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200 kV LINEAR BEAM SWITCH TUBE DEVELOPMENT

LEVEL II

Varian Associates, Inc.

Dennis Boilard

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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APPROVED: Bobby R Gray

BOBBY R. GRAY
Project Engineer

APPROVED: Frank J Rehm

FRANK J. REHM
Technical Director
Surveillance Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

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This report covers the design, fabrication and processing of a linear beam pentode switch tube developed by Varian for RADC. Earlier models were developed by Varian for RADC. Earlier models were developed by Varian under Air Force sponsorship. Design goals were 200 kV video output at 180A load current and 0.04 (0.02 min) duty cycle at pulse lengths up to 100 usec. Important features are the nonintercepting grid convergent electron beam passing through the anode intermediate electrode

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) and voltage depressible collector probe system. The intermediate electrode is positioned between cathode and anode. Primary function of the electrode is to limit the dc voltage in the gun region between electrodes, to about 125 kVdc. No beam tests were done by the contractor. Report includes recommended values for tube operating parameters.

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SUMMARY

This report describes the design, fabrication, and processing of a linear beam switch tube developed by Varian Associates, Inc., for Rome Air Development Center, Griffiss Air Force Base, N.Y. 13441. The current effort is a continuation of earlier work sponsored by the Department of the Air Force.

Design goals were 200 kV video output at 180 A load current and 0.04 (0.02 minimum) duty cycle at pulse lengths up to 100 microseconds.

Important elements of this and previous tubes are the dimpled cathode, nonintercepting grid, grounded anode and voltage-depressible collector-probe system. Additionally, an intermediate electrode has been placed between cathode and anode to limit dc voltage between electrodes to about 125 kV. This technique has been successfully applied in other high-voltage beam technologies to achieve reliable operation.

Gun optics were evaluated in the beam analyzer at low voltage with various combinations of beam perveance and intermediate electrode voltage. Acceptable beam performance was achieved with electrode voltage at 40 to 60% of cathode voltage. High voltage performance will be evaluated during hot test.

The new collector-probe system has been designed to dissipate approximately twice the power handled in the prior switch tube. Anticipated collector-probe power is about 80 kW at 90% depression and minimum duty cycle. Ultimate capability of the collector-probe system is uncertain due to lack of exact knowledge of power density at the tip of the probe.

Processing at Varian was limited to exhaust, high-pot and cathode age. Initial testing will be done at RADC.

EVALUATION

The Linear Beam Switch Tube introduces a new method in switching that can provide a greater flexibility in switching than is presently available. Because of the effectively grounded anode structure, which also serves as a mounting surface, system interface between the energy source and pulse is greatly simplified. Operating at levels up to 200 kV will allow a more sophisticated control of the power pulse for some existing type radar modulators as well as future radar designs.

Bobby R. Gray

BOBBY R. GRAY
Project Engineer

I. INTRODUCTION

This report covers the design, fabrication and processing of a linear beam switch tube developed by Varian Associates, Inc., Palo Alto, CA, on Contract F30602-78-C-0232. The device is shown in Figures 1 and 2. The current effort is a continuation of earlier work sponsored by the Department of the Air Force. Important features retained are the nonintercepting grid, high efficiency resulting from controlled spreading of the electron beam as it enters the collector region, dimpled cathode, and the depressible collector-probe system. Additionally, an intermediate electrode has been placed between focus electrode and anode to limit dc voltage between electrodes to about 125 kV. The objective is to gain high-voltage reliability by dividing the voltage among several gaps.

Figure 3 is a schematic diagram of the switch tube as a series modulator.

The principle of operation is as follows: A pulsed convergent electron/beam is launched from the indirectly heated cathode. Grid voltage controls amplitude and duration of the current pulse. The beam is accelerated by the intermediate electrode and passes through the grounded anode. As the beam enters the collector space, the collector is depressed toward cathode potential causing a corresponding current to flow in the load. When the load is a linear-beam microperveance 2 microwave tube which the switch tube is specifically designed to modulate, the load current is $2 \times 10^{-6} \times (\text{load voltage})^{3/2}$. The switch tube is operated near the highest possible efficiency in order to minimize power dissipation in the collector-probe system.

The objective of the present work was to develop a linear beam hard tube switch capable of operating at pulse lengths up to 100 microseconds with a goal duty cycle of 0.04 (0.02 minimum). Other design goals of the experimental model are shown in Table 1.

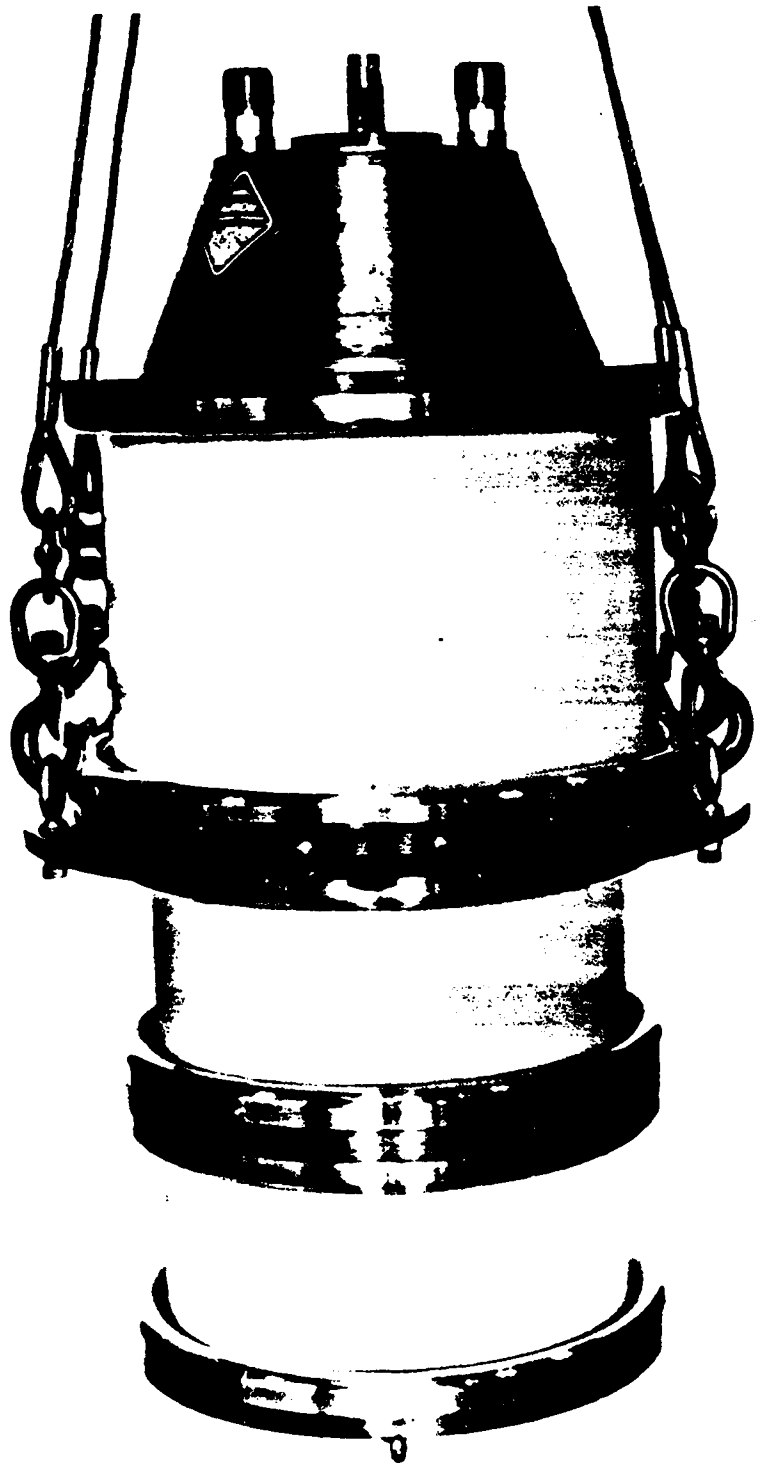


Figure 1. VKW-8273 Switch Tube

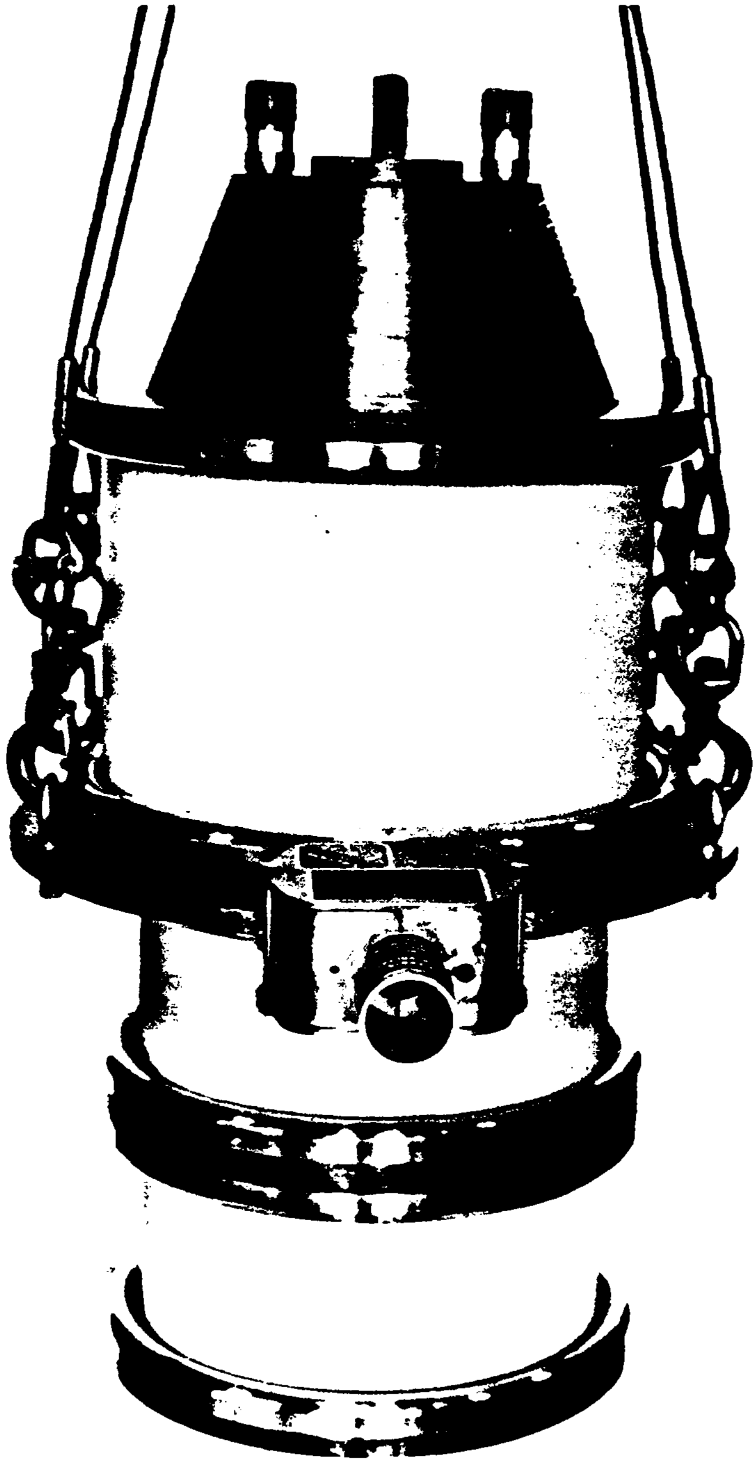


Figure 2. VYW-8273 Switch Tube

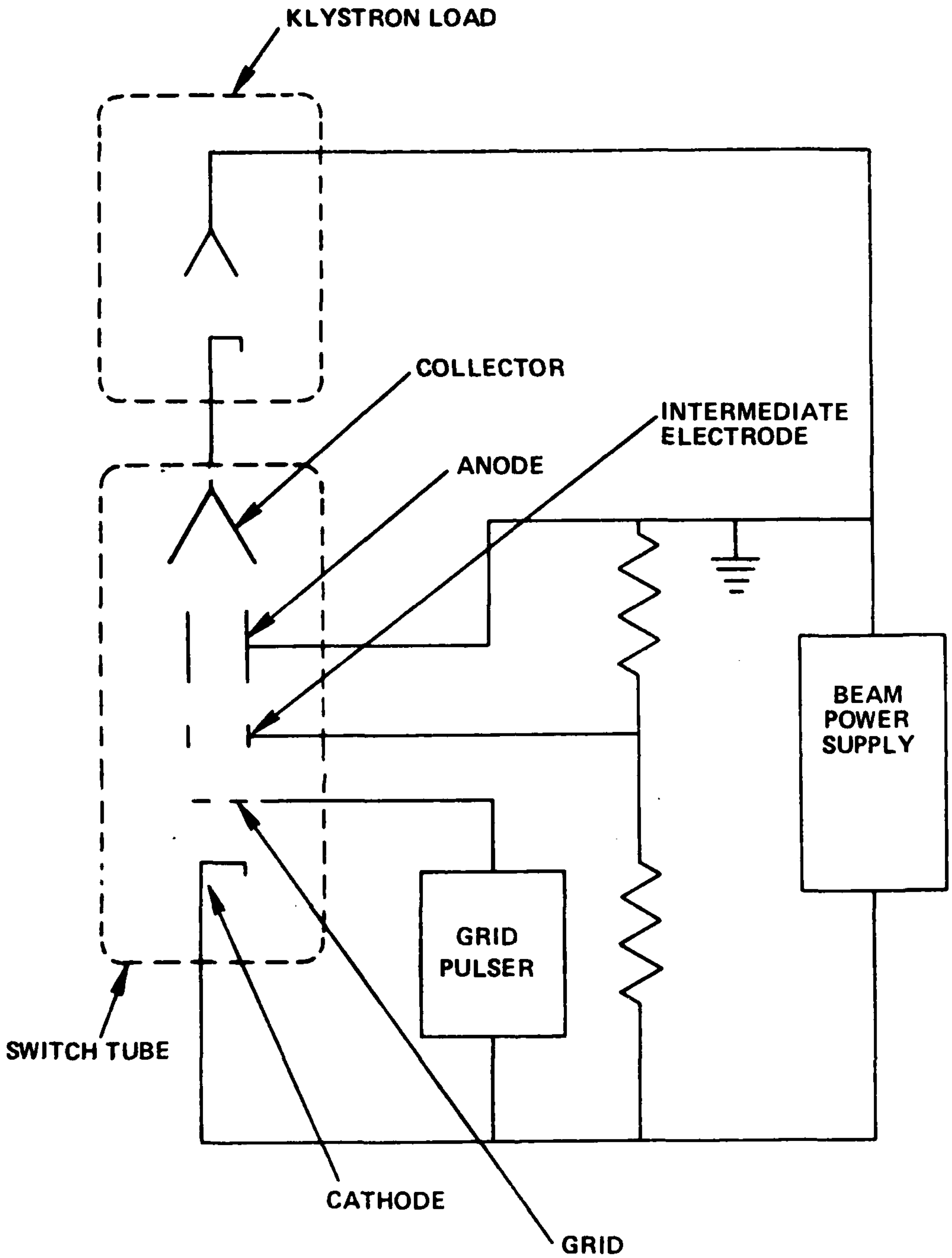


FIGURE 3. SCHEMATIC DIAGRAM SWITCH TUBE SERIES MODULATOR

Table 1

Design Goals

Holdoff	250 kV dc
Intermediate Electrode Voltage	Approx 125 kV dc
E_c Video Out	200 kV
I_c Video Out	180 amperes
Pulse Length	Up to 100 μsec
Duty Cycle	At least 0.02 with 0.04 As a goal
Grid Bias	2 kV max
Positive Grid Drive	6 kV max
Load Impedance	1.6 to 2 uk (Perveance)
Grid Interception	0.5% Ib max
Anode	Ground Potential
Anode Cooling	Water or oil
Collector	Video potential
Collector Cooling	Oil
Appendage Vacuum Pump	Ion pump at ground potential
Size and Weight	Minimum consistent with the state of the art

Exhaust and processing of the experimental model took place at Varian Associates, Inc., Palo Alto, California, in July and August, 1980. The tube was delivered to Rome Air Development Center, Air Force Systems Command, Griffiss Air Force Base, New York in late August, 1980.

