fusion Research Division

Presented at the International Conference on Ion Sources,
Berkeley, CA, July 10–14, 1989, and to be published
in the *Review of Scientific Instruments*

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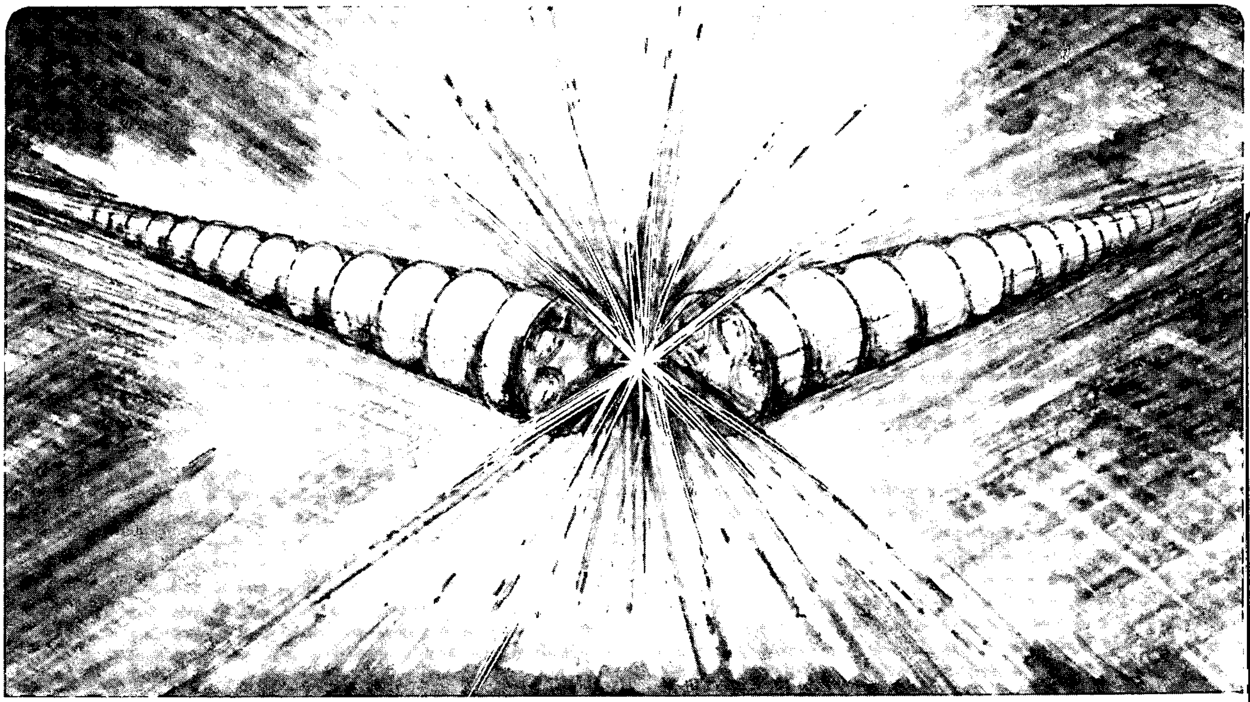
April 1989



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

LBL-27421

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This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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ABSTRACT

In testing a multicusp volume-production H⁻ ion source (20 cm diameter, 23 cm long), we optimized the gas pressure, the plasma electrode bias potential and the magnetic filter. At the optimum pressure of 9 mT, the H⁻ beam output increased linearly with discharge power. The maximum H⁻ beam, measured with a current transformer downstream of the accelerator, was 100 mA while using a 6.67 cm^2 aperture. Presently we are limited by overheating of the cathodes by the plasma ions. Under similar discharge conditions the maximum H⁻ current density was found to vary as $a^{-0.7}$ where a is the aperture radius. Results from emittance measurements showed that the effective H⁻ ion temperature increased with a for a > 0.8 cm. Thus the brightness of the beam decreased with increasing aperture radius. Operating the source with cesium would increase the H⁻ output however our accelerator must be improved to avoid breakdowns caused by the cesium contamination.

