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QUADRUPOLE ION ENTRANCE
M. SK STUDY

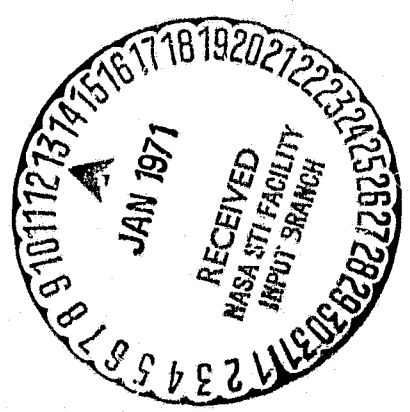
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Greenbelt, Maryland

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**QUADRUPOLE ION ENTRANCE
MASK STUDY**

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ABSTRACT

This report covers theoretical and computer analyses of the unstable ions in a quadrupole mass spectrometer. It covers the use of ion source masking to eliminate penetrating unstable ions. Test results of ion source nozzle masking with the associated decrease in peak tails are also included.

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SUMMARY

This report covers the use of ion masking of the ion source in a quadrupole mass filter to eliminate the penetrating unstable ions that normally appear as tails on either side of the given mass peaks. It covers theoretical as well as extensive computer analyses of the unstable ions and the affect of masking upon these ions.

Results of these analyses show that the peak tails may be reduced by either an angle mask (elimination of small angles) or a position mask (elimination of small amplitudes). By use of the computer data it was possible to determine some relations of all the variables, which define the amplitudes and intensities of the unstable ions. These variables include initial angle of entrance, initial amplitude and phase as well as other parameters such as distance from the stability region, resolution, and number of RF cycles the ion spends in the quadrupole. The relationship of mask size to tail intensity is also developed in this report.

This report also covers experimental results of quadrupole runs with and without masking (amplitude masking), which show considerable improvement of operation of the quadrupole filter when masking is utilized. These test results show good agreement with the analytical predictions.

INTRODUCTION

Understanding the operation of the quadrupole mass filter has been somewhat less than complete. In order to gain greater insight into the modes and parameters of operation, several analytical and empirical efforts have been conducted. The analytical methods include a theoretical approach to the operation of the quadrupole and extensive computer runs of the unstable ion trajectories. Analytically, operation may be improved by implementation of such methods as masking the ion entrance aperture or gating of the ions. Improved operation is obtained by reducing the peak tails which are caused by acceptance of unstable ions by the quadrupole.

The major portion of this report will deal with understanding and manipulating the unstable ion contribution.

THEORETICAL ANALYSIS

The quadrupole mass filter derives its mass discriminating ability by use of the fields of the four rods. Under such fields only a given e/m ratio is stable while all other ions are theoretically unstable for an infinite quadrupole length.

The potential in the space between the hyperbolic rods is given by:

$$V = (V_{DC} + V_{AC} \cos \omega t) (x^2 - y^2)/r_o^2 \quad (1)$$

with gradients in the x and y axes

$$E_y = (V_{DC} + V_{AC} \cos \omega t) (2y/r_o^2) \quad (2a)$$

$$E_x = (V_{DC} + V_{AC} \cos \omega t) (-2x/r_o^2) \quad (2b)$$

The above equations show that the x and y components of motion are independent of each other. The equations of motion are then readily derived to be:

$$M\ddot{x} = eEx \quad (3a)$$

$$M\ddot{y} = eEy \quad (3b)$$

It is possible to transform equations (2) and (3) into Mathieu functions by the dimensionless variables a , q , and τ where:

$$a = 8e V_{DC}/Mr_o^2 \omega^2 \quad (4a)$$

$$q = 4e V_{AC}/Mr_o^2 \omega^2 \quad (4b)$$

$$\tau = \frac{\omega t}{2} \quad (4c)$$

resulting:

$$\frac{d^2x}{d\tau^2} + (a + 2q \cos 2\tau) x = 0 \quad (5a)$$

$$\frac{d^2y}{d\tau^2} - (a + 2q \cos 2\tau) y = 0 \quad (5b)$$

Solutions to the above equations are found in literature and are characterized by stable and unstable regions.

The region of operation of the quadrupole mass filter is usually in the first stability region as shown in Figure 1. The curves a_0 and b_1 are reflected (flipped) upwards at the zero V_{DC} value. This results in an almost triangularly shaped stability region as shown in Figure 2. Figure 2 is divided into four sections representing stability of ions in a given axis. Section I represents an x-stable, y-unstable condition. Section II depicts an unstable region for both x and y axes. Section III is a y-stable x-unstable region, while Section IV is a stable region in both x and y axes. The scan line shown in this figure is the path that the ions take to traverse from zero ac and dc to the full value of these two potentials within the quadrupole analyzer, the variations of the fields as the masses are scanned. The value of the dc potential at q, equal to 0.706 (the perpendicular line through the apex of the stability diagram), determined the resolution of the system. At zero dc all particles are stable. At a dc equal to the apex, the theoretical resolution is infinite.

Unfortunately, however, this is true only for an infinitely long quadrupole. For finite rod lengths, the amplitudes of some of the unstable ions might be smaller than the separation of the rods. This will allow some unstable ions to be detected as stable and will appear on either side of the peak as tails, which can mask adjacent peaks.

Understanding the mechanics of ion trajectories, allows partial elimination of these tails.

The amplitude of an unstable ion is proportional to the number of ac cycles it spends within the quadrupole.

$$A = NA (\omega) \quad (6)$$

where ω is the ac frequency

and N is the number of cycles spent by the ion in the ac field.

The amplitude of an ion, however, is also determined by the distance of the scan line to the stability boundary. The closer the ion to the stability boundary, the smaller its absolute amplitude at any given number of cycles within the quadrupole.

Using Brubaker's¹ approach, the vertical distance between the scan line and the stability region (at any q) can be considered as a spring constant of an oscillator. If the scan line is above the stability region (Section I, II, or III), then this distance is positive; thus an unstable oscillator. If the scan line is within the stability region (Section IV), the vertical distance is negative; thus a stable oscillator. This analysis shows that as the scan line approaches the stability region the spring constant decreases thus giving the ion less amplitude when measured at a given number of cycles down the quadrupole. As shown experimentally, the number of cycles required by an unstable ion, one mass unit away, to reach an amplitude of r_0 (half a rod separation is proportional to the square root of the resolution).

For resolving power of 100:

$$N \approx 3.5 (M/\Delta M)^{1/2} \quad (7a)$$

$$r_0 \approx K (M/\Delta M)^{1/2} A(\omega) \quad (7b)$$

From the above relation, for a given ion energy and a given resolution the length of the quadrupole rods must be long enough to allow the number of cycles to build the amplitude to at least a value of r_0 .

Raether discovered that

$$L \gg r_0 \pi \left(2 \frac{V_{acc}}{V_{DC}} \right)^{1/2} q \quad (8)$$

where V_{acc} = ion accelerating potential. The above analysis applies only to ions which enter the quadrupole in axis with no initial angle. If an angle other than zero is considered, then the amplitude of an ion will increase

-
1. A Study of the Introduction of Ions Into the Region of Strong Fields Within a Quadrupole Mass Spectrometer, W.M. Brubaker, Final Report, Contract NASW-1298, 1967.

proportionally. This increase in entrance angle, or γ , will allow the decrease of the rod length or an increase in resolution for the same number of unstable ions accepted. Unfortunately however, the amplitude of the stable ions also increases which decreases the intensity. Another parameter which influences the amplitude, is the off-axis distance (η) at which the ions enter the quadrupole. Computer analysis has shown (see Section 3) that

$$A_2 = \frac{\gamma_2}{\gamma_1} A_1; \text{ for } \eta = 0 \quad (9a)$$

$$\text{and } A_2' = \frac{\eta_2}{\eta_1} A_1'; \text{ for } \gamma = 0 \quad (9b)$$

This can also be verified mathematically for finite η and γ simultaneously.

Let $X(\omega t, \phi)$ be the amplitude function for either X or Y. Also, let $\tau = \frac{\omega t + \phi}{2}$ giving $X = X(\tau)$. Since the Mathieu function is a second order differential equation there can be two independent solutions $X_1(\tau)$ and $X_2(\tau)$ with a linear combination

$$X = a_1 X_1 + a_2 X_2 \quad (10)$$

By use of initial conditions the coefficients can be obtained

$$a_1 = \frac{\begin{bmatrix} X_0 & X_2(0) \\ X_0' & X_2'(0) \end{bmatrix}}{\begin{bmatrix} X_1(0) & X_2(0) \\ X_1'(0) & X_2'(0) \end{bmatrix}}; \quad a_2 = \frac{\begin{bmatrix} X_1(0) & X_0 \\ X_1'(0) & X_0' \end{bmatrix}}{\begin{bmatrix} X_1(0) & X_2(0) \\ X_1'(0) & X_2'(0) \end{bmatrix}} \quad (11)$$

where

$$X_1 = \sum_{\ell} C_2^{\ell} \cos (\ell + \beta/2) 2\tau \quad (12a)$$

$$X_2 = \sum_{\ell} C_2^{\ell} \sin (\ell + \beta/2) 2\tau \quad (12b)$$

$$X_0 = Y_0 = \eta r_0 \quad (12c)$$

$$X'_0 = Y'_0 = V_0 \sin \gamma = \gamma \sqrt{\frac{2e V_{AC}}{M}} \quad (12d)$$

by substitution

$$a_1 = \frac{2\eta r_0 \sum_{\ell} (\ell + \beta/2) C_{2\ell} \cos [(\ell + \beta/2)\phi] - \gamma \sqrt{\frac{2e V_{AC}}{M}} \sum_{\ell} C_{2\ell} \sin [(\ell + \beta/2)\phi]}{\begin{bmatrix} X_1(o) & X_2(o) \\ X'_1(o) & X'_2(o) \end{bmatrix} \text{Wronskian (W)}} \quad (13a)$$

$$a_2 = \frac{-2\eta r_0 \sum_{\ell} C_{2\ell} \sin [(\ell + \beta/2)\phi] - \gamma \sqrt{\frac{2e V_{AC}}{M}} \sum_{\ell} C_{2\ell} \cos [(\ell + \beta/2)\phi]}{\begin{bmatrix} X_1(o) & X_2(o) \\ X'_1(o) & X'_2(o) \end{bmatrix}} \quad (13b)$$

Substituting in the original equation (10)

$$X = 2\eta A - \gamma \beta \quad (14)$$

$$A = \left\{ \left[\sum_{\ell} (\ell + \beta/2) C_{2\ell} \cos (\ell + \beta/2)\phi \right] \left[\sum_{\ell} C_{2\ell} \cos (\ell + \beta/2) (\omega t + \phi) \right] - \left[\sum_{\ell} C_{2\ell} \sin (\ell + \beta/2)\phi \right] \left[\sum_{\ell} C_{2\ell} \sin (\ell + \beta/2) (\omega t + \phi) \right] \right\} \frac{1}{W} \quad (15)$$

$$B = \frac{1}{W} \sqrt{\frac{2e V_{AC}}{M}} \left\{ \left[\sum_{\ell} C_{2\ell} \cos (\ell + \beta/2)\phi \right] \left[\sum_{\ell} C_{2\ell} \sin (\ell + \beta/2) (\omega t + \phi) \right] - \left[\sum_{\ell} C_{2\ell} \sin (\ell + \beta/2)\phi \right] \left[\sum_{\ell} C_{2\ell} \cos (\ell + \beta/2) (\omega t + \phi) \right] \right\} \quad (16)$$

Note that the functions A and B are functions of a , q (in the C_{21} coefficients) ωt and ϕ , but are not functions of η and γ . Given some initial conditions, or the values of A and B, the trajectory (amplitude) of an ion will be given by the simple relation of equation (14) for any η and γ . From the above, note by increasing η or γ of the entering ions, the amplitude of the unstable ions can be increased, provided of course that the possible decrease in intensity can be tolerated.

By understanding the behavior of ions under given η and γ , the tails of the peaks can be decreased thus providing more desirable operating conditions. In order to illustrate the above statement the maximum amplitude envelope of the ion trajectories are shown in Figure 3. From Figure 3A note that for a larger γ , the amplitude of an ion does not require as long to hit the rods as an ion with smaller γ . The same holds true for η variations. This can be translated into use of a smaller rod length required to eliminate the unstable ions.

With a given normal entrance aperture, however, there is a continuous distribution of ions with all possible η and γ up to some cutoff point as shown in Figures 4A and B. Every ion therefore, can have any combination of η and γ . Such a distribution of η and γ will not allow much data improvement, if any, by increasing the maximum values of η or γ for a given ion. In fact, the total intensity will decrease without much improvement of the peak tails.

Another variable which can have a detrimental affect on the data is the phase (ϕ) at which the ions enter the quadrupole region relative to the ac field.

The affect of phase makes the analysis very difficult, because no matter how much η and γ are increased, there will be some phases at which the amplitude is very small, causing the unstable ions to be detected as tails. If the phase affect is momentarily neglected, it becomes possible to affect the trajectories so as to allow only unstable ions with large amplitudes to enter the quadrupole region.

The trajectories of ions as a function of η and γ are shown in Figure 5A and B. These amplitudes are at a given Δq from the stability region (percent away from stability) as shown, ions of η or γ values greater than the maximum detectable will strike the rods and be eliminated. This also illustrates the relation that the longer the rod, the more unstable ions will be eliminated. The same holds true for the number of cycles spent in the quadrupole. As Δq increases the amplitude of the ions will increase, effectively spreading the intensity of unstable ions in such a manner as to favor the rod collision. The ratio of ions colliding with the rods to the unstable ions transmitted will be determined by the maximum detectable η and γ (η max-det; γ max-det) and by Figures 4A and B.

The net result, or percentage of transmission of unstable ions will be as shown in Figures 6A and B.

The relation of Δq (distance from stability boundary) to the ion amplitudes A_x and A_y are shown in Figures 7A and B. Combining the above trajectories it becomes possible to obtain the theoretical intensity of the tails I_t in terms of Δq , for a given number of cycles down the quadrupole (Figures 8A and B). The intensity is of course, proportional to γ and η and I_t is normalized for maximum intensity at Δq equal to zero. Figures 9A and B show the intensity of tails as a function of Δq .

Since ions can combine any η with any γ (within the maxima), developing a combined affect plot similar to those shown in Figure 9 is desirable. This combination plot will be done in the computer section where actual values are presented.

The above analysis suggests a method for reducing the tails by merely eliminating low values of η or γ . From Figures 5 and 6, note that the ions which contribute to the tails are ions with η or γ below the maximum detectable value. Theoretically, therefore, if these ions are eliminated, the tails would be eliminated. Again it must be emphasized that phase is neglected.

One such method of tail reduction is to eliminate small values of γ by making the ion source exit aperture in the shape of a ring. Such an aperture and the accompanying γ is shown in Figure 10. The trajectories of both stable and unstable ions are shown in Figure 11. The peak shape for unstable ions, maximum detectable γ hitting the rod at Δq equal to zero, would be as shown in Figure 12. A possible added advantage of ion source masking is the reduction of natural ions. Since all ions enter with some finite γ , the probability that such ions will strike the rods increases directly proportional to the sine of the angle. A ring aperture eliminates low angles in at least one axis, but not necessarily in both axes.

A second method of eliminating penetrating unstable ions is to mask the nozzle exit of the analyzer. Prior masking of the ion source completely eliminated small γ but maintained small values of η (including zero); masking the nozzle completely eliminates the low values of η , but maintains small γ (including zero).

When the neutral detection level is compared between the two masking locations, ion source masking is expected to have a considerable lower neutral component.

One type of nozzle masking configuration is shown in Figure 13. Since the phase of ion entrance to the ac field is so important to the amplitude of ion trajectories (thus operation) and such data is presented by the computer runs, consideration of this computer data is advisable prior to any further analysis.

COMPUTER ANALYSIS

Computations of the ion trajectories were run for ions which theoretically are unstable in their y axes. The variable parameters considered were 100 and 200 resolution; 5, 20, and 100 percent of peak width from the stability region; various η and γ values and various phase values. The computer program is normalized to the particular quadrupole so that when the amplitude of the ion oscillations reach unity the ions would impact into the rods, thus being stopped. The limit of motion in the z direction (parallel to the length of the rods) was taken at 16,000 degrees or 44.4 cycles.

Tabulation of points of ion impact, in degrees, or highest amplitude at 16,000 degrees are given in Table 1 for some of the computer runs. Using this table note that γ has a greater effect than η upon the trajectory of an ion. This difference for low values of η and γ however, is only on the order of 25 percent.

In order to more readily visualize the behavior of the ions for the given parameters, several charts were made and are presented in the accompanying figures. The plots show only the upper boundary of the trajectory envelopes. Figure 14 shows the trajectories for several initial phases with given values of η and γ for 5, 20, and 100 percent of Δq (where Δq = one peak width at a given resolution). The above figure is a plot of resolution 200, but as can be seen from Table 1 the points of impact for resolution 100 at the same values of η and γ are not drastically different from the values for resolution 200. The difference appears to be on the order of the square root of resolution, as stated in the previous section.

Figure 14 is the actual maximum trajectory envelope and is to be compared with Figures 5A and B. From this figure (14) it can be noted immediately that the maximum amplitude for $\gamma = 0$, $\eta > 0$ unstable ions is at 90 degrees and 270 degrees phase angle. For ions with initial $\gamma > 0$, $\eta = 0$ the maximum amplitude is at 180 degrees with minimum at zero degrees.

Before involvement of phase, it would be of interest to determine the intensity of tails with some actual expected parameters. Figure 15 shows the geometry of the actual quadrupole.

In order to determine the amplitude of any ion, the number of cycles N (or $\omega/2\pi$) the ion spends within the quadrupole must first be calculated.

To do this, the following must be known:

- a. Mass of ion M
- b. Velocity of ion V
- c. Length of quadrupole L
- d. Separation of rods r_0
- e. Frequency of AC ω_f

TABLE 1. POINTS OF ION IMPACT

INITIAL PHASE (°)	η	γ	PERCENT FROM STABILITY (%)	RESOLUTION	POSITION (°)	AMPLITUDE
0	0	0.0314	5	100	4,141	1.0782
0	0	0.0314	5	200	4,141	1.0707
90	0	0.0314	5	100	3,062	1.0884
90	0	0.0314	5	200	3,062	1.0854
180	0	0.0314	5	100	2,342	1.0881
180	0	0.0314	5	200	2,342	1.0878
270	0	0.0314	5	100	3,062	1.0478
270	0	0.0314	5	200	3,062	1.0453
0	0	0.0314	20	100	3,782	1.0513
0	0	0.0314	20	200	3,782	1.0202
90	0	0.0314	20	100	3,062	1.1357
90	0	0.0314	20	200	3,062	1.1162
180	0	0.0314	20	100	2,343	1.1130
180	0	0.0314	20	200	2,343	1.1039
270	0	0.0314	20	100	3,062	1.1900
270	0	0.0314	20	200	3,062	1.0728
0	0	0.0314	100	100	3,063	1.0419
0	0	0.0314	100	200	3,063	1.0389
90	0	0.0314	100	100	2,703	1.1613
90	0	0.0314	100	200	2,703	1.1601
180	0	0.0314	100	100	2,343	1.2498
180	0	0.0314	100	200	2,343	1.2504
270	0	0.0314	100	100	2,703	1.0947
270	0	0.0314	100	200	2,703	1.0938
0	0.0025	0	5	100	--	--
0	0.0025	0	5	200	15,660	0.0116
0	0.0025	0	20	100	15,661	0.0599
0	0.0025	0	20	200	15,661	0.0358

TABLE 1 (Concluded)

INITIAL PHASE (°)	η	γ	PERCENT FROM STABILITY (%)	RESOLUTION	POSITION (°)	AMPLITUDE
0	0.0025	0	100	100	13,502	1.0464
0	0.0025	0	100	200	13,502	1.0320
90	0.0025	0	5	100	--	--
90	0.0025	0	5	200	15,661	-0.5028
90	0.0025	0	20	100	14,581	-1.0404
90	0.0025	0	20	200	15,661	-0.9322
90	0.0025	0	100	100	8,822	-1.1694
90	0.0025	0	100	200	8,822	-1.1678
180	0.0025	0	5	100	--	--
180	0.0025	0	5	200	15,660	0.0058
180	0.0025	0	20	100	15,661	0.0292
180	0.0025	0	20	200	15,661	0.0175
180	0.0025	0	100	100	15,302	1.1022
180	0.0025	0	100	200	15,302	1.0820
270	0.0025	0	5	100	--	--
270	0.0025	0	5	200	15,661	0.5129
270	0.0025	0	20	100	14,221	1.0047
270	0.0025	0	20	200	15,661	0.9628
270	0.0025	0	100	100	8,462	1.0847
270	0.0025	0	100	200	8,462	1.0829

The velocity of the ion is given by

$$V = 1.39 \times 10^6 \sqrt{\frac{E_v}{M}} \text{ cm/sec.} \quad (17)$$

where E_v is the energy of the ion in ev. Let:

$$E_v = 10 \text{ ev}$$

$$L = 15.24 \text{ cm}$$

$$r_o = 1$$

$$M = 50$$

$$\omega_f = 1.5 \text{ MHz}$$

giving

$$V = 1.39 \times 10^6 \sqrt{\frac{10}{50}} \approx 0.63 \times 10^6 \text{ cm/sec}$$

since

$$t = \frac{L}{V} = \frac{15.24}{.63 \times 10^6} \approx 24 \times 10^{-6} \text{ sec} \quad (18)$$

therefore the number of cycles an ion spends in the quadrupole is

$$\begin{aligned} N &= t\omega_f \\ &= (24) (1.5) = 36 = 12,960^\circ \end{aligned} \quad (19)$$

Armed with the number of cycles for a typical ion, analyzing amplitudes and intensities for given η , γ and ϕ is now possible using the computer runs.

The design of the existing quadrupole is such that the maximum γ is about 0.02 (for an angle of $\alpha = 1^\circ 10'$). The maximum η is about 0.025 equivalent to 0.01 inch diameter. The ion distribution as a function of η or γ is shown in Figures 16A and B. Figure 17 shows the trajectories (maximum amplitude) for different values of η and ϕ at zero γ .

In order to determine the intensity of the tails, Figure 17 is combined with Figure 16A and cutoff at ω equal to 12.960 degrees. By knowing what value of η reaches the value of r_o at a known phase, superimposing r_o in the combined plot, Figure 18 is now possible.

Figure 18 is divided into three sections. Region I indicates the transmission of all ions with η value up to and including maximum detectable (η_{MD}) irrespective of initial phase. Region II will transmit ions of η maximum with initial phase within the bandwidth shown as ϕ_T . Ions with η values less than the maximum will have an increasing bandwidth as η approaches η_{MD} at which time the passable bandwidth is 100 percent. Region III is a region where ions are impacting the rods.

Having a constant intensity distribution with respect to η (Figure 16) and with respect to phase, determination of the percent transmission (tail amplitude) of unstable ions with γ equal to zero is now possible.

Figure 19 shows the percent contribution of each of the above regions. This figure shows that for a resolution of about 200, a Δq of 20 percent, an ion mass of 50, an ion energy of 10 ev and an ac frequency of 1.5 MHz, there is a 34 percent transmission of unstable ions. From this figure, predicting the decrease in tail amplitude is also possible if a nozzle mask was used to eliminate all ions up to a certain value of η . Two mask sizes are considered in this figure, with the appropriate total tail intensity shown below the intensity plot. Figure 20 is similar to Figure 18 except that it shows the amplitudes for ions at $\Delta q = 5$ percent. Since the ions are more stable at that point, a larger value of η is therefore detectable. After rearrangement of the data Figure 21 is obtained showing the total tail intensity. Similar treatment of the ions at $\Delta q = 100$ percent is presented in Figure 22. The change in tail intensity as a function of Δq (for $\gamma = 0$) is shown in Figure 23. The conclusion reached from the above data is that the size of the mask under the conditions stated above need not exceed an η value of 0.0075 or 0.003 inch. A higher η mask will of course decrease the tails further, but will also decrease the total intensity by blocking more of the nozzle aperture.

In order to correctly analyze the tail data, all ions must be allowed to assume any value of γ from zero to some maximum. As a first step, the ion amplitudes will now be considered with η value equal to zero. This is done in order to simplify the problem before combining the two affects.

Figure 24 shows the amplitudes as a function of γ in a similar form as Figure 17 for η . This figure is for $\Delta q = 20$ percent and resolution of 100. The amplitude for a resolving power of 200 is not too different from that at 100.

Data was run at different phases to obtain the change of amplitude as a function of phase. Some of this data is given in Figure 25. The total tail intensity at $\Delta q = 20$ percent is shown in Figure 26. The tails are considerably smaller in the γ parameter than in the η . If a γ mask was used (masking of the ion source exit) it appears that the tails could be reduced considerably without much reduction of the total ion intensity. Final comparison of tail reduction must be made with a combination of γ and η .

The combination of amplitude contributions of η and γ with respect to phase is a linear combination. To provide a clearer visualization of this fact, the data has been plotted on a polar coordinate plot (Figure 27). This plot shows the η and γ components and the resultant from combining these components.

Equal values of η and γ were chosen to show the relative contribution of the two parameters. The resultant can be approximated when γ is equal to or greater than η , by

$$A_y = a(1 - k' \cos(k\phi)) \quad (20)$$

if $\gamma \geq \eta$

where a, k' and k are functions of γ and η . When $\gamma = \eta$ then $k \approx 0.75$ and takes the value of unity when $\gamma \gg \eta$. The general equation for ion amplitude is of the form

$$a = C\{N\gamma (1 + |\sin \frac{\phi}{2}|) + k\eta (1 - N \sin(\phi))\} e^{f(\omega, \eta, \gamma, C)} \quad (21)$$

where C is a function of resolution, Δq , r_0 and N is the number of cycles an ion has spent in the quadrupole fields.

Figure 28 shows the amplitudes of the 0.003 inch mask (minimum η ions) and amplitudes of the maximum η . It also shows the maximum detectable γ . The amplitudes at the maximum γ are too large to be shown here. In order to derive the total intensity of the tails, the ion distributions in ϕ , γ and η are taken independent of each other. This means that a given bandwidth ($\Delta\phi$, $\Delta\gamma$, $\Delta\eta$) contains the same number of ions as any other bandwidth of the same variable.

thus:

$$I_\phi = \frac{\Delta\phi}{2\pi}; \quad I_\gamma = \frac{\Delta\gamma}{\gamma_{\max}}; \quad I_\eta = \frac{\Delta\eta}{\eta_{\max} - \eta_{\text{mask}}} \quad (22)$$

if I_0 is the number of ions entering the quadrupole then

$$I_{\text{tail}} = I_0 I_\phi I_\gamma I_\eta = I_0 \left(\frac{\Delta\phi}{2\pi} \right) \left(\frac{\Delta\gamma}{\gamma_{\max}} \right) \left(\frac{\Delta\eta}{\eta_{\max} - \eta_{\text{mask}}} \right) \quad (23)$$

a computer program was run with

$$\Delta\phi = \Delta\phi_{A \leq 1}; \quad \Delta\gamma = 0.002; \quad \Delta\eta = 0.002$$

thus:

$$I_{s \text{ tail}} = I_0 \left(\frac{\Delta\phi}{360} \right) \left(\frac{.002}{.02} \right) \left(\frac{.002}{.025 - .0075} \right) = 0.0108 I_0 \sum \frac{\Delta\phi_s}{360}$$

The increment $\Delta\phi$, is the phase bandwidth within which the ions will pass through the quadrupole without hitting the rods (see Figure 29). Ions passing through with all possible phases will, obviously, possess a $\Delta\phi$ which is equal to 360. This means one hundred percent transmission of those ions with respect to phase. Depending on initial conditions, ion trajectories, with respect to phase distribution will cross the rod displacement under one of these conditions:

- a. Will not cross r_0 = 100% transmission.
- b. Will cross r_0 once = initial large γ small η , or small γ small η .
- c. Will cross r_0 two times = initial large γ medium η .
- d. Will cross r_0 three times = initial small γ large η .
- e. Will cross r_0 four times = initial medium γ large η or small γ medium η .

The computer run was such that the points of crossover, either positive or negative, were calculated for each ion under the given initial conditions. Knowing the phase at the crossover points and the general phase - amplitude distribution for η and γ , determination of phase transmission is relatively simple. By merely summing all the phase transmissions of all the $\Delta\eta$ and $\Delta\gamma$ increments the final amplitude of the tails can be obtained with any of the mentioned initial conditions. A test case was run for a mass 50 at a frequency of 1.5 MHz, a Δq = 20 percent, six inch quadrupole rods, ion energy of 10 ev and a resolution of 200.

