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# STUDY PROGRAM FOR DESIGN IMPROVEMENTS OF THE X-3060 KLYSTRON

## PHASE III – ELECTRON GUN FABRICATION AND BEAM ANALYZER EVALUATION

## PHASE IV – KLYSTRON PROTOTYPE FABRICATION AND TESTING

**FINAL REPORT**

by

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ABSTRACT

On 20 May 1977, a study program was initiated which would lead to the eventual redesign and improvement of the Eimac X-3060 and X-3075 S-band high power klystrons.

The total redesign and improvement effort was divided into the four phases shown below:

Phase I - Study definition
Phase II - Design improvement
Phase III - Electron gun fabrication and beam analyzer evaluation
Phase IV - Klystron prototype fabrication and delivery.

Phase I was a software study which defined existing problems with the X-3060 and X-3075 klystrons. At the conclusion of Phase I, a JPL decision directed the remaining effort of the improvement program toward only the X-3060 klystron. Results of Phase I were presented in a final report dated January 1978, JPL Contract No. 954782.

Phase II, presented detailed design data for a new klystron which would eliminate the X-3060 design weaknesses described in the Phase I final report. The improvement study further indicated that substantial improvements could be made to both performance and reliability. Results of the design improvement study were reported in the final report dated January 1979, JPL Contract No. 954782.

This report deals with the completion of Phases III and IV, presenting information on the fabrication and beam analyzer testing of a new electron gun for the improved klystron, VKS-8274 JPL.

Also presented are comparative data on the performance of the X-3060 klystron, design predictions for the improved klystron, and performance data taken during recent acceptance testing of the prototype VKS-8274 JPL.

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LIST OF ILLUSTRATIONS

# I. INTRODUCTION

## A. BACKGROUND

The X-3060 klystron was first introduced in 1965. It is a 100 kW CW amplifier klystron, tunable over the 2100 to 2400 MHz range.

Questions have arisen about the field performance record of the X-3060, but its operational performance is difficult to assess. Field reports taken over an 11-year period indicate only 2526 total combined operational hours for six X-3060 klystrons. All tubes, however, are still in operable condition.

An early design defect in the heater/cathode configuration was corrected in 1974 by rebuilding all tubes with an improved potted heater design. Since that time, only one failure has been recorded in field operation. However, because of early "start-up" failures, the age of the present design, and an increased desire to provide the most reliable performance possible, it was prudent to review and critically evaluate the design of the X-3060 to determine whether improved reliability and performance could be achieved. This analysis was performed as Phase I of the present study program.

The evaluation was completed in October 1977. Results of the analysis were presented to JPL personnel in a design review meeting on 27 October 1977 and later in a final report dated January 1978 (Contract No. 954752).

This critical examination of the X-3060 design revealed certain weaknesses and design features which conflict with ultra-reliable klystron performance.

The findings and recommendations of the Phase I evaluation are summarized in Table I-1.

## X-3060
## DESIGN EVALUATION SUMMARY

| PARAMETER | RATING/COMMENTS | RECOMMENDATIONS |
|---|---|---|
| **A. ELECTRON GUN** | | |
| 1. CATHODE FILAMENT | GOOD | MAINTAIN |
| 2. CATHODE LOADING | EXCELLENT | MAINTAIN |
| 3. VOLTAGE GRADIENTS | FAIR | RE-DESIGN |
| 4. MODULATING ANODE | UNNECESSARY | ELIMINATE |
| **B. KLYSTRON BODY** | | |
| 1. TAIL PIPE | UNACCEPTABLE | RE-DESIGN |
| 2. TUBE/MAGNET ALIGNMENT | MARGINAL | RE-DESIGN (ACCOMPLISHED) |
| 3. TUNERS | DISADVANTAGEOUS | RE-DESIGN |
| 4. HIGHER EFFICIENCY | PRACTICAL | RE-DESIGN |
| 5. RF DESIGN PARAMETERS | FAIR | RE-DESIGN |
| 6. MECHANICAL RIGIDITY | MARGINAL | RE-DESIGN |
| **C. MAGNET** | | |
| 1. TUBE/MAGNET ALIGNMENT | MARGINAL | RE-DESIGN (ACCOMPLISHED) |
| 2. INDIVIDUAL CONTROL OF COILS | | RECOMMENDED |
| 3. MAGNET ASSEMBLY | NOT COMPATIBLE (NEW TAIL PIPE DESIGN) | RE-DESIGN |

TABLE I-1

The primary goal of Phase II was to produce a new paper design for the X-3060 klystron which eliminated the deficiencies and undesirable features shown by the Phase I evaluation.

A fundamental requirement of the new design was to increase reliability. A secondary effort was directed toward increasing the efficiency of the X-3060 but only insofar as it did not compromise reliability.

Although Phase II primarily concerned itself with computer designs and analysis, detailed layout and outline drawings were generated to present a more complete comparison between the new and the old designs.

The Phase II effort is completely described in a final report dated January 1979 under JPL Contract No. 954782.

Listed below are major modifications recommended by the Phase II design improvement study.

1. Gun ceramic lengthened to permit operation in air.

2. Modulating anode removed to reduce voltage gradients.

3. Increased drift tube and cavity wall cross section for improved thermal stability.

4. Incorporation of cavity wall cooling for thermal stability.

5. Modified gap and drift tube spacings for greater efficiency.

6. Elimination of complex wide-range tuner and replacement with simple trim tuner.

7. Elimination of complex extended tail pipe design and replacement with conventional waveguide output circuit.

8. Replacement of long taper waveguide with Tchebycheff step transition to maintain waveguide flange interface plane.

9. Modification of collector to incorporate conventional flytrap design (replaces extended tail pipe).

10. Modification of magnet to interface new tube design.

B. PHASE III AND IV DEFINED

1. Phase III

The objective of the Phase III effort is to produce a new design electron gun, which substantially improves the electron gun used on the X-3060 klystron.

A full scale, operational model was produced to verify the desirable design changes suggested by the Phase I and Phase II studies. Through beam analyzer study the correct electron beam diameter and cross-sectional profile were established in conjunction with the desired confining magnetic field. Results are discussed in the following sections.

2. Phase IV

The purpose of Phase IV was to fabricate and fully test a complete prototype klystron and focus magnet assembly. A final demonstration was conducted to verify the improved klystron performance predicted by Phases I and II and establish the incorporation of the electron gun developed in Phase III.

This new klystron is mechanically compatible with existing X-3060 klystron installations and meets the requirements of JPL Specification Document No. 409517.

Results are discussed in the following sections.

## II. ELECTRON GUN FABRICATION AND BEAM ANALYZER EVALUATION

### A. BACKGROUND AND NEW INFORMATION

At the conclusion of the Phase II study, it was clear that removal of the modulating anode from the X-3060 would substantially reduce the voltage gradients within the electron gun structure and thereby reduce any tendency toward arcing during high voltage operation. Computer design techniques were used to modify the focus electrode and anode design to compensate for the removal of the modulating anode. The correct electron trajectories and electron beam size were provided by this computer design.

A logical progression would dictate that the computer design be evaluated in the Varian beam analyzer to verify its performance. However, coincident with the Phase II study, another very high power development program (VKS-8269; 450 kW CW @ 2450 MHz) had produced an electron gun with such excellent performance that the decision was made to scale this newly proven design to fit the VKS-8274 JPL and test this scaled model in the beam analyzer. Beam analyzer testing at this point would be used then to verify the performance of the scaled model as opposed to the more common usage of iterative correction to the Phase II computer design.

This new scaled structure was first evaluated to see that the voltage gradient improvement established in the Phase II computer design would not be compromised. Quite the opposite was true. Because of the new design's larger physical dimensions and more generously radiused electrodes, a significant gain was made. When compared to the Phase II computer design, the highest gradient was reduced by 81%. Compared to the original X-3060's highest gradient of 312 kV/inch the new design's highest gradient of 143 kV/inch represents an improvement of $\frac{312}{143} = 2.18X$.

Figure II-1 presents a comparison of the three designs under discussion. The 250 kV/inch reference line shown represents a generally accepted value for conservative gradient design in a dc application. By any standards, the new VKS-8274 JPL design can be considered ultra-conservative.

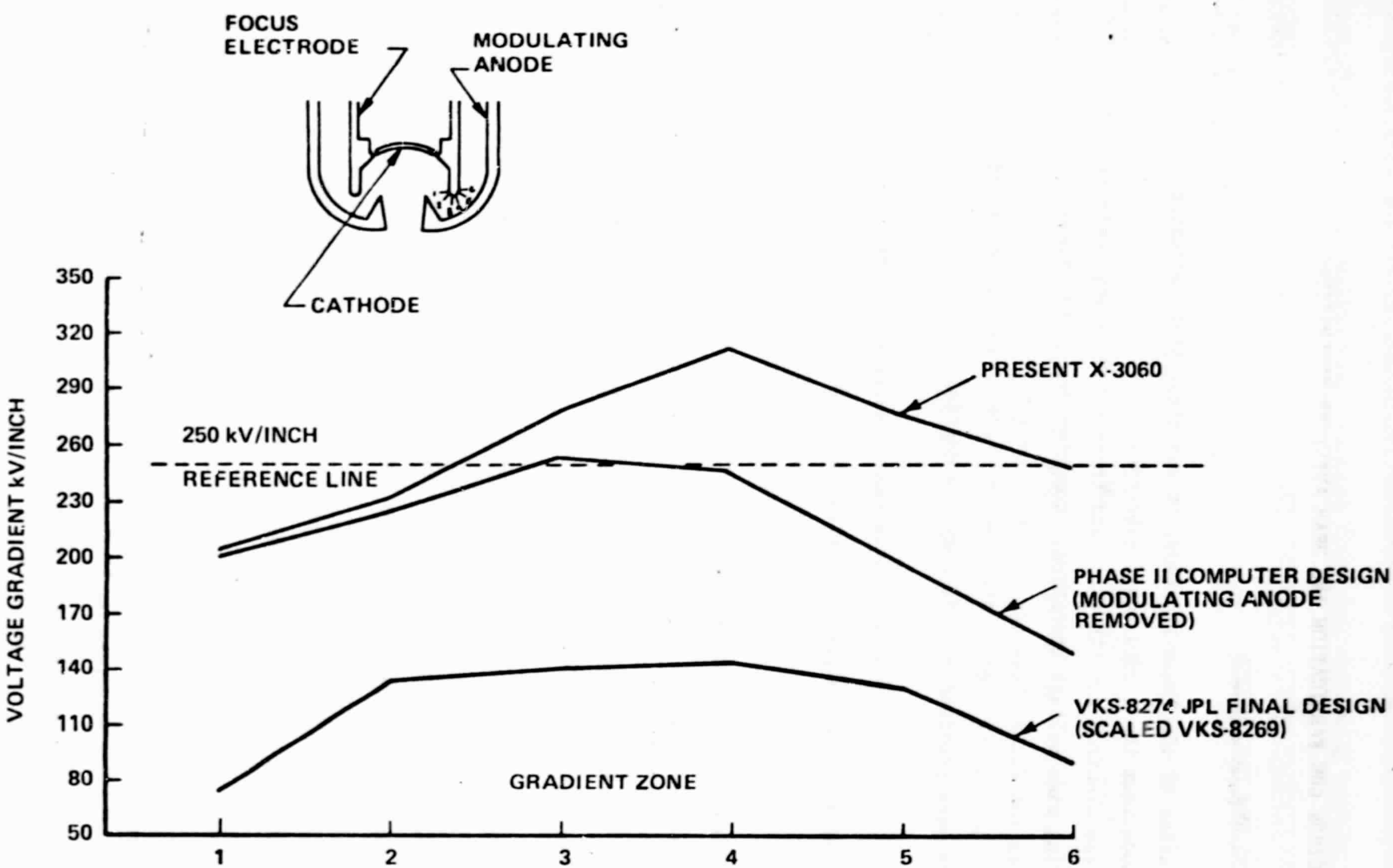



FIGURE II-1. HIGH VOLTAGE GRADIENT COMPARISON: THREE DESIGNS

One additional gain has been made in adopting the new design. Although the new design was scaled "down" from the 450 kW VKS-8269, it represents a scale "up" from the Phase II computer design and the X-3060 structure. The new cathode diameter is 1.263 inches compared to the 1.0 inch diameter of both the X-3060 and Phase II computer design. The increased diameter represents an increased area of 1.595 times and reduces the already conservative cathode loading of 1.375 A/cm$^2$ to 0.862 A/cm$^2$. The 0.862 A/cm$^2$ cathode loading is also in the ultra-conservative region, and will permit operation of the cathode at reduced temperatures; the best insurance possible for long life reliability.

One additional change has been made in the final design of the VKS-8274 JPL electron gun. It had been suggested in the Phase II study that the electron gun insulator be lengthened to provide operation in air, thus eliminating the costly socket tank now used. This suggestion was not acceptable from the standpoint of safety and would require an undesirable transmitter retrofit, therefore the insulator's design length was shortened to insure compatibility with existing socket tanks. Layout drawings of the X-3060 and the new VKS-8274 JPL electron guns are shown in Figures II-2 and II-3.

## B. DESCRIPTION OF THE BEAM ANALYZER

The beam analyzer is a device which scans the cross section of an electron stream. It is used primarily to scan the electron stream emitting from newly designed electron guns to be used on klystrons, TWT's, etc.

Salient features of this machine include a pin hole and split collector arrangement which can be used to scan the electron beam in two transverse directions as well as in the "Z" direction along the beam axis. This scanning examination of the electron beam is accomplished in an ultra-clean, ultra-high vacuum chamber. The ultimate purpose of the device is to determine beam size and cross-sectional current density.

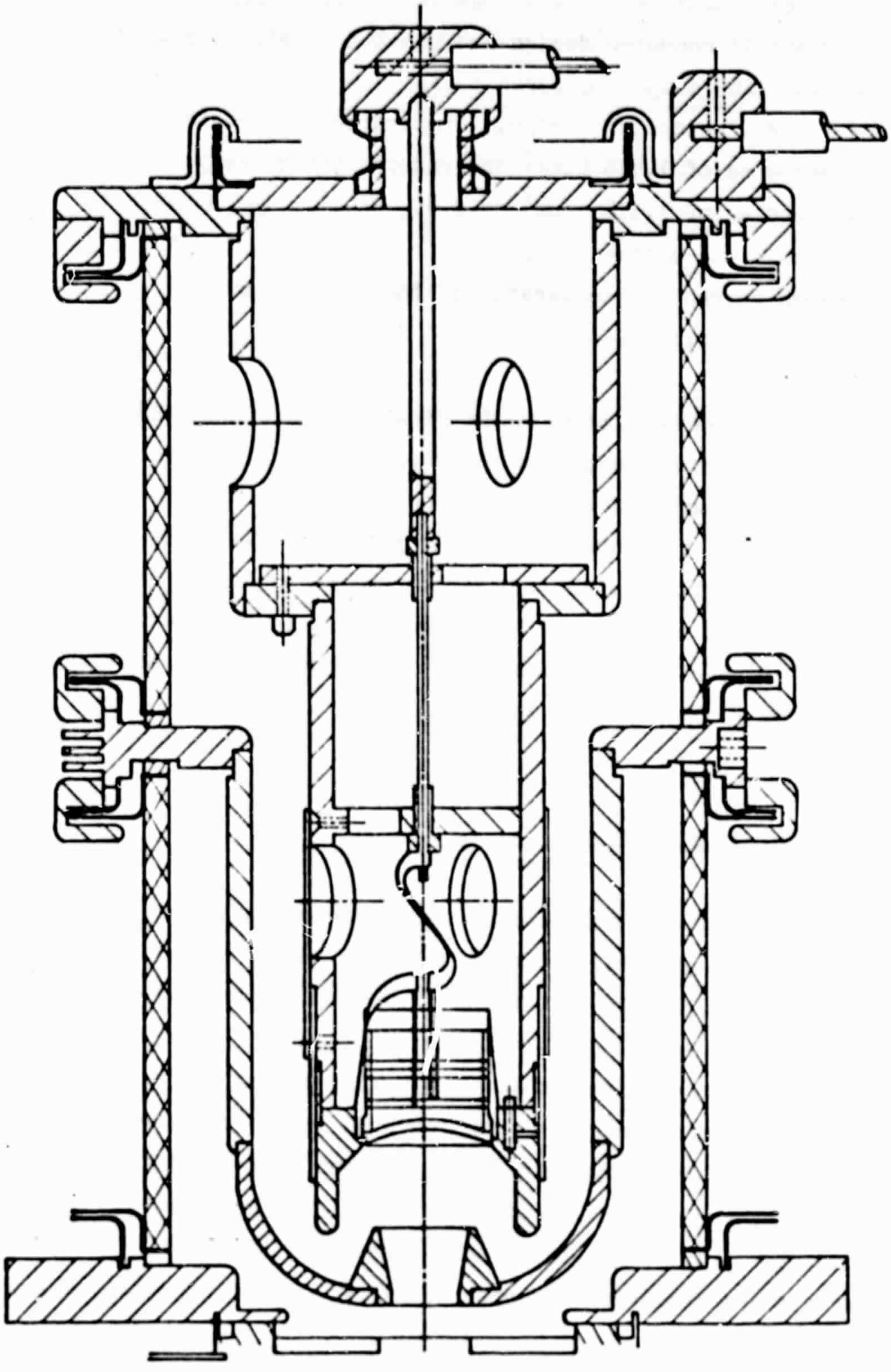


FIGURE II-2. EXISTING X-3060 ELECTRON GUN LAYOUT

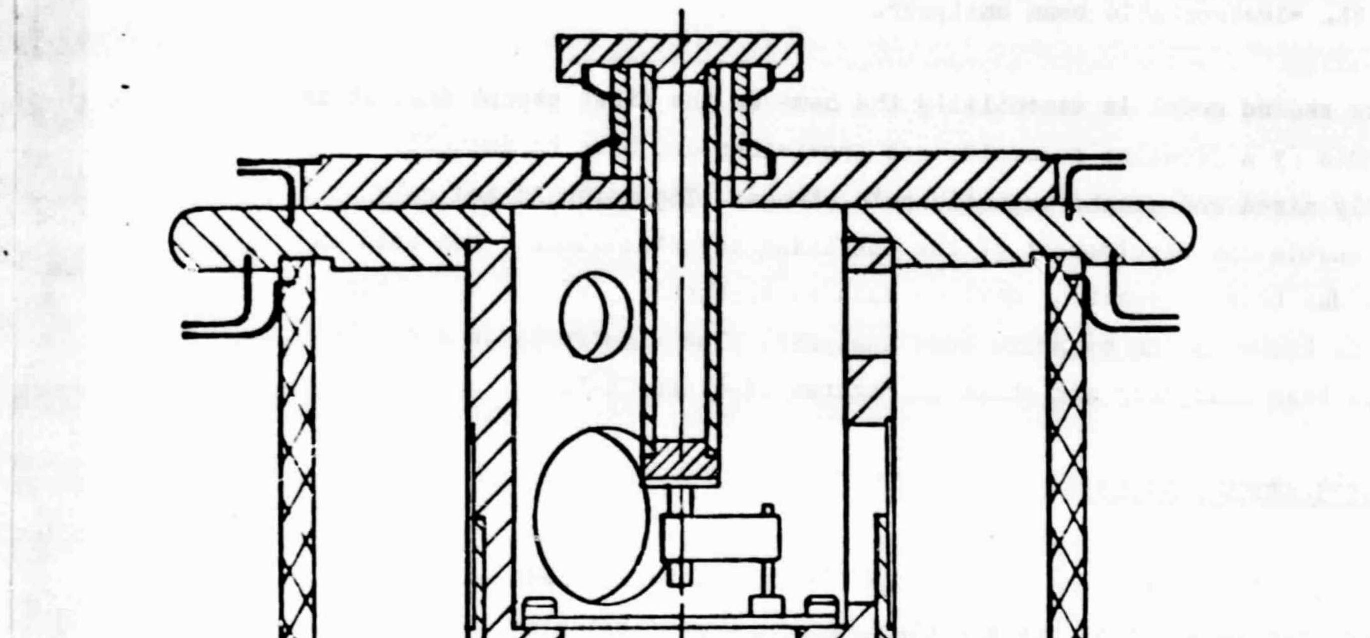


FIGURE II-3. NEW DESIGN LAYOUT VKS-8274 JPL

Currently, two models of this beam analyzer are being used to evaluate each new electron gun design. In the first model, all magnetic materials have been eliminated so that the true beam cross section can be determined without the influence of stray and unwanted magnetic fields. This unit is called the electrostatic beam analyzer.

The second model is essentially the same as the first except that it is surrounded by a focusing solenoid, and provisions are made to install variously sized and shaped magnetic pole pieces. The solenoid and pole pieces enable the development of the confining magnetic field often used in present day beam interaction devices such as klystrons, TWT's, etc. This device is known as the magnetic beam analyzer. The electrostatic and magnetic beam analyzers are shown in Figures II-4 and II-5.

## C. FABRICATION DETAILS

To take full advantage of both the electrostatic and magnetic beam analyzer, two versions of the new electron gun were fabricated. The two guns used many common parts, but were different in that one version used no magnetic components whatsoever, and the other used the proposed magnetic pole piece and magnetic field shaping cylinder. The construction of these two models is shown diagrammatically in Figures II-6, and II-7. The photographs, Figure II-8 and Figure II-9, show the actual test assembly used to evaluate the electrostatic beam.

## D. BEAM ANALYZER RESULTS

The three major goals in the development of an electron gun for the VKS-8274 JPL are shown below:

(1) Correct design perveance
(2) Correct design size electron beam
(3) Minimum longitudinal scalloping in the presence of the design magnetic field.

