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RETROFIT AND ACCEPTANCE TEST OF 30 cm ION THRUSTERS

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16. Abstract

The performance objectives of the 30-cm mercury ion thruster are to produce a thrust of 130 mN with an input power of 2.68 kW. The specific impulse is 3,000 sec and the overall thruster efficiency is 71% or greater for a useful lifetime of 15,000 hours. Under the program described in this report, six government-furnished thrusters were modified to the J-series design and evaluated using standardized test procedures. The thruster performance meets the design objectives (lifetime objective requires verification) and documentation (drawings, etc.) for the design has been completed and upgraded. The retrofit modifications are described and the test data for the modifications are presented and discussed.

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FOREWORD

The work described in this report was carried out over a period of approximately three years at Hughes Research Laboratories (HRL) under the responsibility of several Department and Program Managers. Initially, the program was managed by Dr. R. L. Poeschel within the Ion Physics Department, managed by Mr. J. H. Molitor. In 1979 responsibility was transferred to Mr. D. E. Schnelker within the High Voltage Technology Department, managed by Dr. H. J. King. Mr. Schnelker left HRL during 1979, and Dr. R. L. Poeschel resumed the responsibilty of program manager. Key contributions were made to the program by several members of the Ion Physics and High Voltage Technology Departments as indicated below:

Thruster Design - D. E. Schnelker, S. Kami, and R.E. Jones

Documentation Upgrade - R. E. Jones

Acceptance Testing - C. R. Collett, C. R. Dulgeroff

Hughes also acknowledges the valuable comments and recommendations of Messrs. J. Maloy and R. Zavesky of NASA's Lewis Research Center in formulating iterations on improvements to the thruster design.

N82 - 12133#

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURE		PAGE

SUMMARY

The Retrofit and Acceptance Test program was conducted primarily to modify six government furnished 900-series 30-cm thrusters to the J-series design as it had been defined under NASA contract NAS 3-21052.[1,2] Each of the modified thrusters was then evaluated by a standardized acceptance test. Additional work was performed for evaluating the performance and improving the techniques for fabrication of porous tungsten vaporizors. As a consequence of preliminary test results obtained during this program, and in testing under other programs, iteration was necessary on several of the design modifications to satisfy the objectives of the retrofit activity. The thruster components that required resolution of critical problems were the ion optics assembly, the vaporizer assemblies, and the swaged, coaxial heaters. Other relatively minor adjustments of the design were also made to correct observed or potential failures (wire routing or clamping, etc.).

The standardized procedures[1] for acceptance testing of thrusters were also refined to improve the accuracy and reproducibility of test data. Propellant flow is the most difficult performance parameter to measure accurately, so testing procedures were modified during the program to incorporate the improvements recommended by the NASA Lewis Research Center. Dispersion in the propellant flow data obtained was reduced appreciably (from ±3% to ±1%).

The documentation for the J-series thruster design (drawings, etc.) was upgraded under this program to include all of the modifications incorporated as a consequence of the work under this program, and to approach the standards set by the DOD-D-1000, level-2 specifications. The design can now be considered finalized until new system requirements or test results dictate new thruster design requirements (the J-series thruster design objectives are for production of 130-mN of thrust at 2.68-kW input power, with a specific impulse of 3000 sec and an overall efficiency of 71% over a 15,000-hour useful lifetime).

SECTION 1

INTRODUCTION

The program described in this report was conducted with the objective of performing retrofit modifications on six government-furnished 30-cm ion thrusters, and then acceptance testing these thrusters, using standardized procedures, before delivery to NASA's Lewis Research Center (LeRC). At the outset, it was planned that the six thrusters would be modified in the same way as the "prototype" J-series thruster (SN J1) had been modified under NASA contract NAS 3-21052. Testing of thruster SN J1 under contract NAS 3-21052, and testing of isolator vaporizer components under this program revealed unanticipated deficiencies in some aspects of the J-series thruster design that was the "baseline" at the beginning of this program. Consequently, it was recognized early-on that iterations would have to be made on the design modifications, as determined under contract NAS 3-21052, and this program was subsequently expanded and extended to complete the development of the J-series, 30-cm mercury ion thruster design. The major design deficiency noted was in the ion optics assembly; however, fabrication procedures and material specifications also had to be revised for vaporizer subassemblies and all swaged heaters to achieve acceptably reproducible hardware. The hardware failures (heaters and vaporizers) that led to tightening of tolerances on parts and specifications for heaters and vaporizers also caused a closer scrutiny of all of the drawings and assembly procedures that document the thruster design. An iteration on the upgrading of drawings and inpsection and process documents (IPDs) resulted.

A standardized acceptance test had been formulated under NASA contract NAS 3-21052 and applied to thruster SN J1. Under this program, the test procedures were revised and refined to provide for the measurement of the same basic data, but under a streamlined procedural approach. Procedures were formulated on the basis of using a thruster power processor and control system that is automated like that of the NASA LeRC two-inverter power processor developed for endurance testing of a 30-cm thruster under NASA contract NAS 3-18914. This power processor was used to perform all acceptance tests under this program in order to eliminate any possibility for introduction of power-processor-related anomalies in thruster operation. Nevertheless, inconsistencies in measurement of thruster performance were observed. Thus, it became necessary to vary test procedures in an attempt to minimize the dispersion in test results that would be attributed to test procedures (primarily propellant flow measurement).

The work performed under this program, therefore, constituted considerably more than a straightforward retrofit and acceptance test of six 30-cm ion thrusters. The retrofit modification was, in fact, a final development of the design modifications required to achieve the desired performance capabilities for the 30-cm J-series thruster. Acceptance testing comprised a refinement of test procedures and techniques to provide an accurate, reproducible record of a thruster's performance capabilities. The details of this work are described in the following sections.

SECTION 2

RETROFIT MODIFICATION OF THE GOVERNMENT FURNISHED 900-SERIES, 30-CM THRUSTERS

Six thrusters were furnished for this contract for retrofit to the J-series design by implementing the modifications defined under NASA contract NAS 3-21052, and described in Appendix A. Testing of the first retrofit thruster (SN J1) revealed a thermo-mechanical instability in the ion optics assembly. As a result, investigation and elimination of that instability became the foremost activity under this program.

New criteria for determining the acceptability of vaporizers (porous tungsten vaporizer material) were defined under NASA contract NAS 3-21052, and one task under this program was to remove all the isolator-vaporizer assemblies and perform evaluation tests. These tests revealed that most of the existing components could not meet the new criteria in all regards, nor could the new components from a small sampling that were fabricated and tested under this program using the revised procedures. This led to a redesign of the vaporizers and fabrication of another set of components.

Cathode heaters failed in the initial cathode conditioning on several of the retrofit thrusters, and this led to an investigation of swaged-heater fabrication. Specifications on insulator compaction, welding of the inner to outer conductor, and quality control inspection were revised to ensure that swaged-heater fabrication would produce the heater reliability that had been established previously. This resulted in a very long delay in obtaining heaters. The resolution of the heater problem is still somewhat uncertain.

This section discusses the work performed to enable completion of the retrofit modification with regard to the components described above. Several other minor modifications were incorporated in the later retrofit thrusters to correct deficiencies noted in the endurance testing of the earlier retrofit thrusters. A brief description of these thruster modifications is included.

A. DEVELOPMENT OF THE ION OPTICS ASSEMBLY DESIGN AND FABRICATION PROCEDURES

The performance of the ion optics assembly is governed by the values specified for the aperture parameters as defined and listed in Figure 1. For the J-series, 30-cm thruster, the design values for these aperture specifications are as follows:

$$d_a = 0.114 \text{ cm } (0.045 \text{ in.})$$

$$d_s = 0.191 \text{ cm } (0.075 \text{ in.})$$

$$t_s = t_a = 0.038 \text{ cm } (0.015 \text{ in.})$$

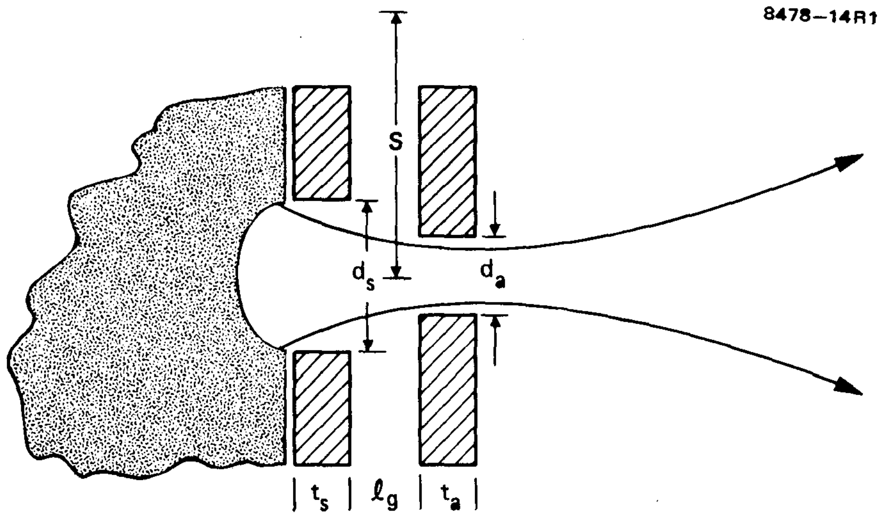
$$\ell_g = 0.063 \text{ cm } (0.025 \text{ in.})$$

$$\phi_a = 0.243$$

$$\phi_s = 0.674$$

$$S = 0.22 \text{ cm } (0.087 \text{ in.}).$$

The grids have approximately 15,000 such aperture pairs, and maintaining these aperture pairs in proper alignment and spacing (ℓ_g) has been a major focus of attention in advancing the thruster design from the 600 to 900 series. The only modifications to the ion-optics-assembly parameters that were determined under contract NAS 3-21052 were a change in d_a from 0.152 cm (0.060 in.) to 0.114 cm (0.045 in.), and a change in t_a from 0.05 cm (0.020 in.) to 0.038 cm (0.015 in.). The ion optics grids for the retrofit J-series thrusters were initially formed and mounted using the same procedures and support ring as specified for the 800-900-series design. Figure 2 shows the electrode support ring for an ion optics assembly of the 800-900-series design. The details of the attachment of the grids to the mounting ring for this design are shown in Figure 3. In this assembly, the screen grid (molybdenum) was fastened directly to the rigid mounting ring (titanium) using countersunk machine screws. The accel electrode was similarly mounted to a molybdenum "stiffening" ring. While this design had proven successful for all of the tests performed on 700-800-series thrusters, the initial testing of the retrofit thrusters using the smaller accel aperture were accompanied by erratic performance that was not noted previously.[3,4]



d_a - ACCEL HOLE DIAMETER

d_s - SCREEN HOLE DIAMETER

t_a - ACCEL GRID THICKNESS

t_s - SCREEN GRID THICKNESS

ℓ_g - SCREEN-TO-ACCEL INTERELECTRODE SPACING

ϕ_a - ACCEL GRID OPEN AREA FRACTION $\frac{\sqrt{3}\pi}{6}\frac{d_a^2}{S^2}$

ϕ_s - SCREEN GRID OPEN AREA FRACTION $\frac{\sqrt{3}\pi}{6}\frac{d_s^2}{S^2}$

S - APERTURE SPACING

Figure 1. Definition of design parameters for ion-optics apertures.

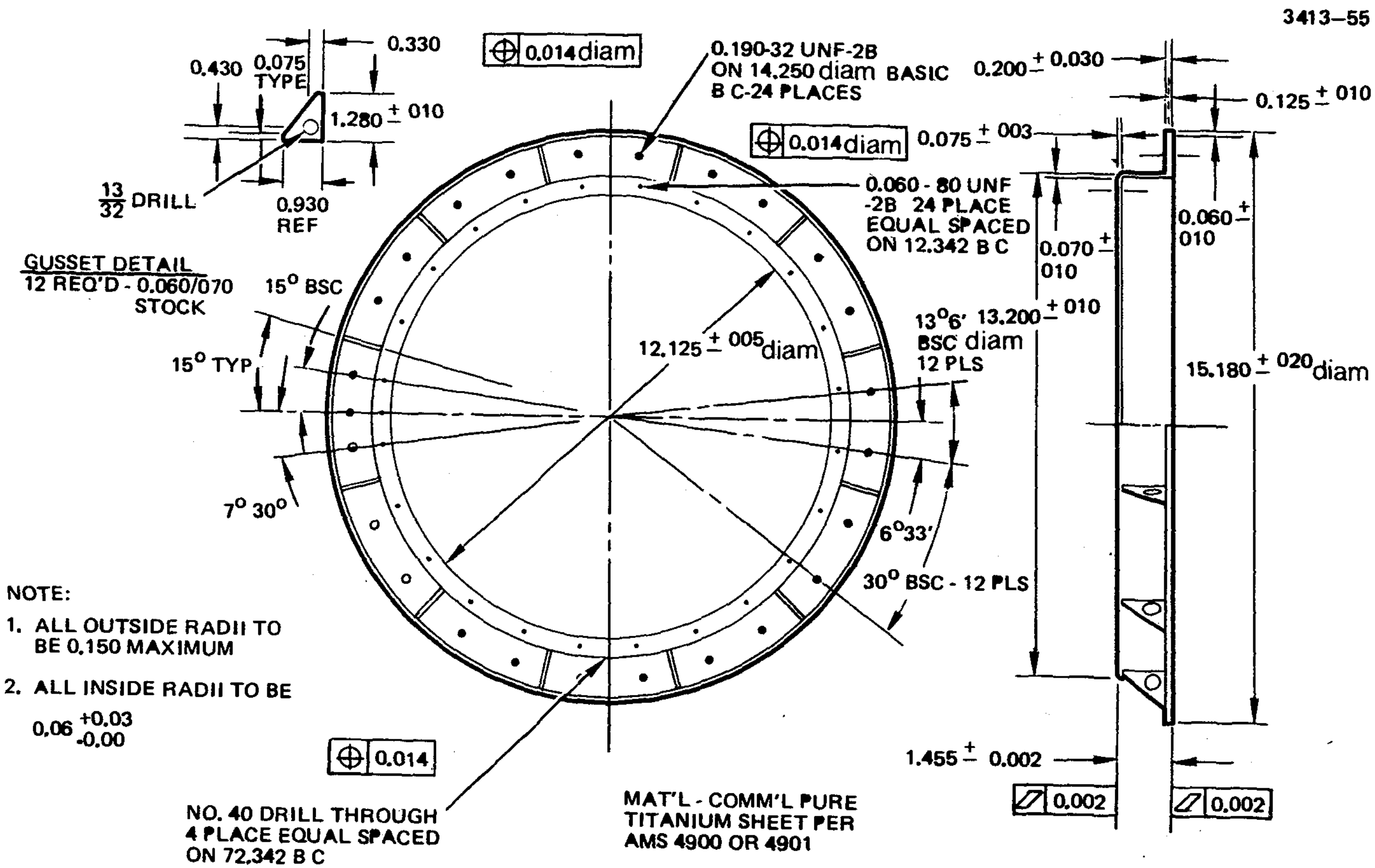


Figure 2. Electrode support ring design for 800-900-series thruster.

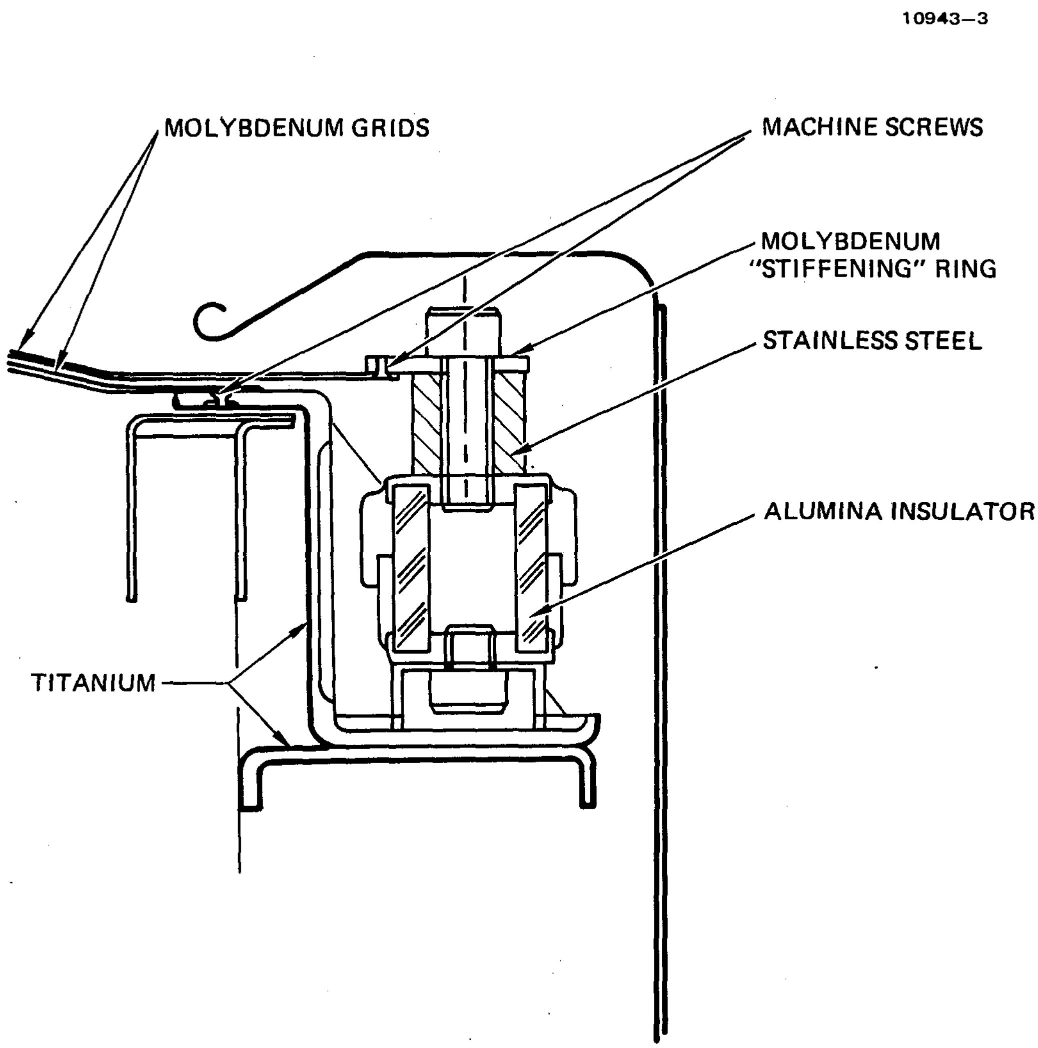


Figure 3. Cross-section of ion-optics-electrode mount used in NASA/Hughes 700-900-series 30-cm thruster.

In testing thruster SN J1, it was noted that the extraction voltages could not be applied at the time called for in the start-up procedure without severe overload of the screen power supply (arcing). It was later determined that the electrodes did, in fact, come into contact for a period of time during heating of the discharge chamber in the start-up sequence. As the discharge chamber and ion-optics-assembly temperature approached the steady-state operating temperature, the contact between electrodes disappeared. Since all of the ion optics assemblies had been retrofitted with the small hole accelerator grids, it was decided to proceed with the testing of these assemblies. Table 1 shows the results of these tests. Perveance was measured at beam currents of 0.75 A and 2.0 A using the procedures prescribed by the acceptance test document (IPD-PR-138). The entry shown as "minimum total voltage" is the value of the total voltage ($V_b + V_{accel}$) for which a further decrease in voltage causes a rapid rise in accelerator current. All of these measurements were made using thruster SN J4, and therefore, the dispersion in the perveance characteristics can be attributed solely to the ion optics assemblies. The performance variations shown in Table 1 were considered unacceptable and the task of identifying and correcting the cause of the difficulty was divided between NASA LeRC, an ongoing NASA technology program (contract NAS 3-21040), and this program. Finite element analyses of the grids and support structure were performed both at NASA LeRC and under NASA contract NAS 3-21040. Temperature distributions were measured on operating thrusters at both HRL and LeRC to support these calculations. The details of the HRL analysis are described in the final report for contract NAS 3-21040.[5,6] Without going into detail, these analyses show that the titanium support ring increases in diameter by a greater amount than the edge of the molybdenum grids. In the 700-900-series assembly shown in Figures 2 and 3, this produces stresses that form moments about the attachment points between the grids and the mount. This moment deforms the flat portions of both of the grids. Because the grids were fastened with countersunk screws, the deformation probably varied from grid to grid and from point to point around the periphery of each grid. Consequently, the deflection of the screen grid and accel grid and the spacing between them was not uniform.

A design modification was proposed and modeled analytically to predict performance. Instead of attaching the grids directly to the rigid titanium structure, the grids were mounted on heavier molybdenum rings by riveting.

Table 1. Perveance Measurement Summary

Electrode Set S/N	Minimum V_T at J_b = 0.75 V	Minimum V_T at J_b = 2.0 V
828	1150	1450
831*	900	1240
832	1140	1450
834*	980	1240
835	not measured	1500
836	1300	1500
837	1180	1320
841*	1200	1620
Design value	650	1240

*Electrodes measure short circuit during warm-up period

These heavier rings were then attached to the titanium mount through "softened" supports, as shown in Figures 4 through 7. In this mounting configuration, the titanium support ring provides rigidity in the axial and azimuthal directions, but is weak in the radial direction. This type of support was accomplished by cutting slots in the titanium mounting ring at the points where the molybdenum grid support ring is attached to the mounting.

In addition to the changes made in the mounting ring and grid support rings, the procedures for forming and stress relieving were modified. Previously, the grids were hydroformed and stress was relieved with a spacer at the flat, supporting edge of the grid. It was originally thought that this technique would ensure that the minimum interelectrode spacing would occur in the curved, active region of the grids. Analysis under this program indicated that use of the spacer distorted the spherical surface of the grids and may have contributed to the non-uniform thermal expansion of the grids that resulted in the unstable, unpredictable performance observed. Consequently, the grids with 900 series serial numbers were hydroformed without spacers, and all grids were stress-relieved in a newly machined fixture without spacers. The stress

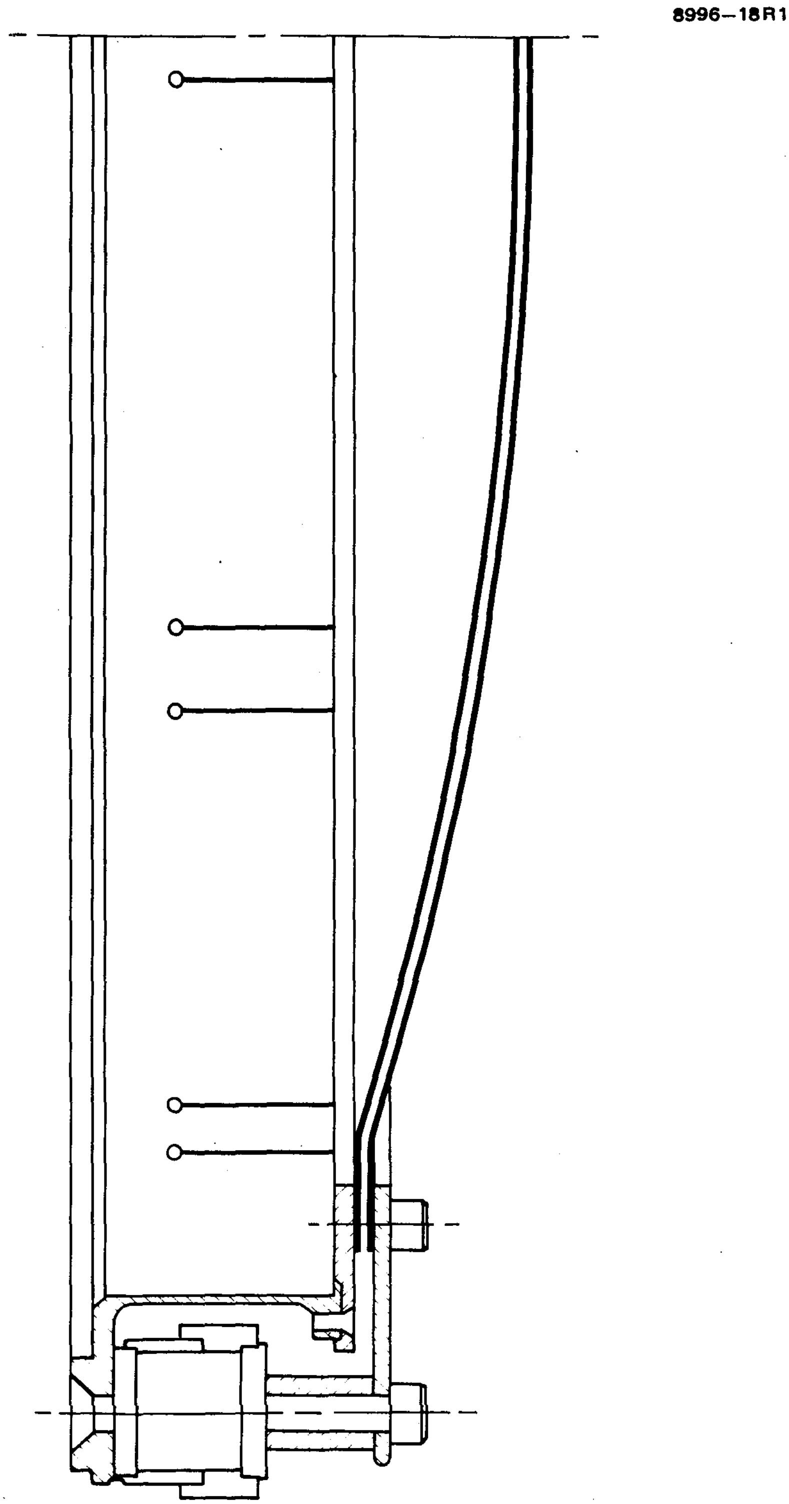


Figure 4. 30-cm J-series ion optics assembly (side view).

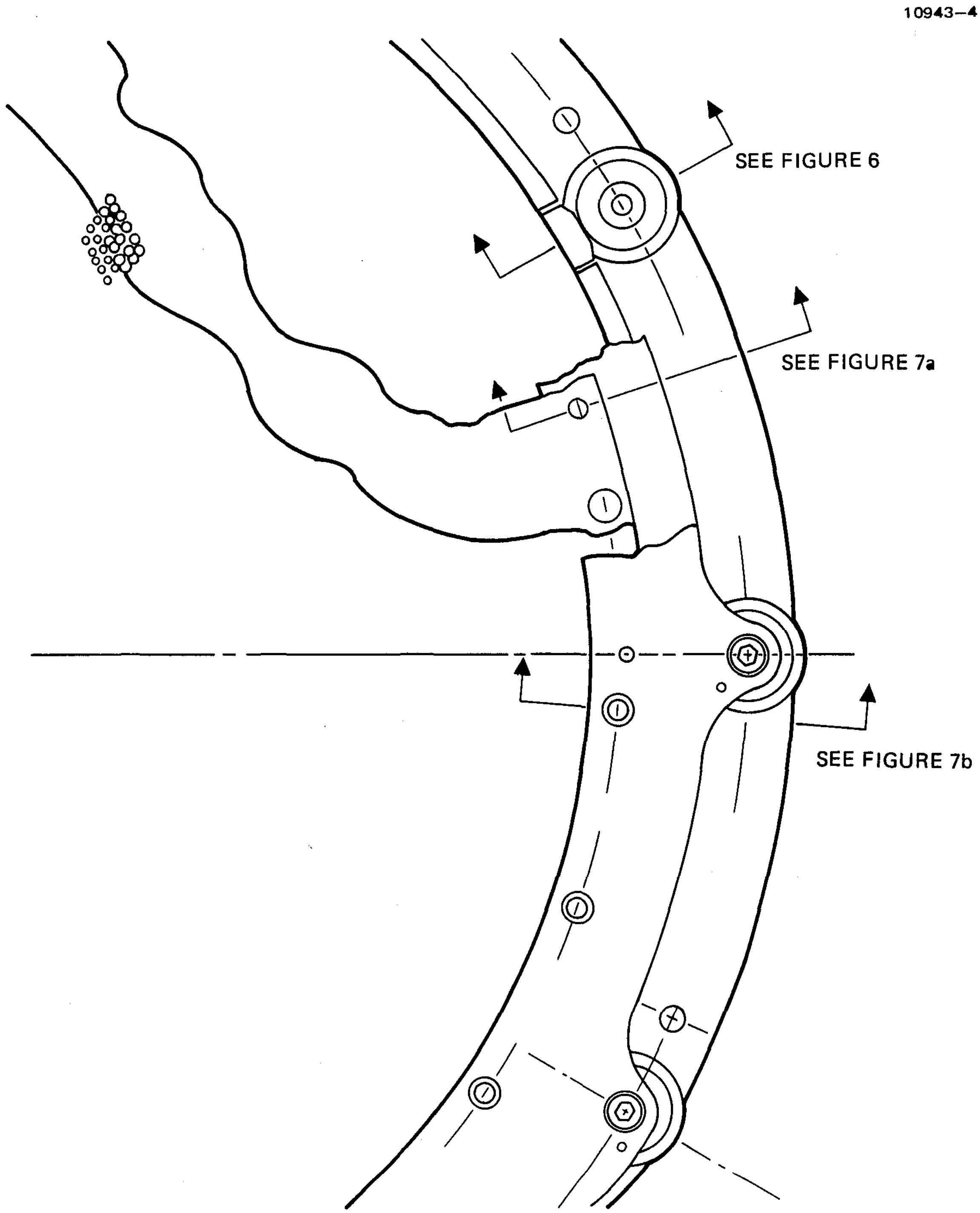


Figure 5. 30-cm J-series ion optical assembly (top view).

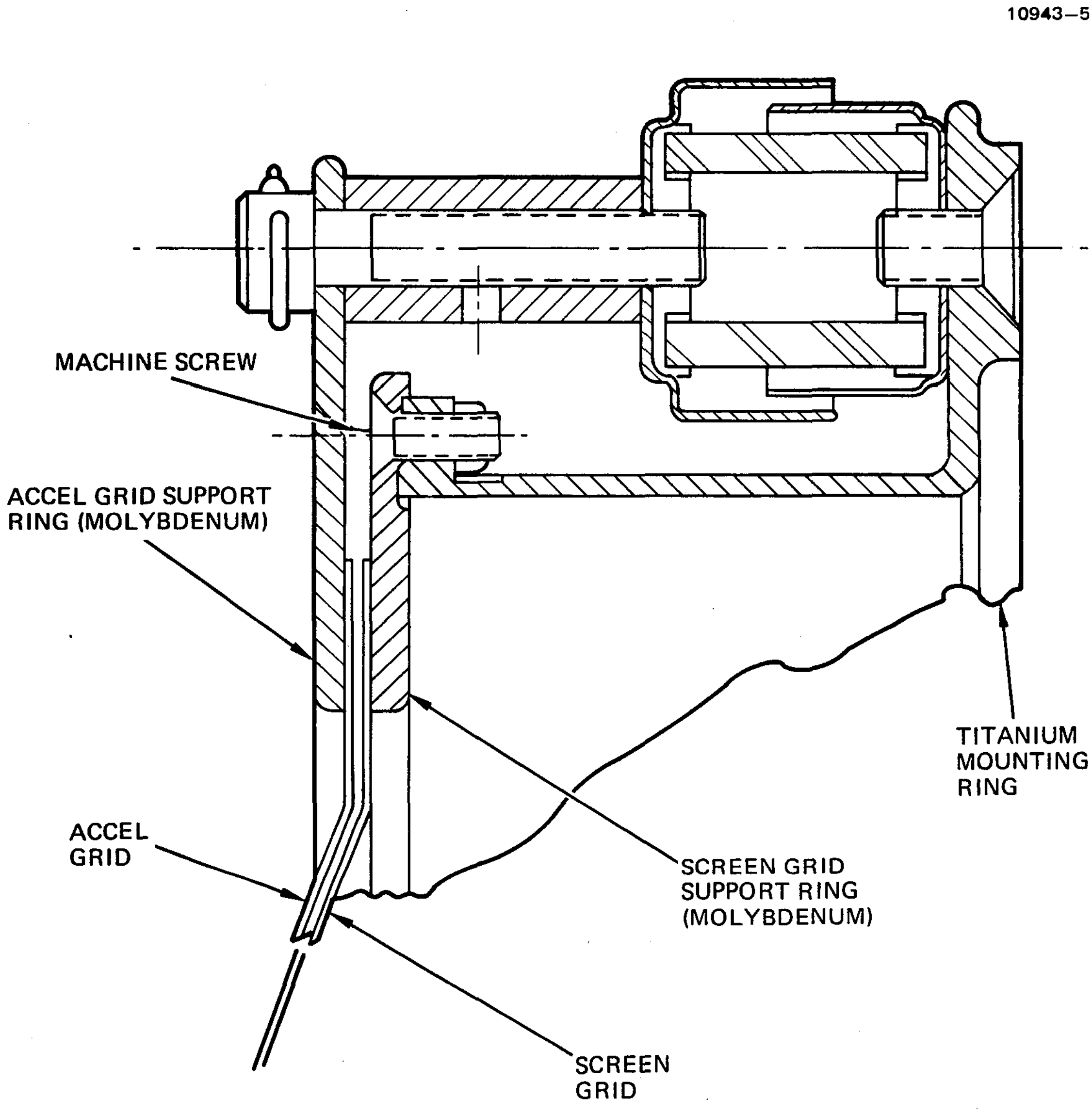
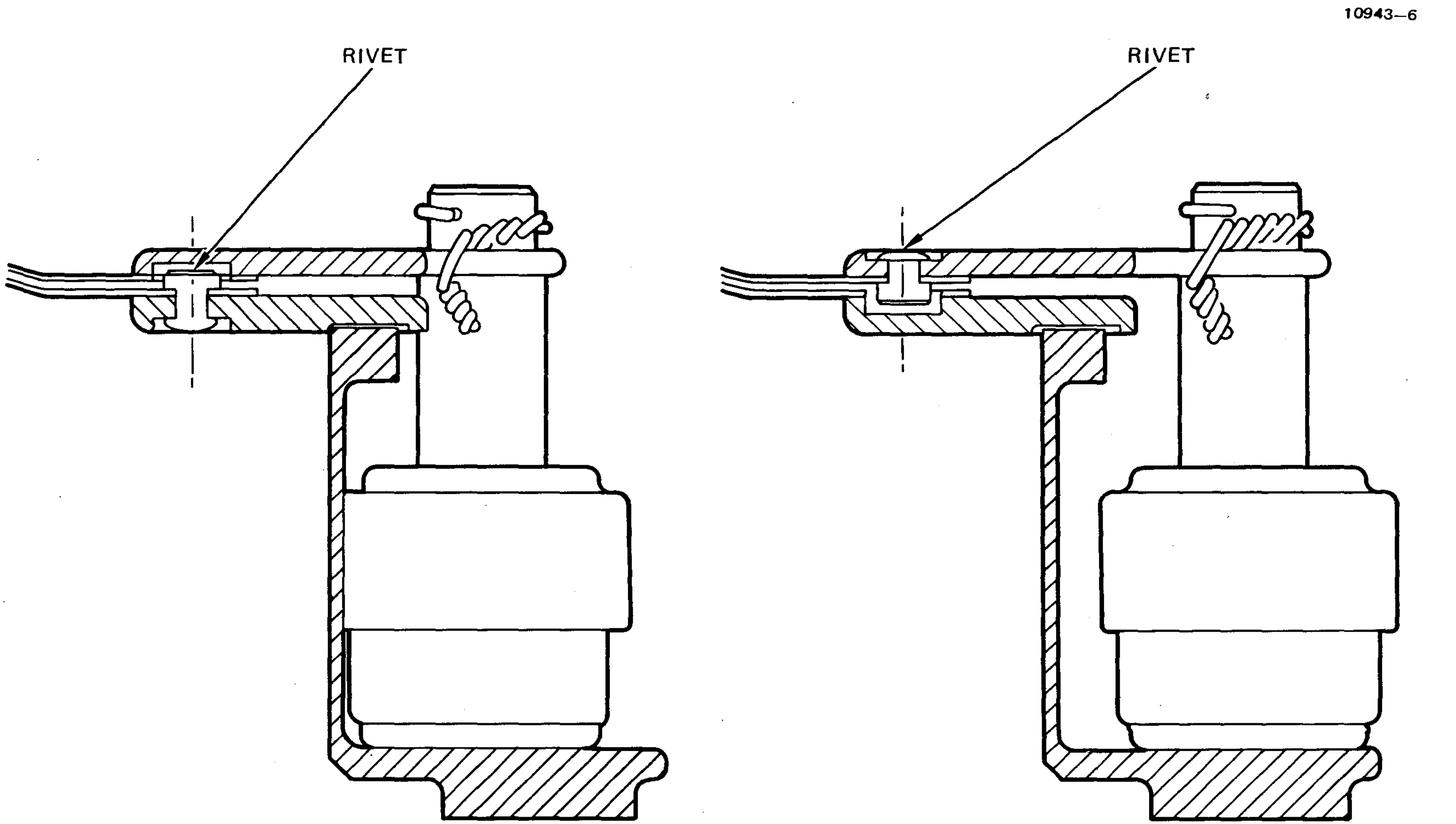


Figure 6. Detail of 30-cm, J-series grid mounting to support ring.



(a) (b)

Figure 7. 30-cm electrode mounting detail-rivet locations.

relief heat treatment is performed in a vacuum furnace, and the time and temperature are specified at 2 hours and 927°C.

The combination of the changes in configuration and fabrication procedures produced the J-series ion optics assemblies that were used to retrofit the six thrusters provided. All of the 900 series ion optics assembly components were fabricated on another NASA contract (NAS 3-21759) and provided as GFE to this program. The perveance measurements performed during the acceptance tests of thrusters SN J2 through SN J7 produced the minimum total voltage values shown in Table 2.* It is apparent that there is far less dispersion in the performance of these assemblies than was seen in the performance of the 800-series mounting as shown previously in Table 1. Consequently, it can be concluded that the ion optics assembly, as modified under this program, can provide the required performance under the normal operating conditions of the J-series thruster.

Table 2. Perveance Measurement Summary

THR S/N	Grid Set S/N*	Minimum V_T at J_b = 0.75 V	Minimum V_T at J_b = 2.0 V
J2	902	830	1220
J3	901	834	1179
J4	837	899	1220
J5	834	790	1090
J6	903	792	1220
J7	904	850	1232

It should be noted, however, that the accel grid mounting is still quite rigid, and differential thermal expansion of the grid support and the mounting ring causes relative motion between the screen and accel grids. This behavior was predicted by the computations in Reference 5 and has been supported by the

*Note that two grid sets have 800-series serial numbers. These grids were reprocessed by the revised procedures (stress-relieved).

results obtained in measuring the perveance limit as a function of ion beam current during the thruster acceptance tests under this program. It should be noted, however, that the validity of the design has been analyzed and verified only for thruster operation under nominal conditions existing in ground test facilities, and not for all possible thermal conditions that could exist in space environments.

B. DEVELOPMENT OF THE J-SERIES VAPORIZER DESIGNS AND FABRICATION PROCEDURES

In a mercury ion thruster, the vaporizer acts as the propellant control valve that meters the flow of propellant gas to the hollow cathode discharges (discharge cathode and neutralizer) and to the discharge chamber. Phase separation and flow control has been successfully demonstrated (SERT II) using porous tungsten as vaporizer material. Mercury does not readily "wet" tungsten, and therefore the capillary forces of the minute pores in the porous tungsten prevent penetration of liquid mercury, while the vapor can flow through the porous material. The vapor flow depends on the temperature of the mercury (vapor pressure) that is in contact with the porous material and the transmission coefficient of the porous material. At the outset of this program, it was recognized that the vaporizer designs and fabrication procedures that had been used in fabricating the 700 and 800-series vaporizers had resulted in assemblies that displayed a relatively wide dispersion of performance characteristics (mercury intrusion pressure and mercury flow versus temperature characteristic). Variations occurred not only between vapor assemblies, but also between purchase lots of vaporizer material. Consequently, a standardized screening test was formulated to evaluate vaporizer performance during the fabrication and assembly of vaporizers (IPD-PR-133). This screening test provides for the following measurements:

- Measurement of the pressure of mercury at ambient temperature that the porous tungsten vaporizer can withstand before mercury begins to intrude the pores (intrusion pressure).
- Measurement of the mercury vapor flow through the porous tungsten vaporizer at four standard temperatures (260°, 280°, 300°, and 320°C).
- Measurement of the vaporizer intrusion pressure at 400°C vaporizer temperature.

- Operation of the assembled vaporizer for 50 hours at elevated temperature and pressure (350°C and 60 psia) with measurement of flow at three points during the test.

Absolute standards for these screening tests were not established during the program; however, selection of components for use on the retrofit thrusters was based primarily on the results of these tests. At the outset, the only isolator-vaporizer components available were those removed from the GFE thrusters. These components were subjected to the above tests, with the results shown in Table 3. It was planned that three new sets of isolator-vaporizer components would be fabricated, and the best six of the nine would be used in the retrofit. The selection criteria was as follows:

- High mercury intrusion pressure.
- Small variation in flow during the 50-hour test.
- Vapor-flow/temperature characteristic in the "typical" operating range.

The values of the vaporizer properties listed in Table 3 that were considered somewhat arbitrarily to be the objectives for satisfying these criteria were:

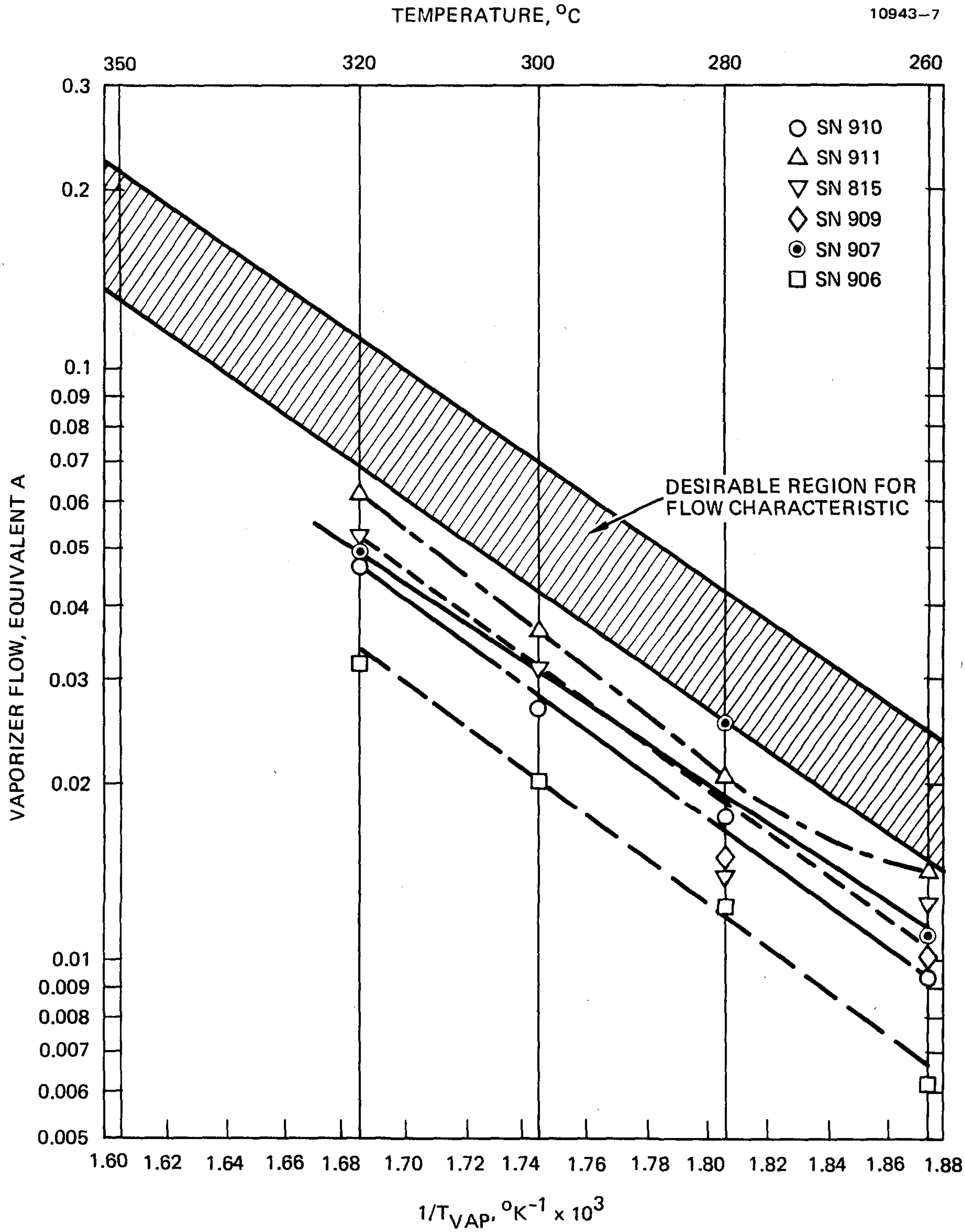
- Intrusion pressure greater than 120 psi.
- Less than 10% increase in flow during the 50-hour test.
- Vapor-flow/temperature values in the shaded region of Figure 8.