The equation used in this program is the amplitude equation given above with the initial conditions evaluated and the evaluation of amplitude equal to the absolute value of unity.

$$|1| = k_1 k_2 \gamma (1 + \sin \frac{\phi}{2}) + k_1 \eta (1 - k_3 \sin \phi) \quad (24)$$

giving

$$|1| = 216.5\gamma + 6.1\eta + 216.5 (\gamma \sin \frac{\phi}{2} - \eta \sin \phi) \quad (25)$$

or

$$.168 \geq |\eta + 36.1 (\gamma + \gamma \sin \frac{\phi}{2} - \eta \sin \phi)| \quad (26)$$

The computer evaluated the above equation for all possible η and γ from known increments and solved for the phase ϕ . A sample of the data output is given in Figure 30.

The smallest phase increment with which the computer was calculating was a one degree increment. Such a large increment would cause the computer to miss a large number of crossover points which at the one degree increment were farther away from unity than the $|1.000 \pm 0.050|$ amplitude tolerance. By knowing the general shape of phase distribution of the trajectories, estimating all the crossovers of almost all of the roughly one hundred incremental combinations of η and γ was possible. From this data it was estimated that for the above mass (m/e 50) and under the above conditions, the y-axis tail should be about 12 percent at 20 percent of Δq . When this is compared with empirical data, there is relatively good agreement.

Note that the distribution of percent ions (tail) with respect to Δq for a given η and zero γ (Figure 23) is similar in shape to the tail distribution of both γ and η and also with respect to the number of cycles the ion spends in the quadrupole.

TEST RESULTS

To evaluate the hyperbolic rod quadrupole in a configuration more closely resembling the upcoming flight systems the high pressure ion source was replaced with the dual filament ion source. It was felt that this source should provide results at least comparable to the high pressure source.

Testing with the dual filament ion source installed in the analyzer began 9 June 1969. The instrument was found to perform at a level much lower than that with the high pressure ion source. With the high pressure ion source, neglecting peak tail, a resolution of one part in 43 with a top-to-base of 59 percent was attained. However, with the dual filament ion source a resolution of one part in 43 yielded only a 46 percent top-to-base ratio and the peak tail was much greater with the dual filament ion source. This comparison is shown in Figures 31 and 32.

In tests using the high pressure ion source and under certain defocused ion source conditions a better peak quality was obtained. This was probably due to lower ion entry angles. A similar approach toward improving the peak quality was then undertaken with the dual filament ion source, however, this technique yielded no improvement. Apparently, the angular output of ion source was either too great to be affected significantly by the focusing system or the ion optics were such that little additional angular constraint by electrode biasing could be imposed upon the ion beam.

The decision then was to reduce the ion energy and proportionally reduce the extraction potential. This test yielded a much improved peak shape and tail reduction at the cost of greatly reduced system sensitivity. That is, the top-to-base ratio went from 48 percent to 71 percent as a resolution of one part in 34, with a sensitivity loss of about 86 percent as shown in Figure 33.

The question then was whether the major improvement was due to the reduction in V_{ion} , ΔV_{ion} or a combination of both factors. This led to the next test where V_{ion} was reduced but the extraction potential was held constant at ten volts. Some peak improvement was obtained but the most improvement was obtained with the proportionally reduced extraction potential. This improvement is shown in Figure 34.

A plot of peak quality versus source sensitivity

$$Q = (1 - T/B) \frac{\Delta m}{m} \quad (27)$$

was made for the series of scans under both operating conditions and is shown in Figure 35. For consistency in measurement and for peak quality calculation the peak shape measurements were made five percent down from the top and five percent up from the base with the measurement confined to a XN idealized trapezoid.

Using this plot, a compromise setting could be obtained. However, this plot does not take into account peak top nonuniformity and peak tail. Therefore, additional data reduction would be required to obtain the most desirable compromise. Even with the compromise condition the dual filament ion source performance would still be below the operating performance provided by the high pressure ion source, therefore, additional testing was warranted.

To reduce the ion energy spread and angular dispersion a number of tests were devised whereby the source side electrodes, passive electron acceleration and anode voltages were dropped below the ion acceleration where a general peak shape and peak tail improvement was noted, but again with a large sensitivity loss. However, with these electrodes near the ion acceleration potential peak characteristics, improvement was obtained with only moderate sensitivity loss.

The major portion of the poorly formed peak top was on the X side of the peak, and as noted on several occasions quad bias was below the accelerator potential. Figure 36 is an example of this phenomenon. Corrective techniques were not immediately forthcoming, however, closer scrutiny of this phenomenon could possibly provide peak top corrective adjustments.

A new series of tests were conducted, including a set of quad bias cutoff curves. In these tests the analyzer was set to the m/e 28 peak top and bias was raised to cutoff the ion current. This was done with an X-Y plotter making automatic plots of the cutoff curve. Plots were made with various ion source conditions and the changes noted in these source voltages mainly affected only the quad bias potential at the cutoff knee with respect to the accelerator potential and not the shape or slope of the curve. Figure 37 is a typical plot of this test series where the ion extraction and basic energy are changed.

The next experiment was to change the focusing conditions of the electron beam in an attempt to minimize the thickness of the electron beam in the ionizing region. This would tend to reduce the ion energy spread and if accomplished would reduce the peak tails. This test produced no significant improvement in the analyzer operation.

An examination of the ion focusing curves shown in Figure 38 revealed that with Ion Focus Lens A at 266.7 volts the ion output is still increasing with Ion Focus Lens B at zero volts. The decision then was to examine the focusing characteristics with Ion Focus Lens B at a negative potential. Figure 39 is a plot of these characteristics. This source condition indicated an increase in source sensitivity of approximately 22 percent but had little affect upon the general peak quality.

Returning to the positive Ion Focus B source tuning condition, the next test was to tie two electron accelerators and anodes together and bias them from 320 volts down to 260 volts with the ion accelerator at 275 volts. In this case, little improvement of the peak shape was obtained with large sensitivity losses.

At this point the ion source investigation was temporarily halted and a five mil wire was installed on the nozzle. A single wire was installed and was aligned with the x-axis (positive rods) of the quadrupole.

Upon retest of the analyzer with the five mil wire mask installed and using a logarithmic electrometer the y peak tail reduction was actually apparent to the extent that the m/e 27-28 (y) valley was down significantly more than the m/e 28-29 (x) valley. Figures 40 and 41 are peak tail comparison scans with and without the mask. Resolution was still limited by the deterioration of the peak top at the higher resolving power. The quadrupole VDC's were then reversed to observe the affect of the mask upon the x-tail. A dramatic x-tail reduction was noted here and while increasing the y-tail back to the no-mask level as shown in Figures 42 and 43.

Testing with the five mil wire was limited because of the one axis affect and therefore, more productive testing was thought possible by changing to a 0.003 inch cross mask. This would then reduce both the x and y tails and also help to determine a threshold mask size. The five mil mask was replaced with this new configuration and data taken for comparison with the previous configuration (see Figure 44). Both x and y tails were reduced, however, the y tail was not fully reduced. It was found that by reversing the rod dc potentials that the y tail was reduced adequately (see Figure 45). This meant that the mask alignment was not within a minimum tolerance requirement. Unfortunately, the dc orientation where the y tail was reduced the most had typically been a condition where the peak top was poor. In the past all quadrupoles have had a preferred rod dc polarity orientation and this instrument was no exception, with the x-side peak top exhibiting similar degradation. This problem clearly had to be rectified if a good top-to-base ratio was to be obtained at the higher resolving powers.

The quadrupole entry and exit boundaries were areas which had not yet been explored. As an approach it was decided to raise the nozzle and einzel lens potentials toward the quadrupole bias potential to reduce the electric field gradient between them. First, the einzel lens potential was changed while making scans of m/e 28. The x-side peak top was somewhat improved at the more positive values, up to about 300 volts where ion cutoff begins. With the einzel lenses set at 295 volts the nozzle voltage was taken positive while making scans of m/e 28. At nozzle potentials above ground the peak shape begins an immediate trend toward flatness of the top and at 120 volts a very good peak shape is acquired. Figures 46 and 47 are scans versus both the nozzle and einzel lens voltages. At nozzle potentials above 120 volts more rapid sensitivity losses occur with little additional peak shape improvement. However, with the nozzle potential at 120 volts the y-side peak tail was considerably larger. Also, peak tails at these operating parameters can be minimized with masking since the tests were performed with the quadrupole x-and-y axis oriented for least tail reduction and considering that the mask has a misalignment.

With the ability to regain the x-side peak top an expanded m/e 28 peak scan was made and quad bias cutoff potential versus peak top position was superimposed upon the scan. The quad bias anomaly on the x-side peak top was no longer present, as shown in Figure 48, and all stable ions above the accelerator potential were able to pass through the quadrupole unimpeded. Following this test, quad bias cutoff curves were generated for the two nozzle potentials. Figure 49 is an x-y plot of these curves. Here there is 28 percent system sensitivity loss with the elevated nozzle potential, but the knee of the quad bias cutoff curve is shifted well above the ion acceleration potential and, also, ΔV required to cutoff the ion beam is less than with the nozzle potential at zero. Curiously, the fact that ΔV_{OB} is less at elevated nozzle potentials should suggest that ΔV_{ion} is less and that the peak tails should be less instead of greater. However, under these conditions the unstable particles have better initial quadrupole entrance conditions and become more stable; thus negating the affects of reduced energy spread. Note that the quad bias cutoff curve is not simply a measure of ion source ion energy spread. Ions entering the quadrupole fields at certain phases will in some cases gain or lose energy, thus creating a larger ion energy spread than the source delivers.

A more thorough understanding of the nozzle biasing affects is necessary. The question being whether the improvement was a function of the quadrupole entrance boundary condition or the ion energy. A test was devised where peak tail, system sensitivity and peak quality were analyzed for ion source nozzle potential variations and for similar variation in ion energy.

The slope of the peak tail, with arbitrarily defined units, was used as a measure of the extent of the tail. Since all runs were made at nearly the same resolution peak top-to-base ratios were considered a measure of the peak quality.

Plots of this data were then made taking one axis, peak top-to-base ratio, slope of the peak tail, and sensitivity versus V_{nozzle} in one case and V_{ion} in the other.

The two variations in source conditions yielded similar data; however, where V_{ion} was reduced the top-to-base ratio improvement at lower ion energies was greater than with the nozzle biasing technique. These plots are shown in Figures 50 and 51.

With the nozzle biasing technique, knowing the effect of neutral particle production becomes important. This required that the ion source be operated in a differentially pumped mode. This operating mode was easily accomplished utilizing existing tooling developed for the high pressure ion source.

Two sets of logarithmic scale mass scans were taken. The first, with the nozzle at zero potential, the second, with the nozzle biased 95 volts positive. System I^+ and I^0 outputs were then plotted for both cases. The result was that biasing the nozzle to 95 volts positive reduced the relative neutral level to about 50 percent of that experienced with the nozzle at zero potential, as shown in Figures 52 and 53.

Summing up the relative advantages and disadvantages of nozzle biasing, a positive bias of 100 volts improved the peak top-to-base ratio approximately ten percent, the neutral level is decreased by fifty percent, and the quad bias level may be set at the ion accelerator potential while maintaining peak top flatness. On the other hand, the peak tail is worse and a sensitivity loss of about twelve percent is incurred. These disadvantages could possibly be overcome with a properly aligned mask, removing the objectionable peak tail and a sensitivity increase of approximately twenty percent could be obtained by operating the Ion Focus Lens B at a negative potential where some increase in neutral current will be incurred (in a straight multiplier).

The data shown previously was taken with units of "nonflight" configuration. The flight configuration unit has a different nozzle configuration plus a deflector multiplier.

The deflector multiplier is designed to eliminate any neutral molecules from the overall signal by deflecting the ions to be counted. Neutral molecules will of course, not be deflected, thus being absorbed by the first dynode and will be eliminated from the overall signal.

A deflector multiplier will provide data with lower background noise. Also, the different geometry of the nozzle is such that it provides a more collimated ion beam which should in turn provide lower tails.

Tests run with the first "flight configuration" unit did in fact show much improved data. A typical mass scan is shown in Figure 54. Note from this figure that the data is the best ever obtained under the same conditions for this type of quadrupole. The data is so improved as to allow the separation of the peaks of carbon dioxide and propane (see Figure 55). The minimum resolution required for such a separation is one part in six hundred and fifty. Resolving powers of over seven hundred and fifty could be obtained with this unit while sacrificing sensitivity. To improve the sensitivity the nozzle was redesigned to allow a higher intensity of ions to enter the analyzer region.

CONCLUSIONS

In the previous sections it was shown theoretically that by masking off small amplitude ions, a large reduction of peak tails would occur. Such a reduction improves the quadrupole operation in terms of better shaped peaks and increased resolution. These predictions were verified by experiment as the actual data in the test results section shows. Although considerable improvement was realized by the use of amplitude masking, including resolutions of close to 1000, it is felt that by use of perhaps angle masking or some optimum combination further improvement can be made.

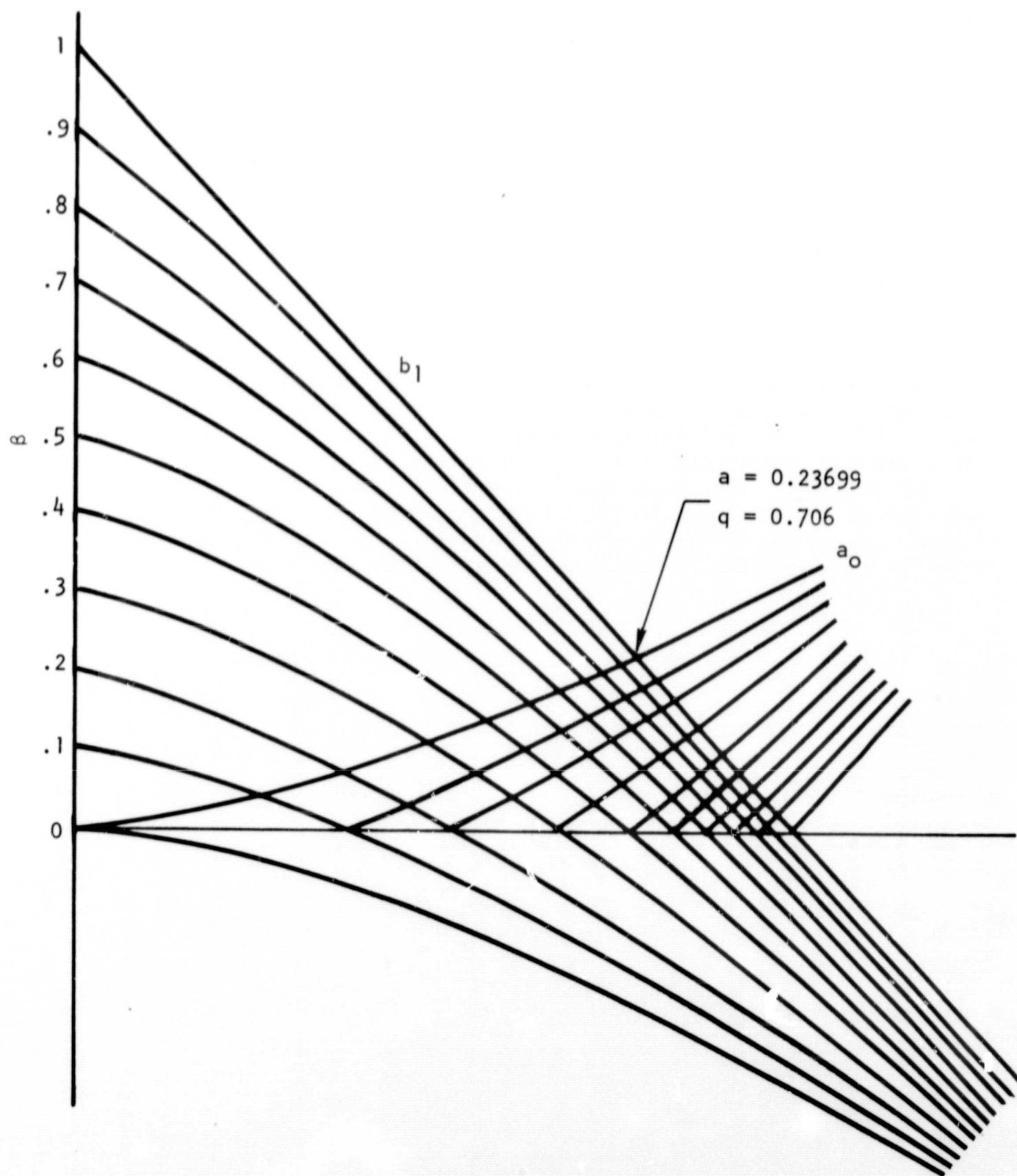


FIGURE 1. First Stability Region

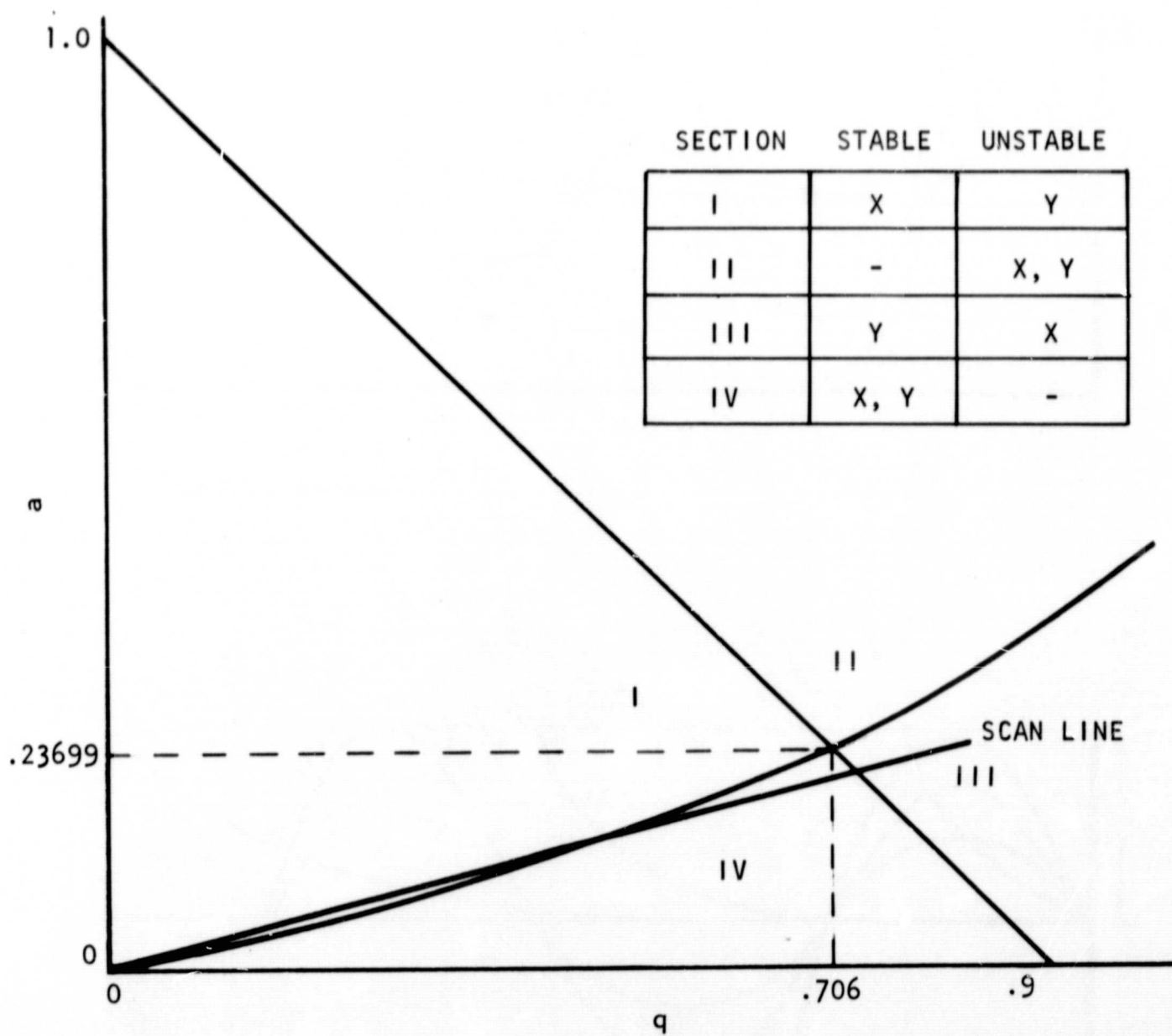


FIGURE 2. Stability of Ions vs Axes

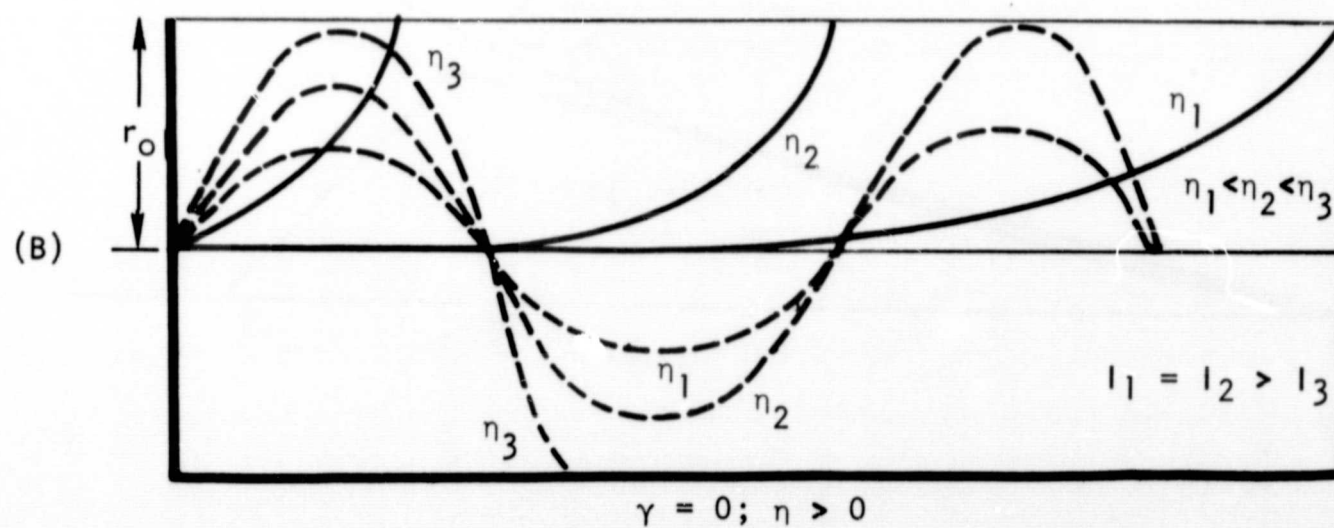
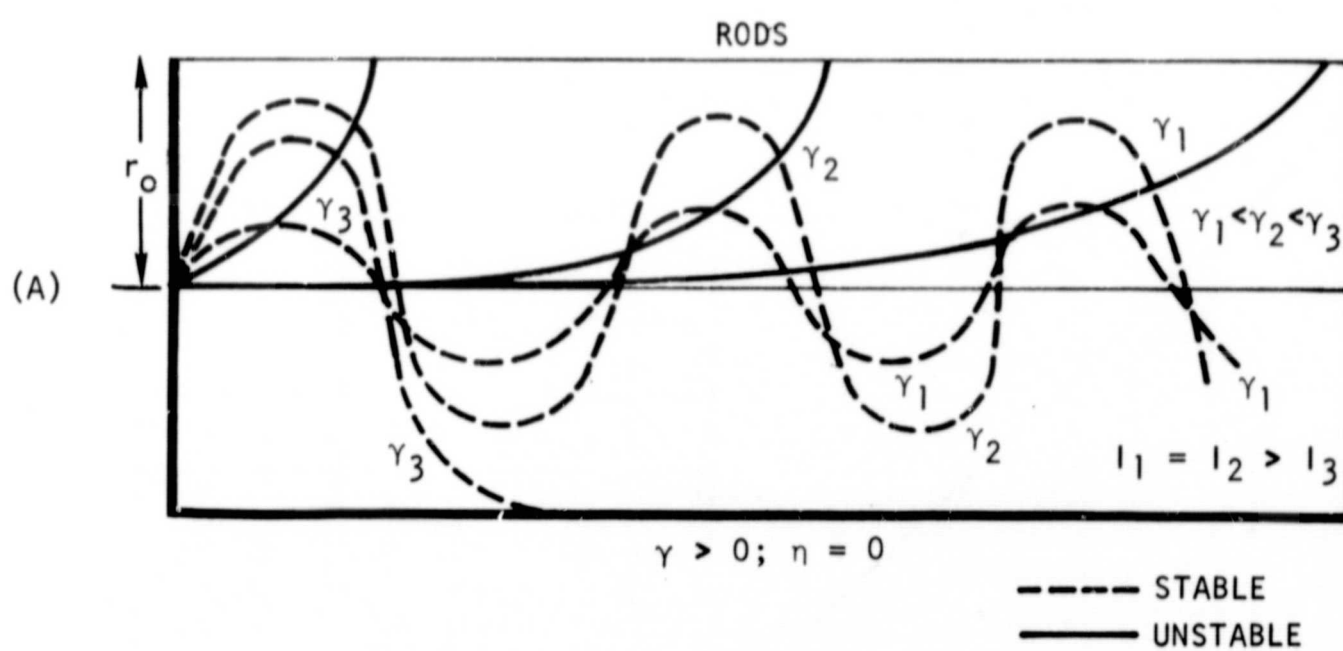