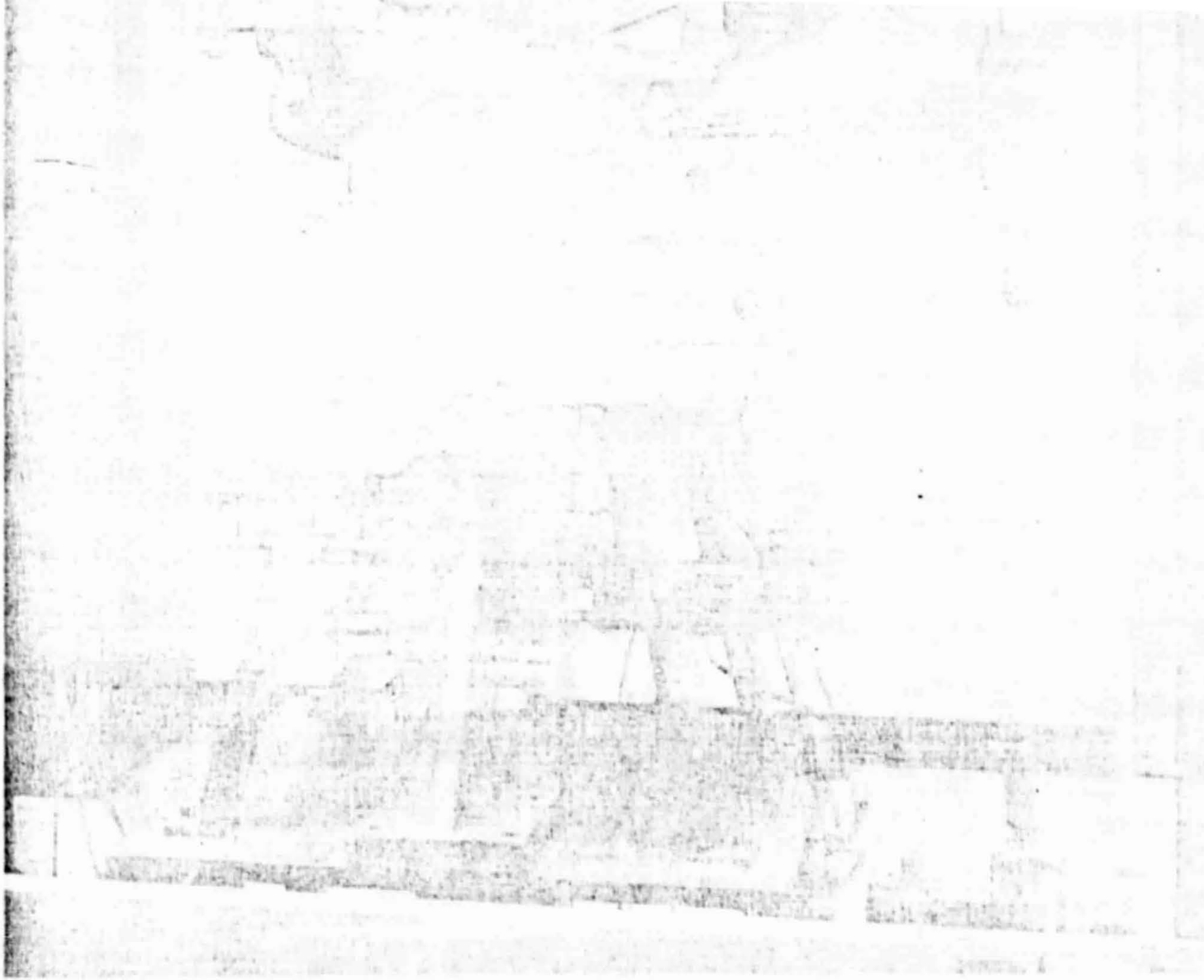


FIGURE II-4. ELECTROSTATIC BEAM ANALYZER

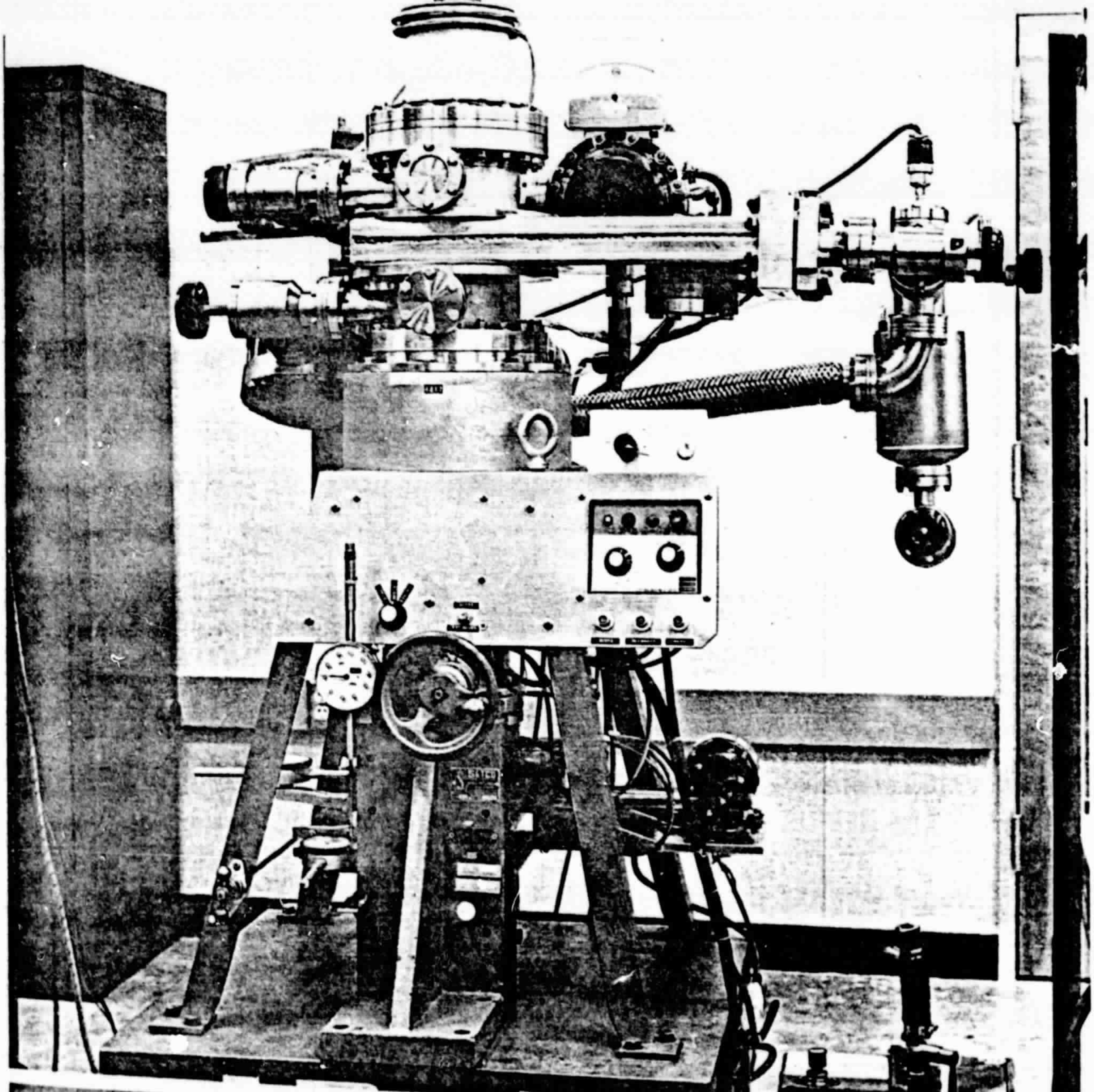
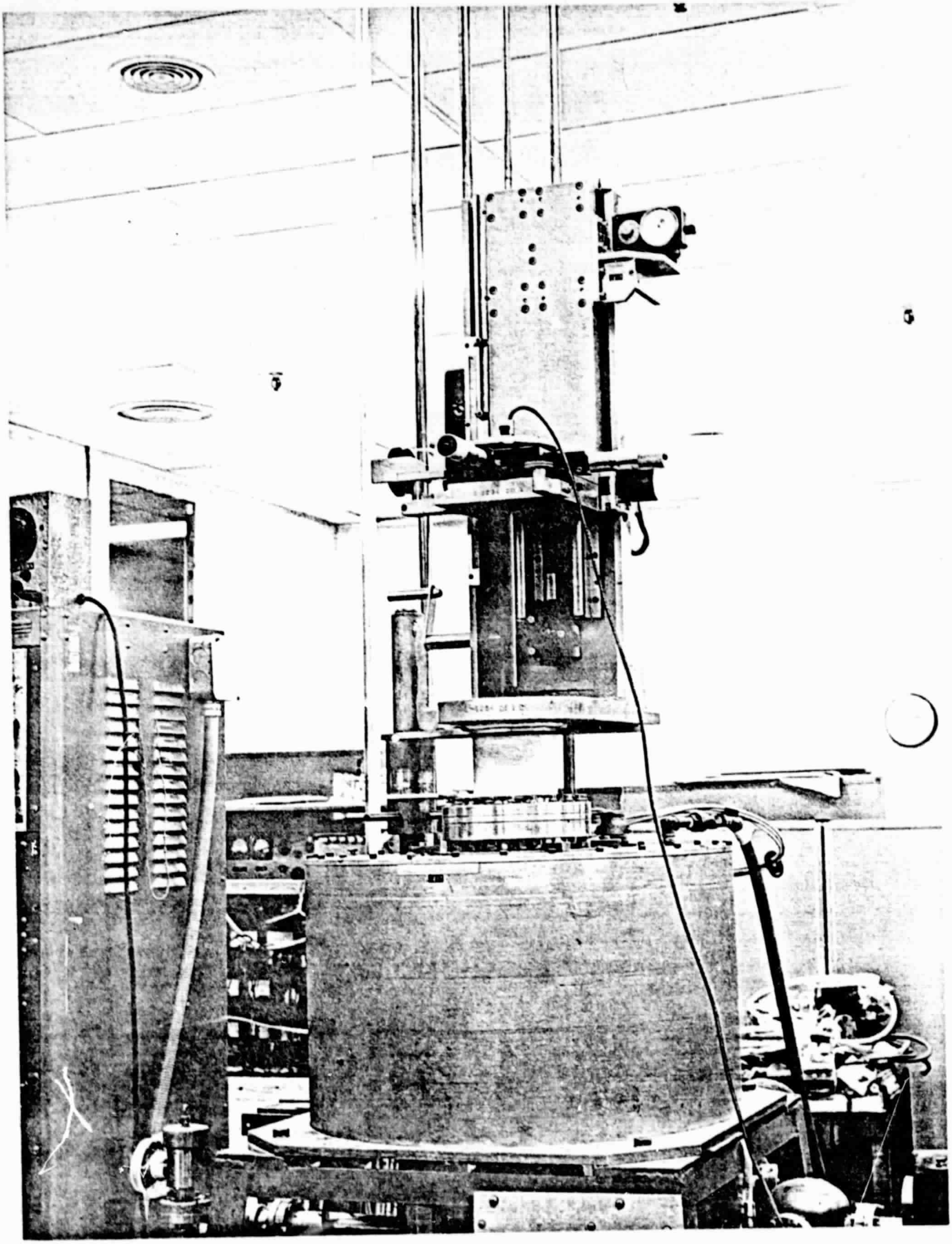


**FIGURE II-5. MAGNETIC BEAM ANALYZER**



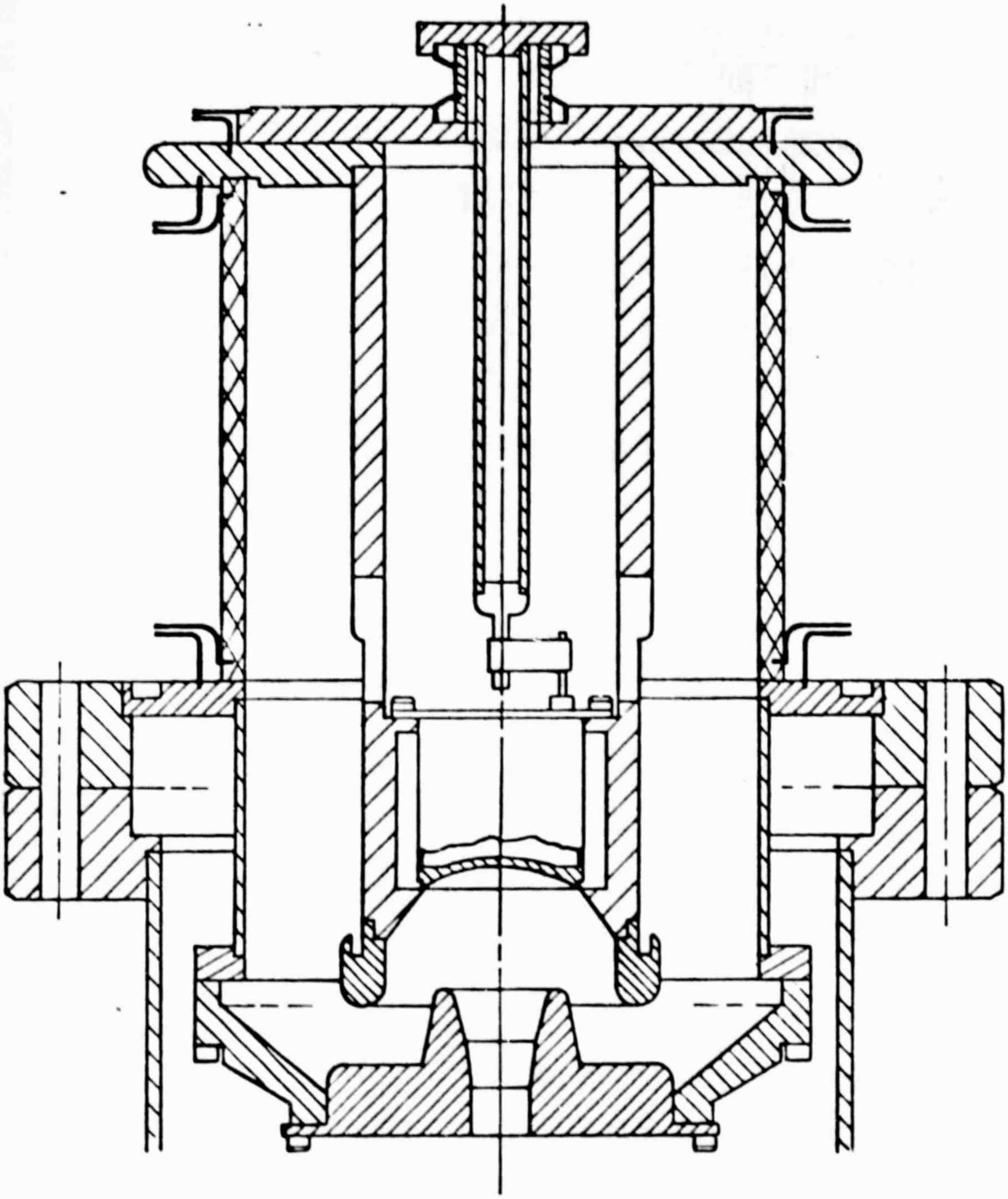


FIGURE II-6. ELECTROSTATIC GUN TEST MODEL (DIAGRAMMATIC)

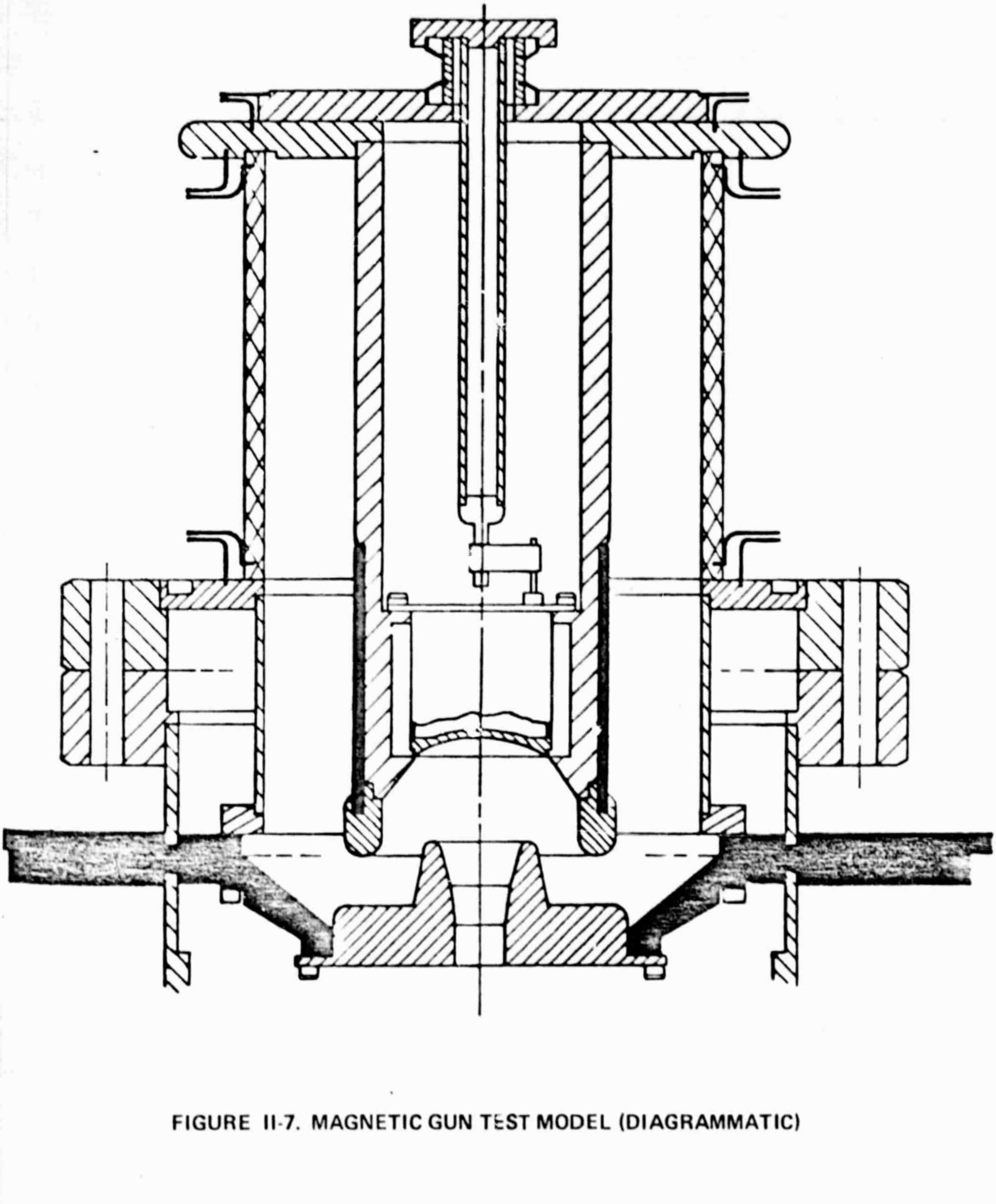


FIGURE II-7. MAGNETIC GUN TEST MODEL (DIAGRAMMATIC)

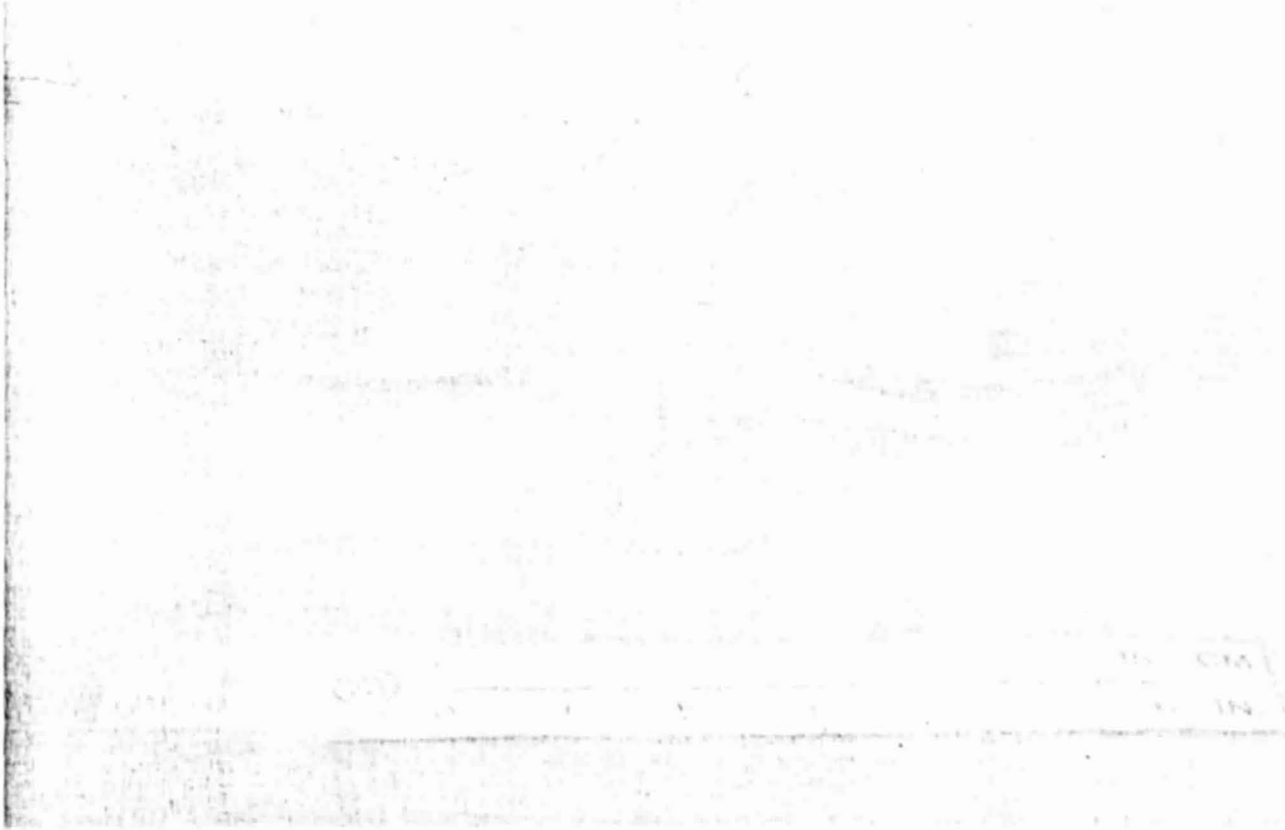




FIGURE II-8. ELECTROSTATIC GUN TEST MODEL DISASSEMBLED

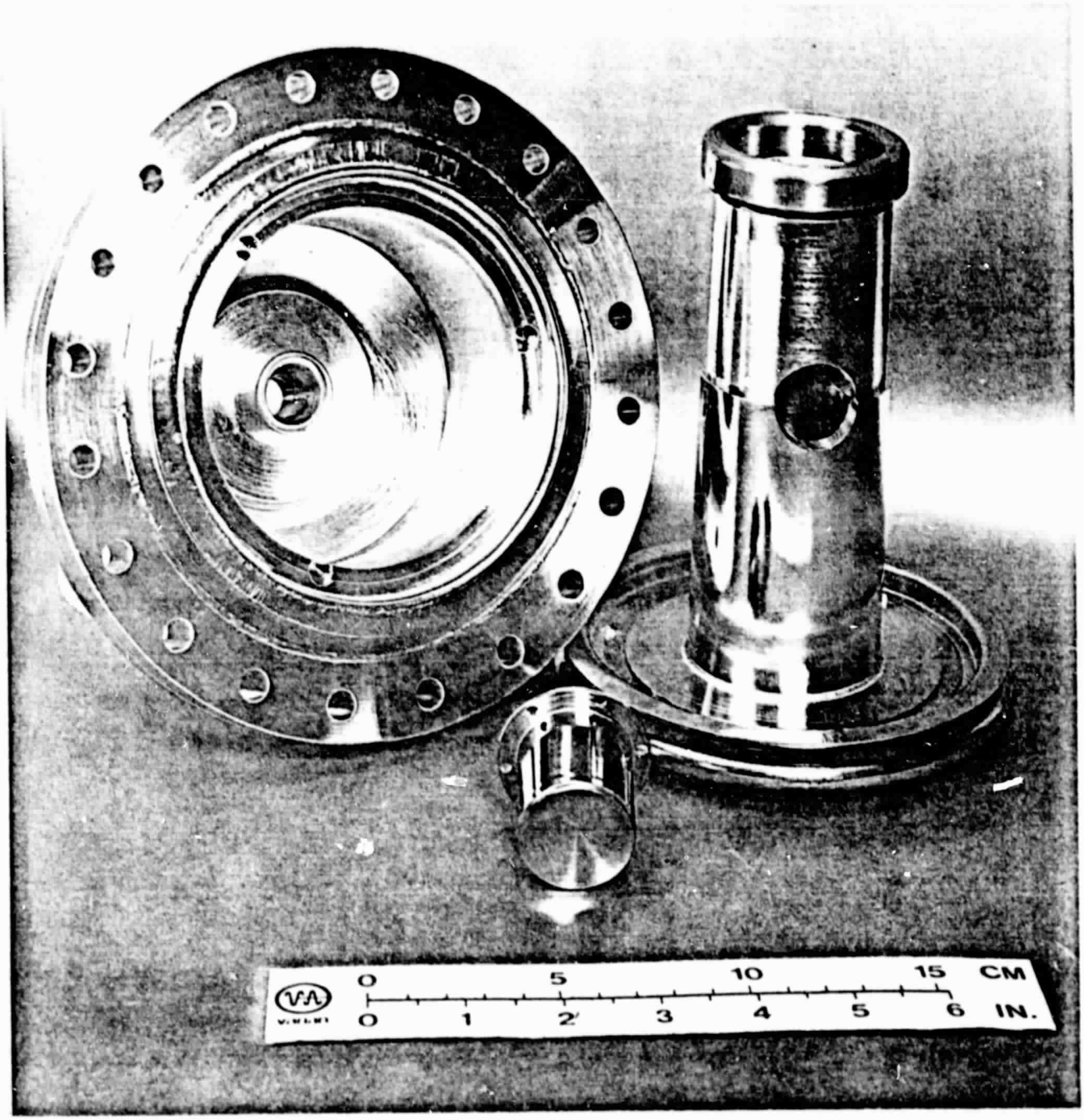

0 5 10 15 CM
0 1 2 3 4 5 6 IN.