It is apparent that none of the main vaporizers met the intrusion pressure screening objective. However, all except one of the cathode vaporizers (SN 817) and one of the neutralizer vaporizers (SN 911) passed the intrusion pressure screening. Six of the 17 vaporizers tested were unable to operate for 50 hours without an increase in flow exceeding the 10% objective. The temperature-flow characteristics are compared graphically against the "desired" behavior in Figure 8.

If the vapor flow through the porous tungsten is a diffusion process, the variation of flow with temperature should be proportional to a exp $(-b\ T_{VAP}^{-1})$ where T_{VAP} is the vaporizer temperature in degrees Kelvin, and a and b are arbitrary constants dependent on the porous matrix. From the flow characteristics shown in Figure 8, it can be concluded that some consistency has been

Table 3. Initial Vaporizer Screening Test Summary

	Vaporizers																
	IV-N						IV-C					IV-M					
Component Serial Number	910	911	815	909	907	906	821	819	823	817	811	807	805A	815	815	817	814
<u>Test Performed</u>																	
1. Measured Intrusion Pressure, PSIA																	
at room temperature	>125	117	>125	>125	>125	>125	121	>125	>125	112	120	94	90	110	104	97	89
at 400°C after 50 hour test	>125	>125	>125	>125	>125	>125	120	>125	>125	107	112	93	94	78	95	80	77
2. Pressured Flow Rates (Equiv. mA, A)	mA	mA	mA	mA	mA	mA	mA	mA	mA	mA	mA	A	A	A	A	A	A
at 260°C	9	14	13	10	11	6	15	11	14	16	21	0.63	0.62	0.75	0.62	1.14	0.61
at 280°C	17	20	14	15	25	12	25	17	22	30	46	1.1	1.06	1.25	1.18	1.84	1.11
at 300°C	27	36	31	27	31	20	45	30	32	45	79	1.89	1.73	2.12	1.94	2.98	1.72
at 320°C	46	61	52	46	48	32	66	51	48	80	122	2.93	2.88	3.39	3.11	4.54	2.6
at beginning of 50 hr. test	93	155	126	108	138	76	159	123	119	258	289	1.31	1.38	1.64	1.43	2.6	1.35
during 50 hour test	104	192	137	107	143	75	155	119	123	261	283	1.32	1.36	1.51	1.39	2.5	1.35
at end of 50 hour test	101	216	148	152	135	74	155	121	117	339	283	1.31	1.24	1.55	1.33	2.1	1.33
3. Change in Flow Rate, %	3.1	39.4	17.5	40.7	2.2	2.7	2.5	1.6	1.6	31.4	2.1	0	10.1	5.5	6.9	19.2	1.5
4. Manufacturer of Porous Tungsten	a	a	b	a	a	a	a	a	a	b	b	b	b	b	b	b	b
a. Spectra-Mat, Inc.																	
b. Hughes Research Labs																	



(a) NEUTRALIZER VAPORIZER

Figure 8. Vaporizer flow (in equivalent amperes) versus inverse vaporizer temperature.

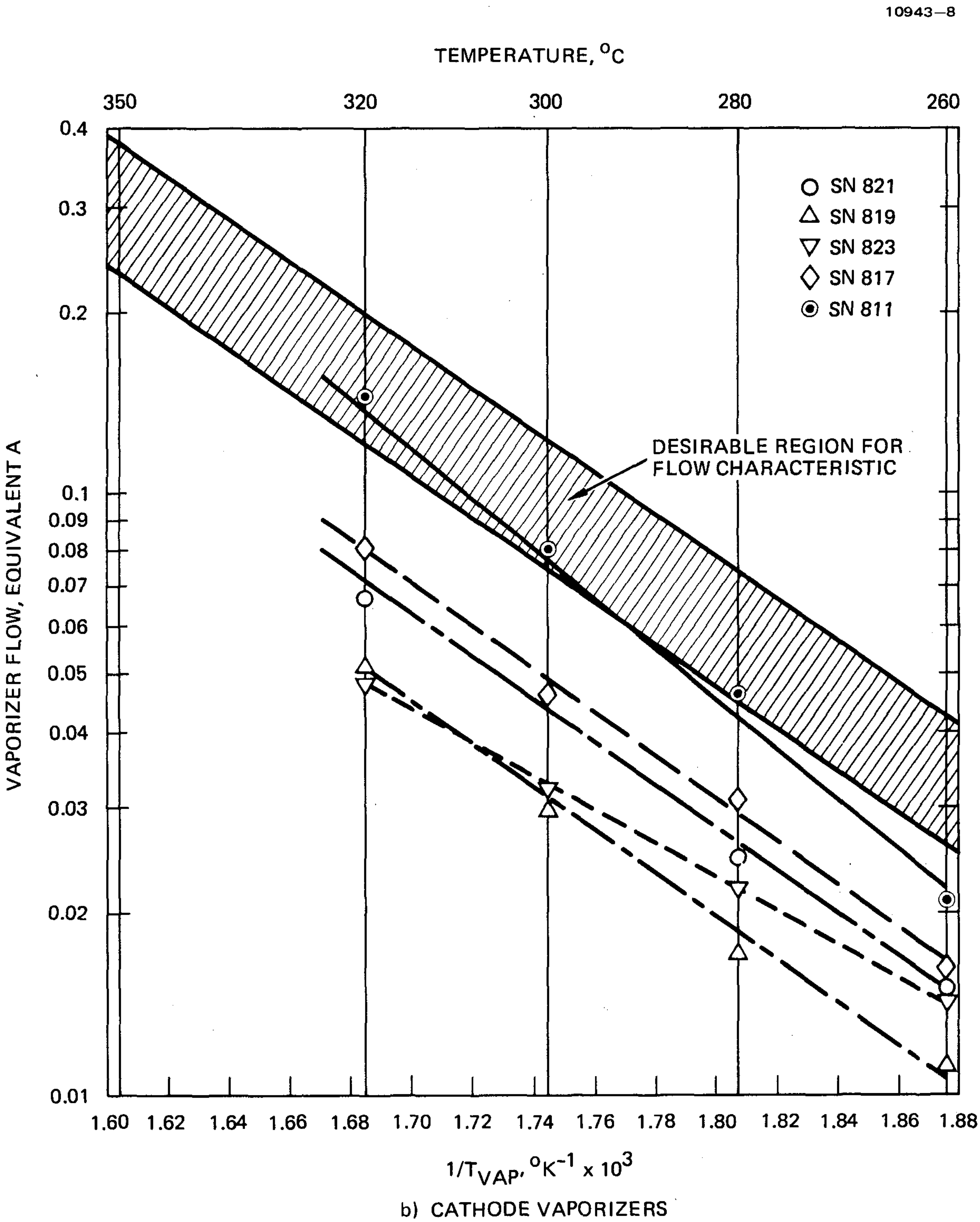


Figure 8. Vaporizer flow (in equivalent amperes) versus inverse vaporizer temperature.

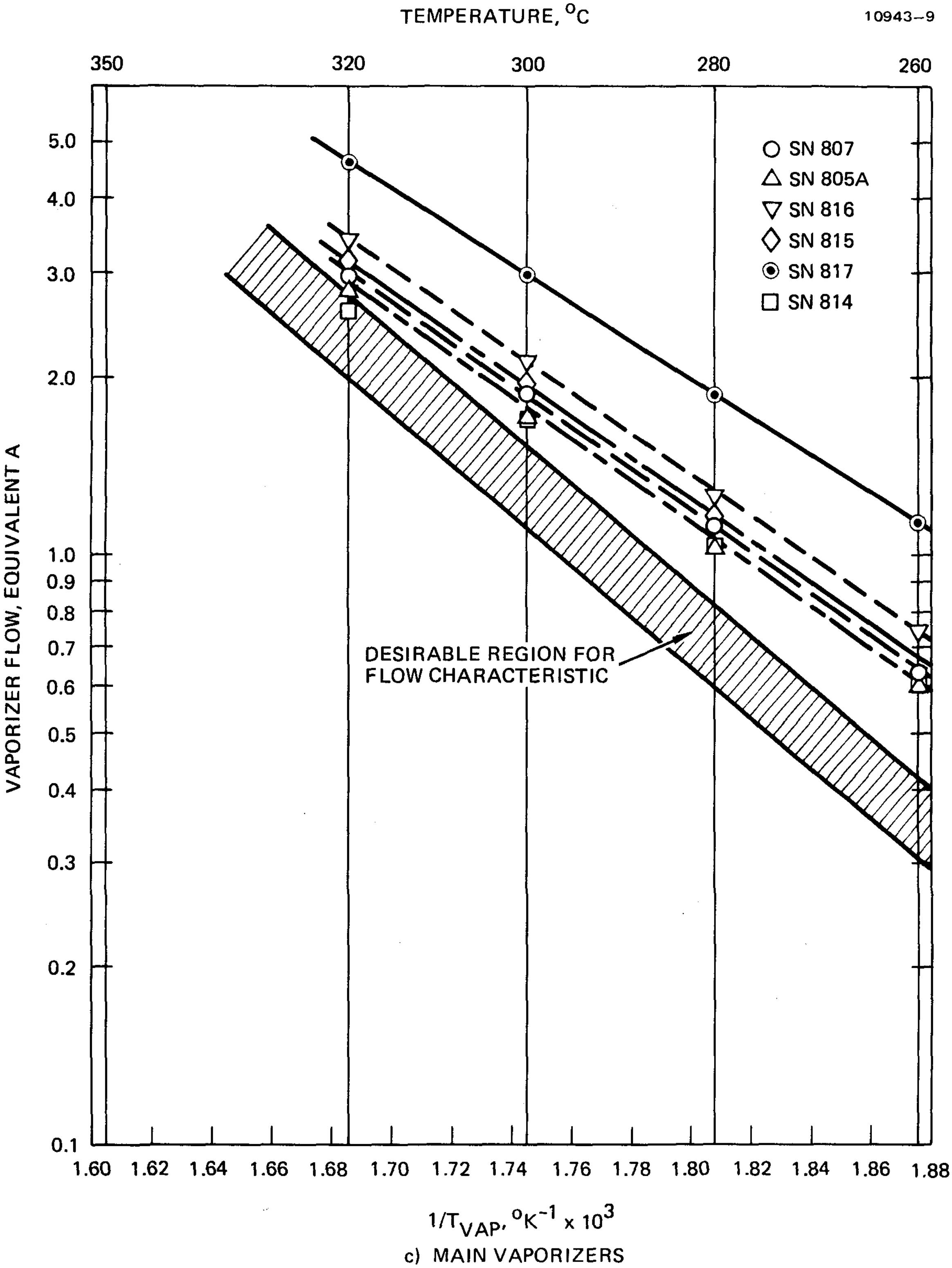


Figure 8. Vaporizer flow (in equivalent amperes) versus inverse vaporizer temperature.

obtained in the transmission of vapor through the porous material. However, the effective transmission area of the porous material was not reproduced very consistently. Consequently, the porous tungsten material specifications were revised for fabrication of vaporizers under this program. Table 4 lists the essential parameters of the revised specifications for procurement of porous tungsten. The flow and intrusion characteristics of three of the first neutralizer vaporizers fabricated are shown in Table 5 and Figure 9. These characteristics show less variation, but still fall outside the desirable region. For neutralizers, this vaporizer material would produce normal thruster operation with a neutralizer vaporizer temperature in the 280-300°C range, and would be quite acceptable. The remainder of the initial lot of porous tungsten vaporizer material procured to the specifications in Table 4 was rejected during the fabrication process (for one reason or another). Because of this, and propellant line failures that are described in the following paragraph, the vaporizer design and fabrication procedures were reviewed and revised.

Table 4. Specification for Porous Tungsten Vaporizer Material

1. Tungsten Powder:
   a. Nominal particle size to be 4.5 microns.
   b. Powder to be classified to eliminate particles and agglomerates above 10 microns.
2. Powder Shape:
   Angular or spherical
3. Size of Porous Plug:
   a. Thickness - 0.152 ± 0.005 cm (0.060 ± 0.002 in.) for main vaporizers
      - 0.117 ± 0.005 cm (0.046 ± 0.002 in.) for cathode and neutralizer vaporizers.
   b. Area - cylindrical discs capable of being machined to a diameter of 1.55 cm (0.61 in.) for main vaporizers and 0.479 cm (0.188 in.) for cathode and neutralizer vaporizers.

Table 5. Vaporizer Test Summary

	IV-N Vaporizers						
	Spectramat Material				Semicon Material		
Component Serial Number	910	911	909	907	4	7	19
<u>Test Performed</u>							
1. Measured Intrusion Pressure, PSIA							
at room temperature	>125	117	>125	>125	119	>125	122
at 400°C after 50 hour test	>125	>125	>125	>125	>125	110	112
2. Measured Flow Rates, mA equivalent							
at 260°C	9	14	10	11	12	10	13
at 280°C	17	20	15	25	25	22	23
at 300°C	27	36	27	31	36	31	41
at 320°C	46	61	46	48	61	58	63
at beginning of 50 hr. test[A]	93	155	108	138	166	164	153
during 50 hour test	104	192	107	143	182	168	153
at end of 50 hour test	101	216	152	135	183	180	159
3. Change in Flow Rate, %	3.1	39.4	40.7	2.2	10.2	9.7	3.9

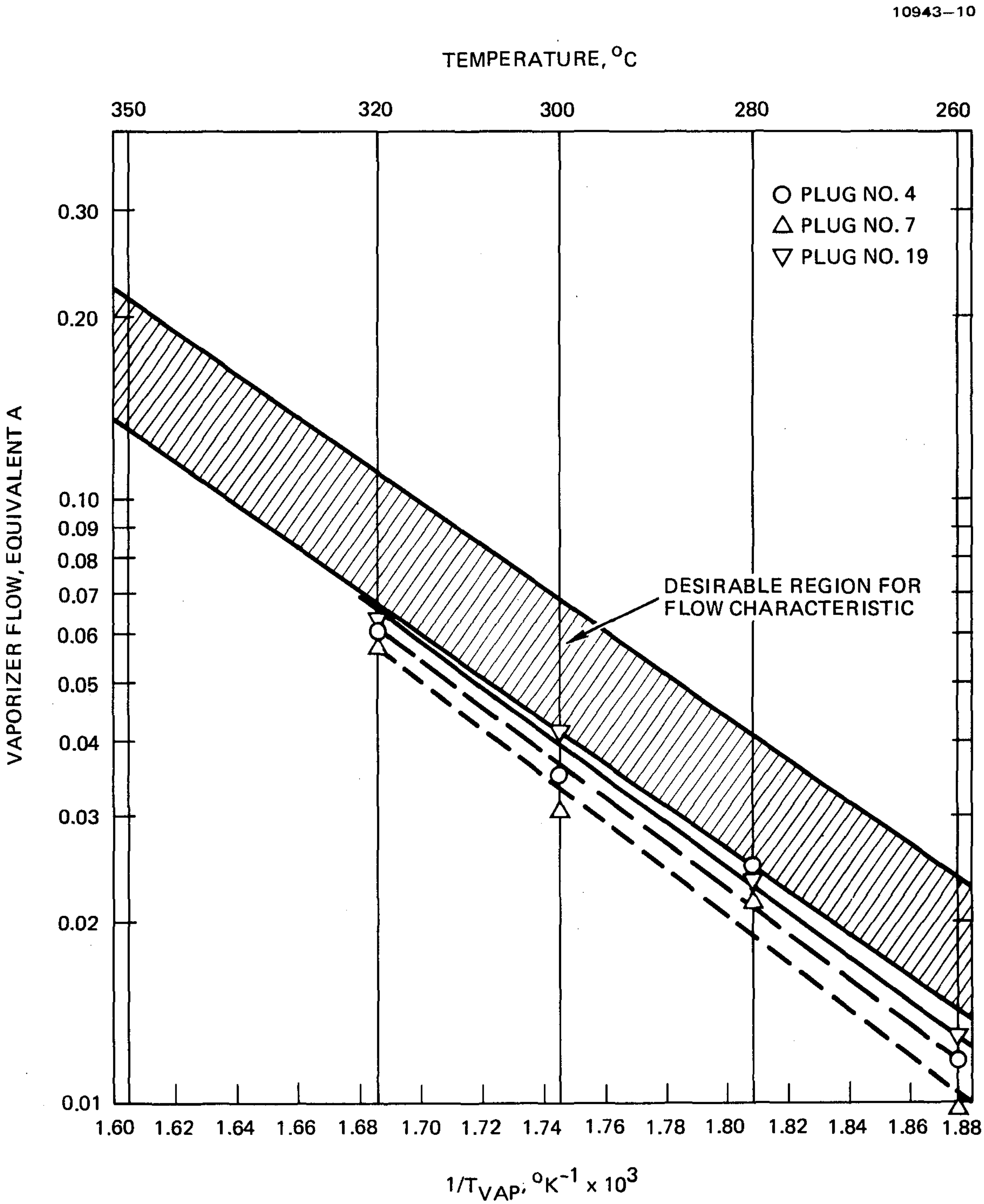


Figure 9. Vaporizer flow (in equivalent amperes) versus inverse vaporizer temperature for neutralizer vaporizers made from porous tungsten fabricated using the specifications shown in Table 4.

The vaporizer configuration that was in use on the 900-series thrusters is shown in Figure 10. As a consequence of manipulating the propellant line for screening tests and then for reinstallation on thrusters, many of the assemblies began to leak at the transition from the tantalum vaporizer housing and the stainless steel propellant line. This was thought to be caused by the difficulty in establishing the correct tolerance between the stainless steel tubing and the hole drilled in the tantalum housing. If the parts fit too tightly, the expansion of the tubing during brazing forces the braze material out of the hole. If the parts fit too loosely, the braze material will not fill the void. Thus, the configuration shown in Figure 11 was adopted. In this case, the transition was both welded and brazed to the propellant line so that the spacing between the tantalum vaporizer housing and the propellant line transition could be readily controlled. All of the vaporizers were retrofitted to this configuration to prevent development of propellant leaks.

Although the vaporizer configuration shown in Figure 11 was satisfactory for eliminating propellant line failures, the seal (by electron beam welding) between the porous tungsten vaporizer plug and its housing evolved as the next problem area. Review of the vaporizer configuration and fabrication procedures used by NASA LeRC in building the vaporizers for the SERT II thrusters resulted in a further design refinement and a newly defined vaporizer task. The configuration for the cathode vaporizer is shown as Figure 12. The essential features of this design are as follows:

- The edges of the porous tungsten plug are sealed by melting (washing) with the electron beam in the electron beam welder.
- The weld between the porous plug and its housing is made from the side (tantalum to beam washed tungsten).
- The wall of the tantalum plug housing has a very thin wall to prevent stresses in the weld upon differential thermal expansion.
- The vaporizer assembly housing has a "built in" temperature sensor receptacle to improve the reproducibility of attaching the platinum resistance-temperature-sensing element.

To obtain the performance goals for the vaporizer assembly, the following process steps were considered necessary, and were used in fabricating five sets of components under this program.

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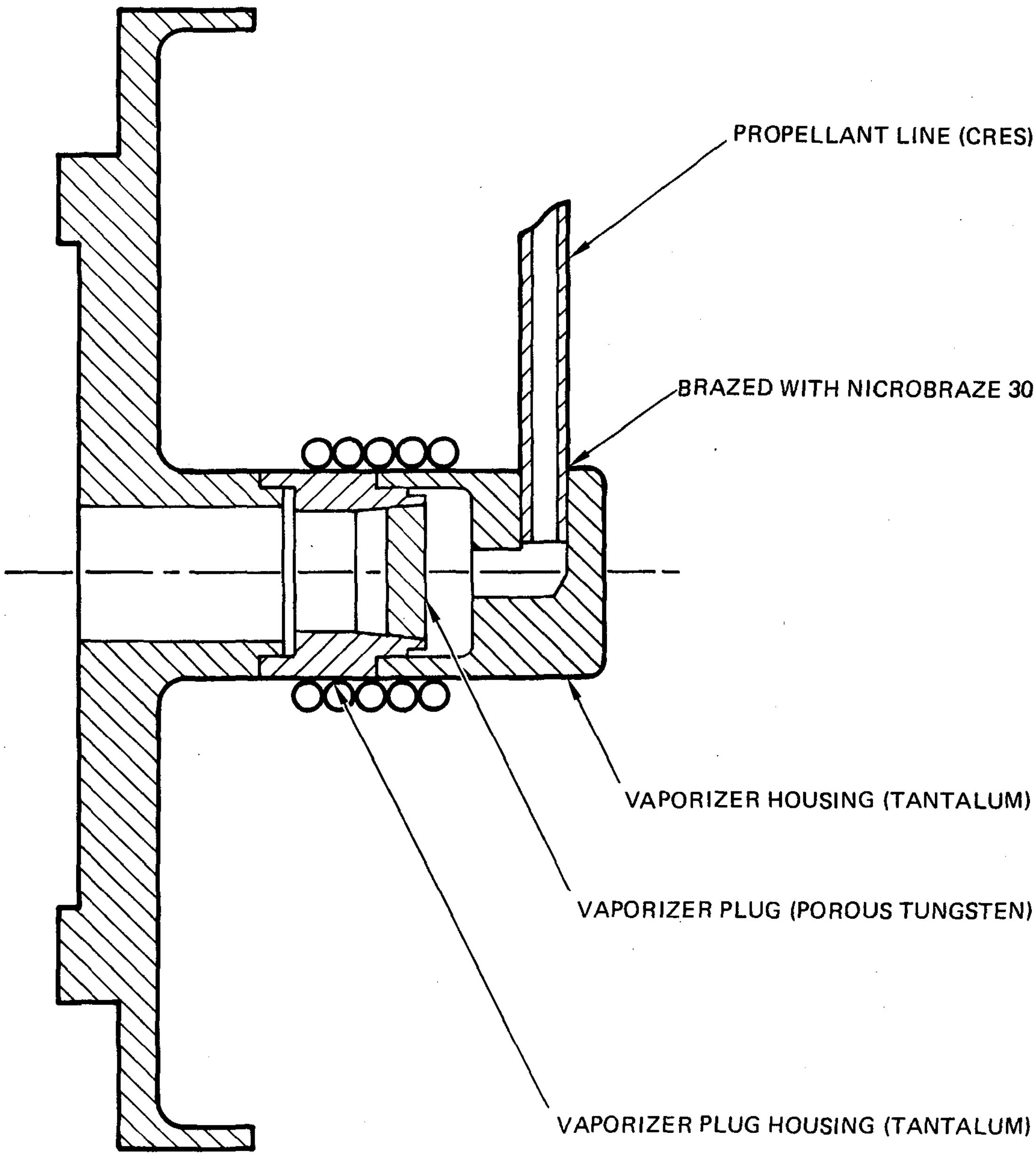

Figure 10. Cathode vaporizer assembly (800-900 series thrusters).

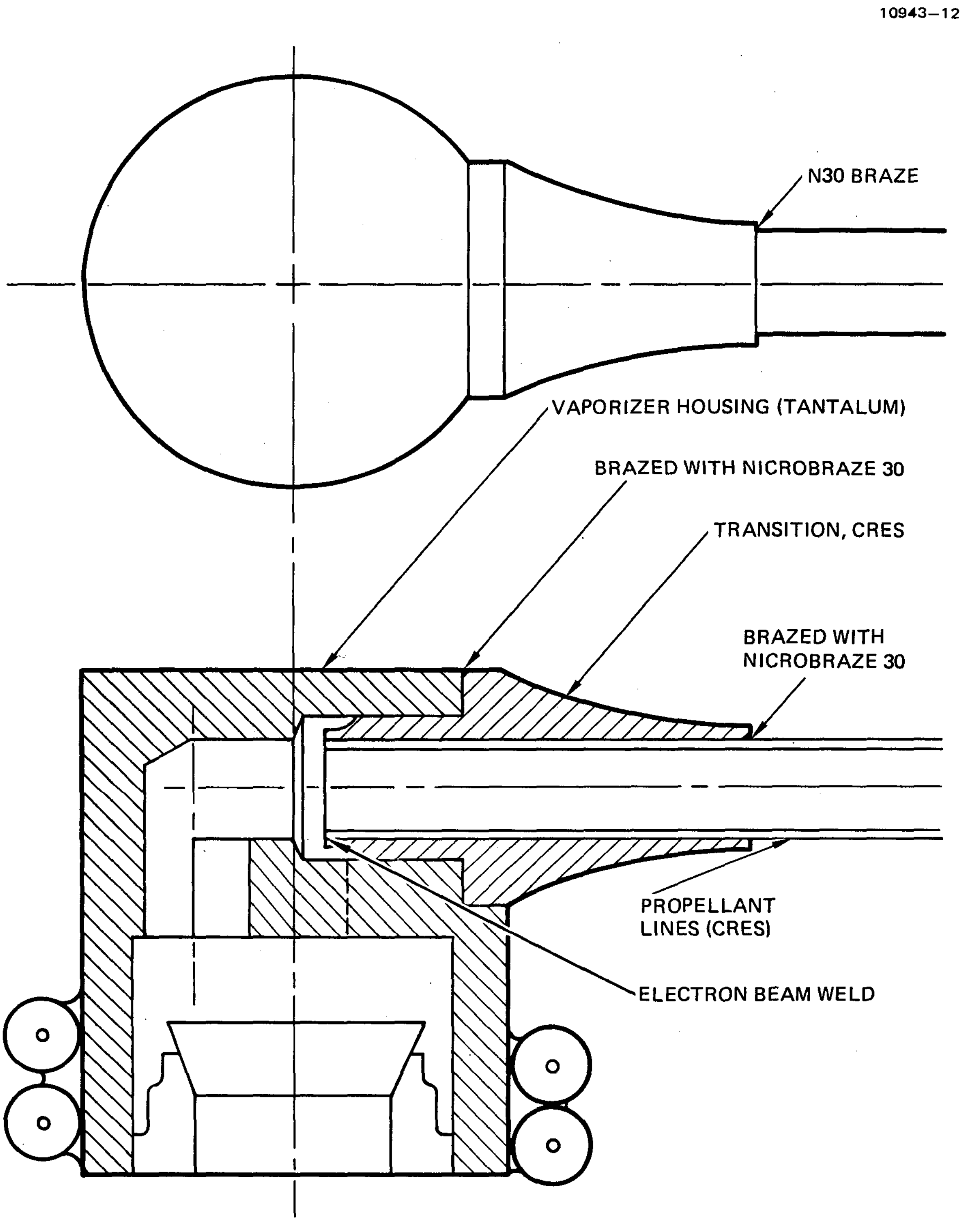

Figure 11. Vaporizer housing to propellant line transition.

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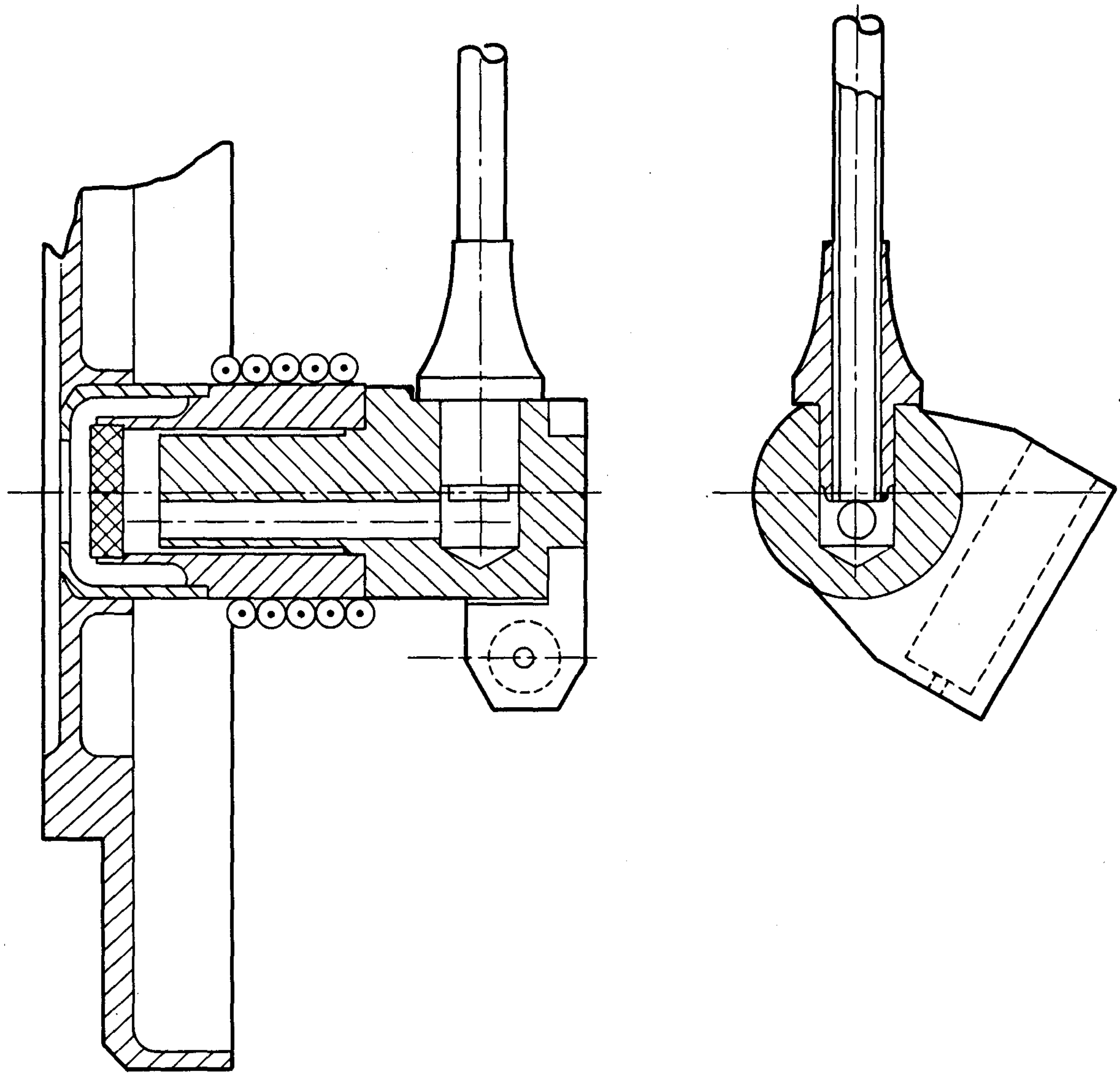

Figure 12. Cathode vaporizer assembly — J-series thruster design.

- The porous tungsten vaporizer plug was checked for porosity and pore size using a porosimeter; to be acceptable, results must fall within, or to the right of the shaded area in Figure 13.
- The porous plug was inspected at 10x magnification and rejected if chips or cracks were visible (or pores smeared over).
- All tantalum parts were vacuum fired at 1000°C for 15 minutes.
- The edge of the porous tungsten plug was electron beam washed to seal 99% of the surface (determined by visual inspection at 10x magnification).
- The "edge washed" vaporizer plugs were vacuum fired at 1650°C for one hour (at vacuum pressure less than 10^{-5} Torr).
- The fired vaporizer plugs were inspected at 30x magnification and rejected if cracks were visible.
- The vaporizer plug was electron beam welded into its housing and inspected again for cracks in the plug or the weld at 30x magnification (or greater).
- The plug and housing assembly was put through thermal cycle and then flow-tested by observing the bubble pattern obtained when flowing gaseous nitrogen through the porous plug while it was immersed in methanol.
- The transmission coefficient for the flow of gaseous nitrogen was measured.

After assembly of the vaporizers, the screening tests (intrusion pressure and flow calibration) were performed as described earlier in this section. The part (drawing) numbers for the J-series thruster vaporizer designs are 1095763 (IV-C), 1095755 (IV-M), and 1095761 (IV-N). The details of the fabrication and assembly procedures can be found in the IPDs numbered:

- IPD-PR-010
- IPD-PR-035
- IPD-PR-047
- IPD-PR-049
- IPD-PR-057
- IPD-PR-074

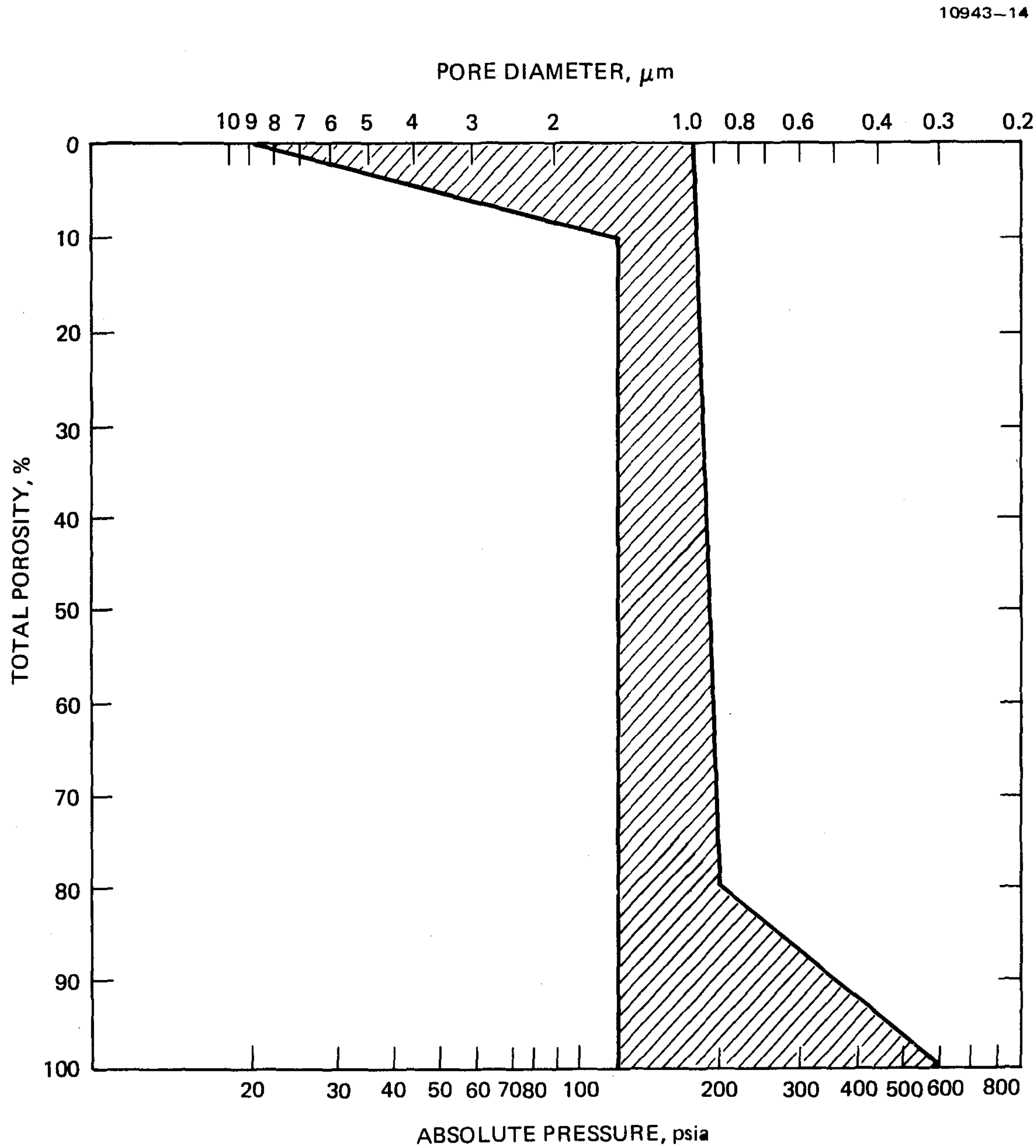

Figure 13. Penetration of porous tungsten plug (percent by volume) versus mercury pressure (absolute). Material is considered acceptable for vaporizers if points fall within, or to the right of, the shaded area.

- IPD-PR-133
- IPD-PR-151

Vaporizer screening test results for vaporizers fabricated to the configuration shown in Figure 12, and by the procedures listed above, are shown in Table 6 and Figure 14. These vaporizers were not all fabricated under this program. However, the test results are included here to show the variation that was still observed in the screening tests. For the cathode vaporizer, the test results show a marked decrease in the dispersion of the flow characteristics. The results for the main and neutralizer vaporizers did not show the same improvement. In the case of the neutralizer vaporizers, two assemblies (SN 904 and SN 905) deviate significantly from the other three assemblies (for which the data shows minimal variation in characteristic). It is thought that these vaporizers were not adequately "baked out" after the intrusion pressure screening test before the flow calibration was performed. The flow characteristic for neutralizer vaporizer SN 903 was initially identical to that of neutralizer vaporizer SN 904 during flow calibration. However, after a bakeout of about 30 hours, additional data was obtained at NASA LeRC (see Figure 14). The main vaporizers displayed similar results, in that the main vaporizer SN 902 changed flow characteristics after installation and operation on the thruster. If it is assumed that the flow calibrations for neutralizer vaporizers SN 904 and SN 905 and for the main vaporizer, SN 902, were in error because of partial intrusion, then the flow characteristics of the remaining vaporizers show relatively little dispersion. Consequently, the improvements in vaporizer material and fabrication procedures were considered to have accomplished their goals; however, the final screening test procedures (IPD-PR-133) require further review and refinement. As will be discussed later, new requirements have been identified for propellant reservoir configuration, mercury filling procedures, and flow data collection. These improvements in flow measuring techniques will have to be incorporated in the screening tests before variations in vaporizer flow characteristics like those seen in Figures 14b and 14c can be attributed to the vaporizer design or fabrication processes.

Table 6. Vaporizer Test Summary

	Vaporizers																	
	CV						NV					MV						
Component Serial Number	901	902	903	904	907	908	901	902	903	904	905	901	902	903	904	905	909
<u>Test Performed</u>																		
1. Measured Intrusion Pressure, PSIA																		
at room temperature	>125	>125	>125	>125	123	>125	>125	>125	>125	>125	123	105	>125	88.7	113	111.7	101.2
at 400°C after 50 hour test	>125	>125	>125	107	120	123	>125	>125	>125	(B)	>125	96	108	121.9	115.5	104.7	102.3
2. Measured Flow Rates, A																		
at 260°C	.010	.010	.010	.012	.012	.014	.012	.007	(C) —	.034	.022	.216	0.72	.261	.192	.166	.714
at 280°C	.019	.019	.018	.022	.022	.025	.022	.024	.021	.062	.036	.363	1.26	.424	.301	.308	.818
at 300°C	.041	.041	.032	.034	.035	.038	.035	.039	.036	.106	.058	.595	1.99	.709	.508	.510	1.088
at 320°C	.051	.051	.045	.053	.053	.062	.057	.064	.057	.181	.094	.959	3.27	1.08	.842	.792	1.389
at beginning of 50 hour test[A]	.101	.113	.117	.111	.121	.138	.111	.116	.123	(B)	.142	.497	2.27	.526	.643	.394	1.834
during 50 hour test	.103	.176	.125	.116	.122	.141	.111	.115	.128		.163	.496	2.46	.538	.679	.404	.514
at end of 50 hour test	.106	.209	.128	.119	.127	.151	.111	.119	.128		.147	.516	2.61	.542	.670	.394	.528

(A) The main vaporizer was operated at a temperature of 290°C and a reservoir pressure of 60 PSIA during the 50 hour test.

(B) Testing terminated after flow calibration.

(C) Measured at NASA LeRC.

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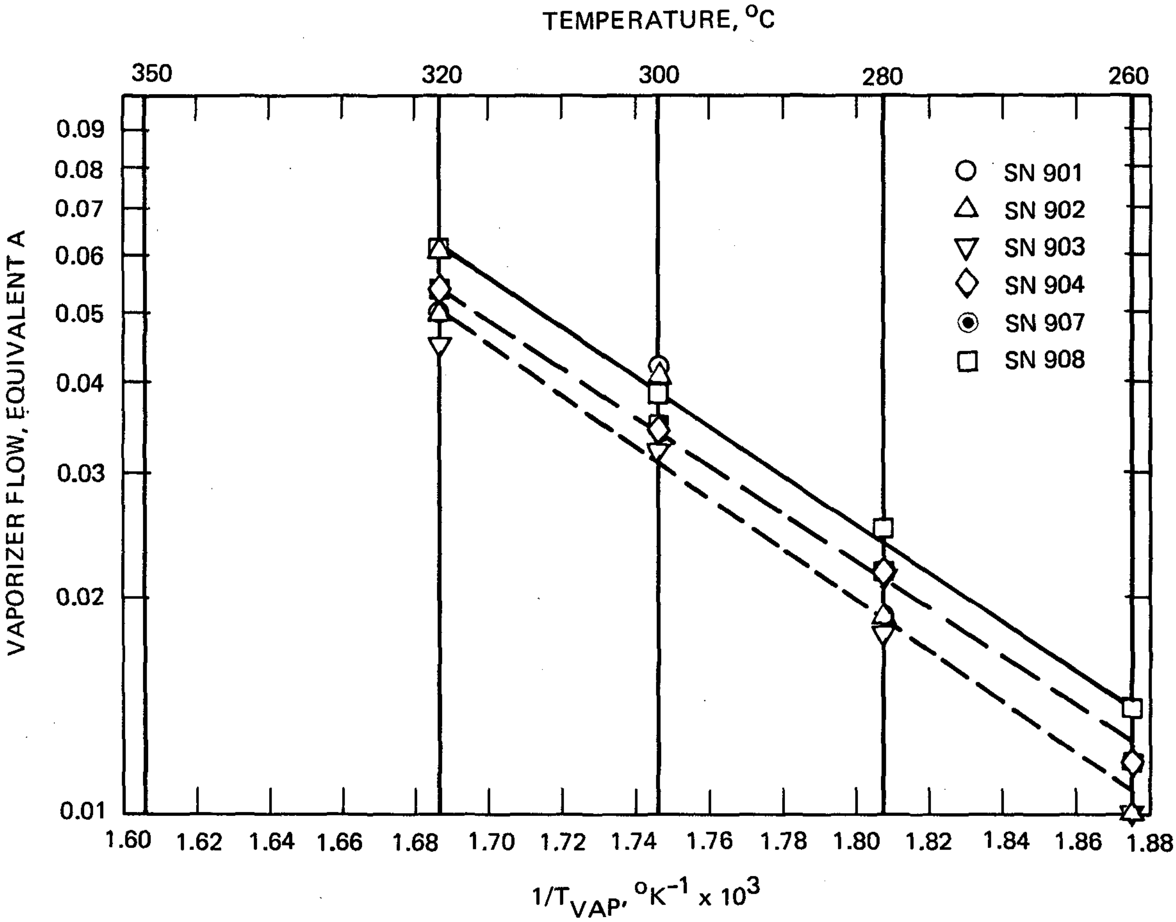
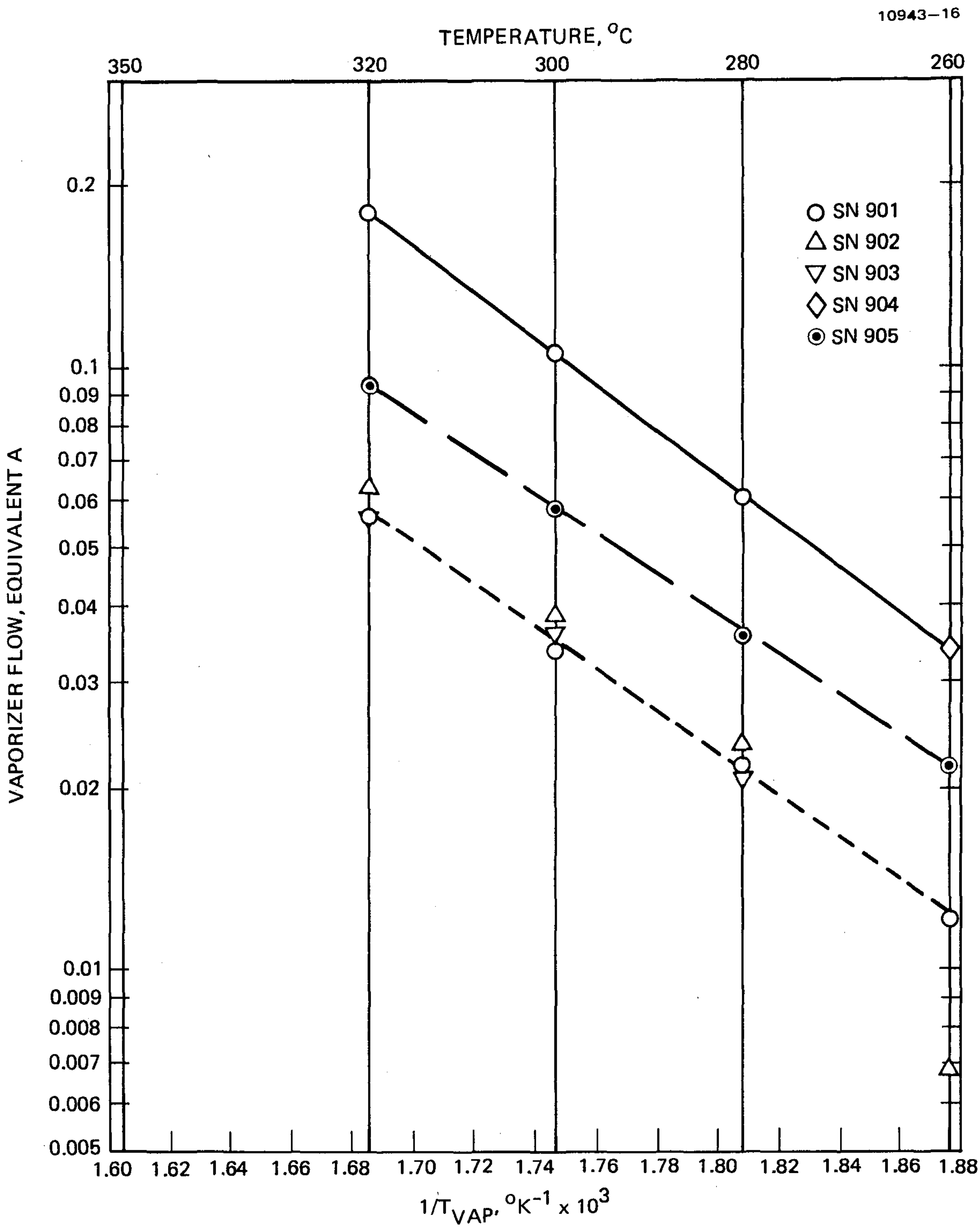


a) CATHODE VAPORIZERS

Figure 14. Vaporizer flow (in equivalent amperes) versus inverse vaporizer temperature.



b) NEUTRALIZER VAPORIZERS

Figure 14. Continued.