FIGURE 3. Stable and Unstable Trajectories

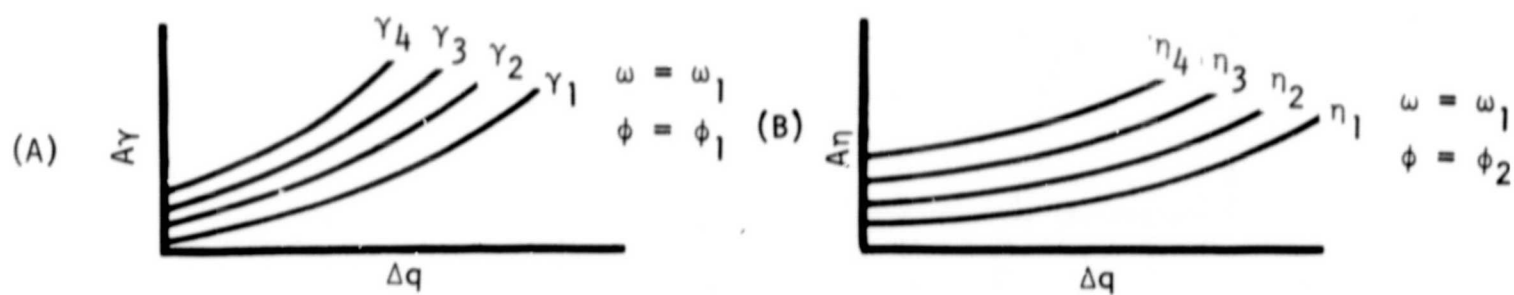


FIGURE 7. Ion Amplitude vs Distance from Stability Boundary

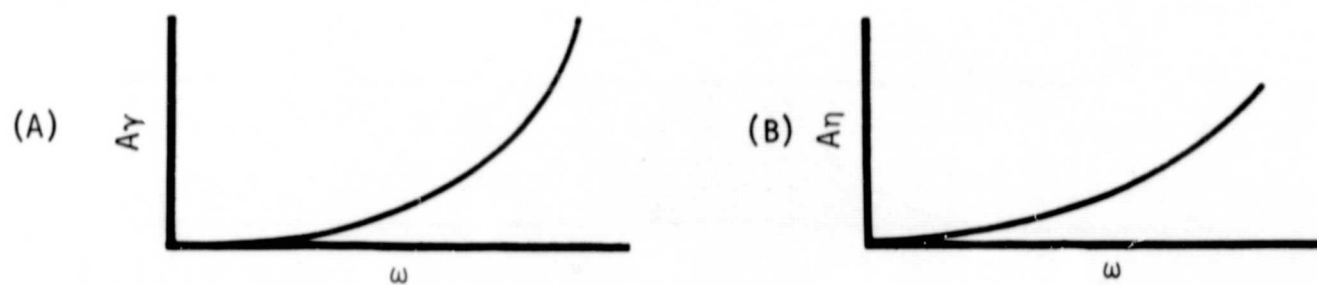


FIGURE 8. Ion Amplitude vs Number of Cycles Spent in Quadrupole

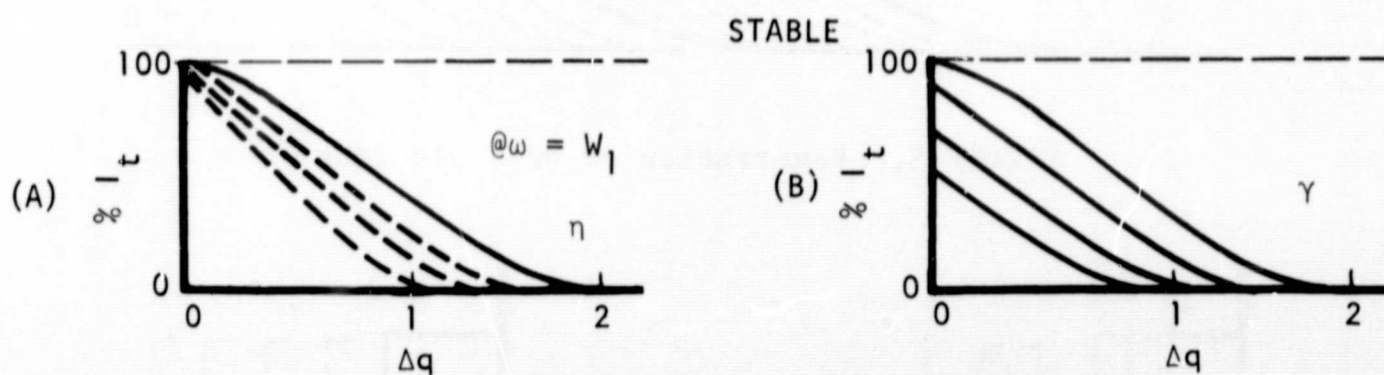


FIGURE 9. Intensity vs Distance from Stability Region

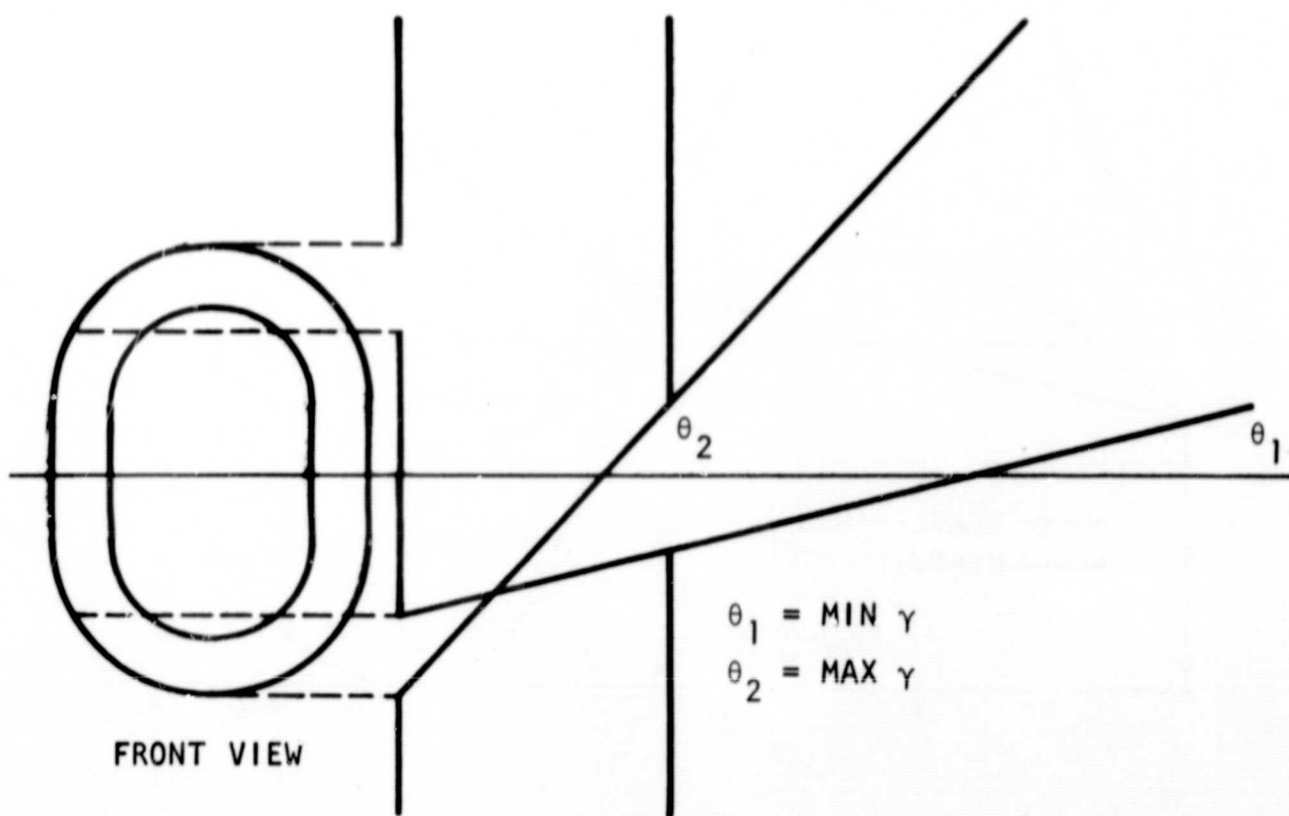


FIGURE 10. Ring-Shaped Ion Source Exit (γ -Mask)

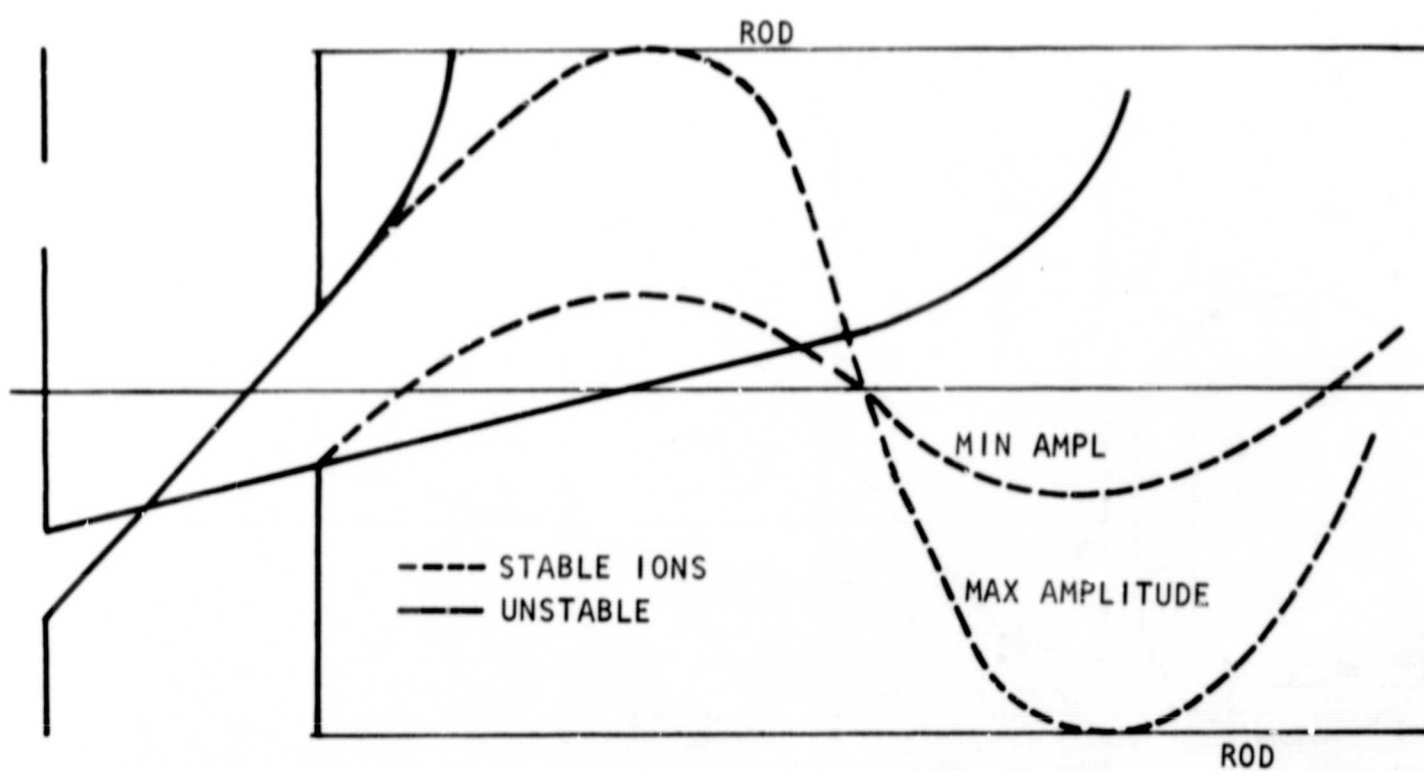


FIGURE 11. Ion Trajectories with γ -Mask

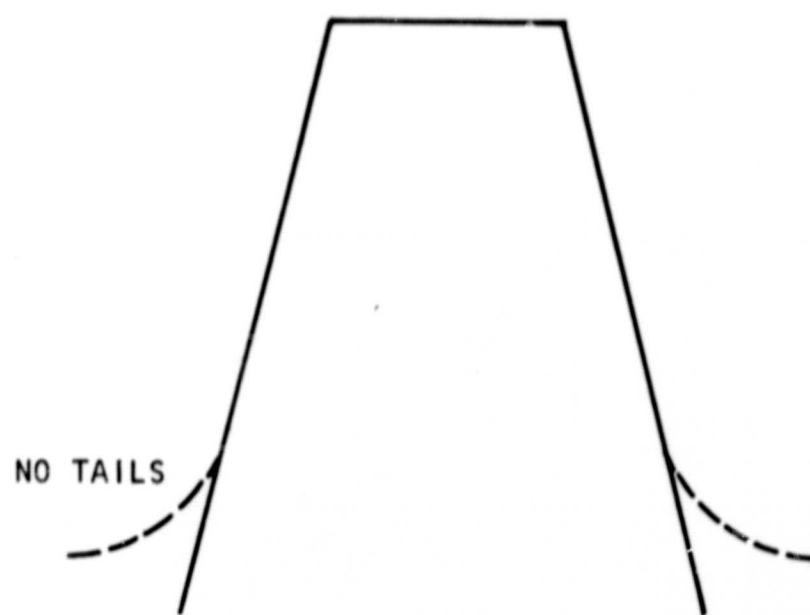


FIGURE 12. Peak Shape With γ -Mask

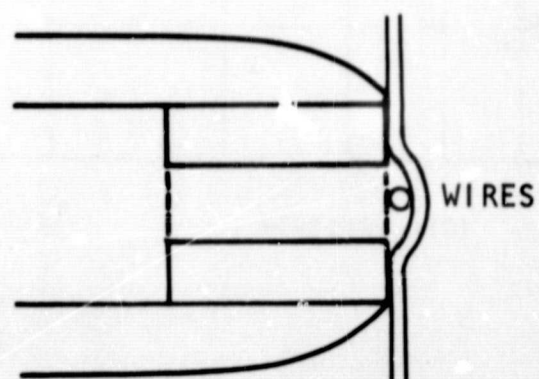
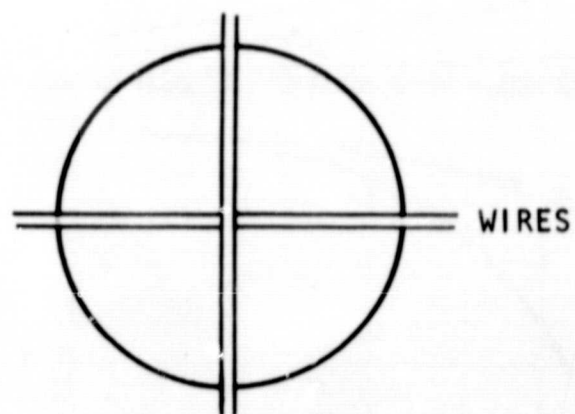


FIGURE 13. η -Mask on Nozzle Exit

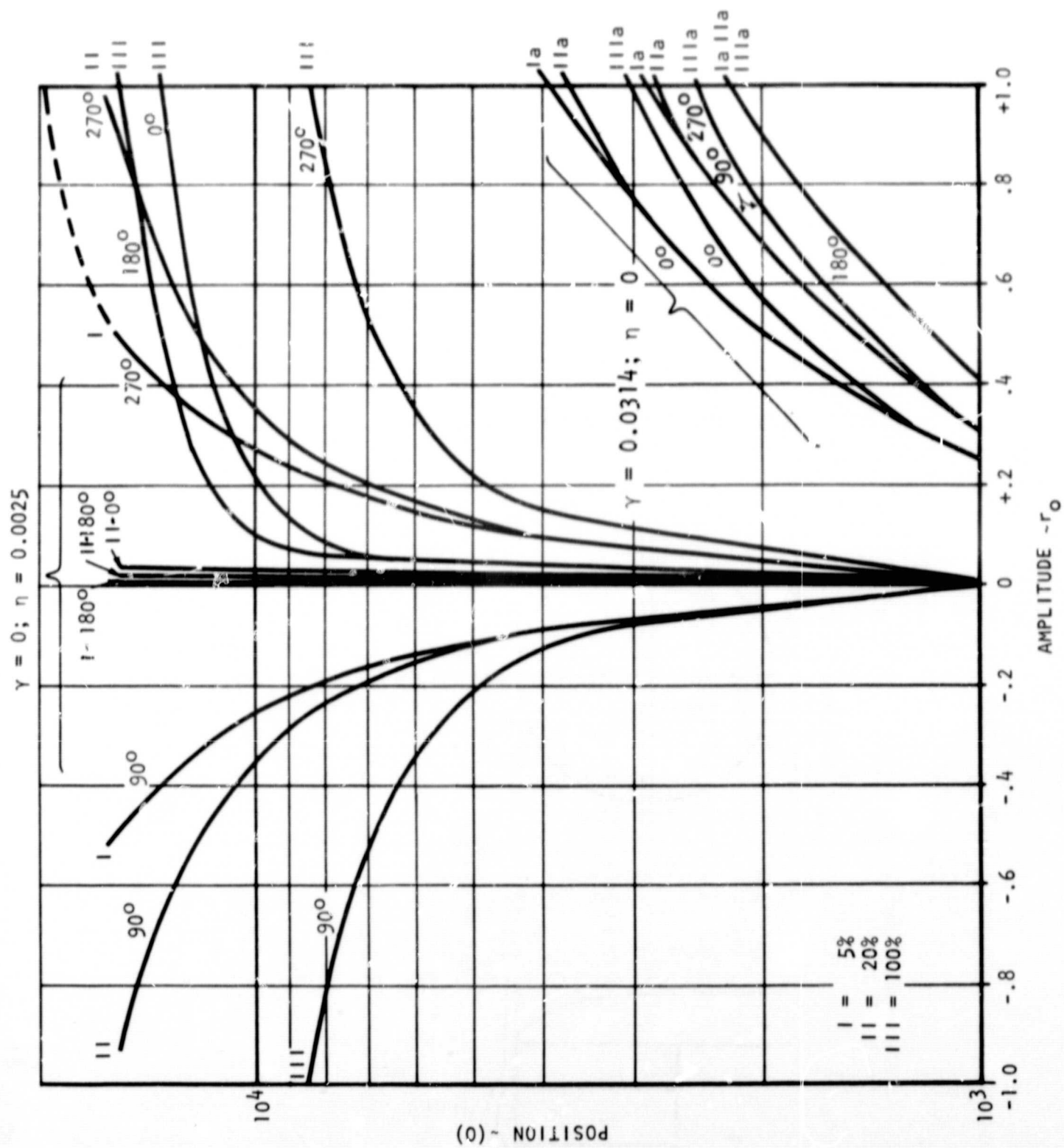


FIGURE 14. Ion Trajectories ($\gamma = 0$ and 0.0314 ; $\eta = 0$ and 0.0025)

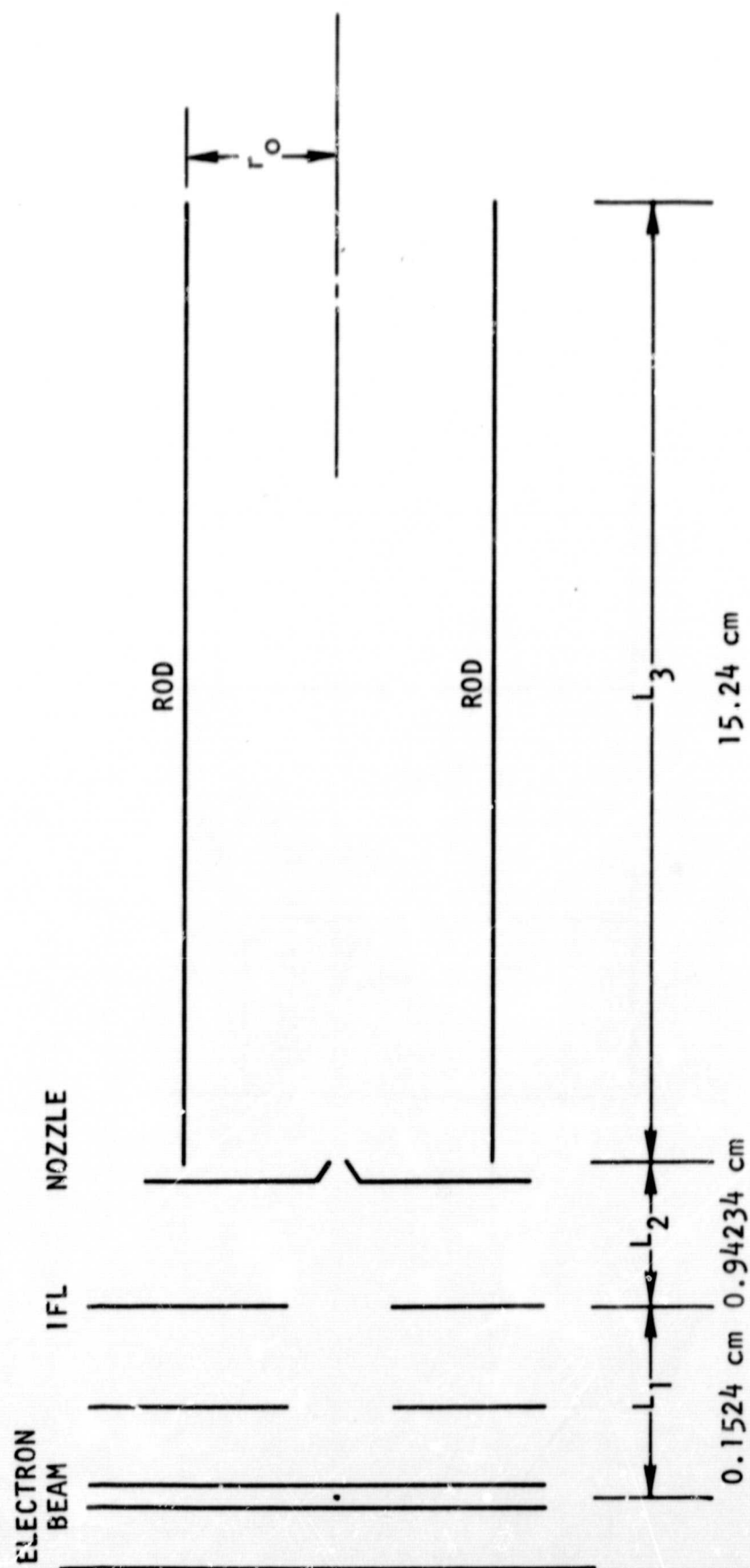


FIGURE 15. Geometry of Quadrupole

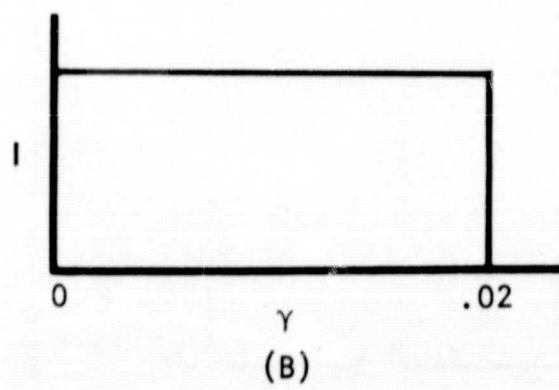
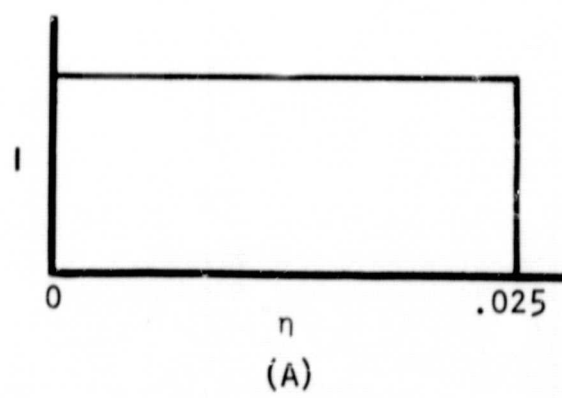


FIGURE 16. Intensity Distribution

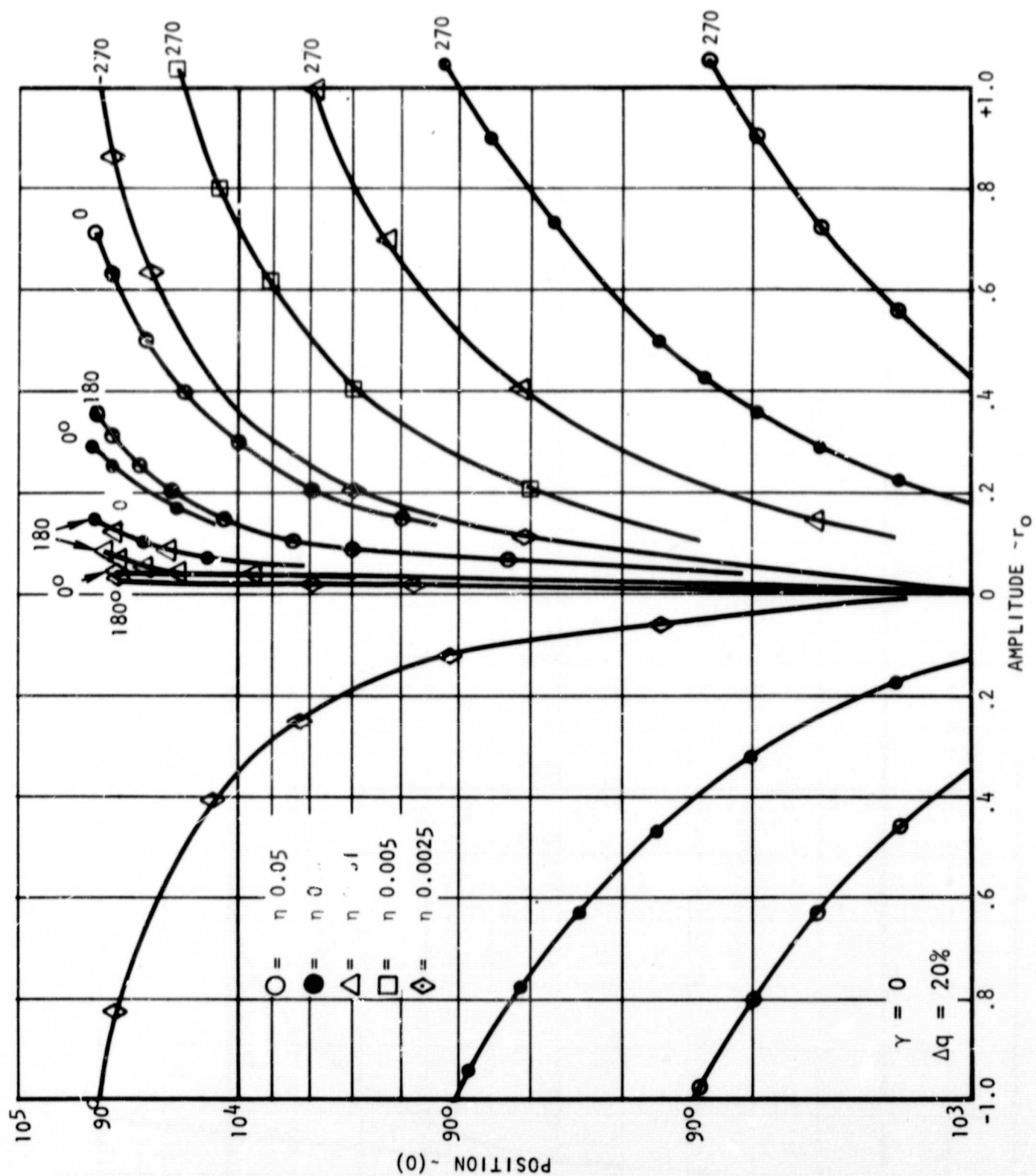
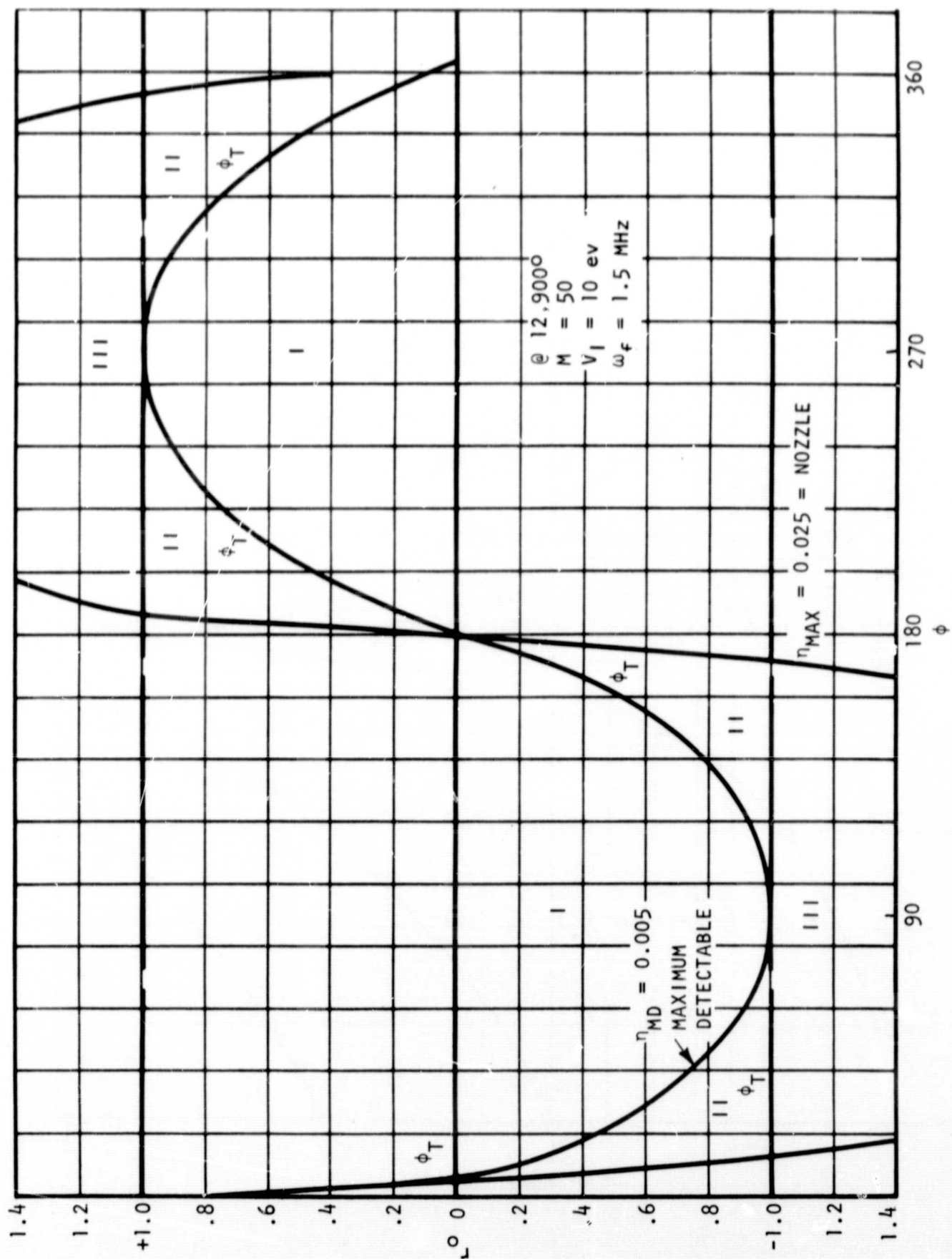
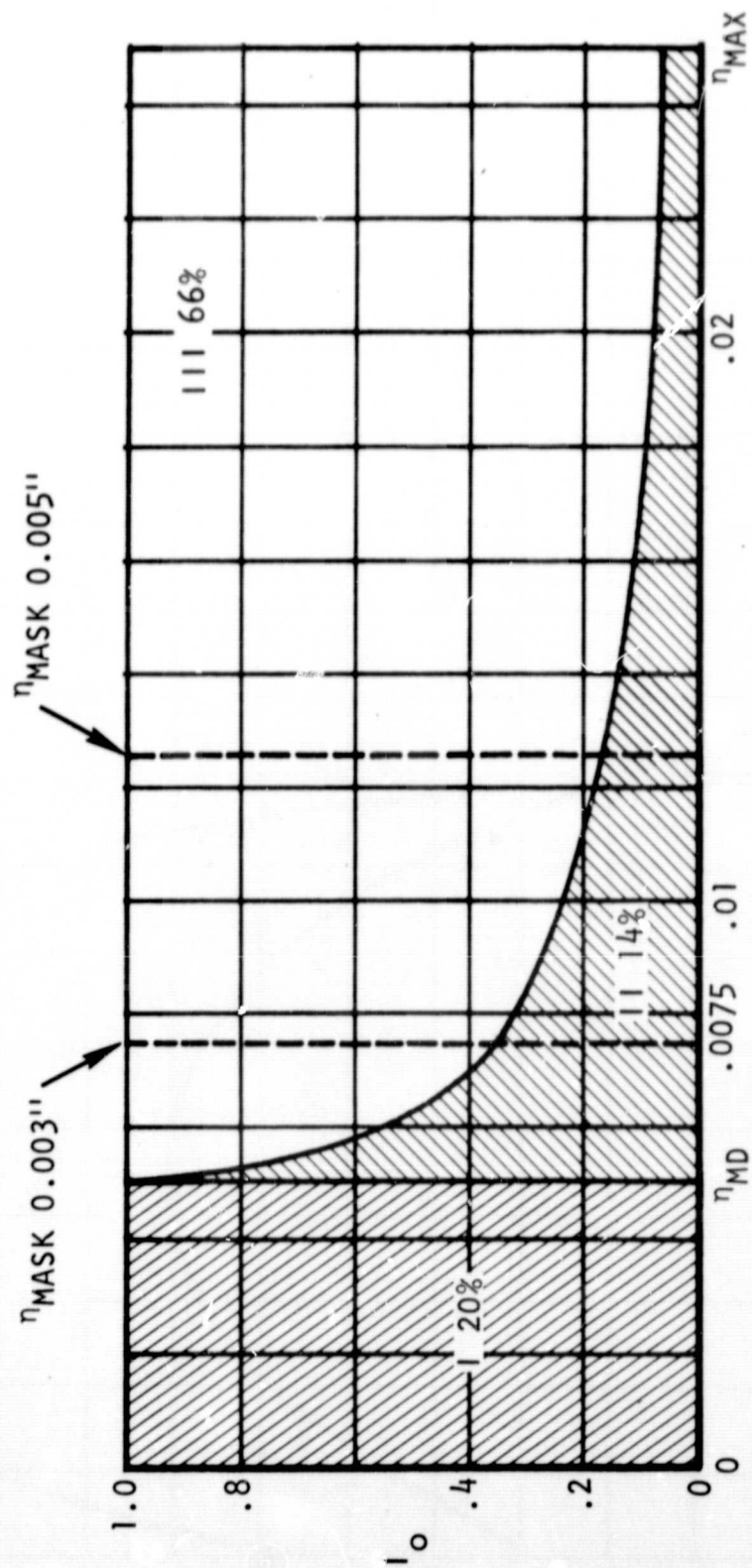


