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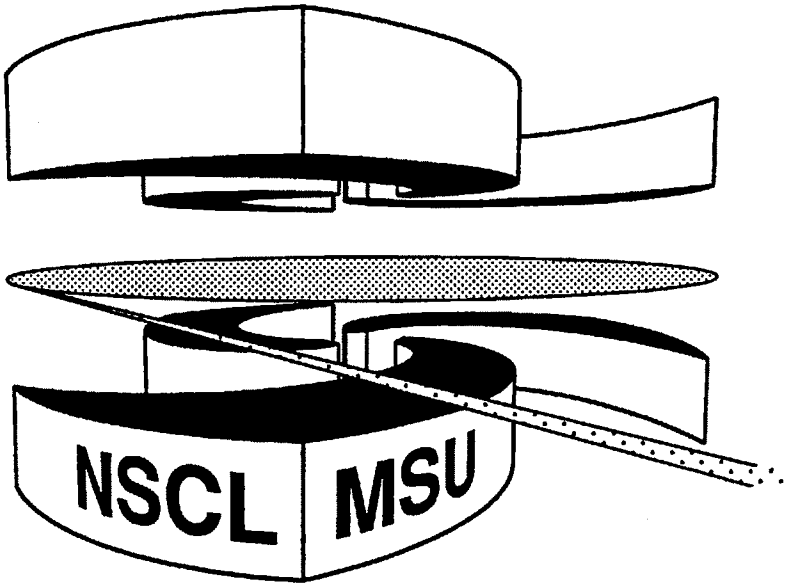
RECENT DEVELOPMENTS FOR METALLIC ION PRODUCTION AT THE NSCL

P. McNEELY, D. COLE, J. MOSKALIK, and A.F. ZELLER



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Abstract

This paper describes studies performed on the NSCL Superconducting-ECR ion source for the production of metallic ion beams. The Room Temperature-ECR ion source as the workhorse for generating metallic ion beams using a solid feed system, will be superceded in the future by the Superconducting-ECR ion source. A series of tests were carried out with a Langmuir probe introduced axially into the plasma chamber of the Superconducting-ECR ion source. These tests determined the location and shape of the plasma and its floating potential. The results presented show the effect of source bias and axial magnetic field on the plasma boundary. Some preliminary results for gold sputtering are also included. The use of a solid metal, saturated in deuterium, to produce deuterium beams in the Room Temperature-ECR ion source has also been studied.

I. Introduction

The production of beams of metallic species for the use with the NSCL experimental program has been well studied with both the Compact and Room Temperature-ECR (RT-ECR) ion source using both ovens and direct solid feed[1]. The laboratory is committed to a proposal, now in the final review stages, to both increase the available beam intensity of light ions for use in producing secondary radioactive beams and to upgrade the available beam energy of heavy ions by injecting beams from the K500 cyclotron into the K1200 cyclotron[2]. A key part of this proposal will be the use of the Superconducting-ECR ion source (SC-ECR) with metallic species to take advantage of its enhanced performance compared to the RT-ECR. Up until now the SC-ECR ion source has been used only for gaseous elements. A vigorous research program has begun to answer the questions necessary to design an appropriate system to provide metallic species. Some initial study results are presented here.

II. Superconducting-ECR Ion Source Development for Metallic Ions

In the past the SC-ECR has been used exclusively with gaseous species, but the Coupled Cyclotron Proposal will require the use of the source for metallic species. As a first step towards the goal of providing metallic ion beams, a series of measurements has been carried out to explore the plasma in the region where the solid feed system would be located. The initial effort will be concentrated in the area of sputter feed[3,4] because of the necessity of using vertical axial insertion rather than the more convenient radial insertion of the RT-ECR. This requirement raises a number of complications to the design of a solid feed system. Design constraints caused by the sample introduction thru the first stage geometry require the solid feed system to be very close to the wall of the plasma chamber. The fact that there is no airlock such as exists on the RT-ECRIS means that the source must be vented in order to change samples or to perform different tests. The vertical nature of the insertion also requires the sample to be firmly clamped to ensure it will not fall off.