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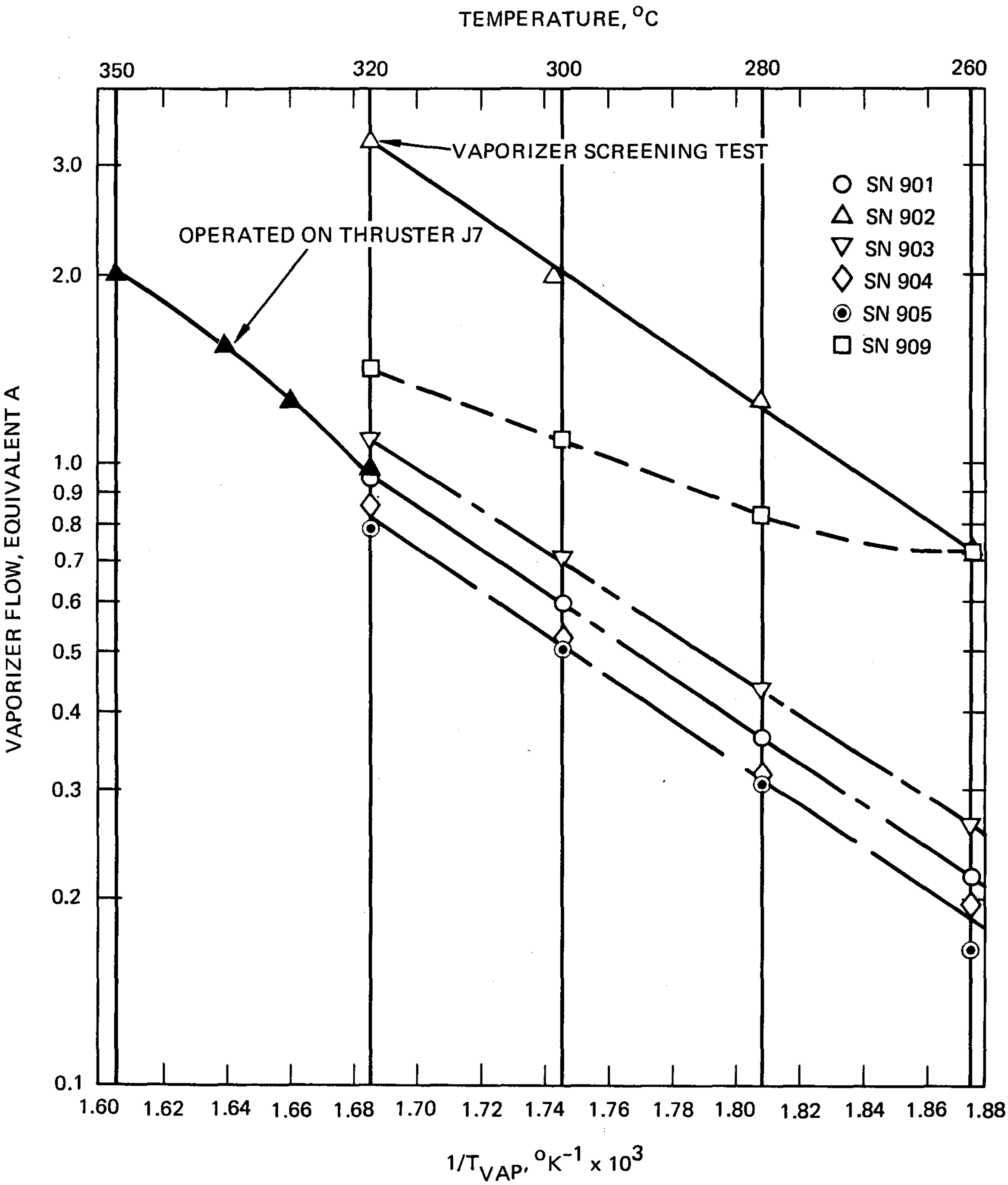

c) MAIN VAPORIZERS

Figure 14. Continued.

The final vaporizer assembly assignment for the retrofit thrusters is shown in Table 7. To date, no anomalies in vaporizer operation have been observed for these vaporizers.

Table 7. Vaporizer Subassembly Assignment for the Retrofit Thrusters (as delivered)

Thruster	IV-M	IV-C	IV-N
J2	903	901	815
J3	825	805	917
J4	819	807	907
J5	821	817	906
J6	811	814	919
J7	901	902	920

C. CATHODE HEATERS

The changing of cathode heaters was not a part of the retrofit modifications planned for the GFE thrusters; however, heater failures occurred on three thrusters during preliminary cathode conditioning and thereby made replacement of the failed heaters a necessity. The cathode heater is a coaxial swaged heater with a configuration as shown in Figure 15. The center conductor is the heating element and is electrically insulated from the outer conductor by compressed magnesium oxide. For the cathode heaters (discharge and neutralizer) the center conductor and sheath material is tantalum. The heater is fabricated in a swaging operation that compresses the outer conductor, magnesium oxide insulator, and center conductor to final diameter, and expands these diameters in a gradual transition to larger diameter for a "lead in" to the active element. The failure of the heaters was traced to poor quality tantalum that formed flakes on the interior of the outer conductor during swaging. These flakes were then compressed and forced into the magnesium oxide insulator, eventually resulting in a short circuit between the center and outer conductor. This failure led to the addition of specifications and assembly instructions to the heater procurement drawing (B1025262 Rev E). The quality controls that are considered essential are:

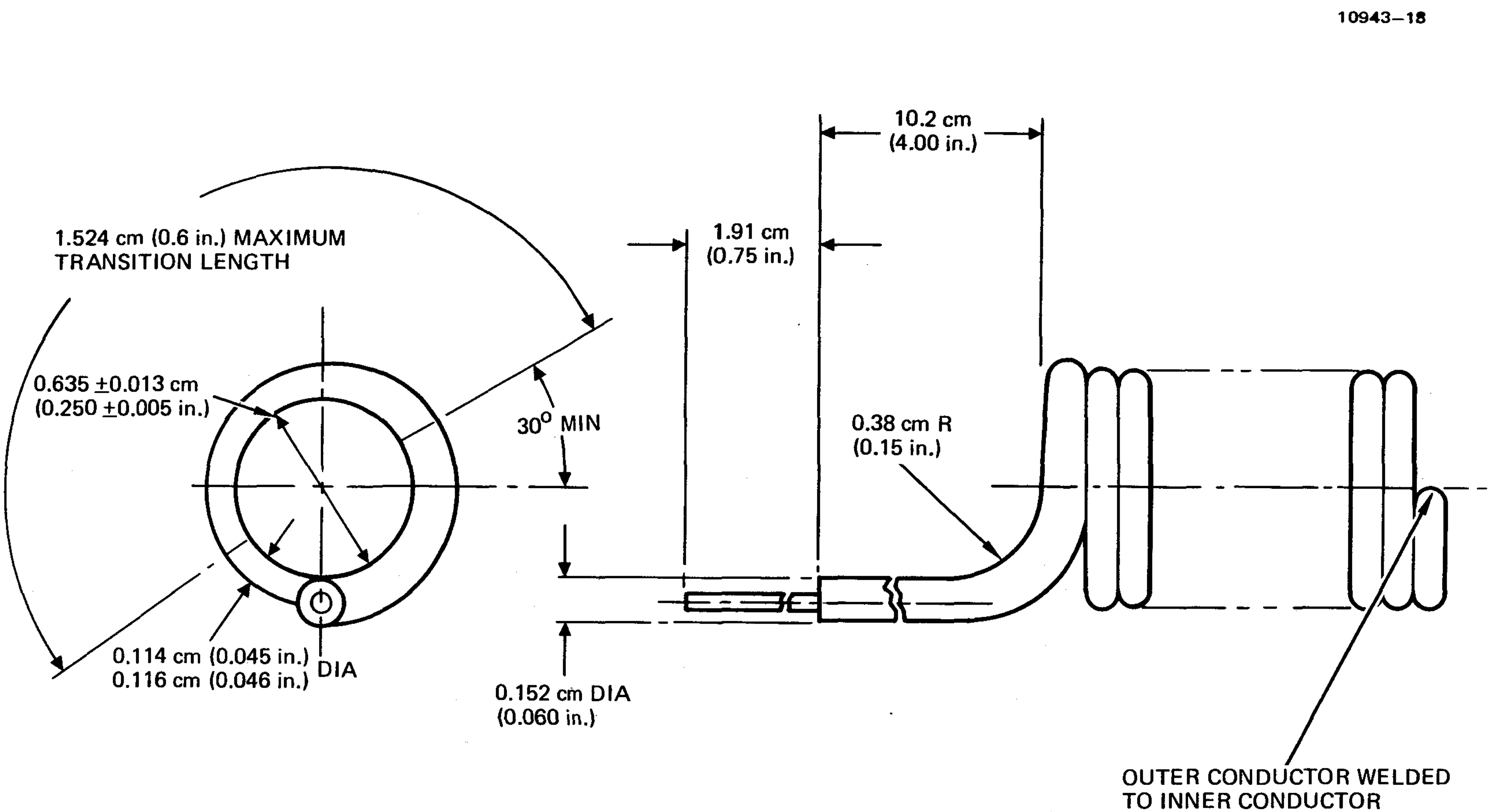

Figure 15. Typical configuration of swaged coaxial heater (dimensions shown are for cathode heaters).

- Magnesium oxide (MgO) insulation of 99% purity.

- Center conductor wire and sheath tubing to be free of nicks, notches, abrasions, reduced diameter or other defects as determined by inspection under 30x magnification.

- All annealing operations to be performed 1204 ± 10^{o}C (2200 ± 50^{o}F) with time in heat zone limited to 6 min.

- Compaction density of MgO insulator to be 90 ± 2% (verified by test).

- Weld of center conductor to outer conductor to be checked by die penetrant test.

- Active section of heater and weld to be radiographed (two views, 90^{o} apart) before coiling of heater.

- Heating uniformity to be checked by infrared scan (transient and steady-state with heater operated in argon atmosphere; acceptable variation is ±50^{o}C from average).

Heaters of this type had been more-or-less routinely supplied by vendors specializing in heater fabrication. Addition of these specifications both escalated the costs and all but eliminated the suppliers willing to bid (with extremely long delivery times). None of the heaters that were delivered in accordance with these manufacturing controls has shown any evidence of deterioration or failure.

In addition to the establishment of more stringent quality controls in heater fabrication, screening tests were instituted for ferreting out potential early failures. Each heater was carefully measured (for heater resistance) and then thermally cycled (in vacuum) to full operating temperature for 100 cycles. The heater resistance was then re-measured, and had to be within ±10% of its original value or the heater was rejected.

These controls were applied to all of the heaters used in repairing or fabricating new parts for the thrusters retrofit under this contract (including the nichrome-center-conductor isolator and vaporizer heaters). No attempt has been made to correlate any relaxation of these control measures with heater failures (since there was no opportunity to do so within the scope of this program). Consequently, a rather rigid adherence to arbitrarily severe acceptance criteria was employed. This resulted in a rather low yield of acceptability in the heaters fabricated (25%). Heater fabrication processes and controls that bear further attention are:

- Materials specifications for tantalum wire and tube (purity, hardness, testing required).

- Number of annealing operations, cleanliness of annealing environment.

- Process for welding center conductor to outer conductor (type of weld, heat sinking, molding of outer conductor before weld).

- Correlation of inspection results with failure rates.

D. OTHER MODIFICATIONS INCORPORATED INTO THE THRUSTERS RETROFIT UNDER THIS PROGRAM

Several other minor modifications were required in performing the retrofit modifications either to accommodate fabrication problems, to correct incompatibilities introduced by the design modifications previously approved, or to correct design deficiencies recently identified under other programs. Five of the more significant modifications are listed below:

- Modification of the outer casing to accommodate the dimensions of the revised ion optics assembly.

- Increasing the number of anode support insulators from six to nine.

- The material of the rivets used to fasten nut plates to the discharge chamber was changed from aluminum to stainless steel.

- The material used for fabricating the wiring cable clamps was changed from MACOR(R) to VESPEL(R).

- The dimensions of the wire diameter and spacing were changed for the wire mesh used to cover the main-keeper-insulator shields. This also required a new procedure for attachment of the wire mesh to the shields.

These and other less significant changes (e.g., dimensions of parts, etc.) have been incorporated in the design documents (drawings and IPD) and in some of the retrofit thrusters. Table 8 identifies which of the five changes listed above that were incorporated in each thruster.

Other requirements for modifications in the thruster design or fabrication procedures have been identified since completing the retrofit of thrusters SN J2 through SN J7 as a result of testing performed by NASA. Some of these requirements were determined under this contract as a result of analyzing the

Table 8. Matrix of Additional Modifications Incorporated in the Retrofit Thrusters

Thruster S/N	J2	J3	J4	J5	J6	J7
Outer casing modification	Yes	No	No	No	No	Yes
Additional anode supports	Yes	No	No	No	No	Yes
Stainless steel rivets	Yes	No	No	No	No	Yes
Vespel harness clamps	Yes	No	No	No	No	Yes
Keeper-insulator shields	Yes	Yes	No	No	No	Yes

thrusters returned to HRL after test. Other requirements have been identified by the staff of NASA LeRC, or under other contracts. The objective here is to make the list of requirements as complete as possible, and representative of the status at the time this report is printed. A brief description of the requirements that have been identified at this point follows.

1. Isolator Insulator Protection

The insulation of two cathode isolators was observed to deteriorate during testing in the Mission Profile Life Test (NASA contract NAS 3-20399). Although the investigation of these failures has not yet been completed, it has been determined that the principal contaminant on the surface of the insulator is carbon. An improvement in protection of these insulators will be required. The form of this improvement depends on whether the insulator becomes contaminated during fabrication, during preliminary testing or handling (test facilities or shipping procedures), or as a consequence of outgassing of materials used in the thruster during operation of the thruster.

2. Spalling of Sputter-Deposited Material

Most of the interior surfaces of the thruster discharge chamber have special coverings to retard erosion by ion sputtering, or to inhibit the spalling of sputter-deposited coatings. One surface that becomes deposited with back-sputtered material (tantalum) has been overlooked, and spalling of relatively large flakes of material resulted during the testing of thruster SN J7 (leading to early termination of an endurance test). This surface is on the interior of the baffle support cylinder (mild steel) that is part of the cathode pole assembly. A grit-blasted tantalum covering for this surface would be the most tractable thruster modification.

3. Vespel Cable Clamp

The cable clamps that secure the wiring harness at the point where the wiring exits the thruster's outer casing represent an unshielded high voltage insulator. Consequently, deposition (of some form of material) on the surface of these clamps has led to electrical breakdown and cracking of the insulator. These clamps will have to be shadow-shielded in the same manner as other high voltage insulators.

4. Isolator Shadow Shields

The isolator shields are re-entrant shadow-shields fabricated from thin stainless steel sheet. The sharp edge of the inner shield is negative with respect to the outer shield, and there is evidence that discharges have occurred between the shields of the two cathode isolators that failed, perhaps contributing to the failure. The conditions for breakdown can be enhanced by any slight distortion of the concentricity of the isolator shields (which can easily occur during installation of the isolator because of the flexibility of the shields). A design revision to eliminate the sharp edge of the inner shield and provide more rigidity would alleviate this potential failure hazard.

SECTION 3

ACCEPTANCE TESTING

A set of test procedures was formulated under NASA contract NAS 3-21052 to provide a standard acceptance test that could be performed on newly fabricated thrusters and periodically throughout the life of the thrusters to determine operating characteristics and performance parameters. In formulating these procedures, an attempt was made to make the instructions and descriptions sufficiently general to enable anyone with an elementary understanding of thruster operation to reproduce acceptance test conditions using an arbitrary set of power supplies. Having experienced considerable difficulty in performing the acceptance tests on thruster SN J1, the test procedures were revised and redefined under this program to facilitate testing. The procedures as now written require a test console with a certain degree of automation, as described in a NASA LeRC document entitled "Thruster Requirements Document" (see Appendix B). Several iterations on the procedures were required, first to provide opportunity for a real time review of the test data by NASA LeRC personnel, and finally, to improve the accuracy of propellant flow measurement. The discussion in this section describes the essential issues raised in evolution of the acceptance test procedures, presents data relating to the problems of obtaining accurate measurement of propellant flow, and compares test results for the retrofit thrusters. A summary of the test data for each thruster is provided in Appendix C. More complete data packages were provided to NASA LeRC; copies may be obtained directly from that center.

A. ACCEPTANCE TEST PROCEDURES

The procedures for performing acceptance testing of the 30-cm J-series thruster are described in six documents in the Hughes IPD (inspection and process document) format. These IPD's are numbered IPD-PR-138 through IPD-PR-143. A short description of each document is as follows:

- IPD-PR-138, 30-cm Thruster Acceptance Procedure, provides detailed instructions for taking data and reducing data.

- <u>IPD-PR-139, Thruster Test Facility</u>, specifies the vacuum facility and thruster interface requirements.
- <u>IPD-PR-140, Power Processor</u>, specifies the power supply requirements and characteristics needed for thruster testing.
- <u>IPD-PR-141, Instrumentation and Calibration</u>, describes the test equipment and methods used for calibration.
- <u>IPD-PR-142, Preliminary Thruster Preparation</u>, describes the measurements and procedures required in installing a thruster in a test facility.
- <u>IPD-PR-143, Data Formats for Thruster Testing</u>, contains the data formats for recording the data in acceptance and performance evaluation tests.

The performance of the thruster testing is governed by IPD-PR-138. The major test elements are:

- Initial cathode conditioning.
- Thruster start-up.
- Determination of the minimum magnetic baffle current for stable operation.
- Measurement of neutralizer-keeper-voltage/vaporizer-temperature characteristics.
- Determination of the minimum emission current (eV/ion) for selected operating points.
- Measurement of thruster efficiencies for ten operating points.
- Documentation of oscillation in specified thruster parameters.
- Documentation of thruster high voltage overload recycle characterstics.
- Documentation of the ion optics system for selected operating points.

The sequence and procedures for performing these tests is described in the IPDs (available from NASA LeRC). Although the sequence of tests may seem relatively unimportant, it was determined during this program that there is a preferred sequence for performing these tests if the data is to be obtained reproducibly without accumulating an excessive amount of thruster operating time. The ten standard test points are specified by selecting the net accelerating voltage, V_b, the ion beam current, J_b, the discharge voltage, V_D, and the discharge emission current, J_E. Two other reference values are required to fully specify the thruster control parameters: neutralizer-keeper voltage, V_{NK}, and the magnetic baffle current, J_{MB}. The values for these parameters are determined as a function of beam current in the tests described in the third and fourth elements above. Table 9 gives a matrix of the test points and tests performed during a standard acceptance test. Test points numbered 1, 4, 6, 7, and 9 are typically referred to as the principal throttling points, and therefore receive the majority of attention in the acceptance test. Test point number 11 provides information about the neutralizer control characteristic that is useful in predicting the effect of the high voltage recycle algorithm on the operation of the neutralizer cathode.

The first quantity that must be determined for operation of a new thruster is the value of magnetic baffle current for obtaining the correct division of propellant flow into the discharge hollow-cathode and the discharge chamber. The form of the characteristic for cathode keeper voltage, V_{CK}, versus magnetic baffle current, J_{MB}, is shown in Figure 16. The value of J_{MB} that becomes the reference value for each value of beam current is determined from this characteristic (as shown in Figure 16) by the following criteria:

- J_{MB} should be about 0.2 A less than the value for which V_{CK} is a minimum
- V_{CK} for the selected value of J_{MB} should not be more than 0.02 V greater than the minimum value of V_{CK}

This characteristic changes during the first few hours of thruster operation, and the minimum value of V_{CK} shifts (usually to a lower value of J_{MB}). Consequently, it is necessary to allow the thruster to "run-in" for a minimum of about eight hours before meaningful characterization can be obtained.

If the thruster is new and being run for the first time, some period of operation is required to obtain stable operation at full-power (to obtain

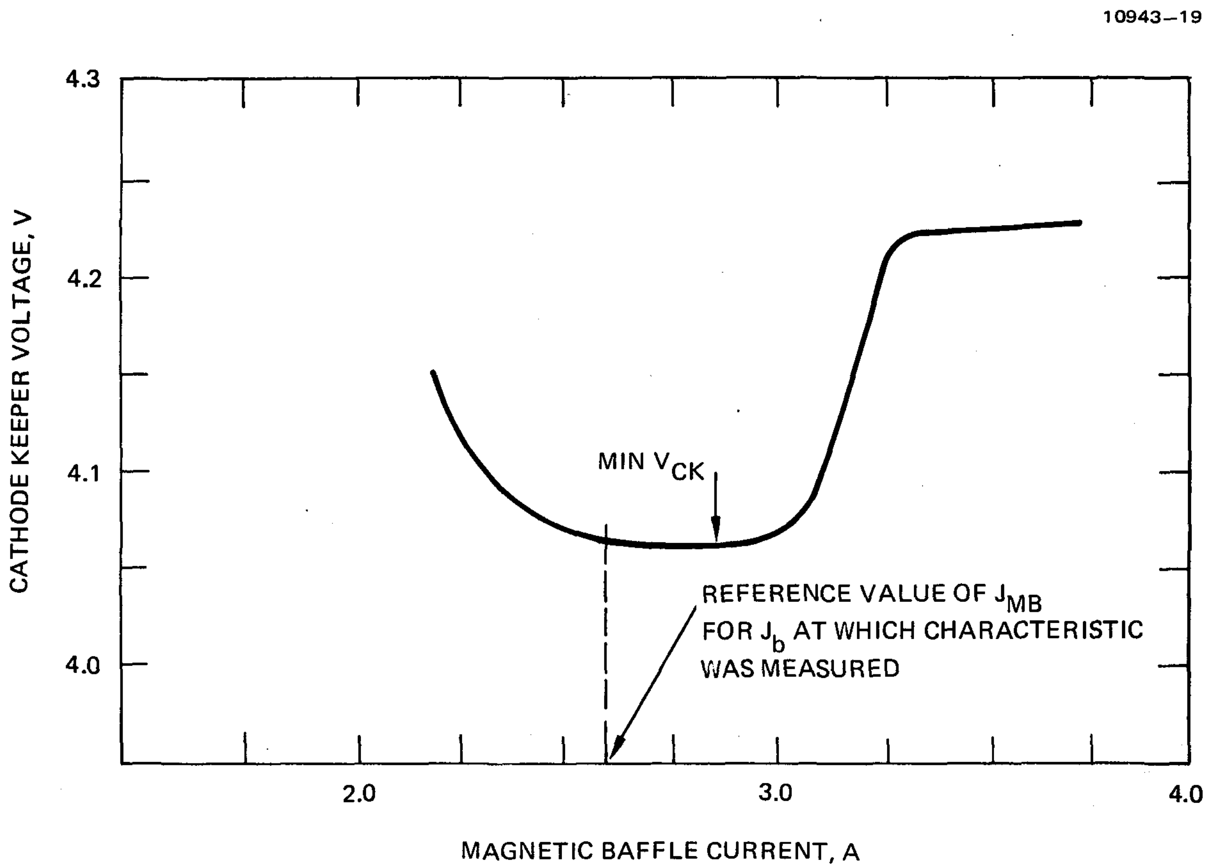

Figure 16. Characteristic of cathode keeper voltage versus magnetic baffle current.

Table 9. Matrix of Acceptance Test Control Parameters and Tests Performed

	Control Parameters											
	Test Point	1	2	3	4	5	6	7	8	9	10	11
	J_b,A	2.0	2.0	2.0	1.6	1.3	1.3	1.0	.75	.75	.75	0
	V_b,V	1100	1100	1100	940	1100	820	700	1100	600	600	0
	V_D,V	32	31	32	32	32	32	32	32	32	31	36
	J_E,A	12	12	11.4	10	8.5	8.5	7.0	5.75	5.75	5.75	0
Tests Performed												
c. Magnetic Baffle Current		●			●		●	●		●		
d. Neutralizer Keeper Voltage		●			●		●	●		●		●
e. Minimum eV/ion		●			●		●	●		●		
f. Electrical and Propellant Efficiencies		●	●	●	●	●	●	●	●	●	●	
g. Oscillatory Behavior		●			●		●	●		●		
h. High Voltage Recycle		●			●		●		●	●		
i. Ion Optics Perveance		●			●		●	●		●		
● Indicates Test Performed												

infrequent overcurrents or "arcs" and operating parameters in normal range). Consequently, the preferred sequence of performing the acceptance test is to "condition" or "activate" the cathode inserts by heating and start the thruster by the algorithm shown in Figure 17. This brings the thruster on at the conditions for test set-point number 9. The thruster operator then adjusts the value of V_{NK} and J_{MB} to keep the thruster operation stable and in "normal" ranges of parameters while gradually increasing the beam current until the 2-A set-point (test point number 1) is reached. The thruster is allowed to operate at this point for approximately four hours without recording data (other than for reference purposes). Operation and monitoring of the thruster during this initial run-in is best performed by an experienced operator, since it is difficult to describe all possible variations or combinations of abnormalities (or apparent abnormalities) that can occur. After the thruster has operated stably for at least four hours at the test point number 1, (TP 1), the magnetic baffle test procedure (c) and the neutralizer characteristic procedure (d) are performed to obtain the values of J_{MB} and V_{NK} that are used for the remaining tests under TP 1, TP 2, and TP 3. Procedures for (i), and then (e) are performed before recording data for determining thruster efficiency. At least three hours of operation must be performed at the beam current level for which the thruster is being tested if the propellant flow data is to be valid (this will be discussed in more detail in the next section). Consequently, the procedures for TP 2 and TP 3 are performed immediately after those for TP 1. In terms of working time, the testing up to this point has required two 12-16 hour days. At least four additional days of testing are required to complete the test — one day each for the test group as follows: TP 8, TP 9, and TP 10; TP 5 and TP 6; TP 4 and TP 7; TP 11 and test procedures (g) and (h) for all applicable TP's. The order of these test groups is not important, provided that the thruster is allowed to stabilize at each new value of J_b for at least three hours (except for procedures g and h). Test times (beam on) have varied from as little as 43 hours to in excess of 100 hours. This variation depends on the amount of time required to stabilize the thruster at $J_b = 2$ A initially, and whether data points have to be repeated (because of beam probe

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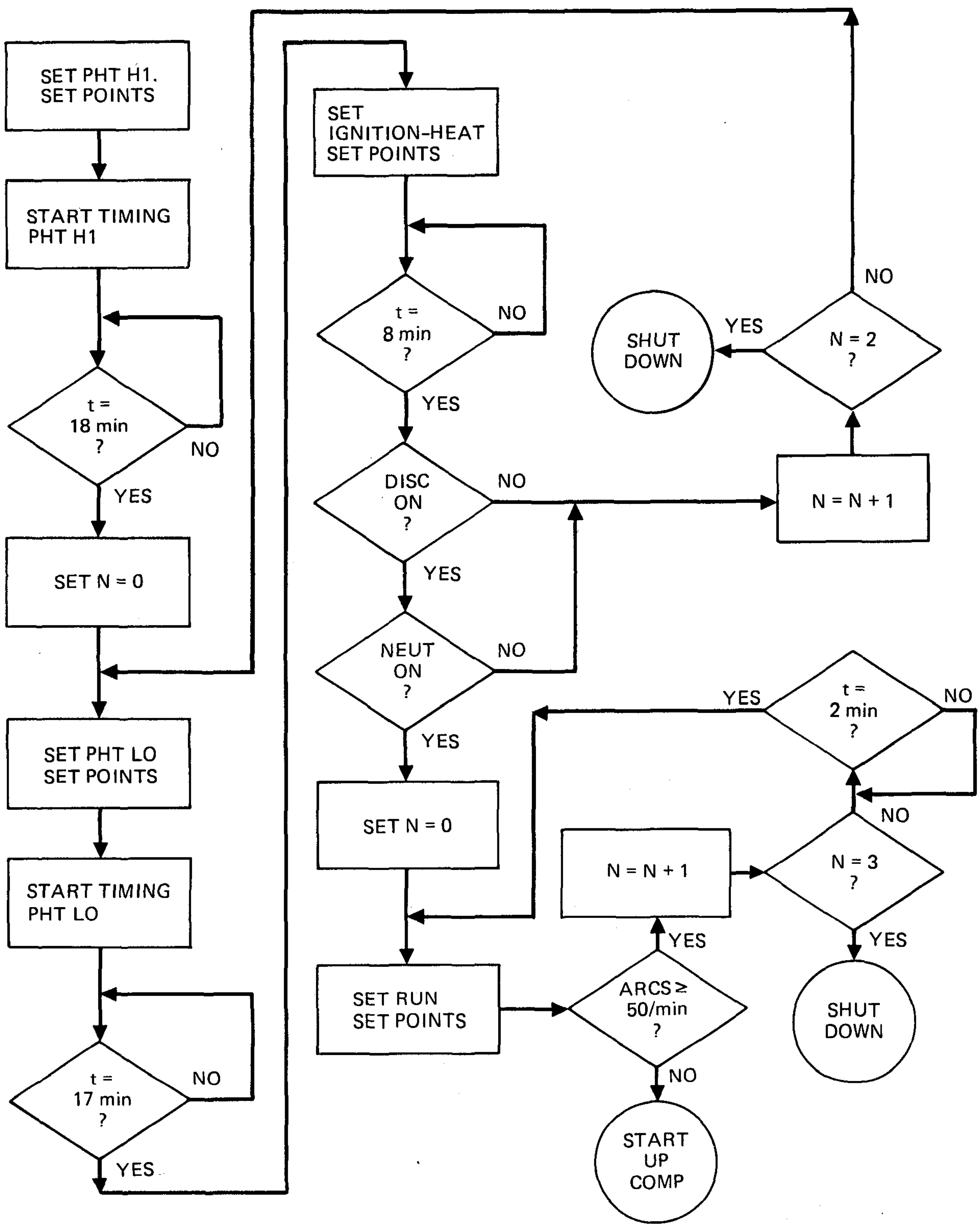

Figure 17. Thruster start-up algorithm.

malfunction, or difficulty in obtaining some particular characteristic because of a narrow range of thruster stability).

The sequence described above differs slightly from that in the latest revision of IPD-PR-138 because of the requirement for three-hour operation to obtain stable propellant flow. The period of three-hours operating time for obtaining thermal equilibrium may not, in fact, be long enough, and therefore further revision of the procedure is considered premature without more test data.

B. PROPELLANT MEASUREMENT

The measurement of the propellant (mercury) flow must be performed with high accuracy to provide a valid data base for comparing one thruster with another, or for monitoring the characteristics of a given thruster over its lifetime. The electrical efficiency of the thruster is determined almost entirely by the thruster control parameters that are established by the operator. The efficiency of the thruster in ionizing the mercury to produce the programmed beam current is, therefore, the most significant measure of a thruster's performance characteristic. The pertinent figure of merit is the propellant or mass utilization efficiency. To be absolutely valid, this efficiency should be defined as the ratio of the number of ions that leave the thruster in the ion beam to the number of neutral atoms that enter the discharge chamber each second. The rate of ions leaving the discharge chamber can be readily determined by measuring both the beam current and the ration of singly to doubly charged ions in the extracted ion beam. The ion beam current can be measured quite accurately; however, measurement of the ratio of singly to doubly charged ions requires a relatively sophisticated probe measurement. An analysis of the accuracy of this measurement technique has been performed under NASA contract NAS 3-21943, with the result that the inherent capability (error $<1\%$) exceeds that of the capability for measuring propellant flow (see Appendix D).

Propellant flow has been measured, traditionally, by recording the volume of mercury remaining in a calibrated supply reservoir, as a function of time.

The accuracy of the measurement depends on several factors. First, since the volume of mercury used per unit of time is relatively small, any change in temperature of the propellant system can produce an apparent change in the mercury remaining in the supply reservoir. Secondly, if a small amount of gas is trapped in the mercury supply lines, it will expand more rapidly than the mercury as it moves nearer the high temperature of the thruster and vaporizer, thereby changing the apparent flow from the reservoir. Finally, because of the small volume of propellant used per unit of time, the propellant flow measurements have to be made over a time interval of at least one-half hour. This imposes a rather stringent stability requirement on the power electronics unit and its control system. In the course of testing the thrusters that were retrofit under this program, procedures were implemented to address the elimination of gas trapped in the propellant system, and to ensure a steady-state temperature before recording flow data.

The retrofit thrusters were tested in the sequence as follows: J5, J4, J6, J3, J7, J2. The first three thrusters in this sequence were tested before attention was focused on the relatively large dispersion in propellant flows being measured. Figure 18 shows the propellant efficiencies measured at each of the test points for these three thrusters. An intensive examination of the propellant system, the reservoir calibration, and the filling procedures was undertaken to improve the accuracy of propellant measurement, primarily at NAS LeRC, but with some work performed under this program. Making use of the information provided by NASA LeRC in TRIM 104, (see Appendix B), the propellant reservoir configuration and filling procedure was modified. The dispersion in propellant flow measurements was markedly reduced, as shown in Figure 19. All of the data shown in Figure 19 was obtained after ensuring that the propellant system was free from trapped gas pockets by using a pressurization criteria derived from the NASA experiments. The propellant utilization efficiency data obtained in acceptance testing of thrusters SN J8, J9, and J10 (not performed under this contract) have been included in Figure 19 to illustrate the improvement in the data. Whereas the scatter in propellant efficiency for the data in Figure 18 is of the order of ±3%, the scatter seen in Figure 19 is only ±1%.

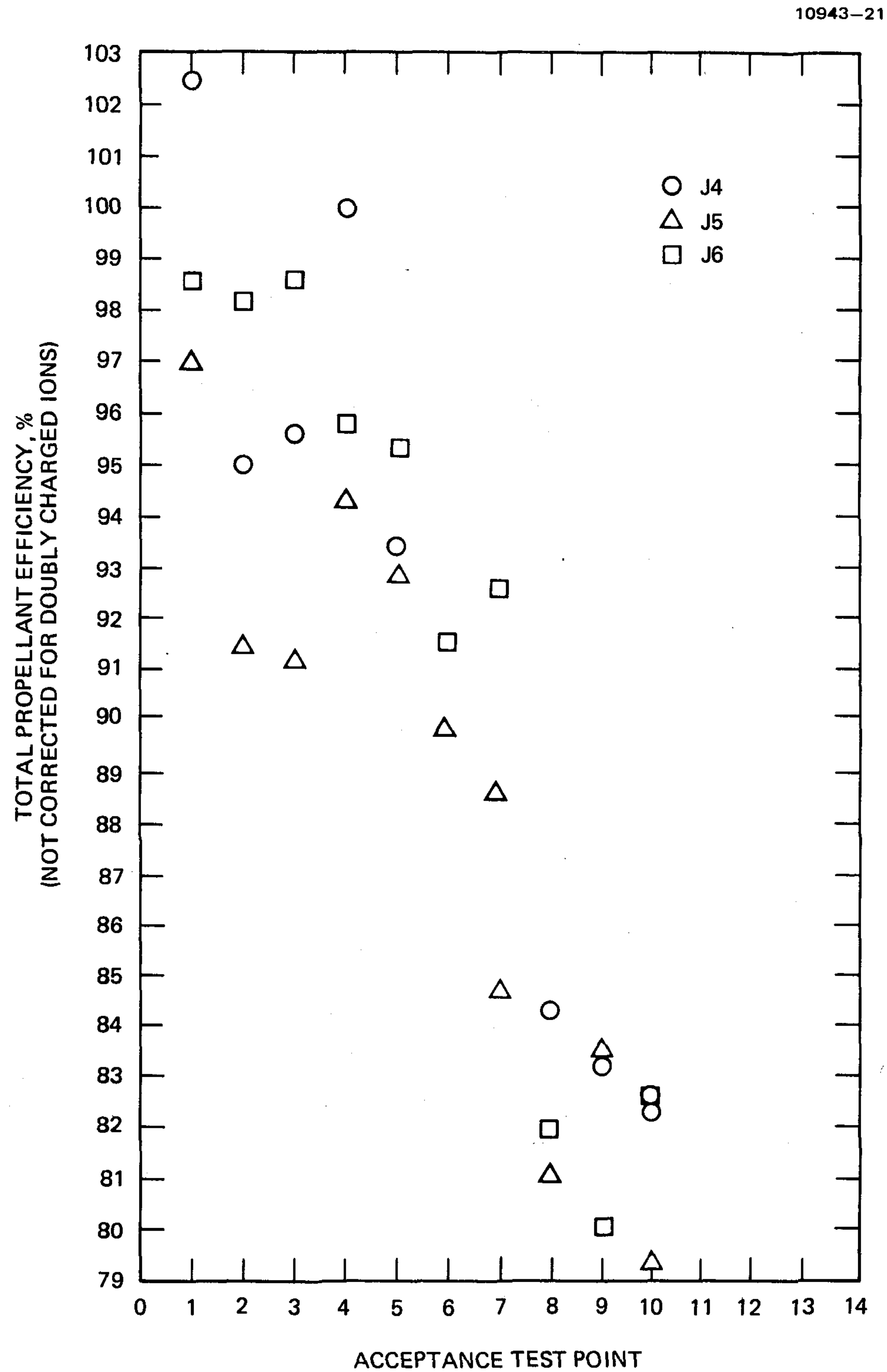

Figure 18. Comparison of the propellant efficiencies measured at each of the acceptance test points for thrusters SNJ4, J5, and J6.

It is likely that Figure 18 displays only measurement error, while the variations seen in Figure 19 may, in fact, be real differences between thrusters.

Some measurement error may still be present, however, since it was determined during thruster testing at NASA LeRC (see Appendix B), and then at HRL in testing of thruster SN J7, that the time required for the propellant system to reach thermal equilibrium is on the order of three hours. This was indicated by the variation of propellant efficiency and manifold temperature with time after the thruster was turned on (see Figure 20). This means that the thruster must be operated at the point under test for a minimum of three hours before propellant flow data is recorded, at least for startup from a cold start. It is not known whether this is adequate for all initial conditions or test facilities, or whether it is necessary to monitor the temperature stability of more of the propellant system components.

Variation in performance between thrusters on the order of ±1% would not be unreasonable since there has been no effort directed towards identifying critical tolerances of thruster dimensions or magnetic field strength that correlate with performance variations. The axial component of magnetic induction measured on the centerline, for example, varies from a minimum value of 58 gauss (thruster SN J8) to a maximum value of 66 gauss (thruster SN J9), with values for other thrusters distributed rather uniformly between these limits (variation ±6%). Based on Figure 19, this variation does not appear to result in significant performance variation; however, this is only one of many possible observations.

C. ACCEPTANCE TEST RESULTS

As a part of the acceptance test for each of the thrusters (SN J2 through SN J7) that were retrofit under this program, the data was reduced and a detailed report was delivered to the NASA program manager. These reports are available through the NASA Lewis Research Center. The symbols, definitions and equations used for describing and processing thruster data are provided

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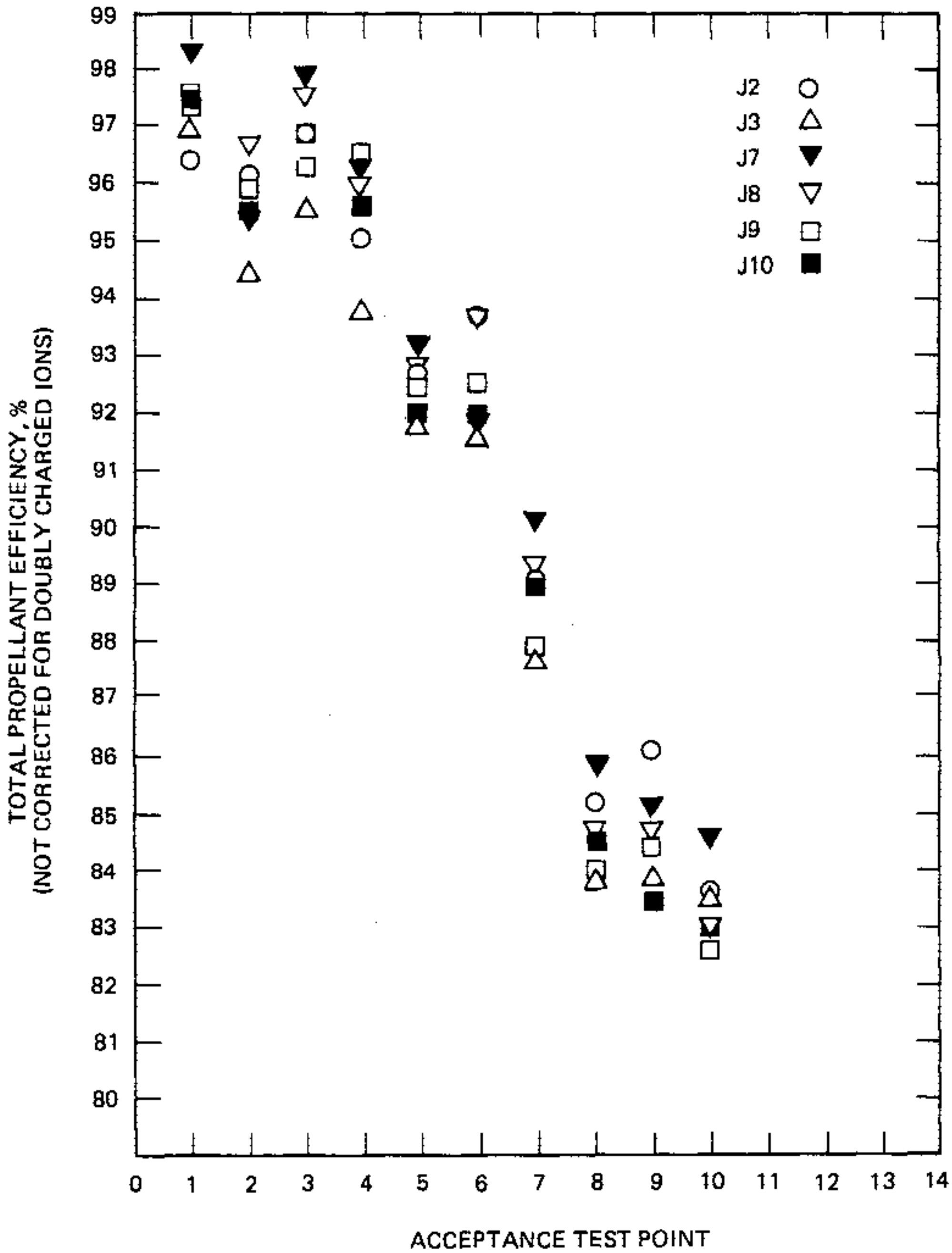

Figure 19. Comparison of the propellant efficiencies measured at each of the acceptance test points for thrusters SN J2, J3, J7, J8, J9, and J10.