II. DESIGN AND CONSTRUCTION

A. COLLECTOR AND PROBE

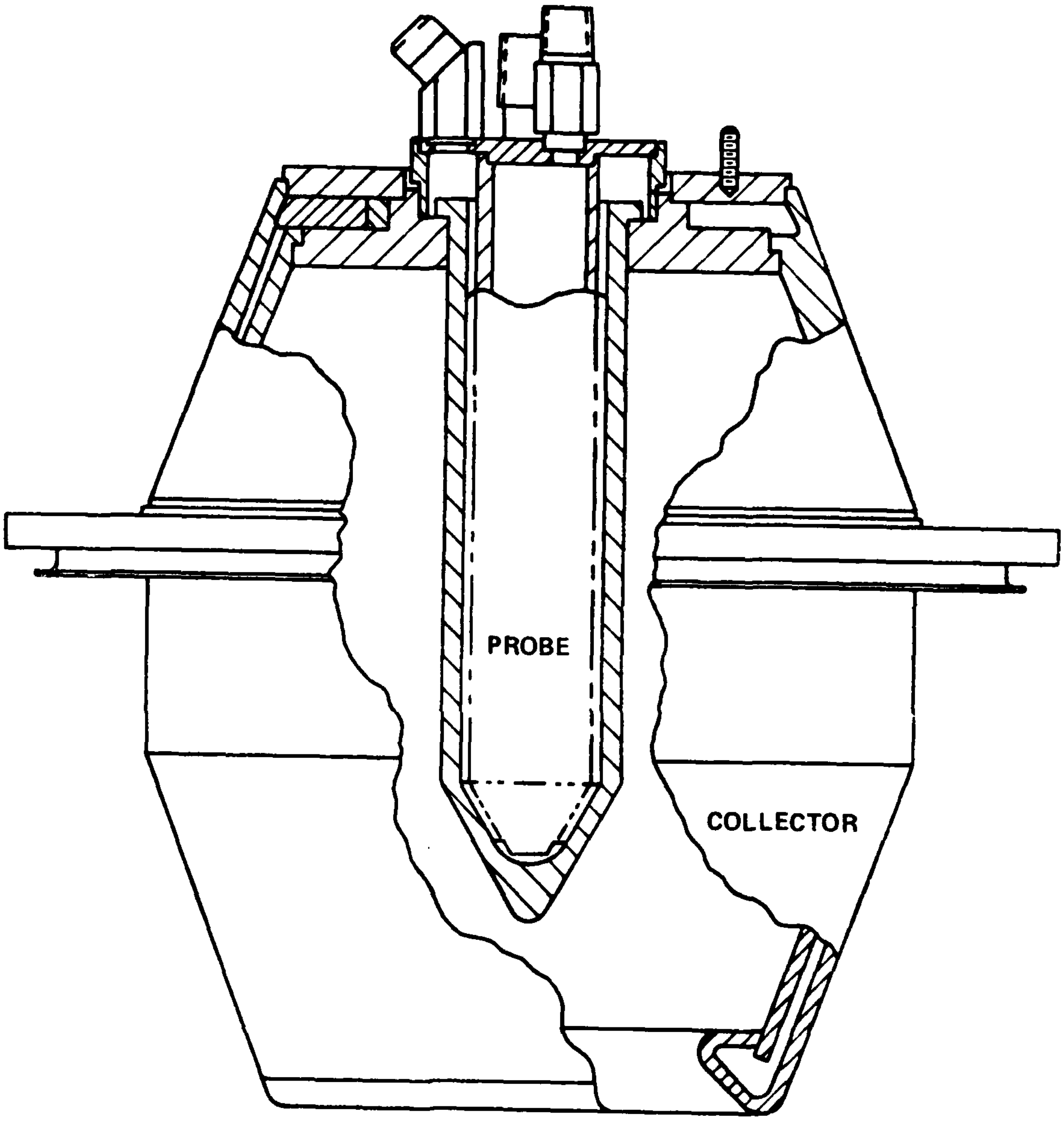
A satisfactory collector-probe had been worked out on earlier versions of the switch tube. It was decided to retain the basic design and improve its power handling capability consistent with the new electrical design goals.

The collector-probe is shown in Figure 4. The center probe decided upon is 2.75 inches in diameter with a 2.1 inch taper at the tip. High velocity coolant enters the probe tip from a sump located along the probe center line. The coolant returns along a series of parallel slots just under the outer surface of the wall. All critical elements of the probe are made of copper for maximum heat transfer.

Specifications for the present tube led to the necessity of additional collector-probe surface for dissipating beam power. To accomplish this, a 14.375 diameter collector ceramic insulator was substituted for the 12.658 diameter ceramic used on the prior tube. The collector body was tapered away from the ceramic to preserve beam entrance conditions worked out earlier. A corona ring was situated on the body to mask the base of the ceramic from evaporation products.

A section of collector body is shown in Figure 5. Coolant flows in parallel paths along the length of the collector and turns around in the U-shaped lip at the beam entrance to the collector. In and out water fittings are mounted at the extreme end of the tube. The collector coolant manifolds are fitted with 1-11 1/2 NPT pipe nipples. 1/2-14 NPT pipe nipples are used on the probe manifolds.

It had been established on earlier programs that the optimum anode-collector configuration was a mirror image of the electron gun-anode region, with a central probe replacing the cathode. The fly trap feature



FIGUPE 4. COLLECTOR-PROBE ASSEMBLY

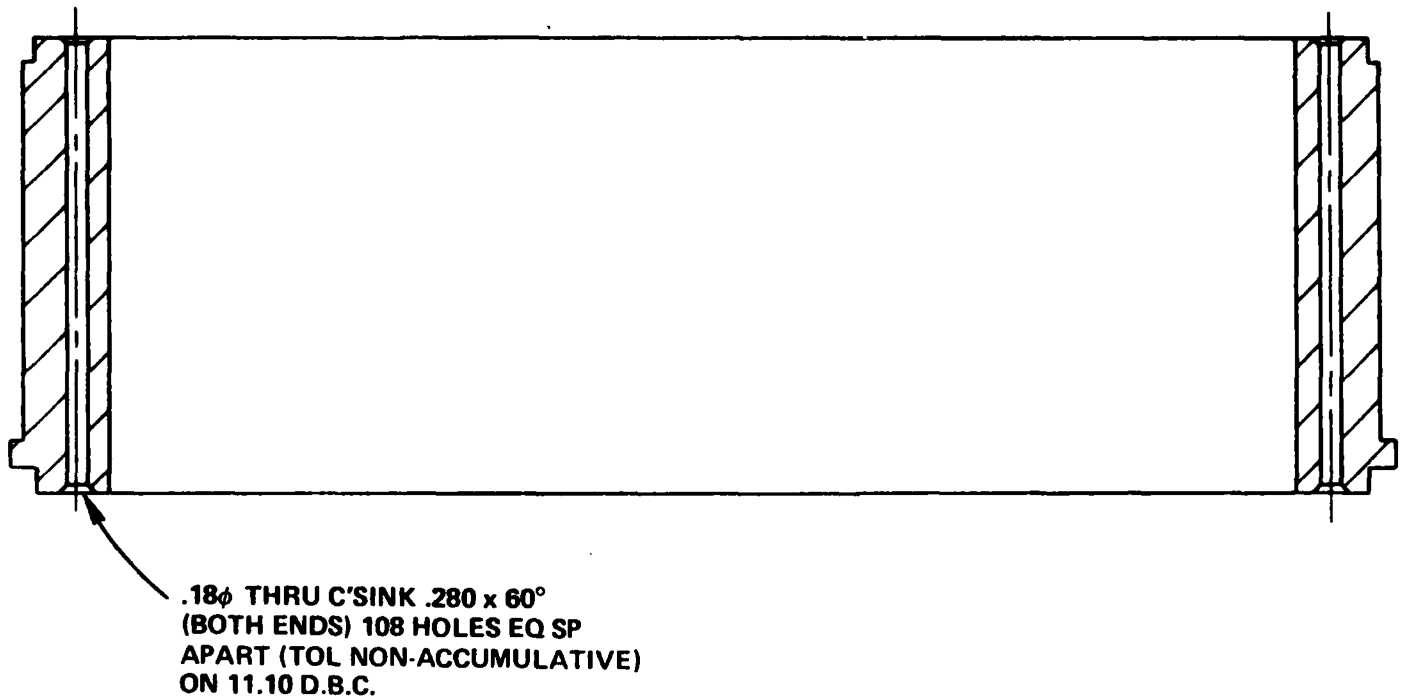


FIGURE 5. COLLECTOR BODY SECTION

for capturing a portion of the returned electrons has been retained. Our latest design has the fly trap supported by the tapered portion of the collector wall.

Early in the program, power dissipation estimates for the collector and probe were projected on the basis of power distribution in the VKW-8253C switch tube. Based on these estimates, we have designed for a power level of slightly less than twice that of the earlier tube.

Computer analysis of electron trajectories in the collector region was done in two steps. Initially, the trajectories of 20 selected electrons were traced from the cathode surface to the point where the converging beam reaches its electrostatic minimum diameter. Electron positions and velocities were then entered into a program in which the collector-probe region had been modeled. The electron trajectories were studied in the presence of the retarding field presented by the negative collector-probe voltage. Beam trajectories were computer studied at a number of electrical conditions and collector-probe geometries.

Figures 6 through 11 are typical print-outs tracing the trajectories of 20 electrons. The collector, probe, and anode are illustrated in half section with the x-axis coinciding with the tube's center line. The line joining the collector tip and anode plate is for the convenience of our computer model. The two elements are actually spaced by the collector insulator located in a distant radial position.

Figures 6, 7, and 8 show beam profiles where cathode voltage is constant and grid voltage (beam current) is varied to achieve variable output voltage and depression.

Figures 9, 10, and 11 show beam profiles where depression has been held constant and variable output voltage has been achieved by varying grid voltage (beam current) and cathode voltage.

Computations based on these and other data have been used to predict collector and probe surface power densities. Thermal design relied heavily