FIGURE II-9. ELECTROSTATIC GUN TEST MODEL ASSEMBLY

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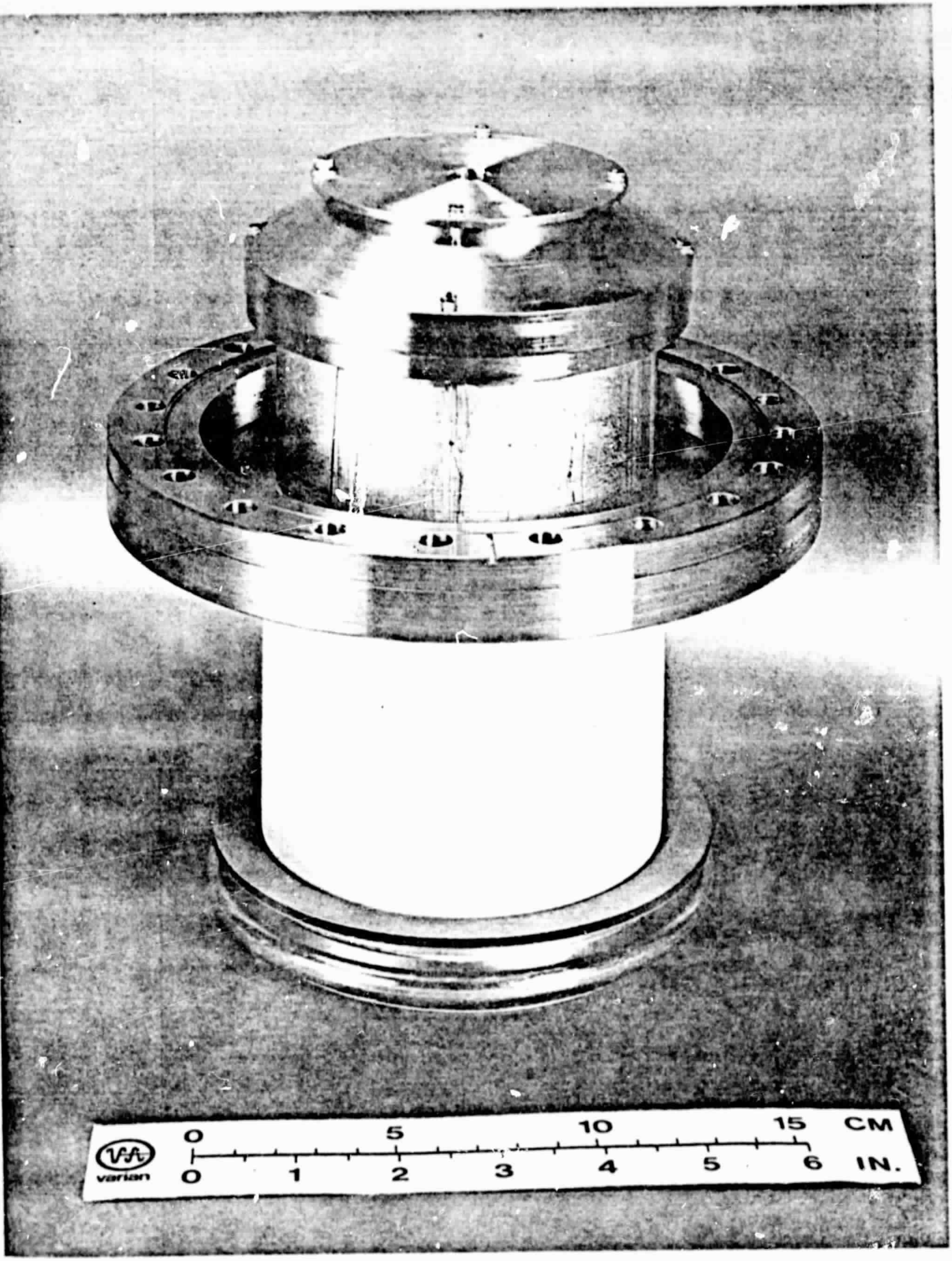

0 5 10 15 CM
0 1 2 3 4 5 6 IN.
varian

1. The rf design of the VKS-8274 JPL was established around a perveance $1.0 \times 10^{-6}$ electron gun. This perveance assures compatability with existing X-3060 installations and represents a conservative value in terms of good klystron performance and electron optics.

2. The desired beam size is determined primarily by the rf design parameters. The filling factor (beam size/tunnel size) is a compromise between the desire to have the best coupling (largest beam) for high efficiency and the requirement that the beam be small enough so that interception by the drift tubes will be minimal, thus insuring thermal stability and reliability. Experience has shown that a filling factor of 65% is a desirable compromise. The design tunnel size for the VKS-8274 JPL is 0.480", therefore, the target beam size is 0.65" x 0.480" = 0.312".

3. Minimum beam scalloping (size change) is an obvious design requirement, for without a consistent beam size, consistent performance is not possible. A badly scalloping beam will change size markedly with variations in both beam voltage and magnetic field, with subsequent changes in power output, gain and phase response. A reasonable target value for beam scallop is less than 10%, the scallop percentage being defined by:

$$\frac{\text{Beam maximum} - \text{Beam minimum}}{\text{Beam maximum} + \text{Beam minimum}} \times 100.$$

a. <u>Electrostatic Test</u>

Testing of any new electron gun design is performed first in the electrostatic beam analyzer, to determine its true characteristics without the presence of magnetic fields.

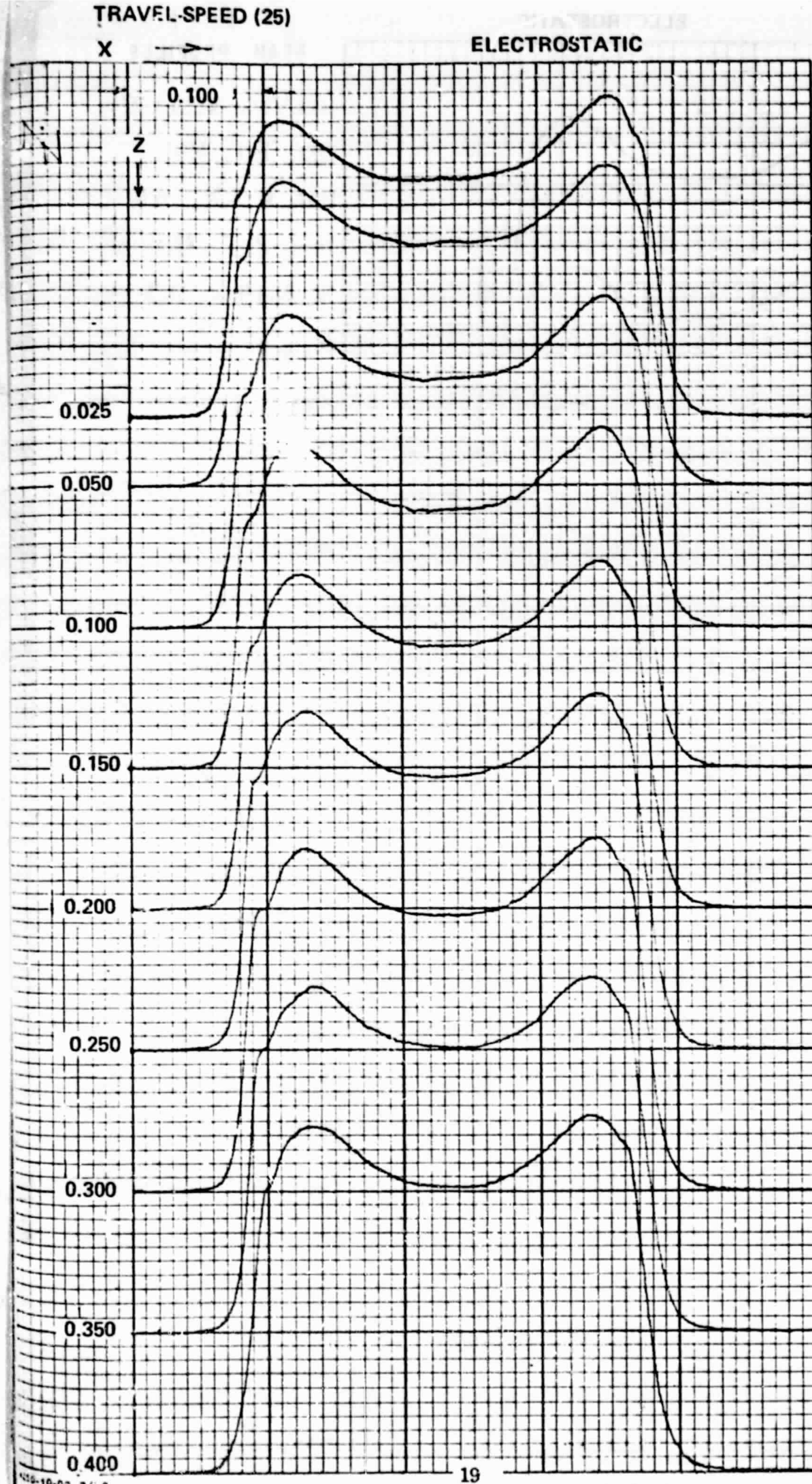
Figure II-10 and Figure II-11 show the electrostatic beam profile in the region of the beam minimum. The region beyond the beam minimum is of no importance in this test since it will later be completely controlled by the confining magnetic field. The beam is cross-sectionally scanned every 0.050" from just below the gun anode (0.025") to a point 0.700" from the anode. The beam minimum can be seen at a point 0.400" from the anode and shows a beam diameter on paper of 0.370". The presented curves are always in error (too wide) by the diameter of the pinhole in the scanning target. In this case, the target pinhole is 0.010" and when subtracted from the apparent width of 0.370" gives a true beam diameter of 0.360". This 0.360" beam, just 15% larger than the target value of 0.312", is considered very suitable for further testing in the magnetic field without alteration of the gun electrodes.

In addition, from the data presented, an excellent beam profile can be seen. The perveance is also on target at $1.008 \times 10^{-6}$.

2. Magnetic Test

After the electrostatic test above was completed, the electron gun was disassembled and rebuilt to include the magnetic elements shown heavily shaded in Figure II-7. It was then installed in the magnetic bear anlyzer for vacuum processing and testing.

Figures II-12 through II-15 show the beam profile in the presence of all the magnetic elements of the electron gun, and operating in the design magnetic field. As in the electrostatic tests, the beam profiles are taken from just below the anode (0.050"). In the magnetic tester, however, profiles are taken over an extended range, in this case, 3.5", to view more critically the confining effect of the




P-1

**BEAM PROFILES**

CODE VKS 8274 JPL

TYPE T-1 R-1

DATE 6-25 19 80

TIME: 7 : 25 A.M. P.M.

$E_h$ 11.19 $I_h$ 11.5 amps

$T_c$ °C br. corr.

$E_t$ 7 kV pulse dc

GUN FOCUS el.
E 7 kV pulse dc

LENS FOCUS el.
E kV pulse dc

$\mu_k$ 1.008

PRESSURE: PM off on

GUN $6 \times 10^{-8}$

TARGET

SOLENOID CURRENTS:

$I_{m1}$ amps

$I_{m2}$ amps

$I_{m3}$ amps

$I_{mg}$ amps

BIAS:
E
TARGET

$\Delta K_a = 0.930$

'0' Ref. TO CATH. 2.12

Rec. Cal. 0.100"/ square

REMARKS:

$I_K = 0.590 A$



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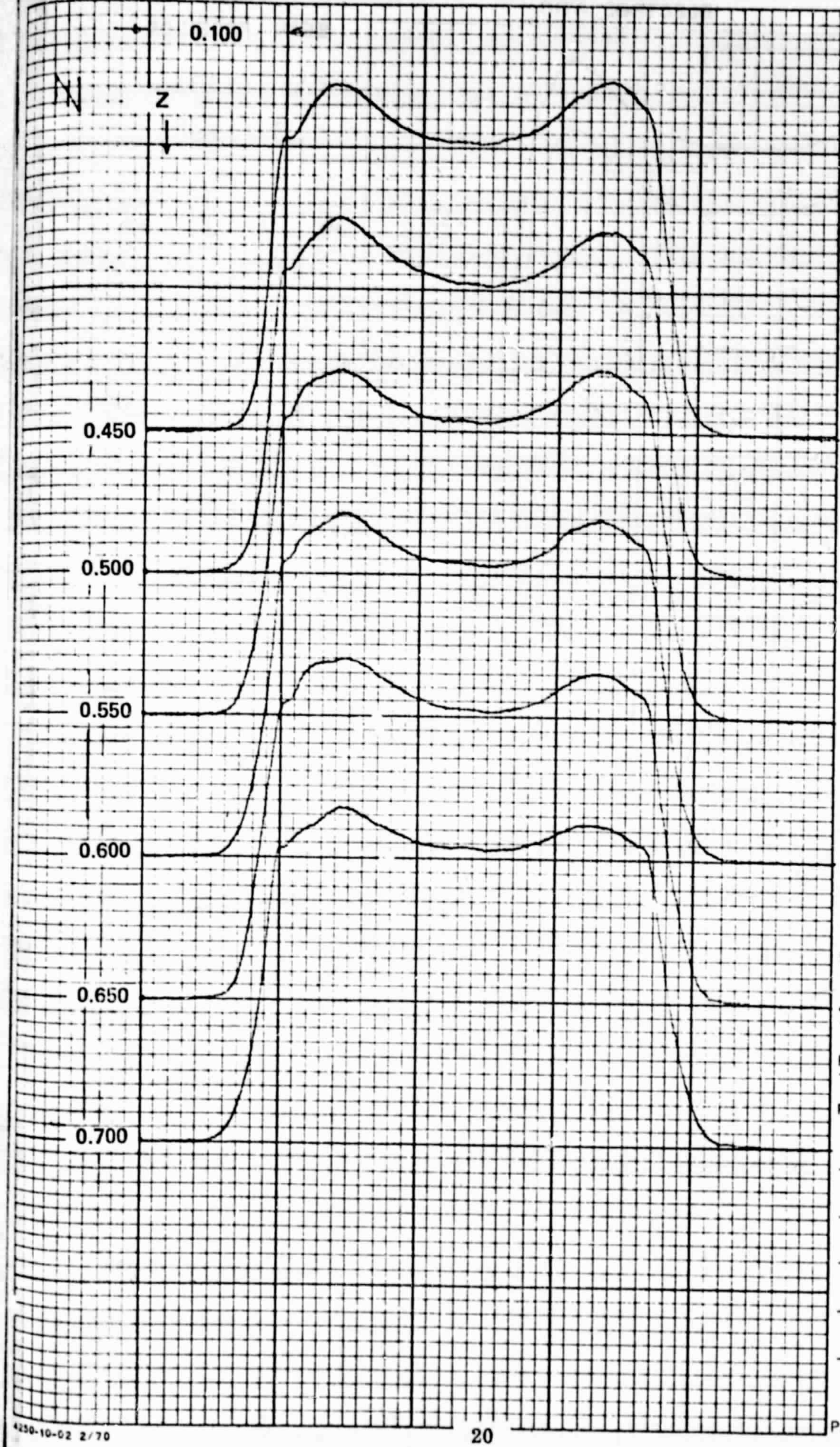
FIGURE II-10

TRAVEL-SPEED (25)

X →

**ELECTROSTATIC**




F-4.1

**BEAM PROFILES**

CODE VKS-8274 JPL

TYPE T-1 R-1

DATE 6-23 1980

TIME: 7 : 40 A.M. ~~P.M.~~

$E_h$ 11.19 $I_h$ 11.3 amps

$T_c$ °C br. corr.

$E_b$ 7 kV pulse dc

GUN FOCUS el. E 7 kV pulse dc

LENS FOCUS el. ~~E kV pulse dc~~

$\mu_k$ 1.008

PRESSURE: PM off on

GUN $6.5 \times 10^{-8}$

TARGET

SOLENOID CURRENTS:

$I_{m1}$ amps

$I_{m2}$ amps

$I_{m3}$ amps

$I_{mg}$ amps

BIAS: ~~E TARGET~~

$\Delta Ka = 0.930$

'O' Ref. To CATH. 2.121

Rec. Cal. 0.100" square

REMARKS:

$I_K = 0.590A$

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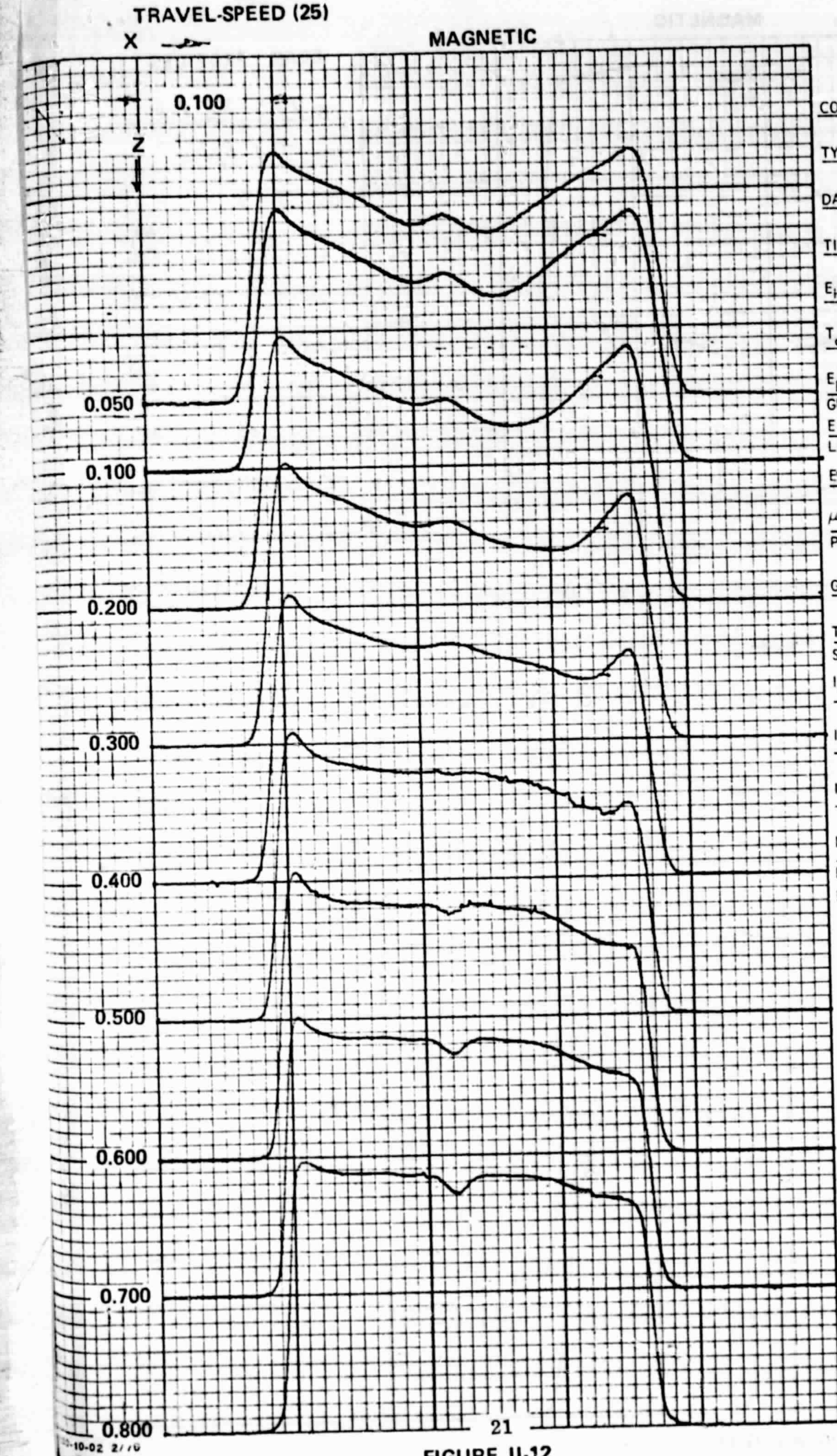
FIGURE II-11




## BEAM PROFILES

CODE *VKS 82 74*

TYPE *T-1 R-1a*

DATE *7-9-* 19*80*

TIME: *8 : 50* A.M. ~~P.M.~~

$E_h$ *10.0* $I_h$ *1* amps

$T_c$ *1100* °C br. corr.