A Langmuir probe[5,6] has been used to determine the plasma density at the radial position to be used for solid feed (for the experimental arrangement see Fig. 1). The probe was constructed from a tungsten filament with pyrex insulator and used a 40 V bipolar power supply. The initial test was performed with no source bias and at very low RF power and high source pressure. The probe was inserted at a slight angle inwards toward the center of the source at 25 mm from the wall of the plasma chamber. It was possible to map the plasma boundary as a function of magnetic field. The boundary was sharp with the probe current rising from tens of μA to nearly a mA in the space of 15 mm. The vacuum of the source was severely degraded by the fullest extension of the probe into the plasma though. Later examination of the probe revealed erosion of the pyrex insulator.

The probe power supply and ammeter were isolated to allow the probe to be operated while the source was biased. The probe was inserted straight down at 18 mm from the wall of the plasma chamber. Data were collected with the source bias both on and off for a series of magnetic fields. These tests indicated that direct solid feed was possible at this radial position but requires a deep insertion of the sample.

The plasma boundary was again seen to be sharp although the observed current was lower, in the nA rather than μA range until the plasma was reached, indicating a lower plasma density at this radius (Fig. 2). The pressure in the source was also lower so the reduced current is not surprising. The initial axial magnetic field profile is shown in Fig. 3. The effect on the plasma of reducing the axial magnetic field can be seen in Fig. 2. The boundary of the plasma can be seen to be expanding as the field decreases. The source bias proved to have a strong effect on the observed plasma conditions. There was a marked decrease in the observed ion current. Near the plasma boundary the observed probe current would often decrease, at times becoming negative. These effects are most likely due to increased electron density rather than a change in ion density caused by the bias supply. As the magnetic field is lowered the electrons are no longer tightly confined to the central region of the source and their density in the outer region near the probe should increase. The ions are confined by an electrostatic potential due to the electrons. As the electron density decreases the plasma confinement should also decrease resulting in the observed growth of the plasma boundary. During these tests one Langmuir probe was destroyed when the pyrex insulator melted and ran down over the probe. This is indicative of heating by electron bombardment rather than from resistive heating of the filament.

The value of the floating plasma potential (the probe voltage where zero current is observed) decreases with decreasing field as can be seen in Fig. 4. These data were taken at the plasma boundary for each magnetic field configuration rather than at a fixed point. The floating potential becoming more negative indicates a growth in the electron density. More electrons must be repelled to reduce the electron current to the same magnitude as the ion current.

A very brief sputter test was carried out again using a gold sample with oxygen support gas. Sputtering was maximized at 210 mm from the first stage baffle at –2.23 kV but requiring both high source pressure (5.36 x 10^{-7} Torr) and high RF power (1.5 kW). Tuning on the Au^{26+} peak charge state resulted in a maximal value of 16 $e\mu$A (Fig. 5).

Further studies with both the probe and sputter feed are planned. The goal is to find the optimal position for solid feed. For the future it is intended to carry out tests with the probe to map the plasma as a function of radial position. Studies are also to be done at source conditions which are the same as standard operating conditions for the coupled cyclotron proposal. Further analysis of the available data will be carried out to determine plasma properties and relate them to source tuning parameters such as pressure, magnetic field, and RF power.

III. Studies for the Production of a Tritium Ion Beam

Much interest exists in the possibility of using a tritium beam for experiments at the NSCL. A study was begun to investigate how such an ion beam could be produced using the existing sources. A gas handling system would be expensive and its eventual contamination creates a disposal problem. To prevent this the concept of sputtering the tritium from a solid target[4,7] was chosen as the method of introduction. This method has been used successfully in the past for hydrogen[8]. The tests were carried out using initially hydrogen and then deuterium. Thin metal foils were used as sputtering targets. The gas was loaded into the sputter matrix by electrolysis. Two matrix materials have been tested: Ti and Pd. These test were carried out with the RT-

ECRIS using the same radial ports and hardware used in direct solid feed or metal ion sputtering. To isolate the metal foil target from the source a commercial ceramic insulator was used. In all cases the support gas in use was oxygen.