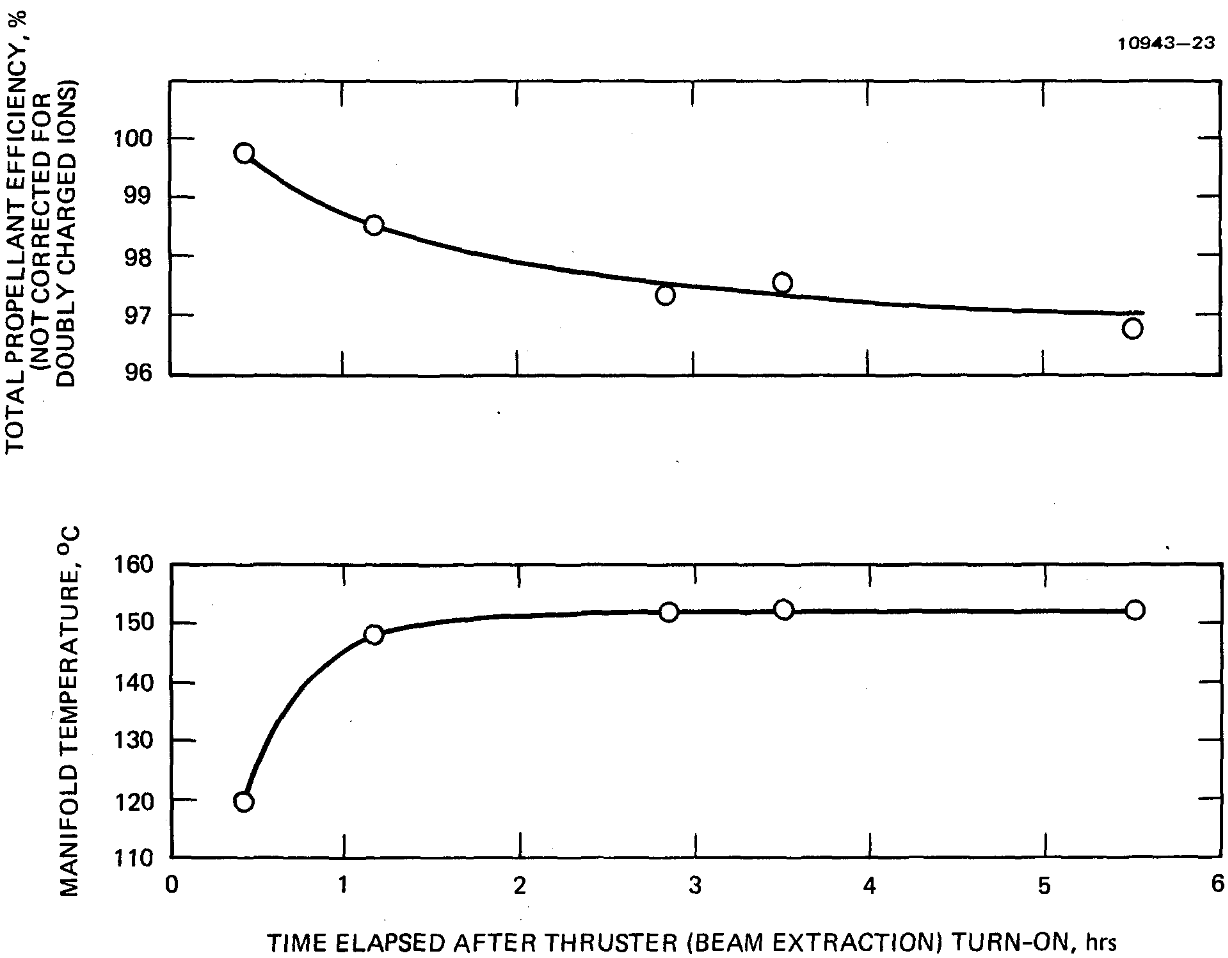

Figure 20. Variation of propellant efficiency and manifold temperature as a function of time after thruster turn on.

in Appendix C with a summary of the more important acceptance test data for each thruster. A short discussion of these data is presented in this section.

The most important characteristics of the thruster from the viewpoint of the thrust system designer are the power input required (P_T), the thrust produced (F), and the effective specific impulse (I_{sp}). These characteristics are shown for the principal operating points in Table 10 (as defined by ion beam voltage, V_b, and ion beam current, J_b). Since the control of the J-series thruster is based on beam voltage and beam current, Table 10 provides a calibration for the thruster tested with regard to the performance that can be anticipated. Some variations would be expected, based on the error in propellant measurement contained in most of these data (discussed in the preceding section). Although the statistical sampling is too small to provide any validity to the averages shown, they should be useful as representative values. It should also be noted that propellant efficiencies measured at NASA LeRC have consistently been 1 to 2% lower than those measured at Hughes. Consequently the values of η_T and I_{sp} shown in Table 10 should be considered optimistic (at least until the remaining source of error can be identified).

Two other important thruster "calibrations" are the reference values for the magnetic baffle current (J_{MB}) and the neutralizer keeper voltage (V_{NK}) as functions of beam current. Figure 21 shows the values of magnetic baffle current determined as "optimum" by the acceptance test procedure (including two points repeated at NASA LeRC).[7] The dashed line indicates a best fit to the data shown that could be acceptable for determining the reference value of magnetic baffle current at any given beam current without appreciable loss of stability or change in propellant flows. However, it would have to be verified experimentally that stable thruster operation would result from using the best fit value of magnetic baffle current for a specific thruster.

Figure 22 shows the neutralizer voltage reference values for each thruster that were determined by the acceptance test procedures. Again, the dashed curve represents a best fit of the data; however, this curve is of value only as a tool in estimating or modeling thruster performance. The neutralizer

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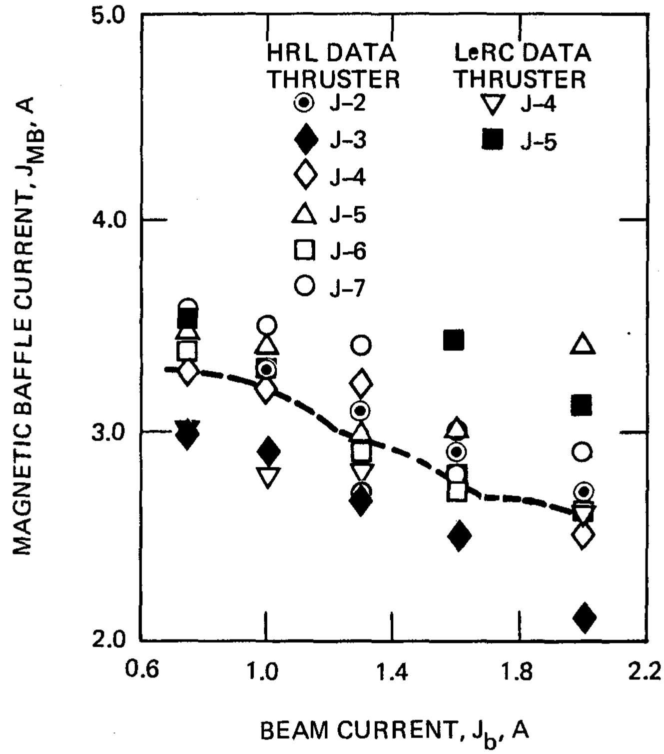

Figure 21. Selected magnetic baffle currents.

10943–2

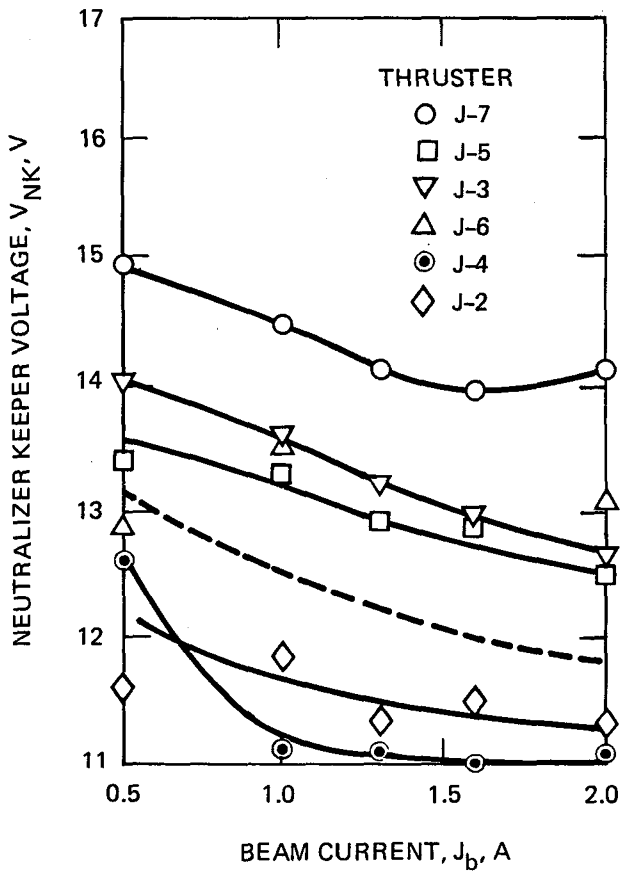

Figure 22. Neutralizer keeper voltage as a function of beam current.

Table 10. Summary of J-Series Thruster Performance Characteristics

Thruster	Performance Characteristics							
S/N	V_b, V	J_b, A	P_T, W	α (1)	F_T (2)	η_T, %	F, mN	I_{SP}, sec
2	1100	2.0	2647	0.977	0.988	74.6	130.5	3091
3	↓	↓	2661	0.966	0.986	73.1	129.3	3066
4	↓	↓	2663	0.964	0.982	72.2	128.5	3049
5	↓	↓	2626	0.967	0.982	72.5	127.7	3043
6	↓	↓	2658	0.982	0.986	77.0	131.3	3179
7	↓	↓	2664	0.958	0.989	73.1	128.5	3094
Average	↓	↓	2653	0.969	0.986	73.7	129.3	3087
2	920	1.6	1874	0.985	0.988	71.7	96.8	2833
3	↓	↓	1877	0.975	0.987	69.2	96.3	2771
4	↓	↓	1890	0.972	0.977	68.1	95.1	2764
5	↓	↓	1889	0.945	0.983	65.0	93.0	2695
6	↓	↓	1861	0.972	0.986	70.9	96.6	2824
7	↓	↓	1890	0.972	0.985	73.3	95.8	2828
Average	↓	↓	1880	0.970	0.984	69.7	95.6	2786
2	820	1.3	1397	0.991	0.989	68.7	74.5	2630
3	↓	↓	1394	0.978	0.986	64.8	72.9	2531
4	↓	↓	1406	0.978	0.978	67.6	72.6	2510
5	↓	↓	1398	0.967	0.982	61.9	72.2	2447
6	↓	↓	1394	0.976	0.985	64.7	73.0	2511
7	↓	↓	1399	0.973	0.983	63.6	72.4	2510
Average	↓	↓	1398	0.977	0.984	65.2	72.9	2523
2	700	1.0	982	0.995	0.988	61.4	53.0	2320
3	↓	↓	980	0.984	0.984	58.4	52.0	2249
4	↓	↓	978	0.983	0.977	59.6	51.7	2251
5	↓	↓	977	0.97	0.982	55.3	51.5	2142
6	↓	↓	978	0.988	0.984	62.8	52.6	2390
7	↓	↓	982	0.98	0.986	59.9	52.0	2306
Average	↓	↓	980	0.983	0.984	59.6	52.1	2276
2	600	0.75	692	0.999	0.988	54.7	37.1	2085
3	↓	↓	691	0.99	0.98	51.3	36.3	1993
4	↓	↓	681	0.99	0.977	50.7	35.6	1941
5	↓	↓	696	0.98	0.983	50.3	36.16	1977
6	↓	↓	691	0.99	0.984	50.2	36.7	1926
7	↓	↓	694	0.99	0.99	52.7	36.7	2035
Average	↓	↓	691	0.992	0.984	51.6	36.4	1992

(1) α is the correction factor for contributions of doubly charged ions to J_b.

(2) F_T is the correction factor for non-axial velocity components of beam ions.

for thruster SN J7, for example, cannot operate stably at a value of V_{NK} on the best fit line since the minimum point of its characteristics (V_{NK} vs T_{NV}) are only slightly less than the values determined by the "best fit" line (in voltage, see Appendix C). Consequently, the dispersion displayed in the data shown in Figure 22 demonstrates the need for individual thruster calibration and the provision in the power processor for accommodating these differences.

The conclusions that can be drawn from the acceptance test data for the retrofit thrusters are as follows:

- There is relatively little dispersion in the important performance measures, even though the test procedures and quality control measures used were undergoing refinement throughout the retrofit activity.
- All of the thrusters can be operated stably by the same power processor by programming a few of the control references.

SECTION 4

DOCUMENTATION

The documentation discussed in this section is the collection of engineering drawings and inspection and process documents (IPDs) used for fabrication of the 30-cm J-series thruster. The design of the J-series thruster, as determined by these documents was reviewed, modified, and considered to be complete and final under the Retrofit and Verification Test contract (NAS 3-21052). There were approximately 200 drawings and 40 IPDs that described the thruster design in somewhat more detail than required by the DOD-D-1000, level 1 standard. However, in the formal terminology of Configuration Management, the design documentation was incomplete for establishing "configuration identification" and a detailed "end item" specification. The work performed under this program upgraded and augmented the existing documents to improve the "technology readiness" status for a more formal configuration management and document control program.

A. INITIAL REVIEW

With the completion of the documentation update to include the retrofit modifications designed under contract NAS 3-21052, the completeness of the drawings and IPDs for the J-series thruster was considered adequate for the status of the thruster development at that time. It was soon learned that further design modifications (primarily in the vaporizer and ion optics assemblies) would be necessary to meet the objectives of the thruster retrofit. Consequently, a new task was added to this program to incorporate into the drawings and IPDs the changes that were required to correct the deficiencies in the thruster design that had been observed in verification and acceptance tests. This work was completed and the drawing and IPD package was placed under control of the HRL document control organization. A formalized procedure was established for providing further engineering changes, subject to Hughes and NASA review and approval. Shortly after the documentation package had been completed and placed under drawing control, closer scrutiny by both Hughes and NASA personnel began to uncover relatively minor, but significant errors of omission, inconsistencies between drawings, and inadequacies in the cross-referenced parts list. The discrepancies noted were of the following general types:

- omission of some critical dimensions or tolerances
- omission of IPD references
- omission of process specifications
- inconsistency of dimensions or tolerances
- incorrect dimensions, callouts, or tolerances
- inadequate criteria for inspection
- confusing or ambiguous instructions
- incorrect sequence of operations

In the end, 89 engineering change requests (ECRs) were written and processed, with 85 being resolved and completed, and four rejected for lack of data to formulate the missing specifications in a meaningful way (so that specifications could be met without radically changing the way in which HRL previously has built or procured thruster parts). The type of specifications that require a more definitive formulation cover the general areas of

- welding (electron beam and TIG)
- materials (impregnated porous tungsten, tantalum, etc.)
- purchased parts (heaters, etc.)

Adequate treatment of these areas could not be performed within the scope of the resources allotted to this task.

To provide a guide to the documentation available for the 30-cm J-series thruster, the final indentured parts list has been included in this report as Appendix E. The completeness of the documentation for the 30-cm, J-series thruster as represented by this parts list now satisfies the requirements of the DOD-D-1000, level 2 standard. Consequently, the objectives of the documentation task are considered to be satisfied.

SECTION 5

CONCLUSIONS

Under this program, six 900 series, 30-cm mercury ion thrusters were modified to the J-series design and evaluated using standardized test procedures. The performance of the retrofit thrusters now meets the design objectives with regard to operating characteristics, electrical efficiency, and mass efficiency. On the basis of preliminary test results (obtained under other programs) it can be inferred that the design objectives for all other thruster properties (not evaluated under this program) will also be satisfied by the thruster design. In order to complete the retrofit modifications and satisfy the evaluation tests, it was necessary to advance the status of several technology areas. First, the design of the ion optics assembly was improved to provide dimensional stability under normal thermal conditions. Second, the porous tungsten vaporizer design was improved to eliminate vaporizer failures (by penetration of the mercury propellant). Third, quality control measures were instituted to improve fabrication of swaged heaters for cathodes and vaporizers. Finally, the procedures for preparation and testing of thrusters were improved to reduce inherent measurement error.

The test data for the six thrusters shows relatively little dispersion, considering that the improvements in fabrication and testing procedures were cumulative throughout the program. If the fabrication and testing uncertainties were factored out, the performance variations would be less than ±2%. Moreover, the thrusters could all be operated with a single power processor, and within a "normal" range of control parameters.

The drawings and IPDs for fabricating thrusters of the J-series design are now quite adequate for reproduction of J-series thrusters by any industrial organization having the appropriate fabrication and assembly skills, and some understanding of ion thruster operating principles. The completeness of the documentation for a formal "configuration management" program is subject to question.

Not all of the initial design objectives were met during the program. The vaporizer design that evolved resulted in characteristics for vaporizer temperature versus propellant-flow that require operation at a temperature approximately 50^{o}C higher than was considered desirable at the outset of the program. If it is necessary to operate the thruster in a higher temperature environment than anticipated (e.g., for a Comet Encke redezvous), the vaporizer design may, in fact, be satisfactory. The adequacy and finality of the J-series design will therefore depend on future definitions of systems requirements and the results of the continuing verification and life tests (under other programs).

REFERENCES

1. C. R. Dulgeroff and R. L. Poeschel, "Retrofit and Verification Test of 30 cm Ion Thruster", NASA CR165233, January, 1981.

2. C. R. Collett, R. L. Poeschel, and S. Kami, "Characteristics of the LeRC/Hughes J-Series 30-cm Engineering Model Thruster", AIAA Paper, 79, 2077 (November 1979).

3. V. K. Rawlin, "Sensitivity of 30-cm Mercury Bombardment Ion Thruster Characteristics to Accelerator Grid Design", NASA TM 78861, 1978.

4. R. P. Vahrenkamp, "Characteristics of a Thruster Operated With Small Hole Accelerator Grid Ion Optics", AIAA Paper 76, 1030 (November, 1976).

5. R. L. Poeschel and J. R. Beattie, "Primary Electric Propulsion Technology Study", NASA CR 159688 (November, 1979).

6. R. L. Poeschel, J. R. Beattie, P. A. Robinson and J. W. Ward, "30-cm Mercury Ion Thruster Technology", AIAA Paper 79, 2052 (Princeton, N.J. November, 1979).

7. J. E. Maloy, R. L. Poeschel, and C. R. Dulgeroff, "Characteristics of 30-cm Mercury Ion Thrusters", NASA TM 81706, (April, 1981).

APPENDIX A

MODIFICATIONS FOR UPGRADING 900 SERIES 30 CM THRUSTERS TO THE J-SERIES THRUSTER DESIGN

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MODIFICATIONS FOR UPGRADING 900 SERIES 30 CM THRUSTERS TO THE J-SERIES THRUSTER DESIGN

The design of the 900 series 30-cm thruster was reviewed under NASA 3-21052, and 20 design modifications were identified to correct failure modes that had either been identified in design validation testing or were considered potential failures. These modifications were implemented in thruster SN 901 to obtain the first of the J-series thrusters (SN J1). A discussion of these design modifications follows.

Screen Grid

Based on the erosion rate of the screen grid during a 4000-hour endurance test, the projected lifetime of the screen grid was estimated to be less than 10,000 hours. Since the design goal for the thruster lifetime is 15,000 hours, it was imperative that a corrective measure be taken. The action taken was to alter the accelerator grid design. Lewis Research Center (LeRC) and Hughes Research Laboratories (HRL) technology programs showed that a low transmission (less than 30%) accelerator grid permits a lowering of discharge chamber voltage without a loss in thruster efficiency. A lower discharge voltage reduces the fraction of doubly charged ions that are produced in the chamber; therefore, the lower energy and fewer doubly charged ions reduces the screen grid wear. The recommended change was to decrease the diameter of the apertures in the accelerator grid from 0.152 cm (0.060 in.) to 0.114 cm (0.045 in.). More will be said later about a modification to the accelerator support brought about by this change.

Insulation of Wire Near Cathode Polepiece

Teflon/Kapton insulated leads connected to the cathode heater, magnetic baffle coil, and cathode keeper pass through the region around the cathode polepiece. Operating temperatures of 300°C caused the insulation to loosen, which could permit a short between the leads and surfaces at different potentials. In fact, this happened to the cathode keeper lead during the endurance test after 4000 hours of operation. To prevent this from occurring, a change in the insulation in the hot region was proposed. Ceramic beads were suggested as replacements, as shown in Figure A-1. The insulation was to remain the same in the cooler regions.

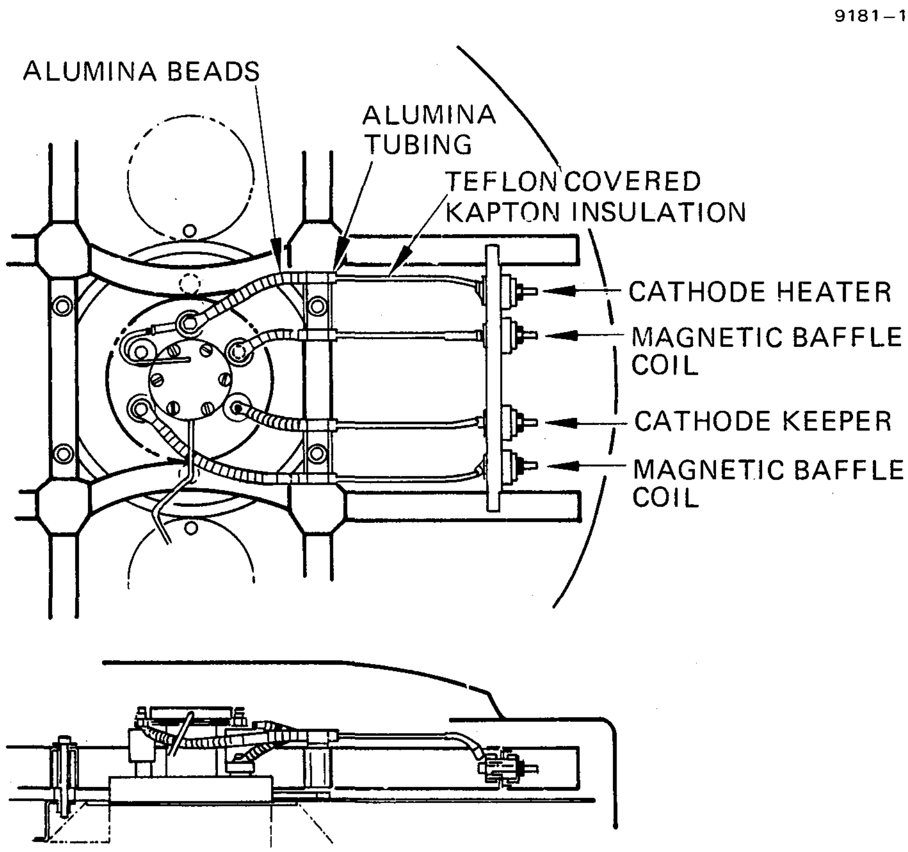


Figure A-1. Modification in wiring to eliminate Teflon/Kapton insulation in proximity to the cathode pole piece.

Cathode Polepiece Wire Mesh Covering

Wire mesh is used to cover surfaces where sputter deposition is anticipated. The mesh inhibits spalling by providing an irregular curved surface for the deposition. In spite of this, large flakes were observed in the interior of the cathode polepiece during an examination following 4000 hours of testing. Tests at LeRC showed that a better choice for mesh size would be a 0.018 cm (0.007 in.) spacing between 0.009 cm (0.0035 in.) diameter wires. This wire size was proposed as a replacement for the original mesh.

Gimbal Bracket Insulators

Two gimbal pads are used to support the thruster. Both are diametrically opposite each other on the outer cylindrical surface of the thruster and are supported by ceramic insulators. Some of these insulators fractured during a vibration test. For this reason, replacement with insulators made of Vespel have been suggested. The Vespel insulator design includes threaded steel inserts, and a temperature limit of 300°C, which would be acceptable since the insulator temperature is not expected to exceed 200°C.

The following are lesser modifications that were also proposed and have been accepted.

Anode

Stainless steel wire mesh was attached to the inner surface of the anode in several places. The purpose of the mesh was to minimize the formation of flakes. Unfortunately, the method of attachment permitted the mesh to lift away from the anode surface. The proposed modification was to use anode material that had the mesh bonded to it.

Baffle Support and Magnetic Coil

The end of the tubular baffle support has openings that permit electrons to pass from the cathode past the baffle into the discharge chamber. The material next to these openings is covered with tantalum foil. This foil interfered with the magnetic coil when it was installed on the support tube. The proposed design increases the magnetic coil diameter and the diameter of the part of the baffle support used to mount the coil. The dimensions of the openings in the end of the baffle support would remain the same.

Cathode Inserts

Tantalum wires were used to attach the porous tungsten inserts to the cathode tube. These wires frequently became brittle and broke during assembly. Rhenium wire was suggested as replacement to decrease the chance of failure.

Neutralizer Erosion Shields

Examination after the 4000-hour test revealed erosion in the neutralizer assembly. An extension of the neutralizer erosion shield was suggested to protect this area.

Wiring Harness

An increase of the harness wire length (to 3.65 m) was proposed to accommodate the interface requirements for thruster testing. A Hughes specification for lead wire was also proposed for wire purchases.

Anode Insulator

Since Lucalox is no longer available, HRL proposed that the anode support insulator be changed to alumina (AL 300).

Vaporizer

Variation in vaporizer behavior was observed in several instances. In order to obtain more uniform vaporizer material, a new specification was proposed. Detailed fabrication instructions were also suggested to be incorporated into the design package.

Neutralizer Fasteners

Neutralizer fasteners were located in places that were close to insulated wire leads. Using excessive torque on these fasteners resulted in damage to the insulation in some cases. This damage was difficult to prevent and detect. The relocation of these fasteners was proposed to avoid the problem.

Wire Harness Clamp

The Mycroy harness clamp broke several times during assembly. The design change proposed that the material be changed to machinable ceramic.

Insulator Shield

Cup shields are used to protect insulators from material deposits. Misalignment of the shields could occur easily creating a short. A self-centering design for the shields was proposed.

Gimbal Pad

Tolerance buildup could create an extremely small clearance between the gimbal pad (at spacecraft potential) and the accelerator grid mounting (at screen potential). This required a custom fit to avoid arcing. A change in the pad dimension was suggested to eliminate this special handling during assembly.

Backplate Structure Base

The backplate was fitted to the backplate structural brace with shims. This procedure was time consuming and inaccurate. The design proposed incorporates spacers that are fitted by custom machining.

Cathode Isolator Heater

Identical main and cathode isolator heaters were fabricated, but the heater used on the cathode isolator had to be partially uncoiled when assembled. This bending of an active part of the heater was undesirable. A request to change the design of the cathode isolator heater to its final configuration was made.

Ground Screen

Once a thruster was attached to the gimbal pads, access to the wiring terminals or inspection of some thruster components required that the thruster be removed from the mount and the neutralizer assembly detached from the ground screen. The proposed design altered the ground screen so that it could be removed without disturbing the neutralizer or the mount.

Propellant Manifold

Performance testing requires individual monitoring of mercury flow to the three vaporizers. This meant that propellant line connections had to be made within the ground screen and required undesirable manipulation of the propellant lines. A manifold was proposed that would be located at the rear of the thruster for acess to the feed lines for the three vaporizers, and that could be used for either single or multiple mercury lines.

Coaxial Heater Terminal

Coaxial heaters are used on the vaporizers and cathodes. The terminals are complex, fragile, and difficult to fabricate. It was proposed to use the simpler terminal that is employed on the 8-cm thruster.

Two additional modifications were proposed and rejected. They dealt with the backplate wire mesh specification and the isolator heaters. It was determined at the design review that there was not a good justification for the proposed changes and they were dropped.

Only fifteen of the design modifications listed and described in the paragraphs above were approved for retrofitting existing thrusters. The modifications incorporated were those affecting the following components or subassemblies:

1. Ion optics electrodes (accelerator aperture diameter)
2. Cathode pole-piece subassembly (wire mesh coverings)
3. Anode (bonded wire mesh)
4. Gimbal pad mounting insulators (Vespel)
5. Porous tungsten cathode inserts (lead attachment)

6. Neutralizer erosion shields (change in area)
7. Wiring harness (wire size and lengths)
8. Anode insulators (alumina)
9. Neutralizer housing subassembly (dimensions)
10. Wire harness clamp (material)
11. Insulator shields (self-centering)
12. Ion optics assembly mounting ring (fastener recess)
13. Backplate structural brace (custom spacers)
14. Outer ground screen (improve fit)
15. Propellant line manifold (test interface).

APPENDIX B
NASA DOCUMENTS

Appendix B

NASA Documents

This appendix is comprised of internal NASA documents that were supplied for reference under Contract NAS 3-21357. The work described in these documents was essential to the conduct of the work performed under this contract.

THRUSTER REQUIREMENTS DOCUMENT

Prepared by: Robert T. Bechtel ____________________ Date 2/12/80

R. T. Bechtel

NASA - Lewis Research Center

1.0 SCOPE

This document identifies the electrical power and control capabilities required to operate a J-series 30-cm thruster according to the algorithms of Refs. 1 and 2 and Section 7.0.

2.0 DEFINITION OF TERMS

2.1 Load resistance is measured at the heater terminal and does not include cable, connectors, or instrumentation impedances (standard thruster is supplied with 12 foot harness per Table I).

2.2 Operating points are the independently selectable current or voltage values required for thruster operation.

2.3 Regulation and low frequency ripple includes all line, load, and thermal variations; accuracy and repeatability of operating point selection; and any low frequency (<100Hz) oscillations.

2.4 High frequency ripple includes all oscillations and variations >100Hz.

2.5 Symbols are defined in Table II.

3.0 The following algorithms are considered as part of this thruster design.

3.1 Pre-condition

3.2 Start-up

3.2.1 Preheat High (PHT Hi)
3.2.2 Preheat Low (PHT Lo)
3.2.3 Ignition Heat (IG/HT)
3.2.4 Run (Normal) - including throttle

3.3 All off-normal detection and correction algorithms.

3.4 The recycle sequence algorithm (see 7.0 below).

3.5 Algorithms of 3.1, 3.2, and 3.3 are detailed in Ref. 2.

4.0 THRUSTER LOADS

The thruster consists of 12 loads consisting of 6 heaters, 1 electromagnet, 3 discharges, the beam and the accelerator grid.

4.1 The 12 thruster loads are listed below:

4.1.1 Main Vaporizer Heater
4.1.2 Cathode Vaporizer Heater
4.1.3 Neutralizer Vaporizer Heater
4.1.4 Cathode Tip Heater
4.1.5 Neutralizer Tip Heater
4.1.6 Isolator Heater (2 in parallel)
4.1.7 Neutralizer Keeper Discharge
4.1.8 Cathode Keeper Discharge
4.1.9 Main Discharge
4.1.10 Magnetic Baffle Coil
4.1.11 Beam Extraction (Screen Grid)
4.1.12 Accelerator Grid

4.2 The electrical requirements of each load are given below and in Table III.

<u>4.2.1 Main Vaporizer</u>

Load Resistance	6.3 Ω nom. 6.8 Ω max.
Operating Points	Continuously variable from 0 to 14.2W ± 1W vaporizer heater power to maintain J_B constant to within ± .03A (0 to 1.5A rms or DC)
	J_B Set Points 0.75A 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Reg. and L. F. Ripple	No Spec.
H. F. Ripple	No Spec.

4.2.2 Cathode Vaporizer

Load Resistance	3.3Ω nom. 3.6Ω max.
Operating Points:	Continuously Variable from 0 to 13.2W ± 1W vaporizer heater power to maintain ΔV_I constant to within ± .05V (0 to 2A rms or DC) ΔV_I Set Points (at load) 32 V 34 V 36 V
Reg. and L. F. Ripple	No Spec.
H. F. Ripple	No Spec.

4.2.3 Neutralizer Vaporizer

Load Resistance	3.3Ω nom. 3.6Ω max.
Operating Points:	Continuously variable from 0 to 13.2W ± 1W vaporizer heater power to maintain V_{NK} constant to within ± .2V V_{NK} Set Points (at thruster) 17.0 V 14.0 16.0 13.5 15.0 13.0 14.0 12.5
Reg. and L. F. Ripple	No. Spec.
H. F. Ripple	No. Spec.

4.2.4 Cathode Tip Heater

Load Resistance:	3.0Ω (hot) nom. 3.3Ω (hot) max.
Operating Points:	18.8 watt (2.5A rms or DC) 54.2 watt (4.25A rms or DC)
Reg. and L. F. Ripple	± 1 watt (± approx. .05A)
H. F. Ripple	± 10%

4.2.5 Neutralizer Tip Heater

Load Resistance:	3.0Ω (hot) nom. 3.3Ω (hot) max.
Operating Points:	18.8W (2.5A rms or DC) 48.0W (4.0A rms or DC)
Reg. and L. F. Ripple	± 1W (± approx. 0.05A)
H. F. Ripple	± 10%

4.2.6 Isolator Heater

Load Resistance:	2.2Ω nom. 2.5Ω max. (main and cathode in parallel)
Operating Point:	108W (7A rms or DC) 55W (5A rms or DC)
Reg. and L. F. Ripple	± 5% (± approx. 0.03A)
H. F. Ripple	± 10%

4.2.7 Neutralizer Keeper (Low Voltage)

Volt/Amp Requirements	$\geq$ 25V @ 0.025A $\geq$ 22V @ 2.4A
Operating Points	2.1A 2.4A
Reg. & L. F. Ripple	$\pm$ 0.05A
H. F. Ripple (> 100Hz)	$\pm$ 5%

Output Z - Inductive, required for recycle algorithm, 7.0

Present values for power processor of Refs. 1 and 3

1.9 mhy @ full load DC
2.2 mhy @ full load DC

4.2.8 Cathode Keeper

Volt/Amp Requirements	$\geq$ 25V @ 0.025A $\geq$ 18V @ 1.0A
Operating Points	1.0A
Reg. & L. F. Ripple	$\pm$ 0.05A
H. F. Ripple (> 100 Hz)	$\pm$ 5%
Output Z	No Spec.

4.2.9 Boost Section (High Voltage for Keeper Supplies)

Volt/Amp Requirements	375 $\pm$ 25V @ 0A 28 $\pm$ 3V @ 0.025A $\pm$ 0.005A

Max. power not to exceed 3.5 watts

4.1.10 Main Discharge

Volt/Amp Requirements	50V @ 0A 45V @ 14A
Operating Points [1]	5.75A 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
Reg. & L. F. Ripple	± 0.2A
H. F. Ripple	± 5%

Output Z - Inductive, required for recycle algorithm, 7.0

Present values for power processor of Refs. 1 and 3

0.48 mhy @ full load DC
0.55 mhy @ 2A - DC

[1] Emission current (J_E) set and measured in negative output without screen current included.

4.2.11 Beam

Volt/Amp Requirements	1100V @ 0.4A 1100V @ 2.1A ≤ 1100V @ < 0.4A
Operating Points	600 650 700 750 800 850 900 950 1000 1050 1100
Reg. & L. F. Ripple(1)	± 50V
H. F. Ripple (> 100 Hz)	± 5%
Output Z, Capacitive, ≥ 1μf	(approx. 1/2 Joule storage)

4.2.12 Accelerator

Volt/Amp Requirements	300V @ 0.A 300V @ .03A 250V @ .10A
Operating Points	300V
Reg. & L. F. Ripple	± 10V
H. F. Ripple	± 5%
Output Z	Capacitive, ≥ 0.1μf

4.2.13 Mag Baffle

Load Resistance	0.2Ω nom. 0.5Ω max.
Current Operating Points	0 to 4.5A in .1A increments
Reg. & L. F. Ripple	± 0.1A
H. F. Ripple	± 5%
Output Z	No Spec.

4.3 The algorithms and phases for which each operating point is required is given below:

	Pre-Cond.	PHT Hi	PHT Lo	IG/HT	Run(Norm.)	Run(Off-Norm.)
Main Vap. (all J_B set pts.)				X	X	X
Cath. Vap. (all ΔV_I set pts.)				X	X	X
Neut. Vap. (all V_{NK} set pts.)			X	X	X	X
Cath. Tip 54.2W		X	X	X[(1)]		X[(1)]
18.8W	X					
Neut. Tip 48.0W		X	X	X[(2)]		X[(2)]
18.8W	X					
Isol. Htr. 108W		X				
55W			X			
Neut. Kpr. 2.4A			X	X	X	X
2.1A					X	X
Boost		X	X	X		X
Cath. Kpr. 1.0A				X	X	X
Boost		X	X	X		X
Discharge (all J_E set pts.)				X	X	X
Beam (all V_I set pts.)					X	X
Accelerator 300V					X	X
Mag. Baffle (all J_{MB} set pts.)				X	X	X

(1) Only if $J_E < 4A$ for 5 sec

(2) Only if $J_{NK} < .7A$ for 5 sec

5.0 CONTROL FUNCTIONS

The following control functions must be provided by the power processor or some other controller.

5.1 Sense J_E and insure that the cathode tip current is set to 0A within 5 sec after J_E exceeds 4A.

5.2 Sense J_{NK} and insure that the neutralizer tip current is set to 0A within 5 sec after J_{NK} exceeds 0.7A.

5.3 Sense J_B and J_A and initiate and control the recylcle sequence in accordance with the attached recycle algorithm. Total sequence time < 600m sec (see 7.0).

5.4 Provide continuous control of 3 vaporizer heaters as described in 4.2.

6.0 TELEMETRY

6.1 The following parameters <u>must</u> be measured and made available for algorithm decisions or thruster operational and performance evaluation:

V_I, J_B, J_A, ΔV_I, J_E, J_{MB}, V_{NK}, J_{NK}, V_{CK}, and V_G.

6.2 The following parameters are <u>useful</u> for thruster operational and performance evaluation:

J_V, J_{CV}, J_{NV}, J_{CT}, V_{CT}, J_{NT}, V_{NT}, J_{CK}, V_A, T_N, T_{CV}, and T_{NV}.

6.3 Platinum resistance vaporizer temperature sensors are provided for temperature measurement. These sensors are Nom. 200Ω @ $0^{\circ}C$ with a gain of $0.77\Omega/^{\circ}C$.

7.0 RECYCLE SEQUENCE ALGORITHM

7.1 Conditions for Initiating Sequence

$J_B > 2.1A$ and/or $J_A > 60mA$ for $>$ 70m sec.

7.2 At Sequence Time t = 0

7.2.1 Turn off screen and accel. voltages
7.2.2 Decrease J_E to $2.6A \pm 0.2A$
7.2.3 Increase J_{NK} to $2.4A \pm 0.05\ A$
7.2.4 Disable J_B, J_A Comparison Circuits

7.3 At Sequence Time t = 150m sec ± 10m sec

Turn on screen and accel. voltages to previous run values.

7.4 At Sequence Time t = 250m sec ± 20m sec

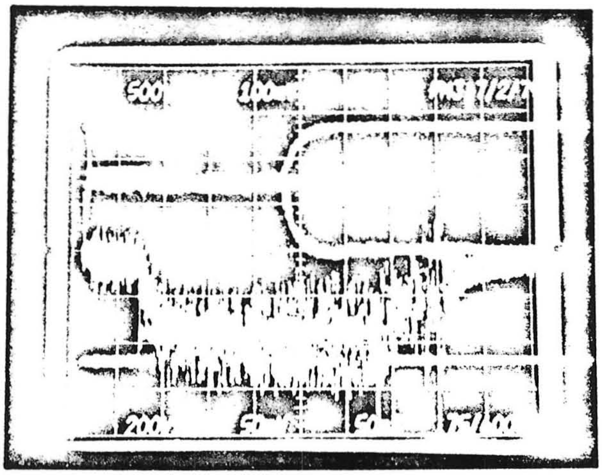
7.4.1 Reset J_E to previous run value
7.4.2 Reset J_{NK} to previous run value
7.4.3 Enable J_B, J_A comparison circuits and reset 70m sec timer to zero if necessary.

7.5 Rise and Decay Times (Typical) are as Follows:

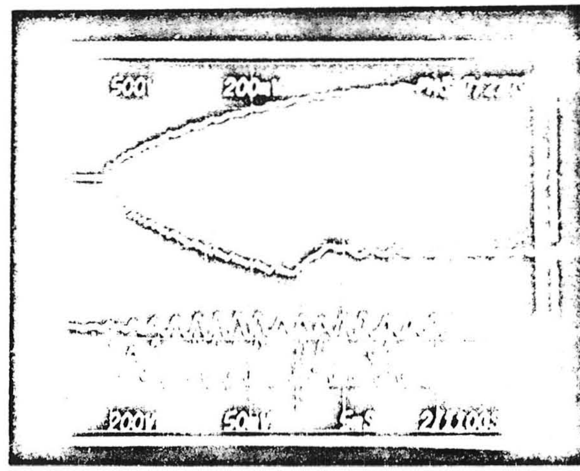
	Rise	Decay
V_S	< 30m sec	< 5m sec
V_{AS}	< 30m sec	< 5m sec
J_E	100 - 150m sec	< 50m sec
J_{NK}	< 5m sec	< 5m sec

7.6 Typical sequences are attached. Photo Set 1, 3, and 4 are for 0.75A J_B at 600V V_I; Photo Set 2, 5, 6, 7 and 8 are for 2A J_B at 1100V V_I.

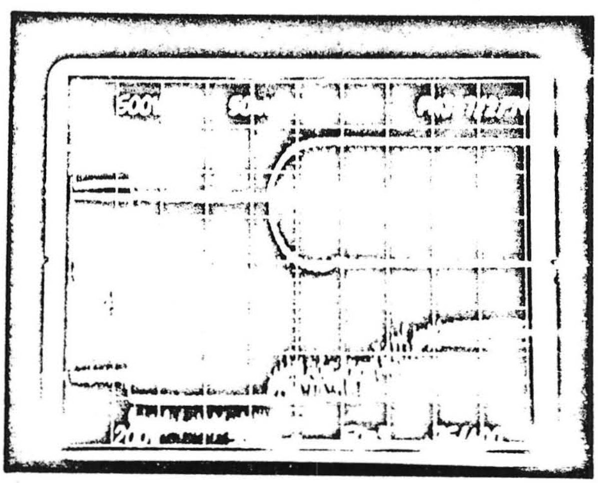
7.7 A flow chart of the algorithm is attached.