$E_b$ *6* kV pulse ~~dc~~

GUN FOCUS el.

E *6* kV pulse ~~dc~~

LENS FOCUS el.

E ——— kV pulse dc

$\mu_k$ *0.991*

PRESSURE: PM ~~off~~ on

GUN *1.5X10⁻⁸*

TARGET

SOLENOID CURRENTS:

$I_{m1}$ *+5.0* amps

$I_{m2}$ amps

$I_{m3}$ amps

$I_{m4}$ amps

BIAS:

E ———

TARGET

$E_{sc}$ *Δka = 0.460*

'0' Ref. *TO-CATH. 2.121*

Rec. Cal. *0.100* square

REMARKS:

*$I_K$ = 461 MA*

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FIGURE II-12

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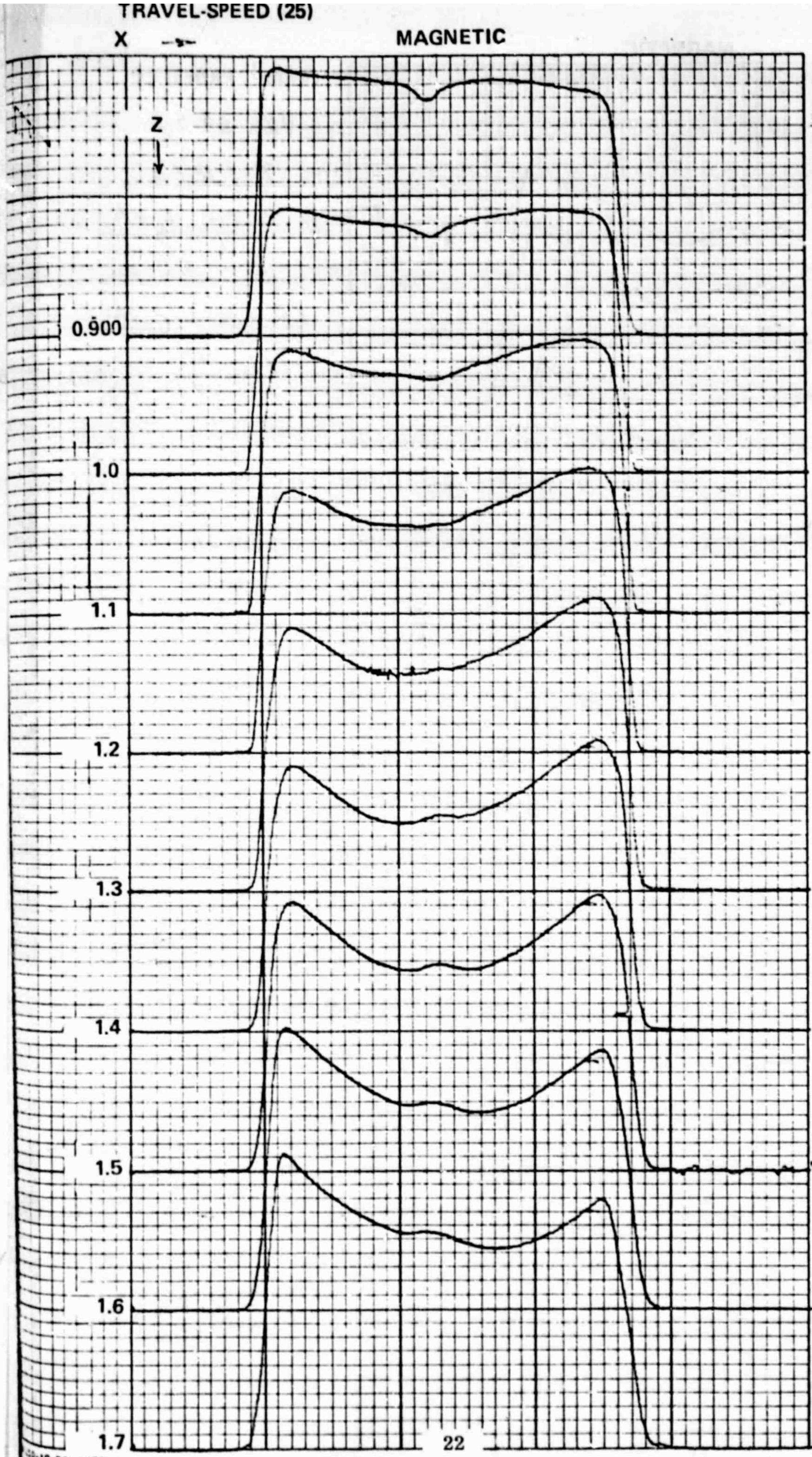


**BEAM PROFILES**

CODE VKS 8274

TYPE T-1 R-1a

DATE 7-9- 19 80

TIME: 9 : 15 A.M. ~~P.M.~~

$E_h$ 10.0 $I_h$ 10.61 amps

$T_c$ 1100 °C br. corr.

$E_b$ 6 kV pulse dc

GUN FOCUS el.
E 6 kV pulse ~~dc~~

LENS FOCUS el.
~~E kV~~ pulse ~~dc~~

$\mu_k$ 0.991

PRESSURE: PM off on

GUN 1.5X10^-8

TARGET

SOLENOID CURRENTS:

$I_{m1}$ + 5.0 amps

$I_{m2}$ amps

$I_{m3}$ amps

$I_{m4}$ amps

BIAS:

E

~~TARGET~~

Δka = 0.960

'O' Ref. TO CATH = 2.12

Rec. Col. 0.100 square

REMARKS:

Ik = 461 MA

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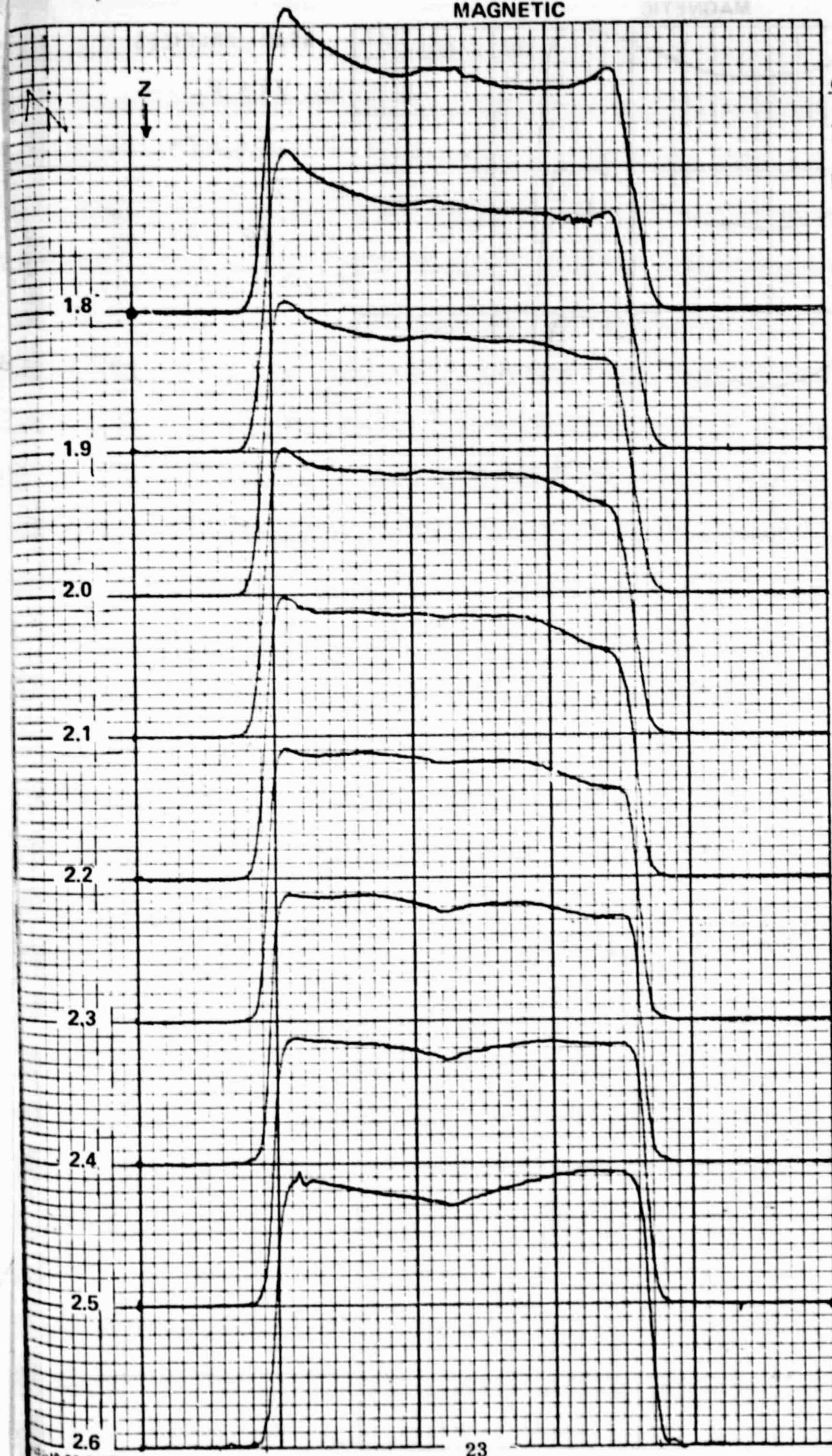
FIGURE II-13




**BEAM PROFILES**

CODE VKS 8274

TYPE T-1 R-1a

DATE 7-9-1980

TIME: 9:40 A.M.

$E_h$ 10.0 $I_h$ 10.61 amps

$T_c$ 1100 °C br. corr.

$E_b$ kV pulse dc

GUN FOCUS el.
E 6 kV pulse dc

LENS FOCUS el.
E kV pulse dc

$\mu_k$ 0.991

PRESSURE: PM off on

GUN $1.5 \times 10^{-7}$

TARGET

SOLENOID CURRENTS:

$I_{m1}$ +5.0 amps

$I_{m2}$ amps

$I_{m3}$ amps

$I_{m4}$ amps

BIAS:
E
TARGET

$\Delta ka = 0.400$

'O' Ref. TO-CATH = 2.12

Rec. Cal. 0.100 square

REMARKS:

$I_k$ = 461 MA

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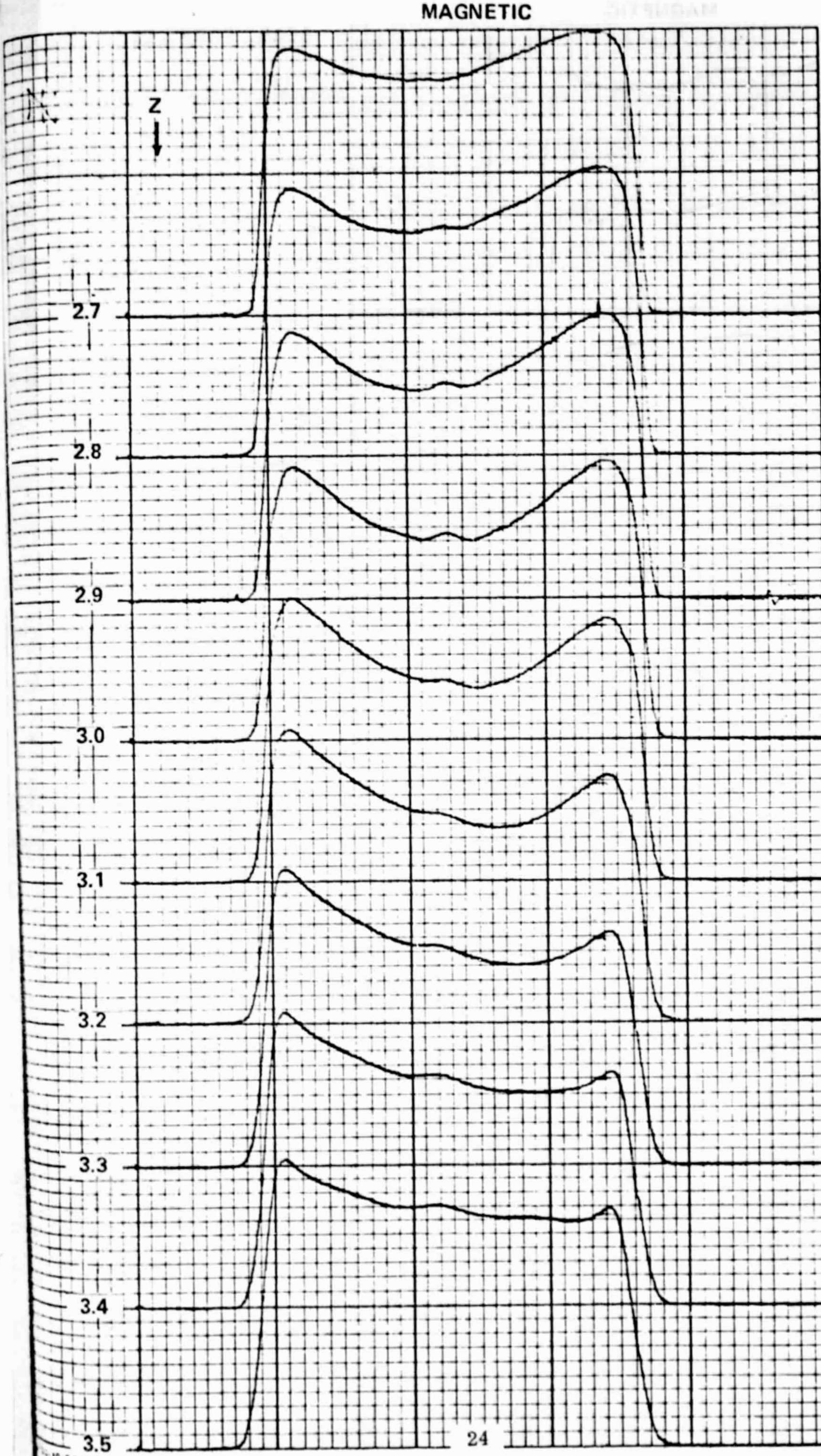
FIGURE II-14

## MAGNETIC




## BEAM PROFILES

CODE VKS 8274

TYPE T-1 R-1a

DATE 7-9- 1980

TIME: 10 : 00 A.M. ~~P.M.~~

$E_h$ 10.0 $I_h$ 10.61 amps

$T_c$ °C br. corr.

$E_b$ 6 kV pulse ~~dc~~

GUN FOCUS el.
E 6 kV pulse ~~dc~~

LENS FOCUS el.
E kV pulse dc

$\mu_k$ 0.991

PRESSURE: PM off on

GUN $1.5 \times 10^{-8}$

TARGET

SOLENOID CURRENTS:

$I_{m1}$ — [illegible] amps

$I_{m2}$ amps

$I_{m3}$ amps

$I_{m4}$ amps

BIAS:
E
TARGET

$E_{kc}$ $\Delta ka = 0.950$

'0' Ref. To-CATH = 2.131

Rec. Cal. 0.100 square

REMARKS:

Ik = 461 mA



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FIGURE II-15

magnetic field. This 3.5" scan represents a distance in the actual klystron which extends well past the input cavity of the klystron. From this point on, the confining magnetic field is uniform and no further change in the beam profile will occur.

Results of the magnetic beam tester are as follows:

a. The diameter of the electron beam at the former beam minimum (Z = 0.400") has been compressed from 0.360" to 0.305").

b. The first inward scallop occurs at Z = 1.0" and the beam diameter is measured at 0.280".

c. The first outward scallop occurs at Z = 1.9" and measured 0.300".

d. The scallop pattern is essentially repeated for the remainder of the Z axis traverse.

Comparison of the largest beam diameter to the design target $= \frac{0.312"}{0.300"} = 1.04"$, just 4% from the design goal.

The beam scallop as defined by

$$\frac{\text{Beam maximum} - \text{Beam minimum}}{\text{Beam maximum} + \text{Beam minimum}} \times 100\%$$

Calculates to be:

$$\frac{0.300 - 0.280}{0.300 + 0.280} \times 100\% = 3.45\%\text{, an insignificant ripple.}$$

The current density profile is quite uniform and compares favorably with well tested electron beams. The minor variations in the beam profiles, as they are scanned on the Z axis, have been previously traced to slight misalignment of the electron and magnetic axis. This is not expected in the actual klystron.

In summary, the beam analyzer tests have shown the production of an excellent electron optical system, and verifies that the excellent performance of VKS-8269 (450 kW @ 2450 MHz) is to a large degree dependent on an excellent electron beam. It permits the prediction of comparable performance in the VKS-8274 JPL.

## III. KLYSTRON PROTOTYPE FABRICATION

### A. MECHANICAL DESIGN IMPROVEMENTS

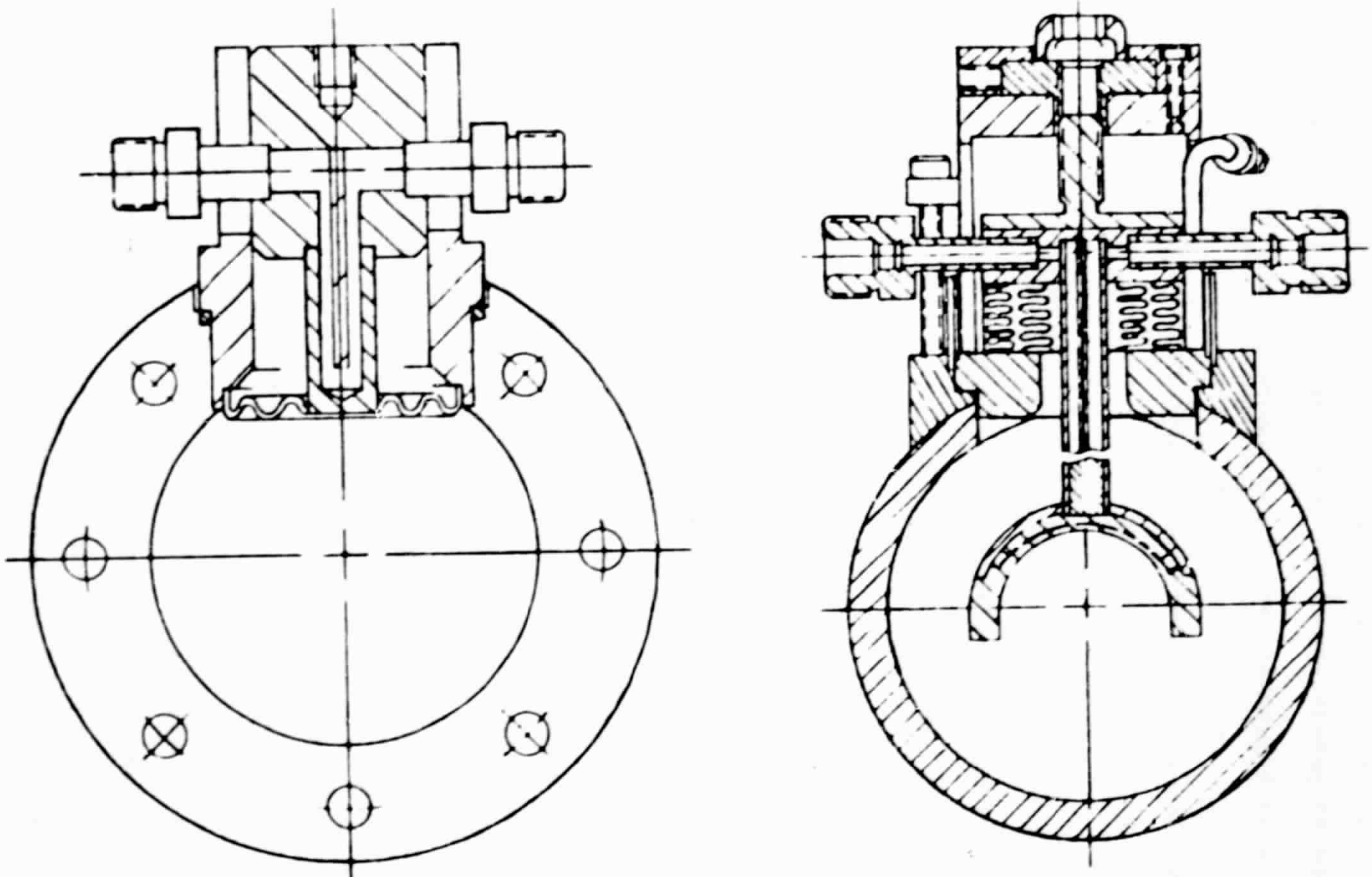
With only one minor exception, all mechanical improvements proposed in the Phase II Design Improvement final report were incorporated in the VKS-8274 JPL klystron. That one minor exception concerns the lengthening of the electron gun insulator to permit operation of the VKS-8274 JPL in air. As mentioned previously, this suggestion was found unacceptable with regard to operational safety and therefore this modification was not incorporated. The insulator's length was changed to permit compatability with existing oil-filled socket tanks.

The mechanical improvements proposed by the Phase II Design Improvements final report and also incorporated in the VKS-8274 JPL prototype klystron are reviewed below.

#### 1. Diaphragm Trim Tuner

The proposed trim tuner used in the VKS-8274 JPL, and the wide-range tuner now used in the X-3060, are shown in Figure III-1. Casual observation will show the complexity of the old tuner design as compared to the new trim tuner. Not so obvious in the old design are the six vacuum-to-water and three vacuum-to-air brazing joints used in the present X-3060 tuner. In addition to the large number, many of the brazing joints are blind; that is, they can neither be inspected nor repaired after the final braze pass. This type of assembly severely compromises reliability and rebuildability. Compared to this, the trim-tuner design has only <u>two</u> vacuum-to-air brazing joints and <u>no</u> vacuum-to-water joints. Neither of the vacuum-to-air joints is blind, and both are easily repairable.

