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Publication Date
1991-09-01

LBL-30529

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Accelerator & Fusion Research Division

Presented at the Fourth International Conference on Ion Sources, Bensheim, Germany, September 30–October 4, 1991, and to be published in the Proceedings

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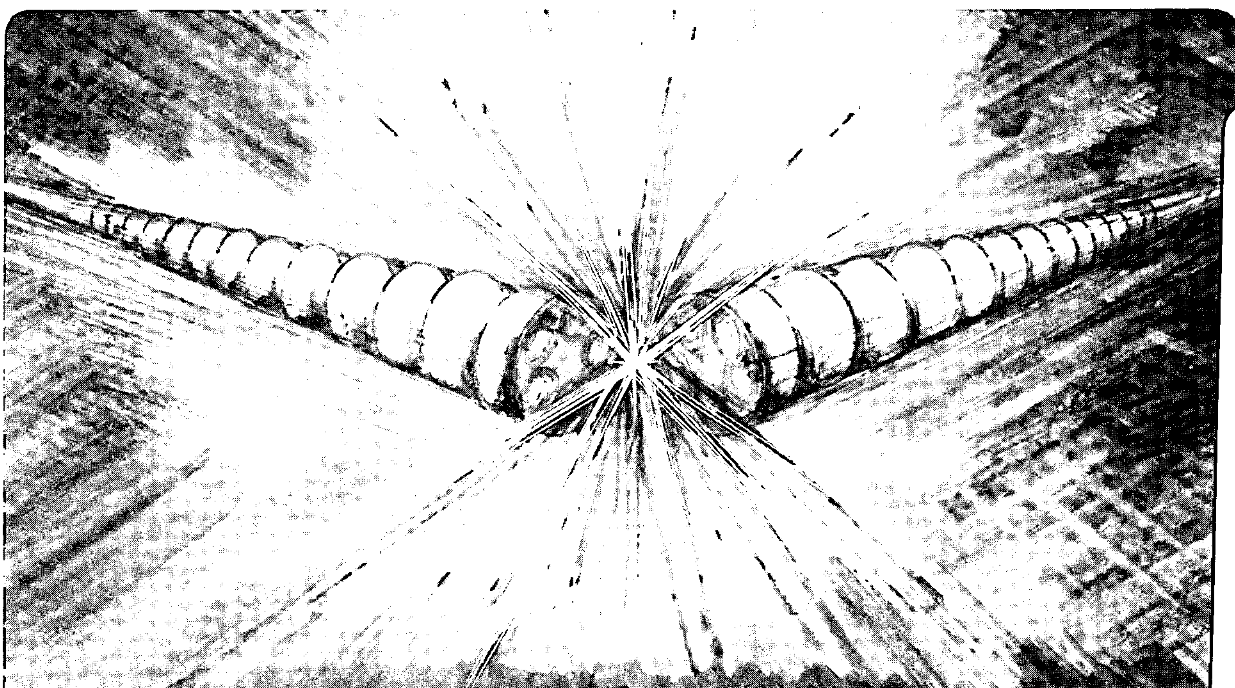

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

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DEVELOPMENT OF A DC LOW PRESSURE D^- SURFACE-CONVERSION SOURCE USING A 10-CM-DIAMETER SOLID BARIUM CONVERTER

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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

A D^- surface-conversion source using a solid barium converter is designed for steady-state operation to produce 200 mA of D^-. A similar ion source of twice the size as the one discussed here will meet the requirements set by the present US-ITER neutral beam injector design. Among the possible types of ion sources being considered for the US-ITER neutral beam design, the barium converter surface-conversion source is the only kind that does not use cesium in the discharge. This absence of cesium will minimize the number of accelerator breakdowns.

I. INTRODUCTION

Neutral beam injectors for the next generation tokamaks, e.g., the International Thermonuclear Experimental Reactor (ITER), will use negative ions to produce deuterium beams at energy of 1.3 MeV. In the US design for the ITER beamline, the main acceleration is done by electrostatic ESQ accelerators.[1] A 300-keV D^- beam with beam current of 1 A is to be injected into the entrance of each ESQ accelerator channel. Eventually, ITER will be operating as a steady state machine, thus the ion sources must produce D^- beams for pulse lengths up to two weeks long.

