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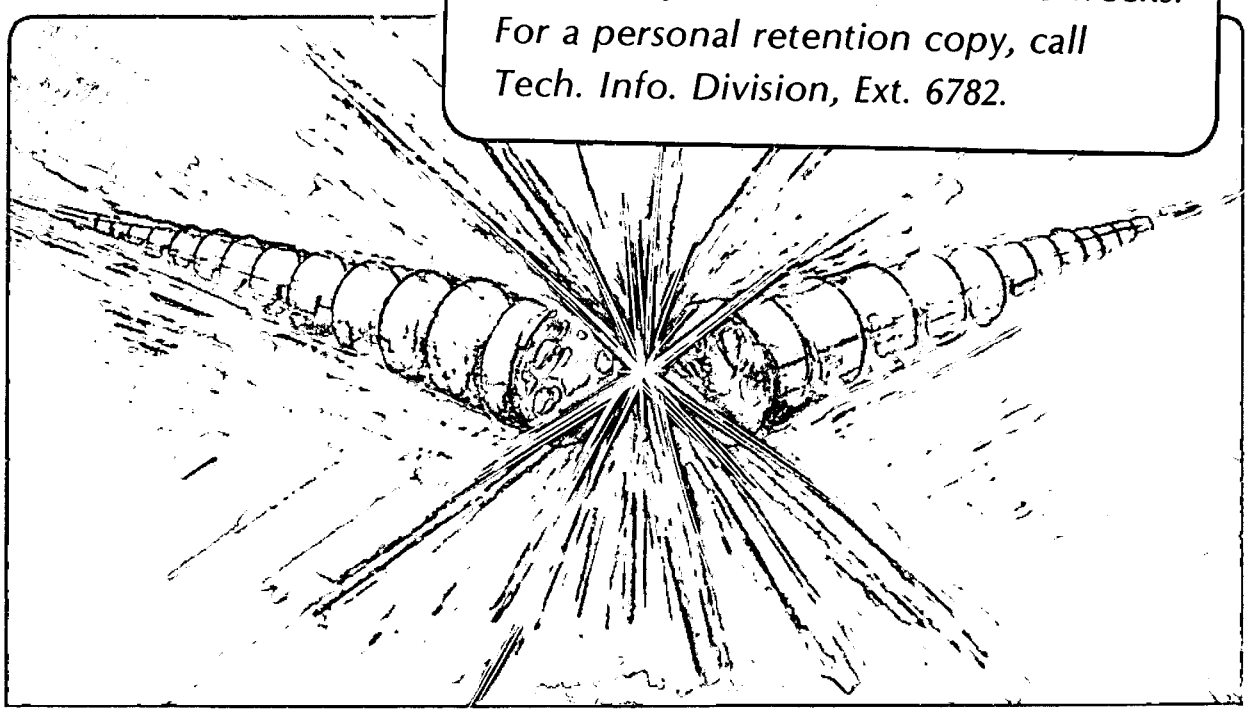

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EFFECT OF A MAGNETIC FILTER ON THE FORMATION AND DEPOSITION OF HIGH-Z IMPURITIES IN A MULTICUSP ION SOURCE*

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Abstract

The presence of a magnetic filter in a multicusp ion source reduces the transport of tungsten to the extractor region by forming a uniform plasma potential region in the source chamber. Because of the reduced numbers of primary electrons in the extraction chamber, the plasma grid floats near the plasma potential and this reduces the amount of impurity ions formed from sputtered grid material.

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Multicusp plasma generators are capable of producing large volumes of uniform and quiescent plasma with densities exceeding 10^{12} ions/c.c.[1,2] Hence, there has been a growing interest in applying such devices as ion sources for neutral beam injection systems.[3-6] Recently, it was found that the addition of a permanent magnet filter arrangement to a multicusp ion source could improve the atomic hydrogen or deuterium ion fraction, the source operability and the plasma density profile at the extraction plane.[7,8] The filter provides a limited region of transverse B-field which is made strong enough to prevent the energetic electrons in the "source" chamber from crossing over into the "extraction" chamber, but is weak enough for some plasma to diffuse into the extraction region. One might suspect that heavy impurity ions such as tungsten would diffuse through the filter at least as easily as the bulk plasma ions. However, data are presented in this letter to suggest that the filter actually reduces the relative number of high-Z impurity ions that arrive at the extractor. The filter is shown to have a two fold effect: one of impeding the transport of tungsten from the cathodes to the extractor, and the other of reducing the sputtering rate of the plasma grid material.