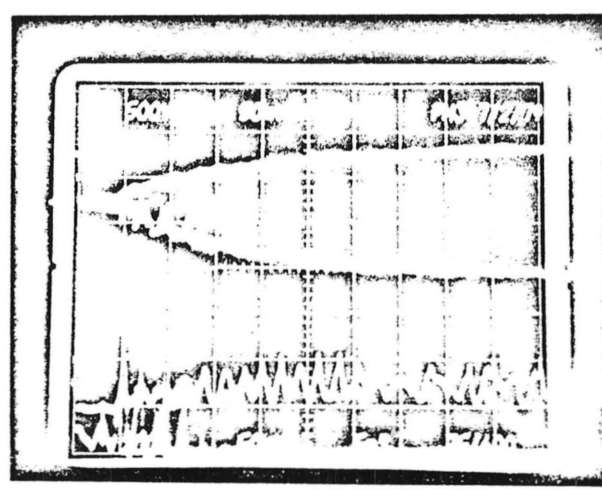
Set #1
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 J_D 4 amp/cm
#4 J_{NK} 1 amp.cm
no delay



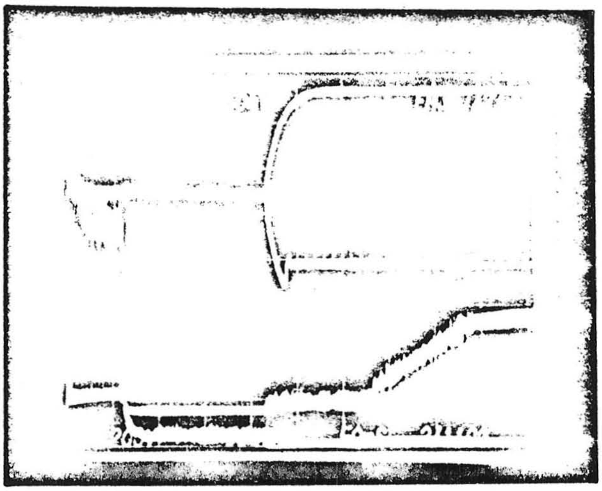
Set #2
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 J_D 4 amp/cm
#4 J_{NK} 1 amp/cm
260 msec delay



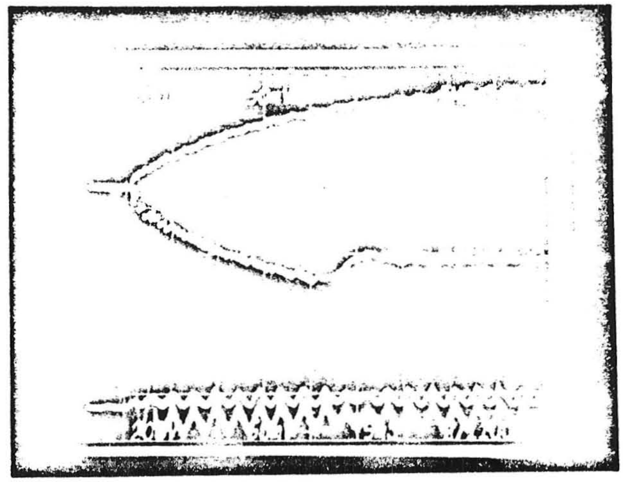
Set #3
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 I_B 0.5 amp/cm
#4 I_A 0.1 amp/cm
no delay



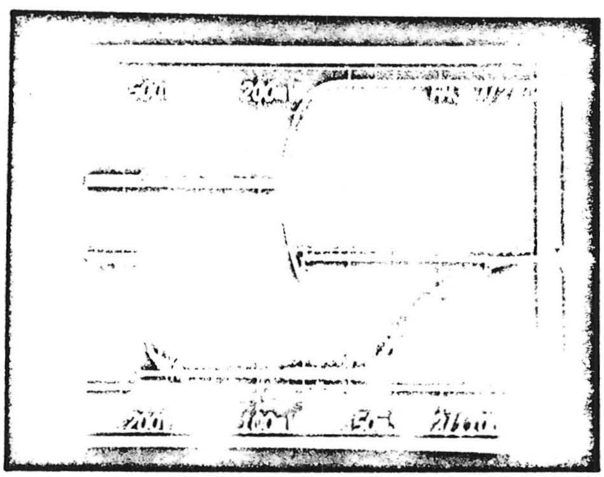
Set #4
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 I_B 0.5 amp/cm
#4 I_A 0.1 amp/cm
260 msec delay



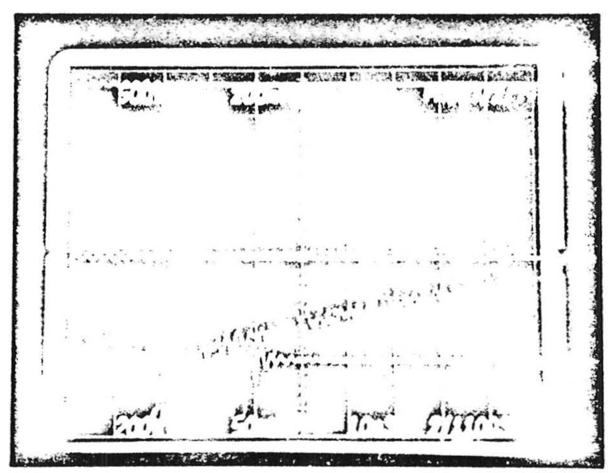
Set #5
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 I_B 1 amp/cm
#4 I_A 0.1 amp/cm
no delay



Set #6
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 I_B 1 amp/cm
#4 I_A 0.1 amp/cm
260 msec delay

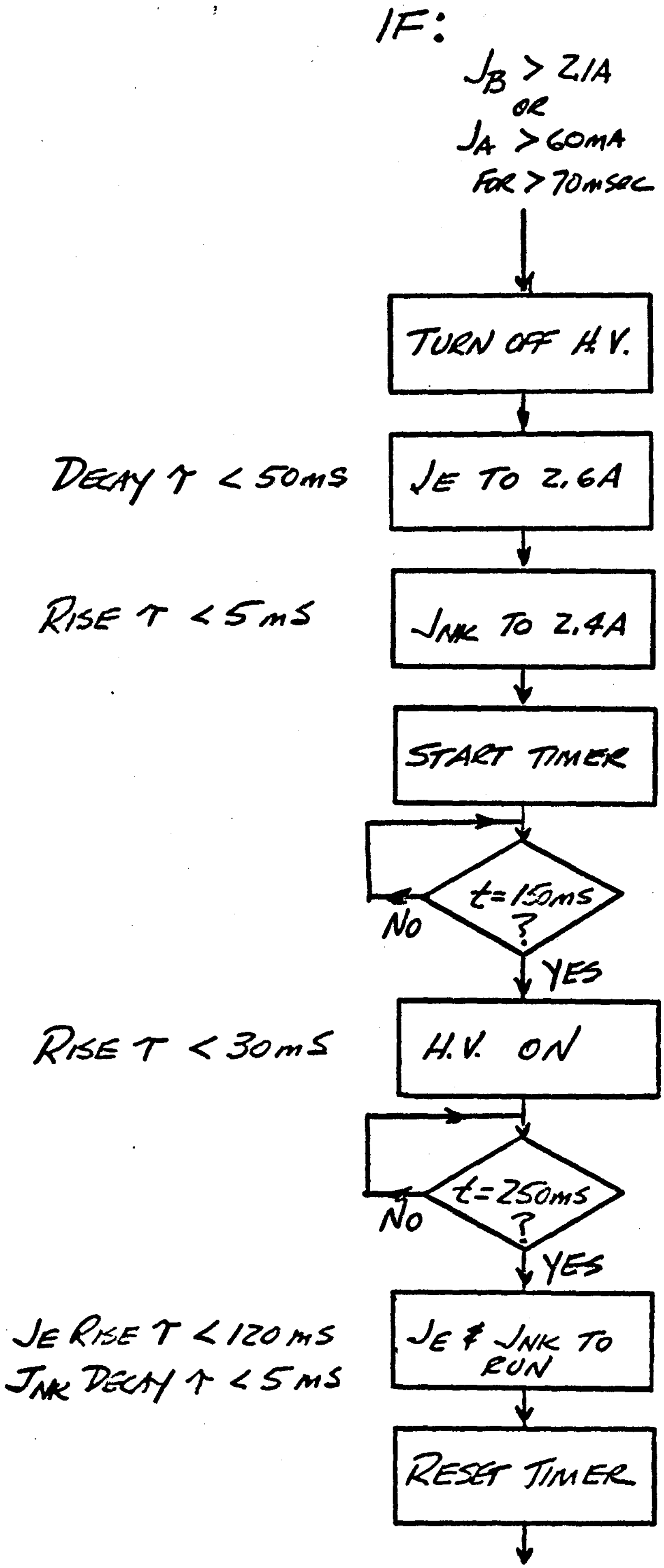


Set #7
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 J_D 4 amp/cm
#4 J_{NK} 2 amp/cm
no delay



Set #8
#1 V_I 500 v/cm
#2 V_A 200 v/cm
#3 J_D 4 amp/cm
#4 J_{NK} 1 amp/cm
300 msec delay

RECYCLE ALGORITHM



8.0 POWER REQUIREMENT MARGINS

8.1 Two potential areas of degradation which might impact power requirements exist. These are cathode degradation and beam extraction degradation. Although no evidence of either of these problems has appeared in any long term tests to date, final verification through 15,000 hours has not explicitly been achieved.

8.2 Cathode degradation could cause difficulty in starting and/or difficulty in maintaining desired emission current levels during steady state. Although neither difficulty has been encountered, present power processor designs carry a 4 to 5 watt power margin for the former and the capability of operating tip heaters during steady state operation for the later. Neither margin has been required to date in J series thruster testing.

8.3 Beam extraction degradation could require higher total extraction voltages for a given beam current. Current power processor designs carry an extra 200V margin (500V total capability) in the accelerator supply if needed. This margin has never been required to date in J series thruster testing.

TABLE I - Thruster Wire List

TERMINAL NO.	TERMINATION	AWG NO.	WIRE NO.
1	Cathode Vaporizer	16	1
2	Neutralizer Keeper	16	2
3	Neutralizer Heater	16	3
4	Neutralizer Vaporizer	16	4
5	Neutralizer Common	16,16	5A, 5B
6	Accelerator	20	6
7	Main Vaporizer	16	7
8	Main Isolator	16	8
9	Discharge (Anode)	16,16,20	9A, 9B, 9P
10	Cathode Heater	16	10
11	Cathode Keeper	20	11
12	Magnetic Baffle (Outer)	16	12
13	Cathode Isolator	16	13
14	Vaporizer Return	16	14
15	High Voltage Return	16,16,20	15A, 15B, 15P
16	Sensor Common	20	16
17	Mag Baffle (Inner)	16	17
18	Main Vaporizer Sensor	20	18
19	Cathode Vaporizer Sensor	20	19
20	Neutralizer Vaporizer Sensor	20	20
21(-) 22(+)	Main Vaporizer Thermocouple		21(-), 22(+)
23(-) 24(+)	Cathode Vaporizer Thermo-couple		23(-), 24(+)
25(-) 26(+)	Neutralizer Vaporizer Thermo-couple		25(-), 26(+)

TABLE II - Symbols

V_{CT}	Cathode Tip Heater Voltage
V_{NT}	Neutralizer Tip Heater Voltage
V_{NK}	Neutralizer Keeper Voltage
V_{CK}	Cathode Keeper Voltage
ΔV_I	Discharge Voltage
V_A	Accelerator Potential
V_I	Beam or Net Accelerating Potential
V_G	Neutralizer to Ground Coupling Voltage
J_V	Main Vaporizer Current
J_{CV}	Cathode Vaporizer Current
J_{CT}	Cathode Tip Heater Current
J_{NT}	Neutralizer Tip Heater Current
J_{NV}	Neutralizer Vaporizer Current
J_{NK}	Neutralizer Keeper Current
J_{CK}	Cathode Keeper Current
J_E	Cathode Emission Current
J_A	Accelerator Drain or Impingement Current
J_B	Beam Current
J_{MB}	Mag Baffle Current
T_V	Main Vaporizer Temperature
T_{CV}	Cathode Vaporizer Temperature
T_{NV}	Neutralizer Vaporizer Temperature

TABLE III - SUMMARY OF RESISTIVE LOADS

	Load, Ω		Electrical Req.		Type Control	Ref. Para	Reg. & L.F. LF Ripple	H.F. Ripple
	Nom.	Max.	Power, W	Current, A				
Main Vaporizer	6.3	6.8	15.2	---	Vary W/J_B	4.2.1	---	---
Cathode Vaporizer	3.3	3.6	14.2	---	Vary W/ΔV_I	4.2.2	---	---
Neutralizer Vaporizer	3.3	3.6	14.2	---	Vary W/V_{NK}	4.2.3	---	---
Cathode Tip Heater	3.0	3.3	54.2	---	Fixed	4.2.4	± 1W	± 10%
(Hot)			18.8					
Neutralizer Tip Heater	3.0	3.3	48.0	---	Fixed	4.2.5	± 1W	± 10%
(Hot)			18.8					
Isolator Heater	2.2	2.5	108	---	Fixed	4.2.6	± 5%	± 10%
			55					
Magnetic Baffle	0.2	0.5	---	4.5	Fixed in .1A Inc.	4.2.7	± .1A	± 5%

REFERENCES

Reference 1 — 30-cm Ion Thruster Subsystem Design Nominal - (Section 5) NASA TMX 79191.

Reference 2 — Bechtel R. T. and James, E. L.: Preliminary Results of the Mission Profile Life Test of a 30-cm Hg Bombardment Thruster - NASA TMX 79261, AIAA No. 79-

Reference 3 — Biess, J. J., et al., Electric Prototype Power Processor for a 30-cm Ion Thruster NASA-CR-135287, March 1977.

TRIM 104

CALIBRATION OF FLOW TUBES FOR MEASUREMENT OF THRUSTER MERCURY PROPELLANT FLOW RATES

March 24, 1980

Prepared By: R. Bechtel

NASA-Lewis Research Center

CALIBRATION OF FLOW TUBES FOR MEASUREMENT OF THRUSTER MERCURY PROPELLANT FLOW RATES

1.0 BACKGROUND

The determination of ion thruster efficiency and evaluation of performance requires accurate determination of neutral mercury propellant flowrate to determine propellant (mass) utilization efficiency. Unlike the electrical operating parameters, the measurement of Hg flow is not a straightforward one. The technique most commonly used is to measure the volume of Hg used per unit time. This can then be converted to mass per unit time and, with the assumption of a single charge per atom, to couloumbs per unit time or equivalent amperes. The ratio of the measured electrical beam current to the equivalent amperes of Hg flow, is the propellant or mass utilization efficiency.

The conversion from volume to charge is given by the equation:

$$\frac{Q}{V} = \frac{N}{M} \times Q_o \times \text{Hg}$$

N = Avogadro's number = 6.022169×10^{23} atoms/mole

M = AMU of Hg = 200.61 gm/mole

Q_o = Charge of Ion = $1.6021917 \times 10^{-19}$ couloumb

Hg = Density of Hg = 13.546 gm/cc @ 20°C

Thus:

$$\frac{Q}{V} = 6.5151723 \times 10^3 \text{ coul/cc}$$

Note that the density of Hg varies approx. .02%/°C and hence small thermal variations about ambient do not affect the calculation.

The conversion of time rate of change of volume to equivalent Amps is given by:

$$J \text{ (Eq - Amps)} = 6.515172 \times 10^3 \times \left(\frac{CC}{Sec}\right)$$

$$= 108.5862 \times \left(\frac{CC}{Min.}\right)$$

$$= 1.80977 \times \left(\frac{CC}{Hr.}\right)$$

The usual method of determining the time rate of change of volume is to measure the difference in height in a glass reservoir per unit time. In order to enhance resolution, tubes having diameters of .040" to .120" are used depending on the expected flowrates. If the glass reservoir is calibrated in CC or ml, then the conversion factors above can be applied directly. If the glass reservoir is calibrated in cm, then the bore diameter must be known. The following table shows the conversion factor for commonly used diameters bore tubes.

d (MILS)	CAL. FACTOR (EQ.-AMP / CM/MIN.)
19.68 (½mm)	0.2132
20.00	0.2201
39.00	0.8369
39.37 (1mm)	0.8528
40.00	0.8803
78.00	3.3475
78.74 (2mm)	3.4113
79.00	3.4339
80.00	3.5214
98.42 (2.5mm)	5.3302
118.11 (3mm)	7.6755
120.00	7.9231

In some instances it may be desired to confirm the bore diameters of a known tube or measure the bore diameter of an unknown tube. Several techniques are available. One is the use of precision pins which can be slipped into the bore. This technique can determine the diameter to the nearest .0001 inch. However, eccentricity over the tube length may not be confirmed by this technique. The calibration technique in this procedure consists of filling with Hg, draining, and weighing to determine the volume. Effective bore diameter can then be calculated and it does not depend on bore roundness or straightness. As a practical matter, past calibrations of many glass tubes have shown that these tubes are usually within several tenths of a mil of the manufacturer's quoted diameter.

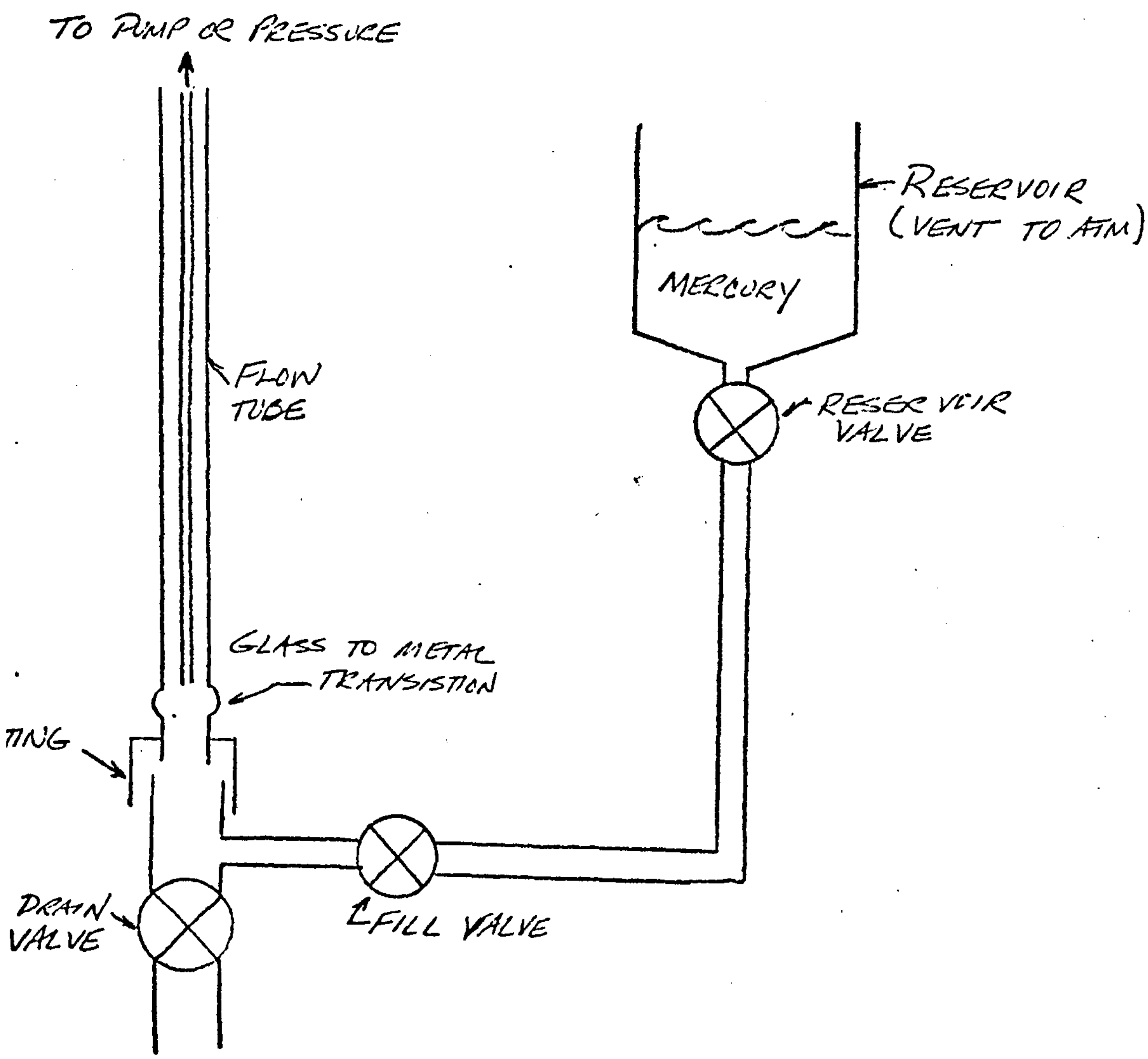
It should be noted that the accurate determinations of the calibration constant is only one factor in the accurate detrmination of the thruster flowrates. Principles of the fill procedure that follows are also applicable to filling thruster test systems when accurate flow measurements are desired

2.0 SCOPE

This paper defines a methode for calibrating mercury flow tubes by a fill, drain and weigh technique. Factors other than calibration of Hg flow tubes, which affect the accuracy of thruster flowrate measurement, are beyond the scope of this document. This method was derived for use with the apparatus described in 3.0. However, the general approach is valid for all types of calibration and feed systems.

3.0 DESCRIPTION OF CALIBRATION APPARATUS

The test setup for performing calibrations is shown in the following figure.



Most of the tubing used is 1/8 inch diameter stainless steel tubing. The number of valves and fittings used should be minimized so that trapped gas and voids in the filled system can be minimized. Voids in the system lead to erroneous results due to compressibility effects as head height changes or due to surface tension effects as varying intrusion into void volumes.

"Zero displacement" or stop-cock type valves are recommended. Circleseal series 9500 miniature plug shutoff valves have been used successfully. The drain valve should be mounted backwards to the indicated flow direction so that the plug of mercury stays in the movable part of the valve during on-off operations.

A vacuum pump capable of achieving 10 micron or better vacuums is needed.

A pressure source for pressurizing the flow tube up to 12 psig is needed.

A weighing system with 0.001 gram accuracy and resoluation is needed.

4.0 FLOW TUBE FILL PROCEDURE

1) Install flow tube in 1/4" swagelok, close drain valve.

2) If line between reservoir valve and fill valve is not filled satisfactorily, close reservoir valve and open fill valve to drain line.

   If line is filled solid to fill valve, leave fill valve closed and check to confirm reservoir valve open.

3) Connect pumping station to top of flow tube, pump to better than 10 micron vacuum. (Diffusion pump pressures are preferred.)

4) If fill valve is open, close fill valve and open reservoir valve to fill line. If fill valve is closed, continue.

5) Open fill valve slowly unitl flow is felt in line. Hg should move into glass portion of tube smoothly without bubbling.

6) Fill to high-level of tube. Record level

5.0 FLOW TUBE CALIBRATION PROCEDURE

1) Record Level at vacuum __________

2) Vent to ATM, record level __________

3) Pressurize to 10 psig, record level __________

4) Cycle all valves until cycling does not cause change in Hg level __________

5) Vent to ATM, record level __________

6) Re-pressurize to 10 psig, record level. Compression should be less than .025 cm __________

6) If compression is acceptable continue, otherwise drain and re-fill.

Record level.	a. ____________ CM
Weigh empty bottle, record.	b. ____________ GM
Drain about 1/3 of tube - record level.	c. ____________ CM
Weigh bottle, record.	d. ____________ GM
Drain another 1/3 of tube - record level.	e. ____________ CM
Weigh bottle, record.	f. ____________ GM
Drain remainder of tube - record level.	g. ____________ CM
Weigh bottle, record.	h. ____________ GM

7) Calculate the mass drained per centimeter height change on each of the three increments and also on the overall height change.

$$\Delta_1 = \frac{d-b}{a-c}\ ; \quad \Delta_2 = \frac{f-d}{c-e}\ ; \quad \Delta_3 = \frac{h-f}{e-g}\ ; \quad \Delta_T = \frac{h-b}{a-g}$$

Δ_1 = ________ gm/cm

Δ_2 = ________ gm/cm

Δ_3 = ________ gm/cm

Δ_T = ________ gm/cm

All the values calculated should be the same within experimental accuracy. It should be considerably better than one percent. If the data is not reasonable, repeat the procedure.

8) If needed, calculate the tube diameter.

$$d = \sqrt{\frac{4\Delta_T}{\pi\rho_T}}$$

at 20°C

$$d = \sqrt{9.40\Delta_T}\ , \text{ mm}$$

$$d = \sqrt{1.457\Delta_T} \times 10^2, \text{ mils}$$

Correlate this diameter with pin-measured diameter or with tubing puchase specification.

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44135

NASA

TRIM 119

Reply to Attn of: 6122

May 5, 1980

TO: Record

FROM: 6122/Manager, Solar Electric Propulsion Office

SUBJECT: Statistical Analysis of 30cm Thruster Steady State Propellant Flow Rate Data

REF: Report on Flow Tube Variation During Warm-up/Startup by C. E. Siegert

Thruster testing in the technology readiness program is designed to document performance of several thrusters. Certain data is obtained on each thruster so that thruster-to-thruster variations can be determined. It is necessary to separate data scatter from real thruster-to-thruster variations. This analysis was performed to determine how much data scatter exists in flow data being taken by the usual method.

Flow Rate Determination

Flow rates are usually determined by measuring the rate of flow tube height change. Typically, at least six data points are taken with time intervals of 5 to 10 minutes when the thruster is operating steady state. The reading time of the main flow tube is accurately timed by countdown. Cathode and neutralizer tubes are read in consistent rhythm after each main reading.

Flow tubes normally used have inside diameters of 2mm for the main vaporizer and 1mm for the cathode and neutralizer. The tubes have millimeter graduations. Readings are estimated to 0.1mm.

Flow rates are calculated from flow tube data by one of two methods. One method is to determine the height change in each interval and multiply the average height change per interval by a constant to determine flow rate for each vaporizer. Another method is to perform a straight line, least square fit of the flow tube height verses time data. The slope of the line is determined and multiplied by a constant to determine the three flow rates. Conversion factors are then used to convert flow rates to "equivalent amperes" units. Flows for the three vaporizers are then summed and compared to the actual beam current to determine efficiency.

Data Discussion

The data base for this analysis was developed during a test on April 21-24, 1980 to measure flow tube variations during thruster startup. The test was conducted by Su Gooder, Cliff Siegert and myself at Port W-1 of Tank 6 EPL. The referenced memo will summarize the results of that test. Data used in this analysis had been taken after the thrusters had reached thermal equilibrium after over night, steady state runs. Thrusters J-1 and 702 were mounted side by side in "Bimod" configuration. Once a thruster was started, it was left to run overnight. In the morning, flow data was taken. Five sets of data exist in which 10-minute flow readings were taken for 1 hour when the thrusters were known to be at equilibrium. Tables attached summarize that data for the following cases:

Table	Thruster	Beam Current	
1	J-1	.739 a	Thruster 702 was off
2	J-1	.739 a	simultaneous data (Tables 2 and 3)
3	702	.739 a	
4	J-1	2.009 a	Simultaneous data (Tables 4 and 5)
5	702	1.958 a	

CAUTION: Do not use the absolute efficiency values contained in this memo. The feed system of thruster J-1 contained too much air to produce good efficiency data. Thruster 702 magnetic baffle current was not set at the optimum value.

This analysis was undertaken to quantify the scatter that exists in the data. If one assumes that the data represents independent measurements of a constant process, standard deviations for data sets can be calculated and compared.

The flow rate measurement data sets do not precisely fit that criteria. The data points are not independent since the end time of one interval is also the start time for the next interval. An error in one measurement will affect two readings. If a single large measurement error is made, relatively large and small height change values will be adjacent. For the 90 height changes in this data set, the maximum and minimum heights were adjacent only five times. It was decided that the standard deviation could be calculated and used as an indicator of variations of the data sets.

An explanation of the entries in Tables 1 through 5 follows. The flow tube height changes for each of the three vaporizers are shown for each interval. The calibration constant for converting to equivalent milliamperes is listed for each tube. Using those calibration factors, utilization efficiencies are calculated for each of the six time intervals.

The entry labeled 10psi compression has direct bearing on the accuracy and repeatability of measurements. The flow system is pressurized to 10psi above atmospheric and the flow tube height changes are recorded. The value is indicative of the trapped air or gas in the system. As flow readings are taken, the pressure on the "bubble" drops as the head height reduces. The bubble then is continuously expanding and subtracting from the fall of the mercury column. Hence "too-low" flows are measured. Tables 1 and 3 show that J-1 had a "poor" fill and 702 had a "good" fill. One of the results of this test is to compare and document results from the two types of fill.

The statistical data in Tables 1 through 5; namely, mean, range, variation, standard deviation and 3σ apply to the six point data set above in each column. The slope and correlation coefficients also apply to the column above. The efficiency calculation in the lower right results from calculating efficiency from the individual flows determined by the slope method.

Observations and Conclusions

The following observations and conclusions resulted from this analysis.

1. Table 6 shows that efficiency readings had less variation in the 702 thruster with the "hard fill" than in the J-1 thruster with the "soft" fill. Even the best hard filled system showed efficiency varied over a range of 0.8 to 1.5 percent. Three-sigma deviation would be expected to be $\pm$1.0 to $\pm$1.7 percent for quarter power to full power operation. Precise flow readings require a "hard filled" system. It may be possible to calculate out the compressibility effects in a "soft-filled" system but that is a complicating factor and such techniques have not been developed.

   It should be pointed out that the data variation noted applies to 10-minute readings. When six such readings are averaged, the accuracy of the efficiency calculated from that mean would be better - perhaps six times better. As stated previously, the 10 minute data points are not really uncoupled since the end point of one interval is the start point for the next interval. The absolute value of the time and height reading errors are the same for a one hour reading as for each of the 10 minute intervals. The accuracy of that one hour reading (or the average of six 10 minute readings in this case) would be much more accurate and less variable than the values shown in Table 6 for 10 minute readings.

2. In Table 7 the data for the 15 flows is arranged in order of increasing standard deviation. The measurement range followed the same order. Most of the "hard" compression feed systems appear near the top of the list and "soft" compression systems appear near the bottom.

3. Table 8 shows that the "average delta" method and the "slope" method of calculation produce the same result. The small variations are probably due to roundoff in making calculations. The correlation coefficient test of the slope method is more difficult to interpret than the standard deviation test that arises from the "delta" approach.

4. Review of Tables 1 through 5 shows that cathode and neutralizer indicated flow rates had a large percentage variation. Ten minute timing intervals are not long enough to obtain definitive cathode and neutralizer data. In general, the longest practical interval time periods will produce more accurate data. Another modification to produce more accurate flow data in a shorter time would be to use smaller bore tubes. Height changes would be larger and reading errors would be a smaller fraction of the total.

5. If test objectives permit, more accurate total flow data would be obtained by taking all mercury flow from a single tube. The three flow terms would be added in the flow tube and two of the three flow error terms would vanish.

6. During the test a definite "stick-slip" tendency of mercury on the glass tube walls was noted. This adds to reading variation - especially in low-flow tubes and short time intervals. The tubes should be cleaned. A small amount of distilled water should cover the mercury in the tube to prevent oxidation of mercury that sticks to the tube walls. This technique was used in SERT II.

7. It is very difficult to estimate heights in the flow tube to one tenth of the smallest division.

   Accuracy may be improved by using height as the independent variable and time as dependent variable. Instead of taking 10 minute readings, 6 centimeter readings should be tried. The mercury height could be more accurately determined at centimeter marks on the tube. Time measurement in seconds would provide very good resolution in time intervals of about 600 seconds.

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Table 1.–Thruster J-1 Flow Data at 0.739 Amp Beam (4/22/80)

Thruster J-1
739 ma Beam

Date 4-22-80
Time $07^{12} - 08^{12}$

10 min INTERVAL	MAIN Δh (cm)	CATH Δh (cm)	Neut Δh (cm)	Effic (%)
1	2.11 ↗	1.40	.32 ↙	84.42
2	2.09	1.48 ↗	.38	83.96 ↙
3	2.05	1.37	.40	86.05
4	2.07	1.35 ↙	.40	85.53
5	2.08	1.43	.46 ↗	84.05
6	2.03 ↙	1.37	.36	87.09 ↗
CAL: Ma / cm/10min	346.4	83.97	84.09	—
10 psi Compression	2.08 cm	0.72 cm	2.99 cm	—
Mean	2.072 (717.6 Ma)	1.40 (117.5)	.387 (32.5)	85.2
range	0.08 (27.7 Ma)	0.13 (10.9)	.14 (11.8)	3.13
variation (%)	3.86	9.29	36.2	3.6
std dev	.0285 (9.8 ma)	.048 (4.0)	.047 (4.0)	1.25
3σ	.0855 (29.6 Ma)	.144 (12.1)	.141 (11.9)	3.76
Slope	2.065 (715.3 ma)	1.39 (117.1)	.405 (34.1)	85.3
Correl Coef	.9999937	.99993	.9996	

Table 2. – Thruster J-1 Flow Data at 0.739 Amp Beam (4/23/80)

Thruster J-1
739 ma Beam

DATE 4/23/80
TIME 07[15]-08[15]

10 MIN INTERVAL	MAIN Δh (CM)	CATH Δh (CM)	Neut Δh (CM)	EFFIC (%)
1	2.09	1.40 ↙	0.48 ↗	83.80
2	2.05	1.51 ↗	0.43	84.64
3	2.10 ↗	1.48	0.45	83.08 ↙
4	2.08	1.41	0.41	84.61
5	2.04 ↙	1.42	0.39 ↙	86.06 ↗
6	2.06	1.43	0.42	85.04
CAL: Ma / cm/10 MIN	346.4	83.97	84.09	
10 psi Compression	2.08 cm	0.72 cm	2.99 cm	
Mean	2.070 (717 ma)	1.442 (121.1)	.43 (36.2)	84.5
Range	.06 (20.8 ma)	.11 (9.2)	.09 (7.6)	2.98
Variation (%)	2.9	7.6	20.9	3.5
Std Dev	.0237 (8.2 ma)	.0436 (3.7)	.0316 (2.7)	1.03
3σ	.0710 (24.6 ma)	.1306 (11.0)	.0949 (8.0)	3.08
Slope	2.068 (716.4)	1.445 (121.4)	0.419 (35.2)	84.7
Correl coef	.999991	.9999157	.99975	

Table 3 .– Thruster 702 Flow Data at 0.739 Amp Beam

Thruster 702
739 ma Beam

Date 4/23/80
Time 07^{15} - 08^{15}

10 MIN INTERVAL	MAIN Δh (CM)	CATH Δh (CM)	Neut Δh (CM)	Effic (%)
1	2,13 ↗	2,05	0,77	75.60
2	2,06 ↙	2,08	0,82 ↑	76.99 ↑
3	2,11	2,11 ↑	0,81	75.49 ↓
4	2,10	2,06	0,77	76.35
5	2,09	2,05	0,79	76.56
6	2,11	2,03 ↓	0,76 ↓	76.34
CAL: Ma / cm/10MIN	347.5	84,14	84,18	—
10 Psi Compression	0.05 cm	0.05 cm	0,00	—
MEAN	2.10 (729.8 ma)	2,063 (173.6)	.787 (66.2)	76.2
range	0.07 (24.3 ma)	0.08 (6.7)	0.06 (5.0)	1.50
Variation (%)	3.33	3.88	7.6	1.97
Std Dev	.0237 (8.2 ma)	.0280 (2.4)	.0242 (2.0)	.576
3σ	.0710 (24.7 ma)	.0841 (7.1)	.0727 (6.1)	1.73
Slope	2.096 (728.4)	2.068 (174.0)	0.789 (66.4)	76.3
Correl Coef	.999995	.999978	.99991	

Table 4.– Thruster J-1 Flow Data at 2.009 Amp Beam

Thruster J-1
2009 Ma Beam

Date 4-24-80
Time 07^{02} - 08^{02}

10 MIN INTERVAL	MAIN Δh (CM)	CATH Δh (CM)	Neut Δh (CM)	EFFIC (%)
1	5.35	1.36	.31 ↓	100.8
2	5.32	1.32 ↓	.39 ↑	101.1
3	5.40 ↑	1.35	.32	99.9 ↓
4	5.31	1.35	.33	101.4
5	5.27 ↓	1.32 ↓	.33	102.3 ↑
6	5.30	1.38 ↑	.32	101.5
CAL: Ma / CM/10MIN	346.4	83.97	84.09	
10psi Compression	2.08 cm	0.72 cm	2.99 cm	
Mean	5.325 (1844.6 Ma)	1.347 (113.1)	.333 (28.0)	101.2
Range	.13 (45.0 Ma)	.06 (5.0)	.08 (6.7)	2.4
Variation (%)	2.4	4.5	24.0	2.4
Std dev	.045 (15.6 ma)	.023 (1.9)	.029 (2.4)	.80
3σ	.135 (46.8 Ma)	.070 (5.9)	.086 (7.2)	2.40
Slope	5.321	1.343	.335	101.25
Correl Coef	.9999931	.9999845	.9995237	

Table 5. - Thruster 702 Flow Data at 1.958 Amp Beam

Thruster 702
1958 Ma Beam

Date 4-24-80
Time: 07^{02} - 08^{02}

10 MIN INTERVAL	Main Δh (cm)	CATH Δh (cm)	Neut Δh (cm)	EFFIC (%)
1	5.88	0.78 ↑	0.50 ↓	91.0
2	5.90	0.75	0.56	90.6
3	5.89	0.71 ↓	0.54	91.0
4	5.93 ↑	0.72	0.57	90.3 ↑
5	5.87 ↓	0.73	0.58 ↑	91.1 ↓
6	5.88	0.74	0.55	91.0
Cal: Ma / cm/10min	347.5	84.14	84.18	
10psi Compression	0.05 cm	0.05 cm	0.00	
Mean	5.89 (2046.8 ma)	.738 (62.1)	.55 (46.3)	90.8
Range	.06 (20.9 ma)	.06 (5.0)	.08 (6.7)	0.8
Variation (%)	1.0	8.1	14.5	0.9
Std Dev	.021 (7.3 ma)	.025 (2.1)	.028 (2.4)	.31
3σ	.064 (22.2 ma)	.074 (6.2)	.085 (7.2)	.94
Slope	5.896	.727	.561	90.8
Correl Coef.	.9999992	.9999753	.999954	

TABLE 6. - REPEATIBILITY OF EFFICIENCY MEASUREMENTS

Thruster	Beam Current	Efficiency Range	Std Deviation
J-1	.739	3.13	1.25
J-1	.739	2.98	1.03
702	.739	1.50	0.58
J-1	2.009	2.4	0.80
702	1.958	0.8	0.31

TABLE 7. - DATA POINTS ARRANGED IN ORDER BY STANDARD DEVIATION

Standard Deviation	Range	Range (percent of mean)	Thruster	Beam Current	Vaporizer	Compression
.021	.06	1.0	702	1958	Main	0.05
.023	.06	4.5	J-1	2009	Cath	0.72
.024	.06	2.9	J-1	739	Main	2.08
.024	.07	3.33	702	739	Main	0.05
.024	.06	7.6	702	739	Neut	0.00
.025	.06	8.1	702	1958	Cath	0.05
.028	.08	3.88	702	739	Cath	0.05
.028	.08	14.5	702	1958	Neut	0.00
.0285	.08	3.86	J-1	739	Main	2.08
.029	.08	24.0	J-1	2009	Neut	2.99
.032	.09	20.9	J-1	739	Neut	2.99
.044	.11	7.6	J-1	739	Cath	0.72
.045	.13	2.4	J-1	2009	Main	2.08
.047	.14	36.2	J-1	739	Neut	2.99
.048	.13	9.29	J-1	739	Cath	0.72

TABLE 8. - COMPARISON OF AVERAGE DELTA vs SLOPE METHOD OF CALCULATION

Thruster	Beam Current	Efficiency Average Delta	Efficiency Slope
J-1	.739	85.2	85.3
J-1	.739	84.5	84.7
702	.739	76.2	76.3
J-1	1.958	101.2	101.25
702	2.009	90.8	90.8

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TRIM 122

Reply to Attn of: 6122

May 5, 1980

TO: 6122/J. F. DePauw

FROM: 6122/C. E. Siegert

SUBJECT: Report on Flow Tube Variation During Warm-Up/Start-Up

REF: Flow Tube Variation During Warm-Up/Start-Up (Test Procedure)
TRIM 105

OBJECTIVES

The purpose of this test was to accomplish the following:

(1) determine the length of time required for the thruster to reach stability so that accurate flow data can be taken.

(2) determine if flow rate changes when second thruster is operated.

INTRODUCTION

This test was performed using thruster J-1 with FM-3 power processor and thruster 702 with FM-2 power processor in 10 foot port of tank 6 in EPL. The thrusters were located in the center section of the 10 foot port and the power processors were mounted to heat pipes and located outside the 10 foot port.

A mercury feed system located outside the 10 foot port had individual feed lines to the main vaporizer, cathode vaporizer and neutralizer vaporizer of each thruster. Each feed line had a precision bore tube as the measuring instrument and a set of valves. The precision bore tubes were filled with mercury from a reservoir and then isolated from the reservoir. The mercury used by the thruster was supplied from the precision bore tubes.

Each tube had been calibrated prior to installation into the feed system. The following table shows the calibration constants for each precision bore tube. (When the calibration constant is multiplied by the number of millimeters of mercury that flowed in one minute the result is equal to equivalent milliamps of flow.)

J-1	main Vaporizer	346.4	ma-min/mm
J-1	cathode Vaporizer	83.97	ma-min/mm
J-1	neutralizer vaporizer	84.09	ma-min/mm
702	main vaporizer	347.5	ma-min/mm
702	cathode vaporizer	84.14	ma-min/mm
702	neutralizer vaporizer	84.18	ma-min/mm

For this test a compression test was performed on the mercury feed system for J-1 and 702 thrusters. The mercury height is noted in each precision bore tube. 10 psi is applied and the height is noted. If there is a change in height there is an indication that the feed line contains trapped gas. This trapped gas will cause inaccurate flow measurements. The results of the compression test were as follows:

702	neutralizer	0.00
702	cathode	0.05 cm
702	main	0.05 cm
J-1	neutralizer	2.99 cm
J-1	cathode	0.72 cm
J-1	main	2.08 cm

The 702 compression was acceptable and J-1 as unacceptable for accurate flow measurements. Since the purpose of this test was not to obtain accurate flow data the system was used as it was. For that reason the data should not be used for absolute level of performance.

TEST DATA

The test data will be presented by discussing the series of figures attached. Complete raw data from the test is attached.

Figure 1

Figure 1 shows the sequence of events that occurred during this testing. On April 21, 1980 the thruster J-1 was started and flow and temperature data were recorded during startup. The thruster J-1 was operated overnight at a 0.75 amp beam to ensure that thermal equilibrium had been achieved. Then transient flow and temperature data was taken when the thruster was throttled from 0.75 amp beam to a 1.0 am beam. After four hours of operation at 1.0 amp the thruster J-1 was throttled to 0.75 amp beam current. Two hours later the thruster 702 was started.

Both thrusters were operated at 0.75 amp beam overnight. On April 23 data was taken on both thrusters while they were operating at the 0.75 amp beam current. The two thrusters were then throttled to the 2.0 amp beam current. Data was not taken until the thrusters had operated at the 2.0 amp beam current for 3 hours. The thrusters were then operated overnight at the 2.0 amp set point and data on both thrusters was taken on the morning of April 24, 1980. The test was then terminated by commanded shutdown of the thrusters.

Figure 2

Figure 2 represents a plot of the height of mercury in main, cathode, and neutralizer flow tubes during the warmup and startup of the thrusters J-1 and 702 and also the temperature of the vaporizers. The height of the mercury increases as the thruster starts to warmup due to the expansion of the mercury in the vaporizer and feed system. Then as the vaporizer temperature increases more the height starts to decrease as the mercury is heated enough to cause flow. Note that mercury flow exists in the vaporizers prior to "Beam On".

Figure 3

Figure 3 represents a plot of the flow of the three vaporizers in milliamps, a temperature plot of the J-1 manifold, total flow in milliamps, and thruster efficiency. The manifold temperature was taken by a thermocouple on the propellant manifold which is mounted on the rear of the thruster.

On the left side of the figure is the transient startup data taken on April 21, 1980. On the right side of the figure is the data after the thruster had operated overnight. Note that the efficiency and total flow of the thruster at about 13:00 on April 21 is about the same as the data taken the next morning. However, the contribution by the main on the 21st is more than the one on the 22nd. The cathode contribution is less on the 21st than it was on the 22nd. Based on this set of data it could be concluded that the efficiency and total flow has stabilized about one hour after the manifold temperature has reached equilibrium; however, the flow distribution between the main vaporizer and cathode vaporizer has not reached their final values.

Figure 4

Figure 4 represents the mercury flow as the thruster was throttled from 0.739 amp to 0.995 amp. Based on this data the total flow and efficiency at about 11:30 have stabilized to their final value, however, the percentage of contribution by the main and cathode have not reached steady state. The sudden shift in main flow rate at 11:00 has been attributed to refilling the feed tubes and gas being trapped in the lines.