A. Comparing volume-production sources with surface-conversion sources

At present, the volume-production sources can produce high current density H^- or D^- beams, in steady state, for an aperture size ≈ 1 cm in diameter. Current density j can vary depending or whether cesium is used in the discharge or not. In pure hydrogen discharge[2,3,4] j can be as high as 20 mA/cm^2. In cesium operation, j is typically 3 times larger, reaching nearly 60 mA/cm.[5,6,7] The main disadvantages in pure volume-production sources are the high source pressure (≈ 10 mT), and the large amount of leakage electrons mixed into the extracted negative ion beam. The high source pressure results in a significant beam loss due to stripping of the negative ions. Both stripping and leakage electrons can lead to electrical breakdown and heat load problems in the accelerator.

Adding cesium vapor to the volume-production can enhance the current density, reduce the optimum gas pressure, and reduce the amount of leakage electrons. On the other hand, cesium vapor will contaminate the accelerator leading to possible problems in accelerator breakdowns for long term operation.

It is important to point out that the ESQ accelerator in the US-ITER design is based on accelerating a large diameter beam of up to 1 A of beam current per channel. In order to obtain this beam current from a volume-production source, a multi-aperture extraction system must be used to produce multiple beamlets.[6] The beamlets will be merged together in the 300 keV preaccelerator before injecting into the ESQ modules. So far, it is not clear how much emittance growth will occur in the merging stage and what will be the final impact on beam quality. Grid transparancy must be included when calculating the effective current density of a volume-production source.

One way to produce a high current steady state beam from a single aperture is to use the surface-conversion source. Earlier surface-conversion sources, using cesium-coated molybdenum converters,[8,9,10] have achieved 1.25 A of dc H^- beams with an average current density of 10 mA/cm^2 over a very large aperture. The equivalent current density of H^- ions produced at the converter surface (including the beam stripping loss in the plasma) was $\approx$ 3 mA/cm^2 which corresponds to an effective positive ion to negative ion conversion efficiency of $\approx$ 7%. Higher conversion efficiency may be possible if the cesium coverage is optimized to form a uniform fractional monolayer[11]. The surface-conversion source typically operates at a source pressure below 2 mT. As mentioned earlier, the presence of cesium is still undesirable in this source.

B. Developments in surface-conversion sources

In an experiment conducted by van Os et al,[12] a solid barium converter was shown to have a conversion efficiency as high as 8%, which is comparable to that of a cesium coated molybdenum converter. Barium, being a much less volatile material, is likely to cause less of a breakdown problem in the accelerator than cesium.

In this paper, we describe the design of a surface-conversion source using a 10-cm diameter solid barium converter. The source is designed to inject up to 200 mA of D^- into the preaccelerator. A similar design of about twice the size of the one discussed here will produce 1 A of D^- ions in a single beam, thus meeting the ITER specifications. Data from recent surface-conversion source experiments at LBL and preliminary data from testing of the new source are discussed in section III.

II. ION SOURCE DESIGN

Results from recent experiments done at LBL have provided useful criteria in the design of the present source.[13,14] The scaling of the negative-ion output with incident positive-ion current on the converter was found to depend greatly on the actual geometry and type of plasma generator. In particular, the plasma electron temperature in front of the converter should be as low as possible and the filaments should be placed far away from the converter to minimize any tungsten contamination of the barium converter surface.