The first evidence was obtained while investigating the characteristics and species distribution of a 10 x 10 cm^2 multicusp source[9] which was arranged with four water-cooled ceramic magnet filter rods as shown in Fig. 1. The plane formed by these rods was located 7.5 cm from the plasma grid leaving a distance of 15.5 cm to the back wall. The transverse B-field generated by the filter extended to a distance of 3.5 cm on each side and the total integrated flux was approximately 85 Gauss-cm. In order to generate an ion current density of 250 mA/cm^2 at the extraction plane, 570 A of arc current were required. This high arc current was provided by sixteen 0.16-cm-diam tungsten

filaments located at the center of the source chamber. The operating temperature of these filaments was high enough that the vapour pressure of tungsten was a few tenths of a millitorr. As a result it was reasonable to expect that considerable tungsten would deposit on all the chamber walls as in the case with no filter. After the source had been operated for several hours, it was found that the source chamber walls were indeed well-coated with tungsten, but the walls of the extraction chamber were relatively free of tungsten deposits (Fig. 2). The tungsten color in the source chamber ended about 1 cm in front of the filter plane beyond which the copper wall color remained predominantly.

In order to explain the difference in the tungsten deposition between the two chamber walls, it was suggested by Green[10] that the plasma potential in the extraction chamber might be more positive than that of the source chamber and thereby reduce the flow of tungsten ions to the extraction region. However, the axial plasma potential distribution obtained by a movable Langmuir probe did not support this argument. Figure 3 shows that the potential of the plasma V_p in the source chamber is always more positive than that in the extraction chamber. This potential gradient is in the favorable direction for accelerating positive ions into the extraction region. Moreover, the B-field of the filter is too weak to confine the massive tungsten ions.

In normal operation, the high arc power delivered to the source chamber generated a source plasma density of 2.5×10^{12} cm^{-3} and an electron temperature T_e of about 11 eV. This relatively high temperature and dense plasma can play an important role in the formation of tungsten ions. The mean

free path λ_i for ionization of the tungsten atoms can be estimated using a semi-empirical formula for the cross section for single impact ionization,[11]

$$\sigma_L = \frac{4 \times 10^{-14} \ln(E/\phi)}{E\,\phi}, \qquad (1)$$

where E is the electron energy and ϕ is the ionization potential[12] in eV. In comparison with known[13] cross-sections for $Au^0 \longrightarrow Au^+$, $Ba^+ \longrightarrow Ba^{++}$, and $Tl^+ \longrightarrow Tl^{++}$, this Lotz formula gives a substantial underestimate (where data is available for comparison). For a slow tungsten atom in a plasma, the ionization mean free path is,

$$\lambda_i = \frac{v_W}{n_e < \sigma_{e,i}\, v >_e}, \qquad (2)$$

where v_w is the mean tungsten speed, n_e the electron density, and $< \sigma_{e,i}\, v >_e$ denotes the reaction rate averaged over the electron distribution. If a Maxwellian distribution is assumed, the integral over the Lotz cross- section can be evaluated numerically. Since the experimental electron population has an enhanced energetic tail, the Maxwellian integration over the Lotz cross-section gives an underestimate for $< \sigma_{e,i}\, v >_e$, i.e., $\lambda_L = v_w/n_e < \sigma_L\, v >_{mx} > \lambda_i$. Figure 4 shows a plot of λ_L as a function of T_e with the assumption that the tungsten atoms have an average energy of $0.\underset{\frown}{3}$ eV.[14] It can be seen that $\lambda_L < 1$ cm for $T_e = 11$ eV which suggests that the tungsten is ionized within a very short distance from the cathode filaments.

Once the tungsten ions are formed, they drift either to the extraction region or to the side walls of the source chamber. Figure 5 is a plot of V_p as a function of the axial position when the source was operated without the filter. The profile shows that V_p is decreasing monotonically towards the plasma grid. Hence, a tungsten ion in the plasma volume will drift forward to the extractor by free-fall motion except when it is near the edge of the plasma volume. As a result, one would expect the source walls including the portion near the extractor to be coated with tungsten. On the other hand, the presence of the filter did create a region with relatively flat V_p profile in the source chamber (Fig. 2). Inside this uniform V_p region, a tungsten ion can move randomly in all directions due to its own thermal energy.
The probability for a tungsten ion to drift into the extraction chamber now reduces to approximately 1/6 or 0.17. The probability also depends on the geometric transparency of the filter elements. Thus, one would expect to find significantly less tungsten on the walls of the extraction chamber and also in the extracted beam.

A more detailed study of the V_p distribution and a quantitative measurement of the tungsten deposits have been conducted in a smaller cylindrical multicusp source unit. When the same kind of filter was installed, the generator was divided into a source and an extraction chamber with lengths equal to 18 and 6 cm respectively. The spatial plasma potential distribution for a much lower arc power was measured by a movable axial emissive probe using the inflection point technique.[14] The small probe filament was heated with a 2.5 kHz square-wave voltage. Probe currents were obtained during the off-period of the heating voltage by means of a sampling oscilloscope. The probe trace was then differentiated and the voltage corresponding to the

resulting maximum was then taken as the local plasma potential V_p. Figures 6 and 7 are the V_p profiles obtained with and without the filter for an arc voltage of 80 V and an arc current of 10 A. The results are very similar to those obtained at much higher arc power in the 10 x 10 cm^2 source unit. Since the source chamber is longer, the region of uniform V_p has increased to about 20 cm.