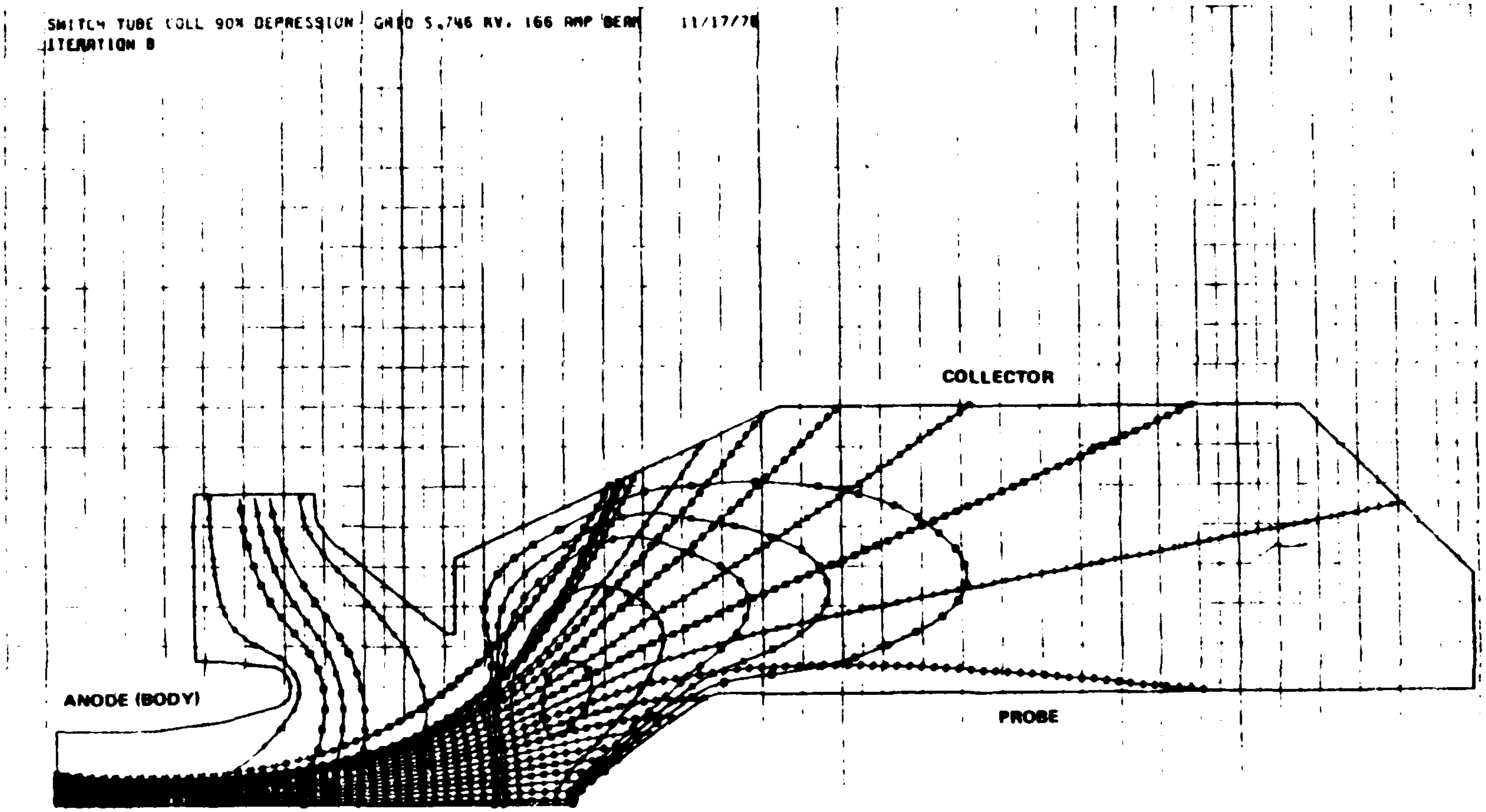


Figure 6. 90% Depression – 166 A Beam

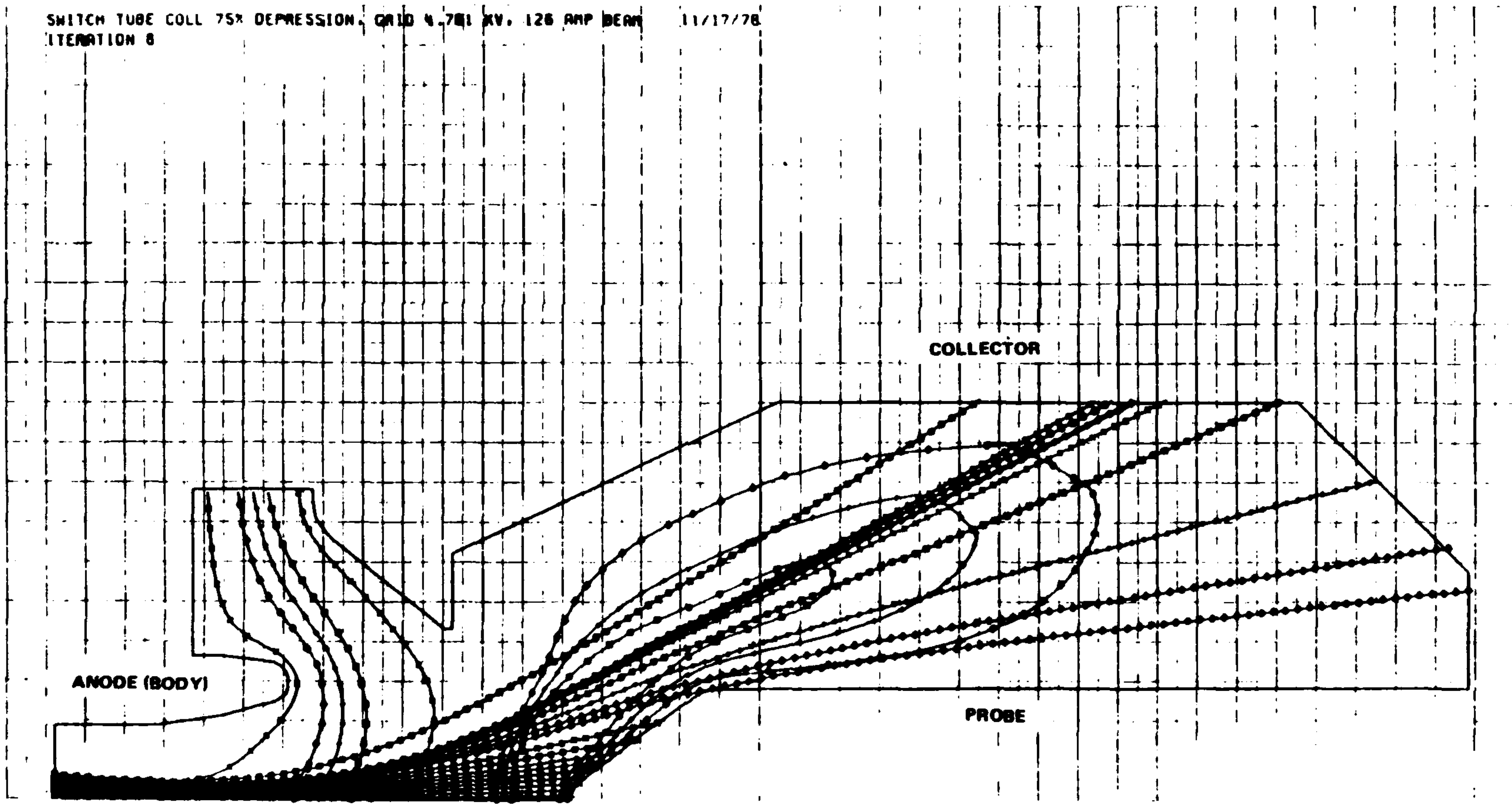


Figure 7. 75% Depression – 126 A Beam

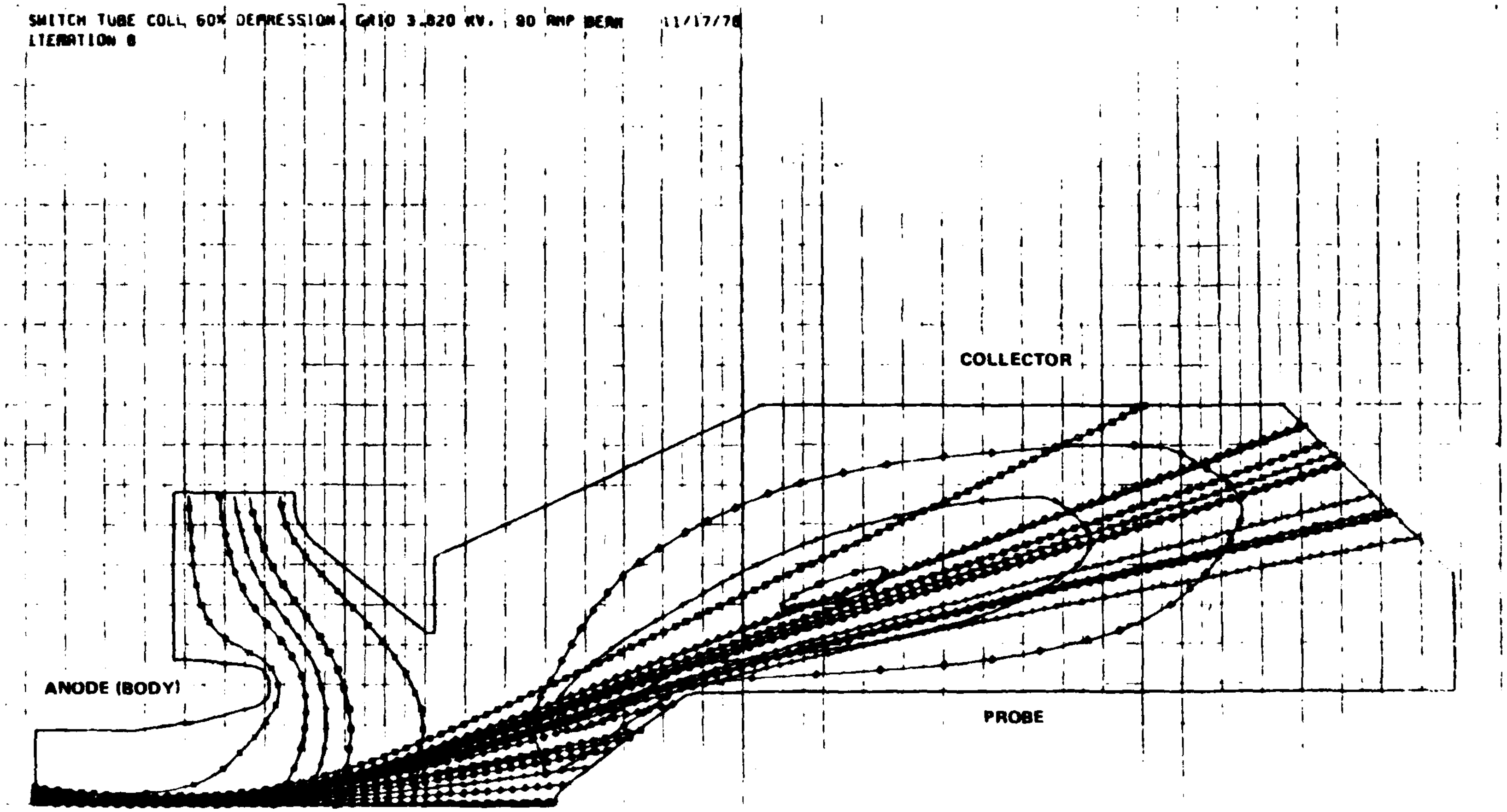


Figure 8. 60% Depression – 90 A Beam

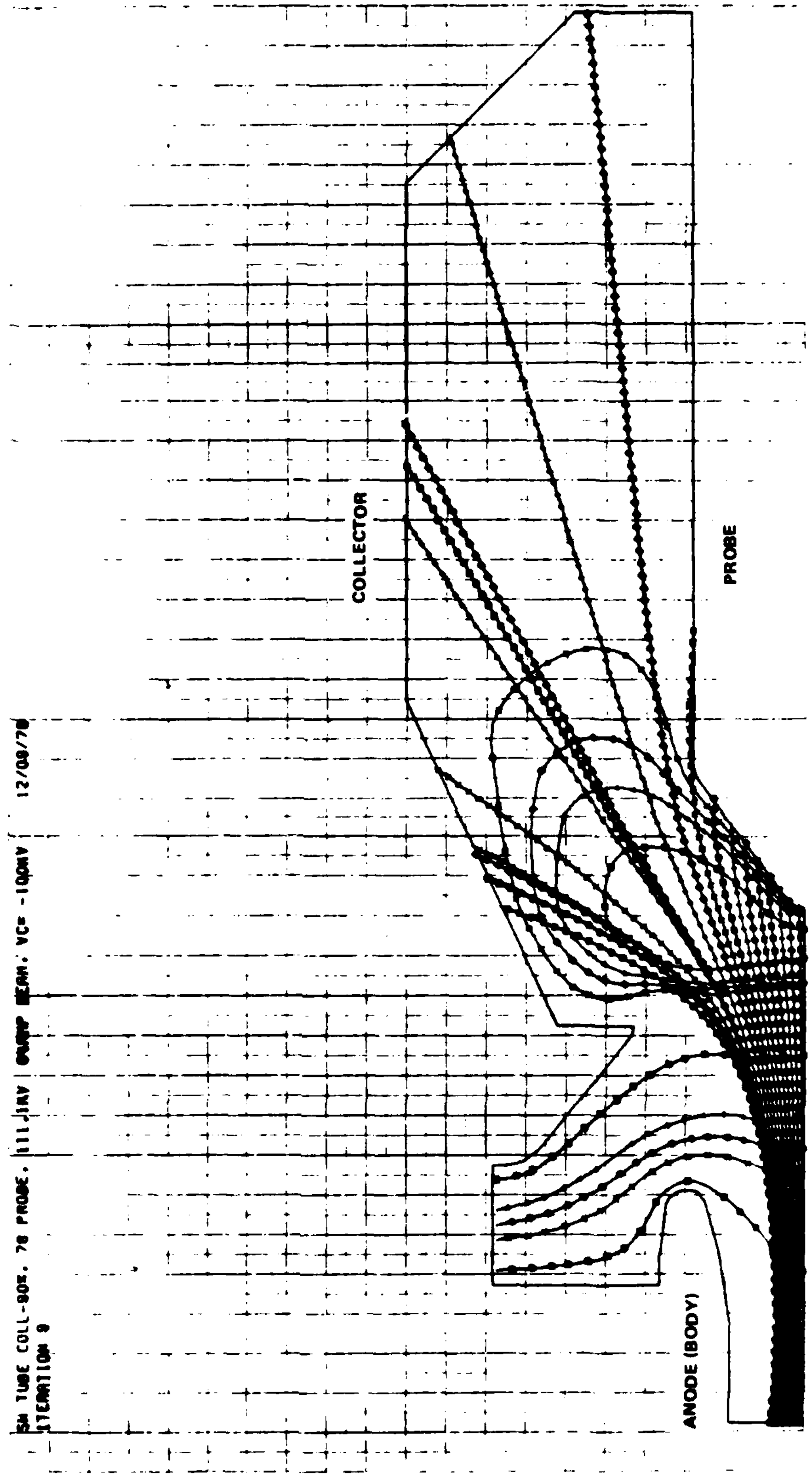


Figure 9. 90% Depression — 64 A Beam

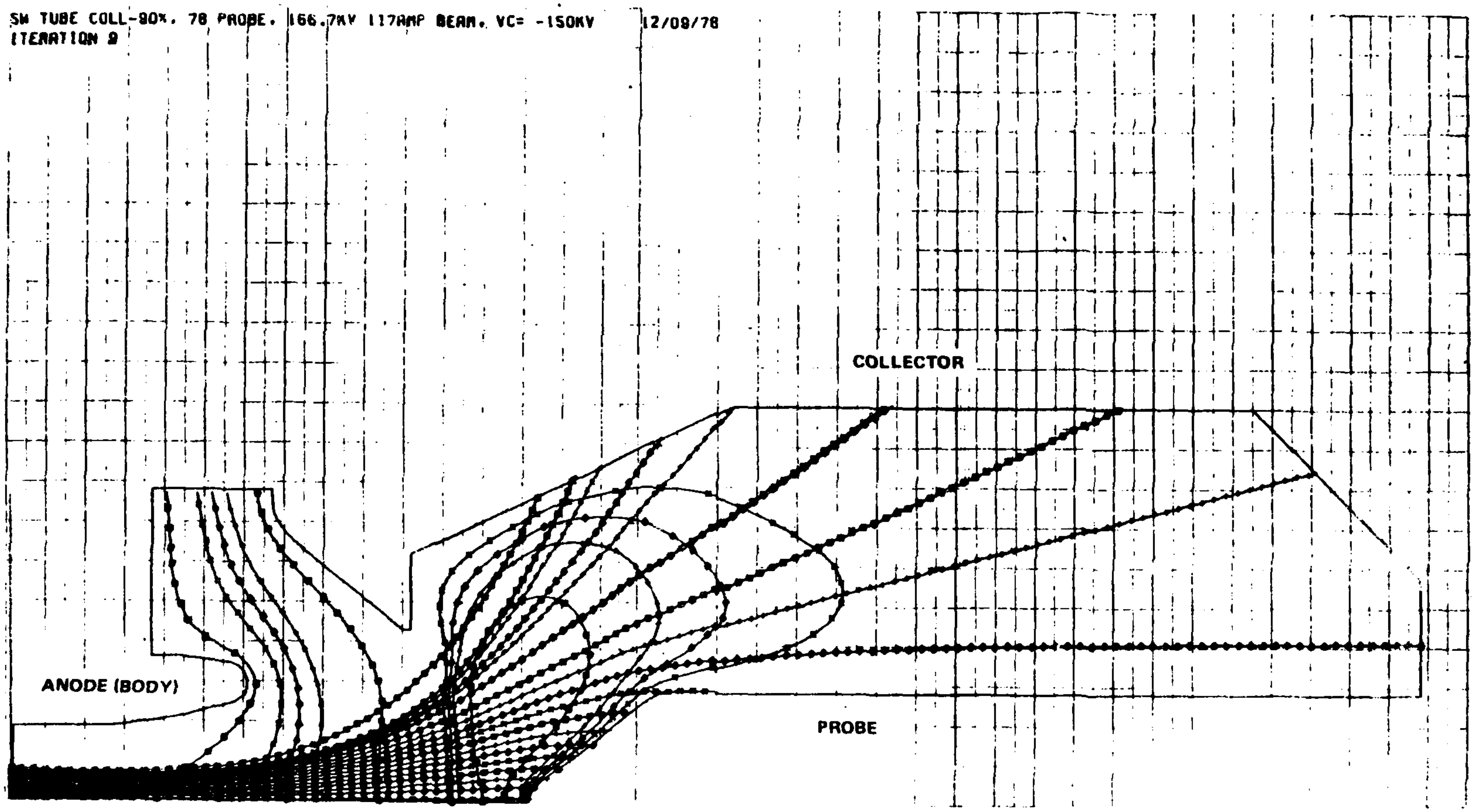


Figure 10. 90% Depression — 117 A Beam

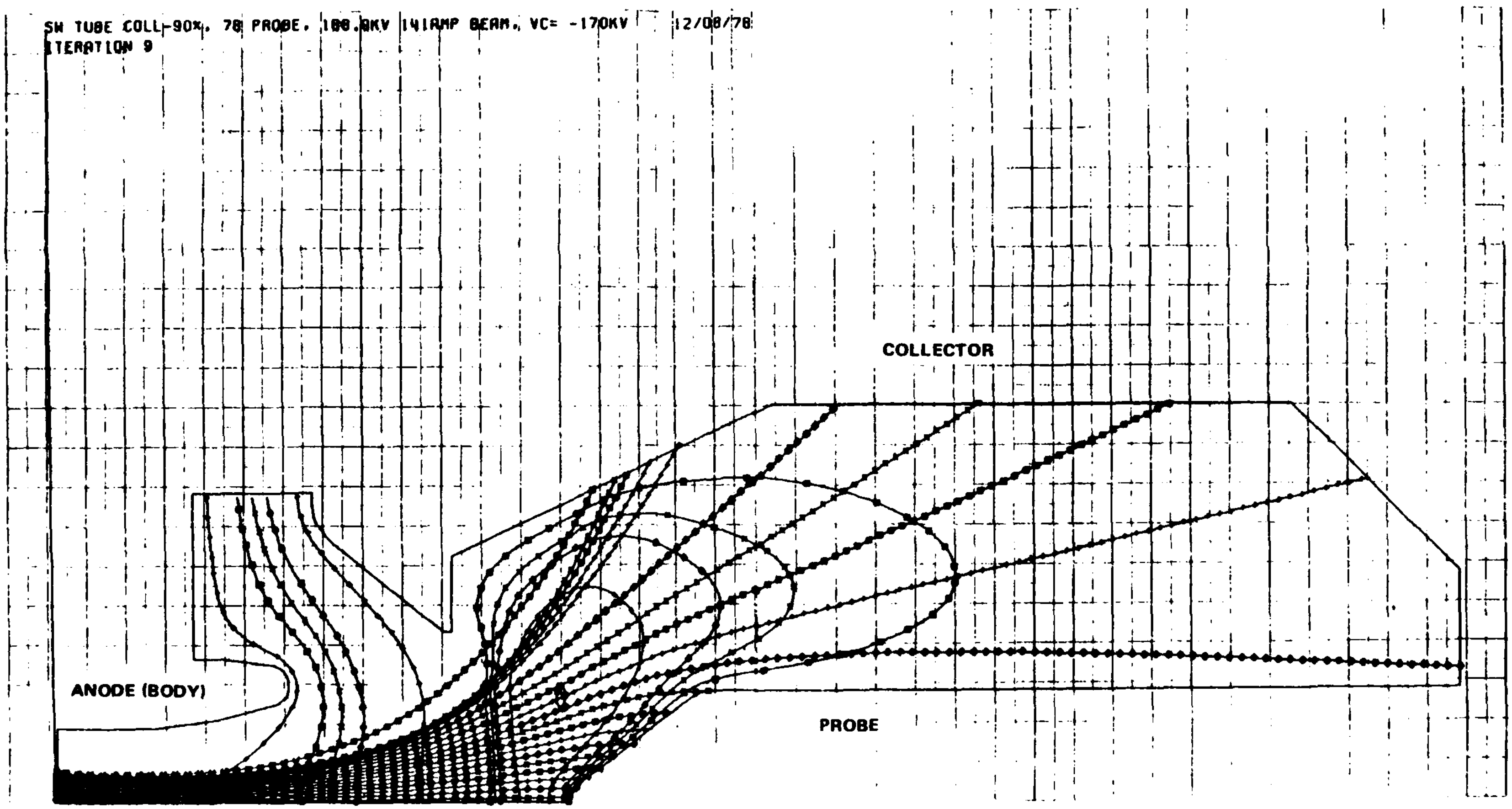


Figure 11. 90% Depression -- 141 A Beam

upon predicted power distribution. The actual probe-collector geometry eventually used was refined slightly for mechanical considerations.

As on the earlier switch tube, predicted power densities were greatest at the probe tip and fell off quite rapidly along the length of the probe. However, it is recognized that density approximations have the greatest possibility of error in the vicinity of the tip.

B. GUN AND COLLECTOR INSULATORS

Procurement and assembly of the 14.375 diameter collector ceramic and the 12.658 diameter gun ceramics became a major undertaking. Drawings of the finished assemblies are shown in Figure 12 and 13.

Purchase lead time was 5 to 8 months for the raw ceramics. Upon receipt, one ceramic was forwarded to a vendor for cutting the backup rings plus an additional piece to be used for supporting the rings during metalize firing.

During the first two attempts at metalizing the largest ceramic bodies, stress cracks developed along the length of the pieces.

After the first failure, temperatures were more carefully monitored. It was found that the furnace temperature rose too rapidly during part of the cycle in the second firing. It was decided to abandon automatic furnace control on subsequent firings.

A manually operated furnace schedule was devised for the next firing. Two additional thermocouples were temporarily installed to calibrate the two permanent platinum thermocouples while making a trial run with one of the previously cracked ceramics. These thermocouples, placed on the O.D. and I.D. of the ceramic, were correlated with the permanent ones to provide the operator with additional temperature information.