A. Ion source geometry

A schematic diagram of the cylindrically symmetric ion source is shown in Fig. 1. The chamber walls are made of oxygen-free copper. The source is surrounded (including top and bottom) by 16 cusps of samarium-cobalt magnets. Like a volume-production source, this source can be considered as composed of two separate chambers: a *driver* chamber and a *conversion* chamber. The two chambers are separated from each other by a cylindrical magnetic filter. A toroidal plasma is produced in the driver chamber by a tungsten filament discharge. In order to reduce the amount of tungsten contamination on the barium converter surface, the 8 filaments are positioned in the driver chamber in such a way that there is no line of sight from the filaments to the converter surface. In the future, the tungsten filament discharge can be replaced by an RF discharge with the antenna located along the minor axis of the torus.

The source is designed for steady-state operation with a power input of more than 50 kW. The magnetic filter stops high energy electrons from flowing into the conversion chamber, thus the plasma in front of the converter will have a lower electron temperature than that in the driver. It also reduces the flow of tungsten ions to the conversion chamber. The strength of the magnetic filter can be adjusted by controlling the electric current applied to the field coil. Typical filter strength is in the order of 100 G-cm.

B. Converter geometry

By adjusting the location of the converter or varying the radius of curvature and shape (by making new units), we can optimize the beam current density and uniformity of the "self-extracted" beam. Figure 2 shows the calculated trajectories of the 200 eV D^- ions leaving a 10-cm-diam converter surface which has a 15-cm radius of curvature with the focus located at 1.5 cm downstream from the 3-cm-diam aperture. For a given geometry, the fraction of negative ions (produced at the converter) that passes through the aperture is determined by the transverse velocity distribution of the negative ions. With a Maxwellian transverse energy spread of 10 eV, the above geometry corresponds to a transmission fraction of about 1/3.

In order to maintain a low work-function on the converter surface, the barium converter must be free of contaminants. Double O-rings (no vacuum grease) with pump-outs are used in the vacuum system. The vacuum system is pumped by two turbomolecular pumps and two cryopumps; base pressure is in the low 10^{-8} Torr range. A load-lock system is used to keep the barium converter from being exposed to the atmosphere during installation into the ion source. The converter is water-cooled for steady state operation and it can be operated at a bias voltage of more than -300 V.

C. Electron filtering and extraction region

There is another magnetic filter (using permanent magnets) located in between the converter and the exit aperture. This filter serves two purposes. One is to minimize the plasma flowing out of the source and thus maximize the plasma density in front of the converter. The other purpose is to keep the high energy electrons (including the secondary electrons from the converter surface) from entering the preaccelerator. Similar to the earlier cesiated surface-production source, a positive voltage bias can be applied to the electrodes behind this filter to suppress electrons.[15]

III. PERFORMANCE EXPECTATION

We assume that a D^+ ion current density of 125 mA/cm^2 can be obtained in front of the converter surface. With 80 cm^2 of converter area and a conversion efficiency of 6%, the total D^- produced at the converter surface is 600 mA. If the D^- ions have a transverse energy of 10 eV, then 200 mA (i.e. 1/3 of the production) of beam current is available at the aperture.

At the time of this writing, we are starting to test this new source. The preliminary data shown in Fig. 3 is obtained by operating the source at 2 mT, 5 kW of arc power, and -100 V converter bias. At an optimum filter strength, the plasma density and the electron temperature in the conversion chamber are respectively 0.38 and 0.61 times lower than that in the driver. Extrapolating these results to higher power, we expect that it would take ≈35 kW to produce the necessary plasma density for the 200 mA D^- beam.

Figure 4 shows the result obtained in a recent experiment at LBL (unpublished data), using a 6-cm-diam barium converter with the source operating at 1.3 mT. The ion source used in this experiment did not provide an optimal condition in producing D^- because the electron temperature in front of the converter was too high, the vacuum system was too dirty, and the tungsten filaments were too close to the converter surface. There was a significant difference between the data taken before and after a discharge cleaning by sputtering the converter with argon ions. With 6 A of converter current (mostly positive ion flux), we obtained 145 mA of steady state D^- ion current, which corresponds to a conversion efficiency of 2.4%. We believe that new features incoorporated in the present design will improve the conversion efficiency to the target value of 6%.