I. INTRODUCTION

There has been significant progress in the development of volume-production H^- source in the past few years. Leung et al[1] reported reaching an H^- current density of 250 mA/cm^2 and Yuan et al[2] measured an ion temperature of 0.5 eV. A large current density together with a low ion temperature can produce a high brightness beam. Unfortunately the data just quoted were not obtained simultaneously; the high current density data were obtained by operating an ion source at high pressure (20 mT), under pulsed high discharge power, whereas the low ion temperature was obtained at low pressure under dc low discharge power. In both cases the aperture diameter was less than 1 cm.

The goal of our experiment is to test the LBL volume-production ion source in a cw discharge mode at a pressure of 5 to 10 mT and to obtain a total beam current in the order of 100 mA in a single channel. In order to produce such a large beam current, we used high power discharge and large extraction aperture. The source must not produce too many electrons, otherwise the accelerator would fail to handle the high space charge and the excessive heat associated with dumping the electrons.

II. APPARATUS

The ion source is similar to the one used by York et al.[3] It consists of a multi-cusp discharge chamber and a magnetic filter region, see Fig. 1. The copper discharge chamber has an inside diameter of 20 cm and is 23 cm deep.

There are 10 magnetic line cusps. Tungsten filaments 1.5 mm in diameter are mounted between cusps. The filter region is established by 4 rows of permanent magnets enclosed in water-cooled rods. The aperture in the plasma electrode is a replaceable unit; we have used aperture diameters ranging from 1 cm to 2.9 cm.

The accelerator consists of five electrodes. It is designed to accelerate 200 mA of H^- beam up to 100 keV energy with a current density of 30 mA/cm^2 at the plasma electrode. Two rows of permanent magnets are embedded in the second electrode, which is biased at 2 keV; the magnets deflect extracted electrons onto this electrode. The function of the third electrode is to suppress secondary electrons born on the second electrode (it has the same potential as the plasma electrode). Acceleration is done mainly in the gap between the third and the fourth electrodes. As shown in Fig. 1, the thickness of the second and third electrodes is small compared with the bore diameter and the acceleration gap, thus beam extraction is tightly coupled with acceleration as in the case of a simple diode. The actual voltage on the second electrode has little effect on the beam optics. The last electrode is at ground potential, hence a positive potential on the fourth electrode will suppress backstreaming positive ions returning from the downstream plasma created by the beam. In reality, we found no significant evidence of backstreaming ions and the fourth electrode was often biased at ground potential. The H^- beam current is measured by a current transformer located behind an electromagnet which bends electrons out of the ion beam.

III. EXPERIMENTAL RESULTS

In searching for the conditions necessary to produce the maximum H^- beam, we varied the gas flow, the plasma electrode bias potential, the magnetic filter and the discharge power. The results from these optimization were very similar to the ones found in the literature.[1-6] The optimum pressure depends on the magnetic filter and the aperture size. It is a compromise between maximizing H^- production in the source and minimizing electron detachment of H^- ions in the beam line. For the same line density inside the accelerator (therefore the same stripping loss), a smaller aperture would allow a higher gas pressure inside the source; therefore the optimum source pressure is always higher for smaller aperture sources. Using the full size 2.9 cm diameter aperture, the optimum pressure we found was near 9 mT (gas flow = 3 T-l/s). The amount of stripping loss in the accelerator was estimated to be 42% at this operating pressure.

The purpose of applying a bias potential to the plasma electrode is to control the amount of extracted electrons. As shown in Fig. 2, a few volts on this electrode can suppress a large fraction of the extracted electrons (the electron current drops exponentially to 1/e level at a bias of 3 V) while the H^- ion current is only slightly affected.

The filter of this source is due to the combined magnetic field from the permanent magnets in the filter rods and in the second accelerator electrode. By adjusting the orientation of the filter rods and changing the size of the magnets in the accelerator, we can vary the integrated filter strength from 300 to 650 Gauss-cm. As found in many other experiments[4-6] the magnetic filter is the key element determining the H^- output as a function of discharge power. Fig. 3 shows this effect for three different values of filter strength. With a strong filter the efficiency of producing H^- is low, reaching a saturation at extremely high discharge power. With a weak filter, the onset of H^- saturation occurred at a lower level and at a much lower discharge power. Since the amount of extracted electron current always increased with decreasing filter strength, the amount of extracted electrons was tremendous in the case of a weak filter. Too many electrons can "choke" the accelerator due to their additional space charge; this might be another reason why the H^- output was reduced.