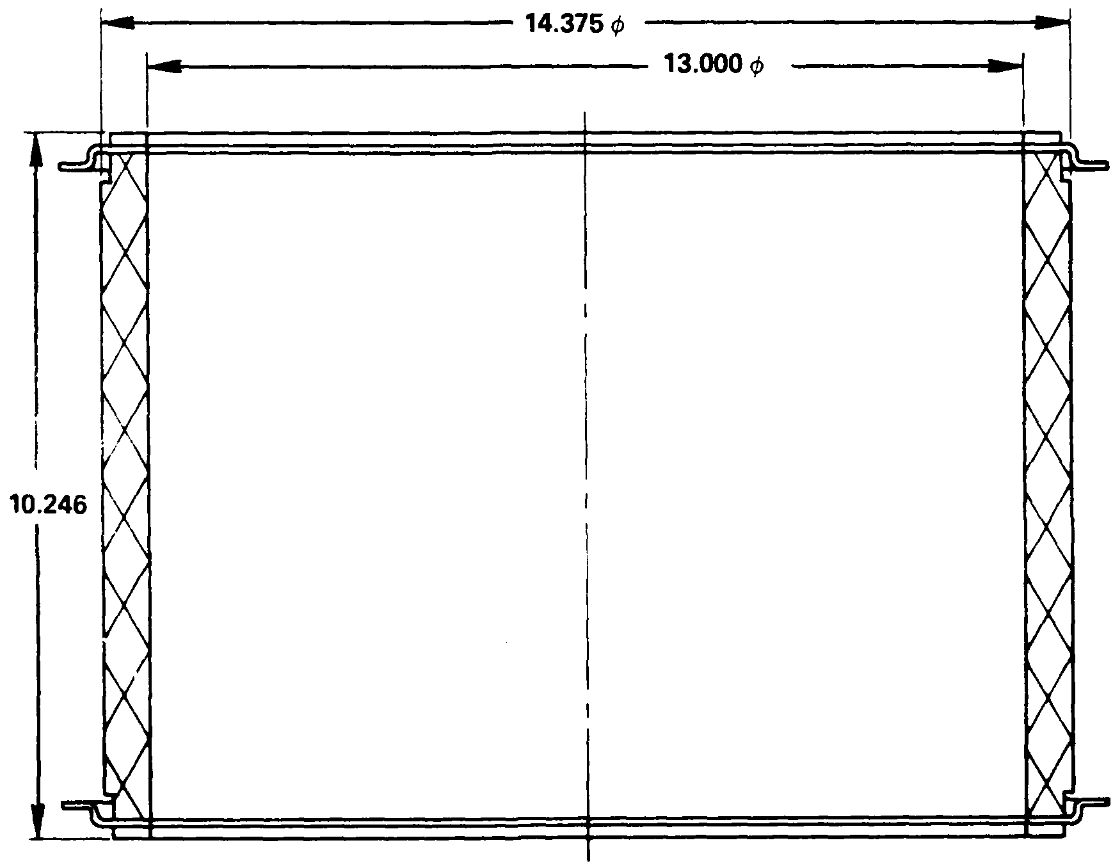


FIGURE 12. COLLECTOR INSULATOR ASSEMBLY

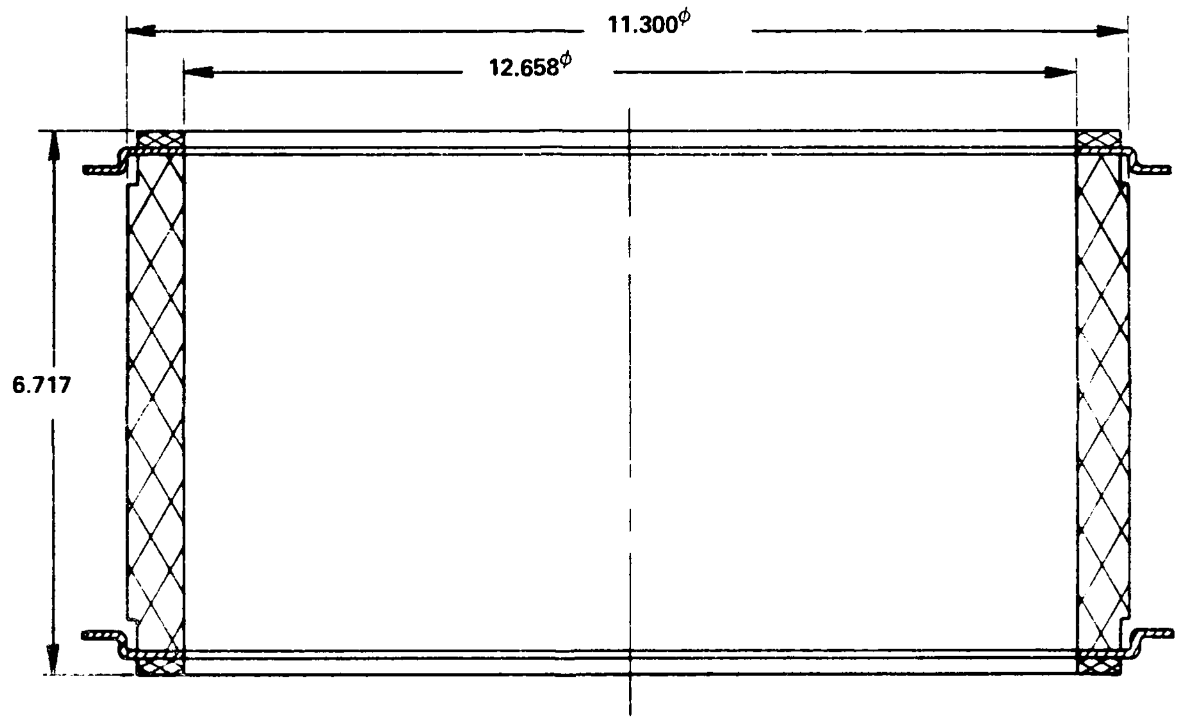


FIGURE 13. GUN INSULATOR ASSEMBLY

The next metalizing firing of the collector ceramic was successful. No difficulty was encountered with subsequent metalizing of the two gun ceramics.

Both gun insulators and the collector insulator were assembled with seal rings and backup ceramics and brazed in a single load in a Varian hydrogen furnace. Our metalizing experience helped in devising an extended 30-hour braze cycle to avoid thermal shock. The braze was successful.

Eight corona rings were added inside and outside of the tube to minimize voltage gradients in the vicinity of the ceramic insulators.

C. GUN

A sketch of the cathode-anode region is shown in Figure 14. Major elements are the grid, cathode, heater, anode and intermediate electrode. Assembly drawings are shown in Figures 15 through 19.

The control grid is supported by 32 beryllium-oxide rods. Each of the insulators was brazed on one end to the molybdenum grid blank and on the other end to a mounting plate. After brazing, the grid pattern was formed in the blank by electrical-discharge machining (EDM) techniques. The grid was electropolished as a final step to attain an extremely smooth finish.

A nickel-cathode button was formed, blanked and finish machined. One hundred twenty-five dimples were machined on the button surface to provide the emitting surface for the beamlets that form the electron beam. Nickelating was applied to each dimple and sinter fired in place. Just prior to sealing into the final assembly, each dimple was coated with barium triple carbonate. Finally, a nickel shadow grid was aligned with the dimples and attached to the cathode button.

The heater was wound of 0.060 diameter molybdenum wire. After winding, the heater was sandblasted to insure adhesion of the "Rockide" ceramic

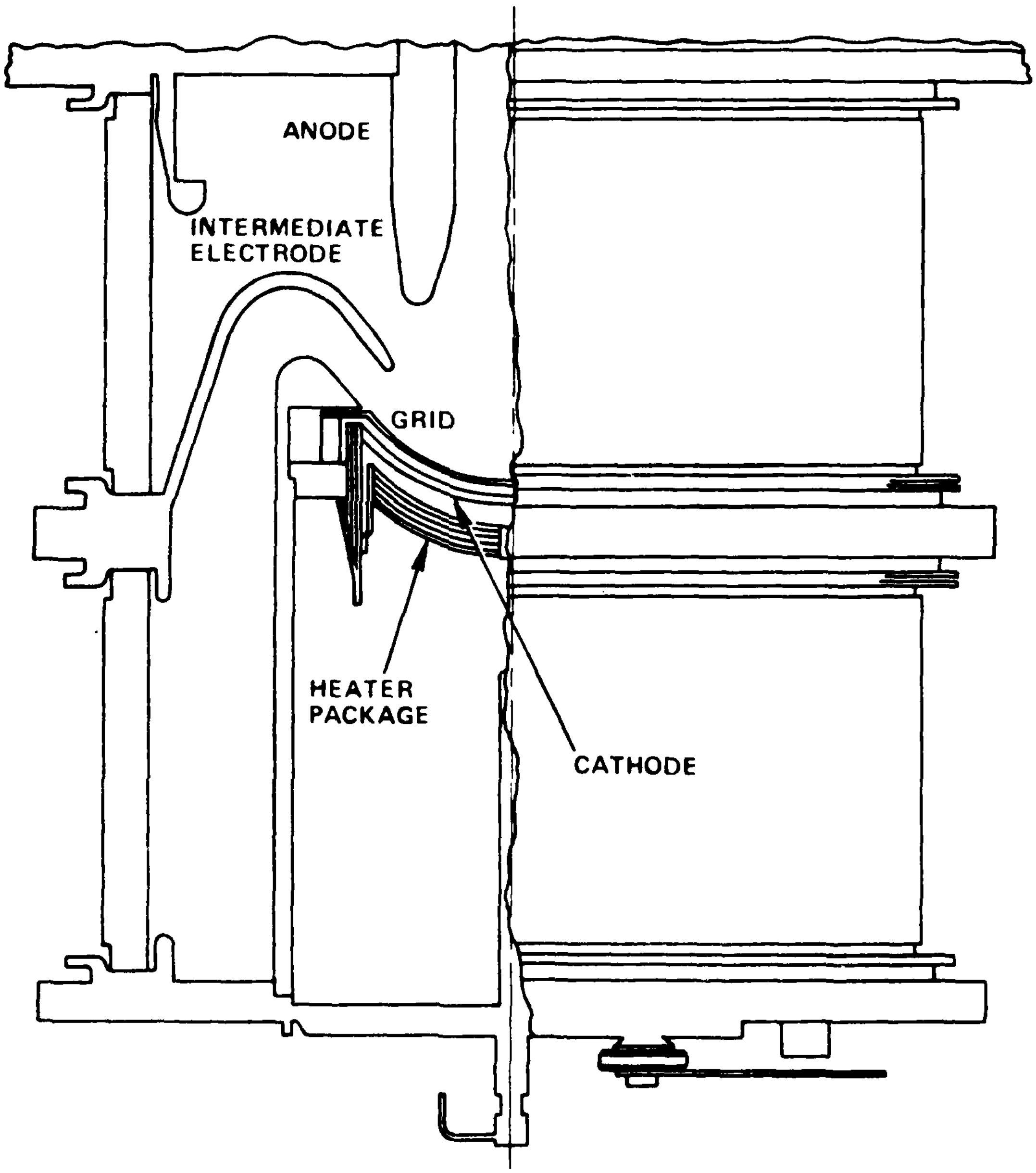
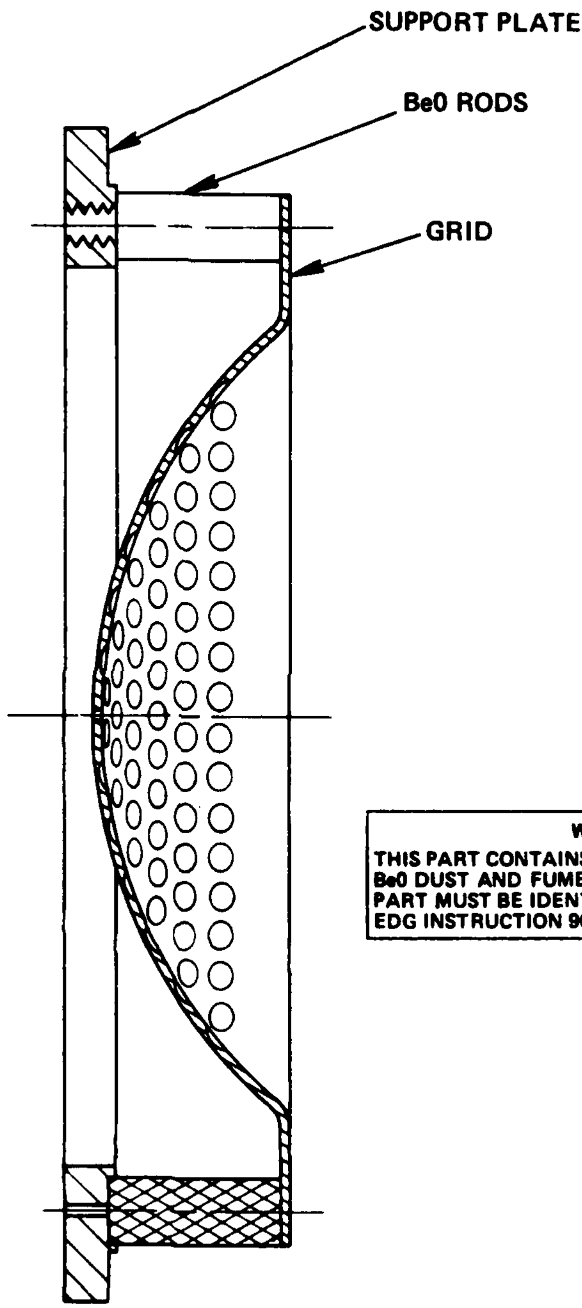


FIGURE 14. CATHODE-ANODE REGION



WARNING
THIS PART CONTAINS BERYLLIUM OXIDE (Be0). Be0 DUST AND FUMES ARE HIGHLY TOXIC. THIS PART MUST BE IDENTIFIED AND PROCESSED PER EDG INSTRUCTION 900.1.

FIGURE 15. GRID ASSEMBLY

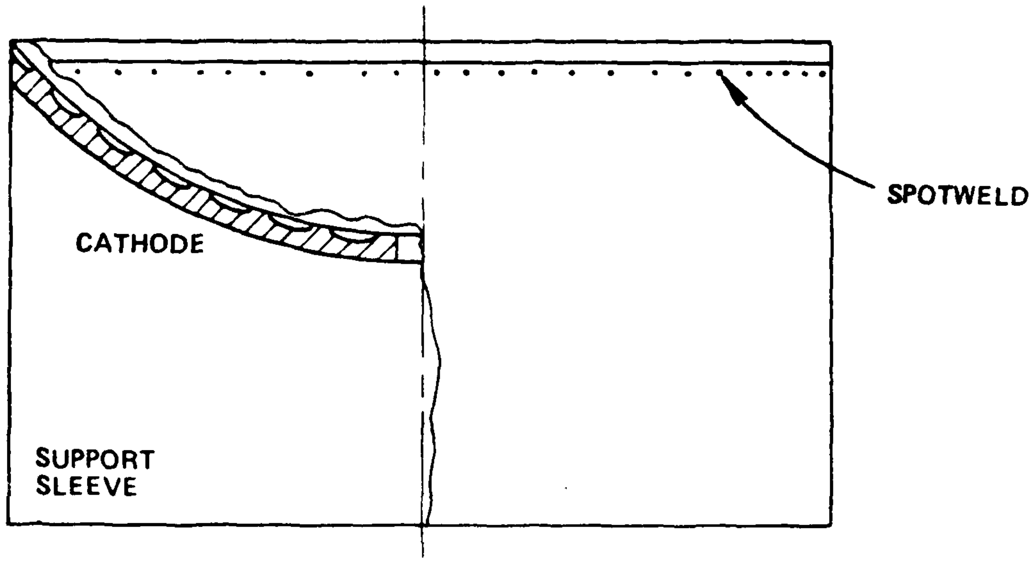
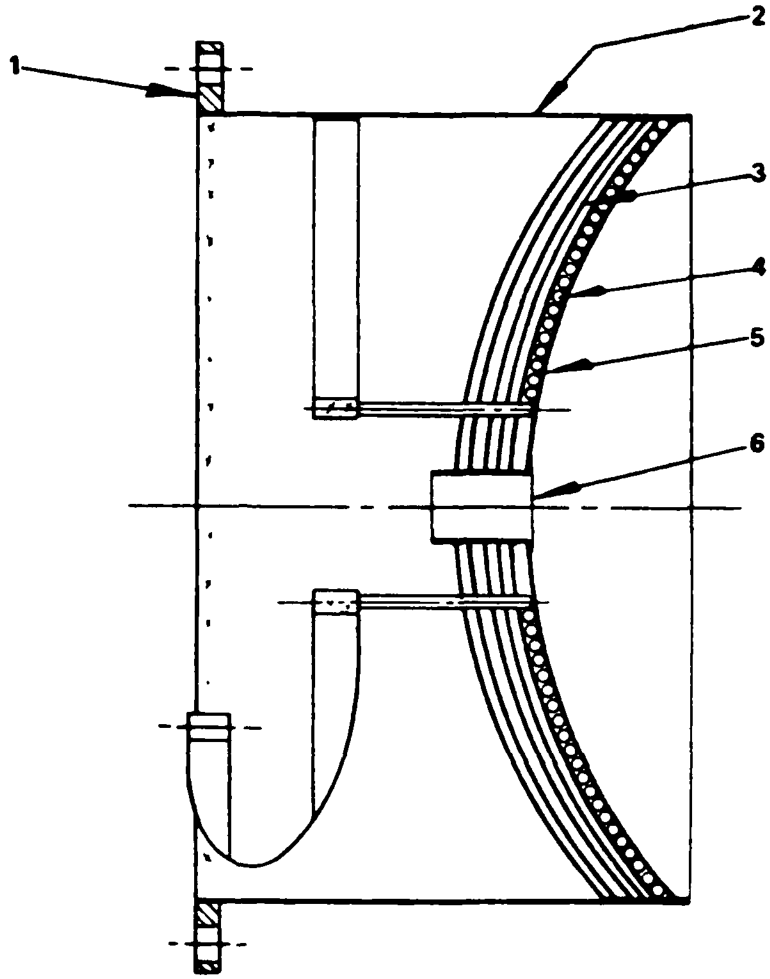


