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BNL VOLUME H^- SOURCE*

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Abstract

The volume H^- ion source under development at Brookhaven is unique in that it has a toroidal plasma region, which feeds ions into the central extraction region through a conically shaped filter field. In pulsed operation, it produces 25 mA of H^- in a 1 cm^2 aperture, with an electron-to-H^- ratio of ≈ 3. At 19 mA, a normalized, 90% emittance of 0.44 π mm-mrad has been measured. Up to 50 mA has been extracted through a 1.87 cm^2 aperture. Although not designed for steady state operation, up to 6 mA has been extracted d.c. The addition of xenon to the discharge was found to improve the source output by 20-70%. The circular magnetic cusp field geometry was found to be more favorable than radial cusp fields.

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I. Introduction

At Brookhaven, a volume H^- ion source of novel design has been under development since 1988.[1] A volume H^- source generally has two distinct regions. In the plasma production region H_2 is ionized by fast electrons, typically coming from a hot filament cathode. Vibrationally excited H_2 molecules are also produced in this region. In the H^- production region, H^- ions are produced primarily via dissociative attachment of these vibrationally excited H_2 molecules. Slow electrons are needed for this process, while fast electrons in this region reduce the output due to H^- destruction. A magnetic "filter field" separates the two regions. Slow electrons, plasma ions, H_2 molecules, etc. can pass through this filter field, while the passage of fast electrons is inhibited. Normally, this filter is a dipole field dividing the source front-to-back. The filter field in the BNL source is approximately conically shaped, and divides the source so that the plasma production region is an outer toroid, while the H^- production is near the axis of the source. The biggest impact of this change seems to be in a much better than normal ratio of electron-to-H^- current in this source. We do not yet have a detailed understanding of why the differences in the source geometry have resulted in this improved source performance compared to a conventional volume source.

II. Source Geometry and Measurement Setup

A schematic of the source is shown in Figure 1. The cylindrical discharge chamber is 6 cm long and 20 cm i.d. SmCo magnets are arranged around the outside of the source, forming circular cusp magnetic fields for plasma confinement. There are normally five concentric rings of magnets on both the front and back faces of the source (although only four are shown in Fig. 1), and three rings of magnets on the sides. The polarities of neighboring rings of magnets are opposing. (A test with radial cusps is described in Section IV). Field lines between a SmCo disk magnet in the center of the back flange, and the innermost circular cusp near the plasma electrode, form an approximately conical filter field. The filament is a single loop of 1.25 mm diameter wire (W or Ta), placed outside the filter region. The cathode voltage is applied to the filament.

Other than for the tests of dc operation, the source was operated with a discharge pulse of ~ 1.2 ms, at a repetition rate of 0.5-1.3 Hz. The gas could either be pulsed or steady state, and the extraction voltage was applied dc. The H^- current was measured on a Faraday cup 10 cm from the source. A strong dipole field between the extractor and the Faraday cup prevented any electrons from reaching the cup. A current transformer on the output of the extraction power supply measured the total supply drain, and the difference between the H^- current measured on the Faraday cup and the total supply current is assumed to be electrons. A slit-and-collector emittance device can also be stepped through the beam at the Faraday cup location.

III. Source Performance

Figure 2 shows a measurement of the H^- current and electron-to-H^- ratio as a function of discharge current, for a 1 cm^2 aperture. A tendency toward saturation in the H^- output at higher arc currents is seen. In Fig. 3, the electron-to-H^- ratio is shown vs. H^- current for a variety of source operating conditions (without cesium). The source is typically operated with the plasma electrode grounded. Floating this electrode usually gives a slight increase in H^-, along with an increase in the e^-/H^- ratio. The source operating pressure is 5-15 x 10^{-3} Torr.

Emittance measurements were taken with a 1 cm^2 extraction aperture.[2] For a 13 mA beam, a normalized, 90% emittance of 0.32 π mm-mrad was measured. The RMS emittance at 13 mA was 0.07 π mm-mrad, corresponding to an effective H^- ion temperature of 0.57 eV. At 19 mA, the emittance was $\epsilon_N(90\%) = 0.44\ \pi$ mm-mrad.