FIGURE 17. Ion Trajectories for Various η Values





TOTAL TAIL INTENSITY

- ~34% WITHOUT MASK
- ~ 9% WITH 0.003" MASK
- ~ 5% WITH 0.005" MASK

FIGURE 19. Intensity of Tail (Approximate) With and Without Masking $\Delta q = 20\%$

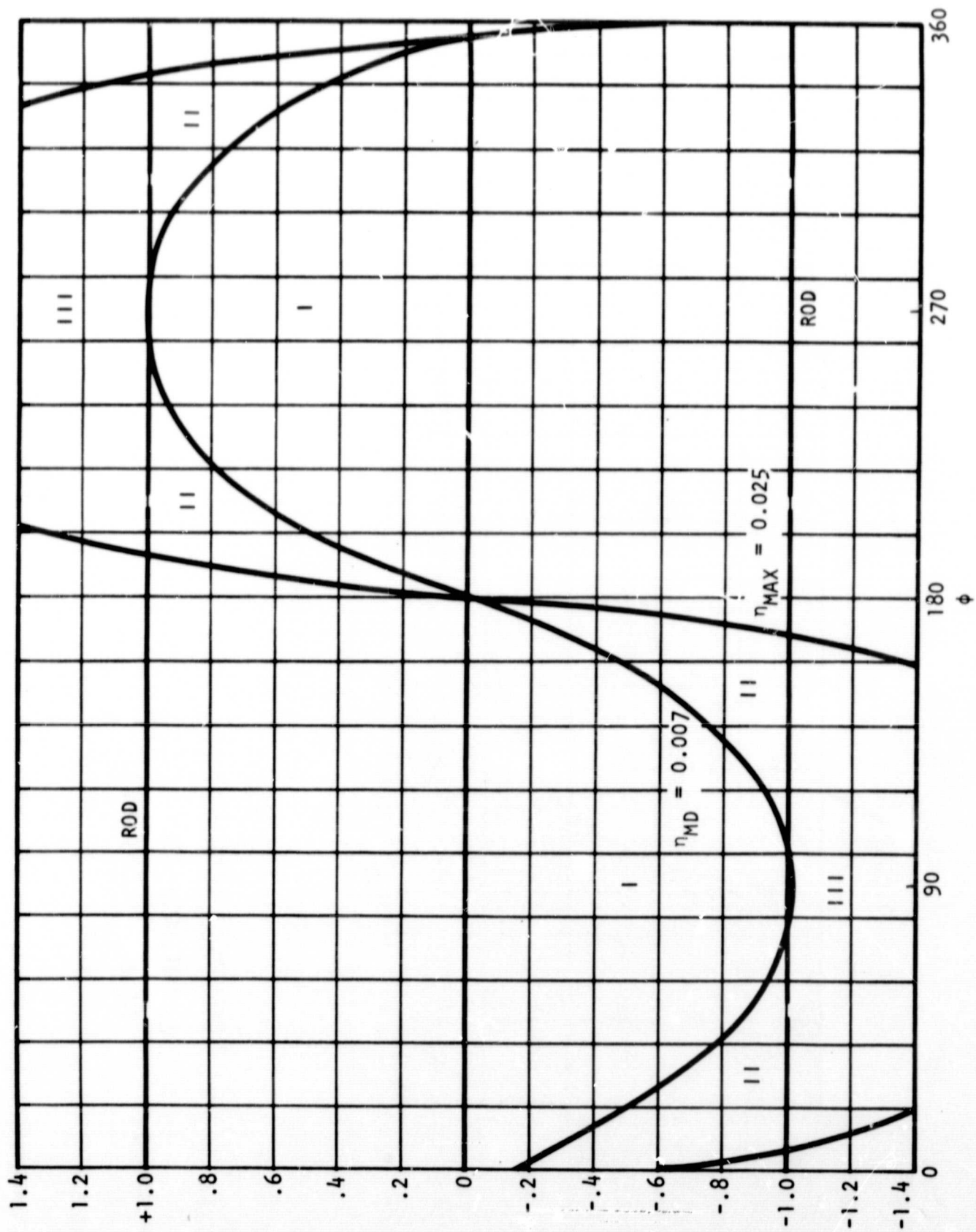


FIGURE 20. Unstable Ion Transmission, $\Delta q = 5\%$

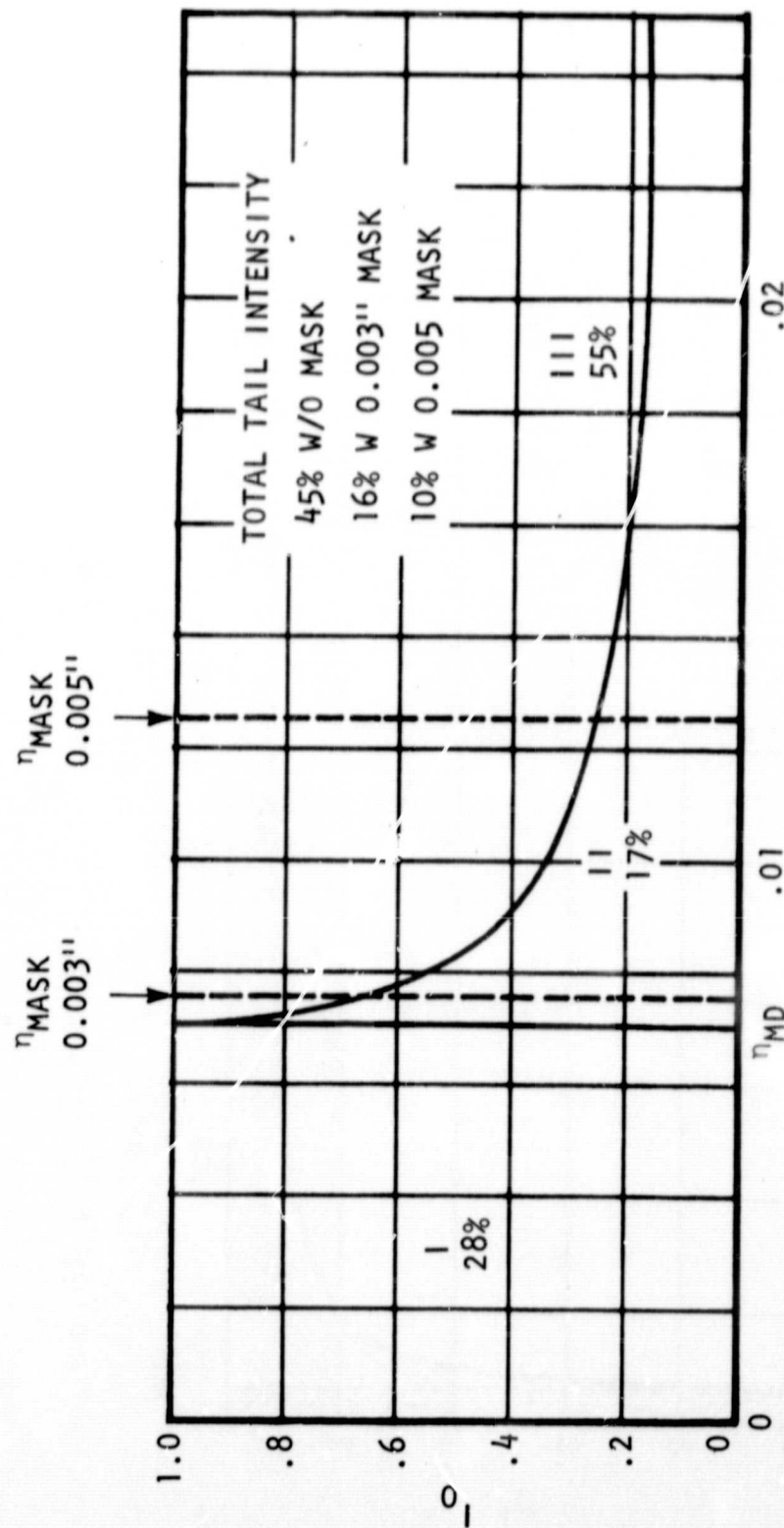


FIGURE 21. Intensity of Tail (Approximate) With and Without Masking, $\Delta q = 5\%$