To obtain a quantitative measurement of the tungsten deposits, several quartz plates were installed in-between the line cusps in both chambers. After the source has been operated for several hours with an average arc current of 20 A, the samples were then removed and were analyzed by the Scanning Auger Mass-spectroscopy method. Quartz samples mounted on the source chamber walls were found to have tungsten layers exceeding 600 Å, but those mounted on the extraction chamber walls were observed to have much less tungsten, definitely less than 200 Å. The tungsten contents in the extracted beam will be studied by a mass spectrometer in the near future and results will be reported.

The second effect of the filter on high-Z impurities comes from the sputtering rate of the plasma grid material by positive ions falling through the sheath. Without the filter, the plasma grid generally floats at about -40 V with respect to the plasma potential and so ions are striking the grid surface with this energy. With the presence of the filter, the grid floating potential changes to about -16 V. This higher floating potential combined with the reduction of primary ionizing electrons in the extraction chamber will reduce the amount of impurity ions formed from sputtered grid material.[15] Other advantages of a higher floating potential have already been discussed else where.[8]

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FIGURE CAPTIONS

Fig. 1: A schematic diagram of the 10 x 10 cm^2 multicusp ion source with a magnetic filter installed.

Fig. 2: A photograph which was taken after filter operation, shows the line of demarcation between the source and the extraction chamber. For the photograph, the filter rod near the wall has been removed.

Fig. 3: The axial plasma potential profile of the 10 x 10 cm^2 source in the presence of the filter.

Fig. 4: A plot of the calculated λ_L as a function of the plasma electron temperature.

Fig. 5: The axial plasma potential profile of the 10 x 10 cm^2 source with no filter.

Fig. 6: The axial plasma potential profile of the cylindrical source obtained with the presence of the filter.

Fig. 7: The axial plasma potential profile of the cylindrical source obtained without the filter.