When the source was operated with deuterium, the D^- output was 50-60% of the H^- output obtained under the same arc conditions.[3] Also, the e^-/D^- ratio was 4-5 times higher than that obtained with hydrogen.

Although not designed for dc operation, we were able to operate the source steady state at reduced arc currents. For these tests, the extraction voltage was pulsed in order to reduce the power on the extractor electrode and Faraday cup. We were able to extract up to 6 mA from a 1 cm^2 aperture, with a 20 A, 150 V arc. This output is the same as that obtained in pulsed operation. The e^-/H^- ratio, however, was 2-3 times higher for dc operation, compared to pulsed.

IV. Source Performance with Radial Cusps

The source was normally operated with the circular cusp field geometry given in Section I, and shown schematically in Figure 4.a. A radial cusp field, as shown in Fig. 4.b., was also tested, however. This type radial cusp geometry is typically what is used in other volume sources. There were 32 lines of magnets, going radially outward on the front and back faces of the source, and connected by lines of magnets on the sides. The conical filter field was formed between the disk magnet in the center of the back flange of the source, and a 8 cm diameter ring of magnets of opposite polarity around the extraction aperture.

At a given discharge current, the H^- output with radial cusps was less than half of that obtained with circular cusps. The e^-/H^- ratio, however, was approximately equal for the two geometries. Further studies would be needed to determine if this reduced output is due to poorer plasma confinement, or a reduced H^- production / increased destruction.

V. Cesium and Xenon Effects

Operation with Cs and Xe injection has been tried on other volume sources.[4] The effects of the introduction of cesium vapor into this source have also been measured.[3] Figure 5 shows the H^- current extracted from a 1.87 cm^2 aperture as a function of arc current, with and without the addition of cesium. Cesium also resulted in a reduction in the electron current, so we were able to obtain > 30 mA of H^- with $e^-/H^- < 1$. The source operating pressure could also be reduced by approximately a factor of two with the addition of cesium. The amount of cesium introduced into the source was not measured, but after turning off the cesium flow, there was only a partial decrease in the H^- current, and the pressure and e^-/H^- ratio remained low. After letting the source up to air, but not cleaning it, the H^- output dropped to nearly the original cesium-free levels, but the source pressure remained low and the electron-to-H^- ratio remained at $\approx$ 1. A thorough cleaning of the source was required to bring it back to the original cesium-free levels.

The introduction of xenon into the source also increased the H^- output, but less dramatically. Gains in H^- current of between 20%-70% were seen under various operating conditions (after optimizing the H^- current with and without Xe). The Xe pressure was ~ 10% of the H_2 pressure in the source. The e^-/H^- ratio typically increased when xenon was added, although in several cases it decreased. The "noise" on the H^- output current pulse increased with xenon.

VI. Acknowledgements

We would like to thank D. McCafferty for the excellent job he has done in modifying and operating the volume source.

References

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Figure Captions

Fig. 1. Cross section of the BNL volume H^- source. The calculated magnetic field is also shown.

Fig. 2. H^- current and ratio of electrons to H^- as a function of discharge current. The source aperture area was 1 cm^2.

Fig. 3. Electron-to-H^- ratio vs. H^- current for various pulsed operating conditions and source geometries (1 cm^2 and 2 cm^2 apertures).

Fig. 4. Schematic of the cusp magnetic geometry for a). circular cusps and b). radial cusps.

Fig. 5. H^- current vs. arc current with and without cesium in the source. The extraction aperture was 1.87 cm^2 and the voltage 16 kV.