The data at $>$ 60 kW were taken by momentarily ($\approx$10 ms) stepping up the discharge power from a steady 45 kW discharge because 60 kW was the maximum dc discharge power that we could operate. At this discharge power or plasma density, heating of the tungsten filaments was dominated by the plasma ions. Further increase in the discharge current must be accompanied by a decrease in the discharge voltage thus limiting the net input power.

Under similar filter, gas pressure and discharge conditions, we varied the aperture size and found that the current density did not remain constant. Fig. 4 shows that the average current density j is proportional to $a^{-0.7}$, where a is the aperture radius. In an earlier paper, McAdams et al[7] reported a scaling of $ja^{0.5}$ = constant. A closer examination of their data shows that $ja^{0.7}$ = constant is probably a better empirical fit. If the gas pressure in the source is kept constant, the gas flow and the pressure in the beam line are reduced for a smaller aperture. This is one of the reasons for j to increase inversely with a. Another reason could be due to a nonuniform current density, e.g. the local current density at the center of the aperture is higher than that at the rim. Such nonuniform current density can also promote emittance growth as the beam propagates downstream.

Fig. 5 shows how the emittance (defined by the 63% contour area) varied with the aperture radius. Ideally the emittance should be directly proportional to the aperture radius, however the data indicates that this is only true for $a < 0.8$ cm. For radius larger than 0.8 cm, the emittance increases more rapidly than linearly. The effective ion temperature (derived from the emittance, and assuming a Gaussian beam), was 1.5 eV for $a < 0.8$ cm. The ion temperature was as high as 4 to 5 eV for the 1.45 cm radius aperture.

Finally, we tested the large aperture volume source by injecting cesium along with H_2 gas[8]. An uncooled molybdenum liner was used to shield the cesium from the cold copper wall of the source. After installing the liner but before using any cesium, we found that the H^- output was reduced compared to the case without the liner, see Fig. 6. In addition, the H^- output depended on the liner temperature. This effect was indicated by a steady drop of the beam current as a function of time measured from the beginning of the discharge pulse. Typically the steady state output was 15% lower than the value at turn-on. After injecting cesium, the H^- output went up. For the same arc power, more cesium produced more H^- beam. The data shown in Fig. 6 indicated a 20% gain (at the high arc power region) over the pure hydrogen operation.

The cesium injection was controlled by adjusting the cesium oven temperature. We at present do not know how to measure the actual cesium injection rate. As we increased the cesium oven temperature, the voltage-holding capability of the accelerator continued to degrade. At about 250°C oven temperature, we couldn't keep the accelerator from breaking down.

ACKNOWLEDGEMENTS

The authors would like to thank C. Matuk, P. Purgalis and R. Wells for their efforts in the mechanical design of the source and accelerator, and Prof. Wulf Kunkel for his valuable suggestions. This work was supported by USASDC MIPR W31RPD-63-A087 and by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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Figure Captions

Fig. 1. Schematic Diagram of the volume-production ion source and accelerator.

Fig. 2 Effect of biasing the plasma electrode. Arc=38kW, gas=10mT, filter=570 G-cm.

Fig. 3 H^- beam current and current density as a function of arc power for various magnetic filter strengths.

Fig. 4 Scaling of H^- current density with accelerator aperture radius. Arc=25kW, gas=15mT, extraction at optimum perveance.

Fig. 5 Scaling of emittance with accelerator aperture radius.

Fig. 6 H- beam current with and without cesium in the discharge.