The initial test with Ti used hydrogen and were positive; *ie* a strong hydrogen signal was observed. It could not be determined if the hydrogen observed was being sputtered from the Ti, was produced by other processes or came from hydrocarbon contamination. The second test used deuterium loaded into Pd. The change to Pd was to reduce the possible effect on future source performance if the metal foil was again vaporized by direct plasma interaction. Additional care was taken in the preparation of the metal foil including heating in a vacuum oven to outgass the foil. Unfortunately the planned run was rescheduled and a long delay occurred between the target being deuterated and the test, likely negating any benefit of these preparations. There were two observations during the test. The first was that the D^+ current increased as the sample was moved in radially closer to the plasma with the sample bias maintained at –500 V with respect to the source bias. The second was that at a position corresponding to the sample being outside the plasma the bias was varied between –0.1 and –3 kV resulting in a sharp increase in D^+ current between –1 and –1.5 kV. With the bias at –3 kV a peak current of 2.1 μA was observed. This current was abruptly lost and could not be recovered.

Examination of the foil revealed that part of it had melted but since the bulk of the sample was still available it was quickly redeuterated and reintroduced into the source. This time the sample was kept an additional 28 mm further away from the plasma. A stronger D^+ signal was observed, and the signal built over time. It reached a maximal value of 200 μA with the source operating at high pressure (7.6 x 10^{-7} Torr), and then began to decay away with improving source pressure. The source was left operating overnight to determine the life expectancy of the sample. The D^+ beam was not recoverable in the morning and observed current had not changed from a background value in the last 4 hours of monitoring. This indicates that the expected life of sample is significantly less than 24 hours.

The amount of tritium desired is in the range of 1-10 nA extracted from the cyclotron. This requires at most 1 μA of D+ from the source. The completed tests have demonstrated that this value is easily achievable. What is still required is to demonstrate a current of 10 μA stably for a period of 24 hours. This will require investigation of metal foils which do not readily diffuse hydrogen as is the case for Pd and do not sputter significantly. The first such material to be tested will be tantalum. Tantalum was chosen since it has a diffusion coefficient several orders of magnitude lower than that of Pd[9] at the same temperature and it sputters poorly.

Acknowledgements

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Figure Captions

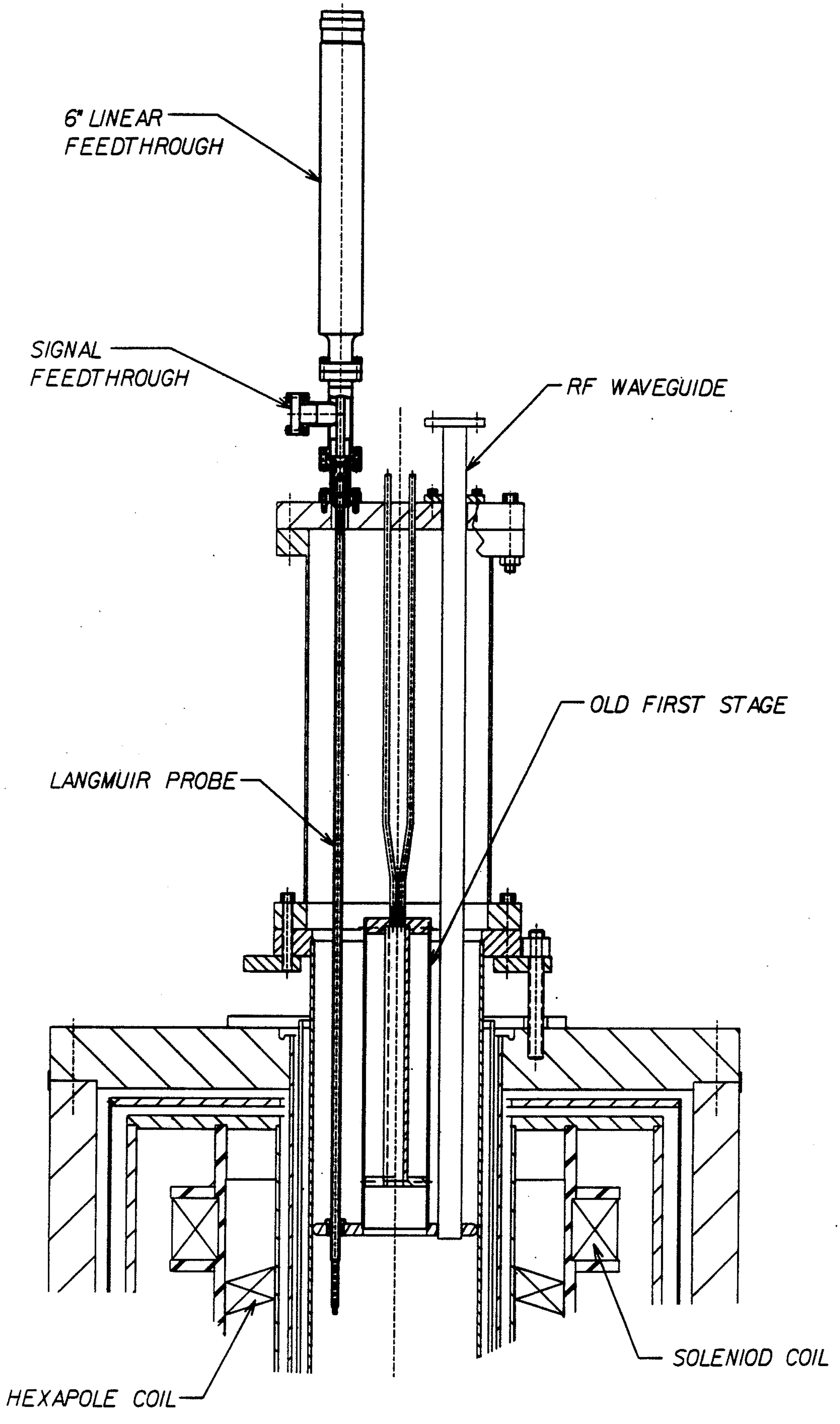
FIG. 1. The experimental arrangement in use for either Langmuir probe or sputter testing showing all major components of the SC-ECRIS.