FIGURE 16. CATHODE ASSEMBLY



1 – HEATER SUPPORT RING
2 – HEATER CYLINDER
3 – HEAT SHIELD
4 – HEATER COIL
5 – PERFORATED HEAT SHIELD
6 – ROLLED SLEEVE

FIGURE 17. HEATER PACKAGE ASSEMBLY

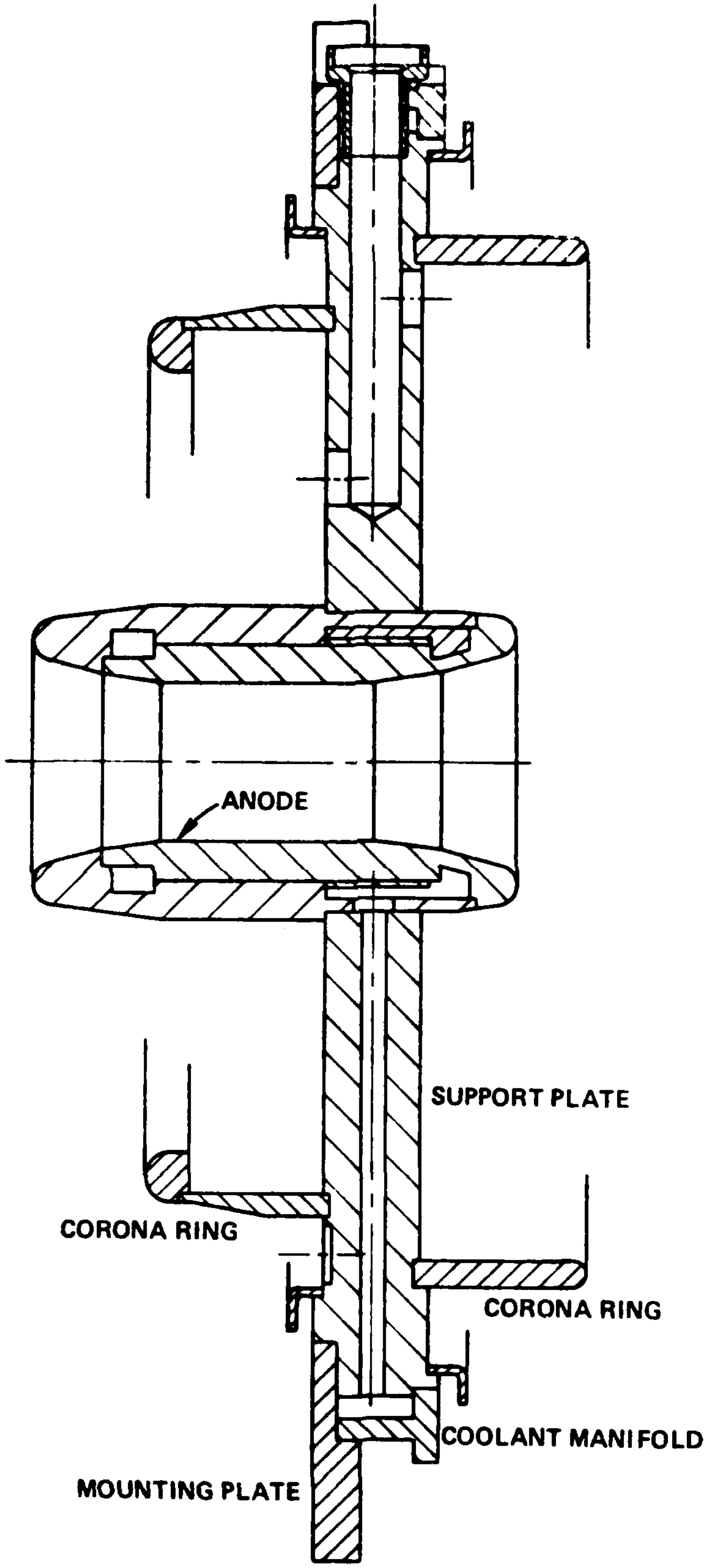


FIGURE 18. ANODE ASSEMBLY

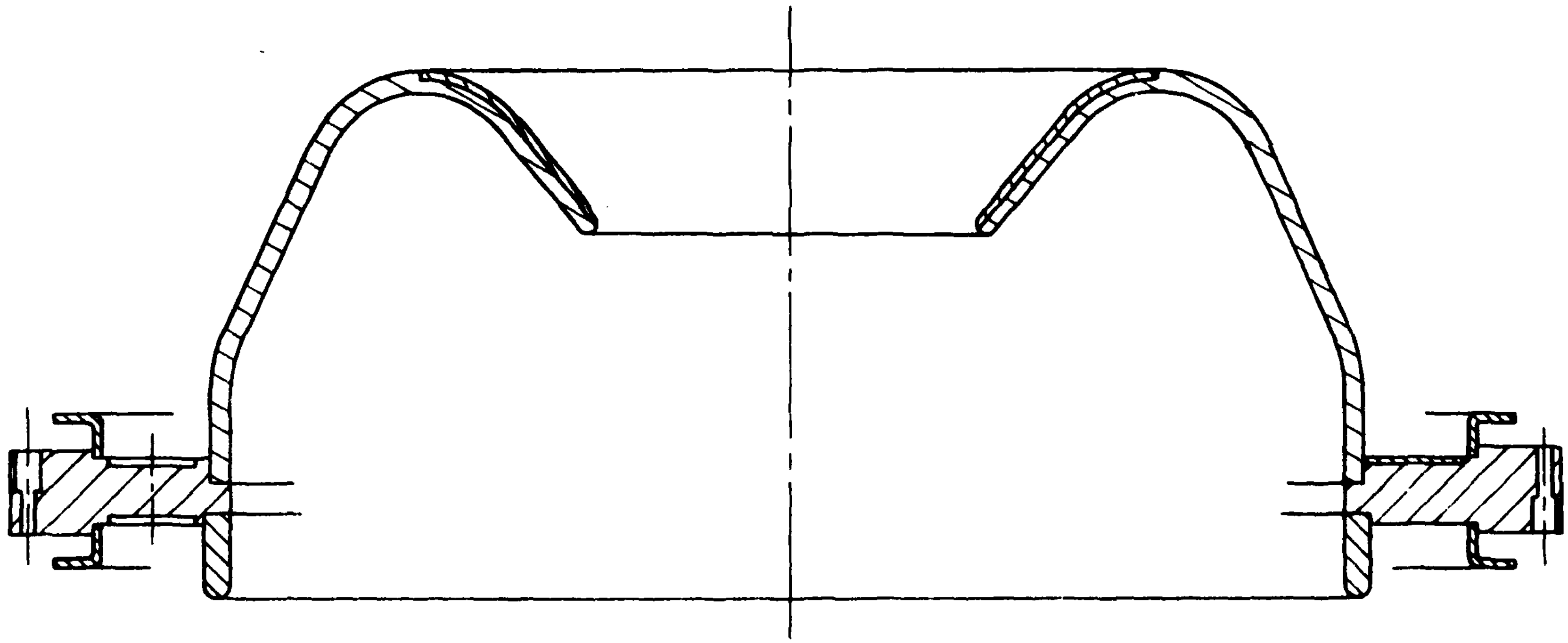


FIGURE 19. INTERMEDIATE ELECTRODE ASSEMBLY

coating. The completed heater was nested between two concave heat shields and hydrogen fired to set its shape. When assembled into the heat-shield package, the heater conforms to the dished back of the cathode button.

Primary components of the anode assembly are the anode and support plate, tube mounting flange, corona rings, and coolant manifold. The tube mounting flange is a 19-inch diameter stainless steel plate with clearance holes for mounting bolts. The anode and support plate are copper. Other parts are primarily stainless steel.

The intermediate electrode was formed as a laminated assembly, the bulk of it being copper to give good heat conduction away from the electrode. Stainless steel was used as the other part of the laminate. Several attempts were made at assembling and brazing before a satisfactory assembly was achieved.

The cathode-grid structure is supported by a copper sleeve, the other end of which is brazed to a copper support plate that forms part of the vacuum wall. Conduction heat loss from the gun elements flows through the high conductance copper path and is dissipated in the tank oil. The reentrant section of the gun that required air venting on the prior tube has been eliminated.

Control grid to cathode spacing was set by precision spacers. Adjustable support sleeves were welded together for permanent alignment. Thin molybdenum heat shields were wrapped around the cathode support sleeve prior to assembling the control grid. Alternate layers of corrugated and flat stock were used to minimize heat loss from the cathode.

The basic gun optics design developed on earlier programs has been retained in our present work. Our experience and developments in other high-voltage beam technologies indicate that high-voltage reliability at the 200 kV level can best be achieved by dividing voltage between several gaps. Primary design effort was directed toward evaluation of effects that may be caused by adding the voltage dividing electrode between anode and cathode.

In our design, full dc beam voltage is applied between cathode and anode. A power supply tap is attached to the intermediate electrode to split the voltage in the desired ratio. It was found during beam analyzer experiments that adjusting the intermediate electrode to 50% of beam voltage provided optimum beam performance in the vicinity of the gun, although the setting wasn't critical.

Initially, optics were studied with computer models. These early models were evaluated with respect to mechanicl design, proximity of support ceramics, and voltage gradients. Typical computer printouts are shown in Figures 20 through 22.

Figure 20 is a copy of a typical printout early in the program. Equipotentials throughout the gun region in the absence of the intermediate electrode were studied. Conditions included a single ceramic insulator bounded on the outside with transformer oil and on the inside with vacuum. The gun surface is represented by the profile marked -210,500 volts. The x-axis represents the center line of the tube.

Several later trial designs are shown in Figures 21 and 22. At this point several intermediate electrode geometries were under consideration. In both figures, the electrode is located approximately mid-way between anode and cathode. The final electrode design most closely resembled the second figure.

The extremities of the gun have been truncated at the 3.25 inch radius in these particular runs. Beam profile, current density, and position of electrostatic beam minimum were studied in these examples.

Once a satisfactory paper design evolved, a scaled down gun was built for experiments in our beam analyzer. A drawing of the beam analyzer is shown in Figure 23. The analyzer is a vacuum chamber in which the gun is mounted for dynamic evaluation. A pin hole and split collector arrangement are used to scan the beam in two transverse directions along the beam axis. Features of the machine include provision for adjusting the anode-cathode

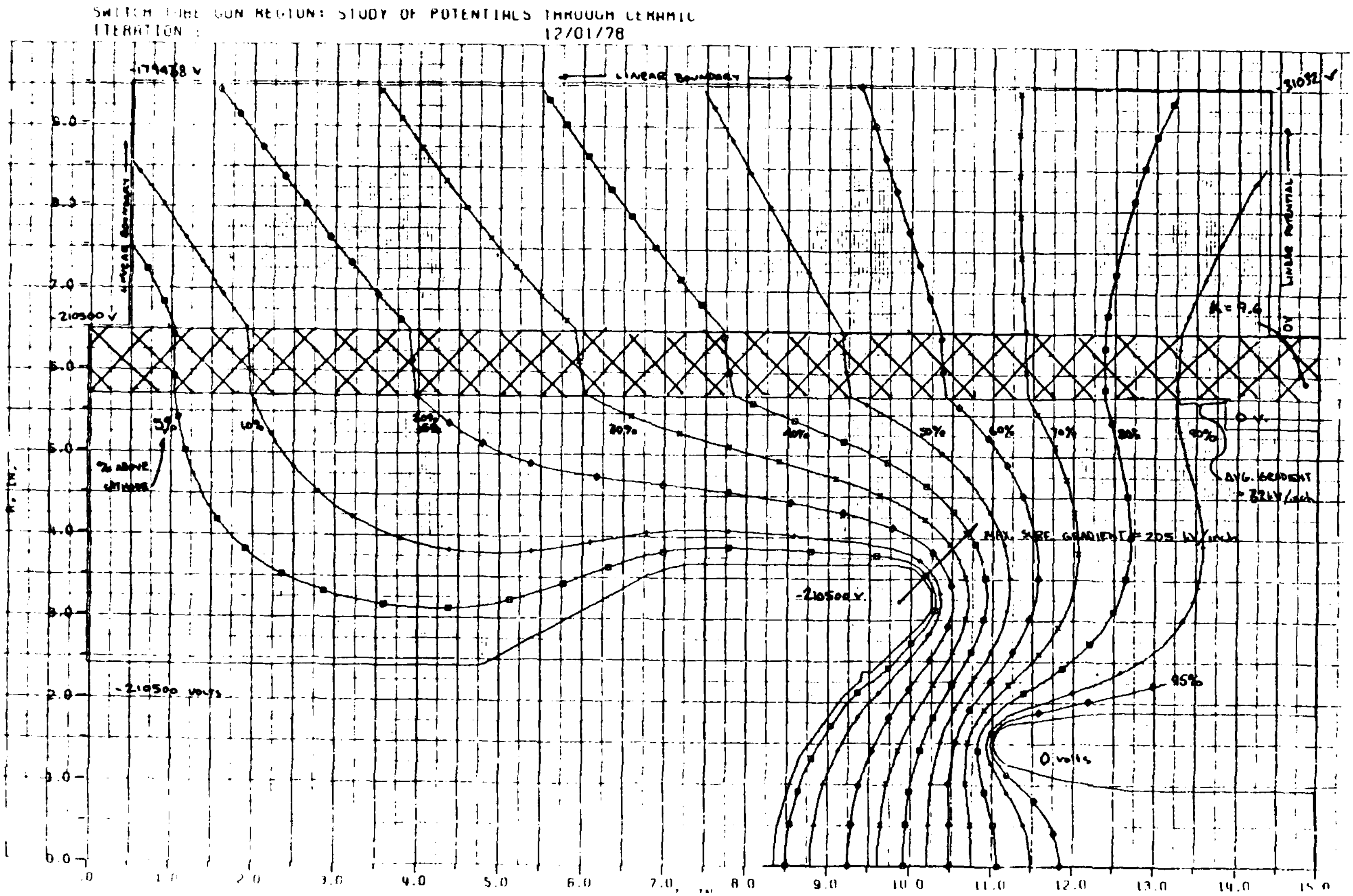
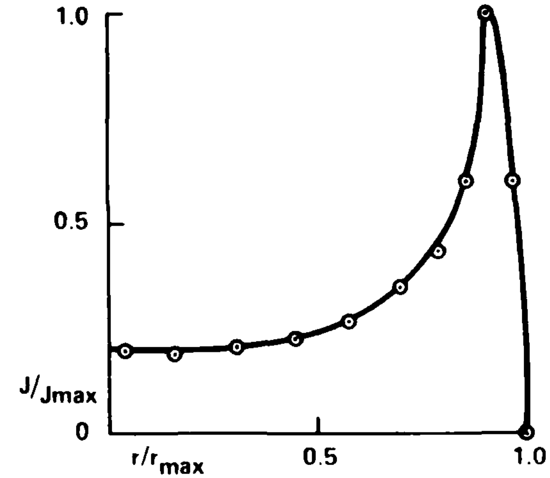


Figure 20. No Intermediate Electrode Assembly

Item	Description
1.	Linear beam switch tube gun for a perveance-2 load
2.	Beam parameters: Voltage = −210500 volts Current = 166 A Perveance = 1.7187 micro-P
3.	Grid drive = 5.746 kV
4.	Plot of normalized current density vs radius, taken at beam minimum: Location of beam minimum−−z = 14.9 inches Jmax = 771 A/in^2, = 119.5 A/cm^2 Radius at beam minimum = .403 inches, = rmax
5.	Equipotential values given below as % of total voltage above cathode potential.