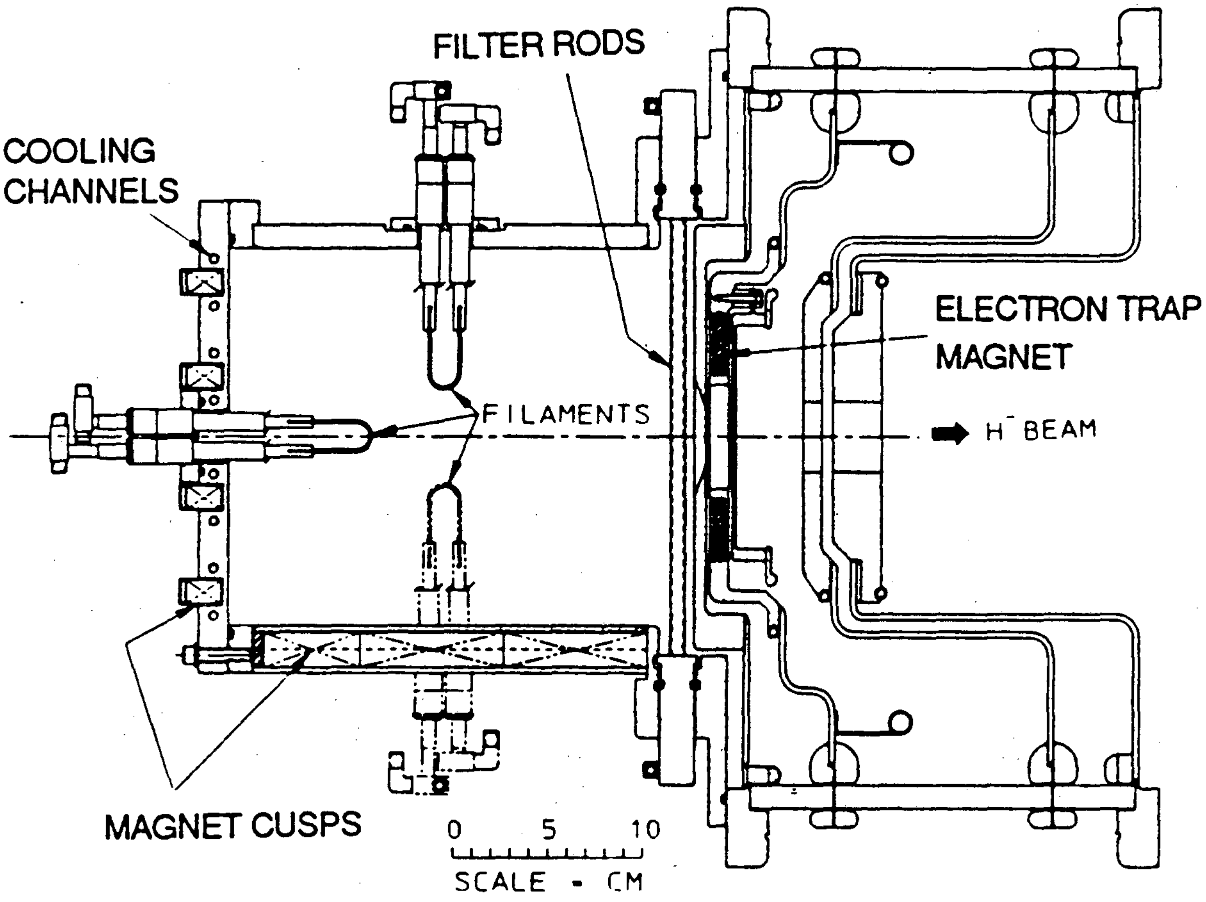

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Figure 1