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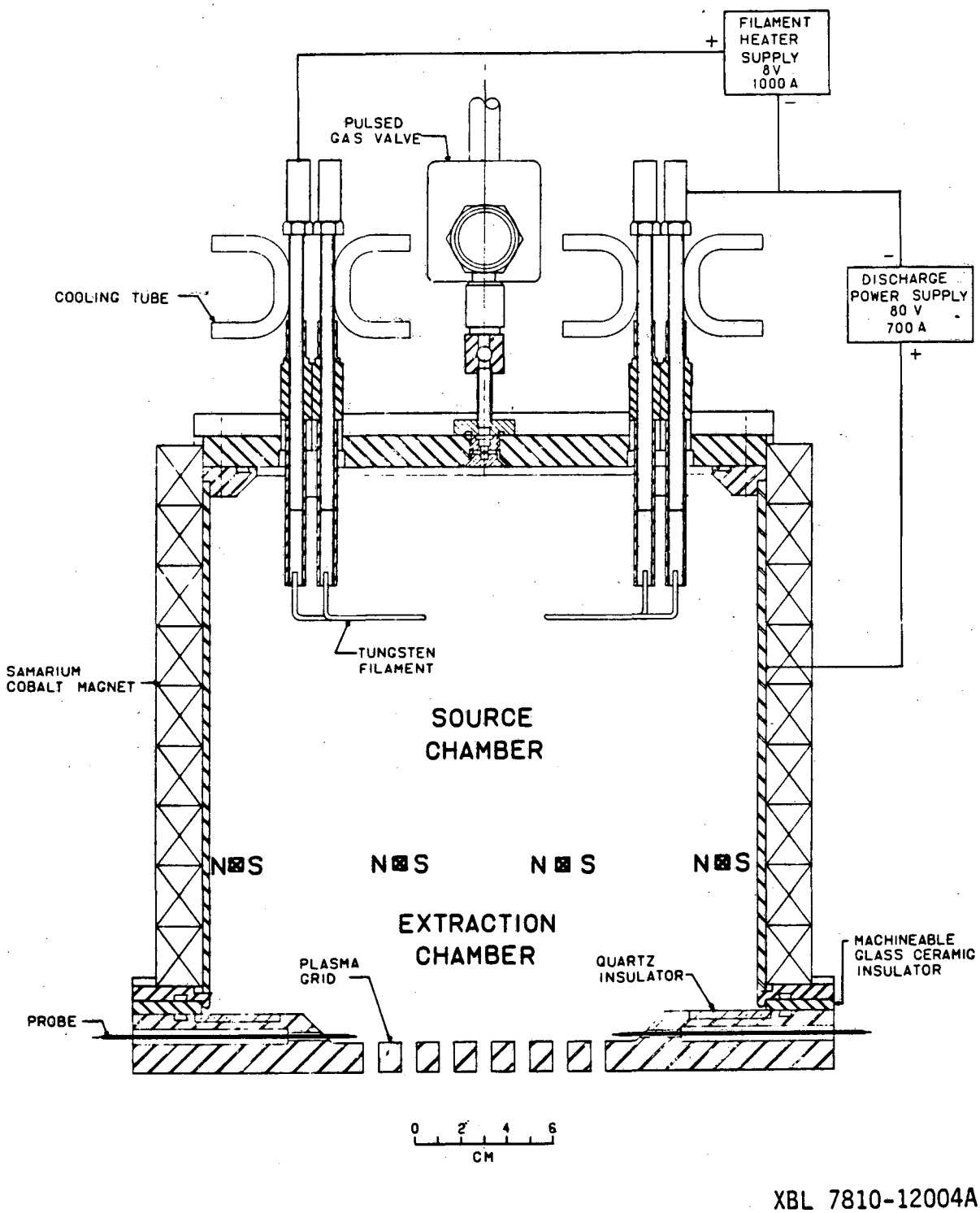
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SUPPLY
8V
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PULSED
GAS VALVE
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TUNGSTEN
FILAMENT
SAMARIUM
COBALT MAGNET
SOURCE
CHAMBER
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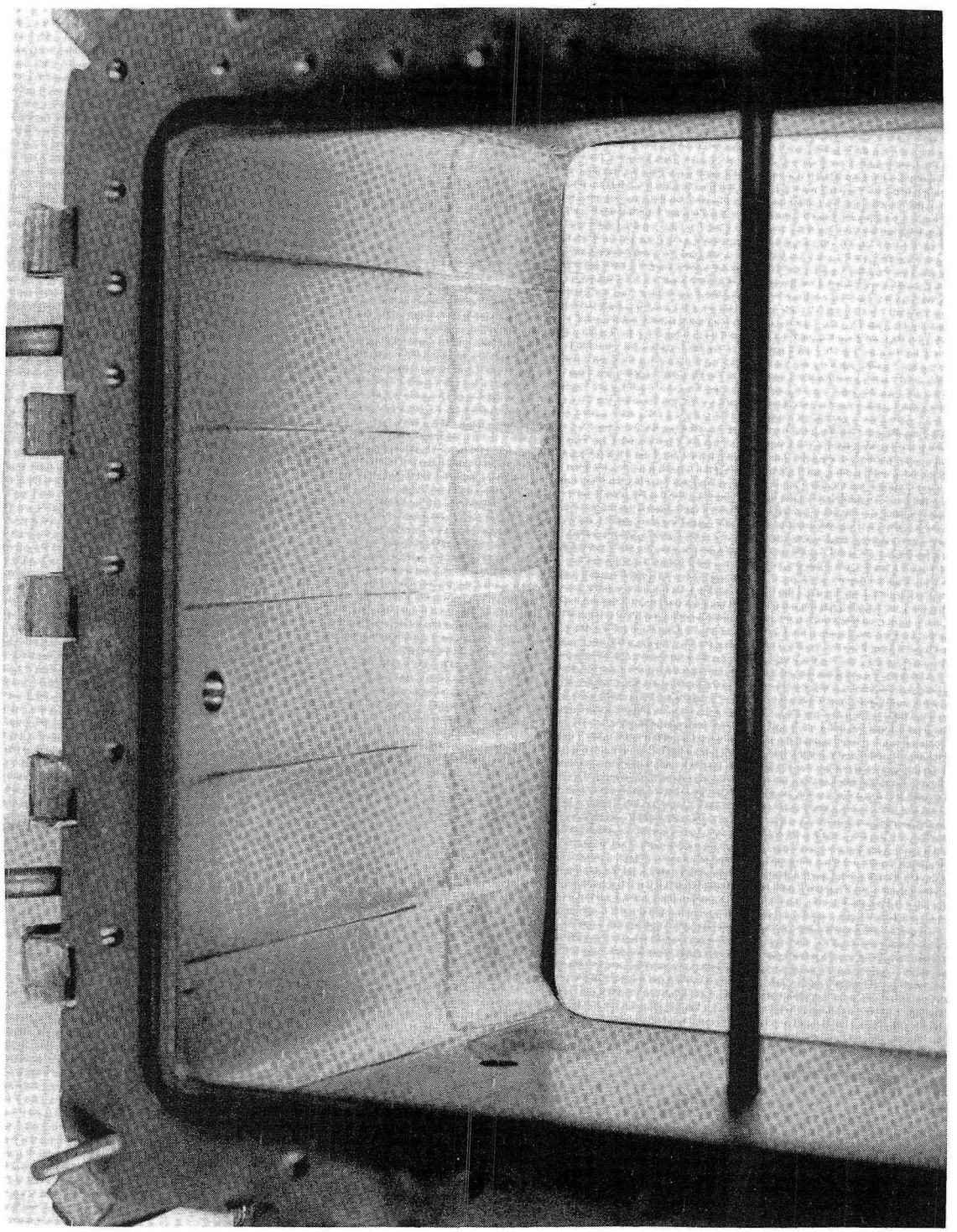
Fig. 1