IV. ACKNOWLEDGEMENTS

The authors would like to thank G. D. Ackerman, D. Moussa, and S. Wilde for their technical assistance. This work was supported by the Office of Energy Research, Office of Fusion Energy, D & T Division, of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

V. REFERENCES

1 O.A. Anderson, L. Soroka, C.H. Kim, R.P. Wells, C.A. Matuk, P. Purgalis, J.W. Kwan, M.C. Vella, W.S. Cooper and W.B. Kunkel, Nucl. Instrum. Meth., B40/41, 877, (1989)

2 J.W. Kwan, G.D. Ackerman, O.A. Anderson, C.F. Chan, W.S. Cooper, G.J. deVries, K.N. Leung, A.F. Lietzke, and W.F. Steele, Rev. Sci. Instrum. 61, 369 (1990).

3 A.I. Krylov, V.V. Kuznetsov, D.V. Penkin, and N.N. Semashko, in *Proceedings of the 5th International Symposium on the Production and Neutralization of Negative Ions and Beams*, edited by A. Hershcovitch, (Brookhaven National Laboratory, Brookhaven, NY, 1990), p. 290.

4 R. McAdams, R.F. King, A.F. Newman, and A.J.T. Holmes, Rev. Sci. Instrum. 61, 412 (1990).

5 K.N. Leung, C.A. Hauck, W.B. Kunkel, and S.R. Walther, Rev. Sci. Instrum. 60, 531 (1989).

6 H. Kojima, M. Hanada, T. Inoue, Y. Matsuda, Y. Ohara, Y. Okumura, H. Oohara, M. Seki, and K. Watanabe, Proceedings of the 13th Symposium on Ion Sources and Ion-Assisted Technology, Tokyo, June 4-6, 1990.

7 J.W. Kwan, G.D. Ackerman, O.A. Anderson, C.F. Chan, W.S. Cooper, G.J. deVries, W.B. Kunkel, K.N. Leung, P. Purgalis, W.F. Steele, and R.P. Wells, Rev. Sci. Instrum. 62 , 1521, (1991).

8 K.N. Leung, and K.W. Ehlers, Rev. Sci. Instrum. 53, 803 (1982)

9 A.F. Lietzke, K.W. Ehlers, and K.N. Leung, *Proceedings of the 3rd International Symposium on the Production and Neutralization of Negative Ions and Beams*, edited by K. Prelec, (Brookhaven National Laboratory, Brookhaven, NY, 1983), p. 344.

10 J. Kwan, G.D. Ackerman, O.A. Anderson, C.F. Chan, W.S. Cooper, G.J. deVries, A.F. Lietzke, L. Soroka and W.F. Steele, Rev. Sci. Instrum. 57, 831, (1986)