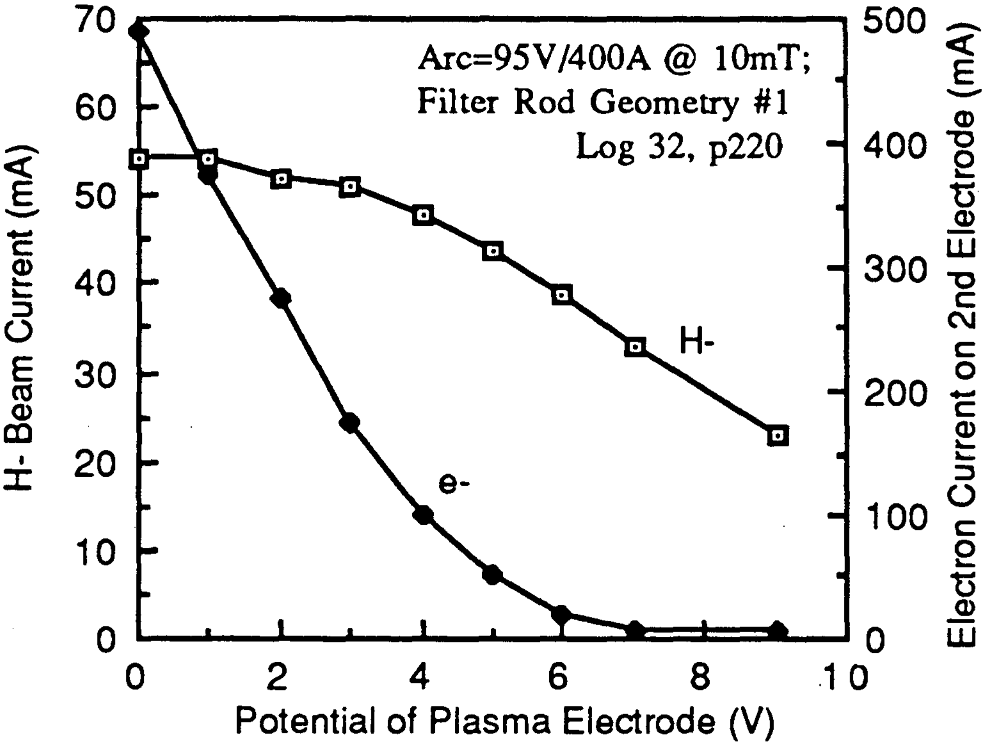

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Figure 2

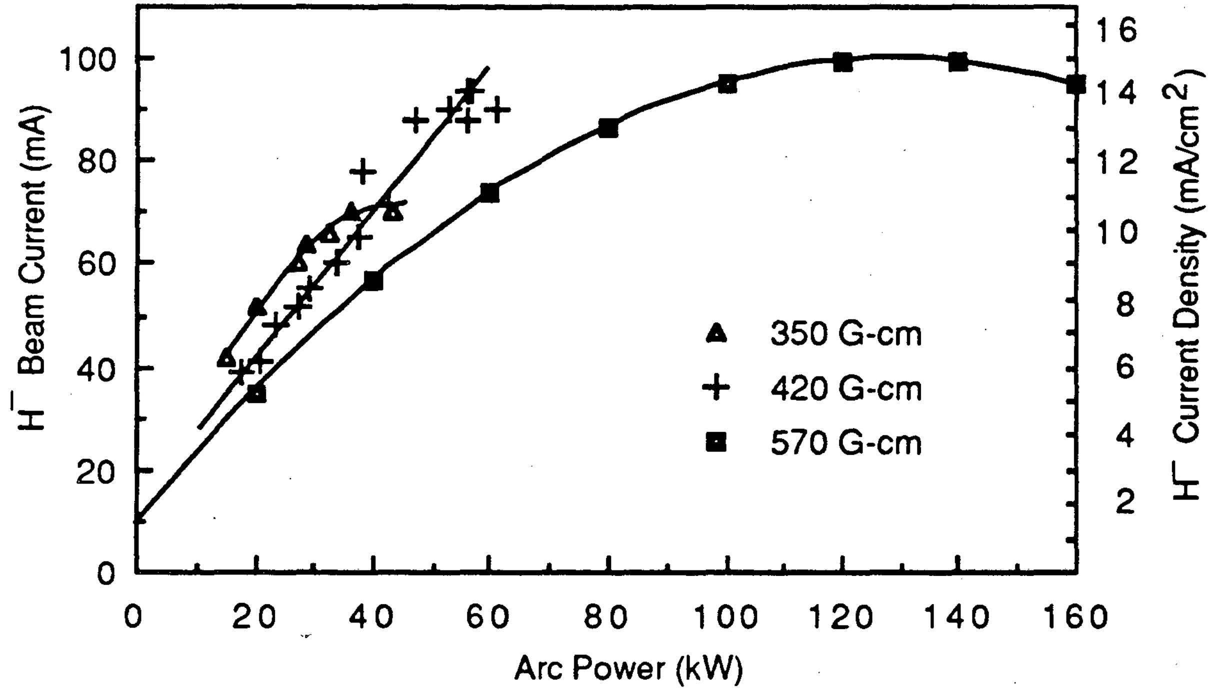