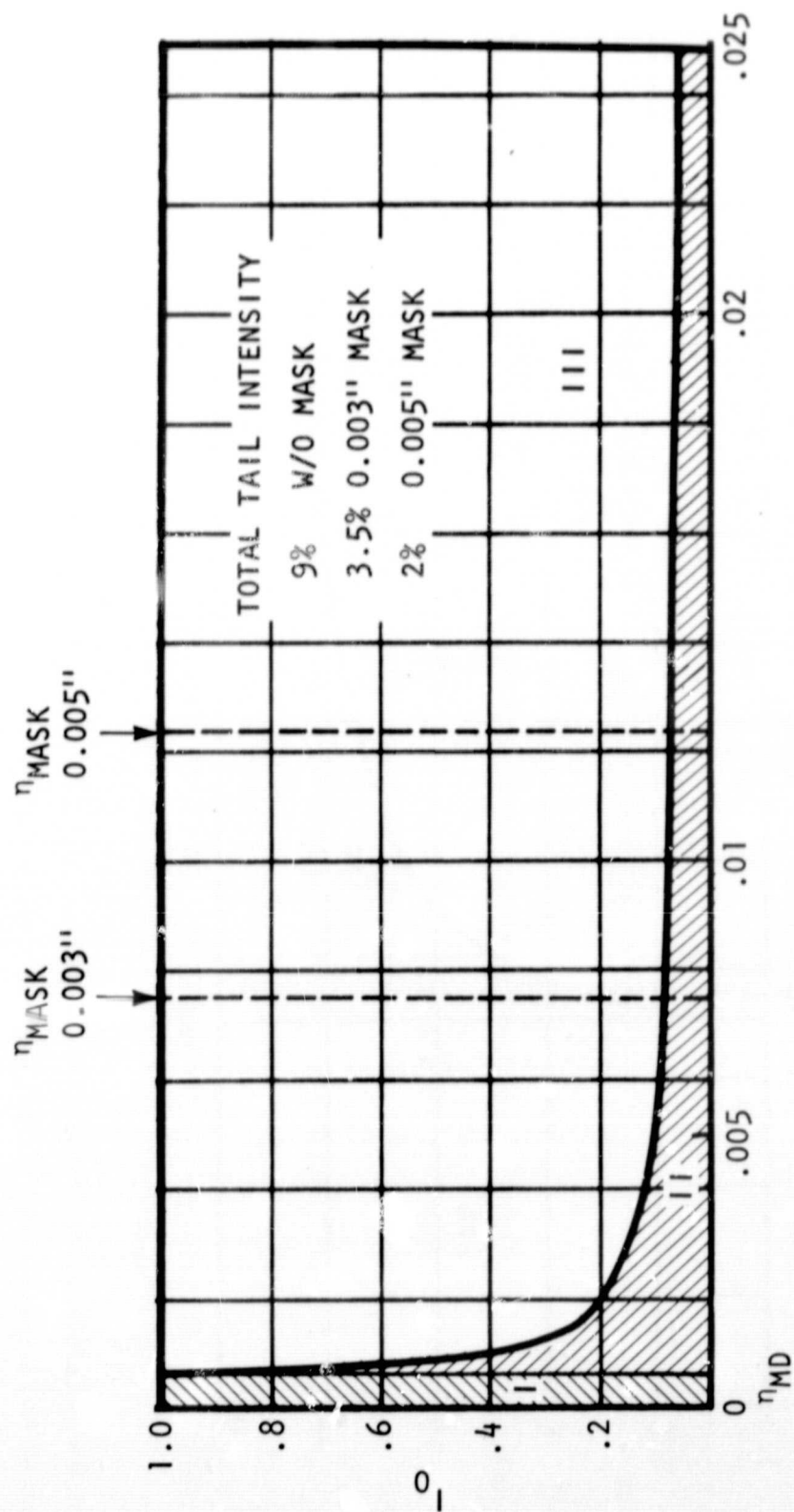


FIGURE 22. Tail Intensity at $\Delta q = 100\%$

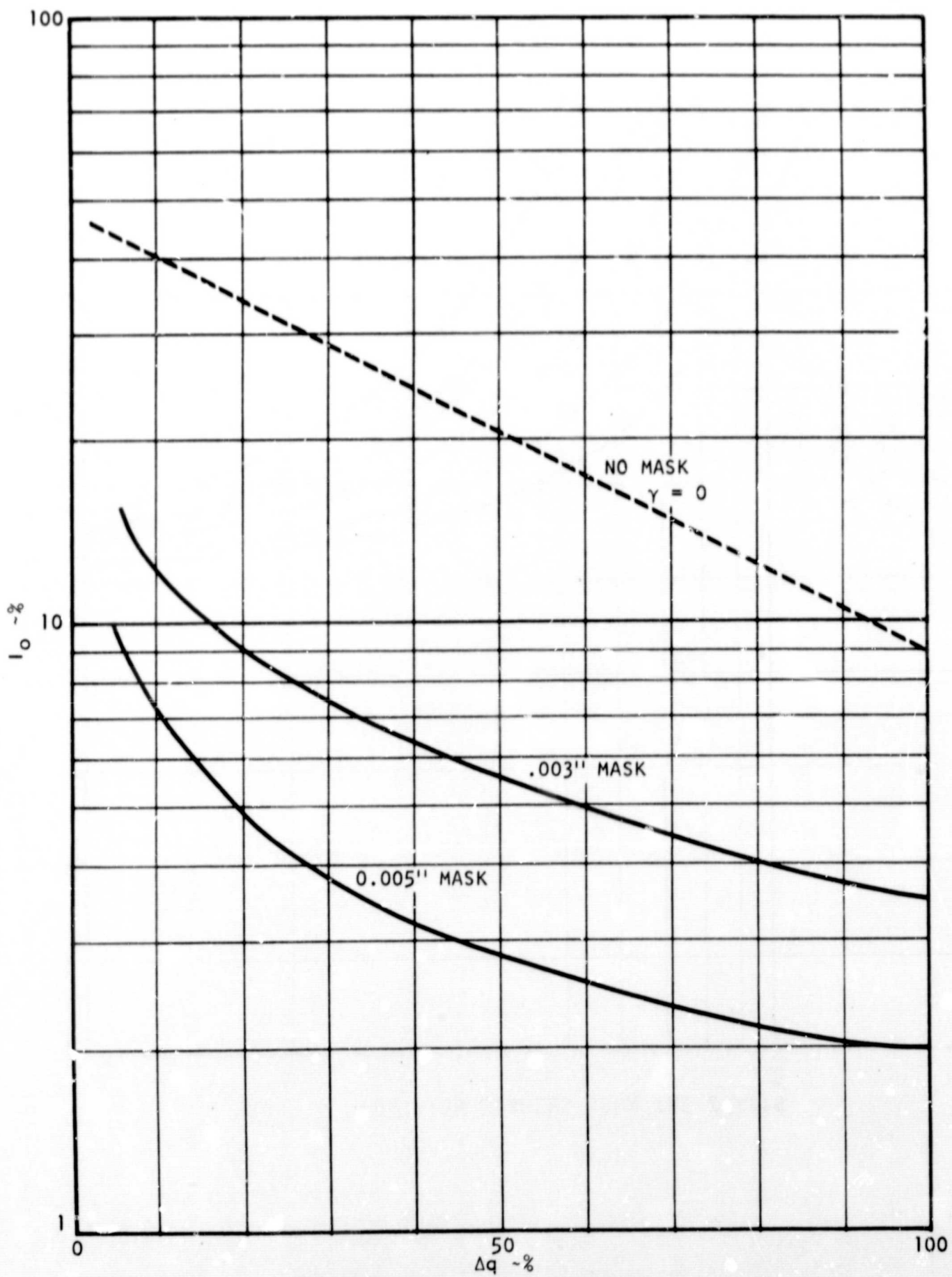


FIGURE 23. Tail Amplitude vs q , $\gamma = 0$

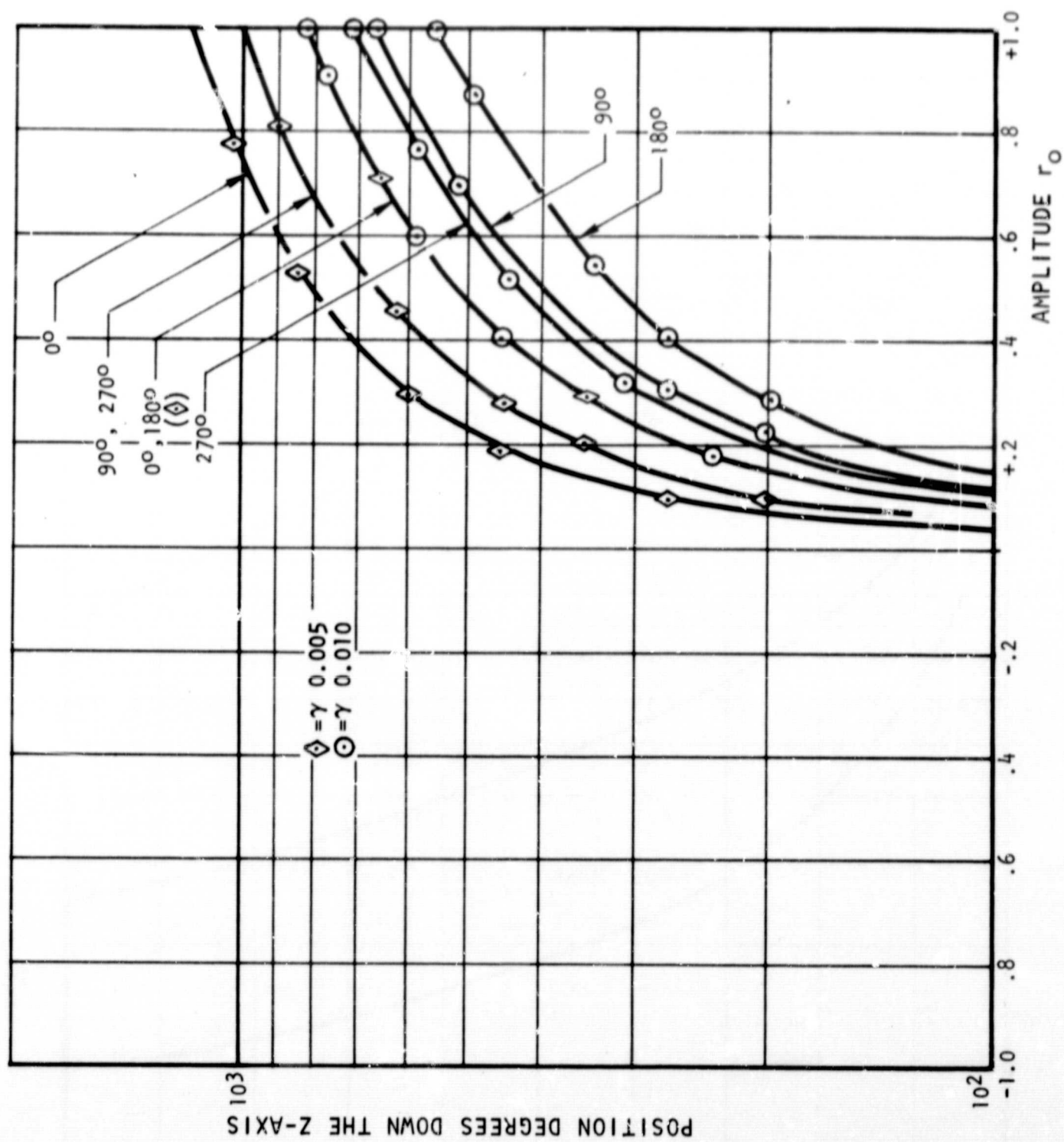


FIGURE 24. Ion Amplitude, $\Delta q = 20\%$; $M/\Delta M = 100$

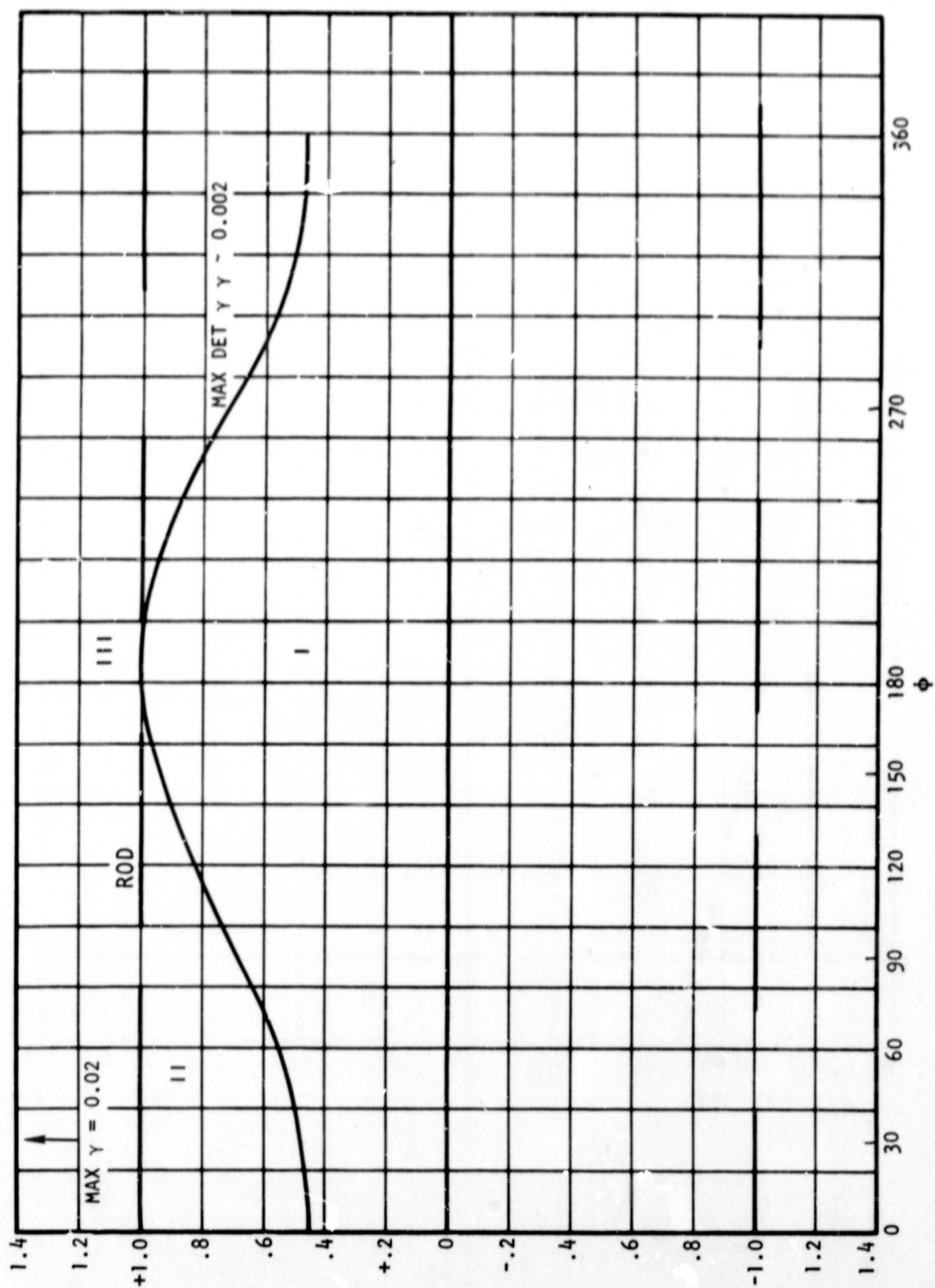


FIGURE 25. Amplitude as a Function of Phase, $\Delta q = 20\%$; $\eta = 0$

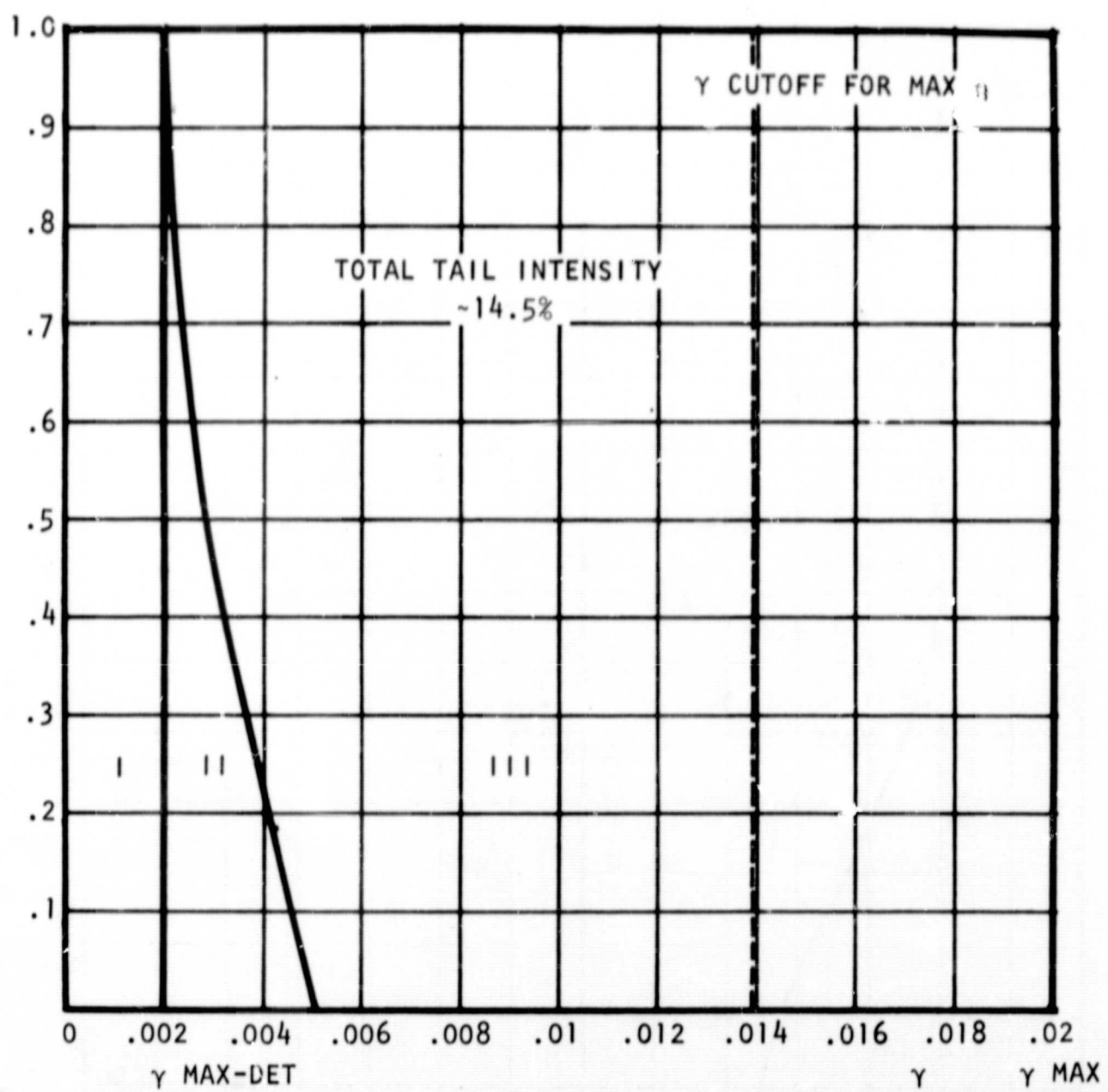


FIGURE 26. Total γ Tail Intensity, $\Delta q = 20\%$

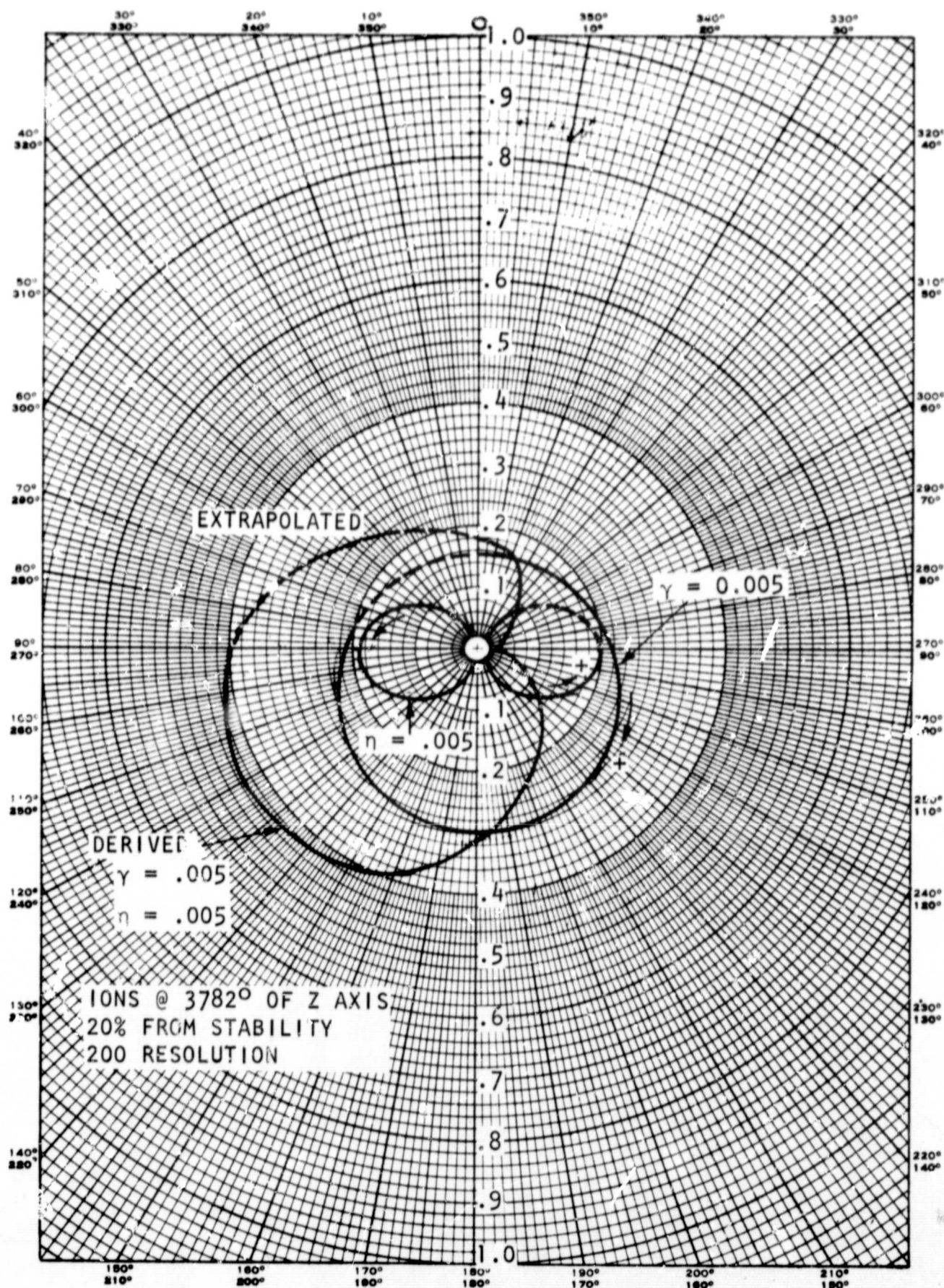


FIGURE 27. Ion Amplitude vs Initial Phase

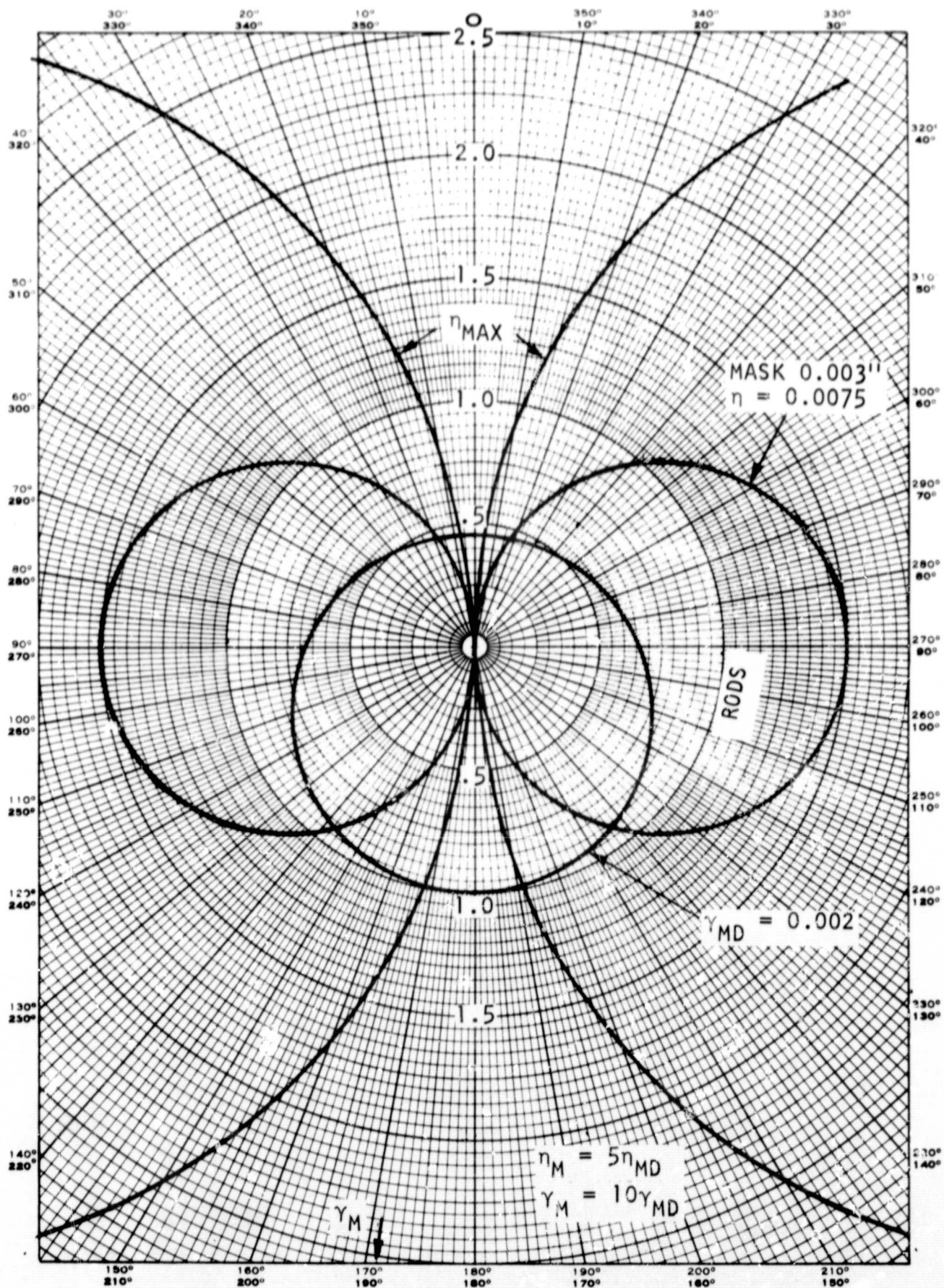


FIGURE 28. Ion Amplitude vs η or γ

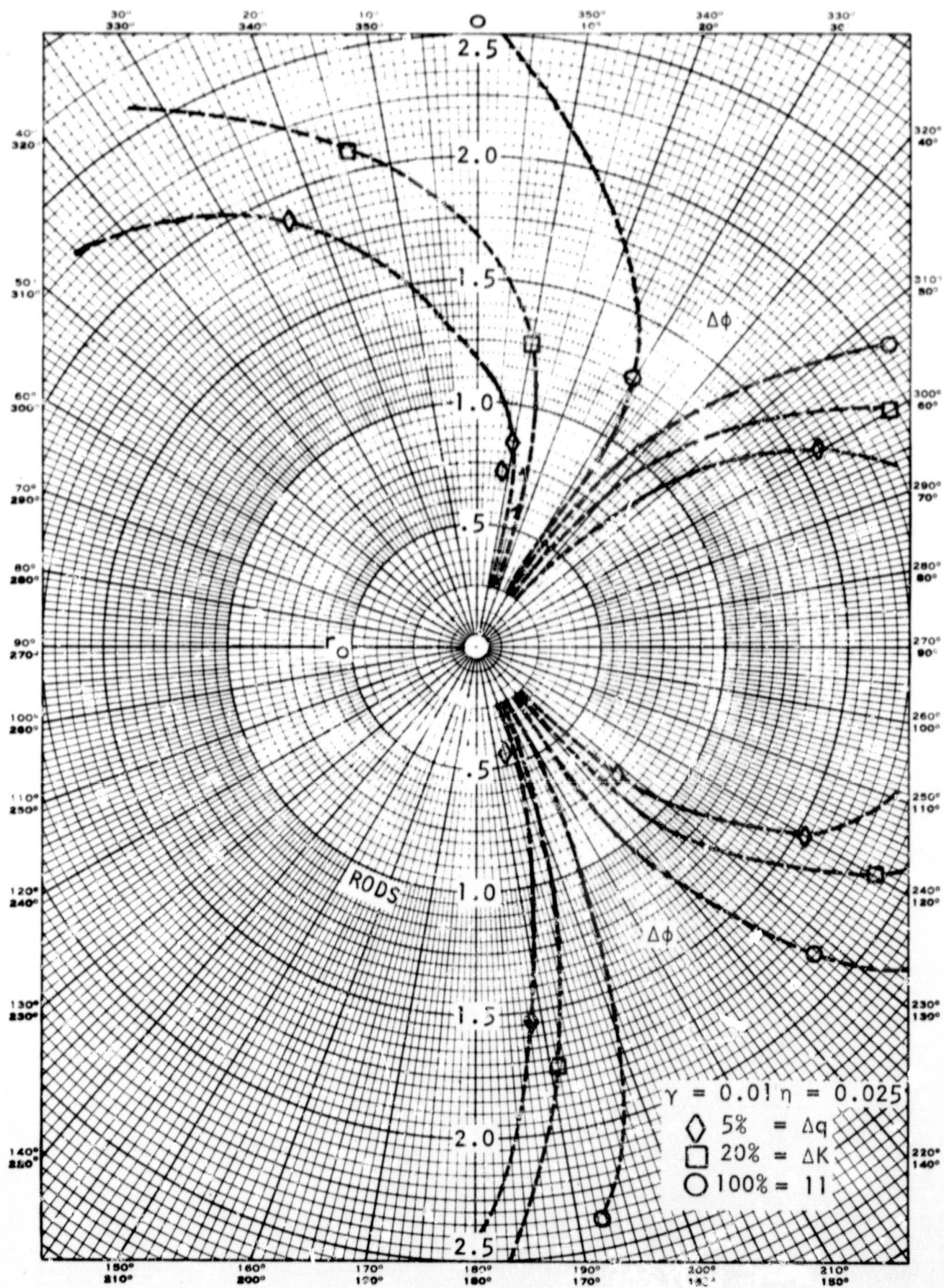


FIGURE 29. Bandwidth of Transmission

Φ	η	γ	A
0.	.0235	.004	1.024
6.	.0215	.006	1.027
13.	.0215	.008	1.027
13.	.0235	.000	-1.021
17.	.0175	.000	-1.020
19.	.0235	.002	-1.028
19.	.0235	.010	1.024
23.	.0195	.002	-1.031
30.	.0115	.008	1.022
31.	.0095	.000	-1.019
39.	.0255	.008	-1.029
42.	.0115	.002	-1.026
43.	.0155	.004	-1.030
44.	.0095	.008	1.026
44.	.0235	.008	-1.030
45.	.0135	.010	1.025
51.	.0215	.008	-1.028
52.	.0175	.006	-1.029
56.	.0095	.002	-1.029
56.	.0235	.016	1.031
60.	.0195	.014	1.025
63.	.0195	.008	-1.025
69.	.0155	.006	-1.022
76.	.0255	.012	-1.024
77.	.0255	.012	-1.028
82.	.0255	.012	-1.029
83.	.0255	.012	-1.024
86.	.0195	.014	1.021
92.	.0235	.016	1.029
94.	.0095	.008	1.021
94.	.0155	.006	-1.023

FIGURE 30. Typical $\Delta\phi$ Data (Sheet 1 of 2)

Φ	η	γ	A
99.	.0135	.010	1.023
99.	.0195	.008	-1.021
112.	.0255	.010	-1.023
114.	.0155	.010	1.025
115.	.0095	.002	-1.026
115.	.0115	.008	1.022
117.	.0075	.006	1.022
130.	.0115	.002	-1.030
130.	.0195	.010	1.027
133.	.0175	.004	-1.023
134.	.0155	.008	1.022
135.	.0215	.010	1.020
146.	.0235	.004	-1.027
149.	.0095	.000	-1.020
150.	.0235	.008	1.019
152.	.0195	.002	-1.029
154.	.0175	.006	1.026
158.	.0095	.004	1.020
163.	.0175	.000	-1.020
166.	.0155	.004	1.024
167.	.0235	.000	-1.021
180	.0235	.002	1.024

FIGURE 30. Typical $\Delta\phi$ Data (Sheet 2 of 2)

RUN #2
IFA 212.5
IFB 208.5

$$R = \frac{77.5}{13.5} \times 7.5 = 43$$

50% T:B

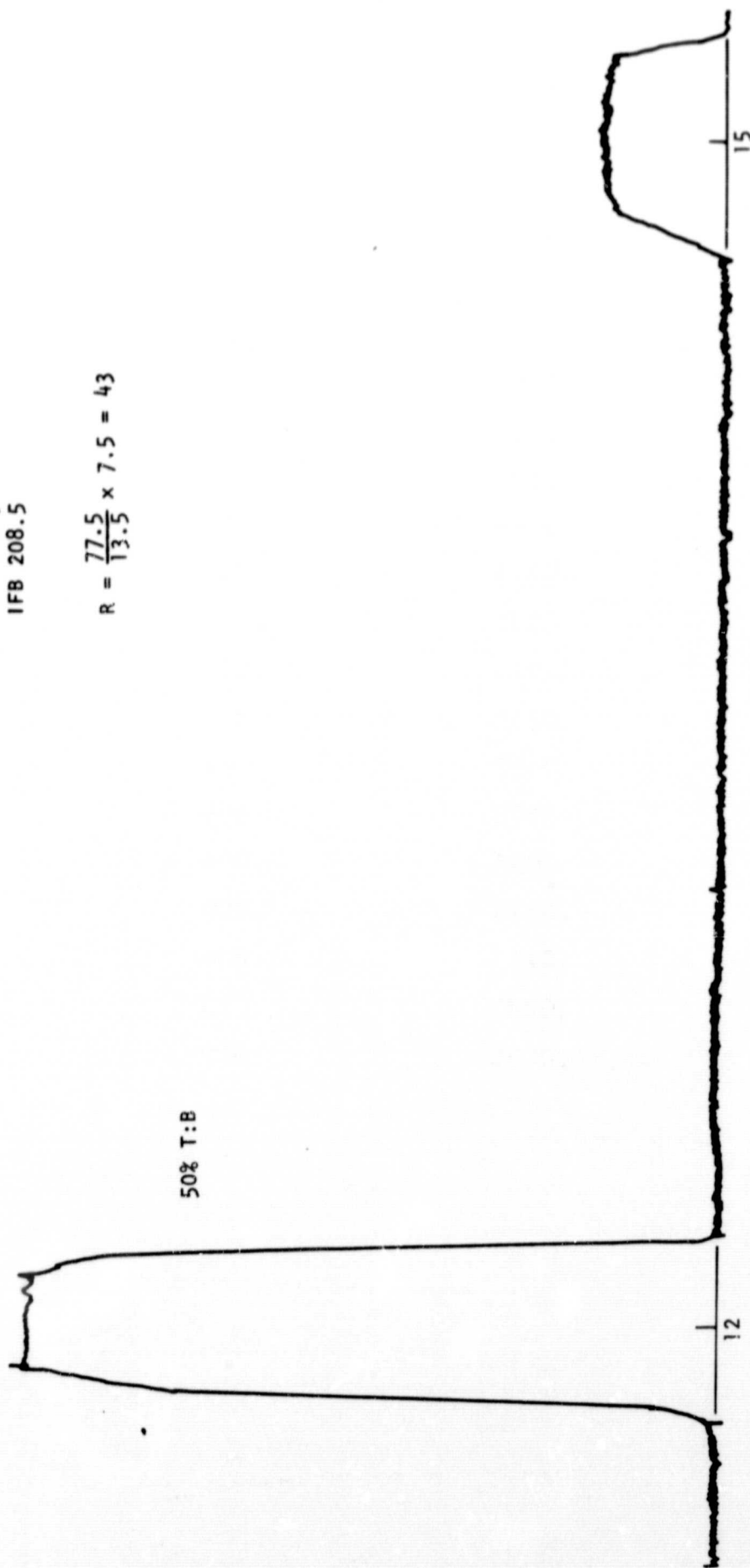
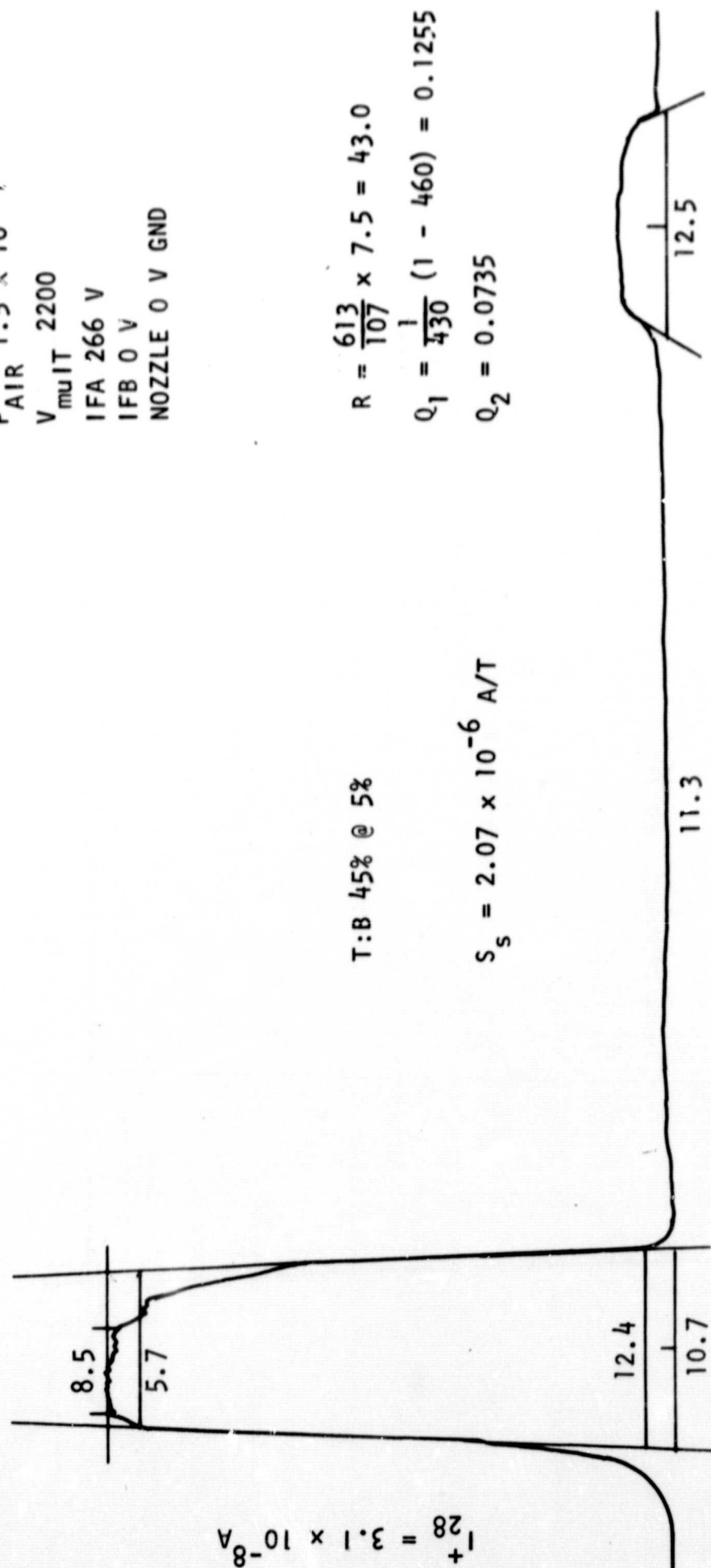


FIGURE 31. High Pressure Ion Source

NOZZLE BIASING TEST

RUN #1
 PAIR $1.5 \times 10^{-6} \text{ T}$
 V_{muIT} 2200
 IFA 266 V
 IFB 0 V
 NOZZLE 0 V GND