11 P.W. van Amersfoort, Ying Chun Tong, and E.H.A. Granneman, J. Appl. Phys. 58, 2317 (1985)

12 C.F.A. van Os, C. Leguijt, R.M.A. Heeren, J. Los and A.W. Kleyn, SPIE, 1061, 568, (1989)

13 C.F.A. van Os, K.N. Leung, and W.B. Kunkel, Appl. Phys. Lett. 57, 861, (1990)

14 C.F.A. van Os, K.N. Leung, and W.B. Kunkel, J. Appl. Phys. 69, 3485, (1991)

15 K.W. Ehlers and K.N. Leung, Appl. Phys. Lett. 38, 287, (1981)

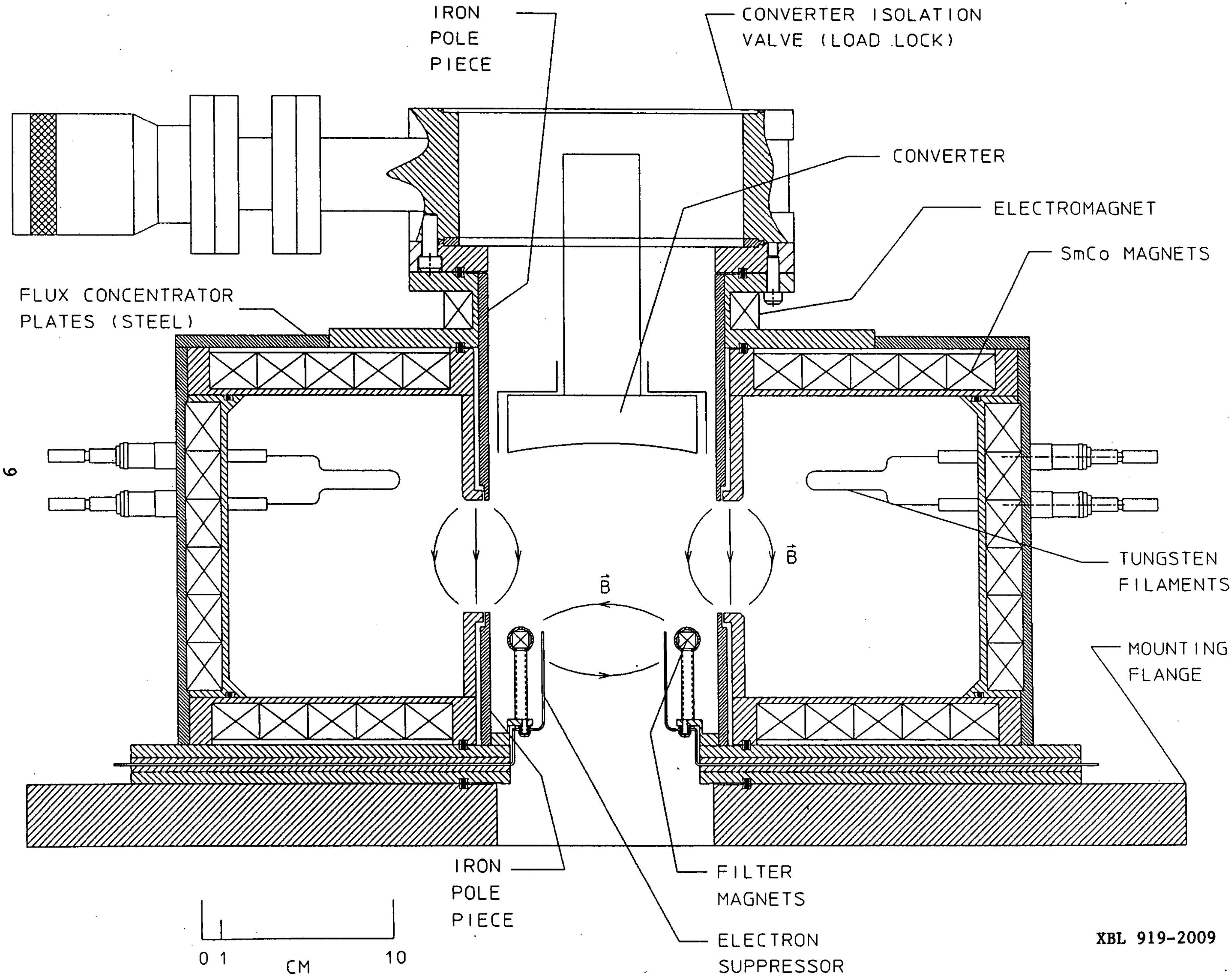
FIGURE CAPTIONS

Fig. 1. Schematic diagram of the barium converter surface-conversion source.

Fig. 2. Simulation of the calculated ion trajectories from the converter surface to the exit aperture and through a 100 keV preaccelerator.

Fig. 3. Plasma parameters measured from initial testings of the new surface-conversion source.

Fig. 4. D^- yield from a 6-cm-diameter barium converter operating at 1.3 mT of source pressure.