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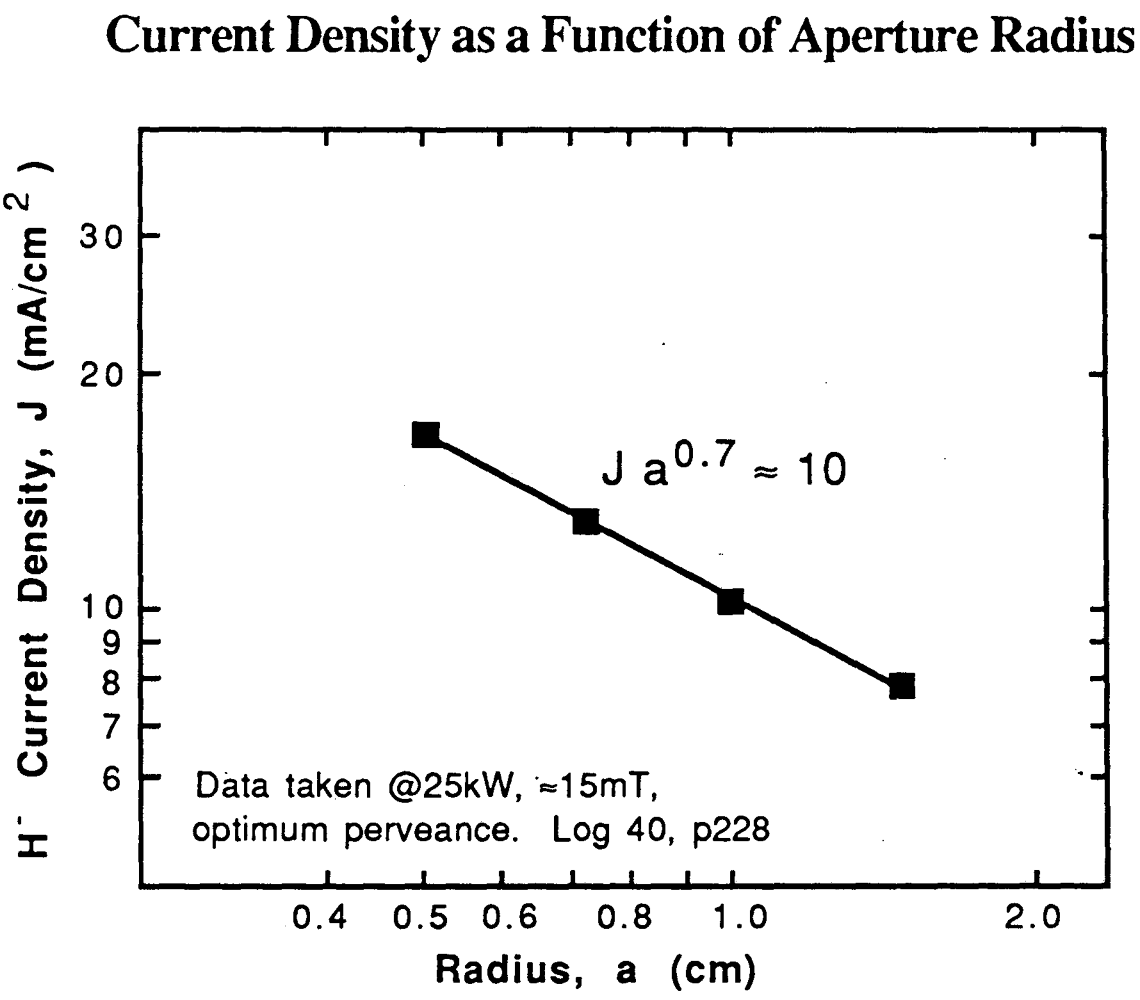
Figure 3