T:B 45% @ 5%

$$R = \frac{613}{107} \times 7.5 = 43.0$$

$$Q_1 = \frac{1}{430} (1 - 460) = 0.1255$$

$$Q_2 = 0.0735$$

$$S_s = 2.07 \times 10^{-6} \text{ A/T}$$

FIGURE 32. Dual Filament Ion Source

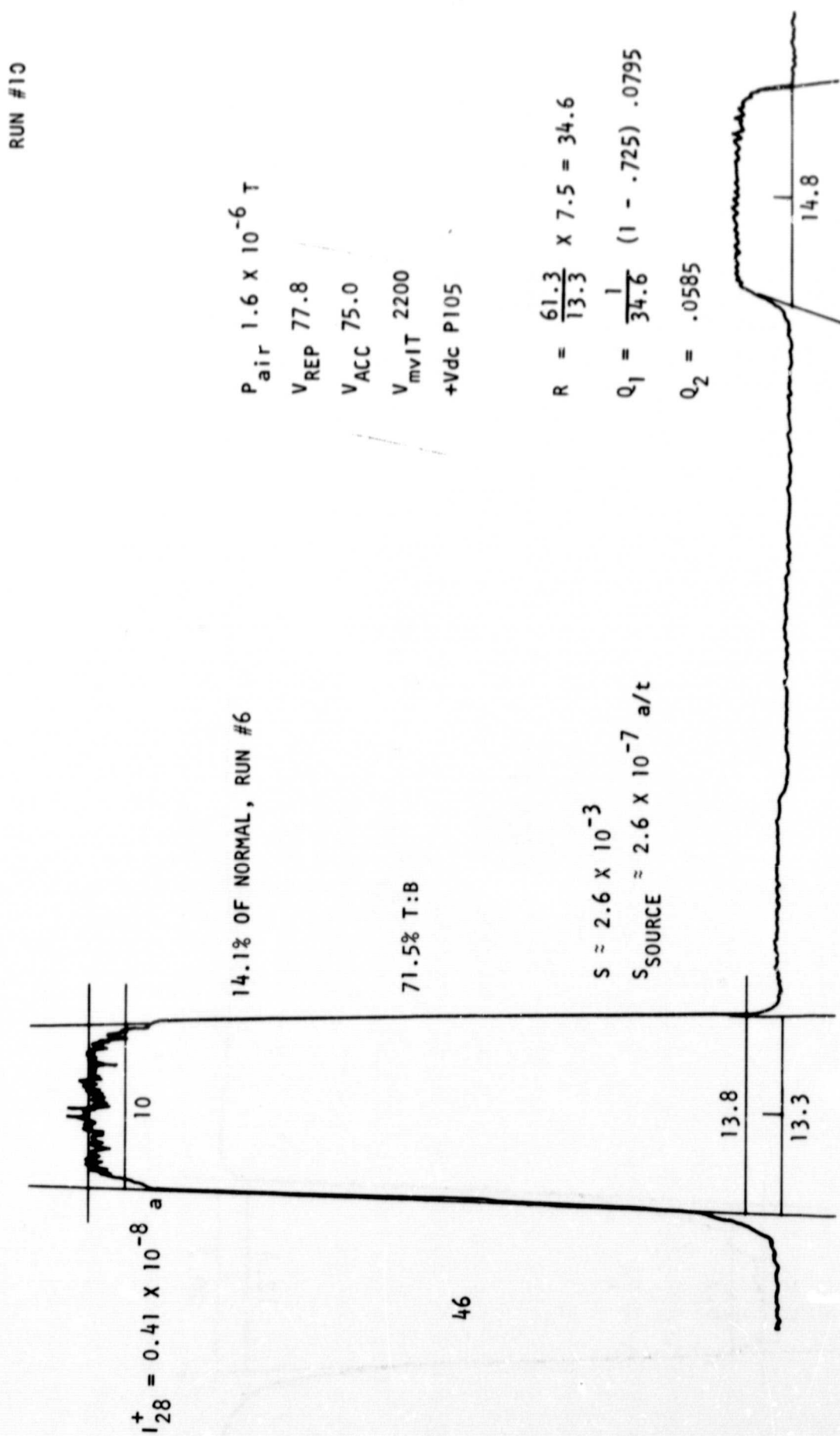


FIGURE 33. Reduced V_{ion} and Proportionally Reduced ΔV_{ion} Test

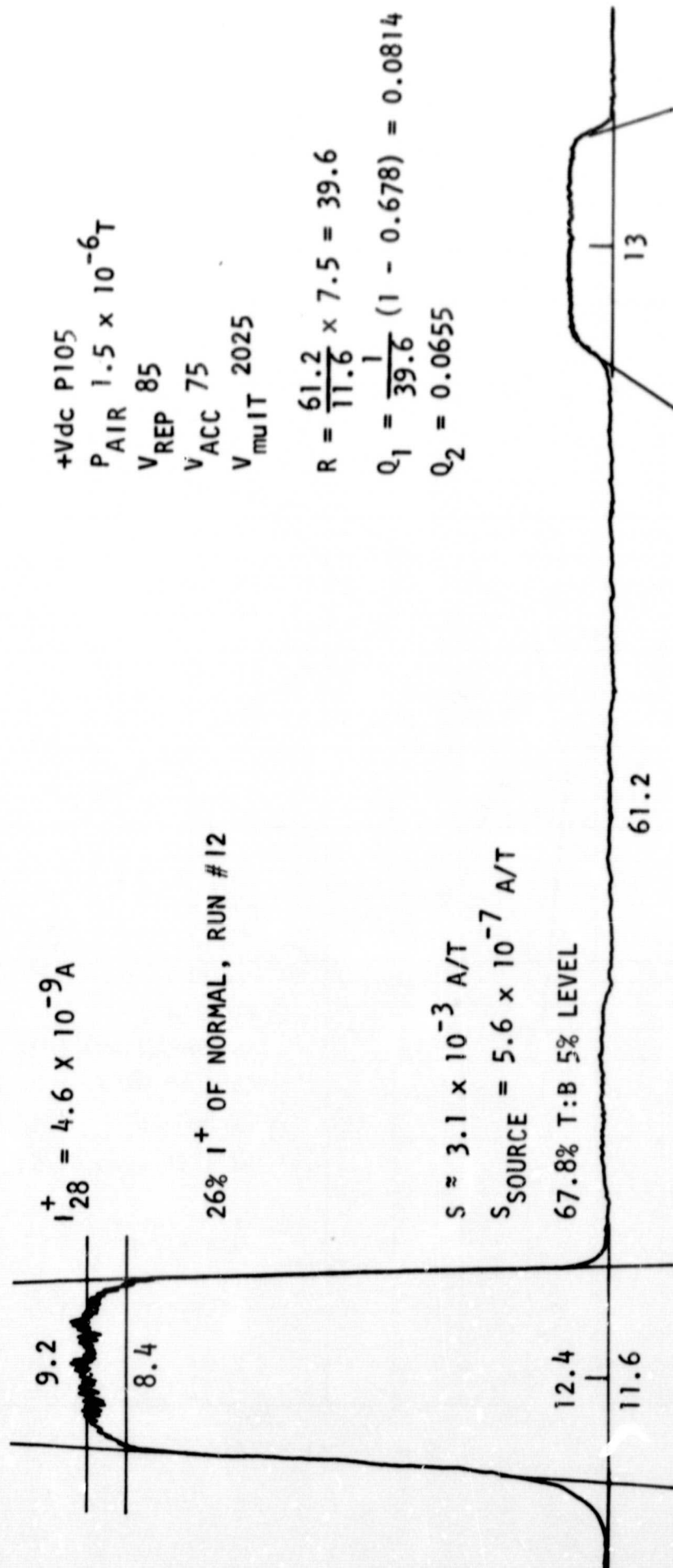


FIGURE 34. Reduced V_{ion} Test W/Constant ΔV_{ra}

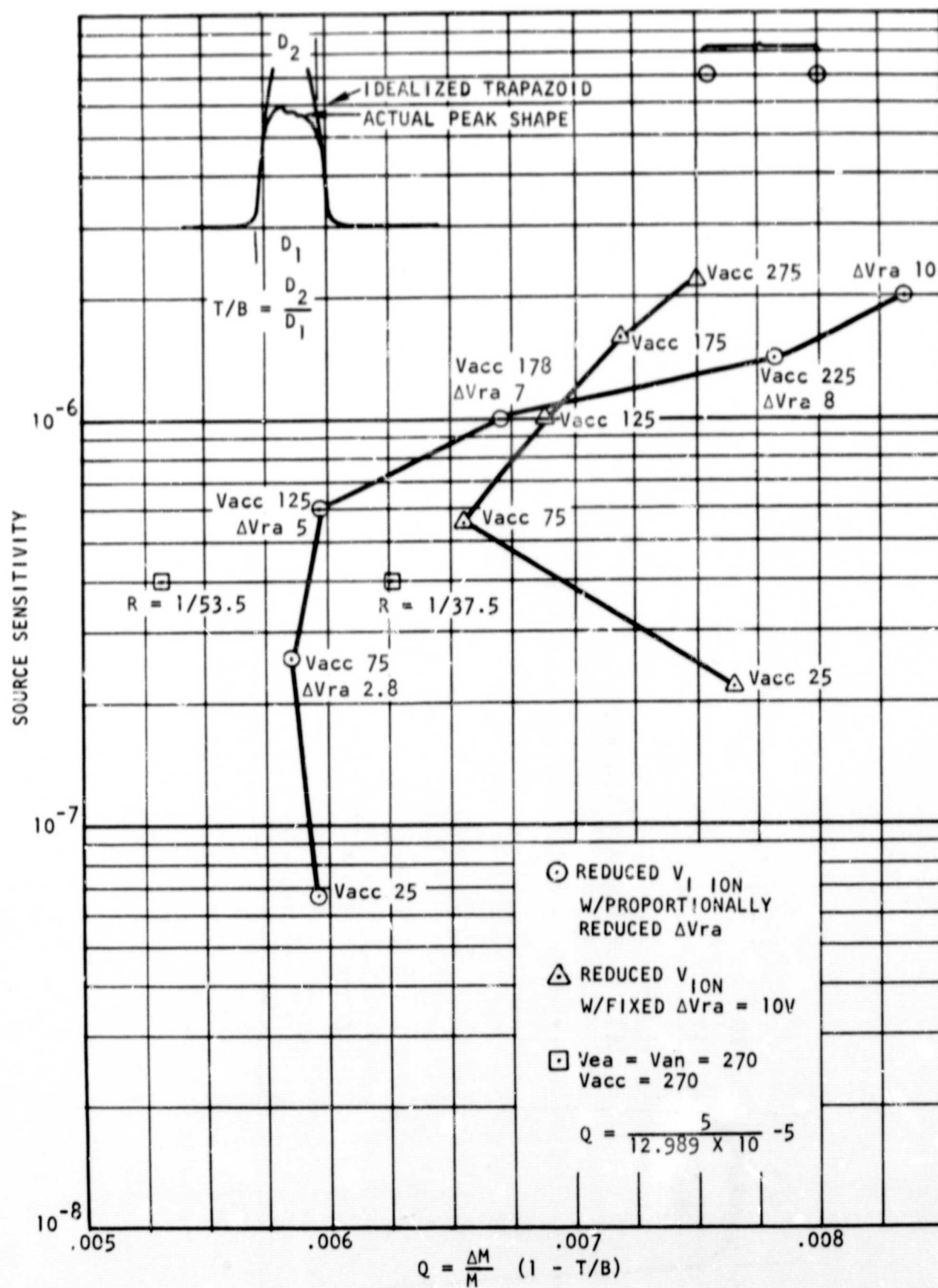


FIGURE 35. Peak Quality vs Source Sensitivity

PEAK SCANED W/QB = 254

V_{ACC} = 275

V_{REP} = 285

V_{NOZZLE} = 0 V

V_{e1's} = 0 V

QB VALUES JUST BELOW CUTOFF +1 V

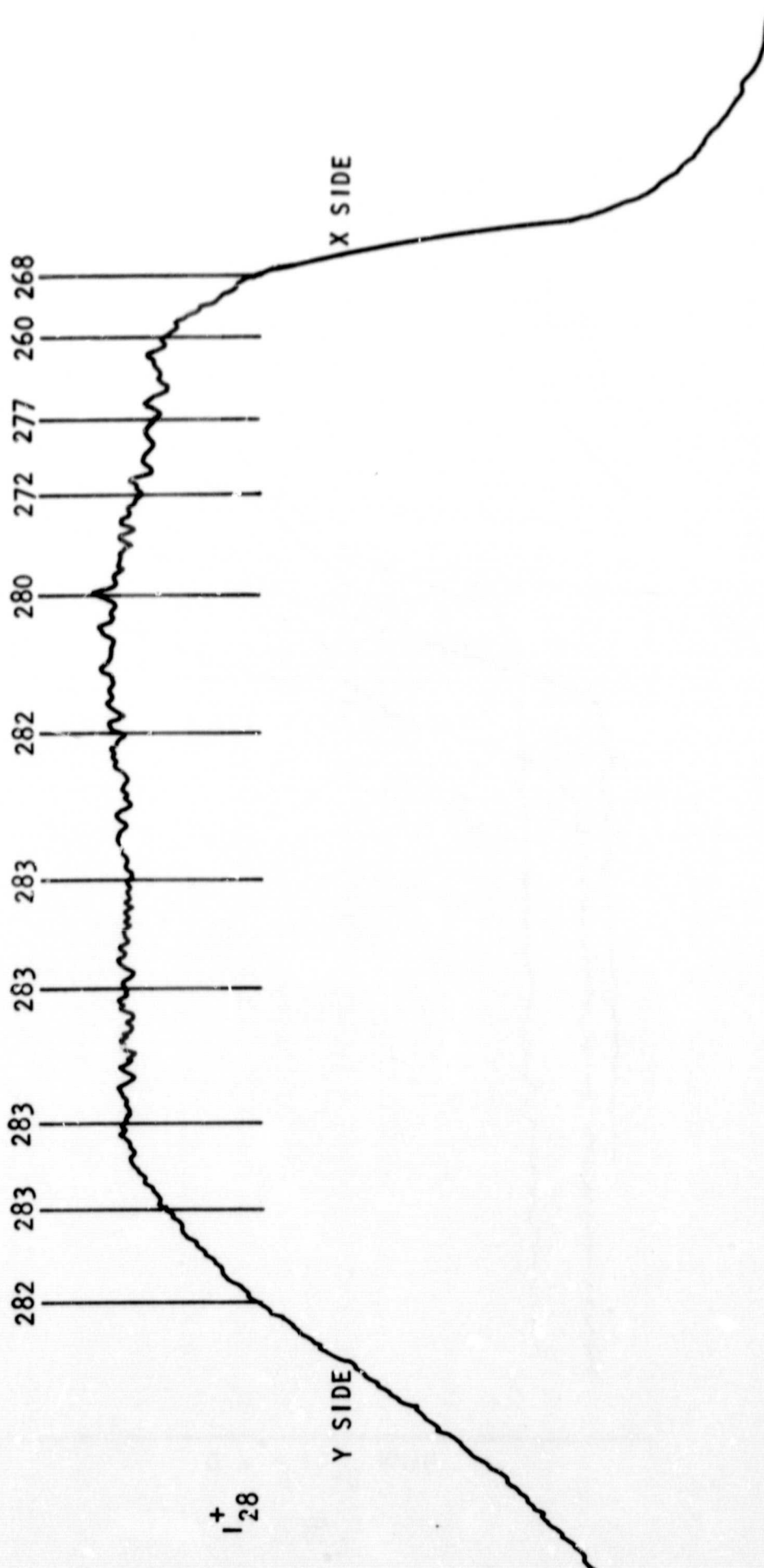


FIGURE 36. QB Cutoff vs Peak Position - Without Mask

$$\begin{aligned}
 V_{ea} &= V_{AN} = V_{ea} = V_{ON} = 324 \\
 V_{REP} &= 285 \\
 V_{ACC} &= 275 \\
 V_{QB} &= 280.5
 \end{aligned}$$

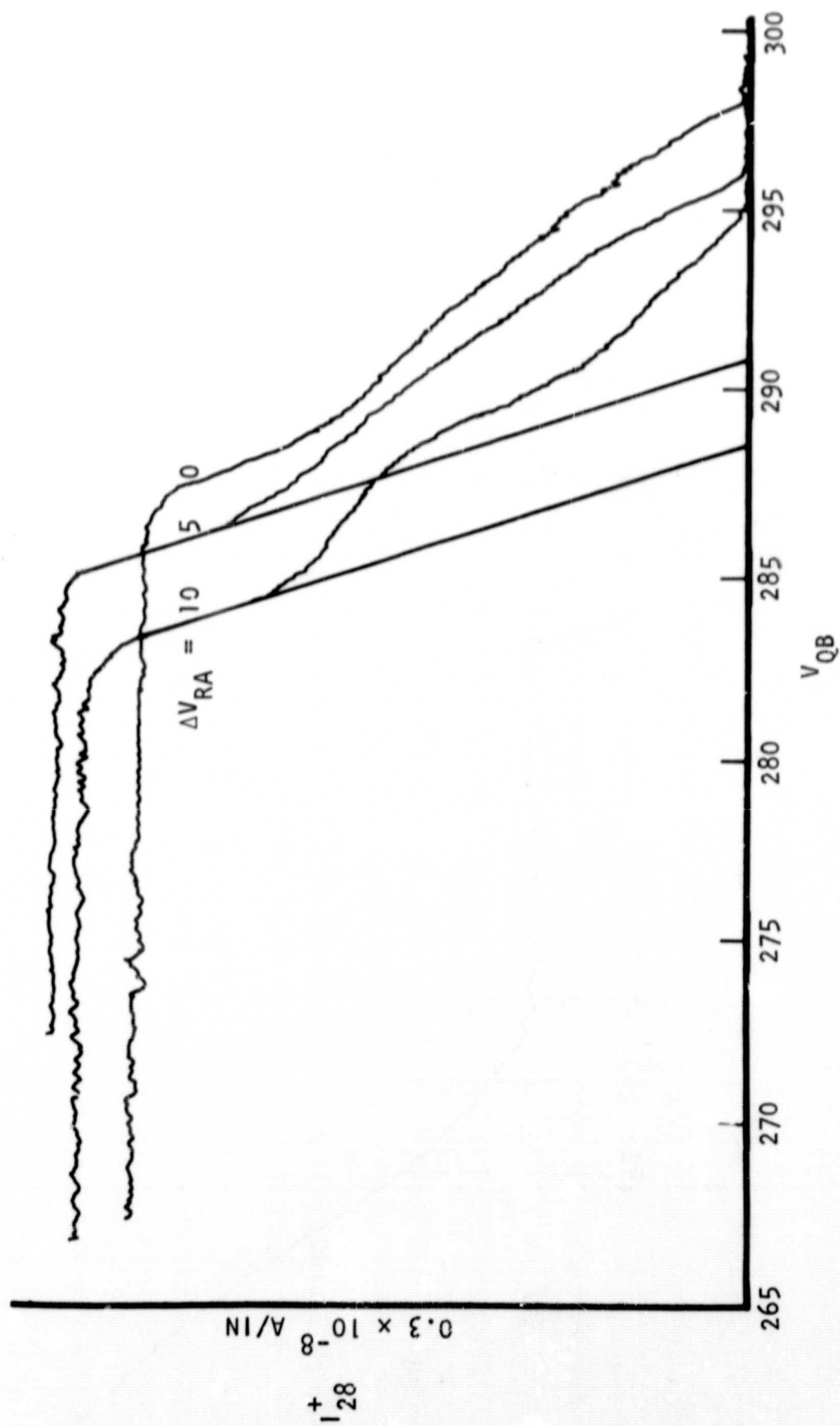


FIGURE 37. Quad Bias Cutoff Runs

W/O MASK

$V_{REP} = 285$

$V_{ACC} = 275$

V_{IFA}

- 1 266.7
- 2 285.0
- 3 250.0
- 4 225.0
- 5 175.0
- 6 125.0
- 7 75.0
- 8 0.0
- 9 278.0
- 10 273.7

RUN #1
AIR SAMPLE 2.0×10^{-7} P PUMP
 $V_{GUIT} = 2025$
 $I_{AN} = 30 \mu A$
GUN #1
DUAL FIL SOURCE

$\Sigma a = an = 324$
 $\Sigma fa = 203$
 $\Sigma fb = 202$

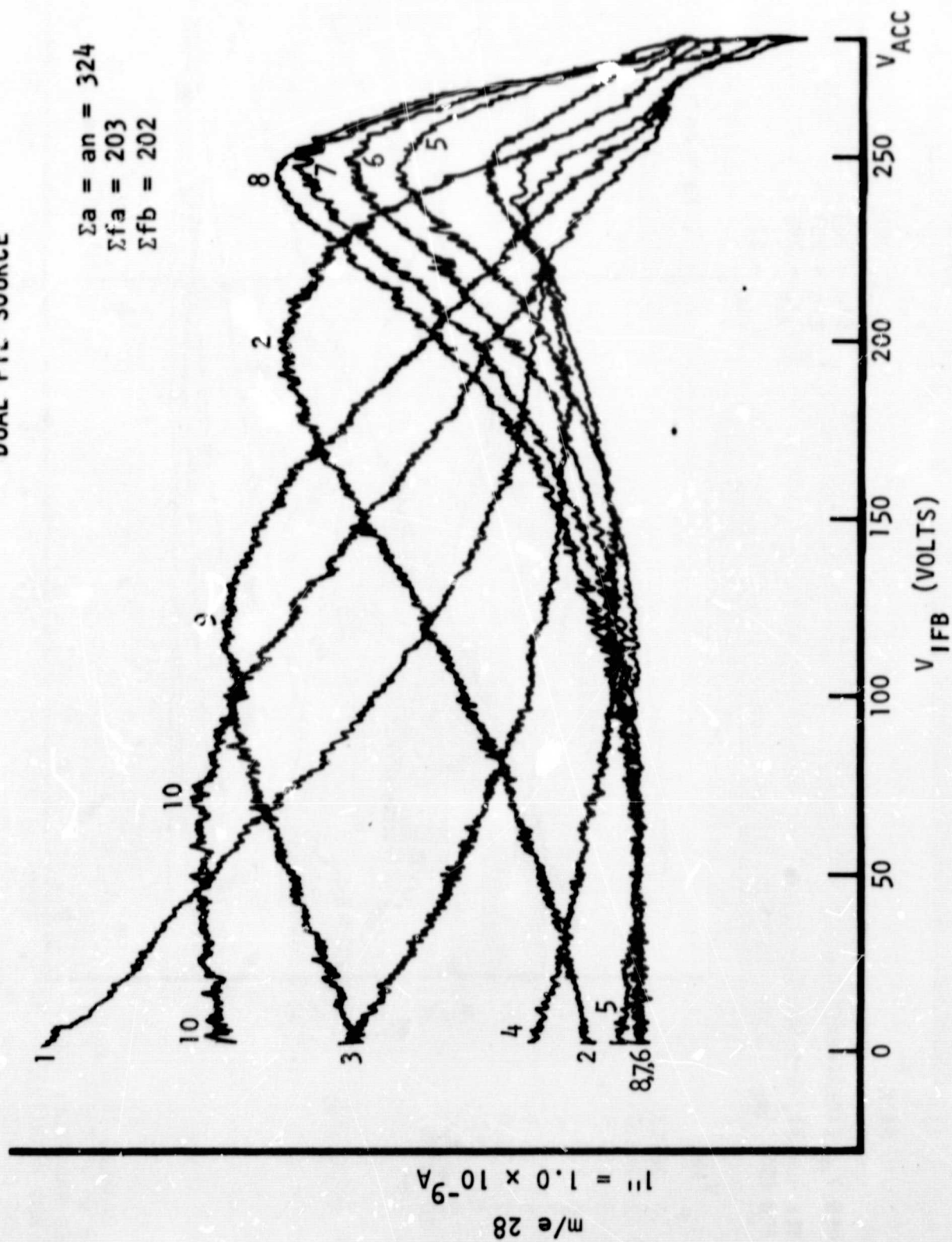


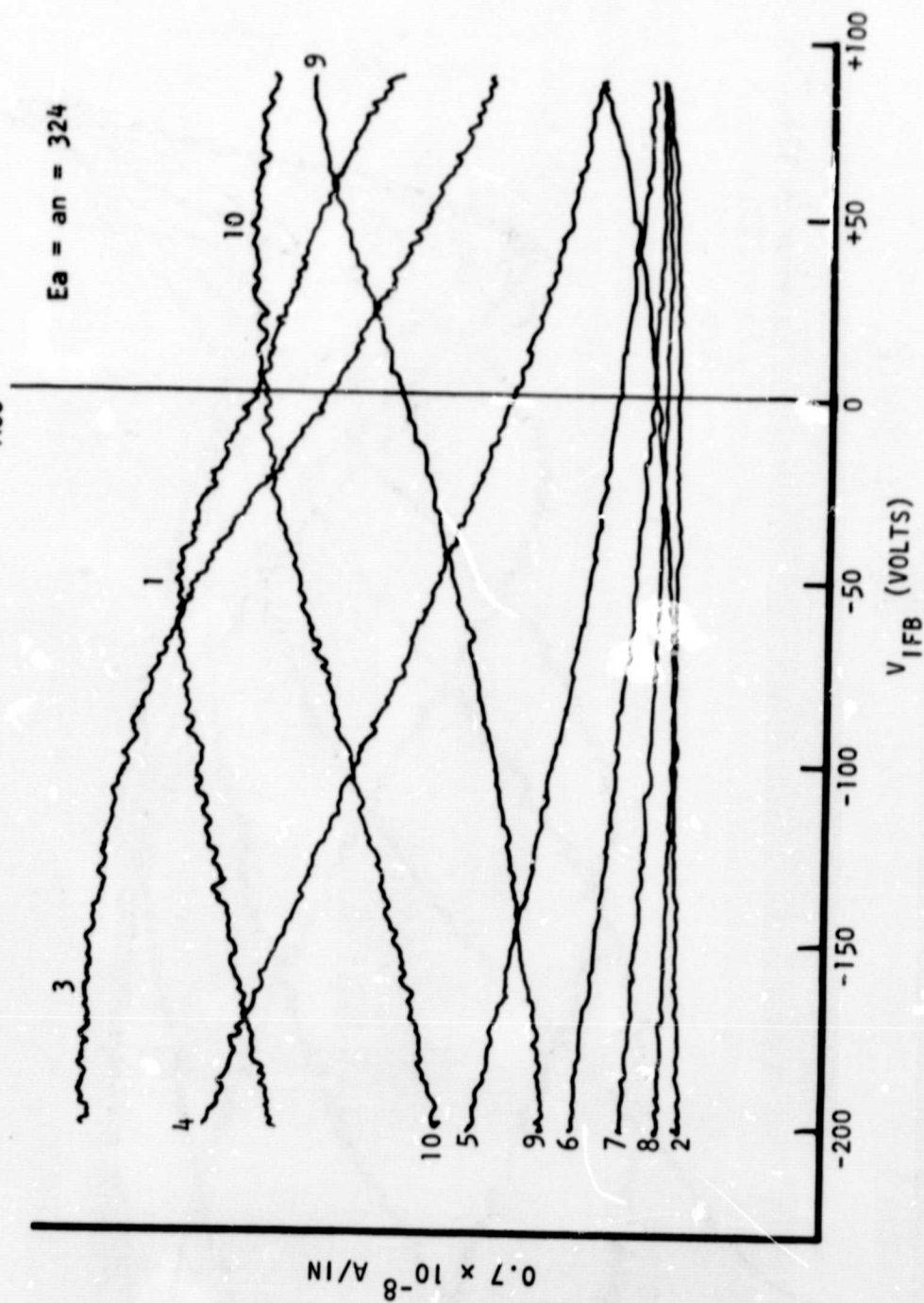
FIGURE 38. Ion Focusing Curves (Lens A)

W/O MASK

NEG I_{fb} EXPERIMENT
SEE RUN #1, 6-9-69
FOR POS. I_{fb}

V_{IFA}	
1	266.7
2	285.0
3	250.0
4	225.0
5	175.0
6	125.0
7	75.0
8	0.0
9	278.0
10	273.7

RUN #7
Pair $1.5 \times 10^{-6}T$
 $V_{MULT} = 2025$
 $E_{fa} = 203$
 $E_{fb} = 203$
 $V_{REP} = 285$
 $V_{ACC} = 275$



*NOTE:
SMALL CHANGES IN E_f ,
 E_a and a_n VOLTAGES
CHANGES RADICALLY THE
SHAPE AND MAGNITUDE
OF THESE CURVES

FIGURE 39. Ion Focusing Curves (Lens E)