CURRENT DENSITY vs RADIUS

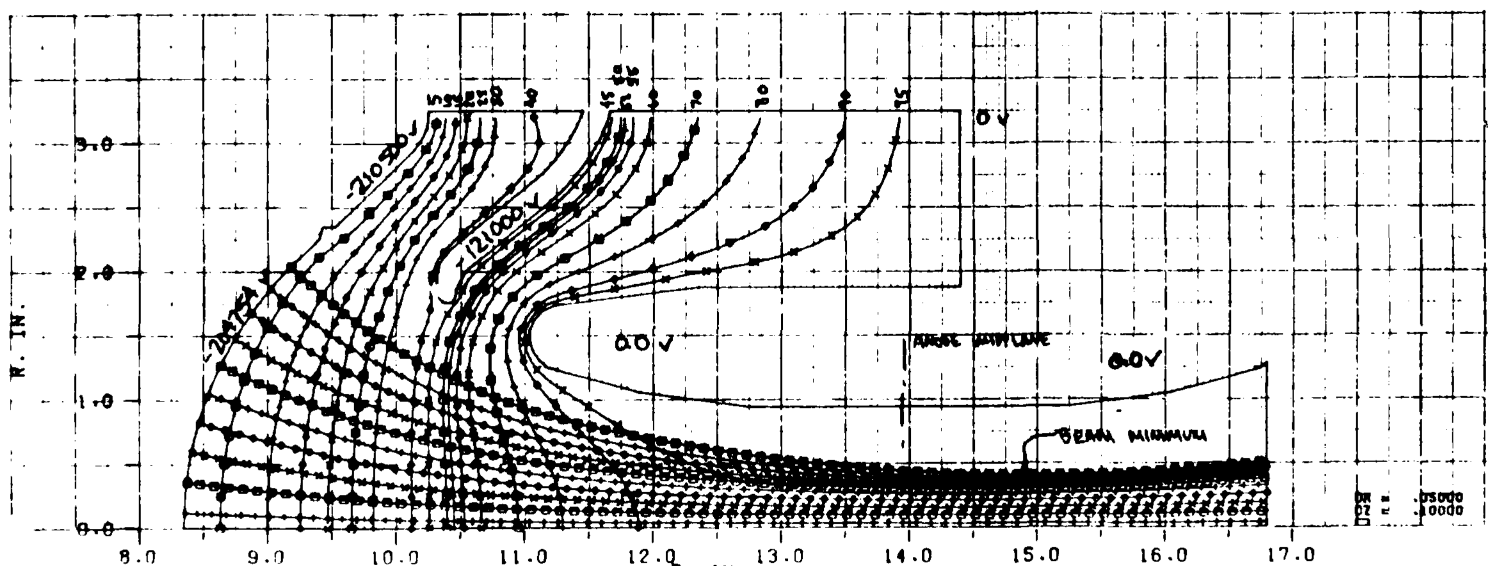
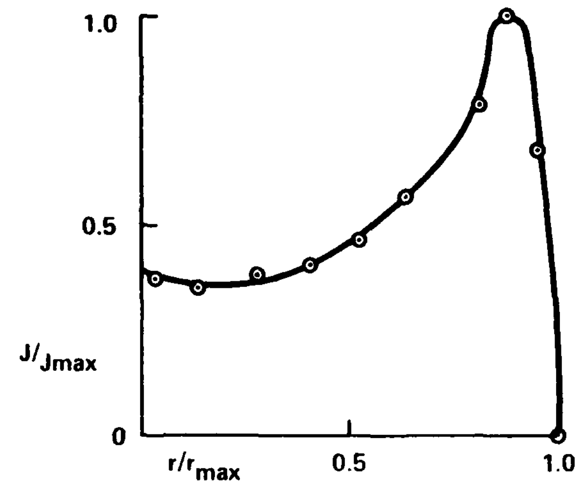


FIGURE 21. INTERMEDIATE ELECTRODE @ 57% OF BEAM VOLTAGE

Item	Description
1.	Linear beam switch tube gun for a perveance-2 load
2.	Beam parameters: Voltage = −210500 volts; Current = 166 A; Perveance = 1.7187 micro-P
3.	Grid drive = 5.746 kV
4.	Plot of normalized current density vs radius, taken at beam minimum: Location of beam minimum—z = 15.1 inches; Jmax = 386 A/in², = 60.0 A/cm²; Radius at beam minimum = .470 inches, = rmax
5.	Equipotential values given below as % of total voltage above cathode potential.



CURRENT DENSITY vs RADIUS

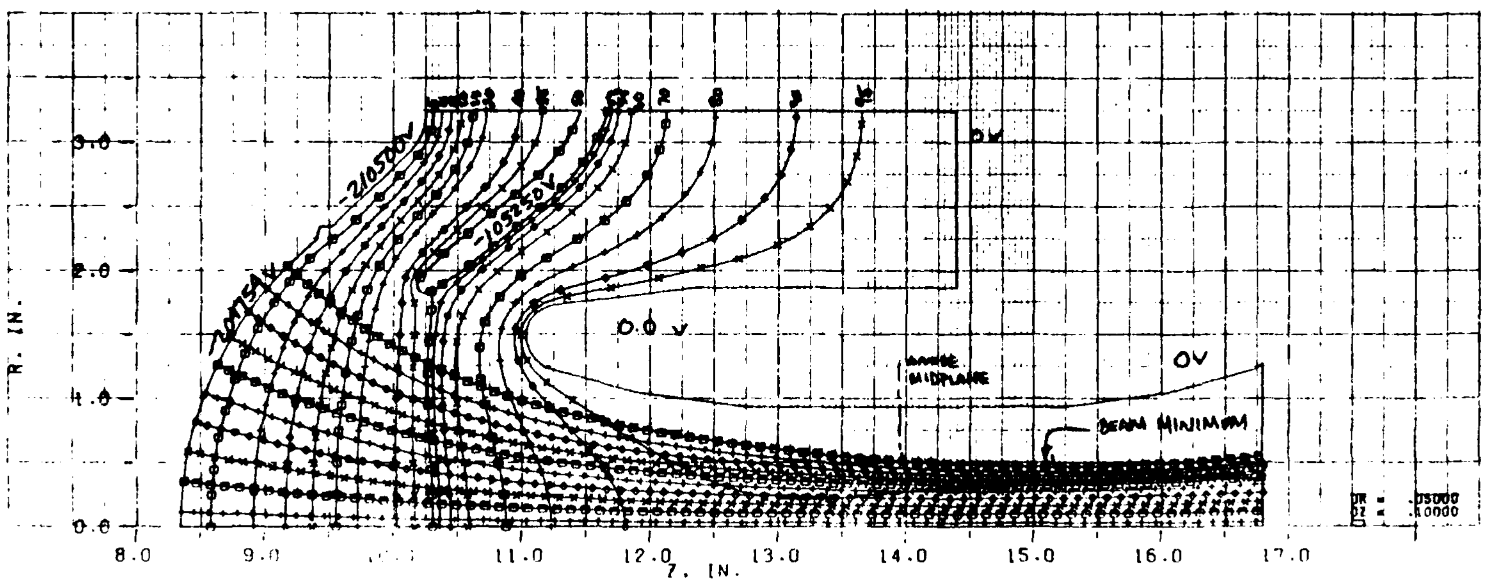


Figure 22. Intermediate Electrode at 50% of Beam Voltage

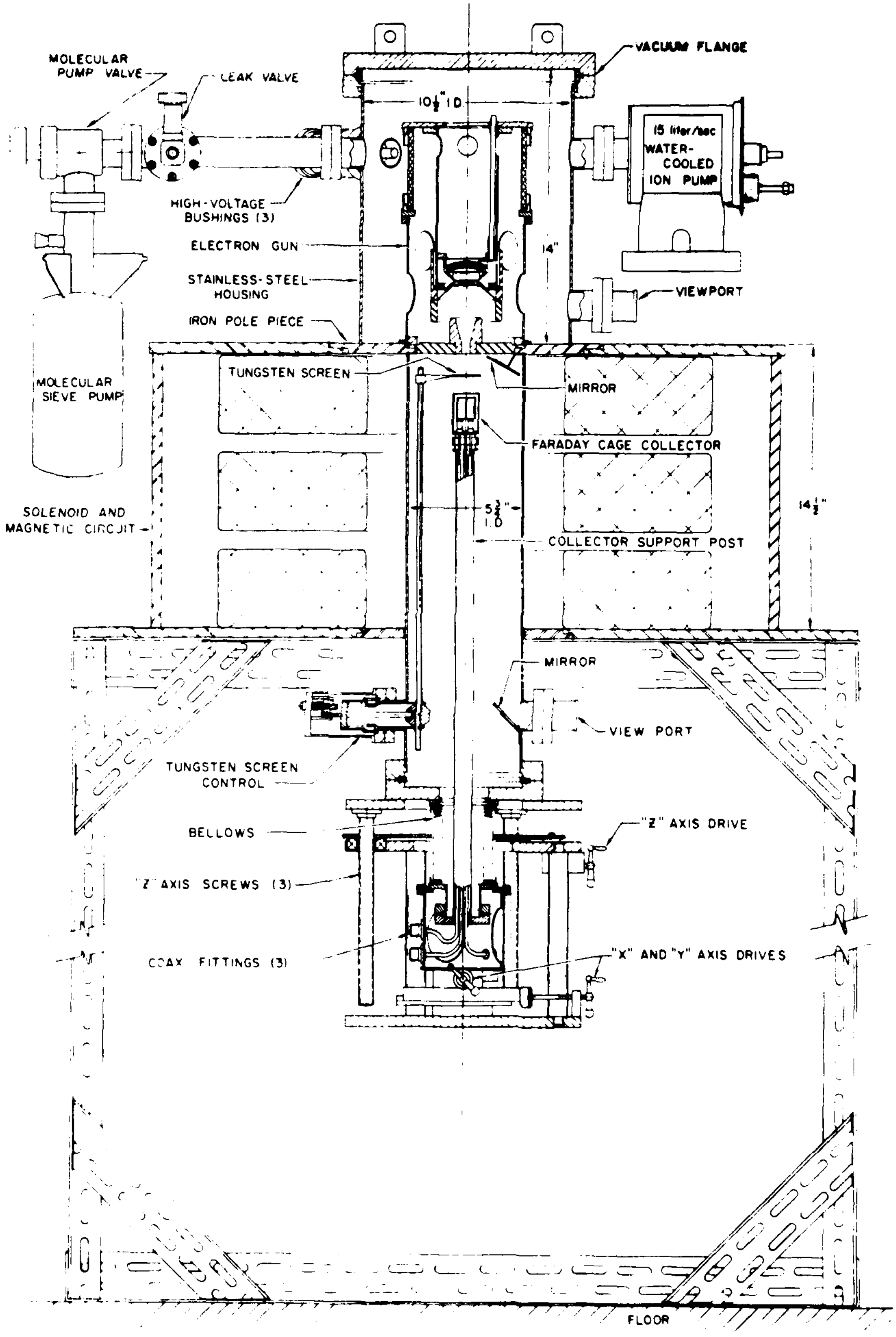


Figure 23. Electron Beam Analyzer

spacing and a means for varying the intermediate electrode voltage. The unit is capable of analyzing scaled structures at voltages less than 15 kV.

The scale model gun containing grid, cathode, and anode, but without intermediate electrode was evaluated first. Beam cross section, location of electrostatic beam minimum, and other performance factors were studied at a number of beam perveances.

Next, the intermediate electrode was added to the assembly and gun optics investigated with various combinations of beam perveance and intermediate electrode voltages. At first, a large electrode current of 6 to 10 ma was noted under all conditions of operation. The current was eventually traced to an equipment problem and was subsequently corrected. During the remainder of the tests the intercepted current was less than 40 μA even at the most severe operating conditions.

Figure 24 is a representative beam current density profile recorded during experiments. As the beam is scanned in the X direction, a voltage proportional to current intercepted by the pin hole collector drives the Y axis of an ink recorder. The resultant plot is then a display of current density vs transverse position in the beam. In this illustration, scans have been made at 13 axial positions.

The converging beam can be traced by following the profile edges as the beam moves from the top to the bottom of the page. Enough subsequent scans were made to find the electrostatic beam minimum. Beam quality was determined and experiments continued until the design was completely evaluated.

Interception was relatively flat with electrode voltage between 40 and 50% of cathode voltage at moderate perveance levels. In the range 50 to 60% cathode voltage at higher perveances, interception was the greatest. The greatest intercepted current observed during any of the tests was 0.004% of beam current.

The final gun design was derived from the configuration tested in the beam analyzer.

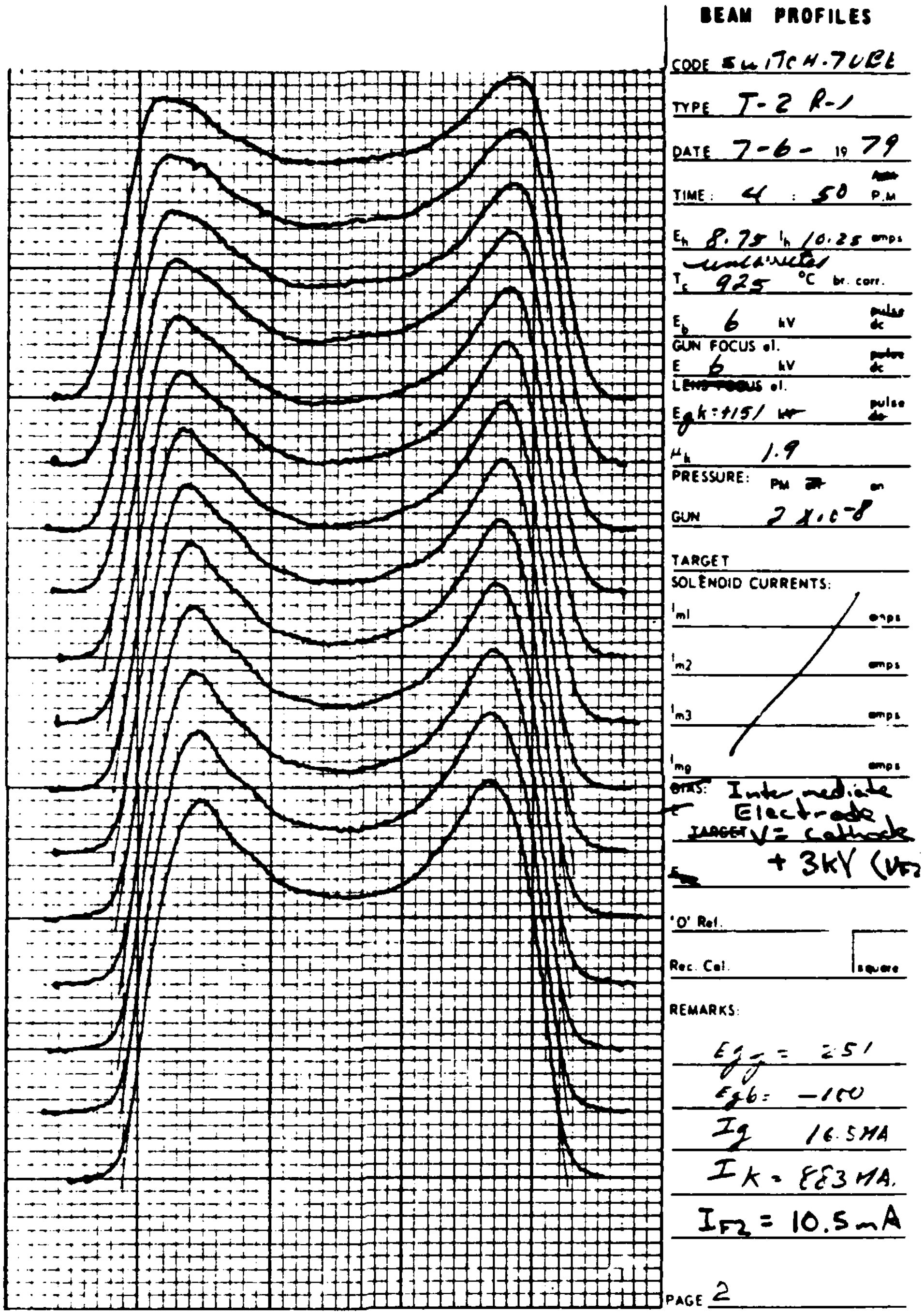


Figure 24. Typical Beam Current Density Profile

D. TUBE ASSEMBLY

Figure 25 is the switch tube outline drawing. The drawing includes hardware that is normally added after tube exhaust and is not attached at this assembly level.

The switch tube is composed of 12 major assemblies that are welded together:

1. Collector-Probe
2. Collector-Ceramic
3. Anode-Mounting Plate
4. Gun Ceramic (upper)
5. Intermediate Electrode
6. Gun Ceramic (lower)
7. Outer Gun Base Plate
8. VacIon® Pump
9. Grid
10. Heater-Cathode
11. Inner Gun Base Plate
12. Exhaust Tubulation

Larger assemblies include smaller subassemblies in some instances.

As a first step, major components were positioned and critical dimensions checked before welding. Minor adjustments were made as required to maintain critical design requirements. As spacings were confirmed, individual components were heliarc welded together. A fixture was built to align anode, intermediate electrode, and cathode assemblies.

The collector-probe assembly (1) was positioned upside down as the foundation on which other assemblies were attached. Assemblies two through eight were successively positioned and welded. The tube was leak checked at this point to assure quality of weld joints.