IRON POLE PIECE
CONVERTER ISOLATION VALVE (LOAD LOCK)
CONVERTER
ELECTROMAGNET
SmCo MAGNETS
FLUX CONCENTRATOR PLATES (STEEL)
B
B
TUNGSTEN FILAMENTS
MOUNTING FLANGE
IRON POLE PIECE
FILTER MAGNETS
ELECTRON SUPPRESSOR
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CM
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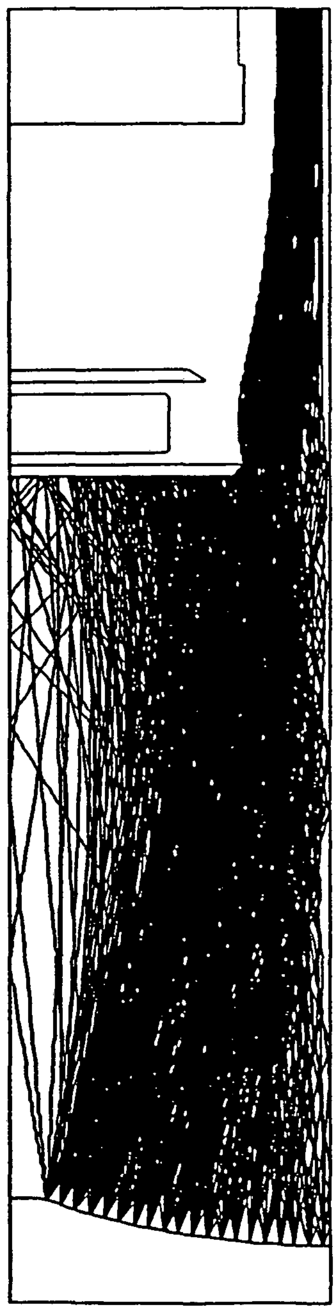