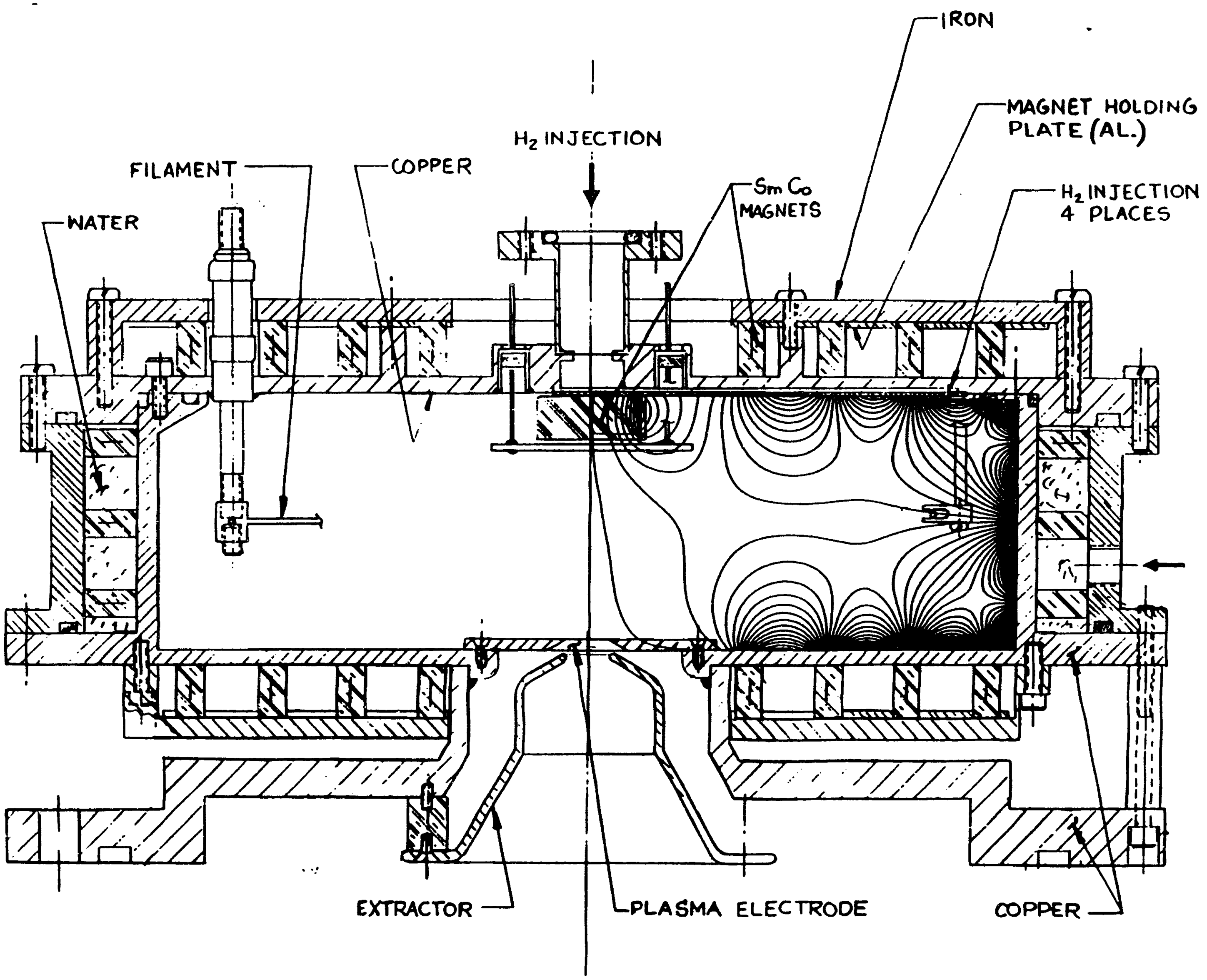

IRON
MAGNET HOLDING PLATE (AL.)
H_2 INJECTION
FILAMENT
COPPER
Sm Co MAGNETS
H_2 INJECTION 4 PLACES
WATER
EXTRACTOR
PLASMA ELECTRODE
COPPER

Figure 1.