In addition to these mechanical advantages, the trim-tuner diaphragm is relatively far removed from the high rf fields at the drift tube gap center and is subjected to far less rf heating than the present X-3060 capacitive paddle. The diaphragm is thermally coupled by large cross-sectional areas of copper to the massive water-cooled copper cavity



A B

FIGURE III-1. TUNER DESIGNS COMPARED

walls. In Figure III-1A, a water-cooled post is shown joined to the diaphragm face. This was a contingency plan only, and no diaphragm cooling was required.

2. Extended Tail Pipe Elimination

The extended tail pipe configuration shown in Figure III-2 was first introduced in the X-3060 klystron in 1965. Its purpose was to minimize the asymmetry normally caused by the exit path of the output waveguide through the focusing magnet, and to reduce to an absolute minimum body current interception caused by the magnetic asymmetry. Mechanical considerations, however, created an extended tail pipe section that is exposed to a rapidly expanding electron beam just beyond the output gap. This extended section has created both direct and indirectly related failures in the X-3060 klystron. The problem is caused by the fact that the electron beam expands in that region faster than was predicted at the time of the design's introducton, and, in addition, secondary electrons return from the collector to impinge on the tail pipe surfaces. For these reasons, and because the tail pipe is electrically part of the klystron body, the body current readings for the X-3060 have been recorded as high as 10% of the total beam current (700 mA). This tail pipe current (reading as body current) completely masks body current interception in any other part of the rf structure and is unacceptable because it requires that body current protective-circuit trip levels be set too high (1.0A). This removes the protection required in the remainder of the rf structure which may suffer damage from relatively low-quantity (0.050 A), but high-velocity electrons.

Under the circumstances just described, protection cannot be provided for the following common field conditions:

a. Low or incorrectly adjusted magnetic field;
b. incorrect tuning;

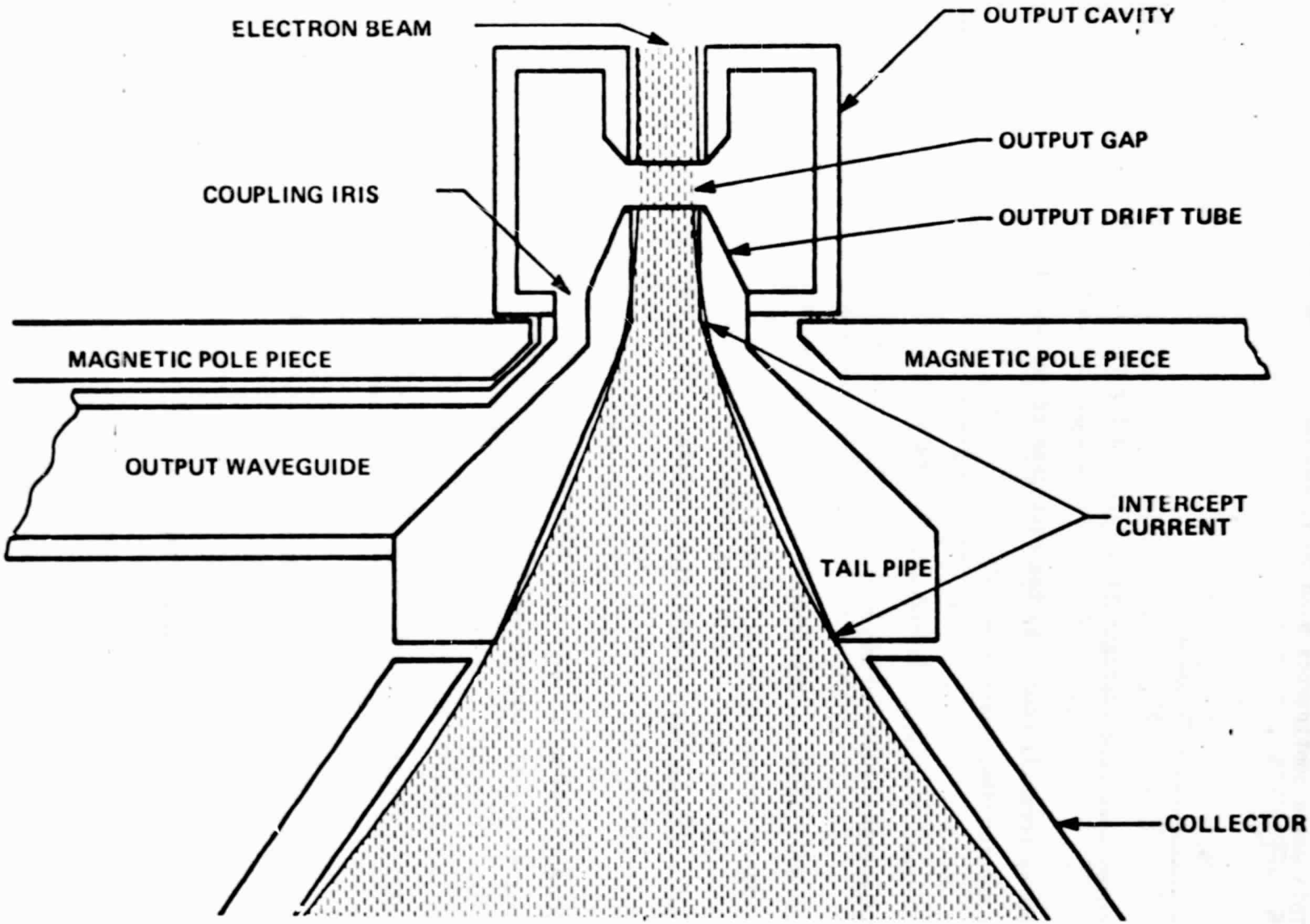



FIGURE III-2. X-3060 EXTENDED TAIL PIPE

c. overdrive;

d. stray magnetic fields (gun region);

e. disturbance of the main magnetic field by accidental introduction of ferrous materials (screwdrivers, wrenches, etc.).

Elimination of the extended tail pipe design was a mandatory condition for reliability. Figure III-3 shows the new design to be employed in the VKS-8274 JPL klystrons. As shown, the new design provides adequate clearance for the expanding beam and transfers tail pipe interception current to the collector where it is properly metered as collector current. With this configuration, body current readings will return to normal values in the order of 0.050 A, and the rf structure can be properly protected with body current protective trips set at 0.100 A.

One additional design change has been made in conjunction with the elimination of the extended tail pipe. A re-entrant output pole piece has been introduced to create a peak in the magnetic field near the output gap. Recent designs have shown that this peaked magnetic field is very beneficial in terms of reducing beam interception in the output region of the klystron. This re-entrant design is shown in Figure III-3.

3. Cavity/Body Construction

During the Phase I investigation of the X-3060, it was found that the rigidity of the rf structure was somewhat lacking, and structural stiffeners were promised for proposed new designs. That is the case, but in addition, recent tests of an X-3060 (May 1978) showed thermal drift attributable to cavity detuning, indicating a need for additional cavity cooling.

The newly designed VKS-8274 JPL incorporates relatively massive copper cavities which have a wall thickness in the order of three times the wall thickness of the present X-3060. Not only does this create a much more rugged rf structure, it permits the passage of water through the cavity walls to insure greater thermal stability. Comparative views of the X-3060

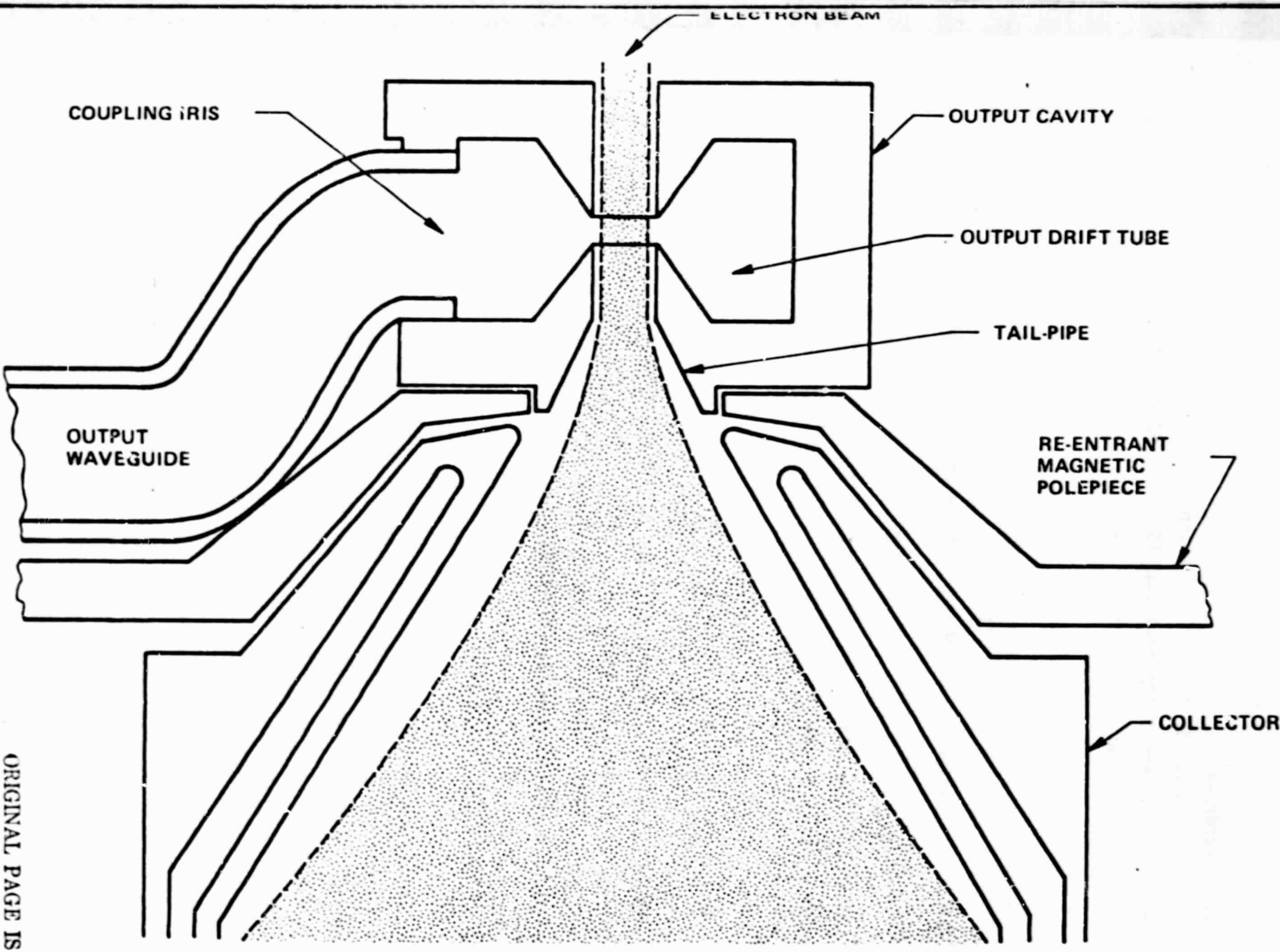



FIGURE III-3. VKS-8274 JPL OUTPUT CIRCUIT cavity structures and the new design are shown in Figures III-4 and III-5. In addition to increased cavity wall thickness and cooling, cavity end walls and drift tubes have increased thermal cross section to provide the best possible thermal stability. This can be seen clearly in Figures III-4 and III-5.

In short, the new rf structure has construction closely paralleling a 450 kW klystron (VKS-8270) known to be operationally stable at an even higher frequency; i.e., 2380 MHz.

## B. ELECTRICAL DESIGN IMPROVEMENTS

Without exception, all electrical design improvements proposed in the Phase II Design Improvement final report were incorporated in the VKS-8274 JPL. Those design improvements are reviewed below.

### 1. Electron Gun Redesign

Findings in the Phase II Design Improvement study showed that a substantial improvement could be made in electron gun voltage gradients by removing the modulating anode. This change, plus incorporation of a new optical design, have been incorporated and successfully tested in the VKS-8274 JPL. The improvements and results are fully discussed in Sections I and II.

### 2. RF Structure Re-design

During the Phase I investigation of the present X-3060 rf design, a number of deficiencies were noted. These deficiencies were a natural result of designing a klystron with a wide tuning range; i.e., 2114 to 2388 MHz.

In particular, drift tube gap spacing and gap-to-gap drift tube distances were compromised to satisfy operation at both ends of the frequency tuning range. In fact, the output cavity drift tube gap in the present X-3060 design is far too long to provide optimum efficiency at

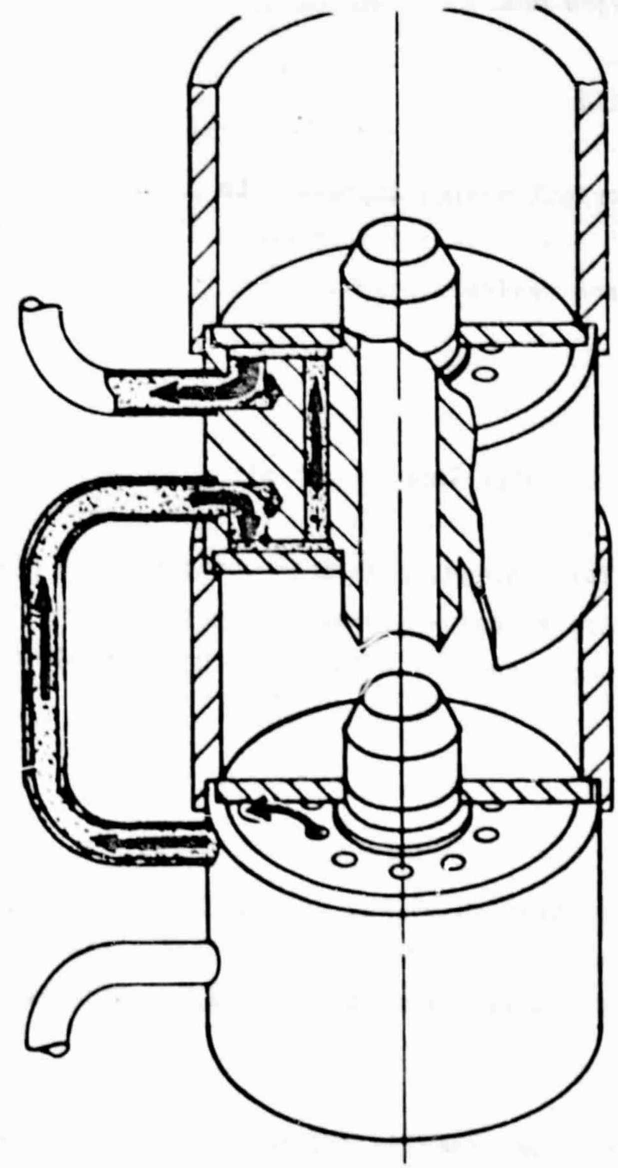


FIGURE III-4. PRESENT CAVITY STRUCTURE X-3060

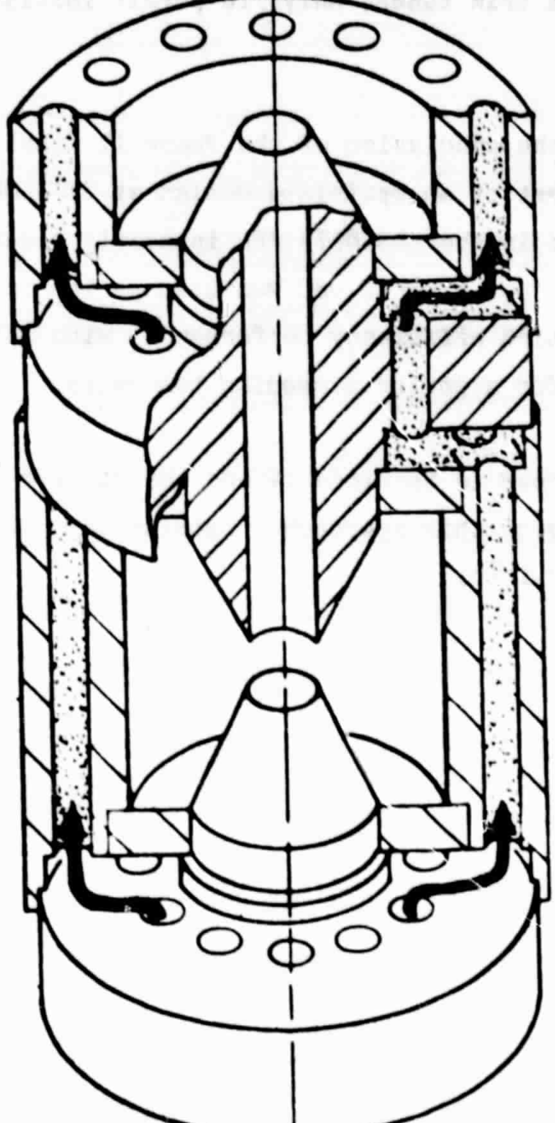


FIGURE III-5. CAVITY STRUCTURE VKS-8274 JPL either 2114 MHz or 2388 MHz, but it was designed that way to provide low gap capacitance, a requirement of wide tuning range cavities. It was suggested in the Phase II final report that the wide tuning range requirement be eliminated and that two tubes be developed, each electrically optimized for its particular frequency, one at 2114 MHz and the other at 2388 MHz. These tubes would have narrow-range trim tuners only, to permit initial factory tune-up.

JPL's decision at the conclusion of the Phase II final report was to proceed with the development of an optimized design at 2114 MHz. The design chosen and implemented in the VKS-8274 JPL is nearly electrically identical to the 5K70SG klystron. The 5K70SG was used as the basic model because it has demonstrated high efficiency performance, with reliability in numerous field applications for a period exceeding ten years.

The test results shown in Sections IV and the Summary Table in Section V verify the validity of this approach. Substantial gains were made in efficiency, gain, and bandwidth.

## IV. TEST RESULTS

The following pages Figures IV-1 through IV-19 include all test results obtained from testing of the VKS-8274 JPL. The klystron exceeded all specification requirements and was tested to 146 kW CW, or 1.46 times its rating of 100 kW.

VKS-8274 SERIAL NO. B1-1 DATE: 4/16/81 BY: AAG

FILAMENT VOLTAGE 10.5 V
FILAMENT CURRENT 11.35 A
MAGNET CURRENT 12.0 A

BEAM VOLTAGE 34 kV
BEAM CURRENT 6.58 A
EFFICIENCY 50.74 %

POWER OUTPUT 113.5 kW
SAT. DRIVE POWER 0.188 W
SAT. GAIN 57.8 dB

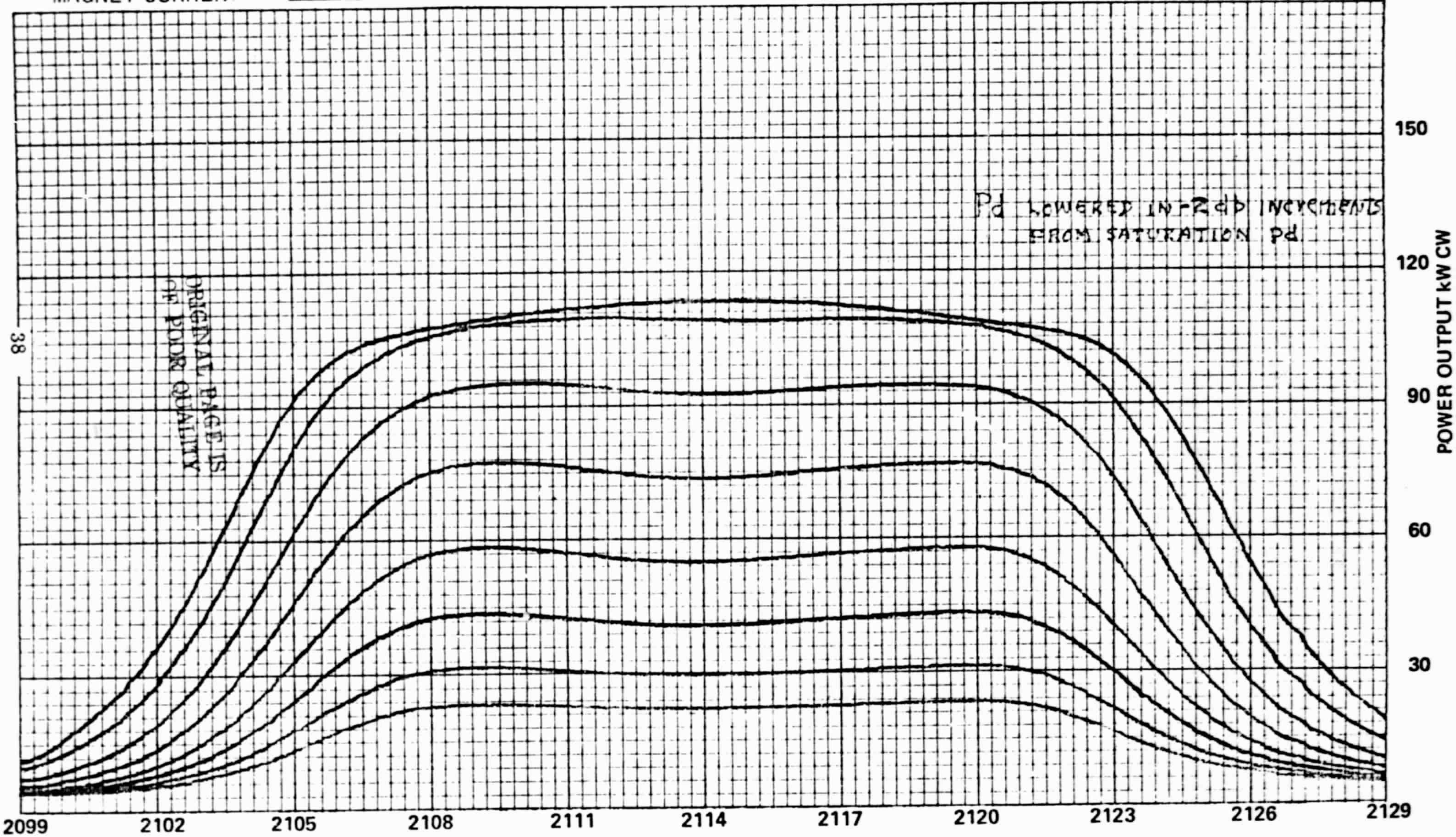





FIGURE IV-1

FREQUENCY MHz

VKS-8274 SERIAL NO. B1-1 DATE: 4/16/81 BY: AAG

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FILAMENT VOLTAGE | 10.5 | V | BEAM VOLTAGE | 34 | kV | POWER OUTPUT | 113.5 | kW |
| FILAMENT CURRENT | 11.35 | A | BEAM CURRENT | 6.58 | A | DRIVE POWER | 0.188 | W |
| MAGNET CURRENT | 12.0 | A | EFFICIENCY | 50.74 | % | GAIN | 57.8 | dB |