Figure 5

Figure 5 represents the flow and efficiency data for both thrusters operating at a 0.75 amp beam current (0.739 actual). The operating point for thruster 702 had not been optimized, therefore, the efficiency is lower than thruster J-1. The purpose of this figure is to show that there exists variation in flow rate measurements of the thruster J-1 flow rates which did not have an acceptable feed system fill and thruster 702 flow rates which did have an acceptable feed system fill. It appears that at this power level (0.75 amp beam current)variation experienced in the measurement of flows was independent of the type of fill the feed system had. At the 2.0 amp level, the efficiency variations of thruster 702 (with a good fill) were significantly less than those of thruster J-1 (with a poor fill).

Figure 6

Figure 6 is a comparison of the flow data taken on J-1 when it was operating alone and when thruster 702 was operating. As can be seen the magnitude of the flow rates and the variations for a given measurement were the same for both operating conditions. It can be concluded that the flow rates of a thruster are not affected by a second thruster operating.

Figure 7

Figure 7 is the data plotted for thruster 702 starting about 3 hours after it had been throttled from 0.739 to 1.995 amp beam current. The data shows that there is slightly over a 1% variation in the main flow rate on April 23, and there is still about a 1% variation on April 24.

Data Variations

The efficiency data discussed above shoed more scatter than expected. In case of the J-1 thruster, apparently the gas in the feed system is a major contributor. However, it was also noted in the test that the mercury meniscus in the feed tube did not drop uniformly. The meniscus changed shape and seemed to stick at certain places. Stick-slip tendency at one place in a tube was repeated several times when the flow tube was repeatedly refilled to cause flow past the same area. The following data was taken to illustrate the point. Time was marked when the column of mercury passed millimeter marks on the flow tube. Time variations show that the height change was not uniform.

The following table shows the time for the mercury level to move one millimeter. The data is for the main vaporizer feed tube for J-1. The two columns are readings by different people on April 23, 1980.

Time	Difference	Time	Difference
08:16:47			
17:16	29	08:23:44	
17:47	31	24:10	26
18:10	23	24:34	24
18:47	37	25:05	31
19:19	32	25:33	28
19:45	26	26:04	31
20:13	28	26:35	31
29:38	25	27:02	27
21:02	34	27:32	30
21:40	28	27:51	19
22:17	37	28:20	29
22:42	25	28:49	29
23:04	22		

This stick-slip tendency was attributed to unclean flow tubes.

RESULTS AND CONCLUSION

(1) For the test configuration in EPL a stable total flow measurement of a thruster is possible one hour after manifold temperature reaches equilibrium or four hours after startup, however, the absolute value of the main and cathode take longer, possibly 8 hours.

(2) An unacceptable fill of the mercury system caused inaccurate flow data regardless of how long the thruster operates at a given set point. When calculation of efficiencies for J-1 at 2.0 amp beam current are made, the efficiencies were 100%.

(3) A variation of flow rates was obtained for the J-1 and 702 thrusters. This variation cannot be attributed only to the acceptability or unacceptability of the "fill" of the system. During the test it was noted that the mercury did not flow evenly in the tubes. The meniscus of the mercury did not maintain its shape. The uneven flow and meniscus are attributed to "unclean" glassware. (During post test tube cleaning, the tubes were examined under a microscope. The bore of the precision tubes was found to be rough and to contain some tiny pits

The bore is not as glossy-smooth as the outside of the glass. The volume of this roughness and the pits is inconsequential but it may account for the stick-slip tendency)

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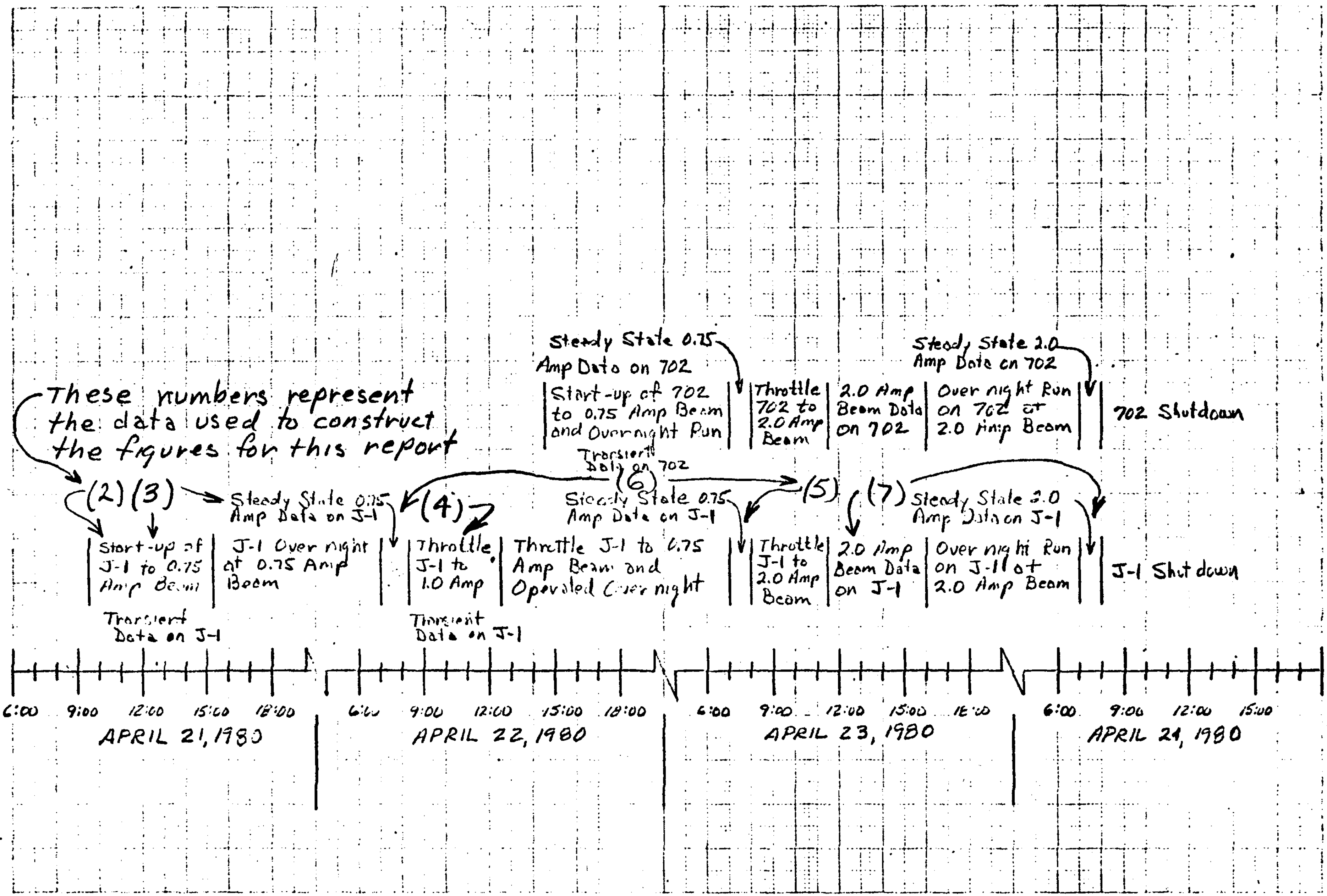
131



Steady State 0.75 Amp Data on 702
Start-up of 702 to 0.75 Amp Beam and Overnight Run
Throttle 702 to 2.0 Amp Beam
2.0 Amp Beam Data on 702
Steady State 2.0 Amp Data on 702
Over night Run on 702 at 2.0 Amp Beam
702 Shutdown
These numbers represent the data used to construct the figures for this report
Transient Data on 702
(2) (3)
(6)
(5)
(7)
(4)
Steady State 0.75 Amp Data on J-1
Start-up of J-1 to 0.75 Amp Beam
J-1 Over night at 0.75 Amp Beam
Throttle J-1 to 1.0 Amp
Throttle J-1 to 0.75 Amp Beam and Operated Over night
Steady State 0.75 Amp Data on J-1
Throttle J-1 to 2.0 Amp Beam
2.0 Amp Beam Data on J-1
Steady State 2.0 Amp Data on J-1
Over night Run on J-1 at 2.0 Amp Beam
J-1 Shut down
Transient Data on J-1
Transient Data on J-1
6:00 9:00 12:00 15:00 18:00
APRIL 21, 1980
6:00 9:00 12:00 15:00 18:00
APRIL 22, 1980
6:00 9:00 12:00 15:00 18:00
APRIL 23, 1980
6:00 9:00 12:00 15:00
APRIL 24, 1980

FIGURE 1

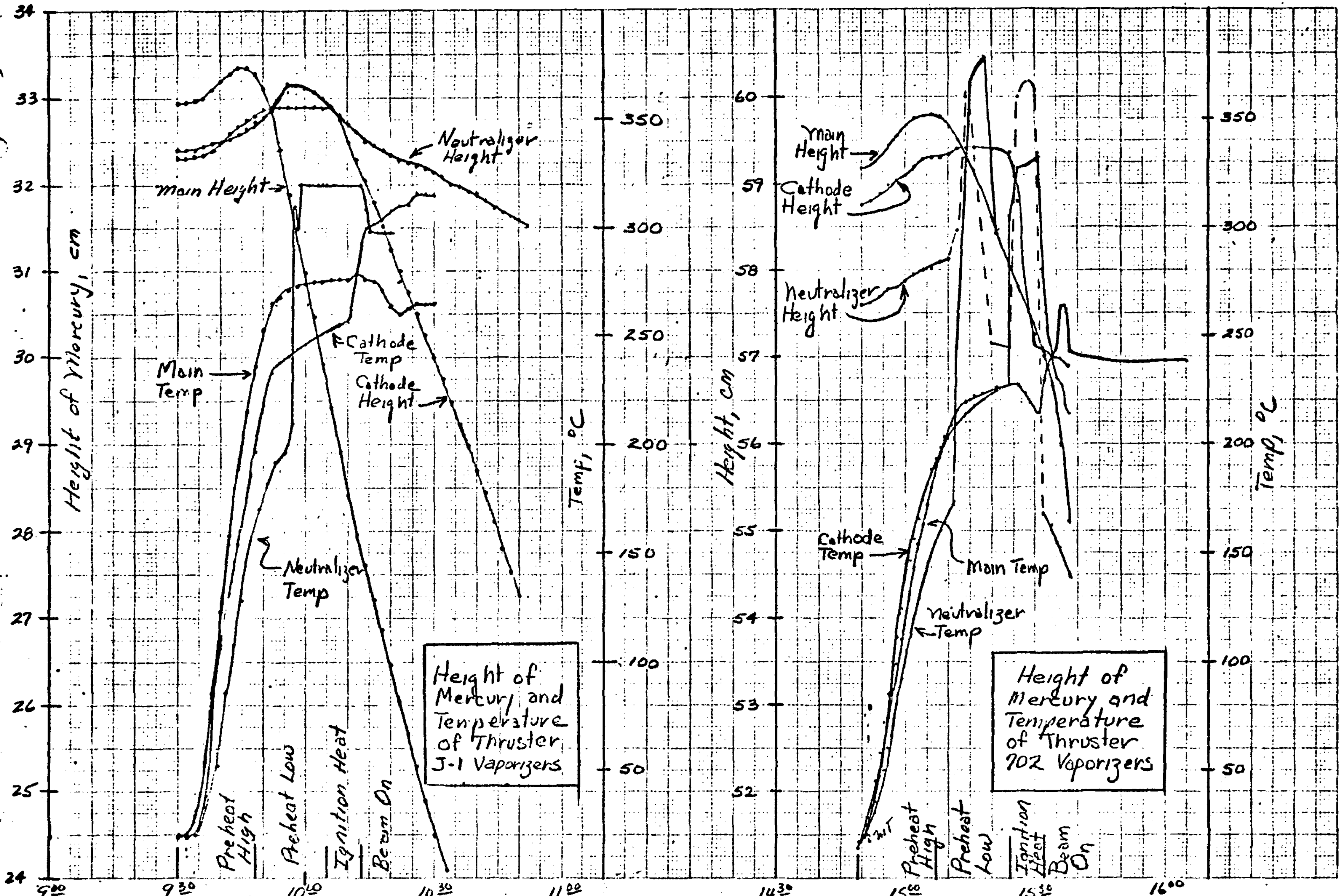

Height of Mercury, cm
Temp, °C
Height, cm
Temp °C
Neutralizer Height
Main Height
Main Temp
Cathode Temp
Cathode Height
Neutralizer Temp
Height of Mercury and Temperature of Thruster J-1 Vaporizers
Preheat High
Preheat Low
Ignition Heat
Beam On
Main Height
Cathode Height
Neutralizer Height
Cathode Temp
Main Temp
Neutralizer Temp
Height of Mercury and Temperature of Thruster 702 Vaporizers
Ignition Heat
Beam On
9:00
9:30
10:00
10:30
11:00
14:30
15:00
15:30
16:00

FIGURE 2

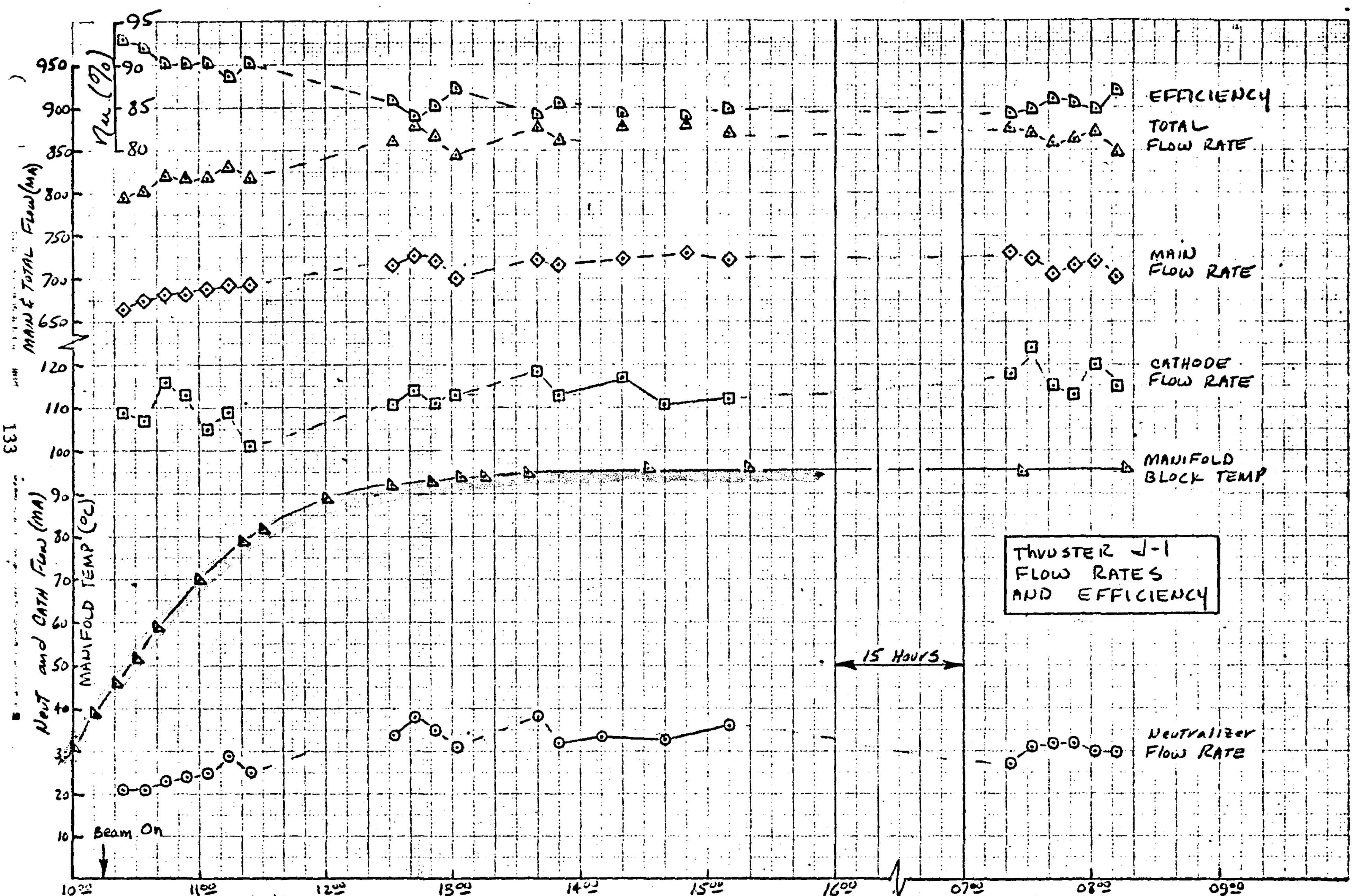
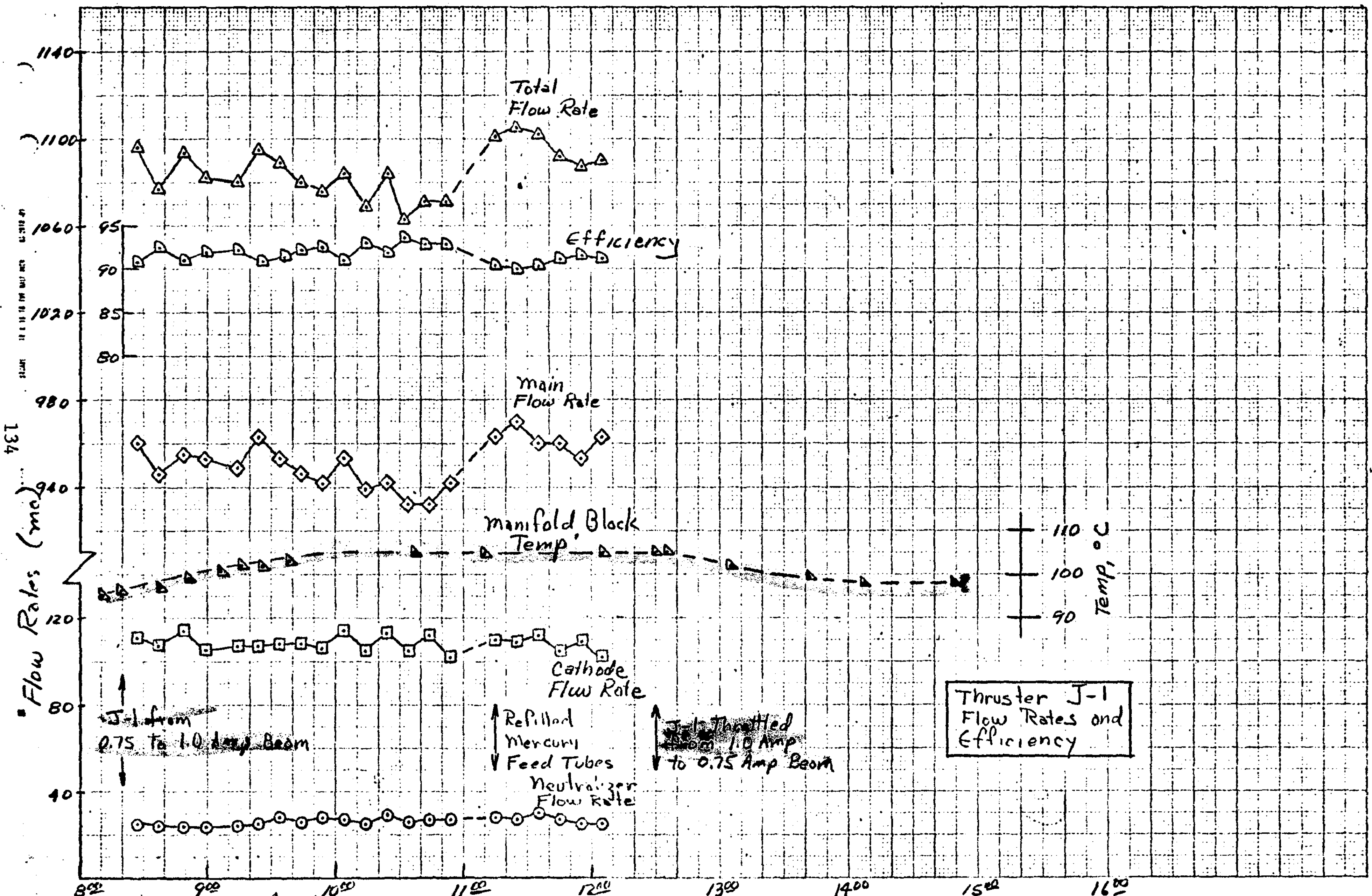

95
90
85
80
η_u (%)
950
900
850
800
750
700
650
MAIN & TOTAL FLOW (MA)
120
110
100
90
80
70
60
50
40
30
20
10
NEUT and CATH FLOW (MA)
MANIFOLD TEMP (°C)
EFFICIENCY
TOTAL FLOW RATE
MAIN FLOW RATE
CATHODE FLOW RATE
MANIFOLD BLOCK TEMP
THRUSTER J-1 FLOW RATES AND EFFICIENCY
15 Hours
Neutralizer Flow Rate
Beam On
10:00
11:00
12:00
13:00
14:00
15:00
16:00
07:00
08:00
09:00
April 21, 1980
APRIL 22, 1980

FIGURE 3



April 22, 1980 FIGURE 4

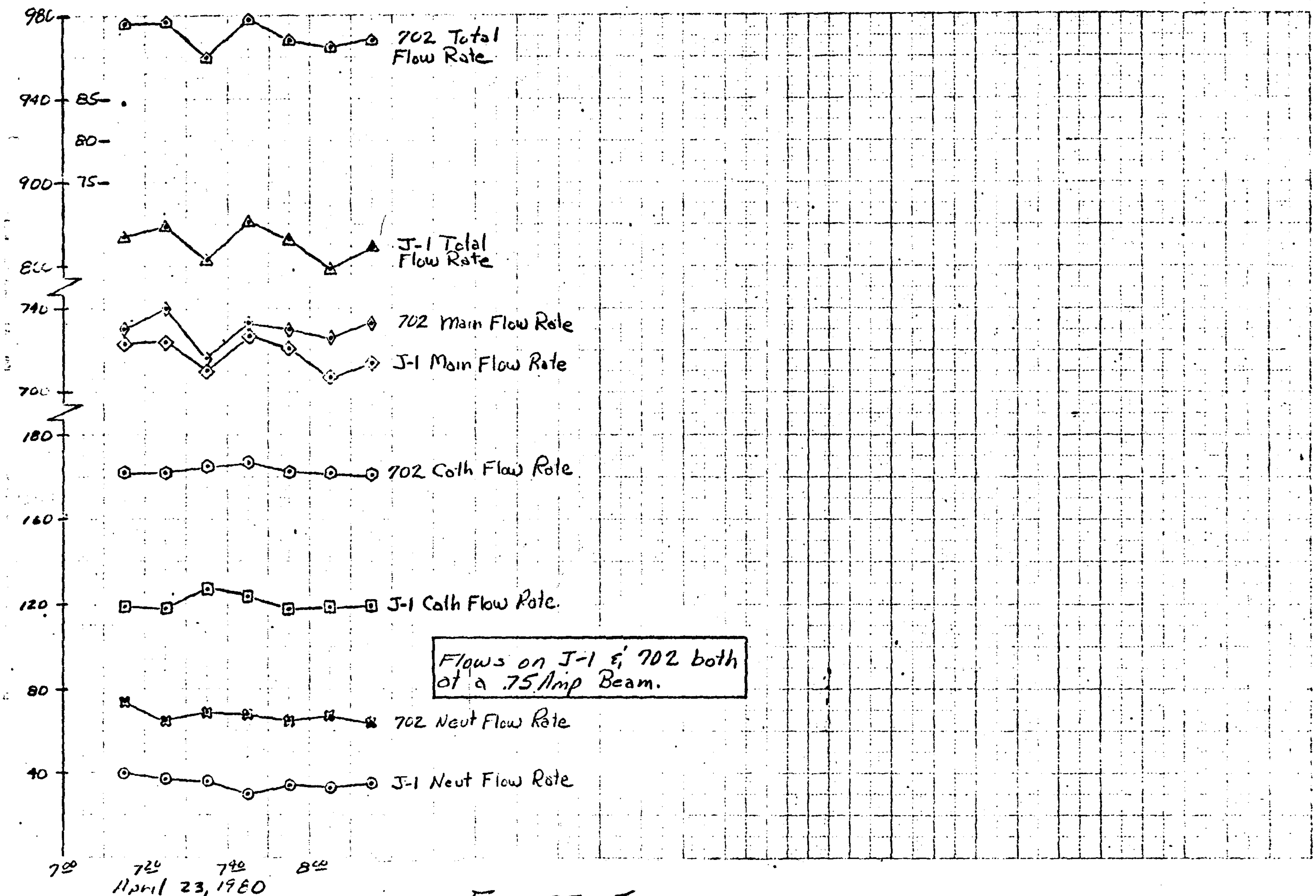

980
940
900
880
740
700
180
160
120
80
40
85
80
75
702 Total Flow Rate
J-1 Total Flow Rate
702 Main Flow Rate
J-1 Main Flow Rate
702 Cath Flow Rate
J-1 Cath Flow Rate
Flows on J-1 & 702 both at a .75 Amp Beam.
702 Neut Flow Rate
J-1 Neut Flow Rate
7:00
7:20
7:40
8:00
April 23, 1980

FIGURE 5

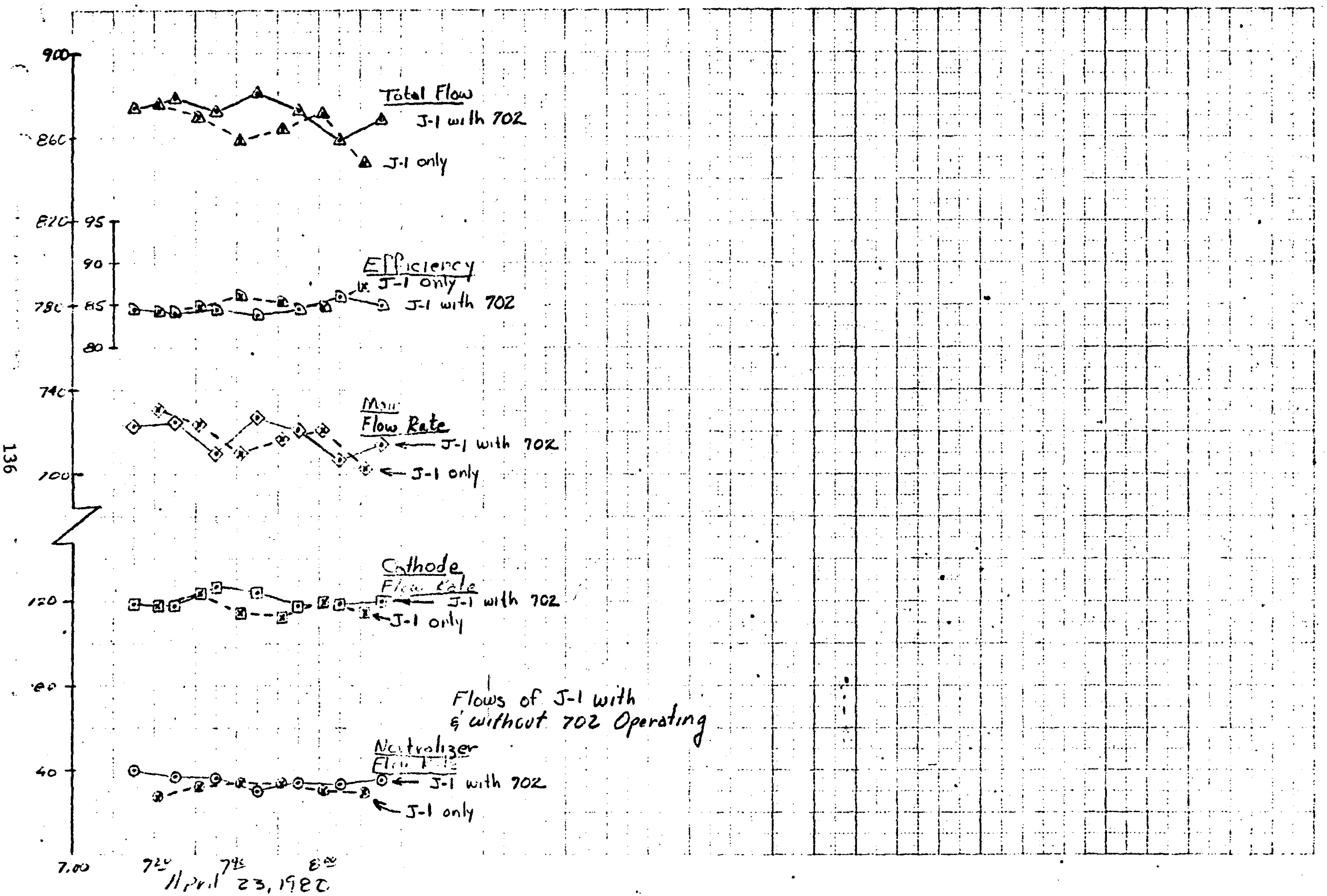
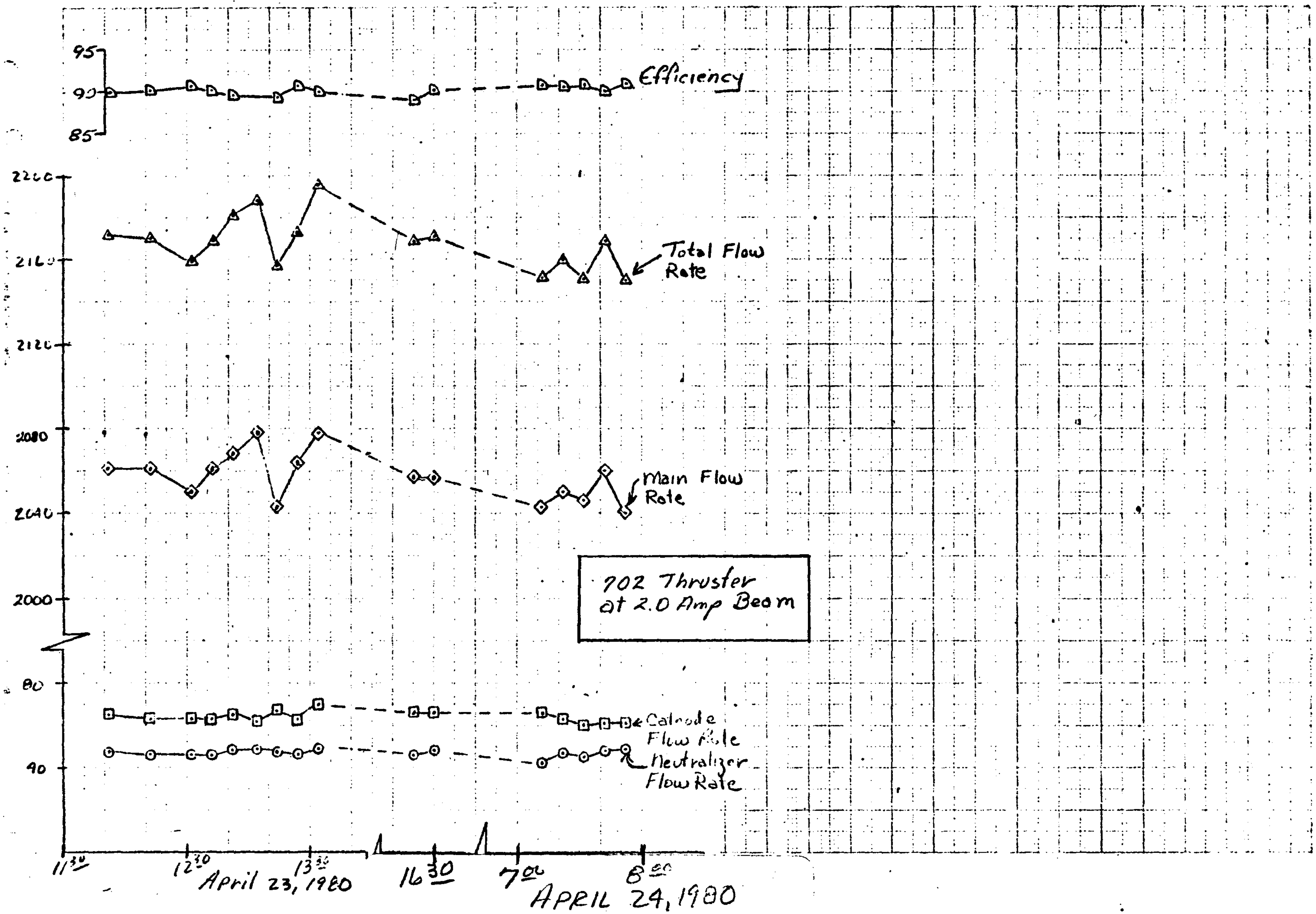

900
860
820
780
740
700
120
80
40
95
90
85
80
Total Flow
J-1 with 702
J-1 only
Efficiency
J-1 only
J-1 with 702
Max Flow Rate
J-1 with 702
J-1 only
Cathode Flow Rate
J-1 with 702
J-1 only
Neutralizer Flow Rate
J-1 with 702
J-1 only
Flows of J-1 with & without 702 Operating
7:00
7:20
7:40
8:00
April 23, 1980

FIGURE 6



Efficiency
95
90
85
2200
2160
2120
2080
2040
2000
80
Total Flow Rate
Main Flow Rate
702 Thruster at 2.0 Amp Beam
Cathode Flow Rate
Neutralizer Flow Rate
11 30
12 30
13 30
April 23, 1980
16 30
7 00
8 00
APRIL 24, 1980

FIGURE 7

(1)

J.O.
DATE 4/21/80
ENG.

TRIM 105 - Flow Tube Variation During Warmup

Height data for Figures (2) & (3)

TIME	J-1	Flow	Tubes	702	Flow	Tubes		
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	NeuT cm		
9 30 45	32.95	32.30	32.40	30.75	30.75	30.50	Pre ht Start	
9 32 00	32.95	32.3	32.40	30.75	30.75	30.50		
9 34 00	32.97	32.34	32.40	30.75	30.75	30.50		
9 36 00	33.00	32.39	32.45	30.75	30.75	30.50		
9 38 00	33.10	32.45	32.48	30.75	30.75	30.50		
9 40 00	33.20	32.50	32.50	30.75	30.75	30.50		
9 42 00	33.29	32.60	32.53	30.75	30.75	30.50		
9 44 00	33.35	32.67	32.58	30.75	30.75	30.50		
9 46 00	33.35	32.75	32.65	30.73	30.75	30.50	Vibration ??	
9 48 00	33.29	32.80	32.72	30.72	30.75	30.50		
9 50 00	33.11	32.87	32.79	30.71	30.77	30.50		
9 52 00	32.85	32.90	32.86	30.70	30.77	30.50		
9 54 00	32.41	32.90	33.00	30.70	30.77	30.51	Neut	on.
9 56 00	31.90	32.90	33.17	30.70	30.77	30.51		
9 58 00	31.50	32.90	33.15	30.72	30.77	30.51		
10 00 00	30.99	32.90	33.13	30.71	30.77	30.51		
10 02 00	30.48	32.90	33.07	30.71	30.77	30.52		
10 04 00	29.95	32.88	33.00	30.70	30.75	30.52		
10 06 00	29.43	32.90	32.90	30.70	30.77	30.52	Fan Turned On	
10 08 00	28.92	32.75	32.80	30.70	30.75	30.50		
10 10 00	28.42	32.50	32.70	30.70	30.75	30.49		
10 12 00	27.97	32.30	32.62	30.69	30.70	30.47	(Fan Turned off	
10 14 00	27.60	32.05	32.50	30.70	30.72	30.48		
10 16 00	27.21	31.80	32.46	30.70	30.72	30.49		
10 18 00	26.87	31.52	32.40	30.70	30.72	30.49		
10 20 00	26.47	31.25	32.35	30.70	30.73	30.49		
10 22 00	26.05	31.00	32.29	30.70	30.72	30.49		
10 24 00	25.68	30.75	32.25	30.70	30.75	30.50		
10 26 00	25.30	30.50	32.23	30.70	30.77	30.51		
10 28 00	24.90	30.27	32.20	30.70	30.78	30.53		
10 30 00	24.50	30.00	32.15	30.71	30.80	30.55		

NASA-C-801B (10-24-51)

J.O.

DATE 4/21/80 (2)

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TRIM 105 - Flow Tube Variation During Warmup

Height data for Figures (2) & (3)

TIME	J-1	Flow	Tubes	702	Flow	Tubes	
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	NeuT cm	
10 32 00	24.10	29.75	32.10	30.72	30.80	30.57	
10 34 00	23.73	29.48	32.00	30.73	30.80	30.57	
10 36 00	23.34	29.22	31.98	30.71	30.80	30.59	
10 38 00	22.98	28.98	31.93	30.71	30.80	30.60	
10 40 00	22.57	23.70	31.90	30.70	30.82	30.60	
10 42 00	22.15	28.45	31.82	30.72	30.83	30.60	
10 44 00	21.76	28.10	31.73	30.72	30.82	30.60	Beam On
10 46 00	21.35	27.8	31.68	30.70	30.82	30.60	
10 48 00	20.96	27.53	31.63	30.71	30.81	30.60	
10 50 00	20.55	27.27	31.60	30.71	30.84	30.60	
10 52 00	20.18	27.0	31.51	30.70	30.80	30.60	D2 P
10 54	19.79	26.75	31.45	30.71	30.80	30.60	
10 56	19.39	26.50	31.39	30.70	30.80	30.60	Closed
10:58	18.99	26.22	31.32	30.70	30.85	30.61	
11:00	18.59	26.0	31.26	30.70	30.85	30.61	
11:02	18.20	25.75	31.20	30.70	30.85	30.65	
11:04	17.8	25.50	31.15	30.70	30.87	30.65	
11:06	17.39	25.21	31.07	30.70	30.85	30.65	
11:08	16.98	24.98	31.0	30.7	30.85	30.65	
11:10	16.60	24.72	30.92	30.70	30.85	30.65	
11:12	16.19	24.45	30.90	30.70	30.85	30.65	
11:14	15.80	24.20	30.8	30.70	30.85	30.65	
11:16	15.40	23.98	30.75	30.69	30.85	30.65	
11:18	14.99	23.72	30.69	30.70	30.87	30.67	
11:20:10	14.55	23.5	30.6	30.70	30.87	30.67	
11:22	14.2	23.23	30.55	30.70	30.87	30.68	
11:24	13.8	23.0	30.50	30.70	30.88	30.68	
11:26	13.41	22.75	30.45	30.70	30.89	30.69	
11:28	13.00	22.50	30.36	30.70	30.89	30.69	
11:30	12.60	22.21	30.27	30.70	30.89	30.69	

NASA-C-8018 (10-24-51)

(3)

J.O.

DATE 4/21/80

ENG.

TRIM 105 - Flow Tube Variation During Warmup

TIME	J-1	Flow	Tubes	702	Flow	Tubes
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	NeuT cm
11:32	51.50	50.60	51.28			
12:32	39.10	42.68	48.85	30.60	30.80	30.60
12:34	38.68	42.40	48.80	30.60	30.80	30.60
12:36	38.20	42.15	48.68			
12:38	37.83	41.88	48.58			
12:40	37.42	41.60	48.50			
12:42	37.00	41.32	48.40			
12 44	36.60	41.05	48.30			
12 46	36.18	40.80	48.20			
12 48	35.78	40.52	48.12	30.60	30.80	30.60
12 50	35.35	40.25	48.02			
12 52	34.92	40.00	47.98			
12 54	34.52	39.70	47.88			
12 56	34.10	39.42	47.80			
12 58	33.70	39.20	47.70			
13 00	33.30	38.95	47.65			
13 02	32.90	38.68	47.60			
13 03	56.48	55.38	56.10			
13 40	48.75	50.70	54.45	30.60	30.83	30.64
13 45	47.70	50.05	54.30			
13 50	46.68	49.35	54.04			
13 55	45.62	48.69	53.81			
14 02	44.19	47.73	53.50			
14 08	42.90	46.95	53.27			
14 10 00	42.5	46.69	53.17			
14 40 30	36.15	42.55	51.90			
15 10 30	29.90	38.55	50.60			

NASA-C-801B (10-24-51)

J.O. ____ DATE 4-22-80

TRIM 105 - Flow Tube Variation During Warmup ENG. [illegible]

Data for Figure (4)

TIME	J-1	Flow	Tubes	702	Flow	Tubes
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	NeuT cm
07 12 00	56.50	55.90	56.10	29.68	30.05	29.85
07 22 00	54.39	54.50	55.78			
07 32 00	52.30	53.02	55.40			
07 42 00	50.25	51.65	55.00			
07 52 00	48.18	50.30	54.60			
08 02 00	46.10	48.87	54.24			
08 12 00	44.07	47.50	53.88			
THrottle up To 1.0 A. at 0816						
08 17 00	55.80	55.27	55.40			
08 19 00	55.25	54.98	55.34			
08 21 00	54.68	54.72	55.27	29.68	30.19	29.98
08 23 00	54.14	54.45	55.20			
08 25 00	53.60	54.18	55.15			
08 27 00	53.03	53.95	55.10			
08 29 00	52.50	53.70	55.03	29.70	30.20	29.99
08 31 00	51.94	53.40	54.98			
08 33 00	51.40	53.15	54.93			
~~08 36 00~~						
08 36 00	50.56	52.80	54.85			
08 37 00	50.30	52.68	54.82			
08 39 00	49.74	52.39	54.76			
08 44 00	48.38	51.7	54.62			
08 49 00	46.99	51.05	54.48			
08 54 00	45.61	50.42	54.36			
08 59 00	44.24	49.8	54.20			
09 04 00	42.87	49.15	54.04			
09 09 00	41.49	48.5	53.9			
09 14 00	40.13	47.88	53.76			
09 19 00	38.7	47.2	53.6			
09 [illegible]4 00	37.35	46.6	53.46			
09 24 00	35.98	45.95	53.3			

NASA-C-801B (10-24-51)

J.O. (5)
DATE 4-22-80
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TRIM 105 - Flow Tube Variation During Warmup

TIME	J-1	Flow	Tubes	702	Flow	Tubes
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	NeuT cm
093400	34.60	45.31	53.16			
093900	33.22	44.68	53.00			
094400	31.87	44.02	52.85			
095400	29.15	42.76	52.52			
100400	26.4	41.4	52.2			
101400	23.69	40.15	51.9			
102400	20.97	38.8	51.56			
103400	18.28	37.55	51.25			
104400	15.59	36.22	50.93			
105400	12.87	35.00	50.61			
Refill tubes						
105500	56.40	55.80	55.87			
111500	50.84	53.18	55.20			
112500	48.04	51.88	54.88			
113500	45.27	50.55	54.52			
114500	42.50	49.30	54.20			
115500	39.75	48.00	53.90			
120500	36.97	46.78	53.60	29.65	30.88	30.64
Removed Pressurize hose				changed "0"		
~~1215~~	~~34.44~~	~~45.30~~	~~53.45~~	Bad data		
~~122500~~	~~31.77~~	~~43.88~~	~~53.13~~			
1230	Throttle	back		TO	3/4	A.