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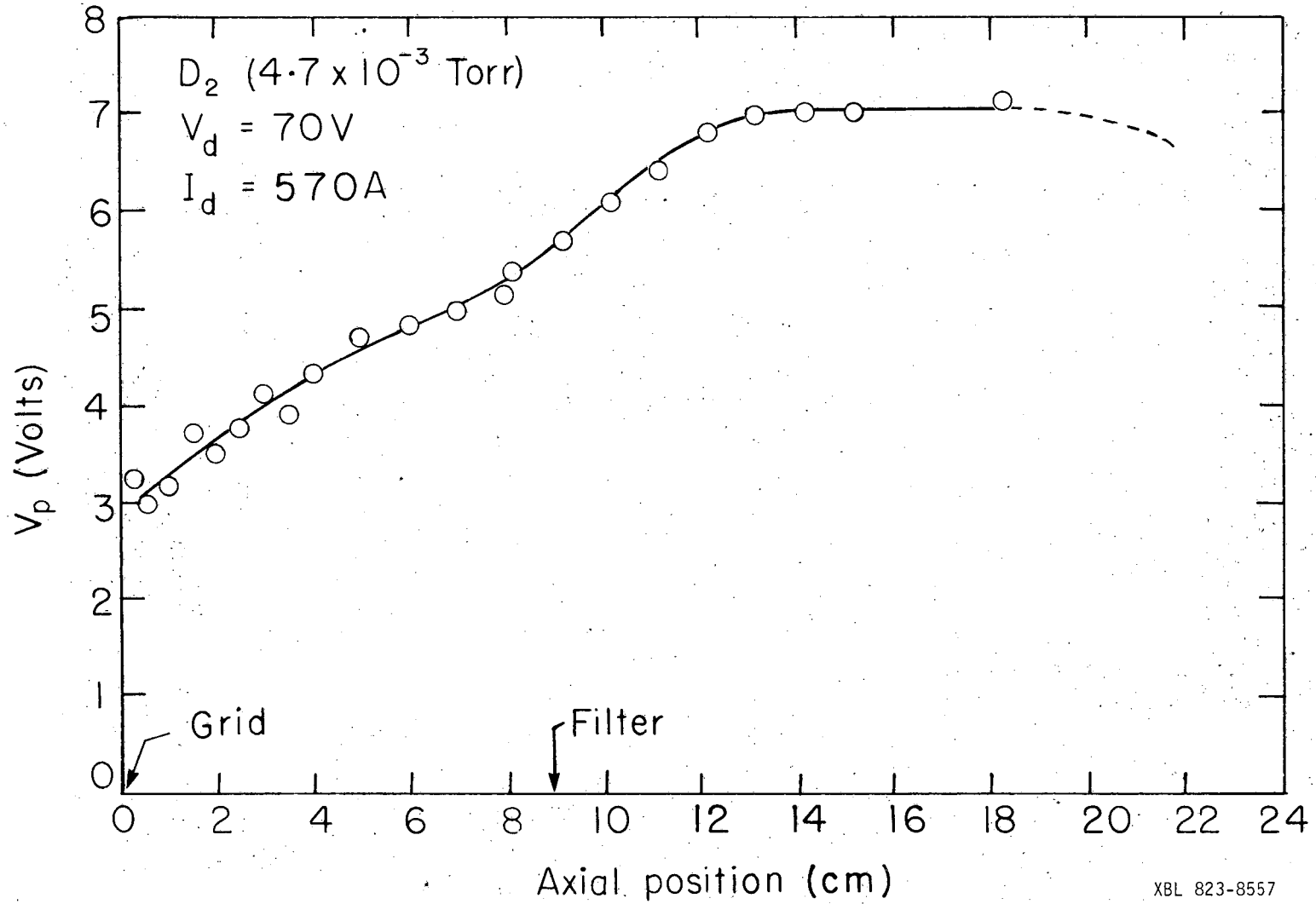
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I_d = 570A
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Filter
V_p (Volts)
Axial position (cm)
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1
2
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4
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Fig. 3