FIG. 2. The Langmuir probe current as a function of distance from the 1st stage baffle plate. In each pair of curves the open symbol is the current with the source bias off while the solid symbol is the current with source bias on at 10 kV. Full magnetic field corresponds to peak of the injection side field of 12.1 kG. The errors on each data point are between 5-10% of the value except near the plasma boundary where larger variation occurs.

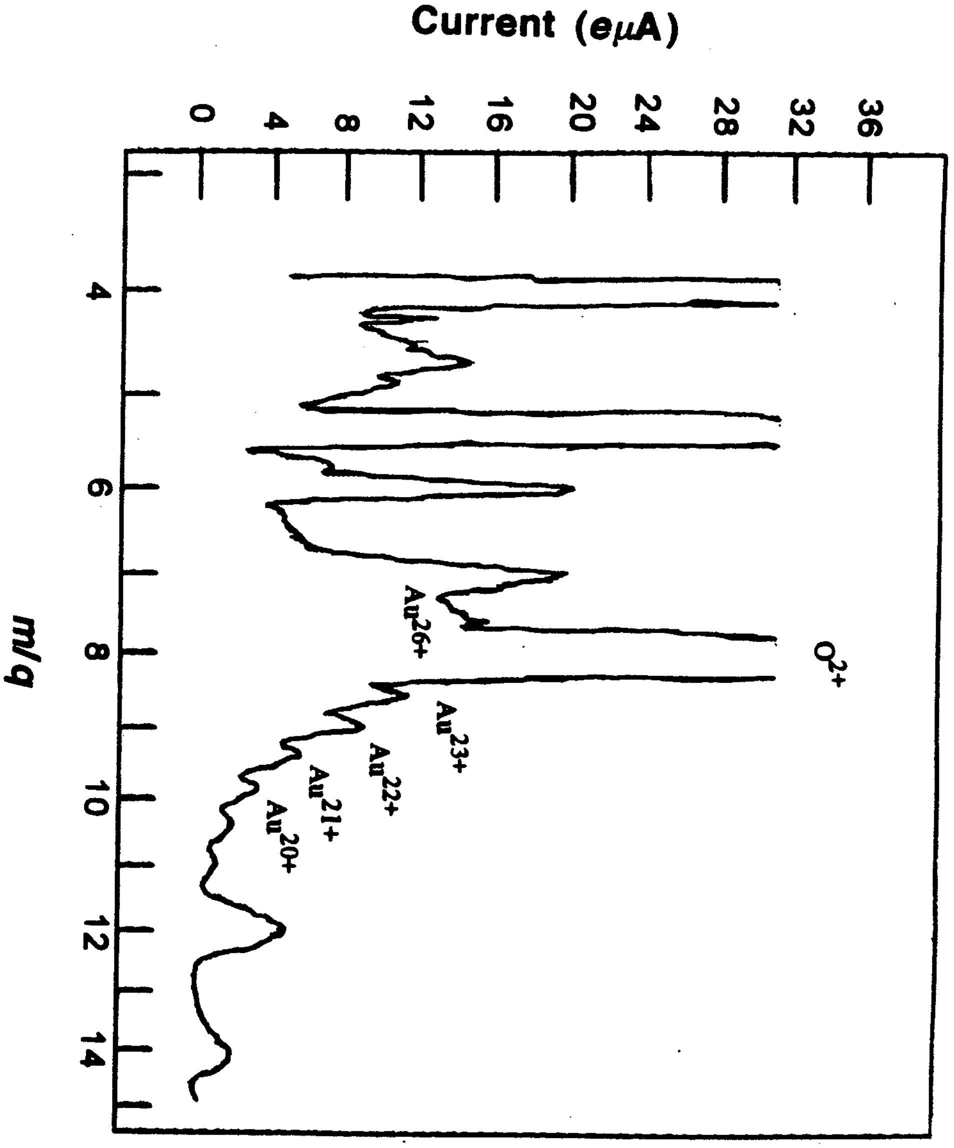
FIG. 3. The initial axial magnetic field profile at the start of the probe tests.