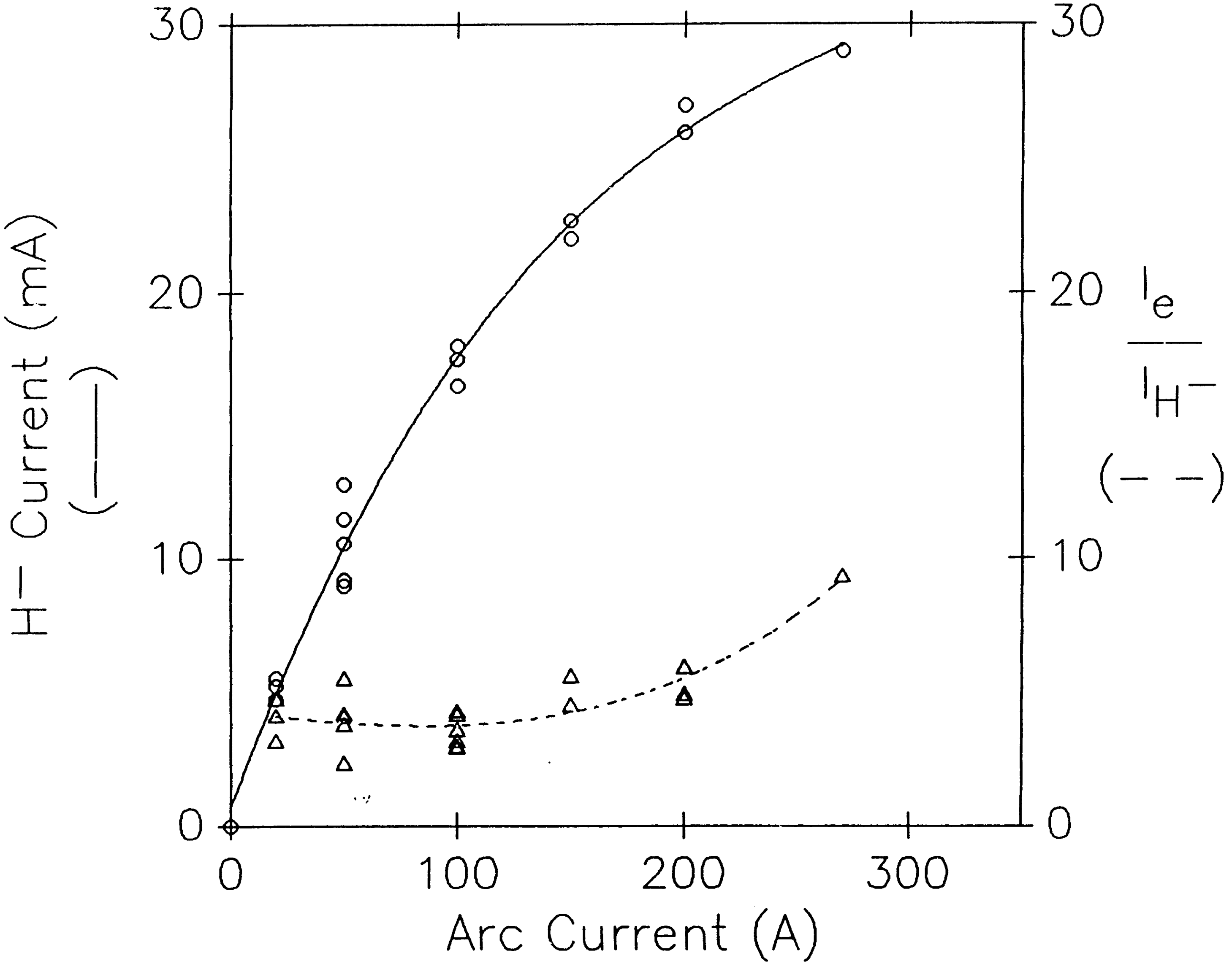

30
20
10
0
H⁻ Current (mA)
(——)
0
100
200
300
Arc Current (A)
30
20
10
0
$\frac{I_e}{I_{H^-}}$
(– –)

Figure 2.