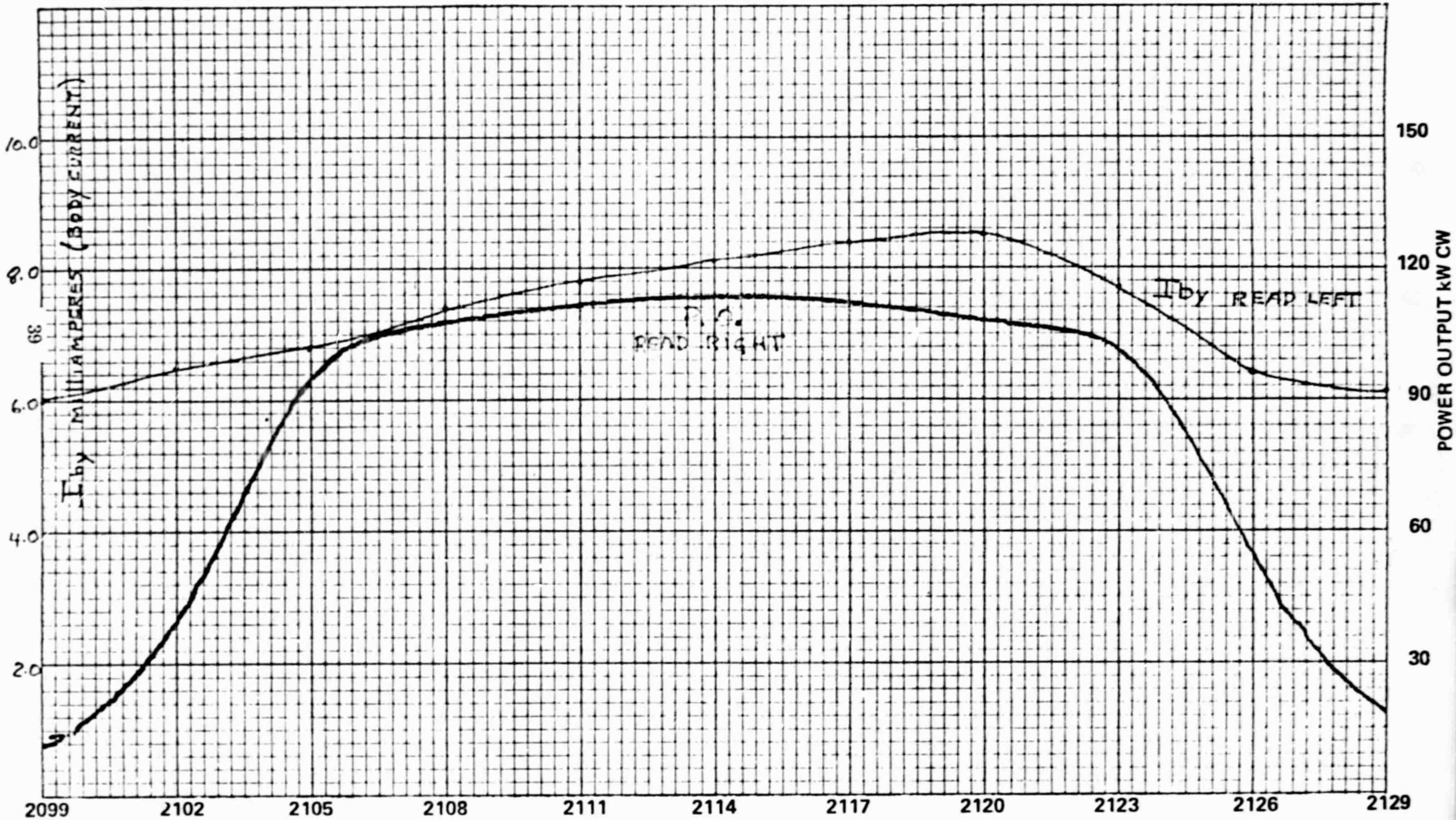



FIGURE IV-2

FREQUENCY MHz

VKS-8274 ______ SERIAL NO. B1-1

DATE: 4/16/81 BY: AAG

FILAMENT VOLTAGE 10.5 V
FILAMENT CURRENT 11.35 A
MAGNET CURRENT 12.0 A

BEAM VOLTAGE 35 kV
BEAM CURRENT 6.87 A
EFFICIENCY 52.0 %

POWER OUTPUT 125 kW
SAT. DRIVE POWER 0.188 W
SAT. GAIN 58.2 dB

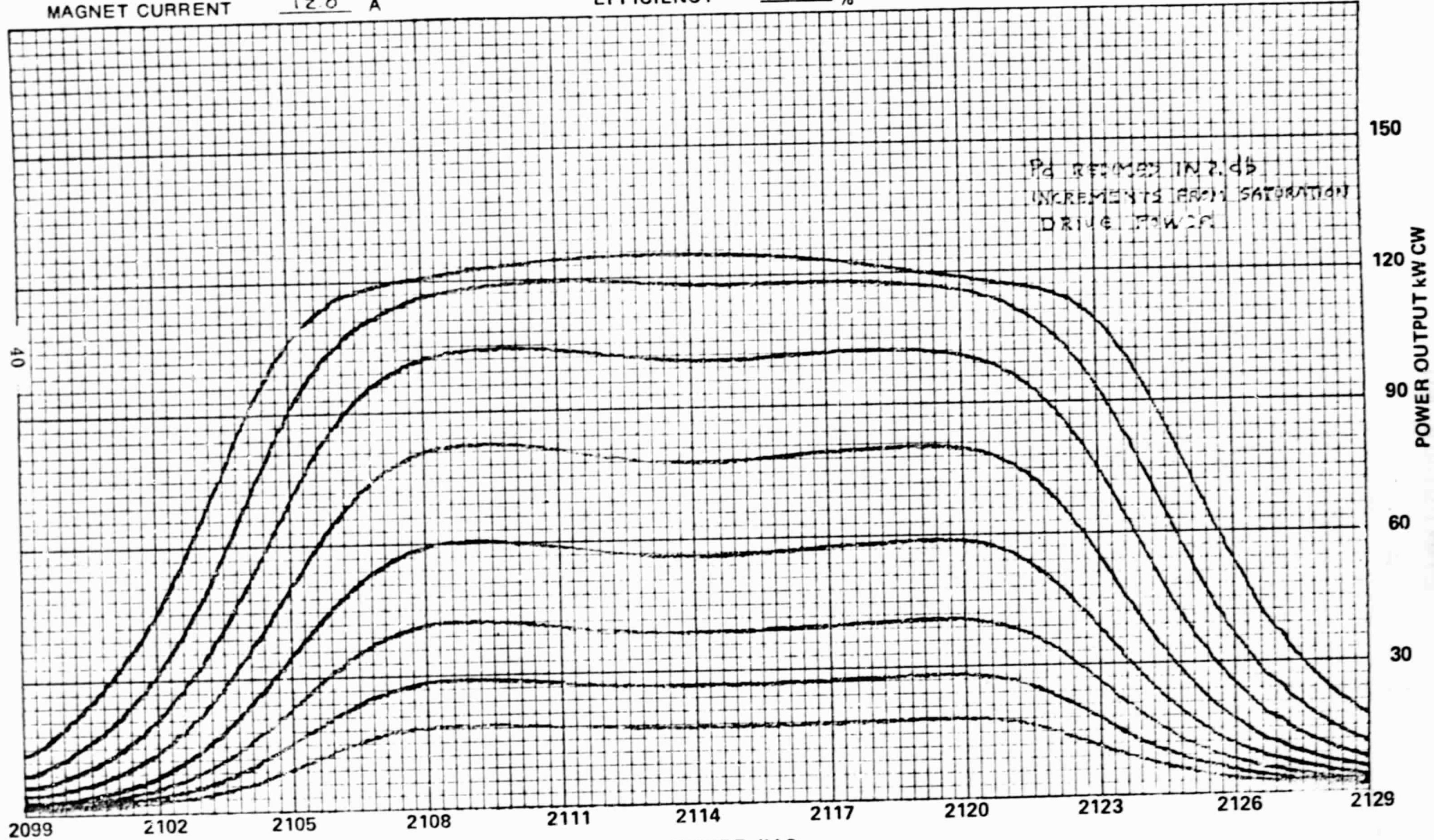



FIGURE IV-3

FREQUENCY MHz

VKS-8274 SERIAL NO. B1-1

DATE: 4/16/31 BY: AAG

FILAMENT VOLTAGE 10.5 V
FILAMENT CURRENT 11.35 A
MAGNET CURRENT 12.0 A

BEAM VOLTAGE 35 kV
BEAM CURRENT 6.87 A
EFFICIENCY 52.0 %

POWER OUTPUT 125 kW
DRIVE POWER 0.188 W
GAIN 58.2 dB

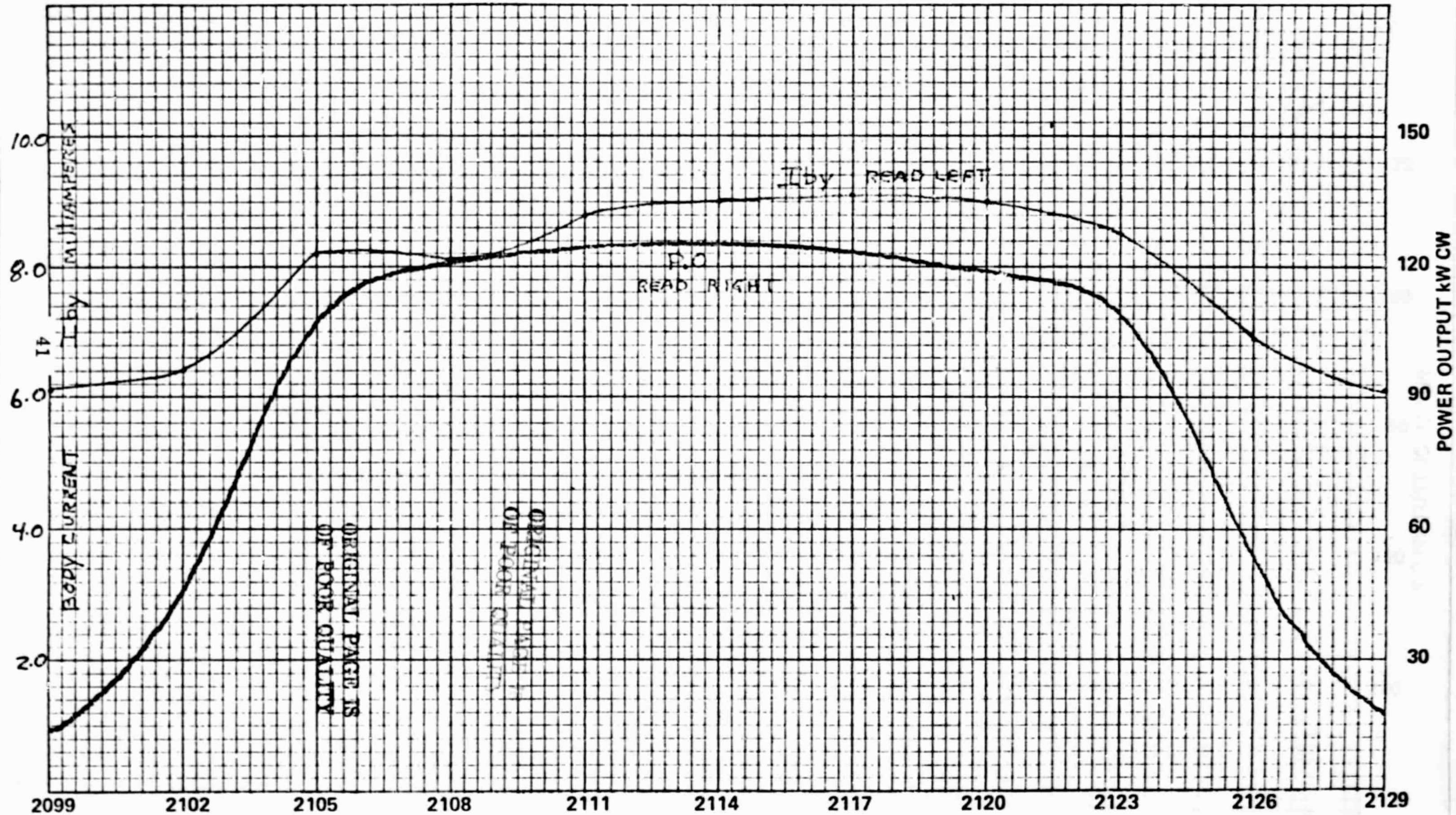







FIGURE IV-4

FREQUENCY MHz

VKS-8274 SERIAL NO. 81-1

DATE: 4/16/81 BY: AAG

FILAMENT VOLTAGE 10.5 V

FILAMENT CURRENT 11.35 A

MAGNET CURRENT 12.0 A

BEAM VOLTAGE 36 kV

BEAM CURRENT 7.15 A

EFFICIENCY 52.8 %

POWER OUTPUT 136 kW

SAT. DRIVE POWER 0.164 W

SAT. GAIN 59.2 dB

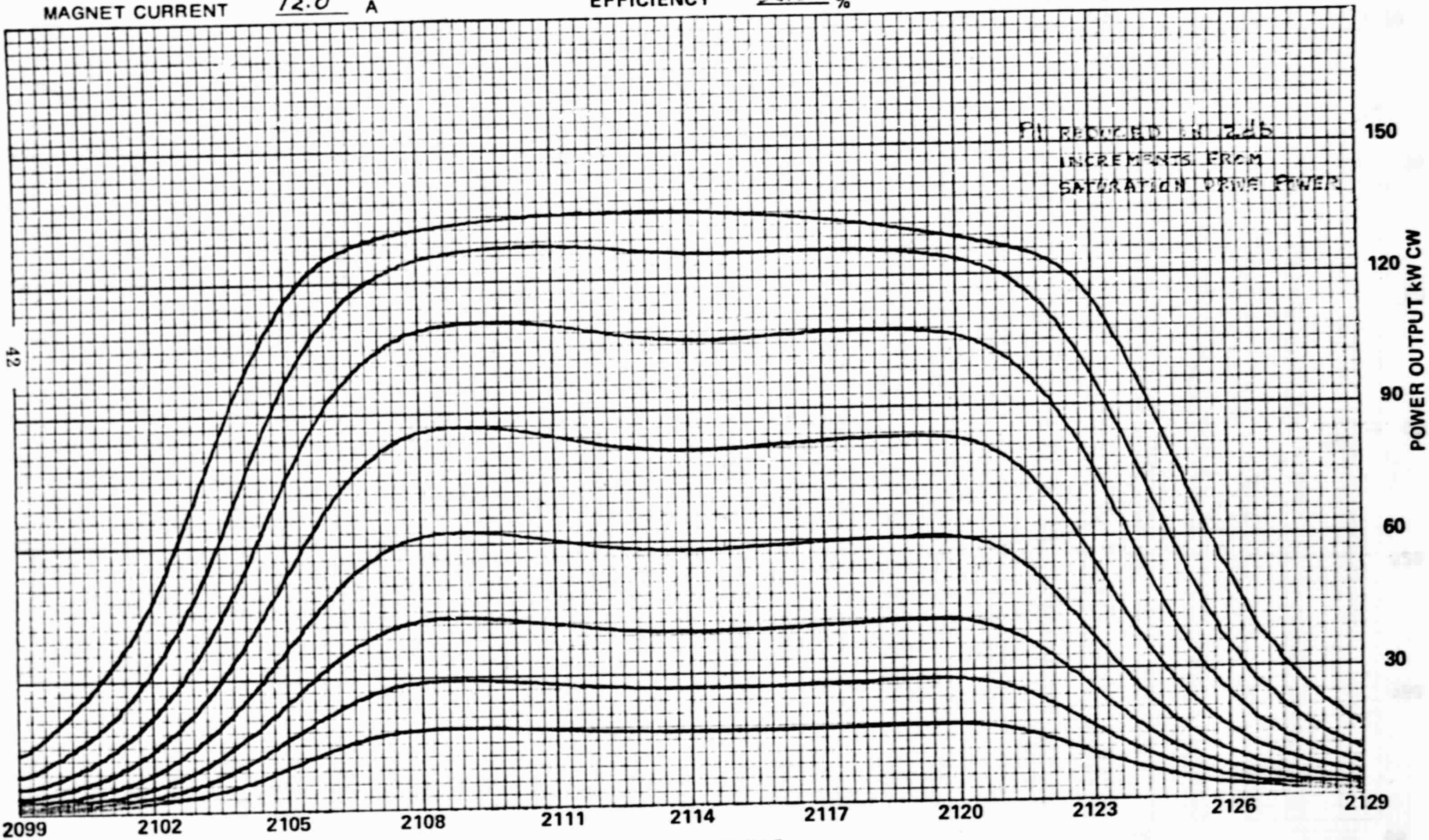



FIGURE IV-5

VKS-8274 SERIAL NO. B1-1 DATE: 4/20/81 BY: AAG.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FILAMENT VOLTAGE | 10.5 | V | BEAM VOLTAGE | 36 | kV | POWER OUTPUT | 135 | kW |
| FILAMENT CURRENT | 11.35 | A | BEAM CURRENT | 7.15 | A | DRIVE POWER | 0.164 | W |
| MAGNET CURRENT | 12.0 | A | EFFICIENCY | 52.4 | % | GAIN | 59.15 | dB |