FIG. 4. The variation of the floating potential with axial magnetic field. The floating potential is the probe bias voltage required for the probe current to be zero.

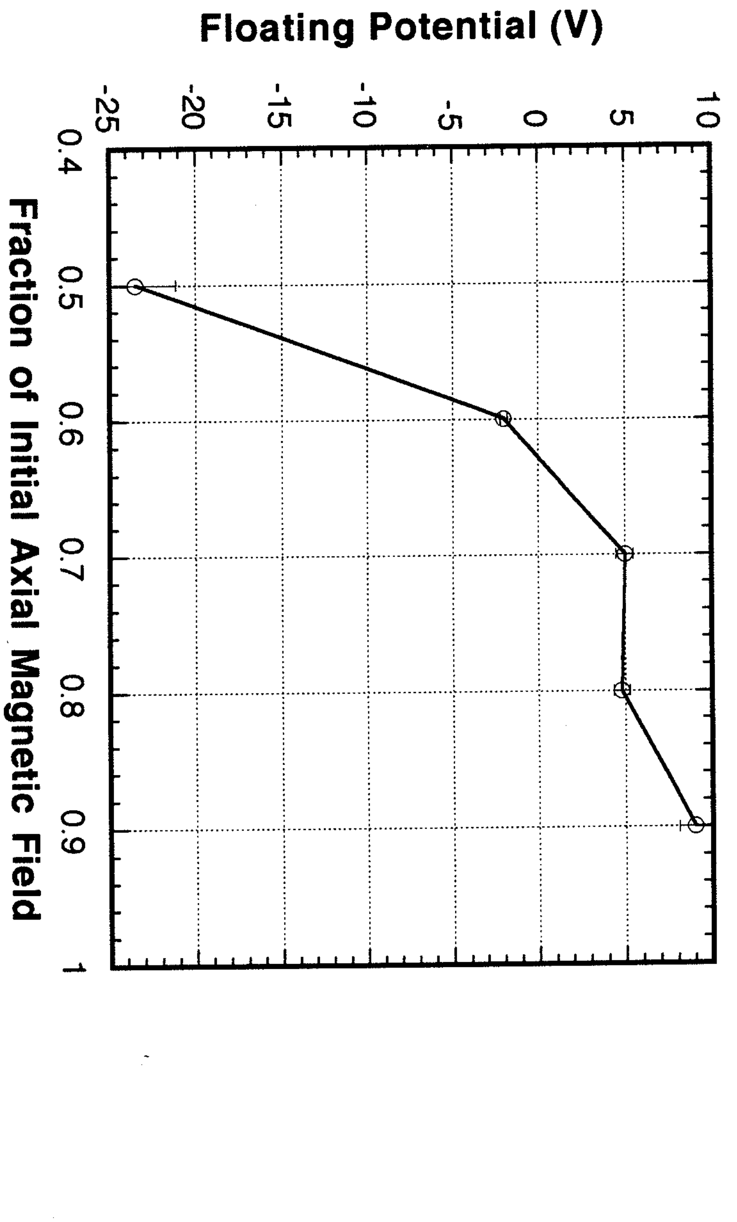
FIG. 5. The charge state distribution for Au sputtered by oxygen at –2.23 kV sputter bias and 1.5 kW RF power optimized for the Au^{26+} charge state.