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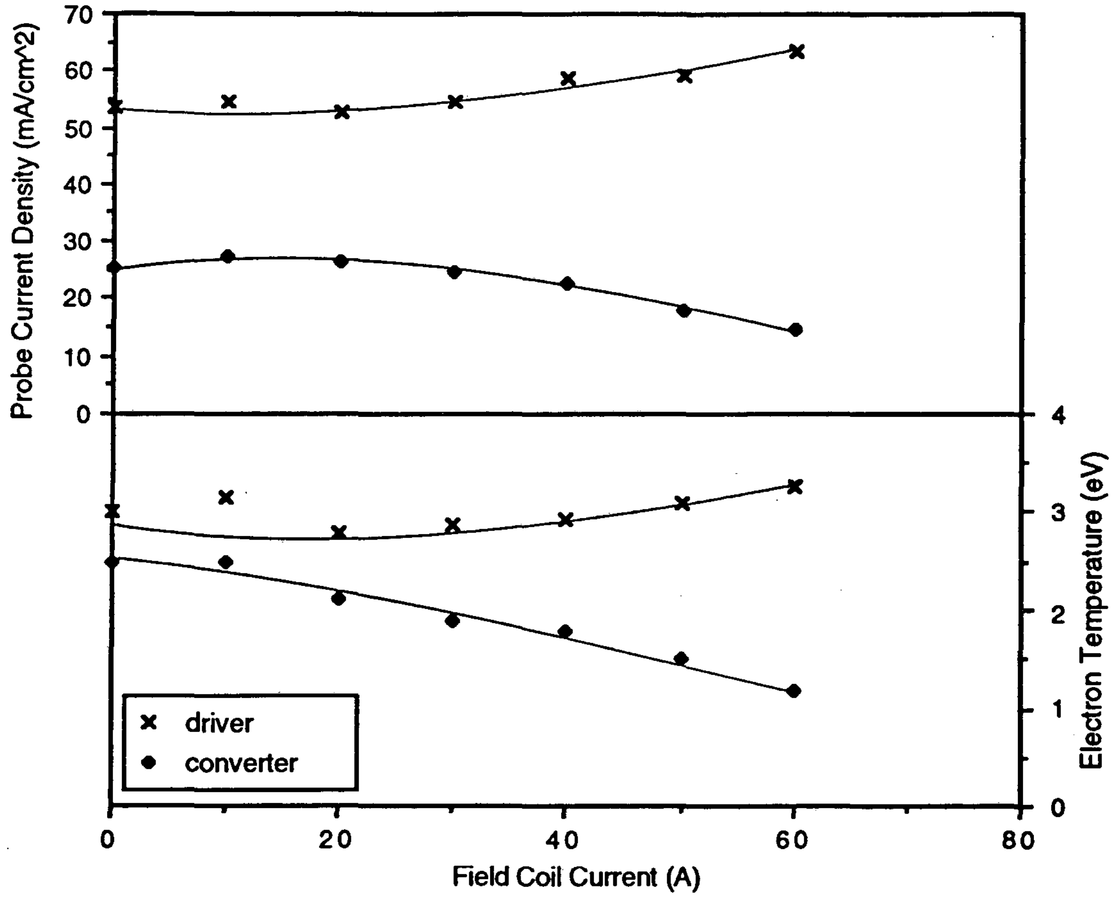
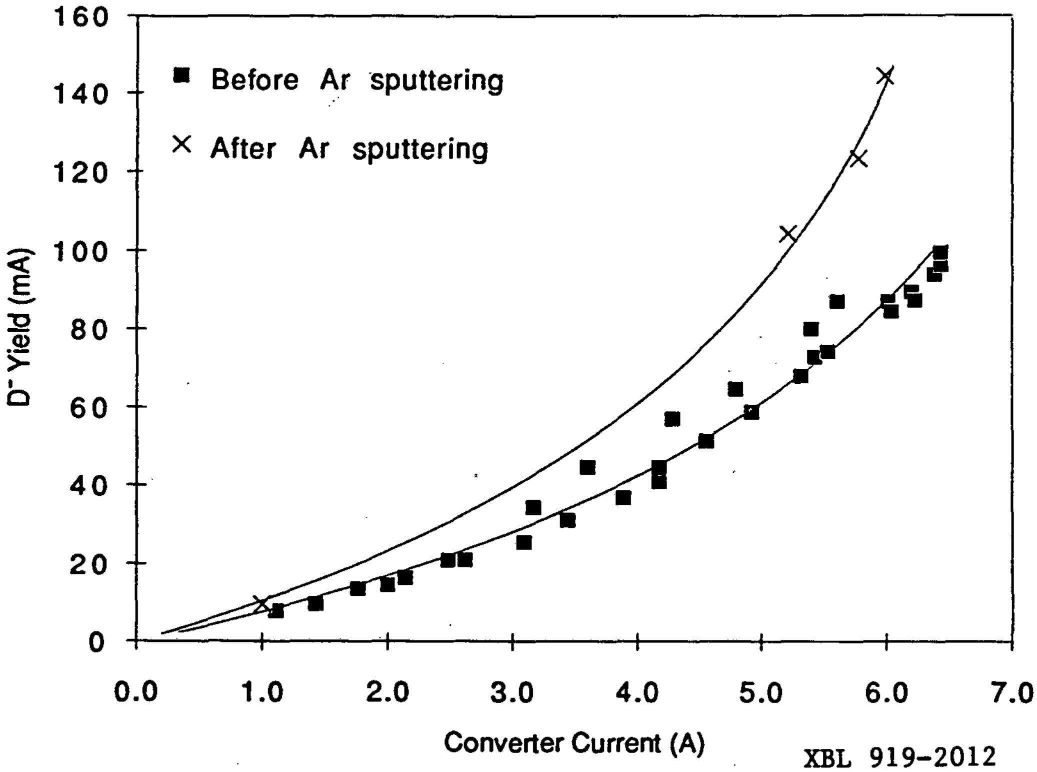

Probe Current Density (mA/cm^2)
Electron Temperature (eV)
Field Coil Current (A)
driver
converter
70
60
50
40
30
20
10
0
4
3
2
1
0
0
20
40
60
80

XBL 919-2011



160
140
120
100
80
60
40
20
0
D⁻ Yield (mA)
Before Ar sputtering
After Ar sputtering
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Converter Current (A)

XBL 919-2012

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