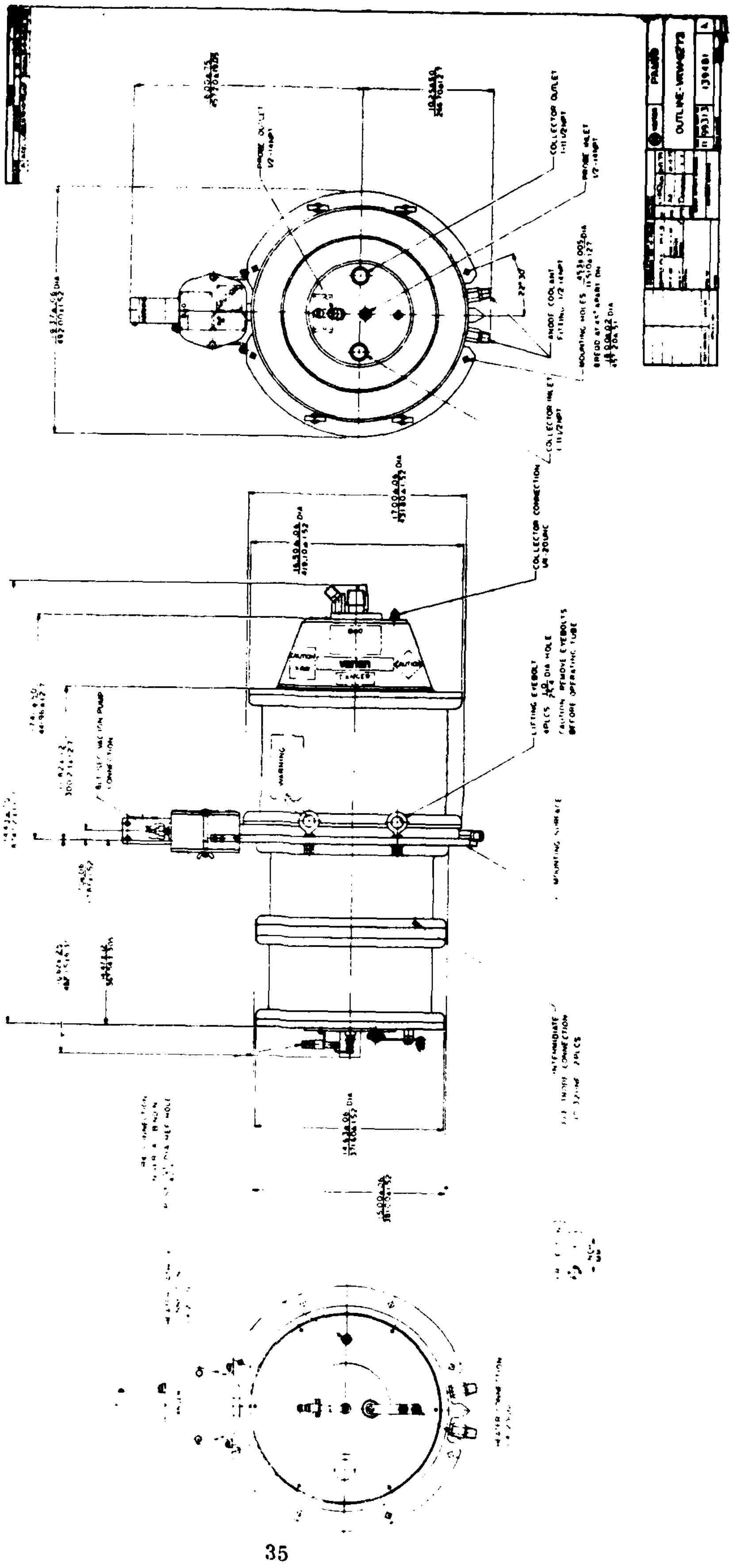


Figure 25. VKW-8273 Outline Drawing

Leads from the grid (9) and the heater-cathode assembly (10) were inserted through the inner gun base plate assembly (11) and appropriate welds made. The exhaust tubulation assembly was added as the final step and the entire assembly leak checked prior to tube exhaust.

III. EXHAUST

After final assembly, the tube was mounted on an exhaust-bakeout station. The tube was pumped with a diffusion pump backed by a forepump. Thermocouples were attached to various parts of the tube to control and monitor tube temperature. Operators attended the tube 24 hours per day.

A bakeout temperature of 500°C was maintained for three days. Tube warmup and cool down was done at a rate of 50°C to 100°C per hour to avoid thermal shock. A vacuum pump was used to evacuate the space inside the oven that surrounds the tube to prevent oxidation during bakeout.

After bakeout, the triple carbonate cathode coating was converted to oxide by slowly increasing heater voltage over a 2-1/2 hour period. The tube was continuously pumped during this process. Pressure reached the order of 10^{-4} mm Hg during cathode conversion. Cooling fans were used to dissipate heat that would normally be conducted into the transmitter tank insulating oil.

After cathode conversion, the tube was sealed from the vacuum pump and heater aged. During aging, liberated gas was pumped by the permanently attached VacIon pump. After cooling the cathode, the grid circuit was high-potted to reduce leakage current.

IV. ACCEPTANCE TESTS

Acceptance tests were performed in accordance with Test Plan/Procedures for 200 kV Linear Beam Switch Tube, 21 April 1980. A copy of the Test Plan is included as Appendix A.

Test results are recorded in Appendix B, Acceptance Test Report, S/N 1, VKW-8273 200 kV Linear Beam Switch Tube. These data should be consulted when establishing tube operating parameters. A discussion of recommended operating values is included in the Conclusions and Recommendations Section.

All three cooling circuits were subjected to a hydrostatic water pressure of 150 psig for 5 minutes. There were no tube leaks.

The heater (cathode) was aged at 20 V for about 144 hours and at 20.5 V for approximately 105 hours. Background gas level was reduced substantially by this extended aging. (24 hour minimum was required by the Test Plan).

Heater voltage and current were recorded in one volt increments from 10 to 22 volts using calibrated precision meters. Current was recorded after a stabilizing period at each level to account for heater resistance change going from one voltage (temperature) to another. A graph of Heater Voltage vs Heater Current is included.

Both gun ceramics were high-pot conditioned to at least 125 kV dc. The collector ceramic was high potted to 155 kV dc. Higher collector voltages were not attempted since this insulator will be subjected to pulse voltages only. Pulse voltage goals for this ceramic is 200 kV at pulse lengths up to 100 microseconds.

Pressure gages were attached as close as practical to the tube water fittings. Pressure drop was recorded successively on each of the three cooling circuits. Drop due to valved connectors was accounted for. Graphs of water flow vs pressure drop for the three cooling circuits are included in the Test Report.

V. CONCLUSIONS AND RECOMMENDATIONS

The switch tube was designed, built, and processed at Varian prior to delivery to RADC. Processing was limited to high-potting and cathode aging without electron beam.

Recommended initial operating parameters are described. Actual nameplate values will be determined during evaluation tests at RADC. Varian will provide engineering personnel to assist with evaluation.

During initial operation of tubes of this construction, beam voltage and power level must be increased slowly to allow the VacIon to pump residual gases liberated by heating and electron bombardment. Performance characteristics are expected to be similar to those of the earlier Model VKW-8253C except it will be capable of higher voltage and power levels and will require an extra power supply tap for operation.

Initial heater voltage should be 20 V, based on Varian's preliminary test experience with the VKW-8253C. At higher voltage and power levels, a moderate voltage increase may be necessary to retain space charge limited operation. RADC's extensive tests with the prior switch tube will provide useful guidelines for setting heater power and approach to outgassing.

Gun optics were evaluated in the beam analyzer at low voltage with various combinations of beam perveance and intermediate electrode voltage. Optimum beam performance was achieved with electrode voltage at 50% of cathode voltage although values of 40 to 60% produced acceptable results.

High voltage performance is expected to conform to beam analyzer results but will have to be experimentally confirmed. The intermediate electrode should be initially set at 50% of cathode voltage and its value varied within the described limits to obtain best operation at 90% depression.

90% depression is chosen as the preferred point of operation because depressions much greater than this will result in a substantial increase in body power; depressions lower than this will result in increased collector-probe power, reaching a maximum at 60% depression for constant switch tube cathode voltage.

We estimate the collector-probe will dissipate about 80 kW at 2% duty and 160 kW at 4% duty when the tube is operating at the maximum conditions of Table 1 and 90% depression. The present collector and probe surface areas have been increased by a factor of approximately X2 with respect to the VKW-8253C. Based on the design analysis contained in the VKW-8253C Final Report, (RADC Final Technical Report TR-77-319, Title: Long Pulse, High Efficiency Switch Tube Development, dated Sept., 1977, Pages 49 and 50.), the new design is expected to readily achieve minimum duty operation. Operation at combined collector-probe power dissipation in excess of 100 kW should be approached with caution due to lack of exact knowledge of power density on the critical tip of the probe. Other operating conditions more severe than those described should be approached with similar caution.

To maintain design cooling capability, coolant should be water supplied at the following flow rates:

Body	12	gal/min
Probe	15	"
Collector	50	"

An earlier computer aided estimate of cooling capability of transformer oil predicted that an oil flow rate 20 times greater than water would be required to maintain the probe at the same temperature in both cases. For this reason water is the preferred coolant.

The switch tube has been handled almost exclusively in the vertical position, gun end down. It should be installed and operated in this position to avoid undue cantilever stress on the ceramics and seals. The packing crate was designed for shipping in this orientation.

No x-ray, high voltage, or rf shielding has been added to the tube. It is the user's responsibility to provide shielding and interlocks. Tube hazards are described in the Preliminary Hazards List forwarded to RADC October 31, 1978.

APPENDIX A

TEST PLAN/PROCEDURES FOR 200 KV LINEAR BEAM SWITCH TUBE

TABLE OF CONTENTS

TEST PLAN/PROCEDURES FOR 200 KV LINEAR BEAM SWITCH TUBE

1.0 SCOPE

This document describes the acceptance tests to be performed on the VKW-8273 switch tube at Varian Associates, Palo Alto, California. The purpose of these tests is to condition the tube, assure cooling circuit integrity and determine heater and coolant flow characteristics.

The VKW-8273 was developed on RADC contract number F30602-78-C-0232.

2.0 TYPICAL EQUIPMENT

Typical equipment used for performing the tests is listed. Equivalent substitutions may be made.

Description	Model or Serial No.
Pressure Gage	USG (VA S/N 3153, 3165)
Differential Pressure Gage	Barton Instrument (VA S/N 45041, 45042)
Heater Power Supply	Varian (No. 19081-301)
Heater Voltmeter	Weston (Model 433)
Heater Ammeter	Weston (Model 433)
High Pot Power Supply)	
High Pot Ammeter)	Universal Voltronics (VA S/N 00094)
High Pot Voltmeter)	
VacIon(R) Power Supply	Varian (Model 921-0015, V1304)
Flow Meter	FP (VA S/N 01429, 01416)
Flow Meter	Schutte & Koerting (VA S/N 00468)

3.0 ACCEPTANCE TESTS

3.1 Hydrostatic Pressure

3.1.1 Objective

To assure mechanical integrity of the cooling channels, the coolant circuits of the switch tube shall show no leakage at a static pressure of 150 psig for 5 minutes.

APPENDIX B

ACCEPTANCE TEST REPORT

S/N 1

VKW-8273 200 KV LINEAR BEAM SWITCH TUBE

REFERENCE: TEST PLAN/PROCEDURES FOR 200 KV LINEAR BEAM SWITCH TUBE, DATED 21 APRIL 1980.

3.1 Hydrostatic Pressure

Time = 5 minutes minimum

Pressure = 150 psig minimum

CIRCUIT	PRESSURE TEST
Body	✓ (OK)
Collector	✓ (OK)
Probe	✓ (OK)

3.2 Heater Age

24 hours minimum at E_f = 20 V minimum ✓ (OK).

3.3 Heater Voltage vs. Current (See attached graph)

E_f (V)	I_f (A)
10	14.0
11	14.4
12	15.2
13	15.7
14	16.4
15	17.1
16	17.7
17	18.2
18	18.9
19	19.6
20	20.2
21	20.8
22	21.3

3.1.2 Procedure

Provide a pressure gage in the external cooling system. Coolant shall be run through one of the three tube cooling circuits until all air is removed. The outlet valve shall be closed and the inlet pressure increased to 150 psig minimum. The pressure shall be maintained at 150 psig min. for 5 minutes. Inspection during and at the completion for evidence of leakage shall be made and the results recorded on the Test Data Sheet.

Repeat the above procedure on the other two cooling circuits.

3.2 Heater Age

3.2.1 Objective

To outgas the high temperature portion of the gun assembly the heater shall be operated 24 hours minimum after tube bakeout.

3.2.2 Procedure

Attach leads from the power supply to the appropriate heater and heater-cathode connectors on the tube. Attach meters for monitoring voltage and current. Provide means for air cooling the cathode region. Slowly increase the heater voltage to 20 volts minimum. Rate of voltage run-up will depend upon safe gas levels as determined by the project team. Heater age does not need to be continuous At completion of all aging, note on Data Sheet that minimum time has been attained.

3.3 Heater Voltage vs. Current

3.3.1 Objective

Knowledge of heater characteristics is useful to the user during tube evaluation. Heater voltage vs. current shall be plotted in the vicinity of the anticipated operating voltage and forwarded to RADC.

3.3.2 Procedure

This Test may be run concurrently with Heater Age.

Attach leads from the power supply to the appropriate heater and heater-cathode connectors on the tube. Attach meters for recording voltage and current. Provide means for air cooling the cathode region. Record values of voltage and current in one volt increments starting at 10 volts and continuing to 20 volts minimum. Plot current vs. voltage on graph paper and forward to RADC.

3.4 D.C. High Pot

3.4.1 Objective

Prior to tube operation, the electrodes and insulators require conditioning at high voltage. D.C. voltage will be applied successively across each of the three large ceramic insulators with the following levels as objectives: collector ceramic, 200 kv; gun ceramics, 125 KV each.

3.4.2 Procedure

Mount the tube in a suitable location for high voltage operation. Attach the supply leads one to either end of one of the ceramics. Amp and volt meters are part of the supply console. Where appropriate, clip lead floating elements together to prevent accumulation of charge. Energize the VacIon pump. Start at a low value and slowly increase the supply voltage as leakage current allows. Rate of voltage increase will depend on safe gas levels and leakage current as determined by the project team.

Repeat the above procedure on each of the other two ceramics. On data sheet, record the highest voltage reached across each ceramic.

3.5 Coolant Flow vs. Pressure Drop

3.5.1 Objective

Knowledge of flow characteristics of each of the three cooling circuits is useful to the user during tube evaluation. Water flow vs. pressure drop shall be plotted for each of the cooling circuits and forwarded to RADC.

3.5.2 Procedure

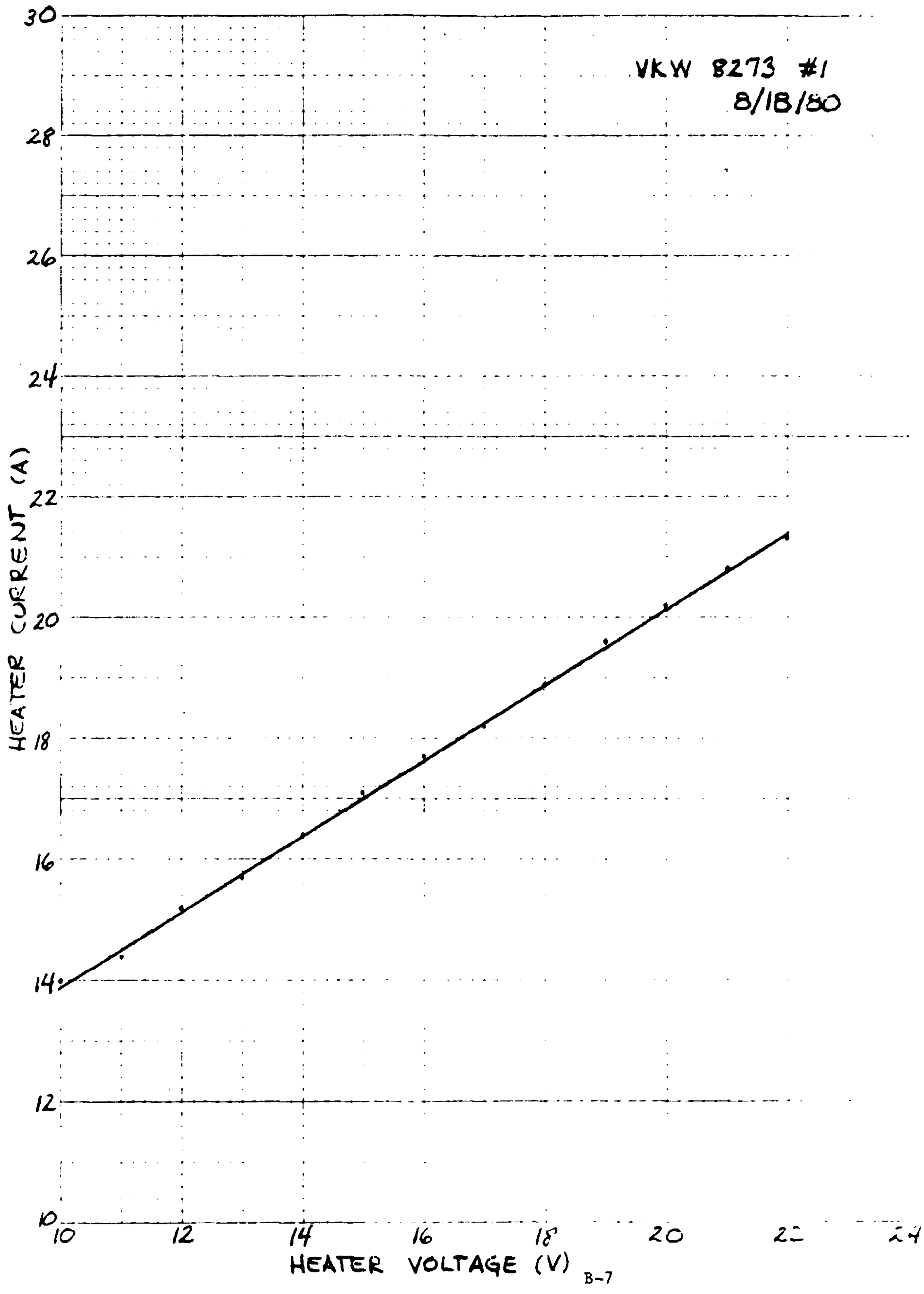
Attach pressure gages (or a single differential pressure gage) as close as practical to the inlet and outlet connectors of one of the cooling circuits. Attach coolant hoses and a flowmeter. Record pressure drop vs. water flow in increments of not more than 5 gpm over a pressure drop range of 0 to 40 psi minimum. (The 40 psi value may be less if maximum available line pressure is reached first.) Repeat the above procedure successively on the other two coolant circuits. Plot flow vs. pressure drop for all three circuits and forward to RADC.