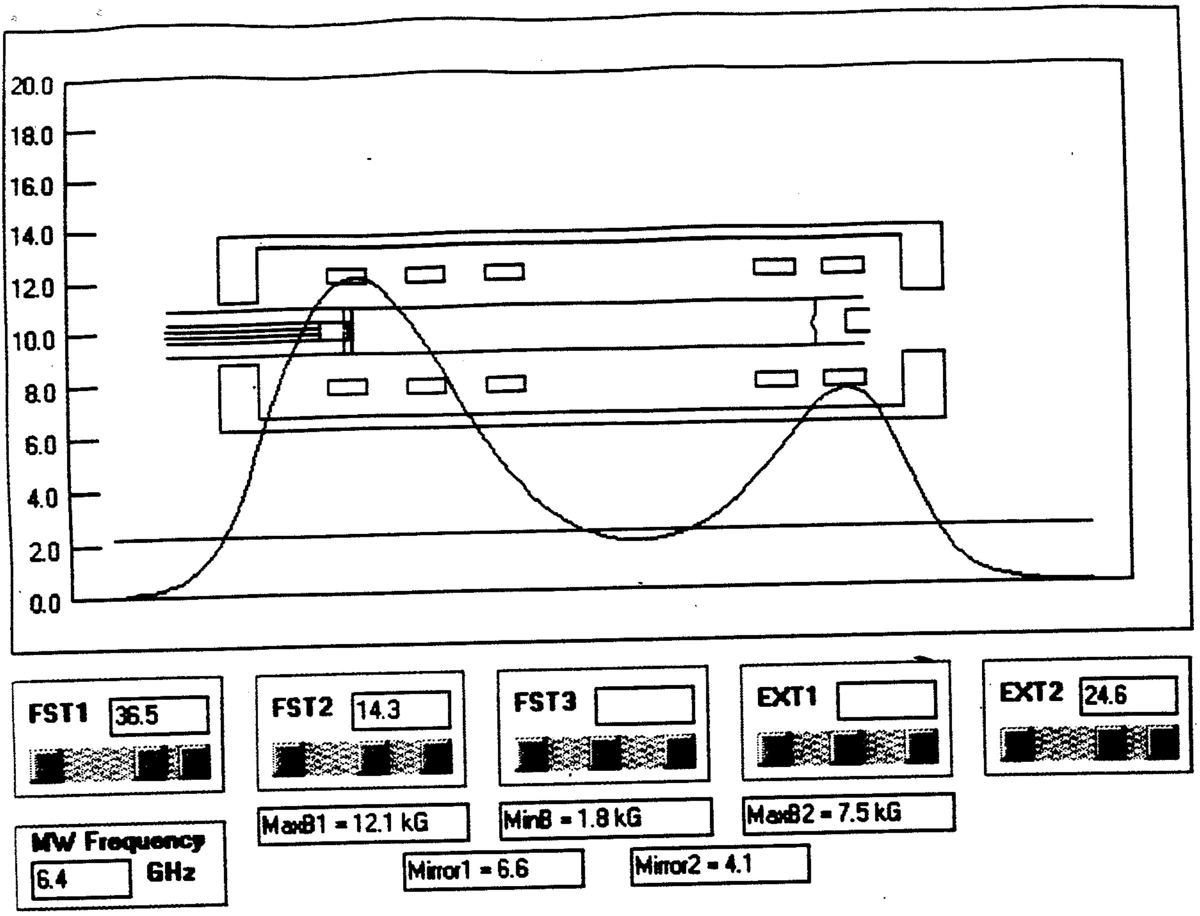
MCNEELY FIG. 1



MCNEELY FIG. 5



MCNEELY FIG. 4



FST1 36.5

FST2 14.3

FST3

EXT1

EXT2 24.6

MW Frequency 6.4 GHz