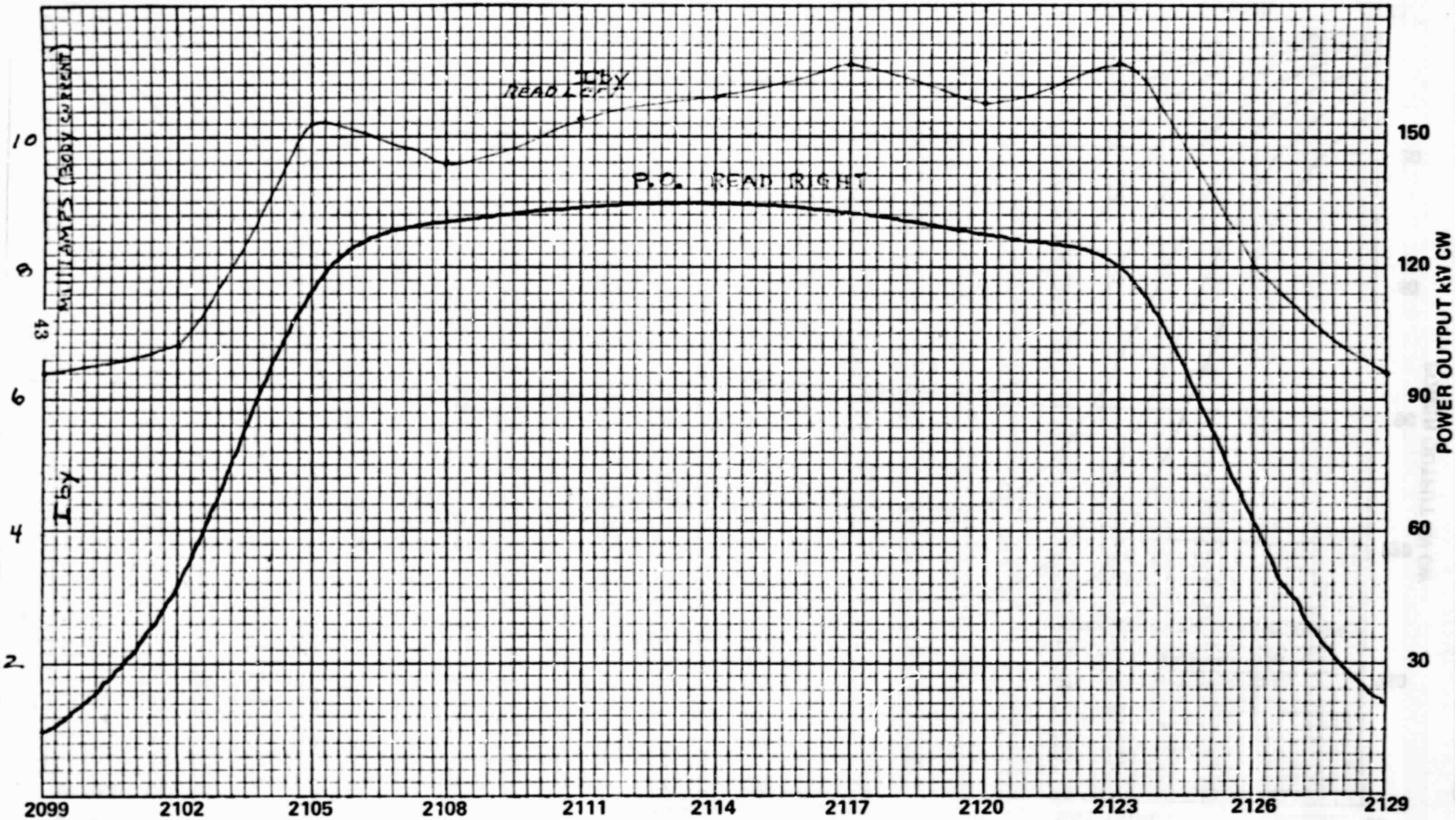



FIGURE IV-6

FREQUENCY MHz

VKS-8274 SERIAL NO. B1-1 DATE: 4/20/81 BY: AAG

FILAMENT VOLTAGE 10.5 V
FILAMENT CURRENT 11.35 A
MAGNET CURRENT 12.0 A

BEAM VOLTAGE 37 kV
BEAM CURRENT 7.44 A
EFFICIENCY 53 %

POWER OUTPUT 146 kW
SAT. DRIVE POWER 0.15 W
SAT. GAIN 59.8 dB

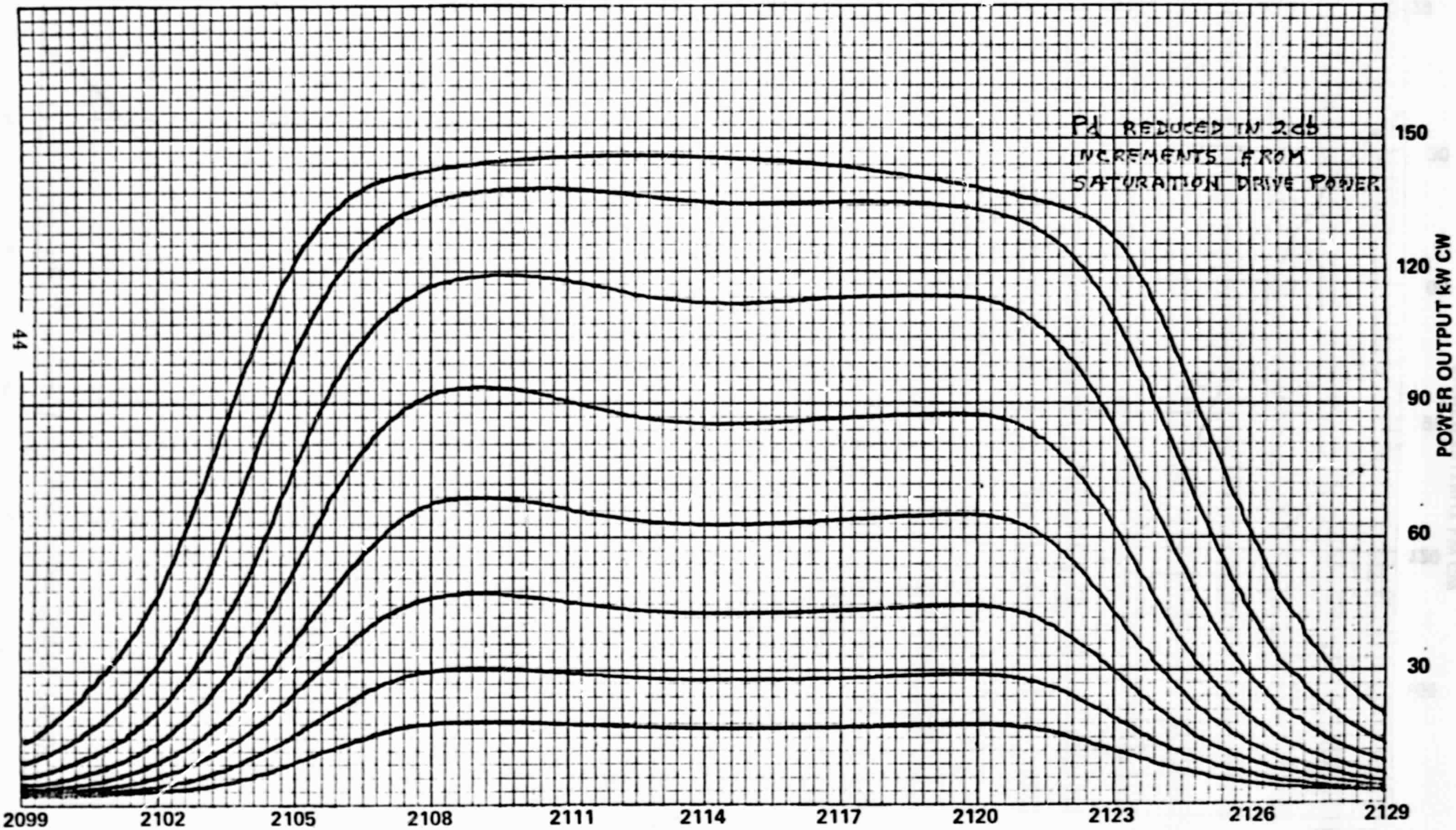



FIGURE IV-7

FREQUENCY MHz

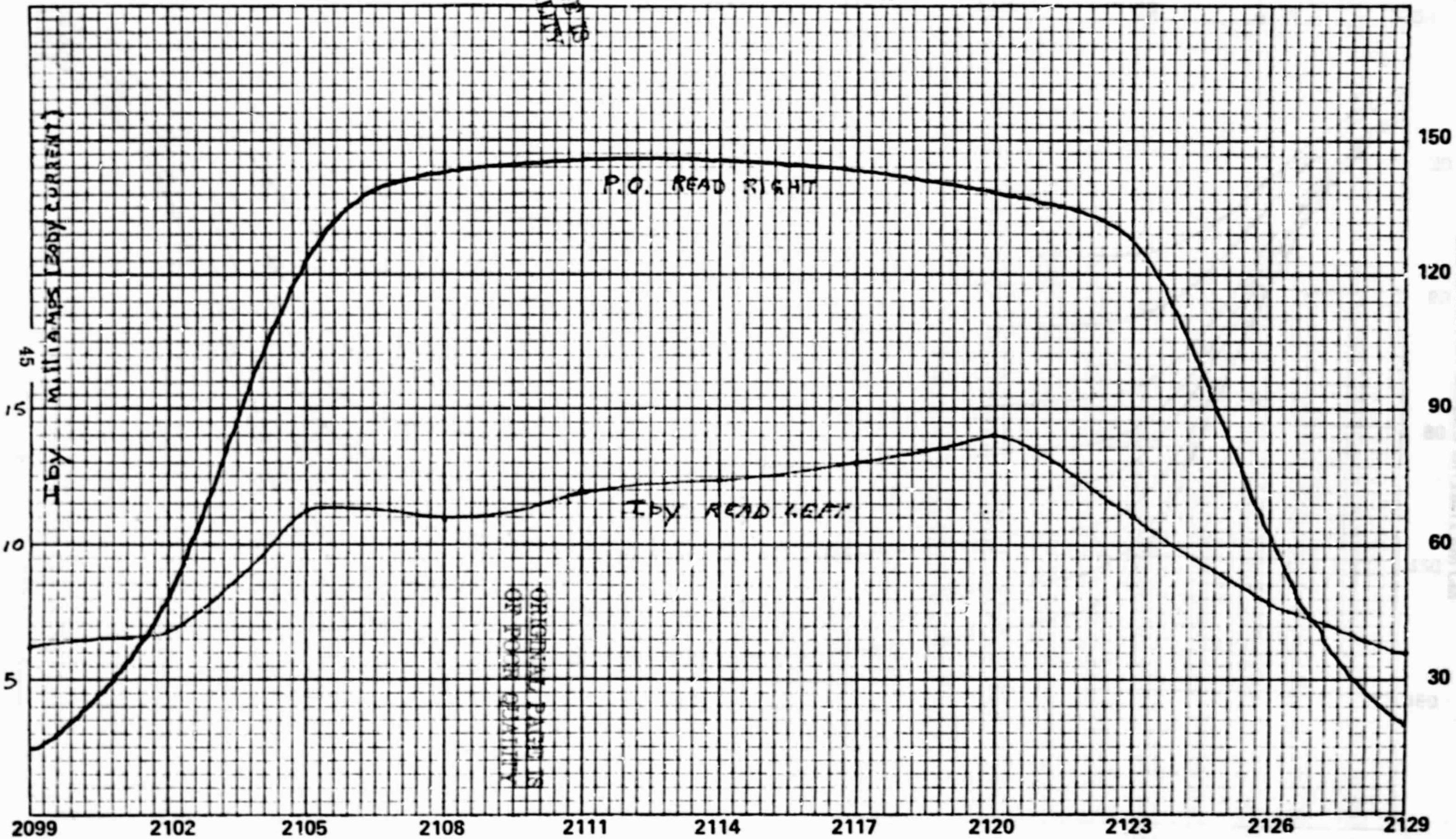
VKS-8274 SERIAL NO. B1-1 DATE: 4/20/81 BY: AAG.

FILAMENT VOLTAGE 10.5 V
FILAMENT CURRENT 11.35 A
MAGNET CURRENT 12.0 A

BEAM VOLTAGE 37 kV
BEAM CURRENT 7.44 A
EFFICIENCY 53 %

POWER OUTPUT 146 kW
DRIVE POWER 0.15 W
GAIN 59.8 dB






ORIGINAL PAGE IS OF POOR QUALITY

FIGURE IV-8

FREQUENCY MHz

VKS-8274 SERIAL NO. B1-1 DATE: 4/20/81 BY: AAG

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FILAMENT VOLTAGE | 10.5 | V | BEAM VOLTAGE | VAR. | kV | POWER OUTPUT | VAR. | kW |
| FILAMENT CURRENT | 11.35 | A | BEAM CURRENT | VAR. | A | DRIVE POWER | VAR. | W |
| MAGNET CURRENT | 12.0 | A | EFFICIENCY | VAR. | % | GAIN | VAR. | dB |

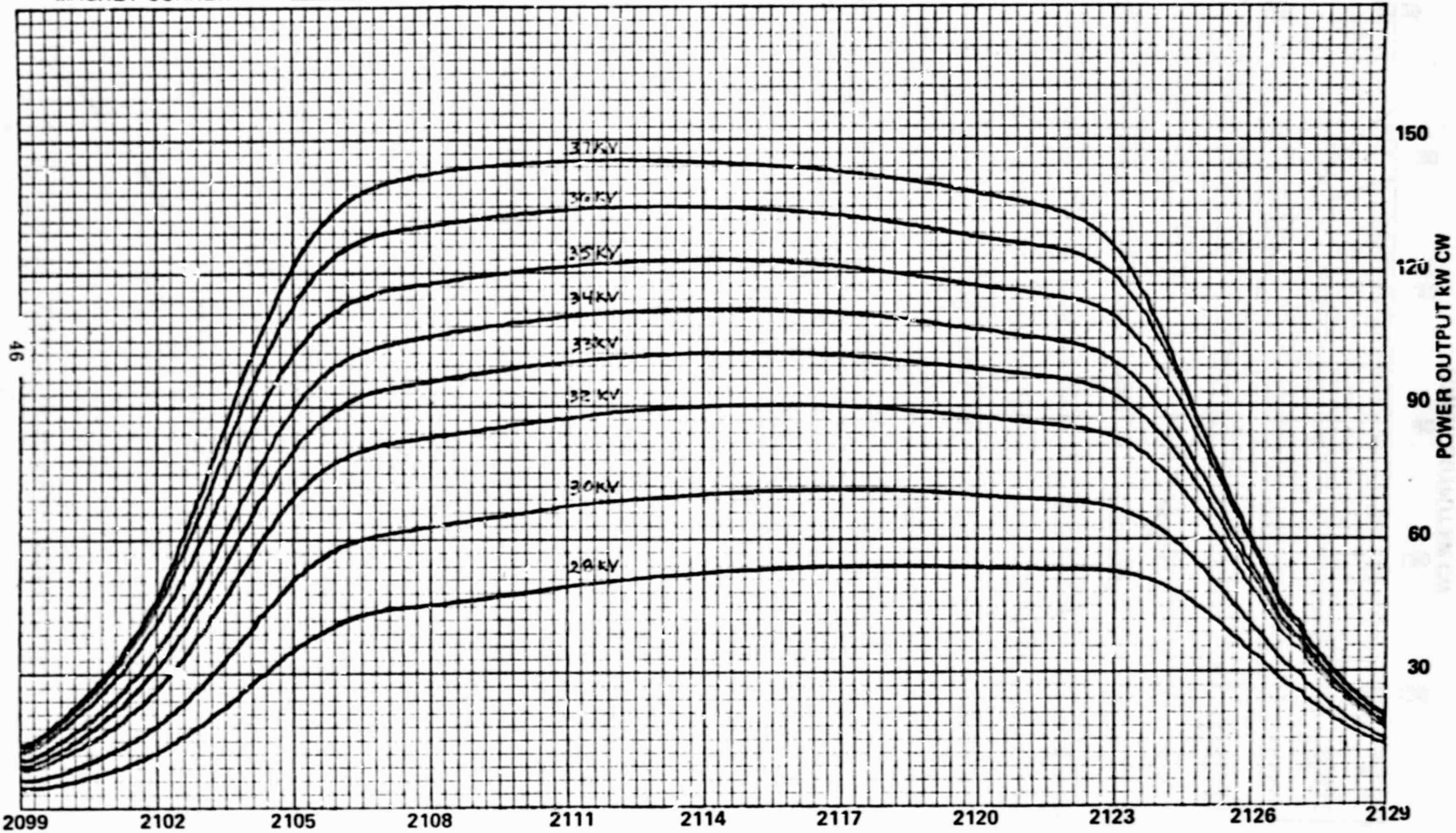



FIGURE IV-9

FREQUENCY MHz

VKS 8274 SERIAL NO. B1-1 FREQUENCY DATE BY

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FILAMENT VOLTAGE | 10.5 V | BEAM VOLTAGE | VAR. kV | POWER OUTPUT | VAR. kW |
| FILAMENT CURRENT | 11.35 A | BEAM CURRENT | VAR. A | DRIVE POWER | VAR. W |
| MAGNET CURRENT | 12.0 A | BODY CURRENT | VAR. mA | GAIN | VAR. dB |

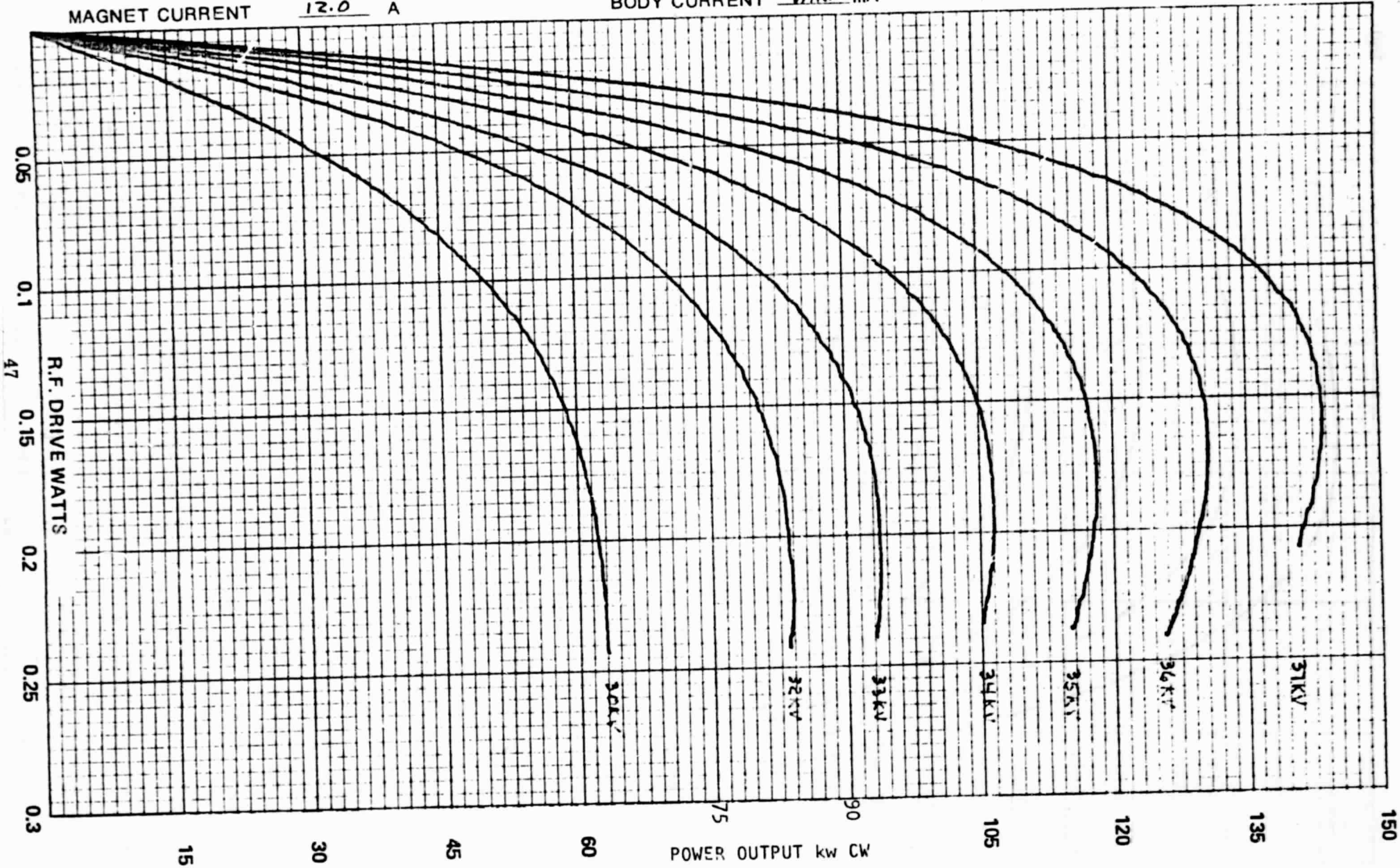



FIGURE IV-10

SERIAL NO. B1-1 DATE BY:

FILAMENT VOLTAGE 10.5 V | BEAM VOLTAGE VAR. kV | POWER OUTPUT VAR. kW
FILAMENT CURRENT 11.35 A | BEAM CURRENT VAR. A | DRIVE POWER VAR. W
MAGNET CURRENT 12.0 A | BODY CURRENT VAR. mA | GAIN VAR. dB

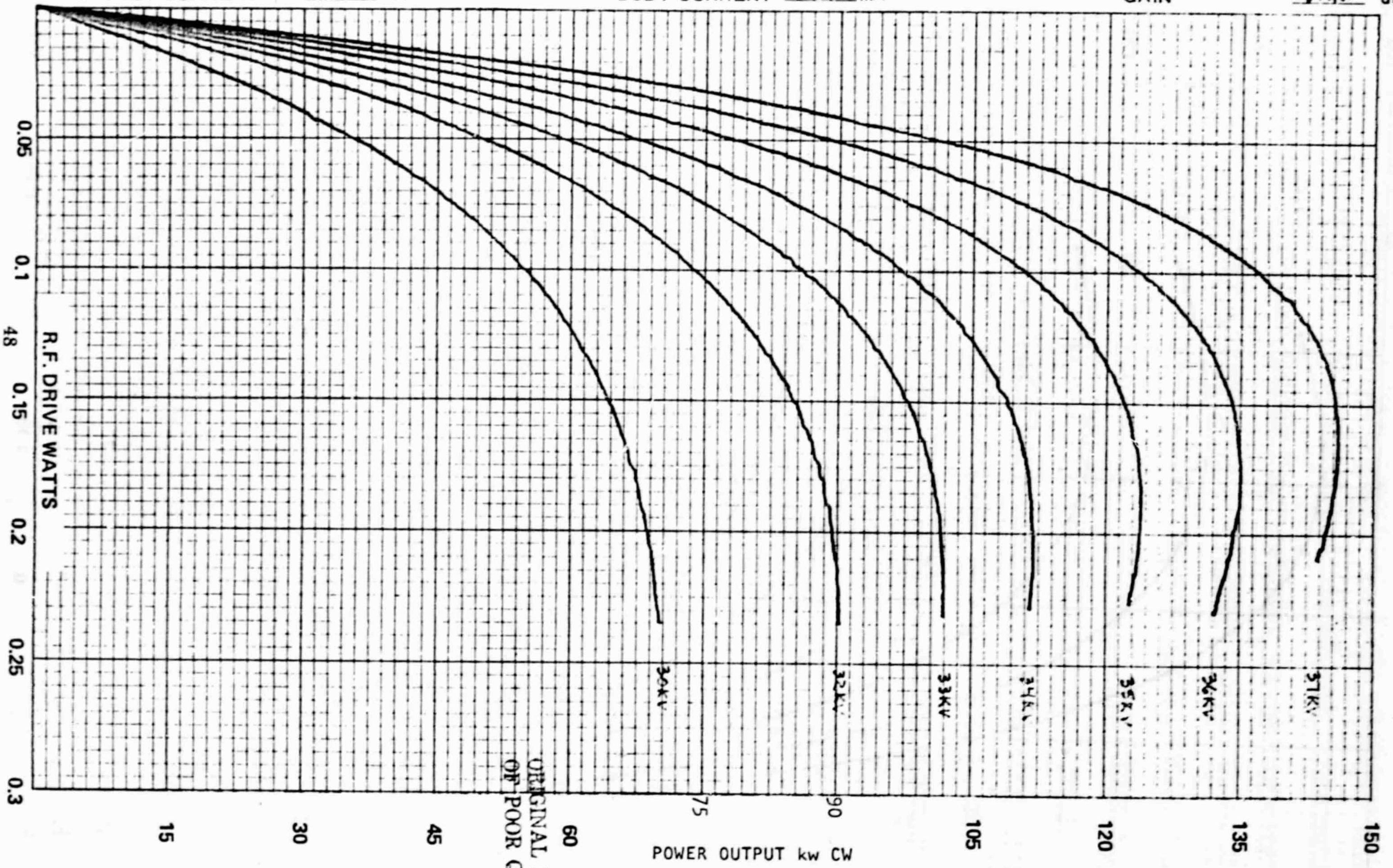



FIGURE IV-11

VKS-8274 SERIAL NO. 131-1 FREQUENCY

FILAMENT VOLTAGE 10.5 V
FILAMENT CURRENT 11.35 A
MAGNET CURRENT 12.0 A

BEAM VOLTAGE VAR. kV
BEAM CURRENT VAR. A
BODY CURRENT VAR. mA

POWER OUTPUT VAR. kW
DRIVE POWER VAR. W.
GAIN VAR. dB

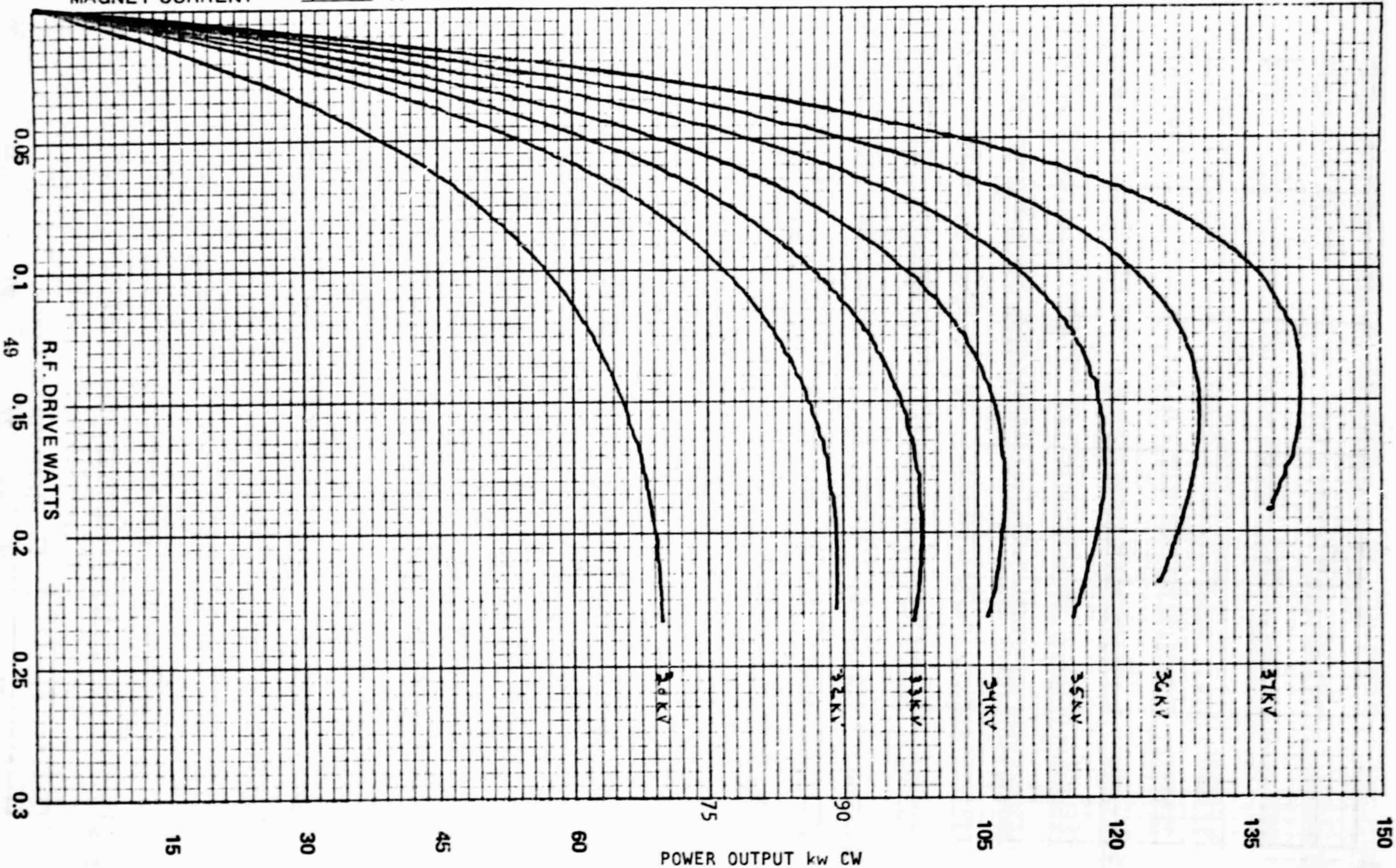



FIGURE IV-12

VKS-8274 SERIAL NO. B1-1 FREQUENCY 2114 DATE: 4/20/81 BY: AAG

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FILAMENT VOLTAGE | 10.5 | V | BEAM VOLTAGE | VAR. | kV | POWER OUTPUT | VAR. | kW |
| FILAMENT CURRENT | 11.35 | A | BEAM CURRENT | VAR. | A | DRIVE POWER | SAT. | mW |
| MAGNET CURRENT | 12.0 | A | BODY CURRENT | VAR. | mA | GAIN | VAR. | dB |