3.4 D.C. High Pot

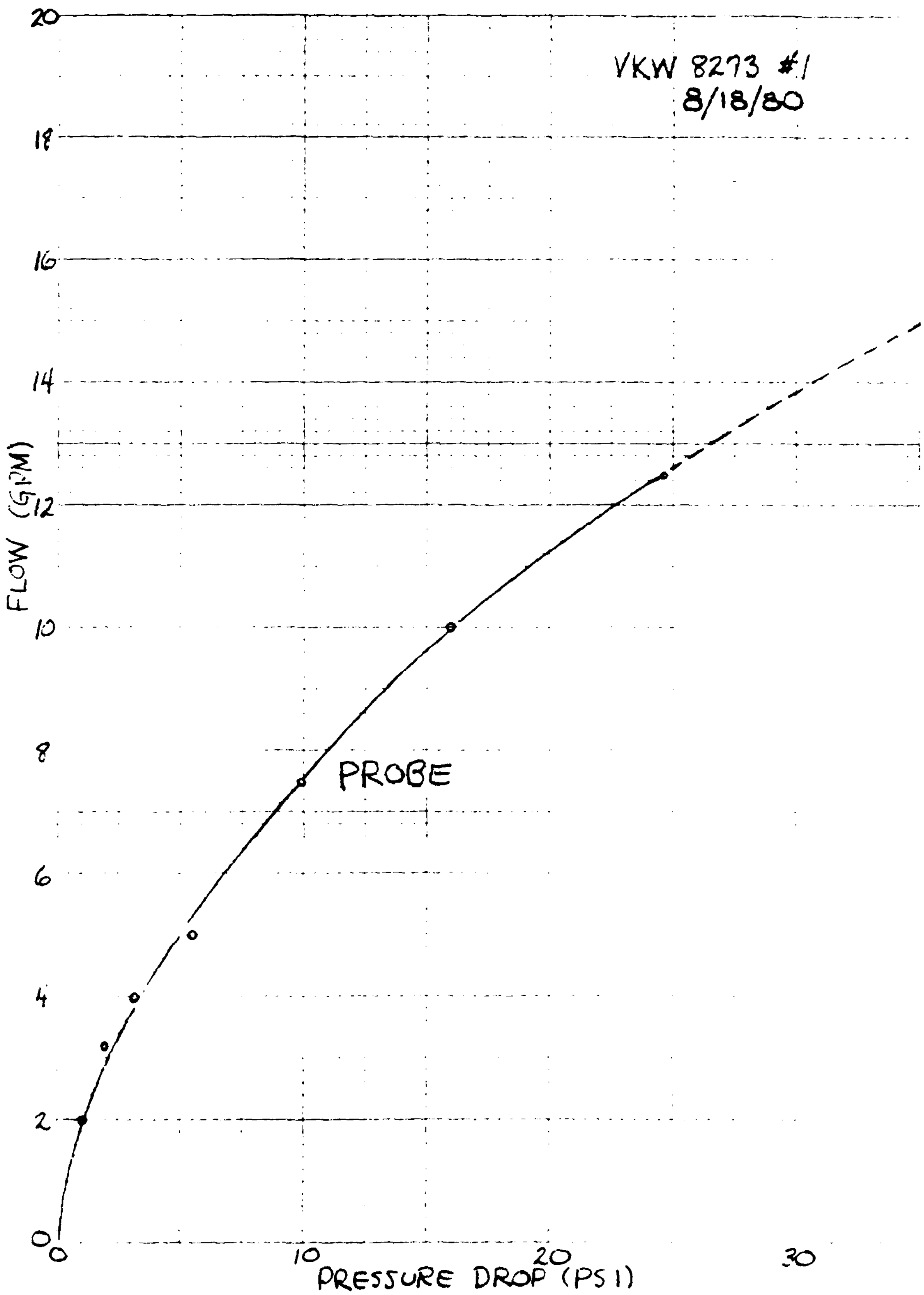
Ceramic	Max. Voltage (KVDC)
Lower Gun	130
Upper Gun	125
Collector	155

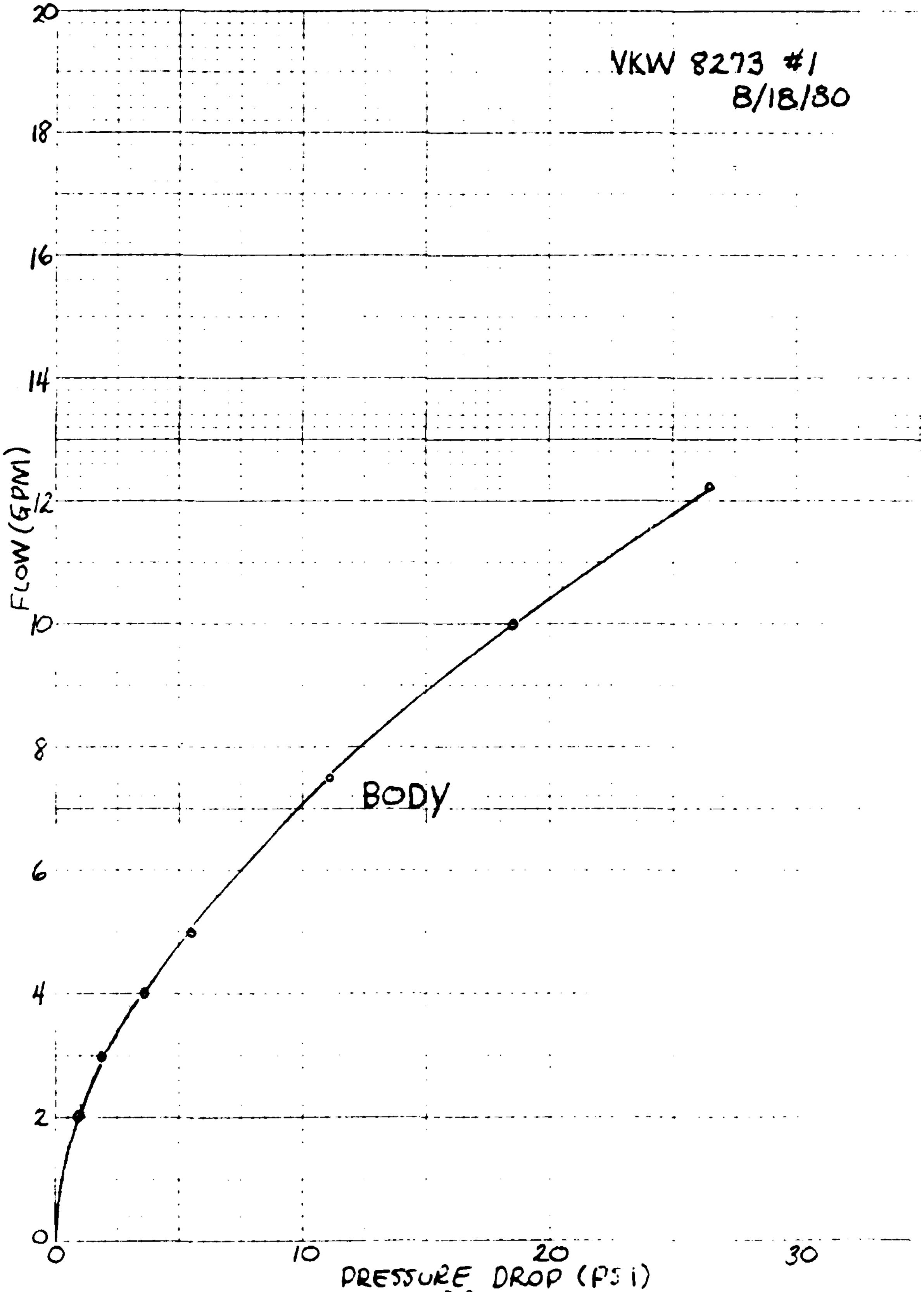
3.5 Coolant Flow vs. Pressure Drop (See attached graphs)

Body Cooling Circuit		Probe Cooling Circuit		Collector Cooling Circuit	
Flow (gpm)	ΔP (psi)	Flow (gpm)	ΔP (psi)	Flow (gpm)	ΔP (psi)
2.0	1.0	2.0	1.0	10	3.5
3.0	1.9	3.0	1.8	14.5	7.2
4.0	3.6	4.0	3.1	20	12.5
5.0	5.5	5.0	5.5	25.2	19.9
7.5	11.1	7.5	9.9	30	27
10.0	18.5	10.0	16.0	35	36.9
12.25	26.5	12.5	24.5	40	48
				45	61
				48.9	72

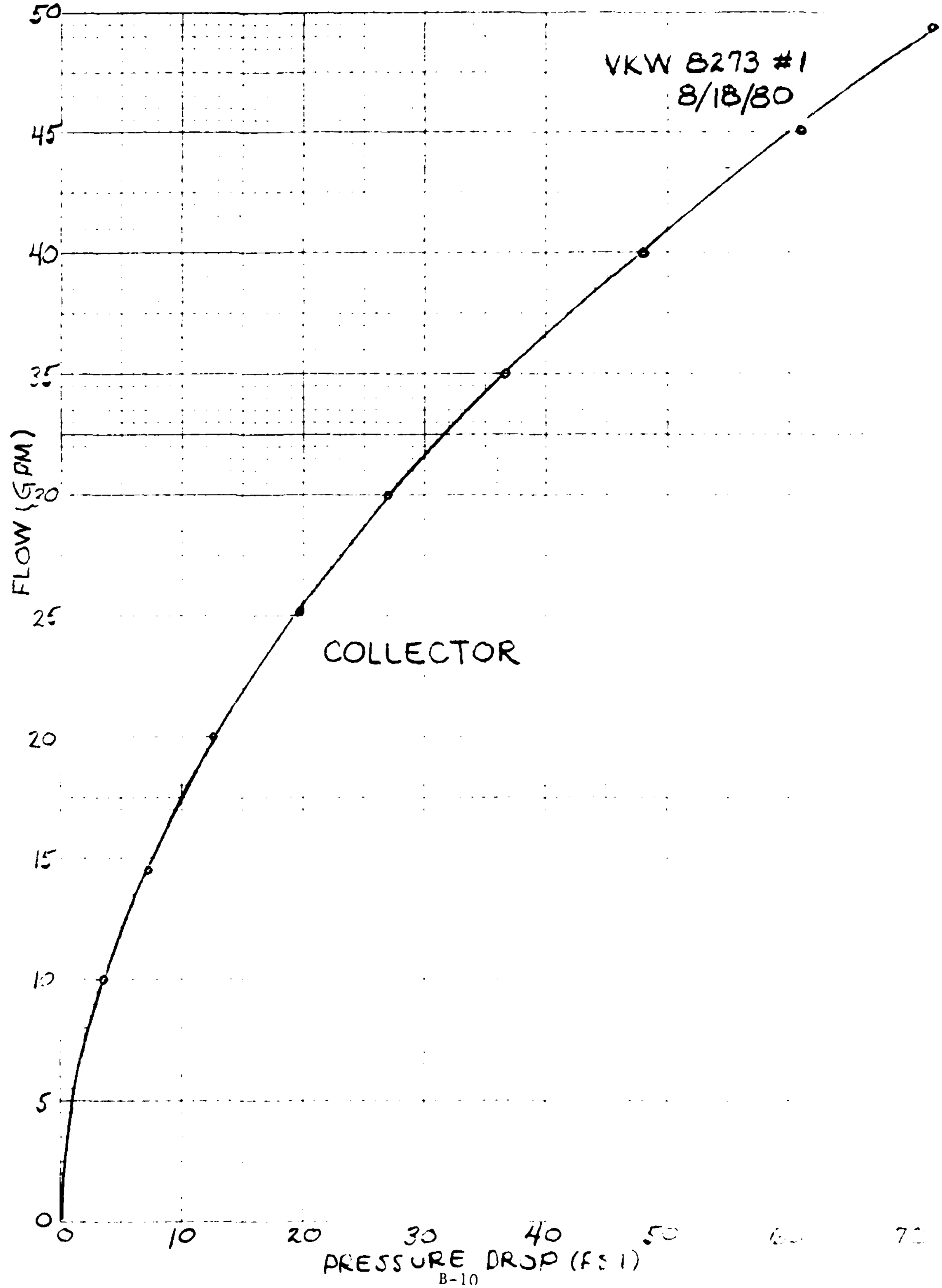


VKW 8273 #1
8/18/80
30
28
26
24
22
20
18
16
14
12
10
HEATER CURRENT (A)
10
12
14
16
18
20
HEATER VOLTAGE (V)


VKW 8273 #1
8/18/80
FLOW (GPM)
PRESSURE DROP (PSI)
PROBE
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30



VKW 8273 #1
8/18/80
BODY
FLOW (GPM)
PRESSURE DROP (PSI)
0
10
20
30
2
4
6
8
10
12
14
16
18
20


VKW 8273 #1
8/18/80
COLLECTOR
FLOW (GPM)
PRESSURE DROP (PSI)
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40

APPENDIX C

RELIABILITY PREDICTION

FOR THE

VKW-8273

LINEAR BEAM SWITCH TUBE

VKW-8273

LINEAR BEAM SWITCH TUBE

RELIABILITY PREDICTION

1.0 PRODUCT DESCRIPTION

The VKW-8273 is a high voltage, linear beam switch tube designed for series cathode modulation of linear beam microwave amplifier tubes having an electron beam microperveance of approximately 2.0. The tube is patterned after the linear beam tetrode switches developed under earlier U.S. Air Force efforts, except an additional electrode is positioned between the cathode and the anode.

The objective of the current program is to deliver an experimental model capable of a video output of 200 kV, 180 amp pulses at pulse lengths up to 100 microseconds.

The important features of the switch tube are:

1. The non-intercepting grid

2. The intermediate electrode between the cathode and the anode

3. A convergent beam passing through the grounded anode

4. The depressible collector-probe system

The electron gun assembly is similar in design and function to electron guns of other linear beam tubes such as klystrons and traveling wave tubes. The gun utilizes a control grid for beam pulsing and a second grid mounted on the cathode surface to aid focusing. Beam current is drawn from an indirectly heated, dimpled, oxide coated cathode.

An intermediate electrode is positioned between the cathode focus electrode and the grounded anode to prevent arcing problems that may otherwise develop across a single 250 kV insulator.

The collector-probe system operates at a depressed potential of approximately 90% of cathode potential. When the beam traverses the anode to collector space, the collector is depressed toward the cathode potential causing an equivalent current to flow in the load connected to the collector.

The entire tube is submerged in oil during operation and the anode, collector and collector probe are forced liquid cooled. In addition, an 8 litre/second VacIon pump is used to pump and monitor gas levels within the tube.

2.0 FAILURE RATE AND MTBF PREDICTION

Since no reliability data on switch tubes was available, a comparison of other linear beam tubes was made. The VKW-8273 Switch Tube is similar in size and design to a low frequency klystron amplifier tube, but without the RF interaction circuit. An estimate of the failure rate and MTBF was developed from previous pulsed klystron performance. The FAA Report #FAA-RD-76-172, "High Power Microwave Tube Reliability Study," August 1976, was used as a guide to determine the base failure rate (λ_b) for the switch tube. After the determination of λ_b was made, the overall failure rate (λ_p) was calculated by the method in MIL-HDBK-217C. The overall failure rate is:

$$\lambda_p = \lambda_b \times \pi_E \times \pi_L$$

Where π_E is the environmental factor, and π_L is the learning factor.

An equivalent pulsed klystron power-frequency density range of 10-25 MW x GHz was selected as closely fitting the size and power of the switch tube while recognizing that the latter is not an RF device. The failure rate (λ_k) for such a klystron is estimated at 120 failures/10^6 hours. This λ_k value was then adjusted to eliminate failures due to the RF circuit; i.e. tuner problems, internal RF arcing, RF window failures, RF waveguide arcing and focusing failures.

$$\lambda_b = 0.7 \times \lambda_k = 0.7 \times 120$$

$$\lambda_b = 84 \text{ failures}/10^6 \text{ hours}$$

The environmental factor (π_E) for a ground fixed system is 1.0 and the learning factor (π_L) is 2.3 since the fabrication is similar to a klystron amplifier, but with fewer sub-assemblies.

The estimated failure rate then for the VKW-8273 beam switch is:

$$\lambda_p = \lambda_b \times \pi_E \times \pi_L = 84 \times 1.0 \times 2.3$$

$$\lambda_p = 193.2 \text{ failures}/10^6 \text{ hours}$$

and the estimated MTBF is:

$$MTBF = 10^6/\lambda_p = 5176 \text{ hours.}$$

3.0 RELIABILITY MODEL

The VKW-8273 is a component, and as such has a simple one element block diagram. The reliability mathematical model is the simple exponential function $R = e^{-t/MTBF}$, where R is the probability of success, t is the mission time, and MTBF is the mean time to failure. $R = e^{-t/5176}$

TABLE VI-35. PULSED KLYSTRONS BASE FAILURE RATES

PEAK POWER X FREQUENCY (MW) X (GHz)	FAILURES PER 10^6 HOURS (λ_b)
Below 10	80
10-25	120
25-35	180
Above 35	240

TITLE VI-36. PULSED MAGNETRONS BASE FAILURE RATES

PEAK POWER X FREQUENCY (MW) X (GHZ)	FAILURES PER 10^6 HOURS (λ_b) DUTY CYCLE Below 0.001	Above 0.001
Below 5	410	440
5-10	430	460
Above 10	450	470

REF: Report # FAA-RD-76-172

"HIGH POWER MICROWAVE TUBE RELIABILITY STUDY,"

August 1976

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of
Rome Air Development Center

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