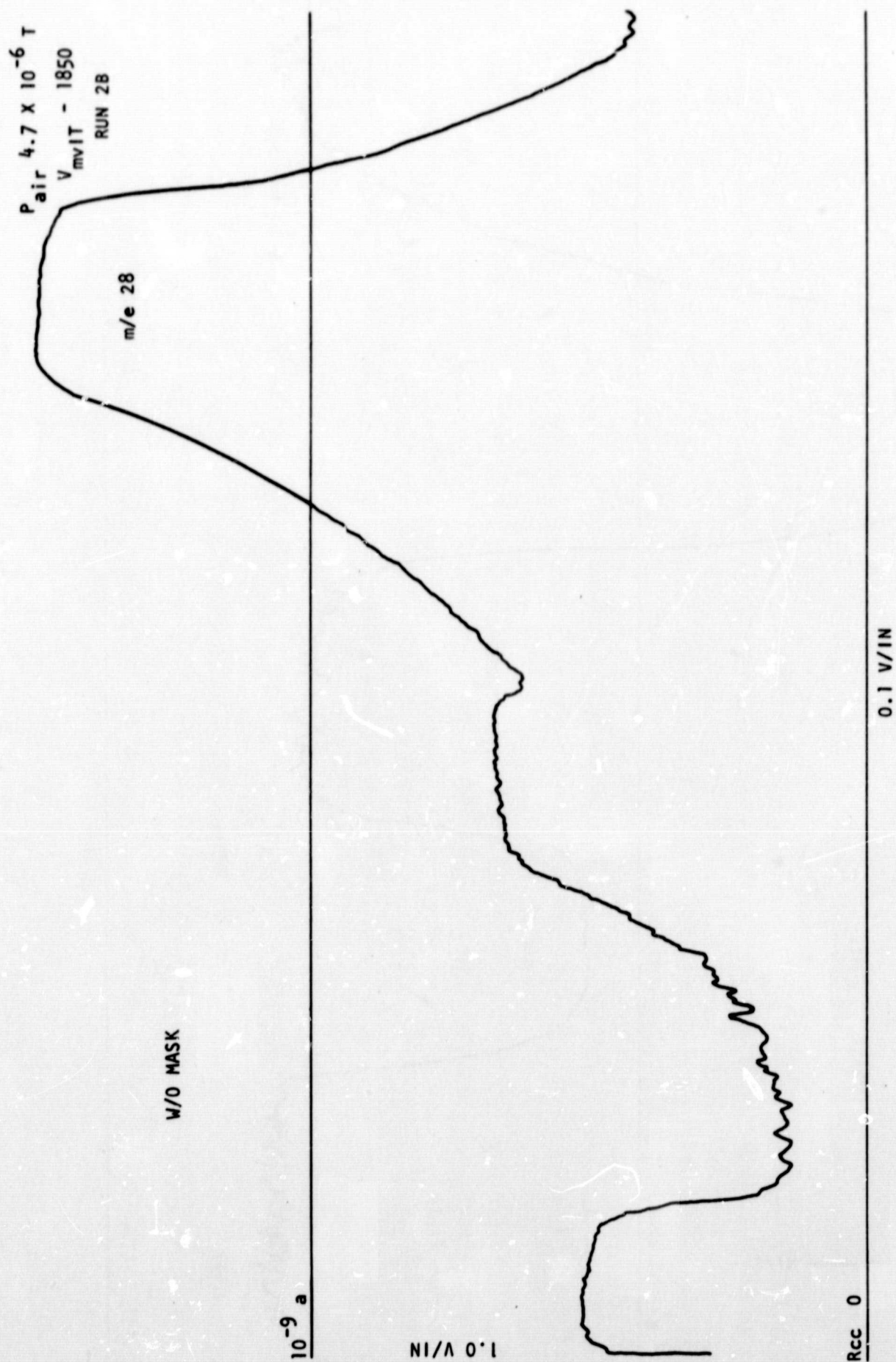


FIGURE 40. Peak Shape Without Mask

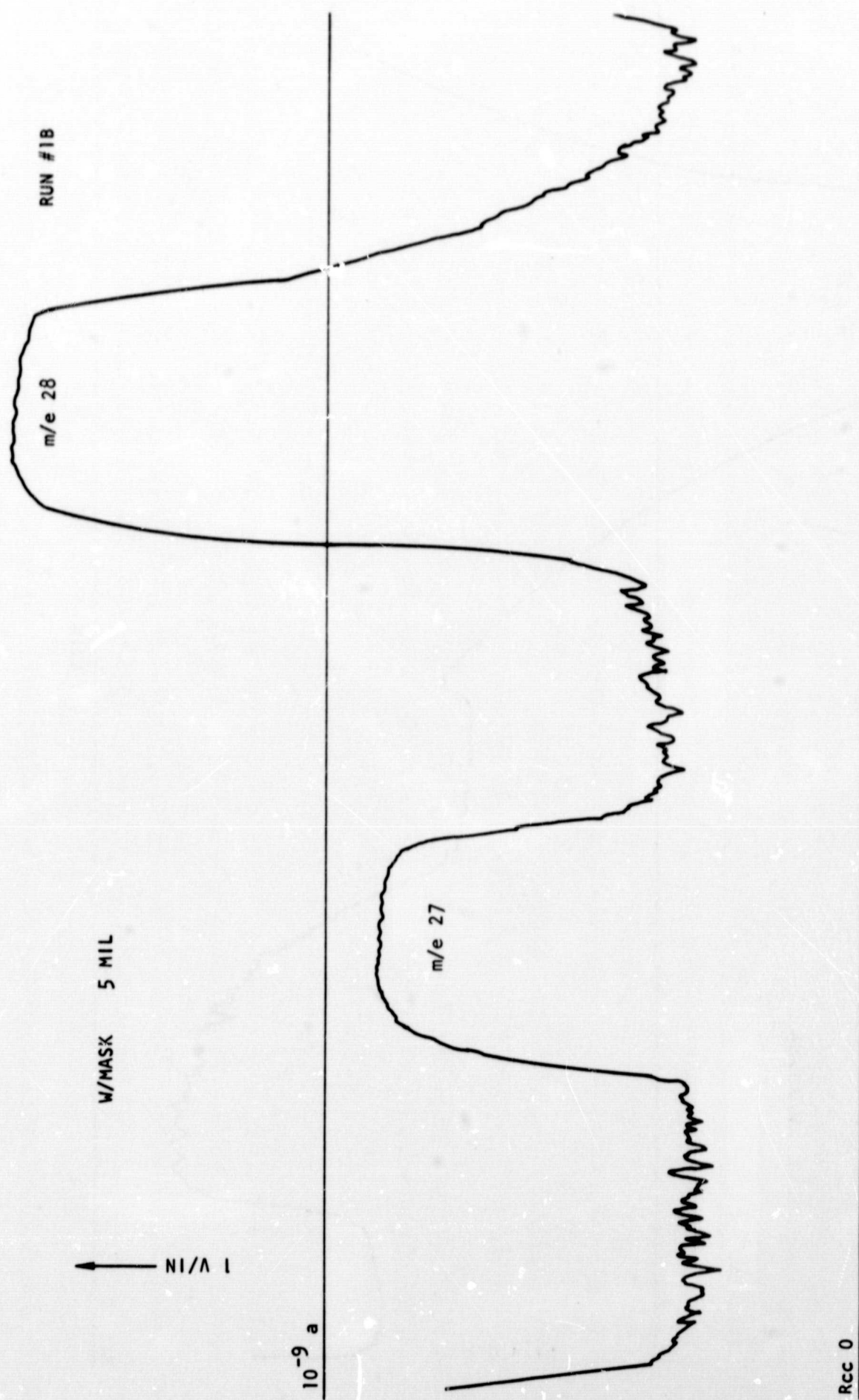


FIGURE 41. Peak Shape With 0.005 Inch Mask on Y-Axis

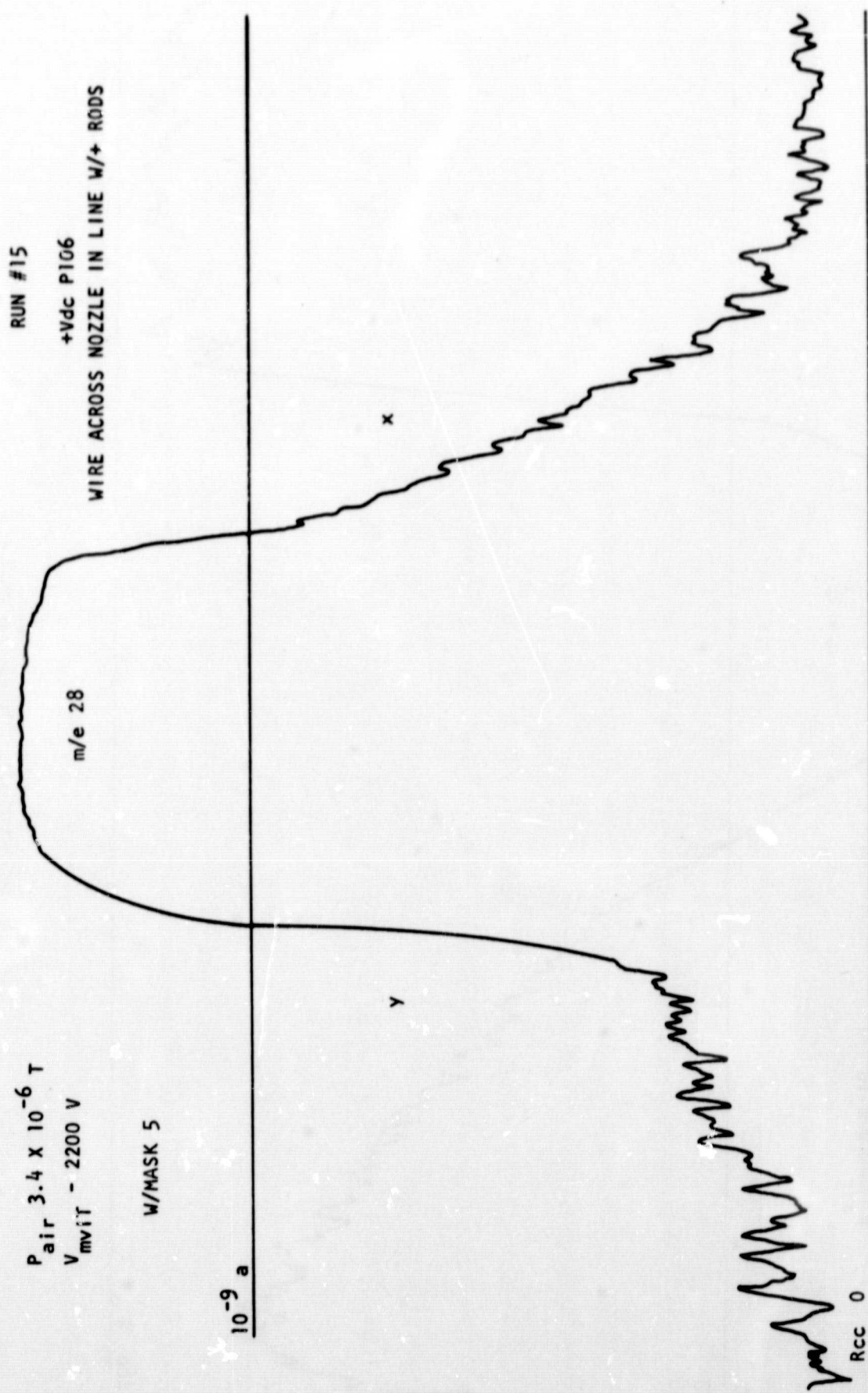


FIGURE 42. Mask on Y-Axis

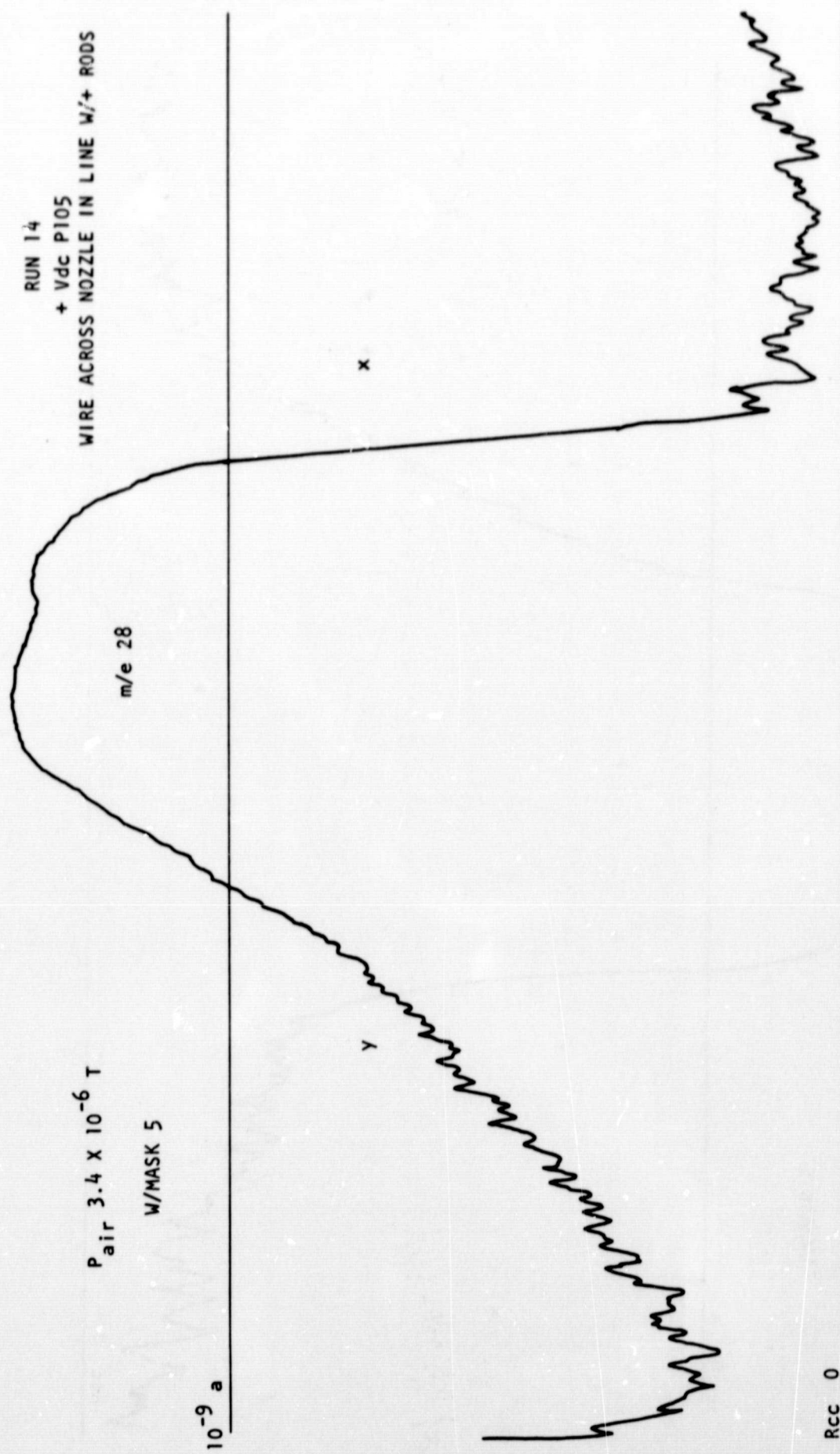


FIGURE 43. Mask on X-Axis

RUN #1
SEE RUN 2

W/3 MIL CROSS
+ Vdc P106

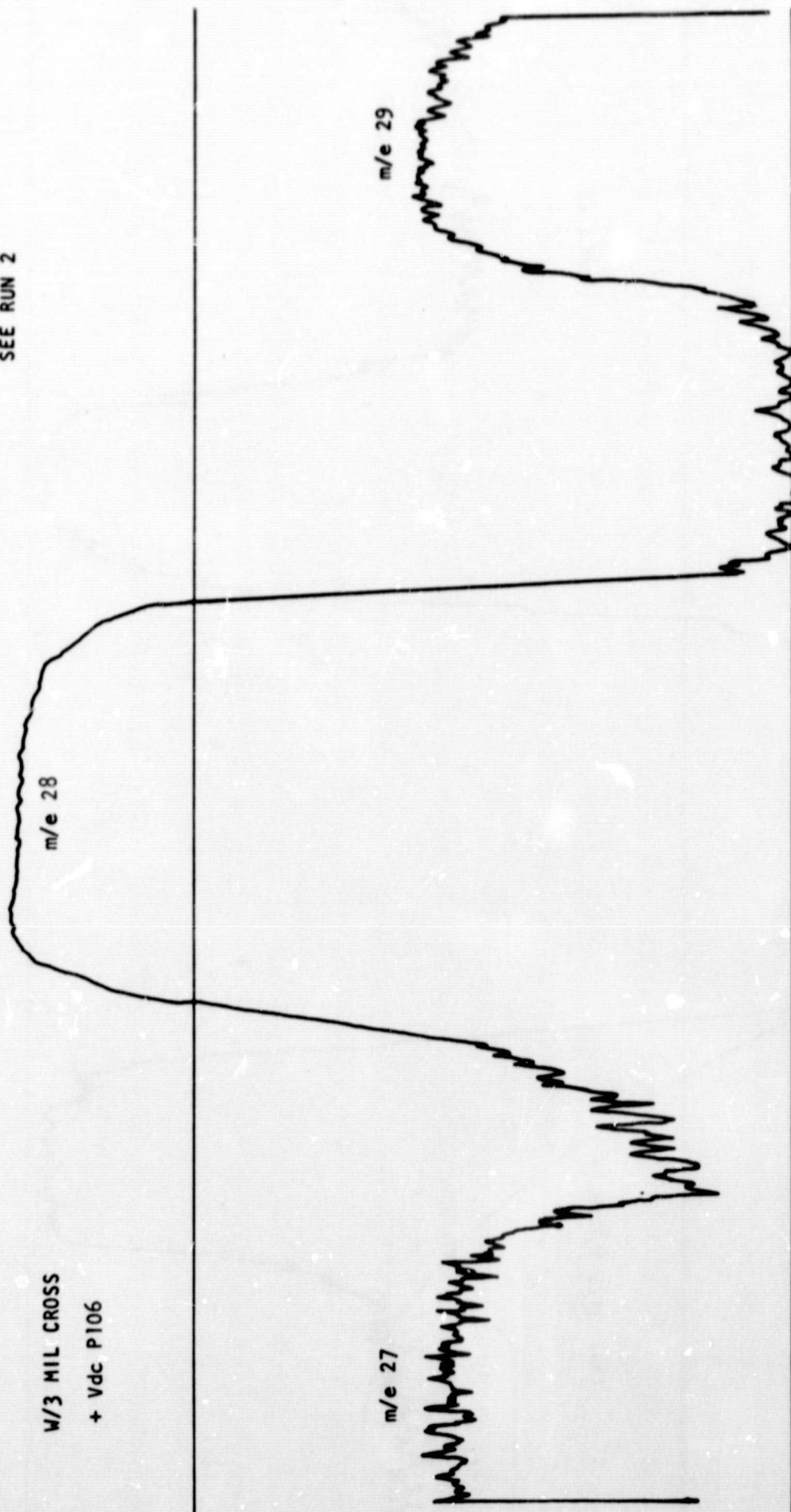


FIGURE 44. Peak Shape With 0.003 Inch Cross Mask

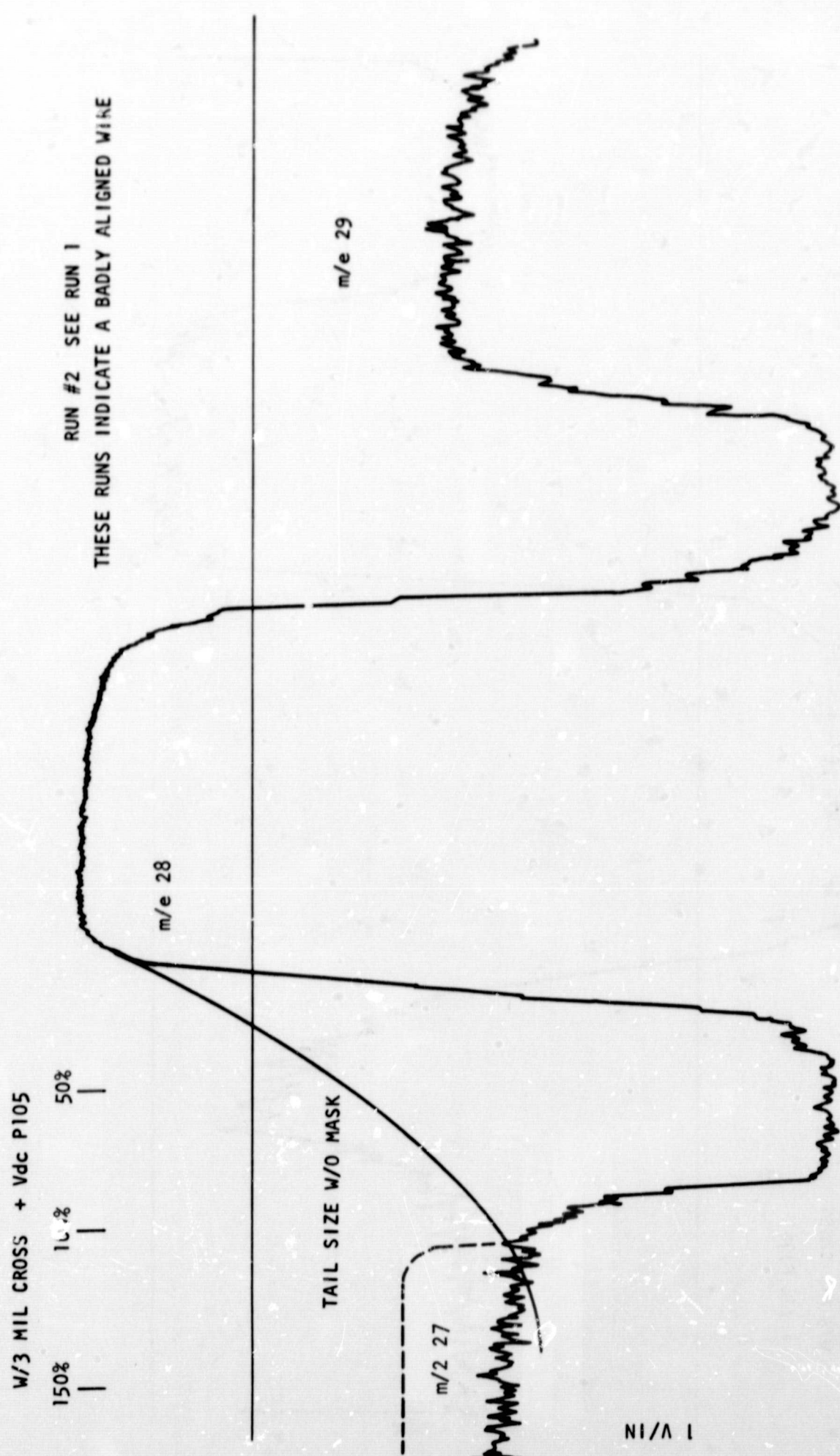


FIGURE 45. Peak Shape With 0.003 Inch Cross Mask
(Rod DC Potential Reversed)