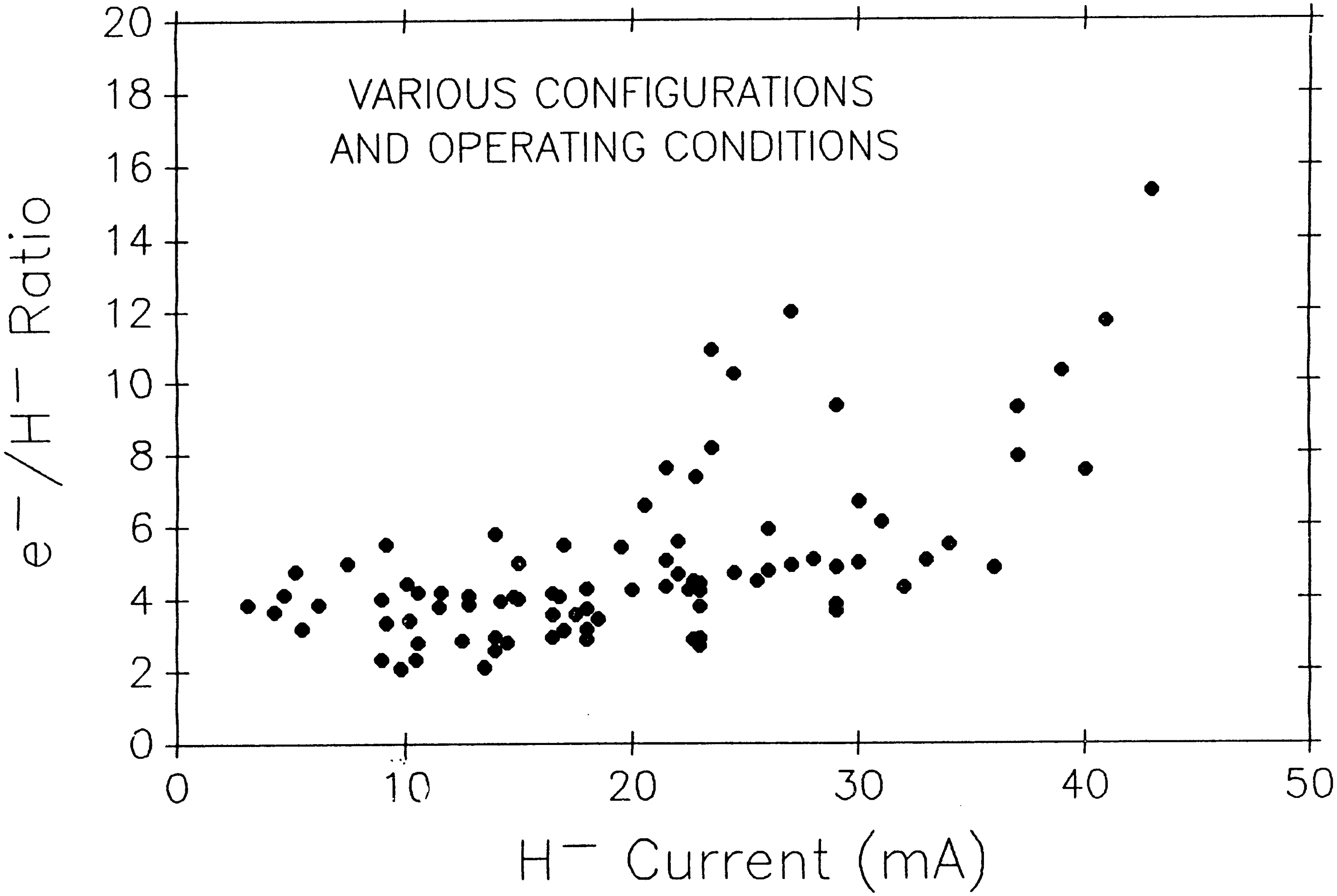

VARIOUS CONFIGURATIONS
AND OPERATING CONDITIONS
e^-/H^- Ratio
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
H^- Current (mA)

Figure 3.