NASA-C-8018(10-24-51)

J.O. ⑥

DATE 4/22/80

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TRIM 105 - Flow Tube Variation During Warmup

TIME	J-1	Flow	Tubes	702	Flow	Tubes		
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	NeuT cm		
123000	Throttle back to 3/4 a							
1235	54.60	54.81	55.40					
1245	52,50	53,38	55,00	59,10	58,25	57,10		
1255	50,40	51,95	54,60					
1305	48,30	50.55	54,25					
1315	46,20	49,15	53,86					
1325	44,10	47,75	53,49					
133500	42,00	46,37	53,10					
134500	39,94	44,98	52,75	59.15	58,47	57,33		
135500	37,80	43.55	52,35				03713973	
140500	35,75	42,13	52.02					
141500	33,67	40,78	51.66					
14:30 Readjust Vb & Vs Set PT								
Readjust Ie to 6,13								
144000	Start Thruster 2 Normal Start							
145000	55,20	55,86	55,56	59.18	58.75	57,60		
145200				59,27	58,80	57,62		
145400				59,31	58,88	57,68		
145600				59,45	58.98	57,78		
145800				59,55	59.04	57,80		
150000	53,16	54,50	55.15	59,67	59.10	57,88		
150200				59,75	59.20	57,95		
150400				59,77	59,28	58,00		
1506				59,80	59,30	58,04		
1508				59,78	59.30	58,10		
151000	51,05	53,10	54,82	59.66	59,34	58,14		
151200				59.51	59,40	58,45		
151400				59,30	59,40	58,45		
1516				59.16	59,42	over 60		
1518								
1520	49,00	51,78	54,50	58,60	59,40	57,15		

NASA-C-801B (10-24-51)

J.O.
DATE 4/22/80
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(7)

TRIM 105 - Flow Tube Variation During Warmup

Data for Figure (5) & (6)

TIME	J-1	Flow	Tubes	702	Flow	Tubes	
HR MN SC	Main cm	CATH cm	NEUT cm	Main cm	CATH cm	NEUT cm	
15 24 00				58.04	59.36	57.10	
15 26 00				57.80	58.80	>60	Perking.
15 28 00							
15 30 00	46.96	50.40	54.15	57.25	57.14	>60	
153200				57.10	57.12	55.2	← Beam ON
153400				56.66	57.00	55.06	
36				56.00	56.98	54.80	
38				55.10	56.98	54.5	702 shut down
154000	44.95	49.00	53.85				
4/23/80							
07 05 00	56.21	55.30	56.00	58.85	58.70	59.10	J. DP
07 15 00	54.12	53.88	55.52	56.75	56.65	58.22	
07 20 00	[illegible]	53.17	55.29	55.75	55.65	57.84	
07 25 00	52.03	52.48	55.08	54.62	54.60	57.45	
07 30 00	50.99	51.69	54.85	53.60	53.54	57.02	
0735	49.98	50.97	54.65	52.56	52.52	56.63	
07 40 00	48.93	50.22	54.42	51.50	51.48	56.25	
0745	47.88	49.49	54.20	50.45	50.41	55.82	
0750	46.85	48.79	54.0	49.41	49.40	55.45	
0755	45.80	48.08	53.79	48.35	48.35	55.05	
0800	44.78	47.37	53.56	47.28	47.31	54.65	CES
0805	43.76	46.66	53.40	46.26	46.30	54.26	
0810	42.70	45.95	53.16	45.18	45.28	53.88	
0815	41.70	45.23	52.98	44.15	44.27	53.50	

0830 Both Thrusters Throttled from 0.75 to 2.0 Amp Beam Current

NASA-C-8018 (10-24-51)

J.O. ______ (8)

DATE 4/23/80

ENG. ______

TRIM 105 - Flow Tube Variation During Warmup

Data for Figure (7)

TIME	J-1	Flow	Tubes	702	Flow	Tubes
HR MN SC	Main cm	CATH cm	NeuT cm	Main cm	CATH cm	Neut cm
Thrusters	both	at	2.0 amps			
11 32 00	55.78	55.50	55.42	58.20	58.70	58.62
11 52 00	45.08	52.72	54.80	46.34	57.15	57.51
12 12 00	34.40	50.00	54.18	34.48	55.65	56.42
12 32 00	23.85	47.28	53.52	22.68	54.15	55.32
12 42 00	18.60	45.88	53.20	16.75	53.40	54.77
12 52 00	13.45	44.50	52.88	10.80	52.62	54.20
	Refill Tubes					
12 54 00	55.48	55.55	55.40	58.28	58.62	58.70
1304	50.02	54.20	55.10	52.30	57.90	58.12
1314	44.65	52.78	54.77	46.42	57.10	57.55
1324	39.30	51.40	54.42	40.48	56.35	57.00
1334	33.92	50.00	54.05	34.50	55.52	56.42
15:44	Vince Started Research Thruster					
16 10 00	55.93	55.50	55.60	58.40	58.84	59.00
16 20 00	50.55	54.08	55.30	52.48	58.05	58.45
16 30 00	45.18	52.67	54.96	46.56	57.26	57.88
4/24/80						
07 02 00	55.15	55.08	55.30	57.60	58.68	58.50
07 12 00	49.80	53.72	54.99	51.72	57.90	58.00
07 22 00	44.48	52.40	54.60	45.82	57.15	57.44
07 32 00	39.08	51.05	54.28	39.93	56.44	56.90
07 42 00	33.77	49.70	53.95	34.00	55.72	56.33
07 52 00	28.50	48.38	53.62	28.13	54.99	55.75
0802	23.20	47.00	53.30	22.25	54.25	55.20
REFILL						
0805	55.63	55.29	55.05	58.41	58.90	58.49

NASA-C-801B (10-24-51)

TRIM 105 - TEMPS DURING WARMUP

J O. ______

DATE 4/21/80

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Time		J-1 Temp			702 Temp				Gimbal Temps				
									Th 702		J-1		
HR	MN SC	T_V °C	T_{CV} °C	T_{NV} °C	T_V °C	T_{CV} °C	T_{NV} °C		#1 °C	#2 °C	#3 °C	manifold °C	
09	30	19	20	13	17	17	13		21	21	21	20	PRHT Hi
	32	19	21	13	17	17	13		21	21	21	20	
	34	29	31	20	17	17	13		21	21	21	20	
	36	54	33	39	17	17	13		21	21	21	20	
	38	86	80	62	17	17	13		21	21	21	21	
	40	123	106	86	17	17	13		21	21	21	21	
	42	158	131	108	17	17	13		21	21	21	22	
	44	189	154	128	17	17	13		21	21	21	22	
	46	215	176	146	17	17	13		21	21	21	23	
	48	236	197	160	17	17	13		21	21	21	24	PRHT Lo
	50	253	218	172	17	17	13		21	21	21	25	
	52	265	233	182	17	17	13		21	21	21	27	
	53	267	238	186									VAP On
	54	271	241	210	17	17	13		21	21	21	28	
	55	273	244	305									
	56	274	246	298	17	17	13		21	21	21	29	
	58	275	249	310	16	17	13		21	21	21	31	
10	00	275	251	310	16	17	13		21	21	21	32	
	02	276	253	310	16	17	13		21	21	21	34	
	04	276	255	310	16	17	13		21	21	21	35	
	05	276	256	310									IG/Hi
	06	279	280	311	16	17	13		21	21	21	37	
	07	276	300	310									
	08	275	302	310	16	17	13		21	21	21	38	
	10	271	304	310	16	17	13		21	21	21	39	
	12	264	308	311		16	13		21	21	21	41	
	13	260	310	311									BEAM
	14	263	311	304		16	13		21	21	21	42	
	15	265	316	298								43	
	16	265	316	298								44	
	18	265	315	298		16	13		21	21	21	45	

C 801 (10-24-51)

.727 85%
.118
021 TRIM 105 - TEMPS DURING WARMUP

(2)

J.O. ____

DATE 4/21/80

Time		J-1 TEMP			702 TEMP				GIMBAL TEMPS			
									Th 702		J-1	
		T_v	T_{cv}	T_{nv}	T_v	T_{cv}	T_{nv}		#1	#2	#3	manifold
HR	MN SC	°C	°C	°C	°C	°C	°C		°C	°C	°C	°C
10	20	265	315	298		16	13		21	21	21	46
	22	265	315	298								47
	24	266	315	298			13				21	48
	26	266	314	298							21	50
	28	266	314	298								51
	30	266	314	298		16	13		21	21	21	52
	34	266	314	298							21	55
	36	266	313	298								56
	38	266	313	298							21	58
	40	266	313	298								59
	42	266	313	298		16	13		21	21	21	60
	48	266	313	298								64
	52	266	312	298								67
	56	266	312	298		16	13		21	21	21	68
11	00	266	311	298								70
	04	266	311	298								72
	08	266	311	298								74
	12	266	311	298								76
	16	266	311	298								77
	20	266	311	298								79
	24	266	310	298								80
	28	266	310	298								82
	30	266	310	298		15	13		20	20	21	82
12	00	266	310	298								89
12	28	266	310	298								92
12	32	266	310	298	15	15	13		20	20	22	92
12	50 00	266	310	297								93
13	04 00											94
13	15											94
13	35 00											95
14	32 00											96

C 801 (10-24-51)

15 19 00 96

(3)

TRIM 105 - TEMPS DURING WARMUP

J.O. ____ DATE 4/22/80

Time		J-1 Temp			702 Temp				Gimbal Temps			
									Th 702		J-1	
HR	MN SC	T_V °C	T_{CV} °C	T_{NV} °C	T_V °C	T_{CV} °C	T_{NV} °C		#1 °C	#2 °C	#3 °C	manifold °C
07	07 00	266	311	294		16	14		20	20	25	95
→ THROTTLE = 1A												
08	1600	266	311	294								96
	1630	271	311	292								
	1700	275	310	290								
	1730	278	310	289								
	1800	277	310	289								
	1900	277	310	289								96
	24	277	310	289								96
	38	277	310	289								97
8	51	278	310	289								99
	55	278	310	289								99
9	06	278	310	289								101
9	16	278	310	289								102
9	26	278	310	289								102
9	37	278	310	289								103
10	37	278	309	289								105
11	10	278	309	289								105
11	28	278	309	289								105
12	05	278	309	289	16	16	13		20	20	26	105
12	30 00	Throttle TO 3/4										
12	32 00	267	312	294		Printout		26	59			105
12	35 00	267	312	294								105
13	0500	267	312	293								102
13	41	267	311	293								99
14	17 00	267	311	293	16	16	13	26	21	21	26	98
14	30	Readjust J_B & V_S Set PT										

C 801 (10-24-51)

④

TRIM 105 - TEMPS DURING WARMUP

- J O. ____________

DATE ____________

Time		J-1 Temp			702 Temp				Gimbal Temps			
									Th 702		J-1	
		T_V	T_{CV}	T_{NV}	T_V	T_{CV}	T_{NV}		#1	#2	#3	manifold
HR	MN SC	°C	°C	°C	°C	°C	°C		°C	°C	°C	°C
14	49 00				17	17	14					98
14	51 30				24	28	20					
14	53 00				37	45	31					
14	54 00				47	58	39					
14	55 00				60	72	50					
14	56 00				74	85	60					
14	57 00				87	99	71					
14	58 00				99	111	81					
14	59 00				110	124	92					
15	00 00											
15	01 00				132	146	111					
15	02 00				143	156	120					
15	03 00				154	165	129					
15	04 00				163	174	137					
15	05				172	181	143					
15	06				180	188	150					
15	07				189	193	155					
15	08				196	198	160					
15	09				203	202	164					
15	10											
15	11				211	208	172					
15	12				215	209	254					
15	13											
15	14				219	214	325					
	15				220	215	358					
	16				222	217	372					
	18				223	220	378					
	20				?							
	21				226	224	298					

C 801 (10-24-51)

(5)

TRIM 105 - TEMPS DURING WARMUP

J.O. ____ DATE 4/22/80

Time		J-1 Temp			702 Temp				Gimbal Temps				
									Th 702		J-1		
HR	MN SC	Tv °C	Tcv °C	Tnv °C	Tv °C	Tcv °C	Tnv °C		#1 °C	#2 °C	#3 °C	manifold °C	
15	24 00				227	305	335						
15	26 00				227	327	377						
15	28 00				223	328	380						
15	29 30				219	330	381						
15	31 00				214	332	382						
15	32 00				229	280	379	Beam ON				97	
15	33 00				236	253	335						
15	34 00				240	240	332						
15	35 00				244	230	332						
15	36				263	228	366						
15	37				263	218	333						
15	38				242	214	288						
15	39 30												
16	00 00	266	312	293	238	346	331		22	22	26	97	702 on about 1550
4/23/80													
07	00 00	266	311	293	247	314	330		28	29	28	98	
08	46 00	266	311	293	246	314	330		28	28	28	98	
08	48 xx	Command Both Thrusters To Throttle To 2.0A											
08	55 xx	Both thrusters at 2.0A											
08	56 00	303	315	287	276	313	319		28	28	28	98	
09	37 00											121	
10	06 00											131	
10	22 40											134	
10	59 00											137	
11	38 00											138	
12	04 00	303	312	289	287	280	220					138	
4/24/80													
~~07~~	~~04 00~~	~~286~~	~~277~~	~~320~~	~~38~~								
07	04 00	304	311	289	286	277	320		33	33	32	138	stable at 20a both Th

C 801 (10-24-51)

THROTTLE DOWN

J O.

DATE 4/24/80

(6)

$J_B = 2A$

	J-1					702				TIME		
	T_V	T_{CV}	T_{NV}	T_M		T_V	T_{CV}	T_{NV}				
	304	311	289	137		286	278	320		09	52	40
THROTTLE TO 0.75A												
	268.	304	296	136		256	318	330		10	04	
	268	305	295	125		~~249~~	318	330		10	24	
	268	305	294	119		248	318	330		10	36	
	268	305	295	114		247	319	330		10	46	
	268	305	294	109		245	319	330		11	02	

C 801 (10-24-51)

APPENDIX C
ACCEPTANCE TEST DATA

APPENDIX C

ACCEPTANCE TEST DATA

This appendix defines the symbols and equations used in this report for describing the thruster characteristics and reducing data. Tables and curves presenting the more important data from the acceptance tests of the retrofit thrusters is included also.

1. Symbols, Definitions and Equations

The symbols for the thruster parameters which follow are related to the power supplies and test circuit as shown in Figure C1.

a) DIRECTLY MEASURED PARAMETERS

SYMBOL	SUPPLY IDENTIFICATION	DESCRIPTION
V_{MV}	V_1	Main Vaporizer Voltage
V_{CV}	V_2	Cathode Vaporizer Voltage
V_{CH}	V_3	Cathode Heater Voltage
V_{IH}	V_4	Isolator Heater Voltage
V_{NH}	V_5	Neutralizer Heater Voltage
V_{NV}	V_6	Neutralizer Vaporizer Voltage
V_{NK}	V_7	Neutralizer Keeper Voltage
V_{CK}	V_8	Cathode Keeper Voltage
V_D	V_9	Discharge Chamber Voltage
V_{AS}	V_{10}	Accelerator Supply Voltage
V_{Accel}		Accelerator Potential
V_S	V_{11}	Screen Supply Voltage
V_b		Beam (Net Accelerating) Potential
V_{MB}	V_{12}	Magnetic Baffle Voltage
V_G		Neutralizer to Ground Coupling Voltage
V_T		Total Accelerating Voltage

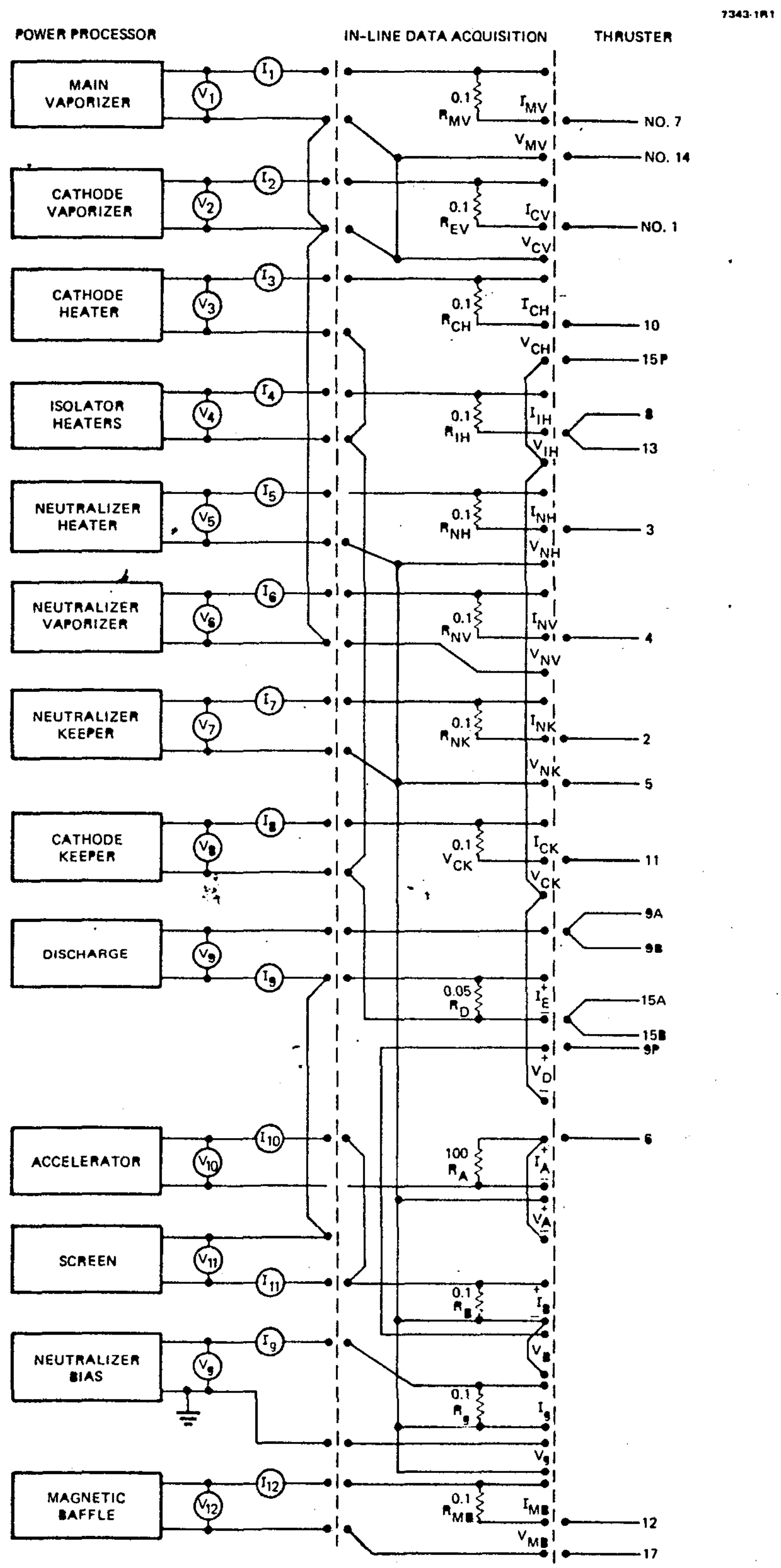


Fig. C.1 Acceptance Test Circuit Diagram

SYMBOL	SUPPLY IDENTIFICATION	DESCRIPTION
J_{MV}	J_1	Main Vaporizer Current
J_{CV}	J_2	Cathode Vaporizer Current
J_{CH}	J_3	Cathode Heater Current
J_{IH}	J_4	Isolator Heater Current
J_{NH}	J_5	Neutralizer Heater Current
J_{NV}	J_6	Neutralizer Vaporizer Current
J_{NK}	J_7	Neutralizer Keeper Current
J_{CK}	J_8	Cathode Keeper Current
J_E		Cathode Emission Current
J_D	J_9	Discharge (Anode) Current
J_{Accel}	J_{10}	Accelerator Drain or Impingement Current
J_S	J_{11}	Screen Current
J_b		Beam Current
J_{MB}	J_{12}	Magnetic Baffle Current
J_G		Neutralizer to Ground Clamp Current
T_{MV}		Main Vaporizer Temperature
T_{CV}		Cathode Vaporizer Temperature
T_{NV}		Neutralizer Vaporizer Temperature

b. VALUES OBTAINED FROM $\vec{E}\times\vec{B}$ PROBE

α	Thrust reduction factor due to doubly charged ions
F_T	Thrust reduction factor due to non-axial ion trajectories
J_b^+	Singly charged ion beam current
J_b^{++}	Doubly charged ion beam current

c. DIRECTLY MEASURED PROPELLANT FLOW RATES

$\dot{m}_{MV}$	Main Propellant Flow Rate
$\dot{m}_{CV}$	Cathode Propellant Flow Rate
$\dot{m}_{NV}$	Neutralizer Propellant Flow Rate

d. RELATIONS BETWEEN DIRECTLY MEASURED PARAMETERS

$$V_b = V_S + V_D - |V_G| \text{ , V}$$

$$V_{Accel} = V_{AS} - |V_G| \text{ , V}$$

$$V_T = V_b + V_{Accel} \text{ , V}$$

$$J_S = J_b + J_{Accel} \text{ , A}$$

$$J_D = J_E + J_b \text{ , A}$$

$$J_b = J_b^+ + J_b^{++} \text{ , A}$$

e. CALCULATED POWERS

P_b = Beam Power = $V_b J_b$, W

P_D = Discharge Power = $V_D J_E$, W

P_N = Neutralizer Power = $V_{NK} J_{NK} + V_G J_b$, W

P_V = Vaporizer Power = $V_{MV} J_{MV} + V_{CV} J_{CV} + V_{NV} J_{NV}$, W

P_t = Total Input Power = $[P_b + P_D + P_N + P_V + (V_S + |V_{AS}|) J_{Accel} + V_{CK} J_{CK} + V_{MB} J_{MB}]$, W

f. OTHER PERFORMANCE CALCULATIONS

γ = Total Thrust Reduction Factor = αF_T

β = Discharge Chamber Utilization Corrector Factor = $[\frac{\gamma}{F_T}(1 + \sqrt{\frac{2}{2}}) - \sqrt{\frac{2}{2}}]$

$\dot{m}_t$ = Total Propellant Flow Rate = $\dot{m}_{MV} + \dot{m}_{CV} + \dot{m}_{NV}$, A eq.

η_{mD} (unc) = Uncorrected Discharge Propellant Utilization = $\frac{J_b}{\dot{m}_{MV} + \dot{m}_{CV}} \times 100$, %

η_{mD} = Corrected Discharge Propellant Utilization = $\beta \, \eta_{mD}$ (unc) , %

$\eta_{m(Unc)}$ = Uncorrected Total Propellant Utilization = $\frac{J_b}{\dot{m}_t} \times 100$, %

η_e = Electrical Efficiency = $(\frac{J_b V_b}{P_t} \times 100)$, %

η_T = Corrected Total Thruster Efficiency = $\gamma^2 \frac{\eta_e \, \eta_{m(Unc)}}{100}$, %

F = Corrected Thrust = $2.0391 \, \gamma \, J_b \sqrt{V_b}$, mN

I_{SP} = Corrected Specific Impulse - $100.08 \, \gamma \, \frac{J_b}{\dot{m}_t} \sqrt{V_b}$, sec.

2. Thruster Performance Data and Characteristics

The data contained in the following pages is organized by thruster and is comprised of the following:

- Acceptance Test Data/Performance Summary
- Magnetic Baffle Current Characterization and Reference Selection
- Neutralizer Characteristics and Reference Selection
- Ion Optics Characteristics (Perveance) and Minimum Extraction Voltage
- Minimum Discharge Loss Characteristic

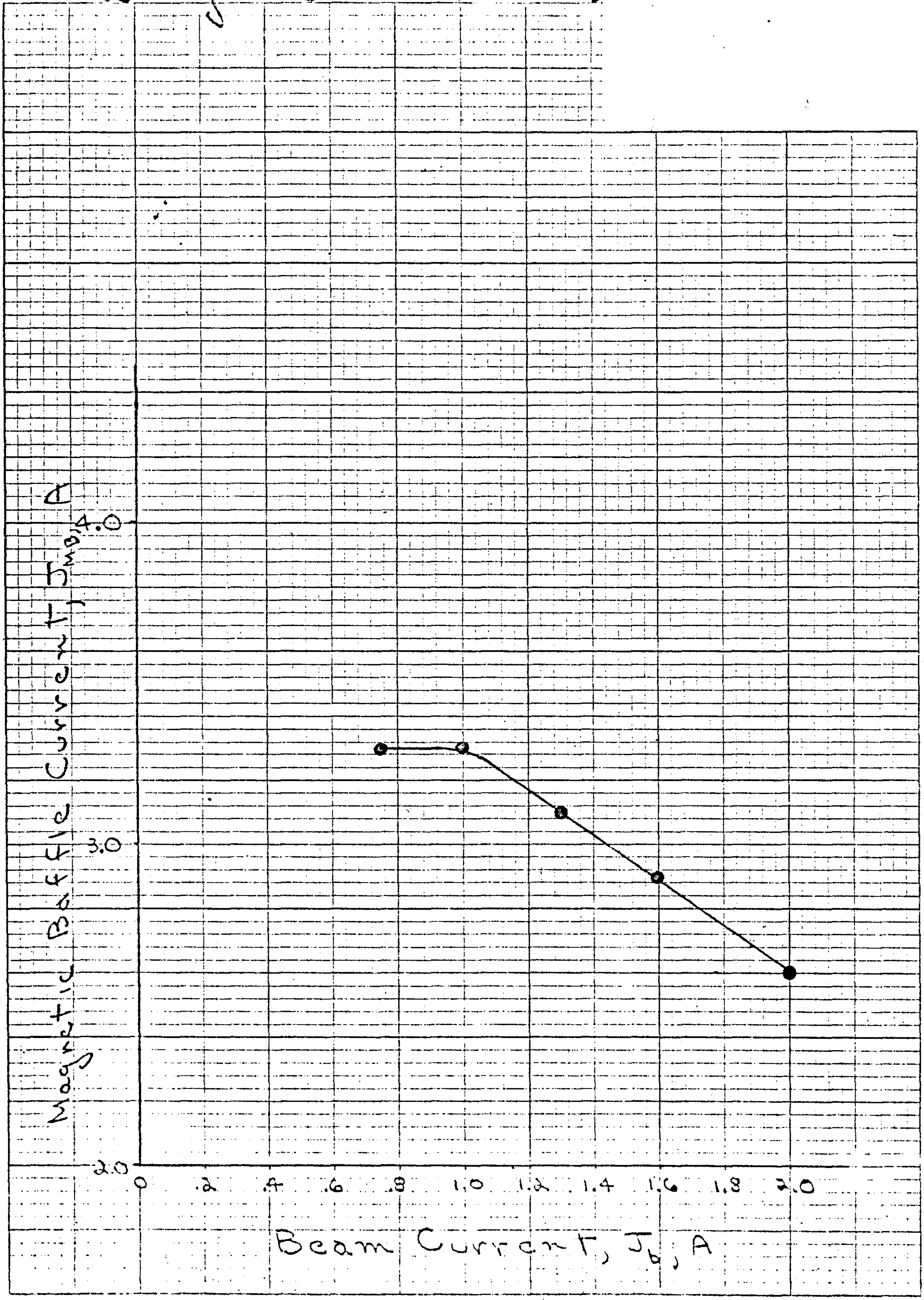
ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

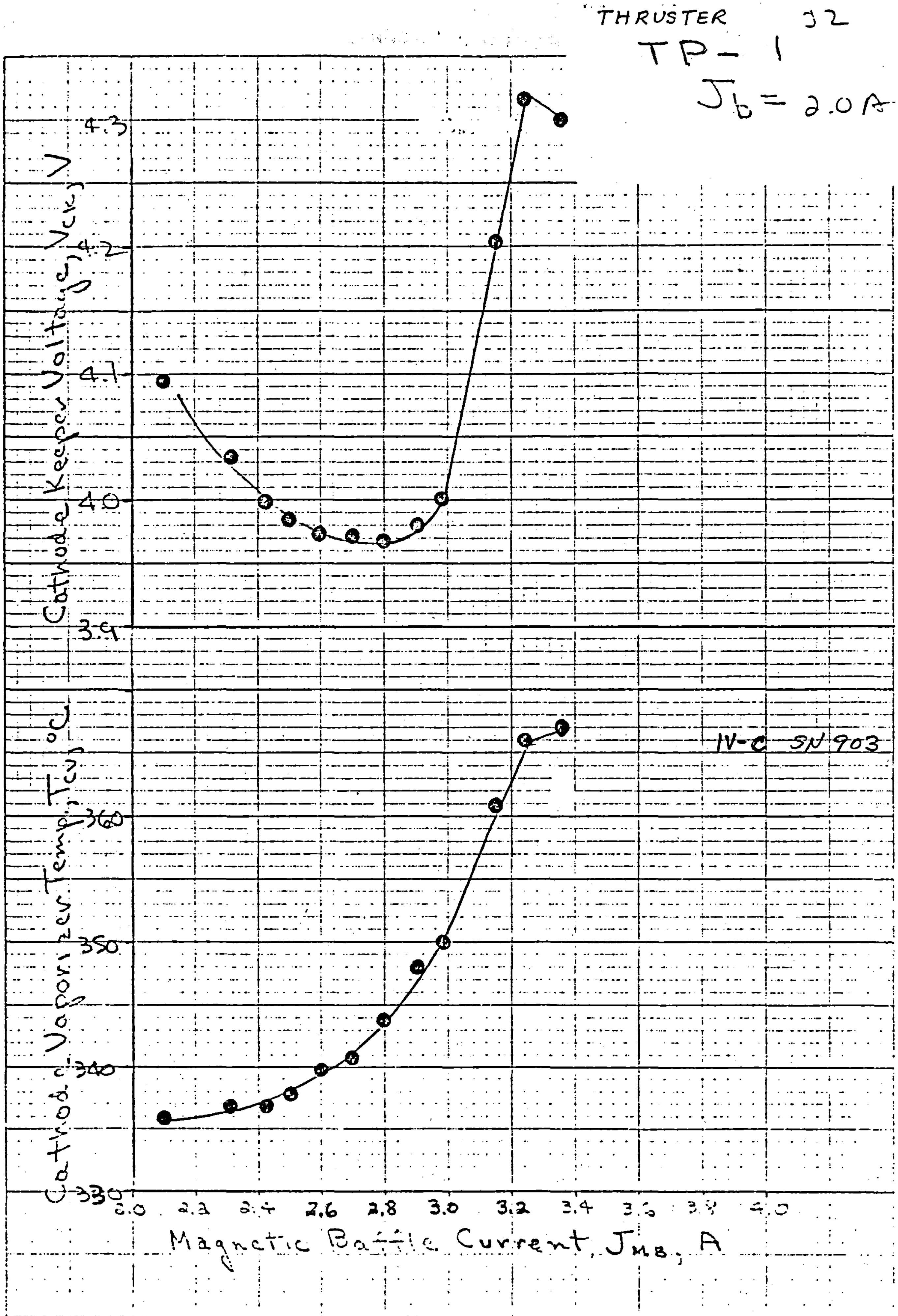
THRUSTER J2

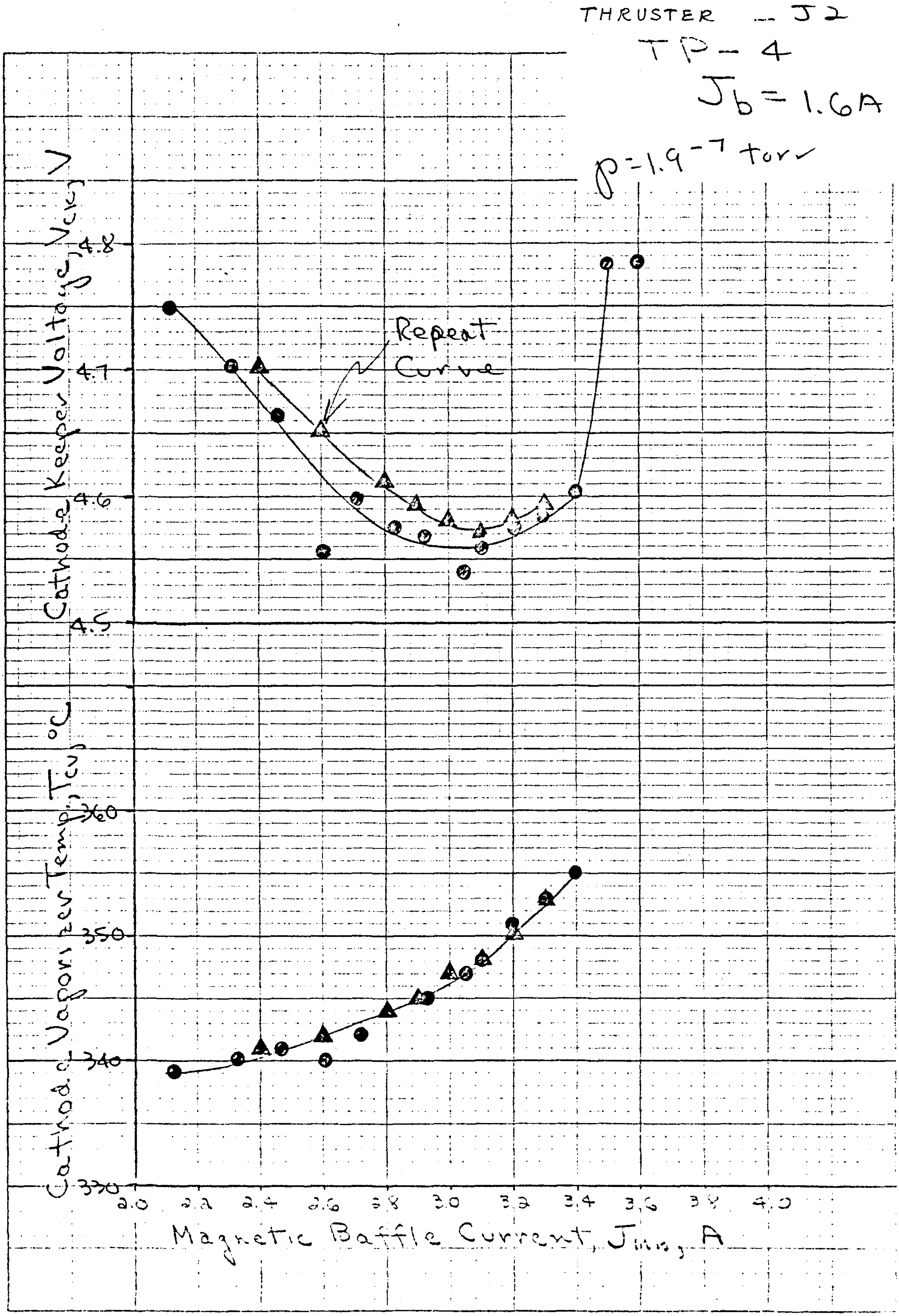
	TEST POINT		1	2	3	4	5	6	7	8	9	10
OPERATING PARAMETERS	V_b	V	1100	1100	1099	936	1101	819	700	1101	600	600
	J_b	A	1.998	1.997	1.995	1.594	1.303	1.302	1.000	.751	.752	.752
	V_D	V	32.01	30.97	32.02	32.05	32.02	32.00	32.00	31.98	31.98	31.00
	J_D	A	14.0	14.0	13.4	11.59	9.8	9.8	8.0	6.51	6.51	6.49
	J_E	A	12.0	12.0	11.4	10.0	8.5	8.5	7.0	5.76	5.76	5.74
	J_{MB}	A	2.60	2.60	2.6	2.90	3.10	3.10	3.30	3.30	3.30	3.30
	V_{CK}	V	3.92	3.99	4.06	4.62	4.97	4.88	5.72	6.58	6.55	6.64
	J_{CK}	A	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
	V_{Accel}	V	-308	-307	-308	-304	-306	-301	-299	-304	-296	-296
	J_{Accel}	mA	3.31	3.57	3.50	2.49	1.93	2.17	1.57	1.80	1.24	1.31
	V_{NK}	V	13.38	13.43	13.40	13.49	13.31	13.33	13.89	13.70	13.70	13.71
	J_{NK}	A	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
	V_G	V	9.47	9.47	9.46	9.38	9.35	9.28	9.16	9.18	9.02	9.06
FLOWS	T_{MV}	°C	349	349	349	340	332	333	322	311	311	312
	T_{CV}	°C	335	337	333	350	347	345	352	355	355	357
	T_{NV}	°C	291	291	289	298	297	298	298	302	303	303
	$\dot{m}_{MV}$	eq. A	1.993	1.995	1.986	1.572	1.305	1.302	1.015	.764	.759	.781
	$\dot{m}_{CV}$	eq. A	.056	.060	.053	.078	.072	.065	.080	.086	.084	.087
	$\dot{m}_{NV}$	eq. A	.023	.024	.023	.027	.027	.023	.027	.031	.030	.031
	$\dot{m}_t$	eq. A	2.072	2.079	2.062	1.677	1.404	1.390	1.122	.881	.873	.899
	η_{mD} (unc)	%	97.5	97.2	97.8	96.6	94.6	95.2	91.3	88.4	89.2	86.6
	η_{mD}	%	93.7	94.1	94.4	94.4	93.2	93.8	90.5	88.1	88.3	86.4
	η_m (unc)	%	96.4	96.1	96.8	95.1	92.8	93.7	89.1	85.2	86.1	83.6
POWER	P_b	W	2198	2197	2193	1492	1435	1066	700	827	451	451
	P_V	W	12.41	13.00	12.30	13.64	13.98	13.88	14.36	15.53	15.53	15.34
	P_t	W	2647	2634	2623	1874	1766	1397	982	1070	692	686
	η_e	%	83.0	83.4	83.6	79.6	81.3	76.3	71.3	77.3	65.2	65.7
BEAM	α		.9773	.9814	.9796	.9855	.9911	.9909	.9951	.9981	.9994	.9985
	r_T		.9880	.9880	.9884	.9878	.9893	.9893	.9878	.9877	.9881	.9883
	γ		.9656	.9696	.9682	.9735	.9805	.9803	.9831	.9858	.9875	.9868
	β		.9611	.9681	.9650	.9771	.9847	.9858	.9917	.9968	.9993	.9975
	J_b^{++}/J_b^{+}		.0848	.0686	.0759	.0424	.0321	.0254	.0169	.0063	.0013	.0050
MISC.	η_T	%	74.6	75.3	75.9	71.7	72.5	68.7	61.4	64.0	54.7	53.5
	F	mN	130.5	130.0	130.6	96.8	86.4	74.5	53.0	50.1	37.1	37.1
	I_{sp}	s	3091	3091	3108	2833	3022	2630	2320	2791	2055	2024
	p_{tank}	pa	8.6^{-5}	1.18^{-4}	1.18^{-4}	1.02^{-4}	1.26^{-4}	6.0^{-5}	1.46^{-5}	4.79^{-5}	4.39^{-5}	4.26^{-5}

Thruster J2

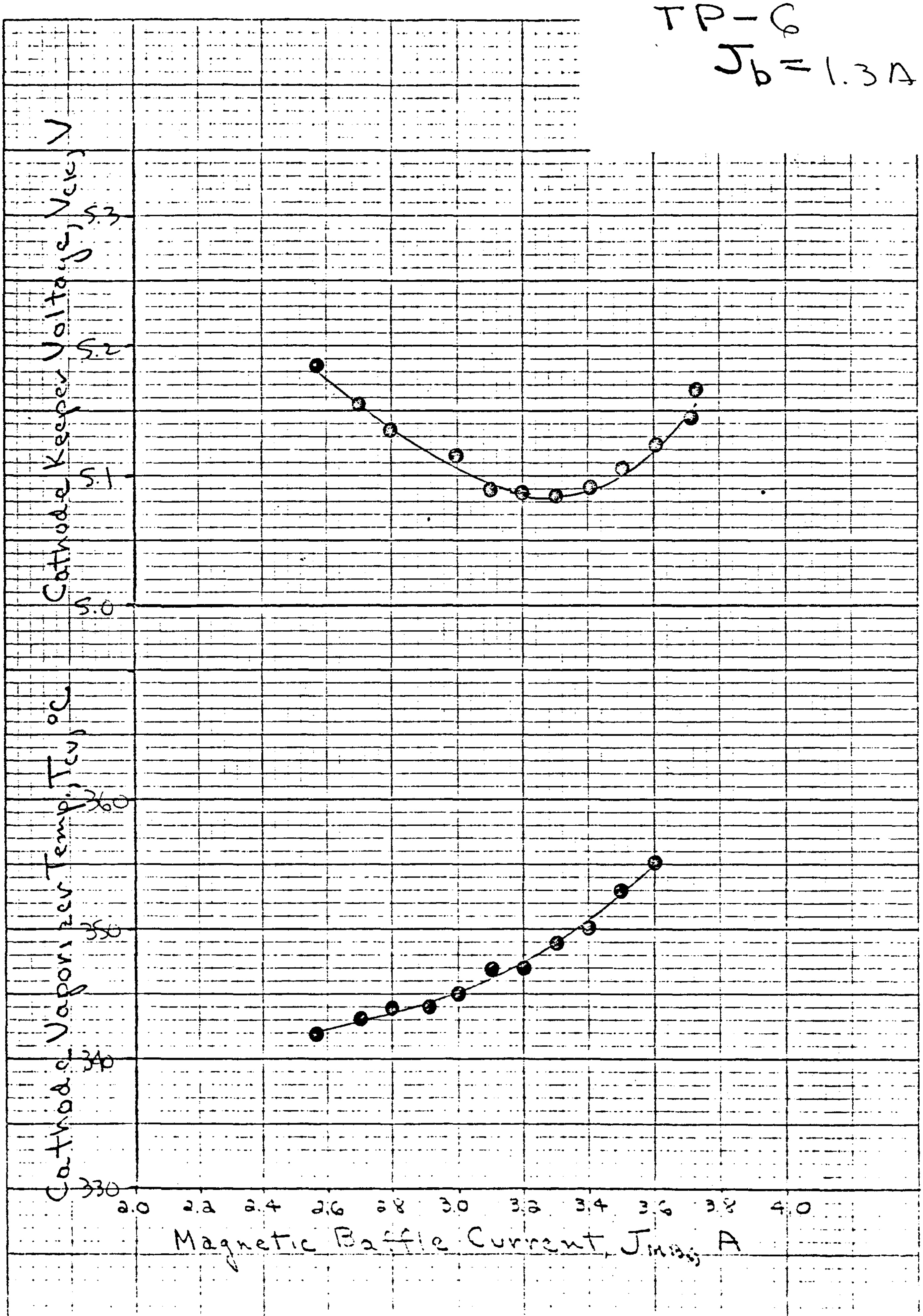
Selected Magnetic Baffle Currents

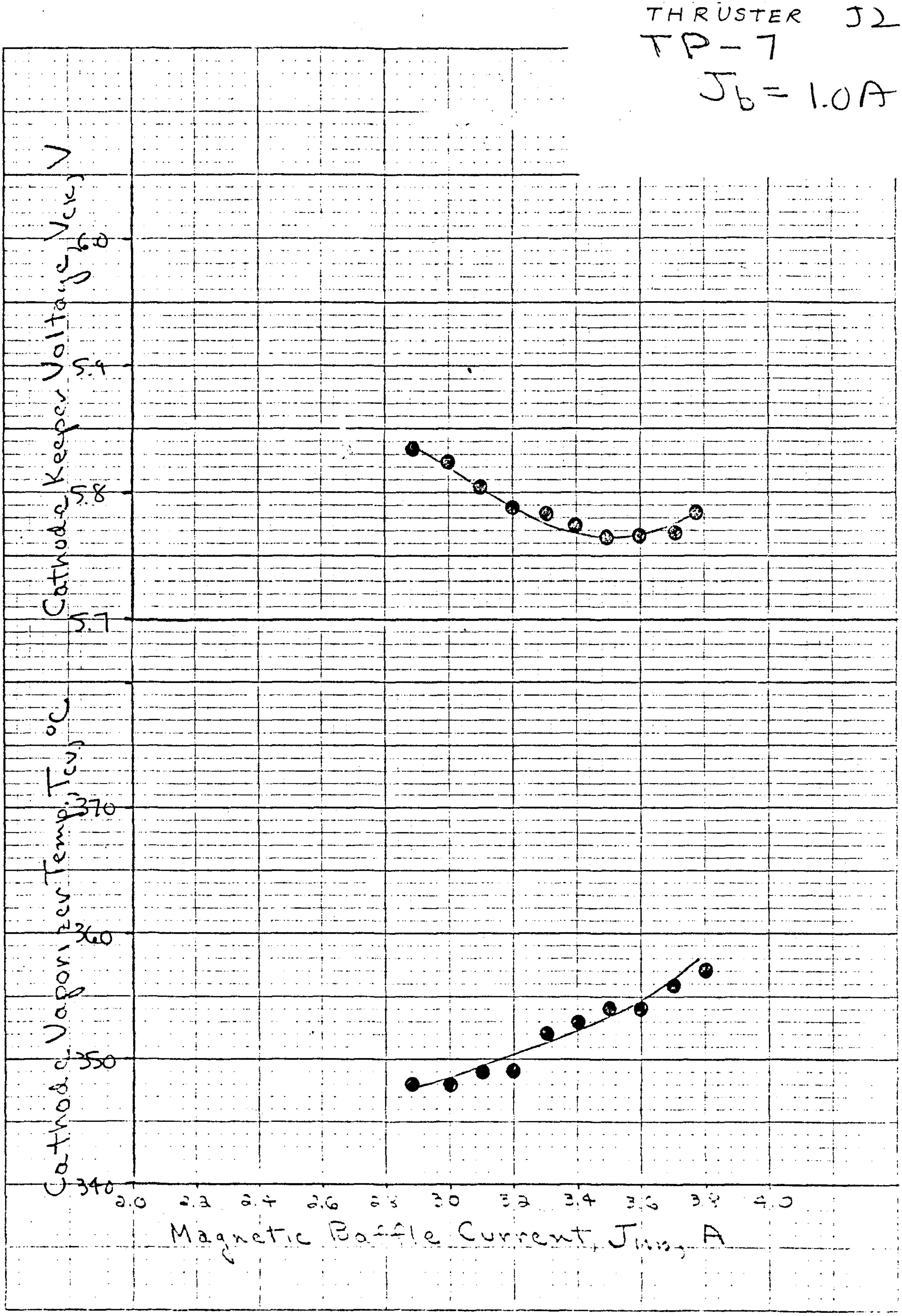



THRUSTER J2
TP-1
J_b = 2.0A
IV-C SN 903
Cathode Keeper Voltage, V_{CK}, V
4.3
4.2
4.1
4.0
3.9
Cathode Vaporizer Temp, T_{CV}, °C
360
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A