MaxB1 = 12.1 kG

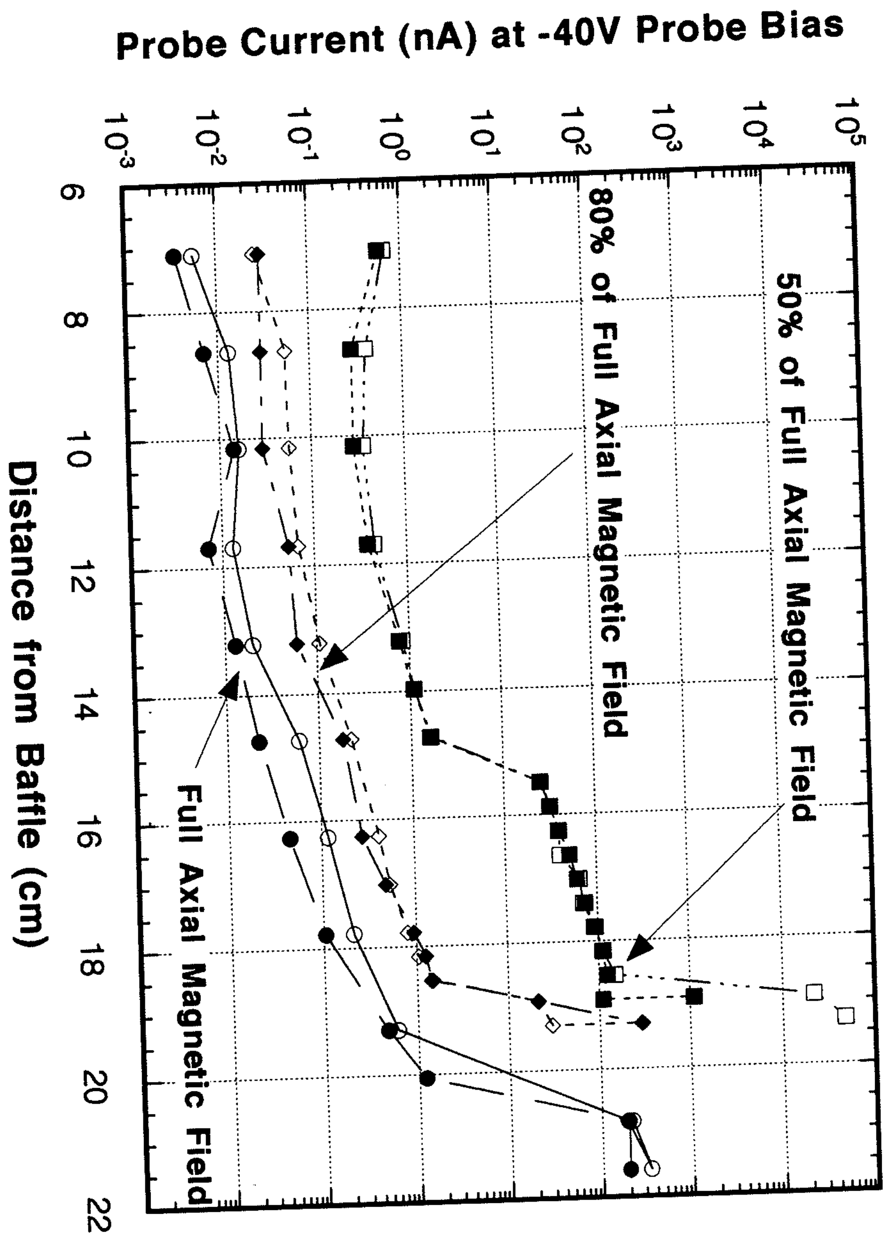
MinB = 1.8 kG

MaxB2 = 7.5 kG

Mirror1 = 6.6

Mirror2 = 4.1

MCNEELY FIG. 3



MCNEELY FIG. 2