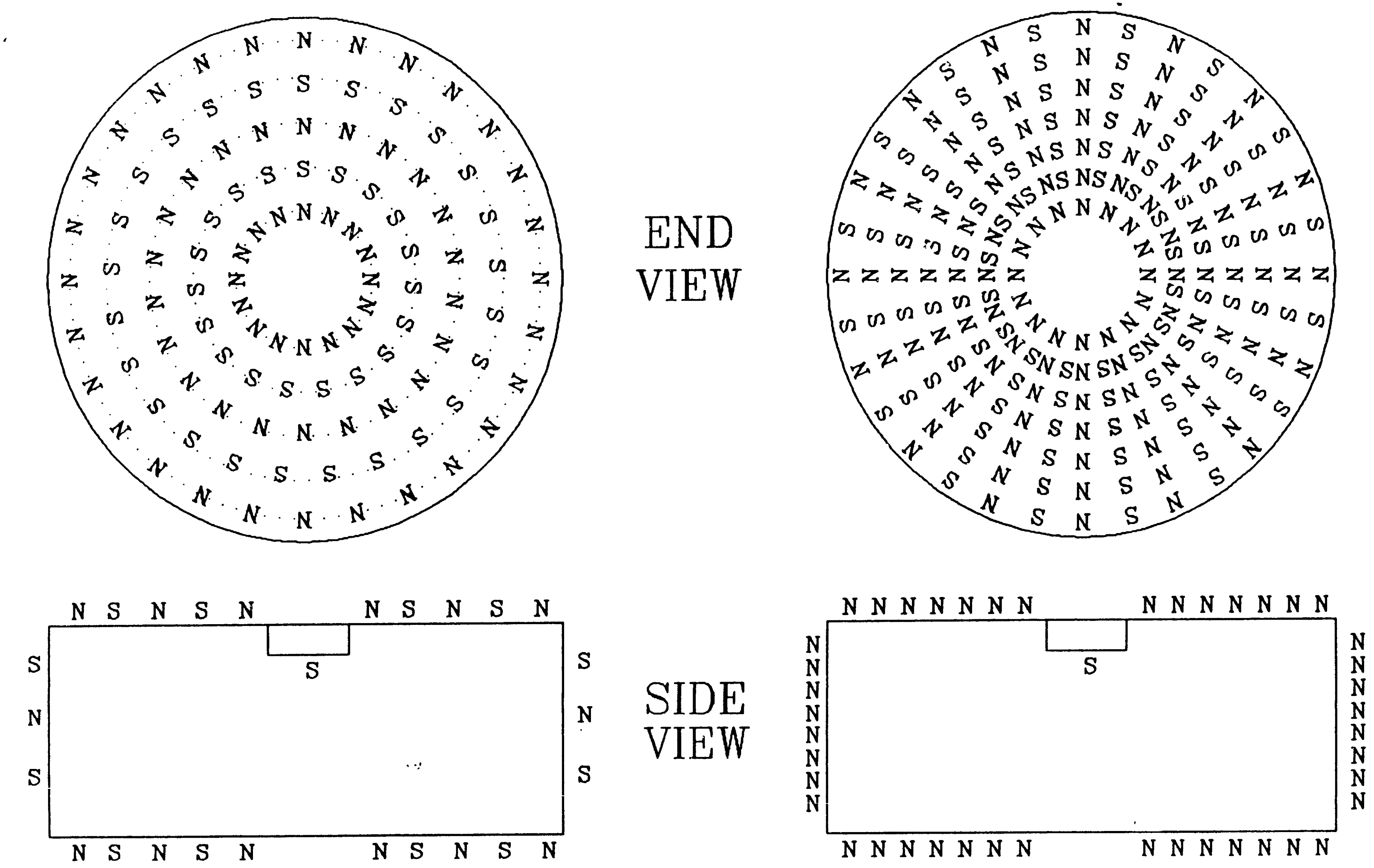
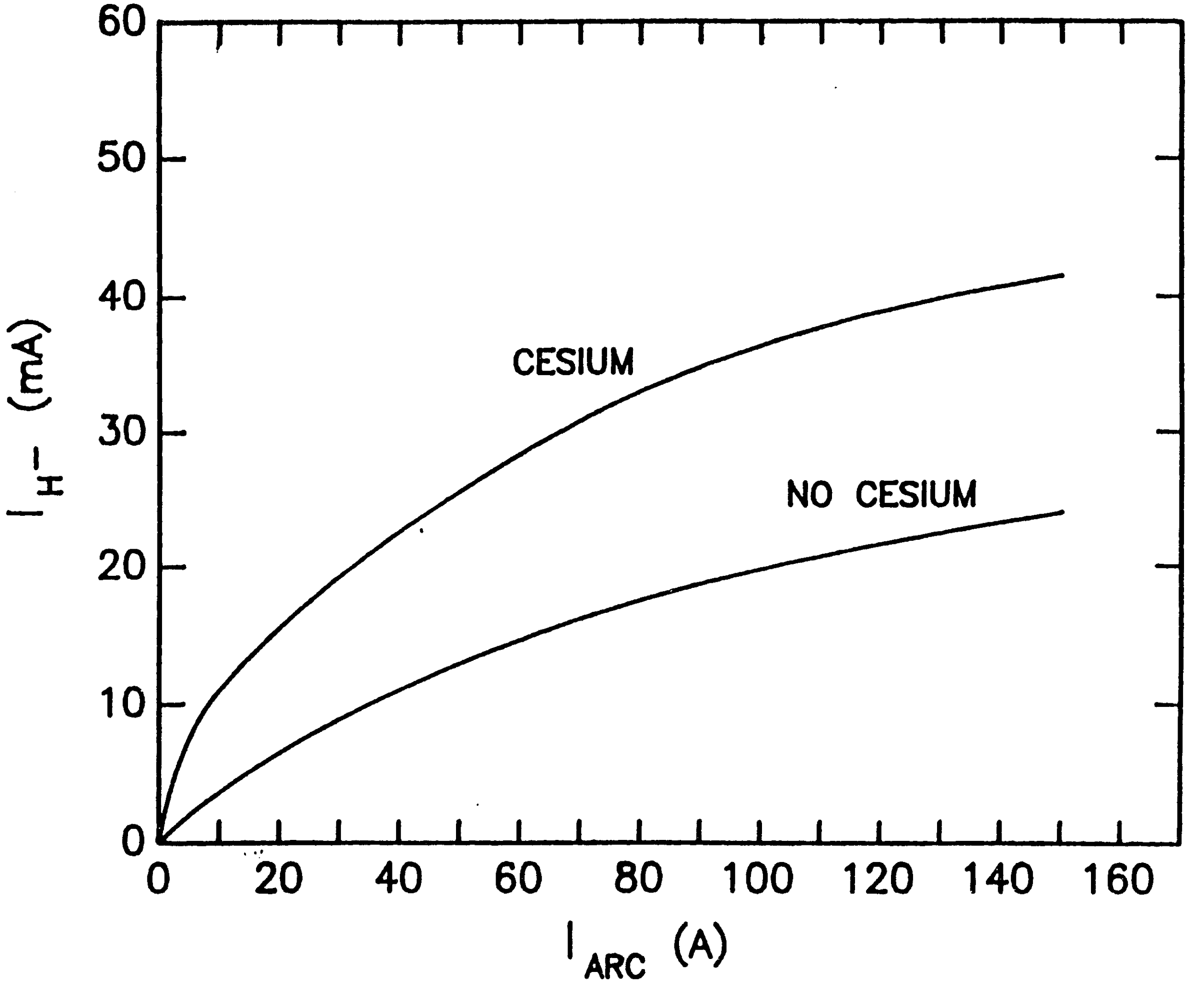


Figure 4.



60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
I H⁻ (mA)
I ARC (A)
CESIUM
NO CESIUM

Figure 5.

END

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