Current Density as a Function of Aperture Radius

$J\,a^{0.7} \approx 10$

Data taken @25kW, ≈15mT, optimum perveance. Log 40, p228

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Figure 4

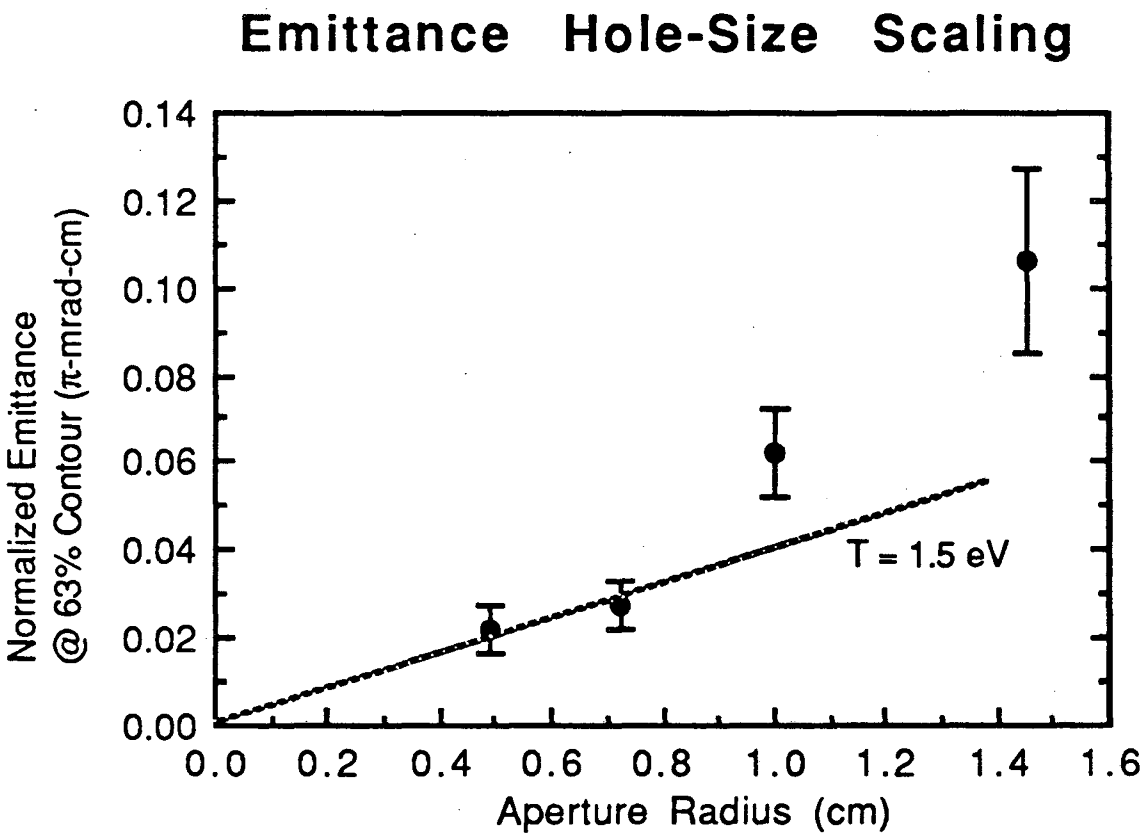

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Figure 5

Effect of an Uncooled Molybdenum Liner Operating with and without Cs in the Discharge

(experiment done with a 66% transparent multi-hole aperture)

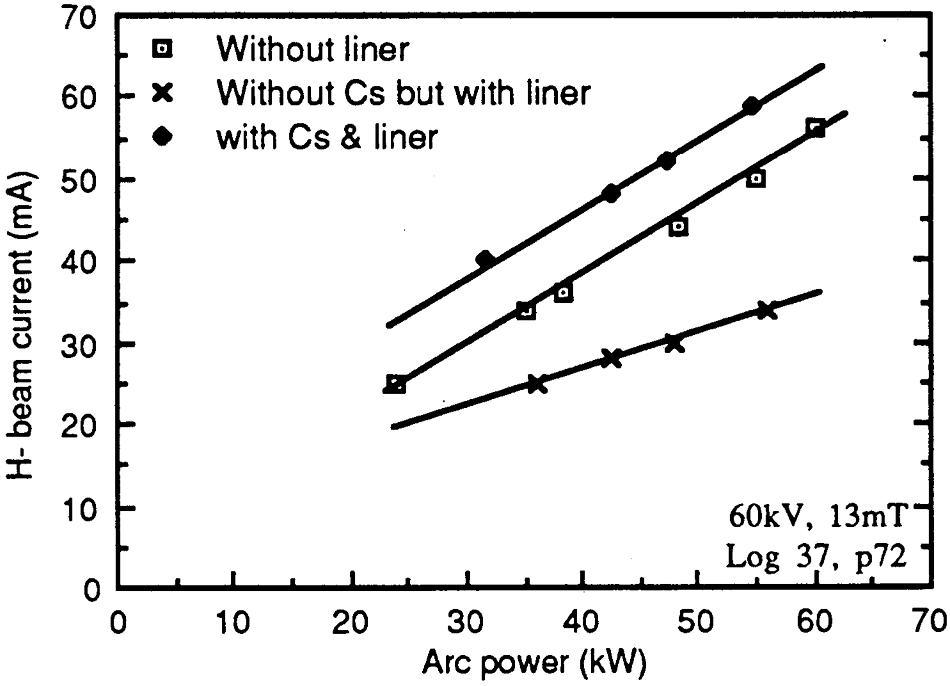

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Figure 6

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