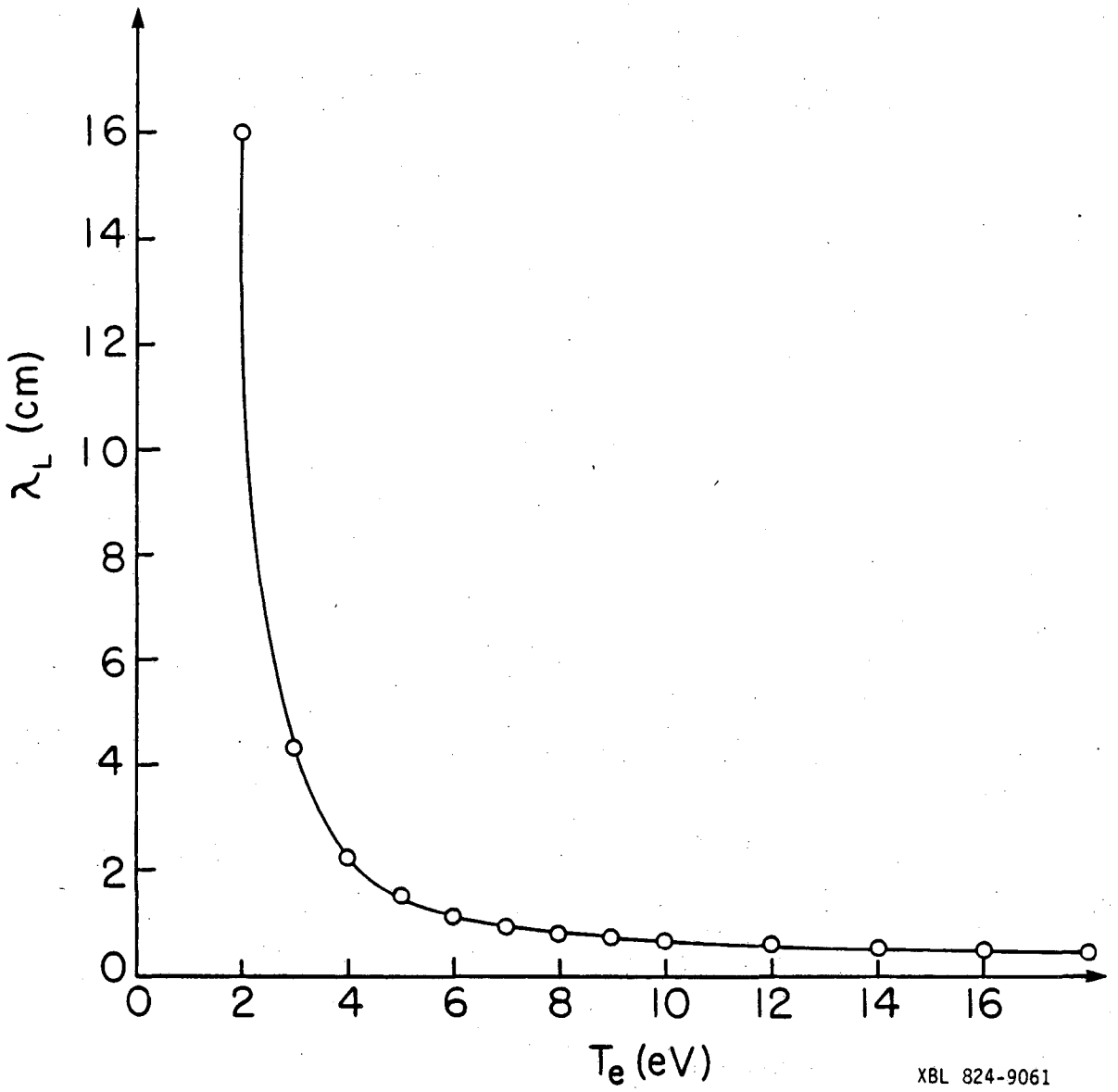
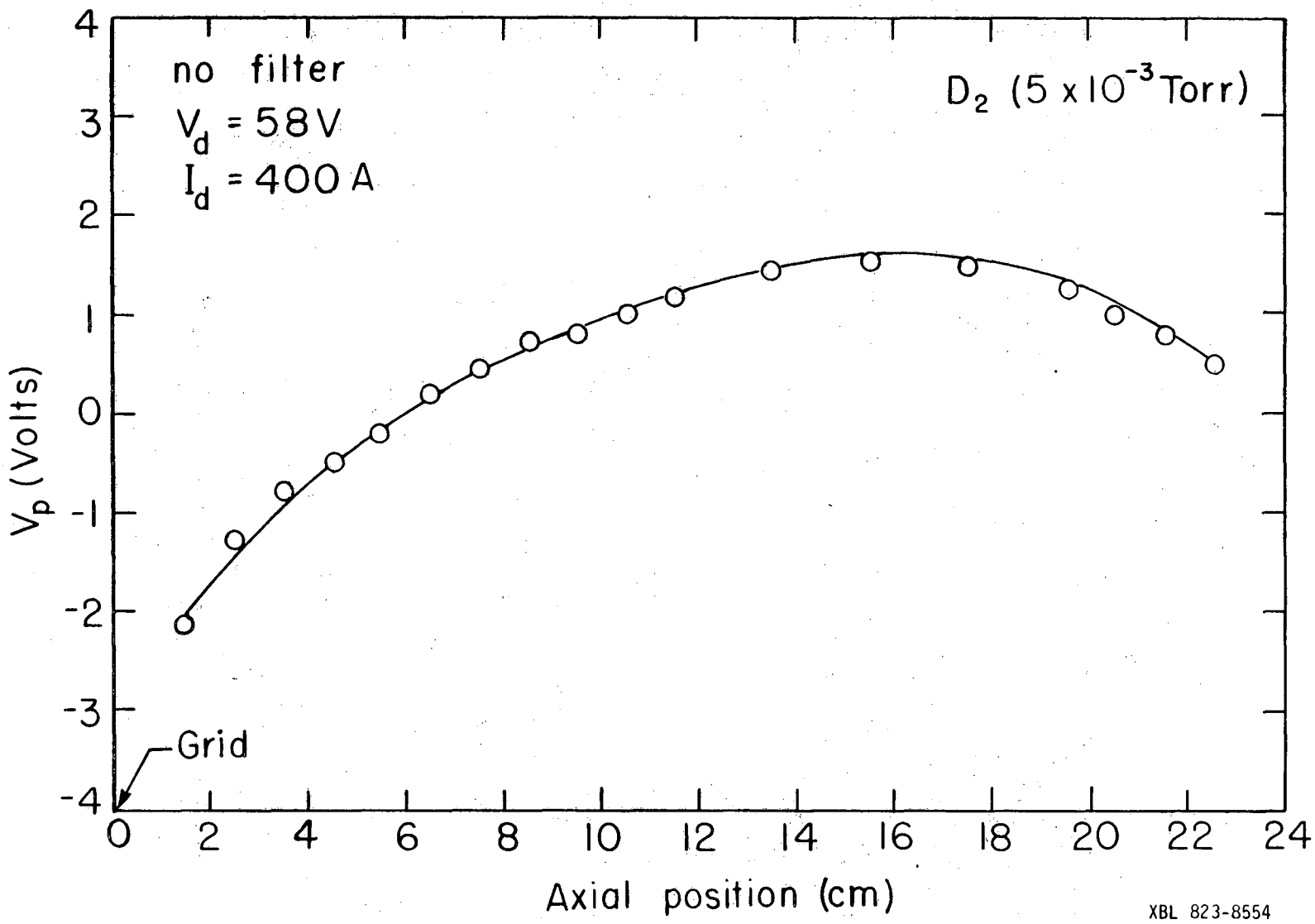