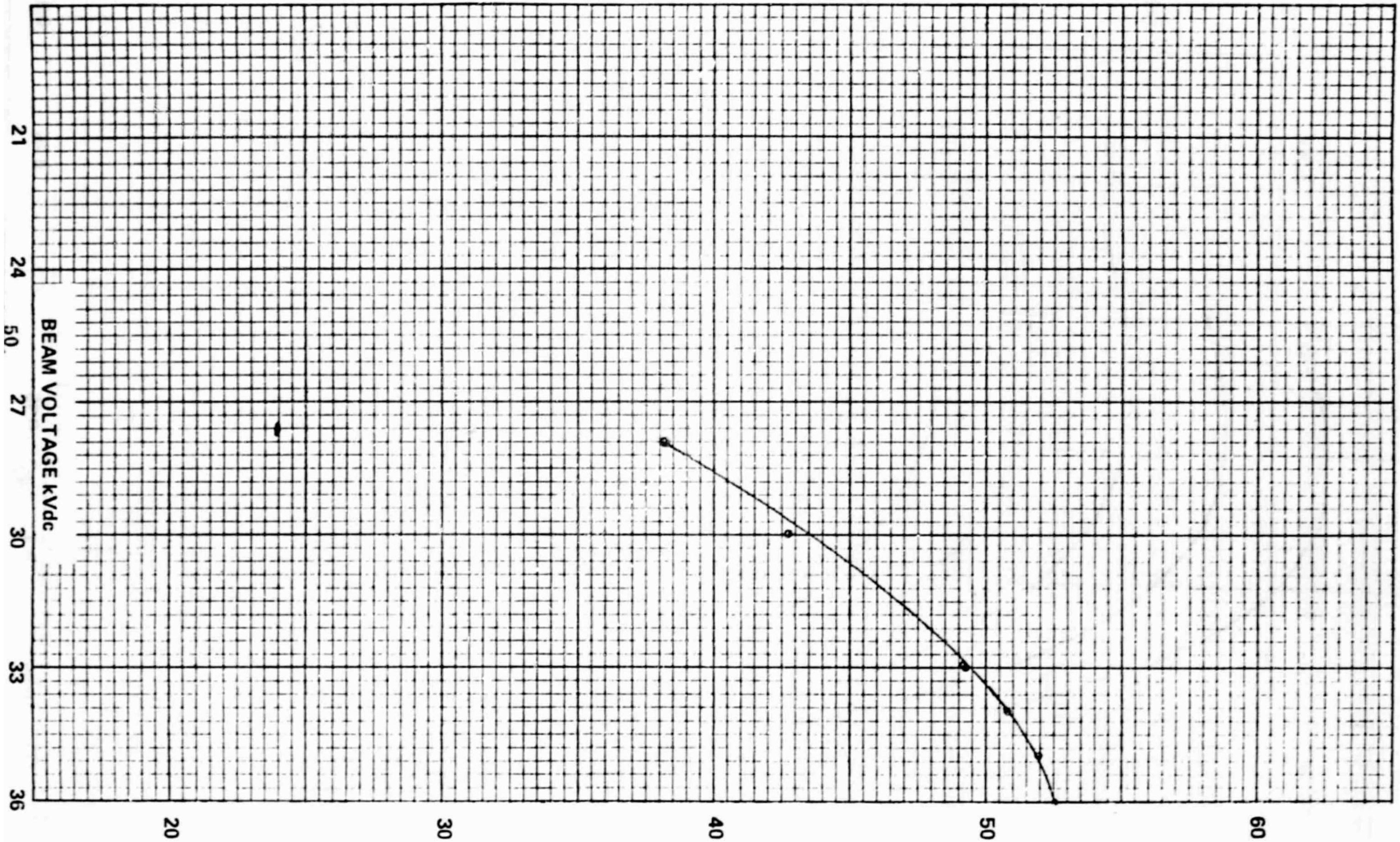



FIGURE IV-13

VKS-8274 SERIAL NO. B1-1 FREQUENCY 2114 DATE: 4/20/81 BY: AAS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FILAMENT VOLTAGE | 10.5 | V | BEAM VOLTAGE | VAR. | kV | POWER OUTPUT | VAR. | kW |
| FILAMENT CURRENT | 11.35 | A | BEAM CURRENT | VAR. | A | DRIVE POWER | SAT. | mW |
| MAGNET CURRENT | 12.0 | A | BODY CURRENT | VAR. | mA | GAIN | VAR. | dB |

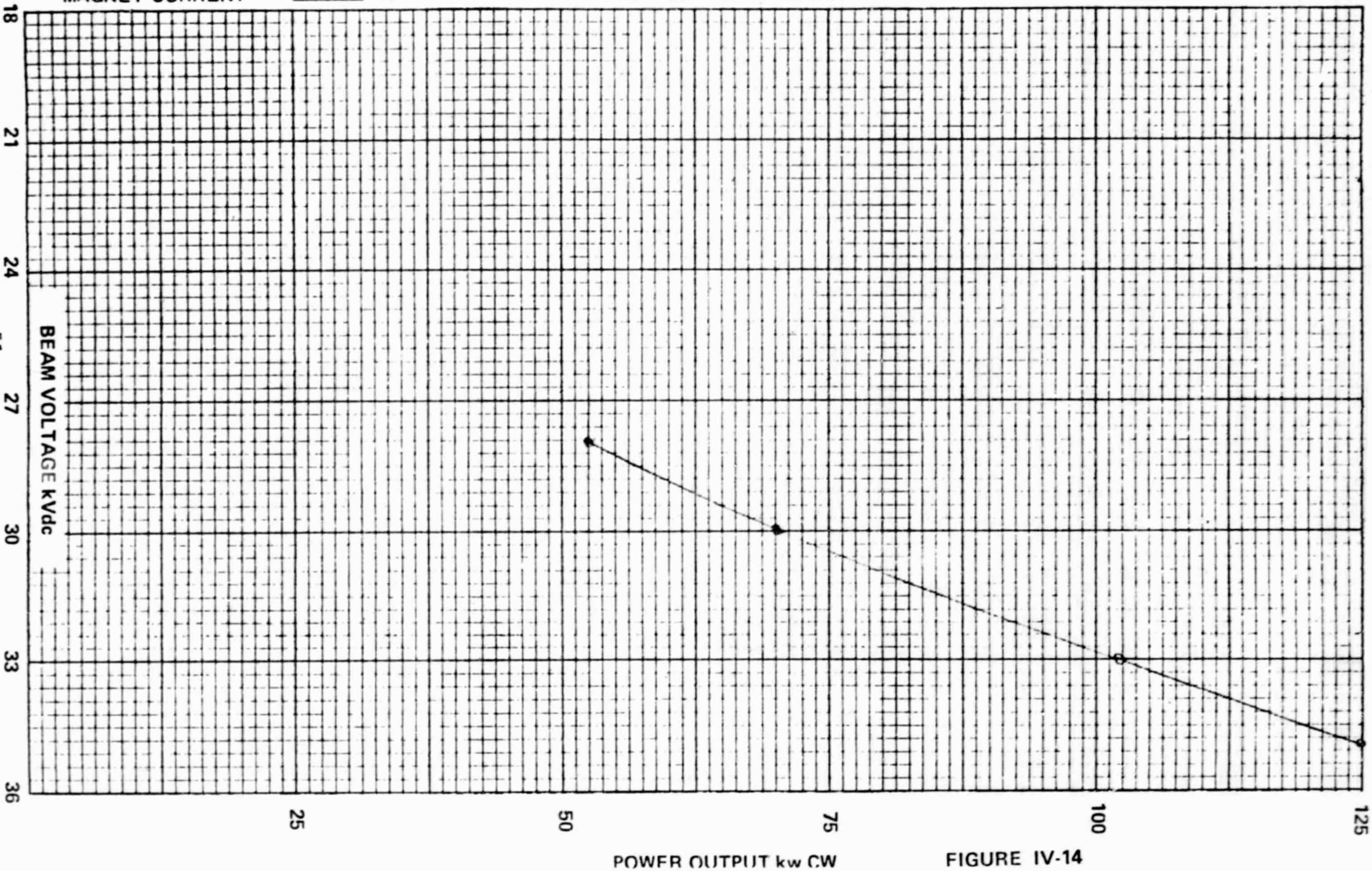



FIGURE IV-14

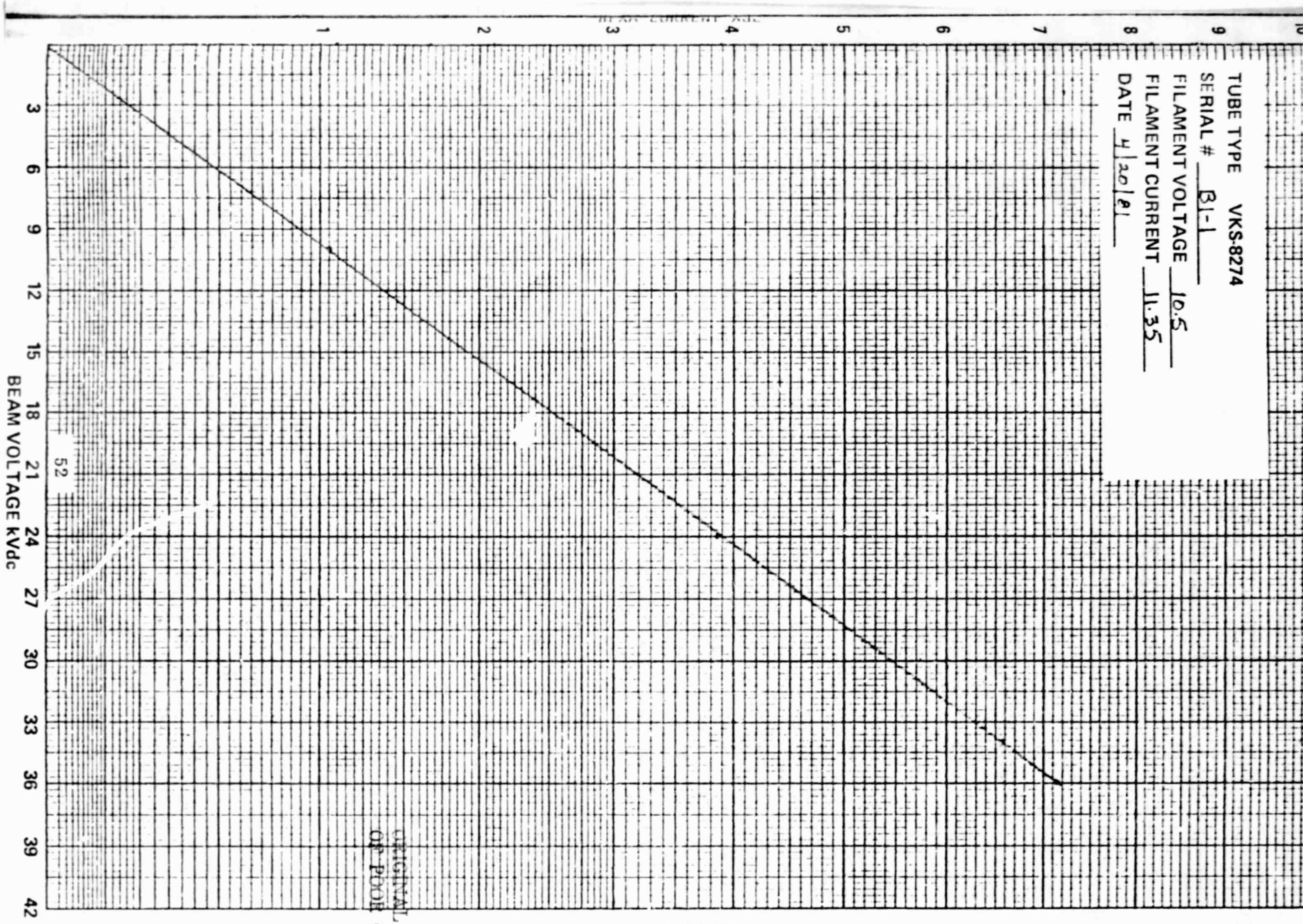

TUBE TYPE VKS-8274
SERIAL # B1-1
FILAMENT VOLTAGE 10.5
FILAMENT CURRENT 11.35
DATE 4/20/81
BEAM VOLTAGE kVdc
3 6 9 12 15 18 21 24 27 30 33 36 39 42
1 2 3 4 5 6 7 8 9 10

FIGURE IV-15

## CERTIFIED TEST REPORT

## VKS-8274 KLYSTRON

Serial No.: B1-1

| | Broad Band Tuned at 2114 MHZ | |
|---|---|---|
| Power Output | 111 | kw |
| Beam Voltage | 34 | kv dc |
| Beam Current | 6.56 | A dc |
| Beam Power Input | 223 | kilowatts |
| Efficiency | 49.7 | percent |
| Drive Power | 0.196 | w |
| Gain | 57.5 | db |
| Bandwidth (-1 db) | 19.19 | MHz |
| Body Current No rf drive | 5.1 | MA dc |
| Body Current Sat. rf drive | 8.6 | MA dc |
| Focusing Magnet Current | 12.0 | A dc |
| Focusing Magnet Voltage | 120 | V dc |
| Heater Voltage | 10.5 | V ac |
| Heater Current | 11.35 | A ac |

Coolant Water

| | | |
|---|---|---|
| Collector | | |
| Flow | 65 | gpm |
| Pressure drop | 32 | psi |
| Body | | |
| Flow | 7 | gpm |
| Pressure drop | 65 | psi |
| Electro-magnet | | |
| Flow | 2.5 | gpm |
| Pressure drop | 67 | psi |

Date: APRIL 21 1981

Signed : Art Goldfinger

Approved: M. A. Gregg



FIGURE IV-16

CERTIFIED TEST REPORT

VKS-8274 KLYSTRON

Serial No.: B1-1

| | Broad Band Tuned at 2114 MHZ |
|---|---|
| Power Output | 12.5 kw |
| Beam Voltage | 35 kv dc |
| Beam Current | 6.87 A dc |
| Beam Power Input | 240 kilowatts |
| Efficiency | 51.9 percent |
| Drive Power | 0.188 w |
| Gain | 58.2 db |
| Bandwidth (-1 db) | 19.2 MHz |
| Body Current No rf drive | 5.8 MA dc |
| Body Current Sat. rf drive | 9.2 MA dc |
| Focusing Magnet Current | 12.0 A dc |
| Focusing Magnet Voltage | 12.0 V dc |
| Heater Voltage | 10.5 V ac |
| Heater Current | 11.35 A ac |

Coolant Water

| | |
|---|---|
| Collector | |
| Flow | 65 gpm |
| Pressure drop | 32 psi |
| Body | |
| Flow | 7 gpm |
| Pressure drop | 65 psi |
| Electro-magnet | |
| Flow | 2.5 gpm |
| Pressure drop | 67 psi |

Date: APRIL 16 1981 Signed : ART GOLDFINGER

Approved: ______________

FIGURE IV-17.

CERTIFIED TEST REPORT

VKS-8274 KLYSTRON

Serial No.: B1-1

| | Broad Band Tuned at 2114 MHZ | |
|---|---|---|
| Power Output | 136 | kw |
| Beam Voltage | 36 | kv dc |
| Beam Current | 7.15 | A dc |
| Beam Power Input | 257 | kilowatts |
| Efficiency | 52.8 | percent |
| Drive Power | 0.164 | w |
| Gain | 59.2 | db |
| Bandwidth (-1 db) | 18.9 | MHz |
| Body Current No rf drive | 6.1 | MA dc |
| Body Current Sat. rf drive | 11.1 | MA dc |
| Focusing Magnet Current | 12.0 | A dc |
| Focusing Magnet Voltage | 120 | V dc |
| Heater Voltage | 10.5 | V ac |
| Heater Current | 11.35 | A ac |

Coolant Water

| | | |
|---|---|---|
| Collector | | |
| Flow | 65 | gpm |
| Pressure drop | 32 | psi |
| Body | | |
| Flow | 7 | gpm |
| Pressure drop | 65 | psi |
| Electro-magnet | | |
| Flow | 2.5 | gpm |
| Pressure drop | 67 | psi |

Date: APRIL 16 1981 Signed : ART GOLDFINGER

Approved: ____________

FIGURE IV-18.

## CERTIFIED TEST REPORT

## VKS-8274 KLYSTRON

**Serial No.:** B1-1

| | Broad Band Tuned at MHZ |
|---|---|
| Power Output | 146 kw |
| Beam Voltage | 37 kv dc |
| Beam Current | 7.44 A dc |
| Beam Power Input | 275 kilowatts |
| Efficiency | 53 percent |
| Drive Power | 0.15 w |
| Gain | 59.8 db |
| Bandwidth (-1 db) | 19 MHz |
| Body Current No rf drive | 6.5 MA dc |
| Body Current Sat. rf drive | 14 MA dc |
| Focusing Magnet Current | 12 A dc |
| Focusing Magnet Voltage | 120 V dc |
| Heater Voltage | 10.5 V ac |
| Heater Current | 11.35 A ac |

Coolant Water

| | |
|---|---|
| Collector | |
| Flow | 65 gpm |
| Pressure drop | 32 psi |
| Body | |
| Flow | 7 gpm |
| Pressure drop | 65 psi |
| Electro-magnet | |
| Flow | 2.5 gpm |
| Pressure drop | 67 psi |

Date: APRIL 20 1981 Signed : ART GOLDFINGER

Approved: ______________

FIGURE IV-19.

## V. COMPARATIVE DATA

Table V-1 shows comparative data among the existing X-3060 performance data, the Phase II study predictions, the VKS-8274 JPL performance data, and the requirements of JPL specification #309517.

COMPARATIVE DATA

X-3060: PHASE II PREDICTIONS: VKS-8274 JPL: SPECIFICATION REQUIREMENTS

| PARAMETER | UNITS | EXISTING X-3060 PERFORMANCE DATA | PHASE II IMPROVEMENT PREDICTIONS | VKS-8274 JPL PERFORMANCE DATA | SPECIFICATION REQUIREMENTS |
|---|---|---|---|---|---|
| Frequency | MHz | 2114 | 2114 | 2114 | 2114 |
| Beam Voltage | kV | 36.0 | 36.0 | 36.0 | 40 Max. |
| Beam Current | Adc | 7.7 | 6.96 | 7.15 | 10 Max. |
| Power Output | KW CW | 112.0 | 132.0 | 136.0* | 110 Min. |
| Efficiency | % | 40.4 | 52.7 | 52.8* | 40 Min. |
| Saturation Gain | db | 54.7 | 59.3 | 59.2* | 50 Min. |
| Saturation BW | MHz | 10.4 | 16.7 | 18.9* | 14 Min. |
| Small Signal Gain | db | 58.0 | 61.0 | 62.8* | — |
| Small Signal BW | MHz | 6.4 | 13.8 | 17.2* | — |
| Body Current No RF | MA dc | 30.0 | -- | 6.1* | — |
| Body Current Sat. RF | MA dc | 540.0 | 50-75 | 11.1* | 100 Max. |
| Electron Gun High Voltage Gradients (worst case) | kV/inch | 312. | 254. | 143. * | |
| Cathode Loading | Amps/cm$^2$ | 1.375 | 1.375 | 0.862* | |

*Notable improvement over X-3060 performance

TABLE V-1