W/3 MIL CROSS

RUN #3

$V_{\text{NOZZLE}} = 0 \text{ V}$

EINZEL LENS RUN

$V_{\text{ACC}} 275$

$V_{\text{REP}} 285$

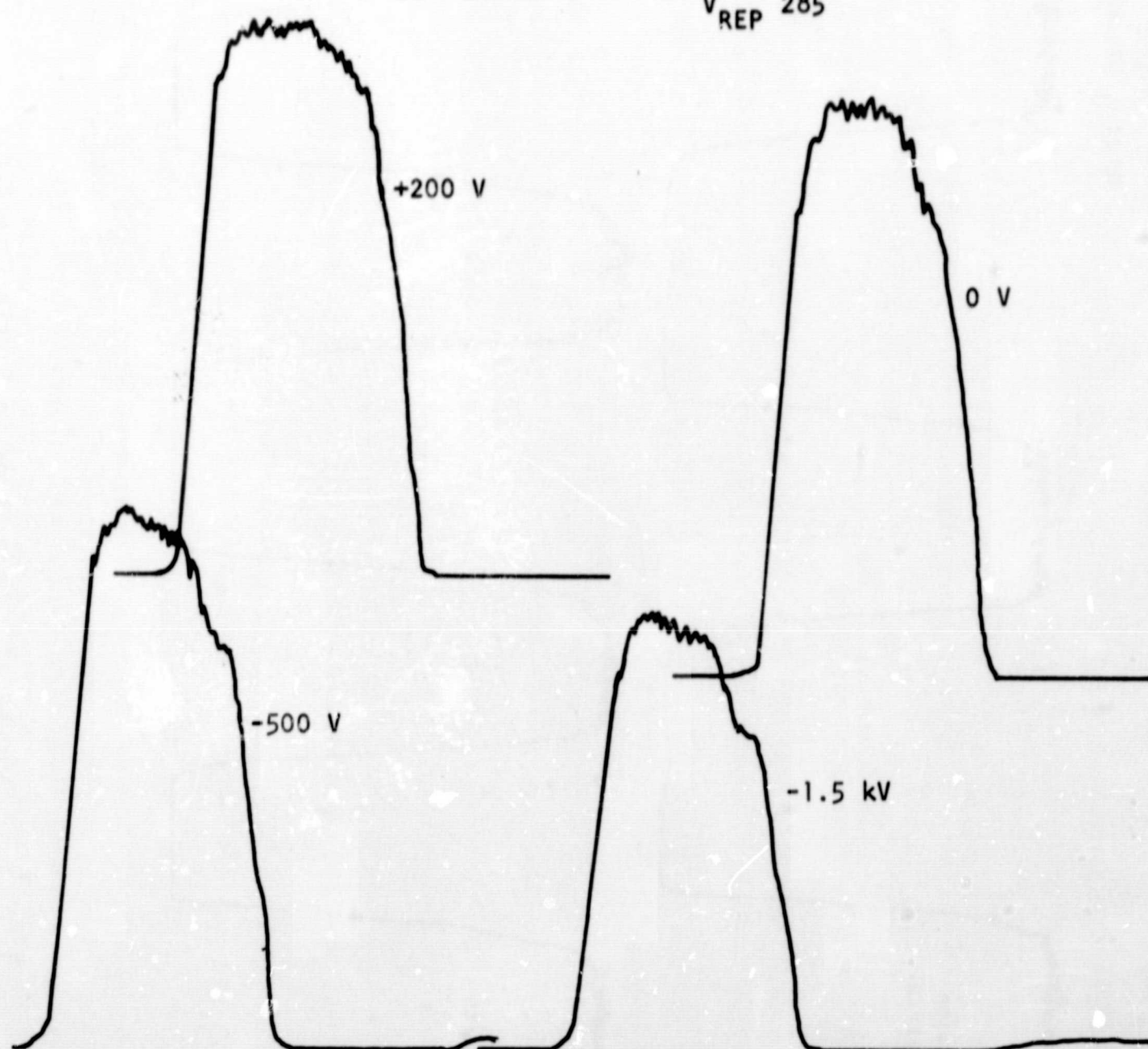


FIGURE 46. Peak Shape vs Einzel Lens Potential

V_{ACC} 275
 V_{REP} 285
 W/3 MIL CROSS

W/el's AT +295
 RESET V_{NOZZLE} POSITIVE
 BELOW V_S ARE NOZZLE POTENTIALS

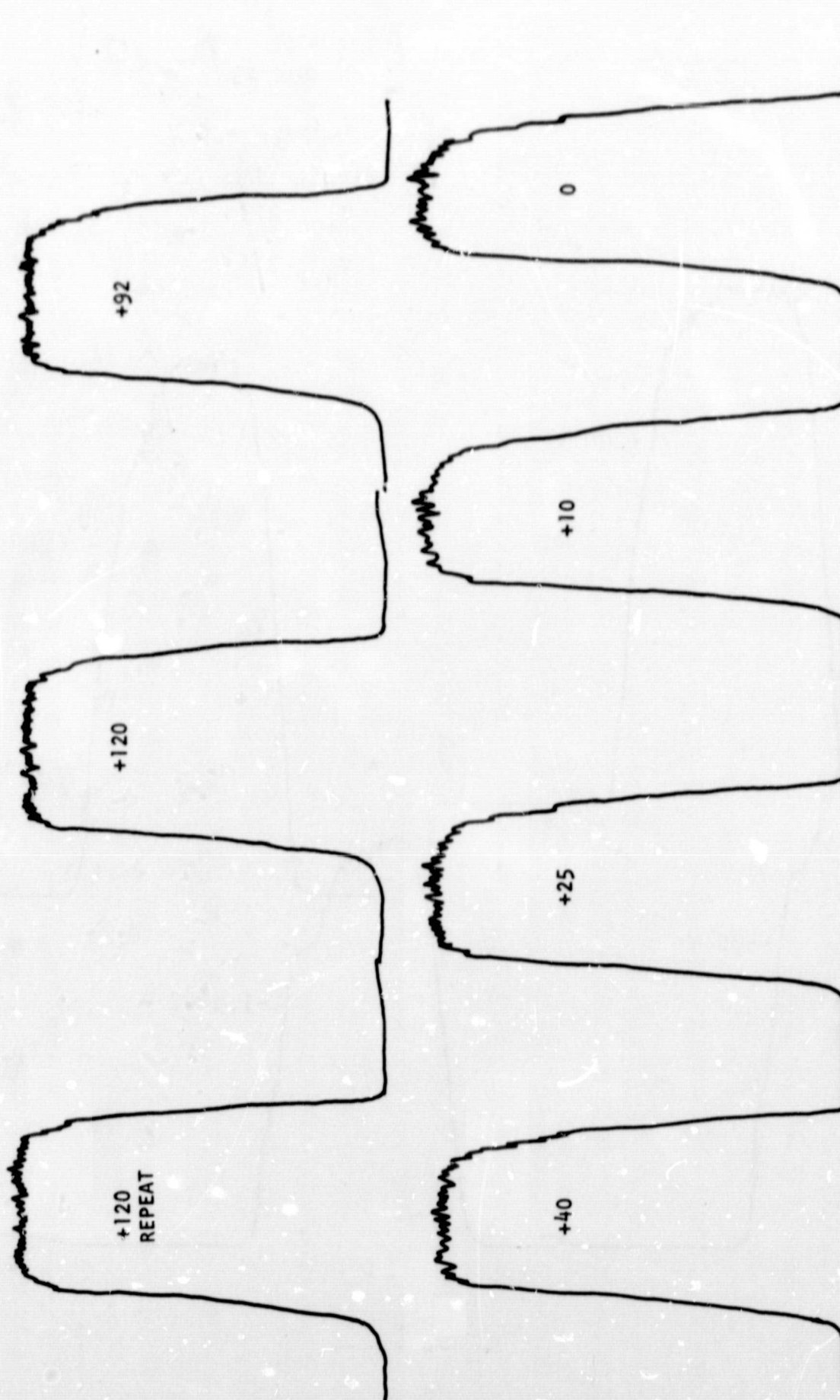


FIGURE 47. Peak Shape vs Nozzle Potential

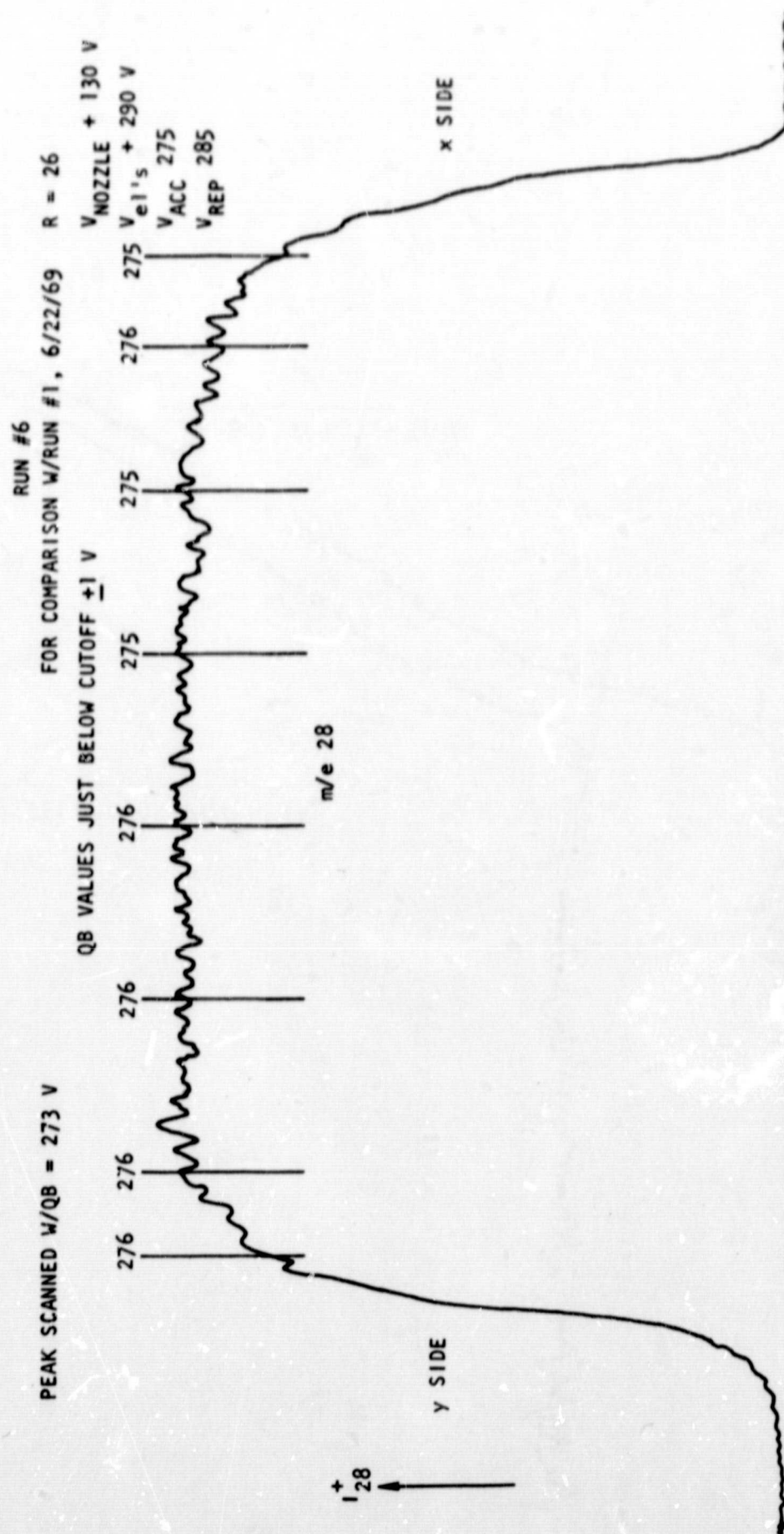


FIGURE 48. QB Cutoff vs Peak Position

W/3 MIL CROSS

RUN #1 QB CUTOFF LINEAR

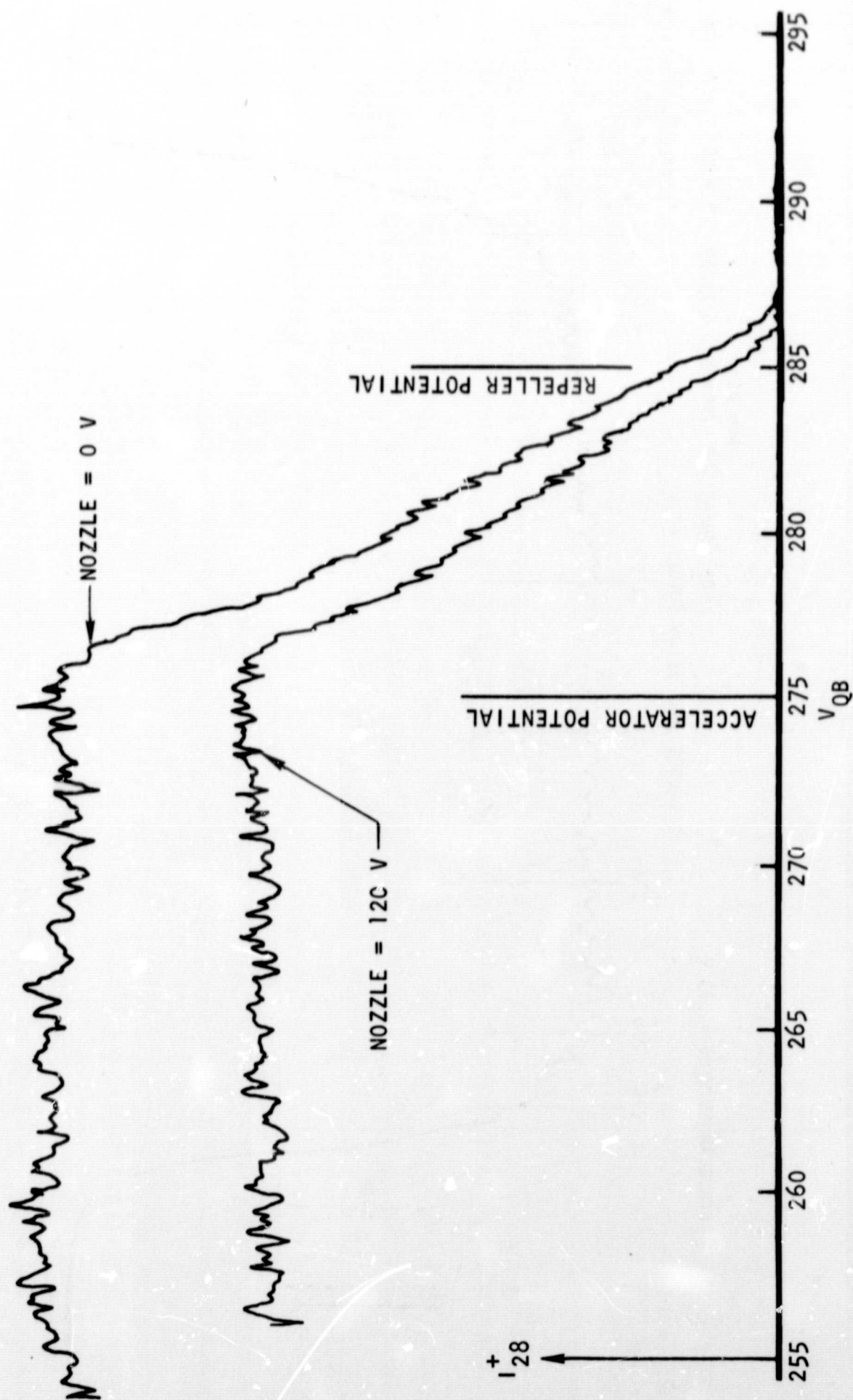


FIGURE 49. Quad Bias Cutoff Curves vs Nozzle Potential

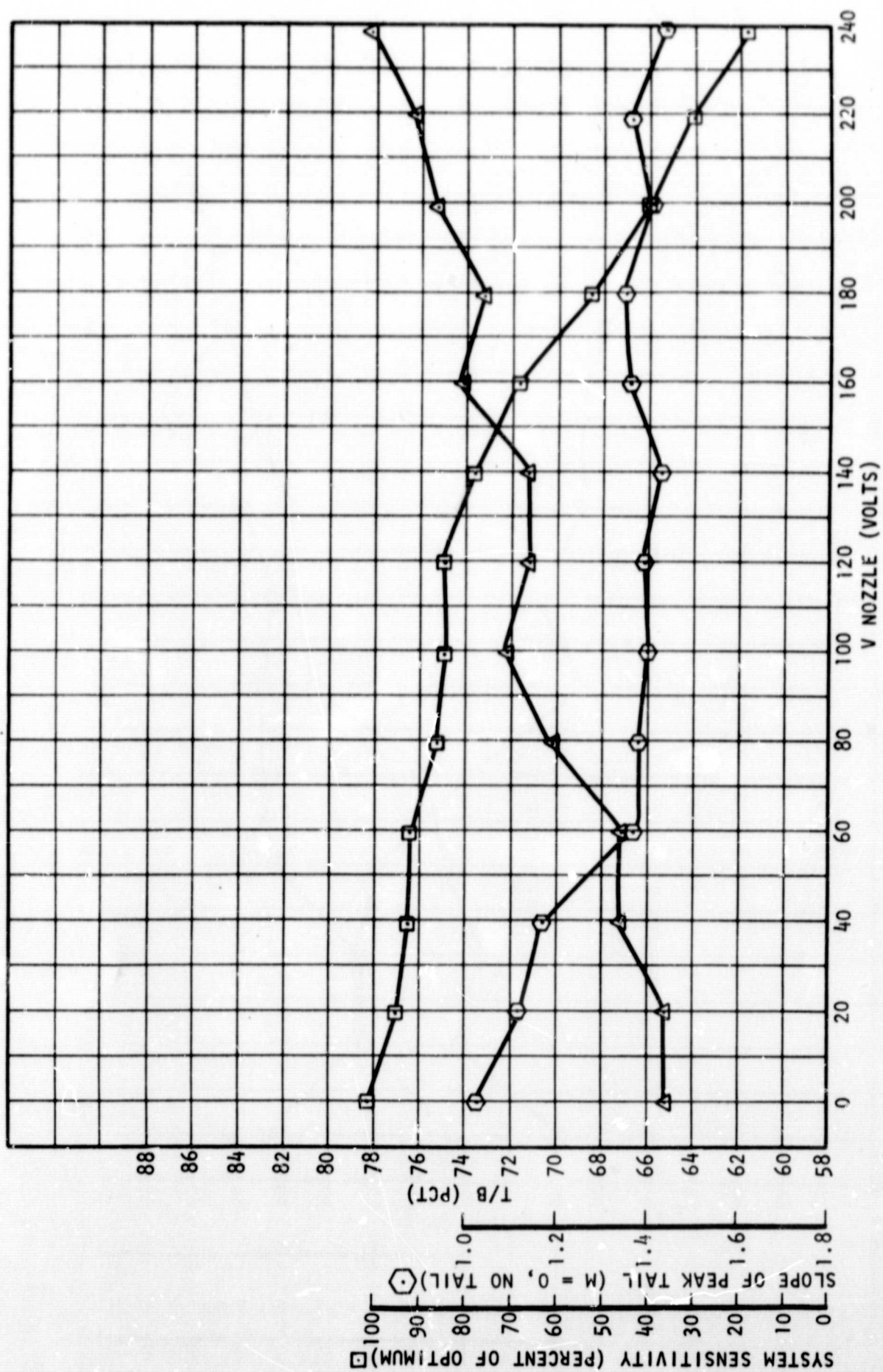


FIGURE 50. Nozzle Potential vs Peak Parameters

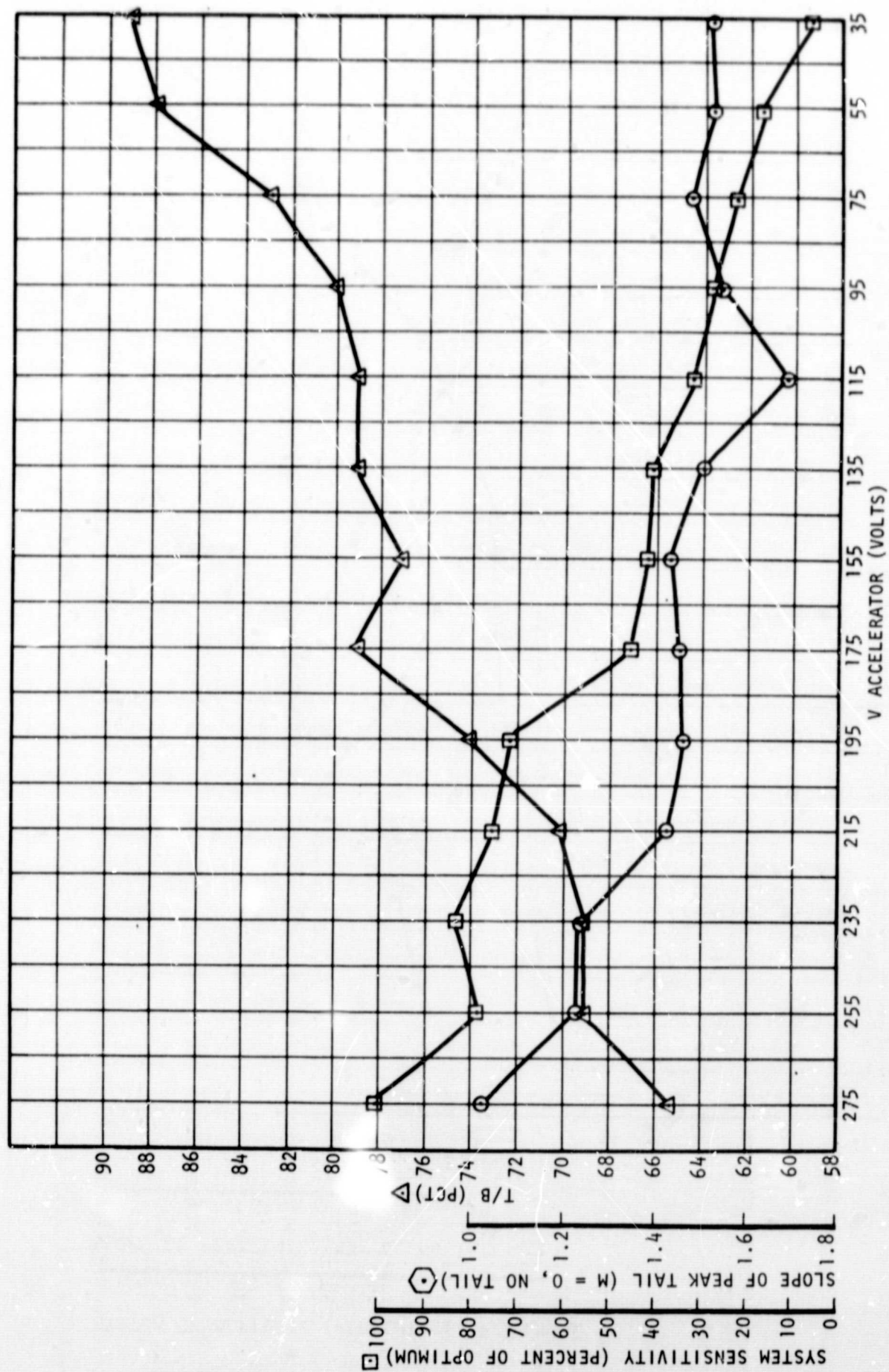


FIGURE 51. V_{ion} vs Peak Parameters

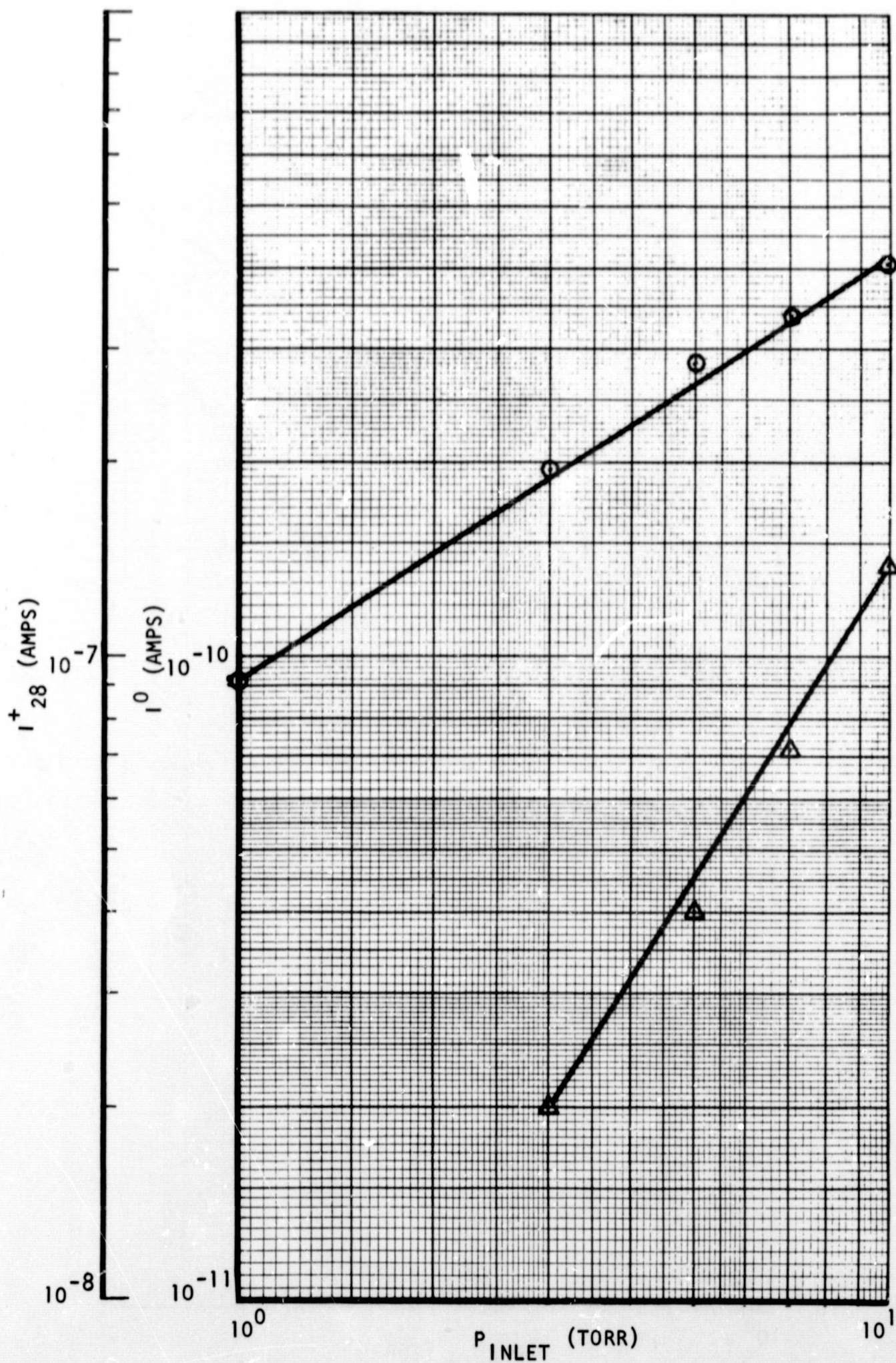


FIGURE 52. Relative I^+ and I^0 Intensities
(With Nozzle $V = 95$)

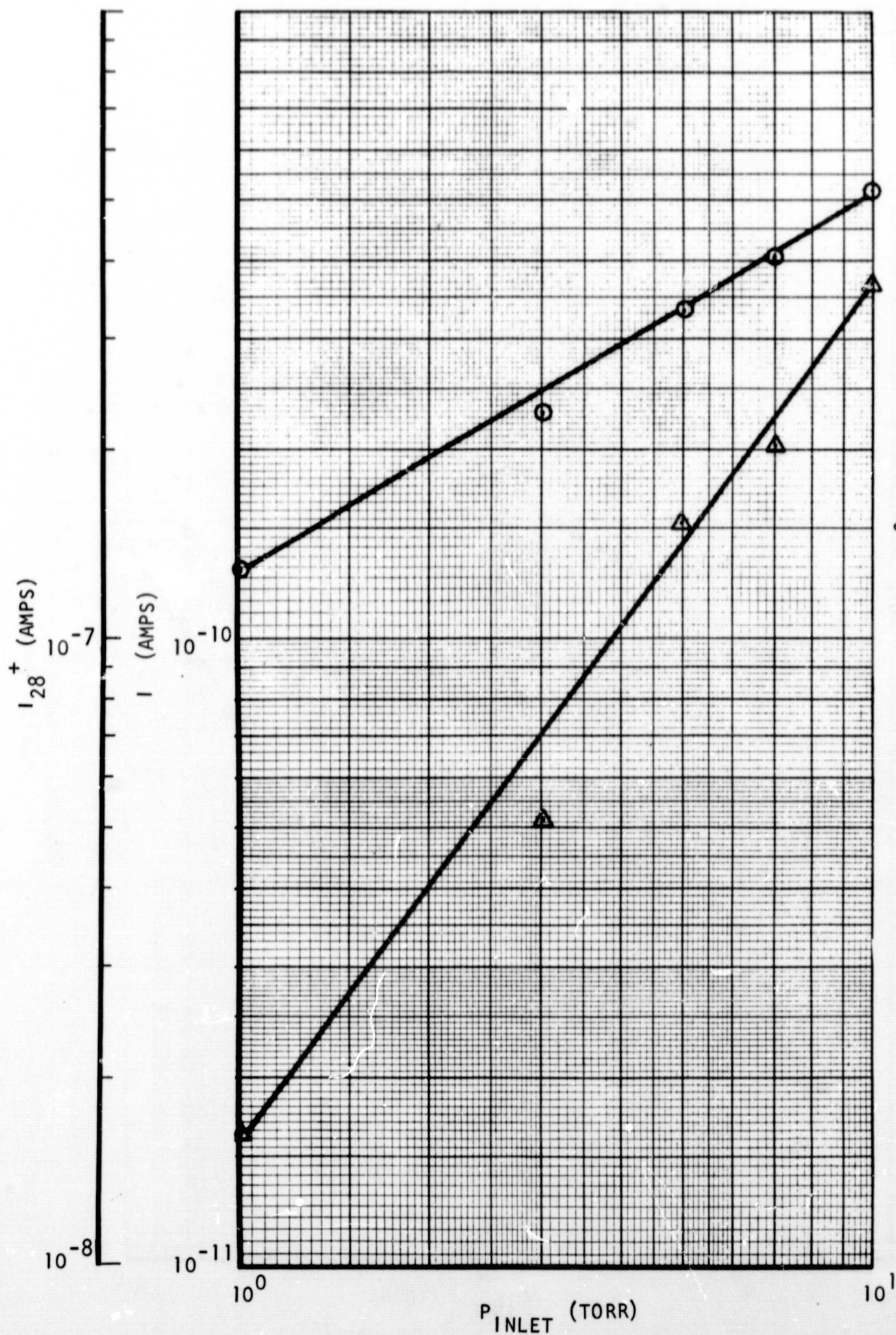


FIGURE 53. Relative I^+ and I° Intensities
(With Nozzle $V = 0$)

$I_{Ps} = 4.7 \mu A$
W/O MAGNET

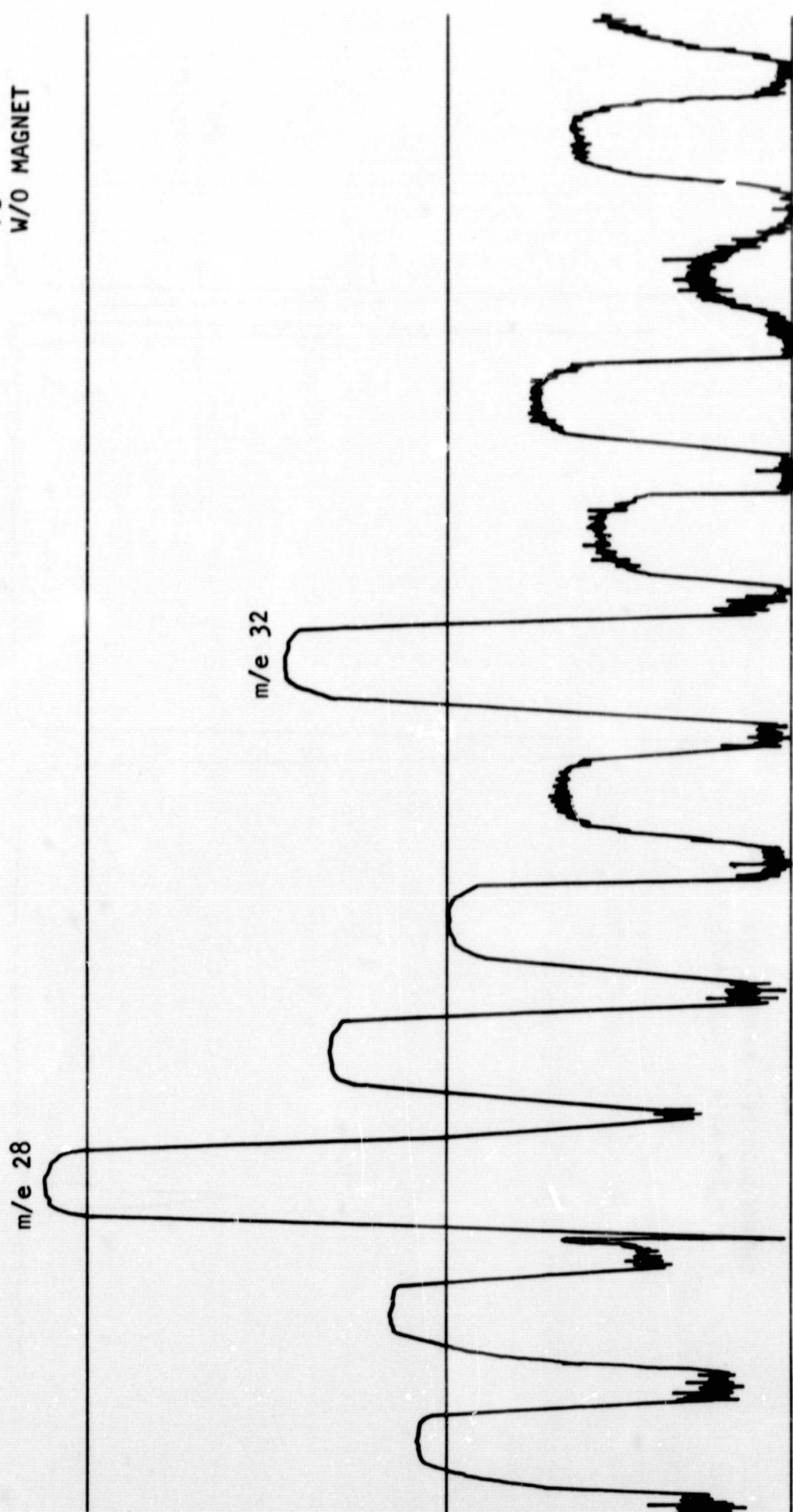


FIGURE 54. Dynamic Range V_{mvIT} - 2 kV

RESOLUTION

CARBON DIOXIDE - PROPANE MIX
 $M/\Delta M = 605$ WITH $0.003''$ CROSS MASK

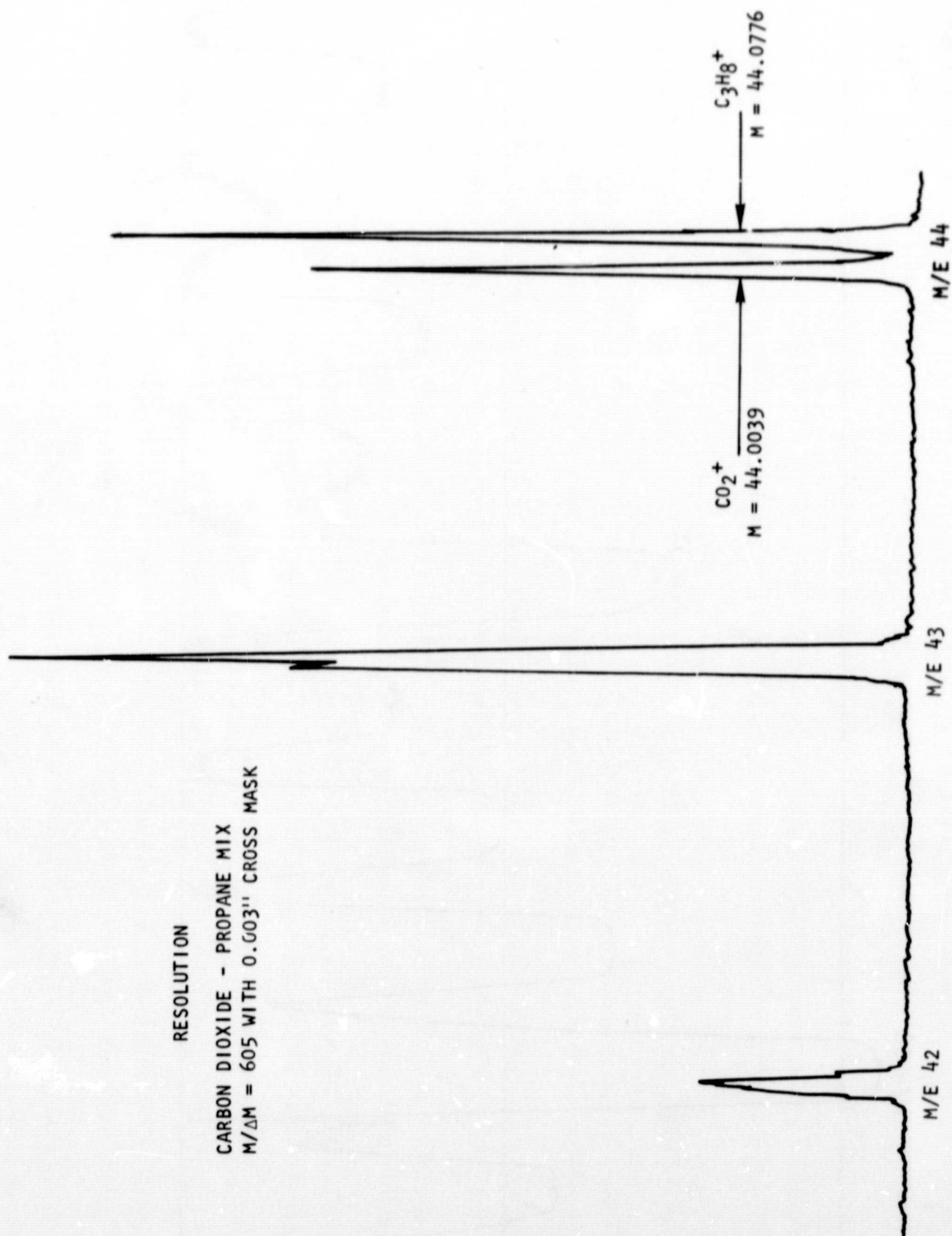


FIGURE 55. Hyperbolic Quadrupole Mass Spectrometer