Fig. 4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I_d = 400 A
D_2 (5×10^{-3} Torr)
Grid
V_p (Volts)
Axial position (cm)
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Fig. 5

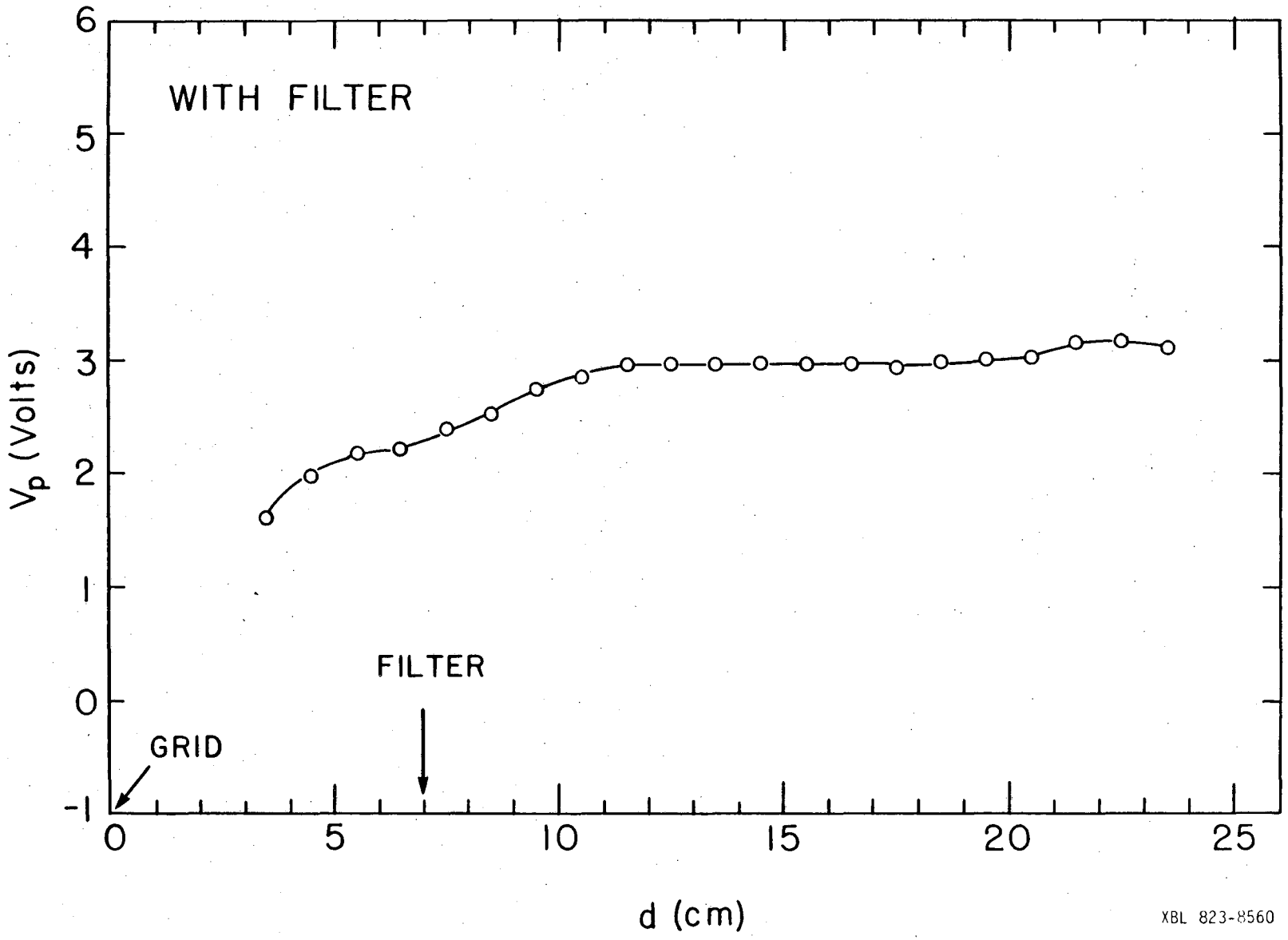
WITH FILTER
FILTER
GRID
V_p (Volts)
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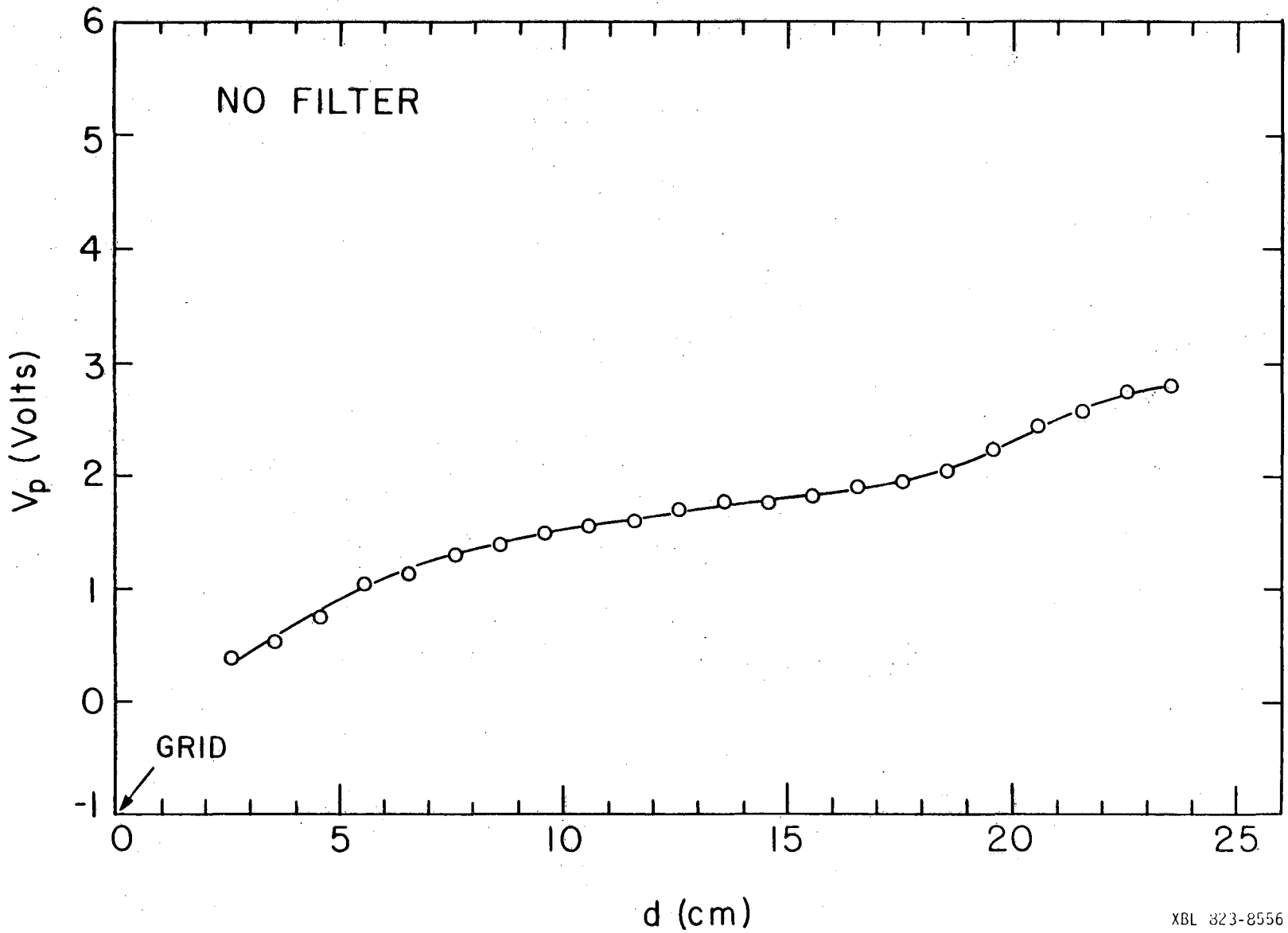
Fig. 6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XBL 823-8556

Fig. 7

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