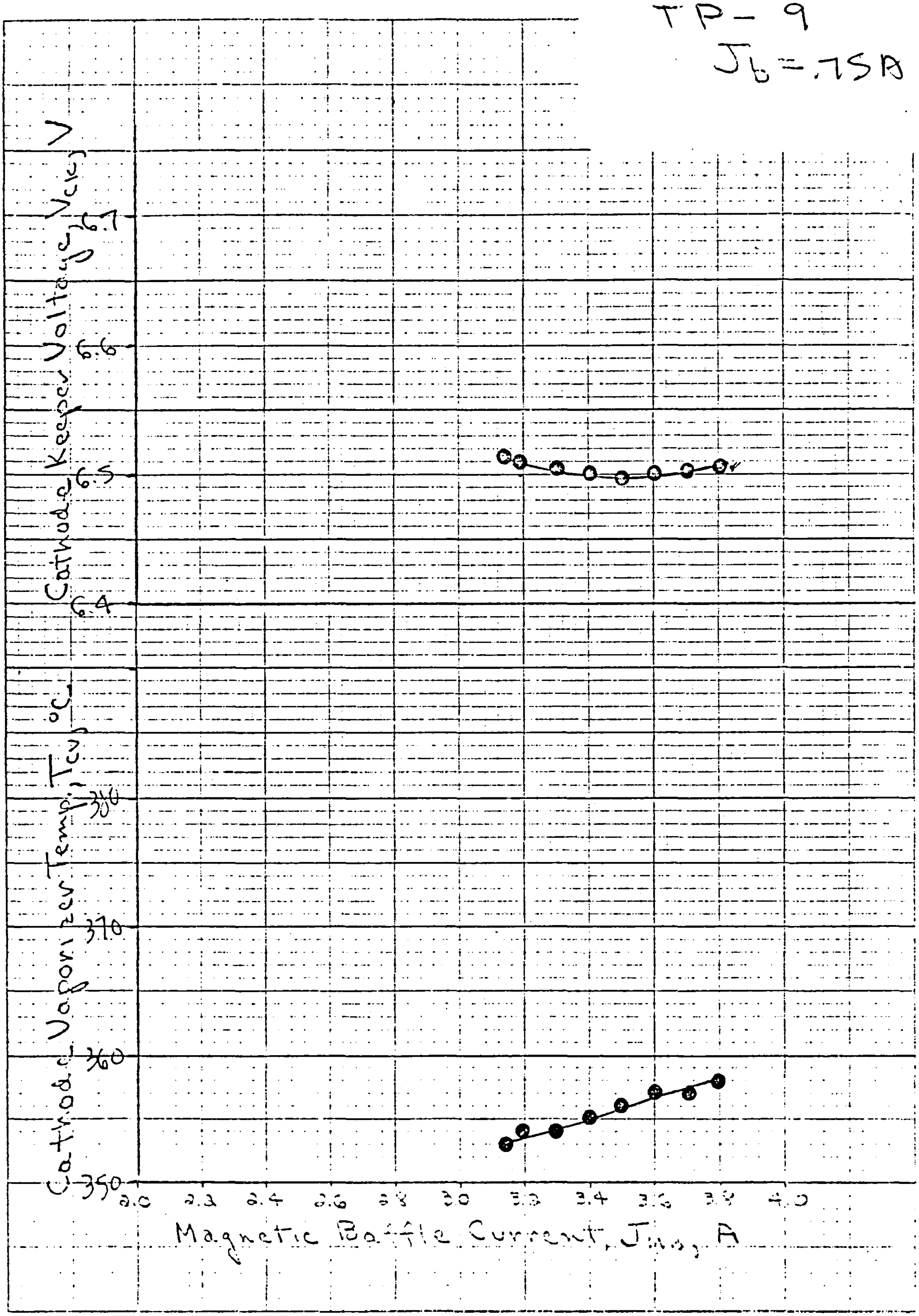

THRUSTER J2
TP-4
Jb = 1.6A
p = 1.9-7 torr
Repeat Curve
Cathode Keeper Voltage, VCK, V
Cathode Vaporizer Temp., TCV, °C
Magnetic Baffle Current, JMB, A
4.8
4.7
4.6
4.5
360
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0

Thruster___ J2
TP-6
$J_b = 1.3$ A



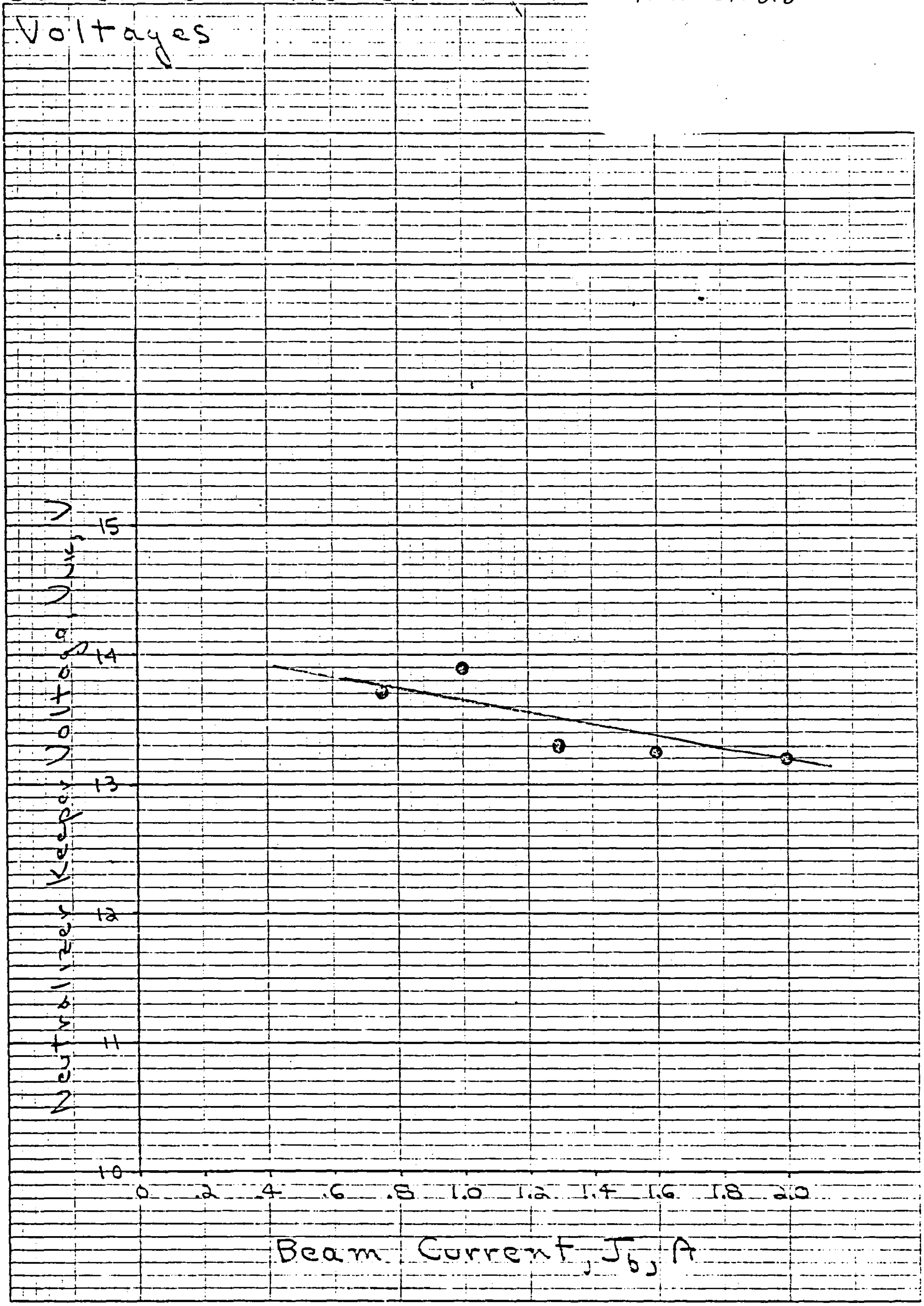

THRUSTER J2
TP-7
Jb = 1.0A
Cathode Keeper Voltage, Vck, V
6.0
5.9
5.8
5.7
Cathode Vaporizer Temp, Tcv, °C
370
360
350
340
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, JMB, A

THRUSTER J2
TP-9
$J_b = .75A$



Selected Neutralizer Keeper Voltages

Thruster J2
IV-N SN 815



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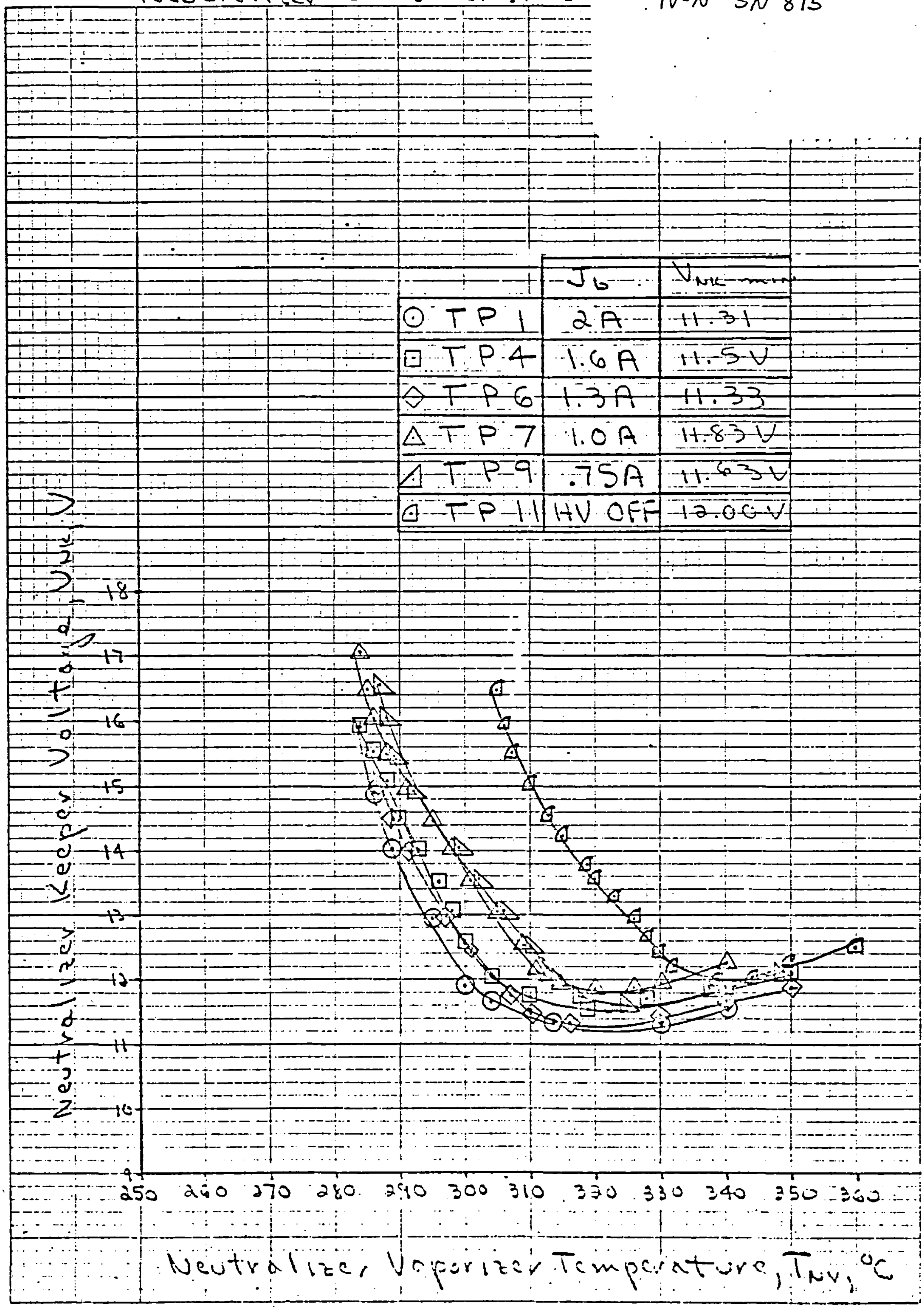
KEUFFEL & ESSER CO. MADE IN U.S.A.

Thruster J2
IV-N SN 815

Neutralizer Characteristics



Minimum Voltage for J_b

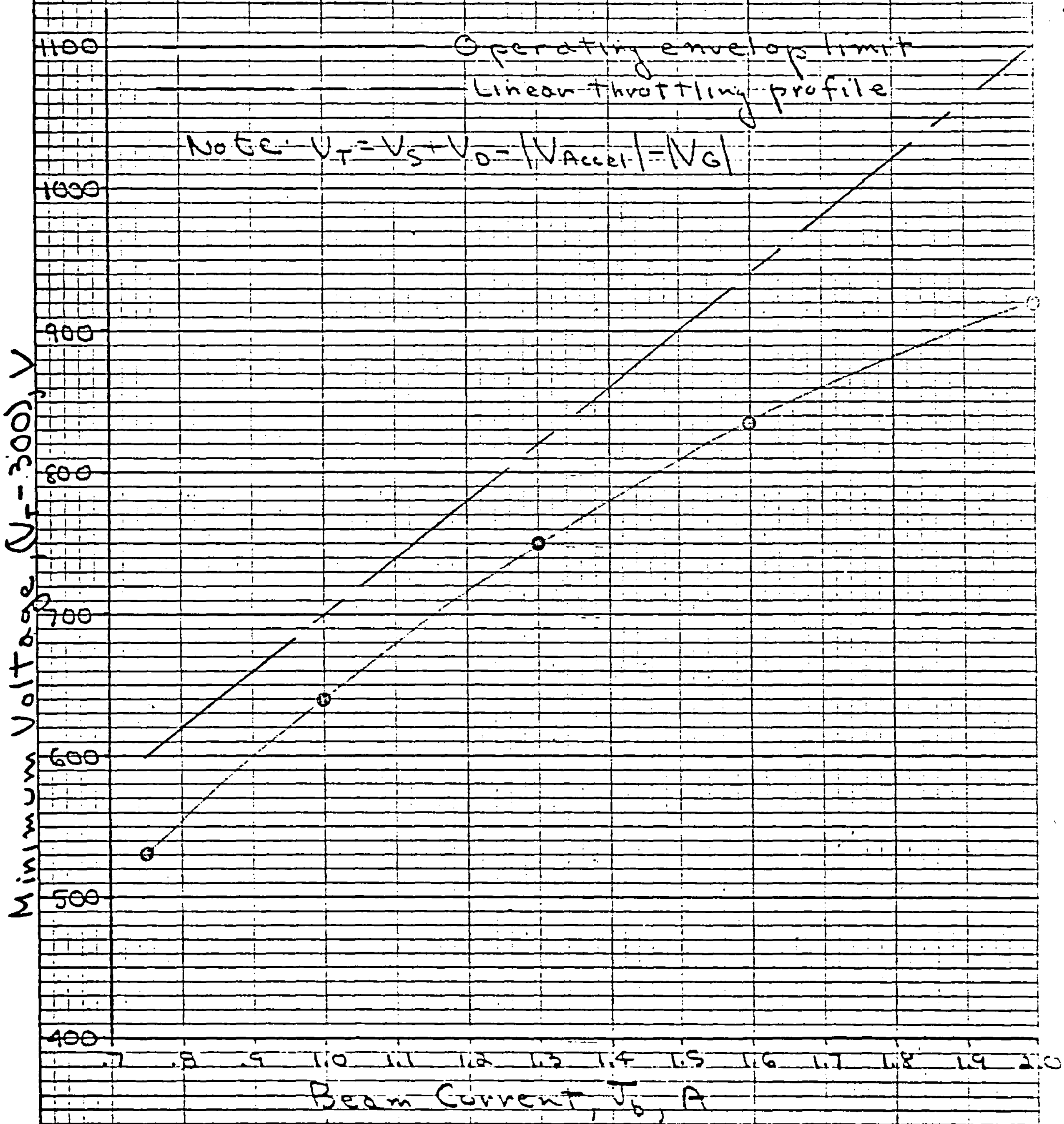
(Assumes $V_{AS} \doteq -300V$)

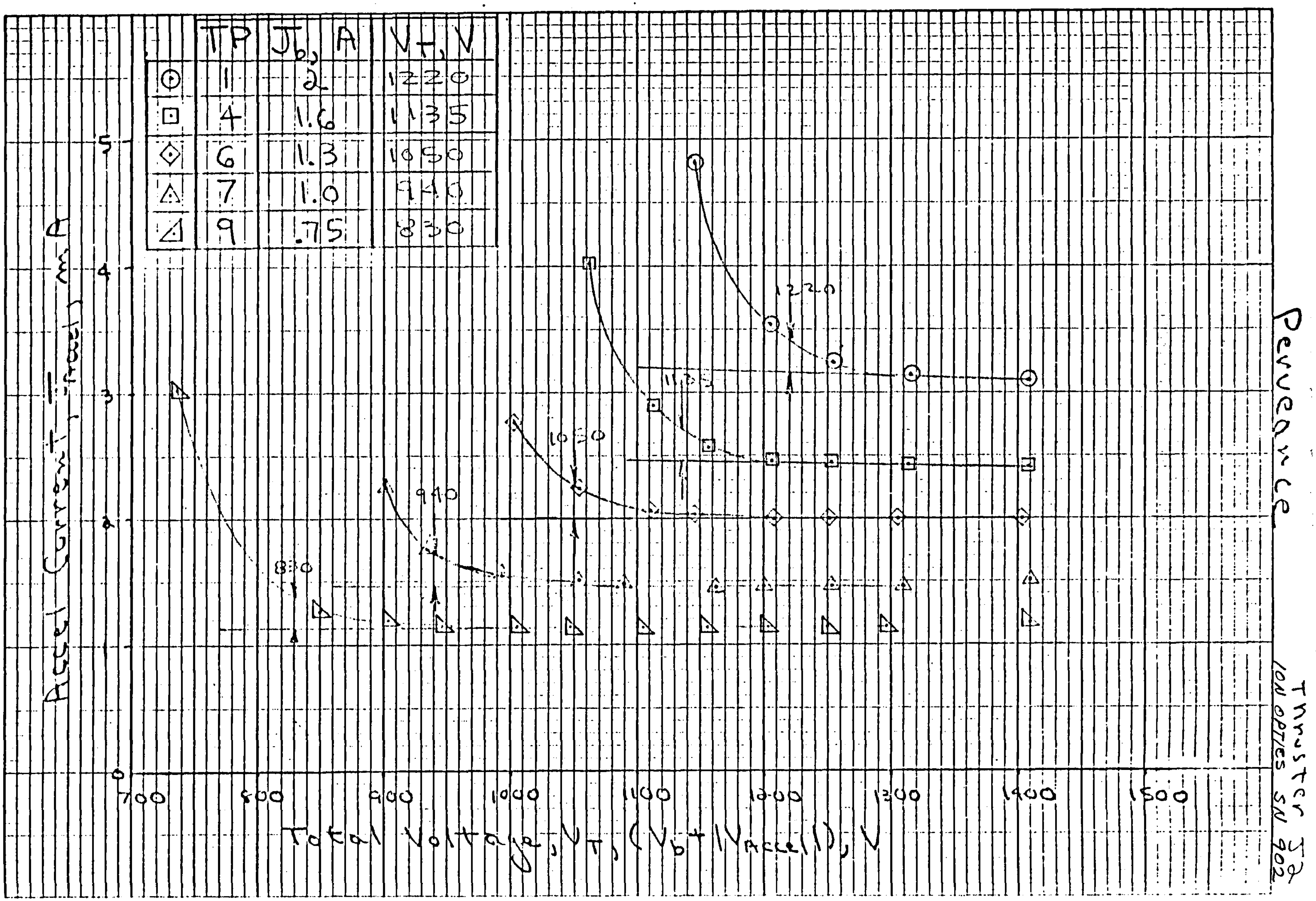
THRUSTER J2

ION OPTICS SN 902

Note:

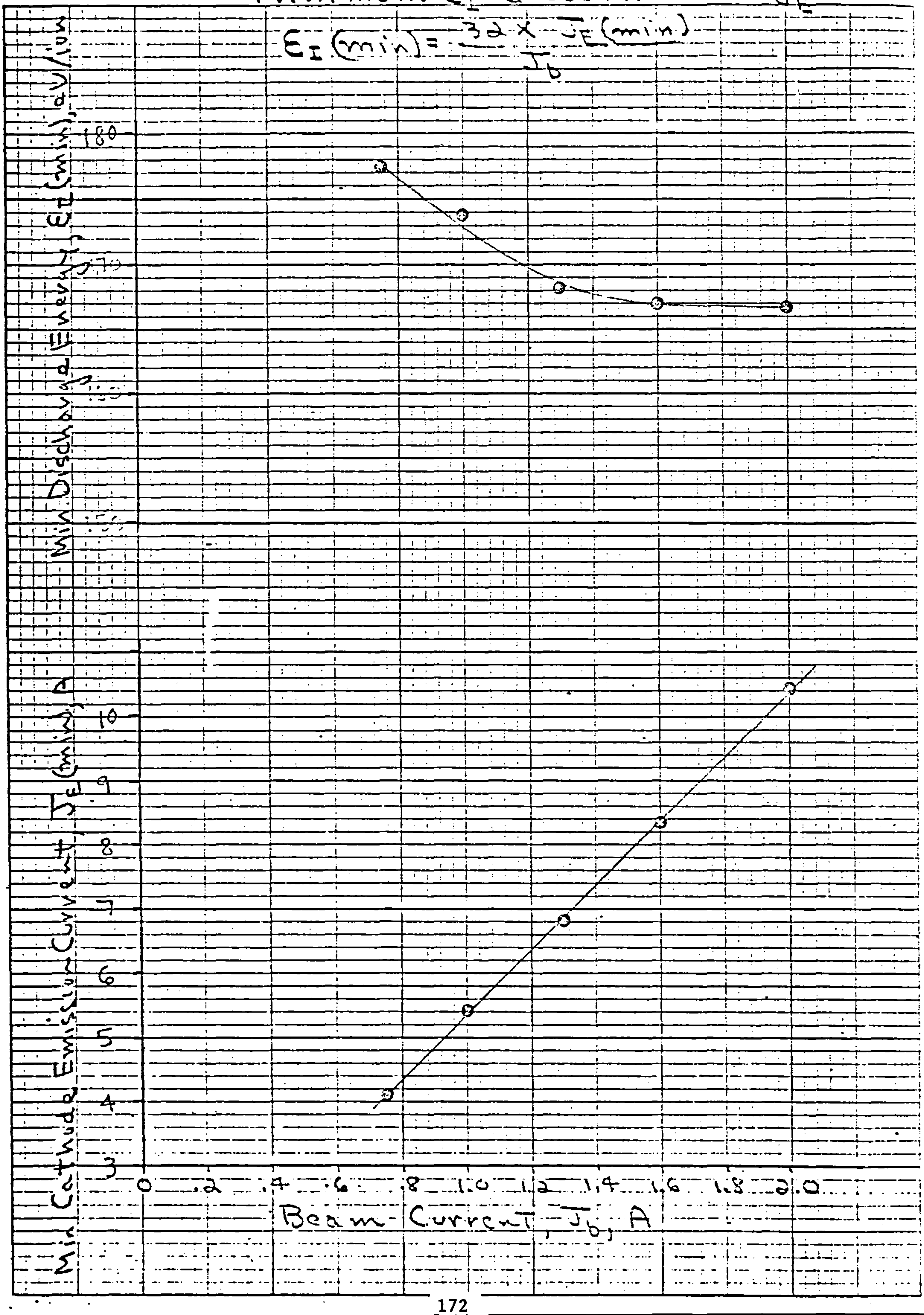
$V_T = V_S + V_D + |V_{Accel}| - |V_G|$




TP | J_b, A | V_T, V
1 | 2 | 1220
4 | 1.6 | 1135
6 | 1.3 | 1050
7 | 1.0 | 940
9 | .75 | 830
1220
1135
1050
940
830
Perveance
Accel Current, mA
Total Voltage, V_T, (V_b + |V_{Accel}|), V
700
800
900
1000
1100
1200
1300
1400
1500
Thruster J2
ION OPTICS SN 902

Thruster J2

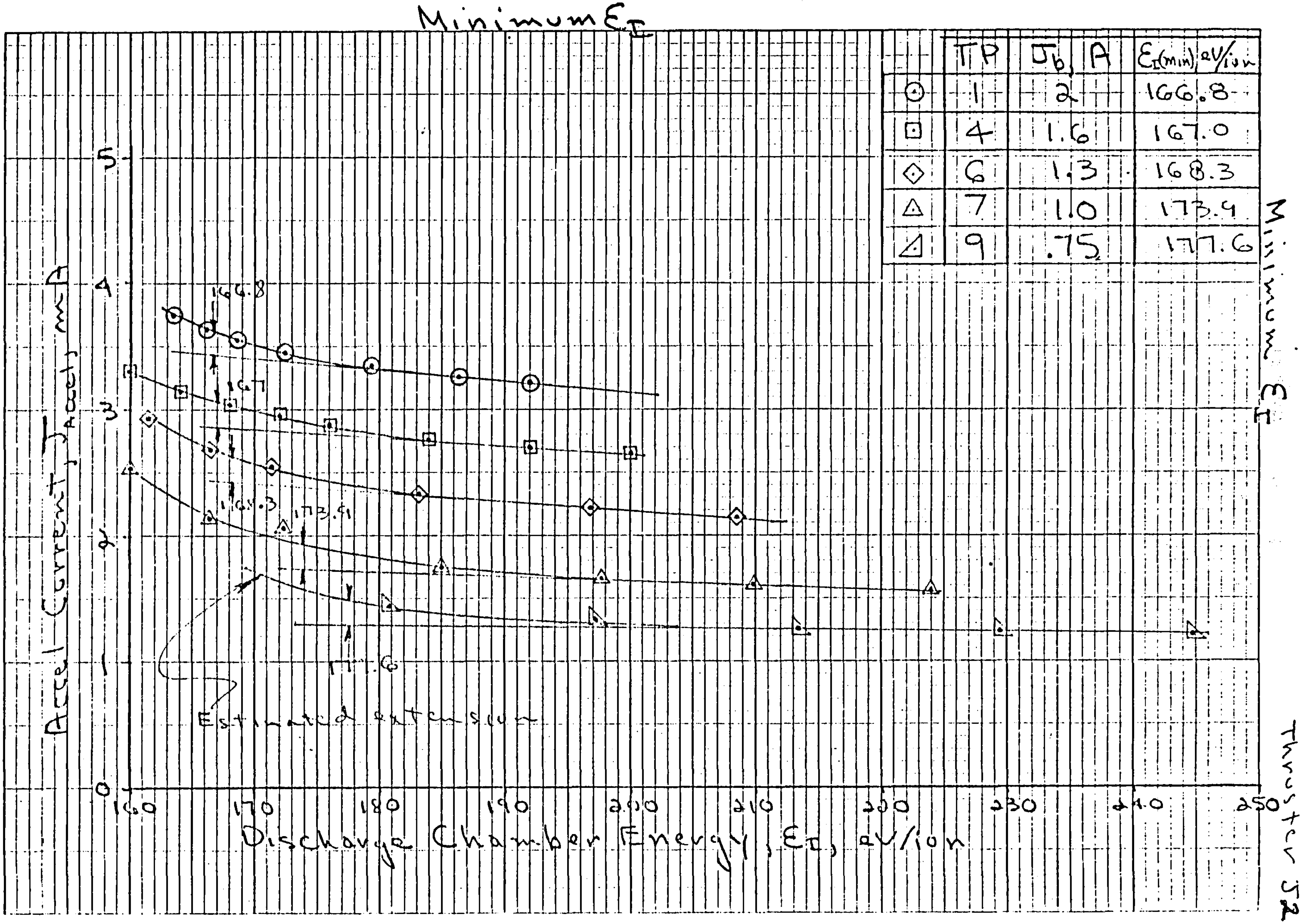
Minimum E_I and Minimum J_E



K•E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

46 0780

Minimum E_I



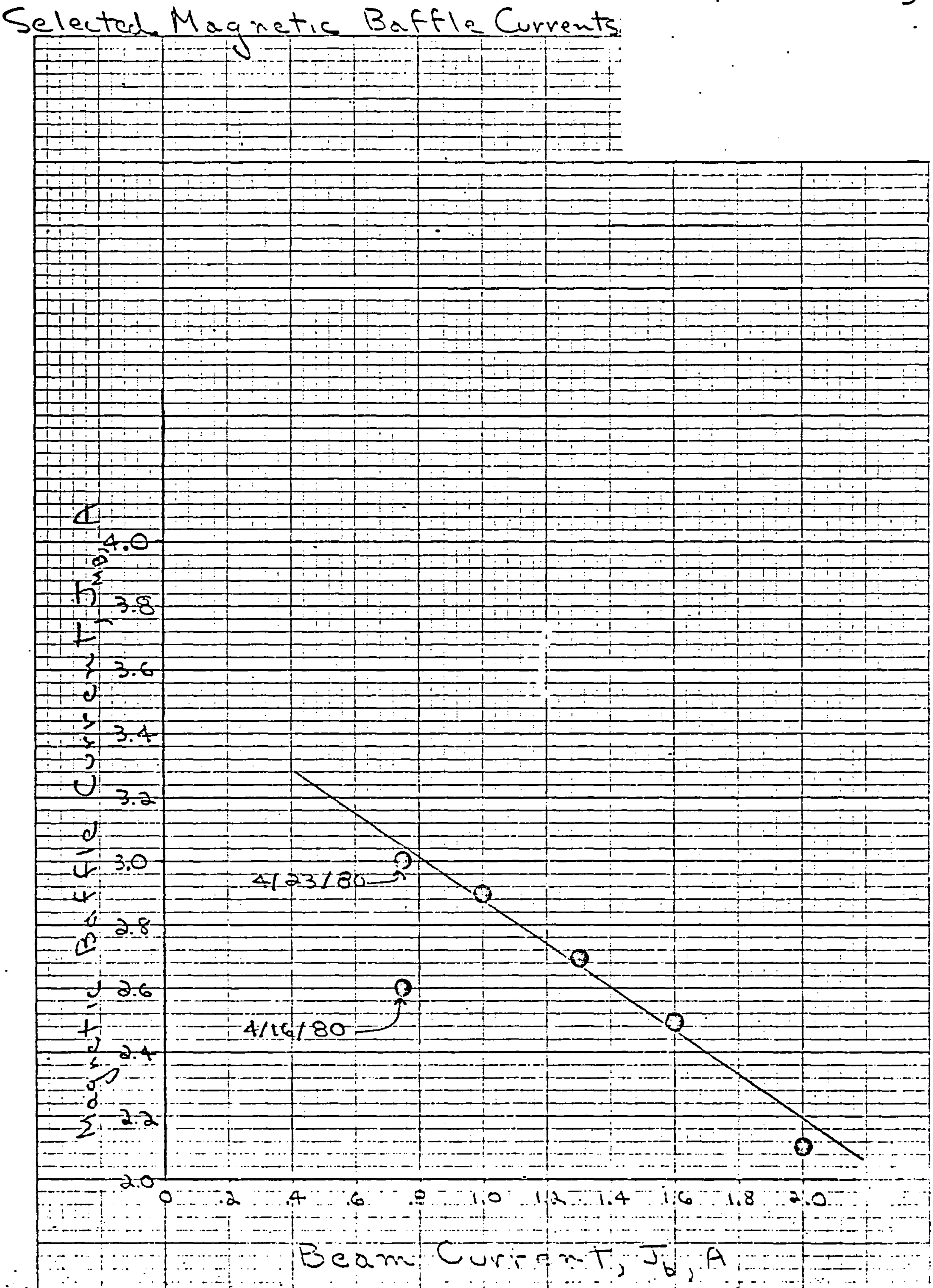
	TP	J_b, A	$E_{I(min)}$ eV/ion
⊙	1	2	166.8
⊡	4	1.6	167.0
◇	6	1.3	168.3
△	7	1.0	173.9
◺	9	.75	177.6

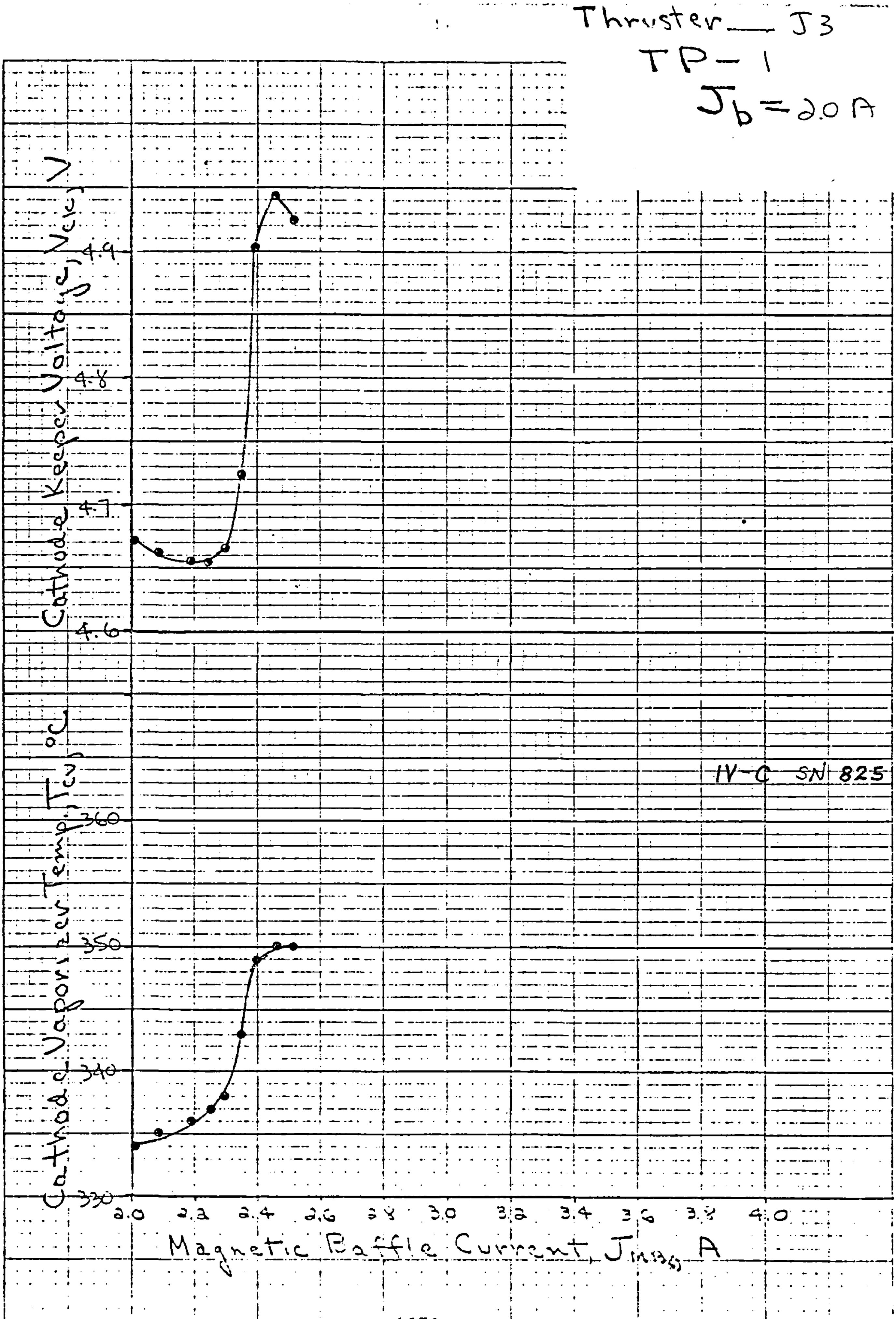
ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

THRUSTER J3

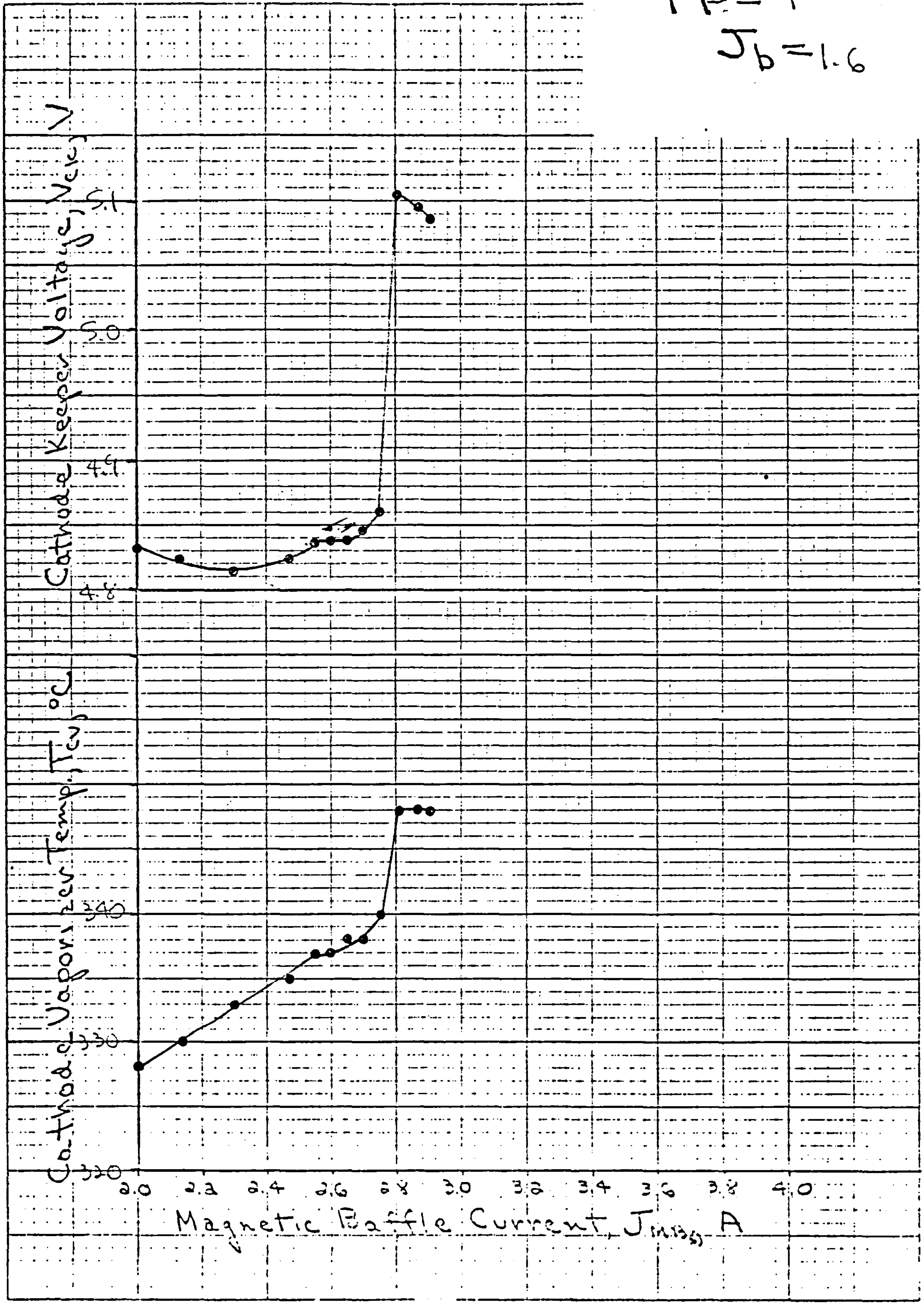
	TEST POINT		1	2	3	4	5	6	7	8	9	10
OPERATING PARAMETERS	V_b	V	1101	1100	1100	940	1099	817	698	1099	597	596
	J_b	A	2.007	2.002	2.003	1.600	1.300	1.297	.997	.751	.750	.750
	V_D	V	32.0	31.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	31.0
	J_D	A	14.0	14.0	13.4	11.6	9.8	9.8	8.0	6.49	6.49	6.49
	J_E	A	12.0	12.0	11.4	10.0	8.5	8.50	7.0	5.74	5.74	5.74
	J_{MB}	A	2.1	2.10	2.10	2.5	2.70	2.70	2.90	3.00	3.00	3.00
	V_{CK}	V	4.30	4.22	4.30	4.80	5.31	5.34	5.99	6.72	6.75	6.88
	J_{CK}	A	.957	.957	.958	.967	.957	.967	.954	.956	.967	.953
	V_{Accel}	V	-340	-340	-340	-336	-341	-334	-331	-339	-328	-327
	J_{Accel}	mA	4.14	4.11	3.90	2.96	1.93	2.27	1.75	1.10	1.25	1.52
	V_{NK}	V	15.08	14.70	14.72	14.99	15.34	15.28	15.71	15.73	15.72	15.80
	J_{NK}	A	1.81	2.10	2.10	1.81	1.81	1.81	1.81	1.81	1.81	1.80
	V_G	V	10.55	10.61	10.61	10.84	10.96	11.09	11.14	11.40	10.90	11.16
FLOWS	T_{MV}	°C	314	313	311	309	297	296	287	276	275	274
	T_{CV}	°C	326	330	321	336	340	338	338	344	344	357
	T_{NV}	°C	298	306	304	304	306	306	309	316	311	316
	$\dot{m}_{MV}$	eq. A	1.971	2.016	2.002	1.593	1.287	1.294	1.006	.754	.755	.716
	$\dot{m}_{CV}$	eq. A	.073	.078	.065	.084	.097	.090	.095	.103	.103	.144
	$\dot{m}_{NV}$	eq. A	.026	.027	.030	.028	.029	.030	.034	.039	.036	.038
	$\dot{m}_t$	eq. A	2.070	2.121	2.097	1.705	1.413	1.414	1.135	.896	.894	.898
	η_{mD} (unc)	%	98.2	95.6	96.9	95.4	93.9	93.7	90.6	87.6	87.4	87.2
	η_{mD}	%	92.5	91.1	91.8	91.3	90.5	90.3	88.1	86.2	85.9	85.6
	η_m (unc)	%	97.0	94.4	95.5	93.8	92.0	91.7	87.8	83.8	83.9	83.5
POWER	P_b	W	2210	2202	2203	1504	1429	1060	696	825	448	447
	P_V	W	8.35	11.42	8.41	9.70	11.3	10.9	12.0	13.5	13.2	15.4
	P_t	W	2661	2648	2638	1887	1763	1364	980	1069	691	687
	η_e	%	83.1	83.2	83.5	79.7	81.1	76.0	71.0	77.2	64.8	65.1
BEAM	α		.9657	.9721	.9689	.9747	.9785	.9785	.9838	.9909	.9898	.9893
	F_T		.9860	.9877	.9874	.9874	.9877	.9857	.9841	.9851	.9816	.9867
	γ		.9522	.9601	.9567	.9624	.9665	.9645	.9682	.9761	.9716	.9761
	β		.9416	.9525	.9470	.9569	.9634	.9634	.9724	.9844	.9825	.9817
	J_b^{++}/J_b^{+}		.1324	.1051	.1186	.0944	.0790	.0790	.0585	.0322	.0362	.0379
MISC.	η_T	%	73.1	72.4	73.0	69.2	69.7	64.8	53.4	61.6	51.3	51.8
	F	mN	129.3	130.0	129.6	96.3	84.9	72.9	52.0	49.6	36.3	36.4
	I_{sp}	s	3066	3008	3033	2771	2950	2531	2249	2714	1993	1992
	p_{tank}	pa	2.9^{-4}	1.2^{-4}	1.3^{-4}	2^{-4}	1.6^{-4}	2^{-5}	7.5^{-5}	1.2^{-4}	1.9^{-4}	8.7^{-5}

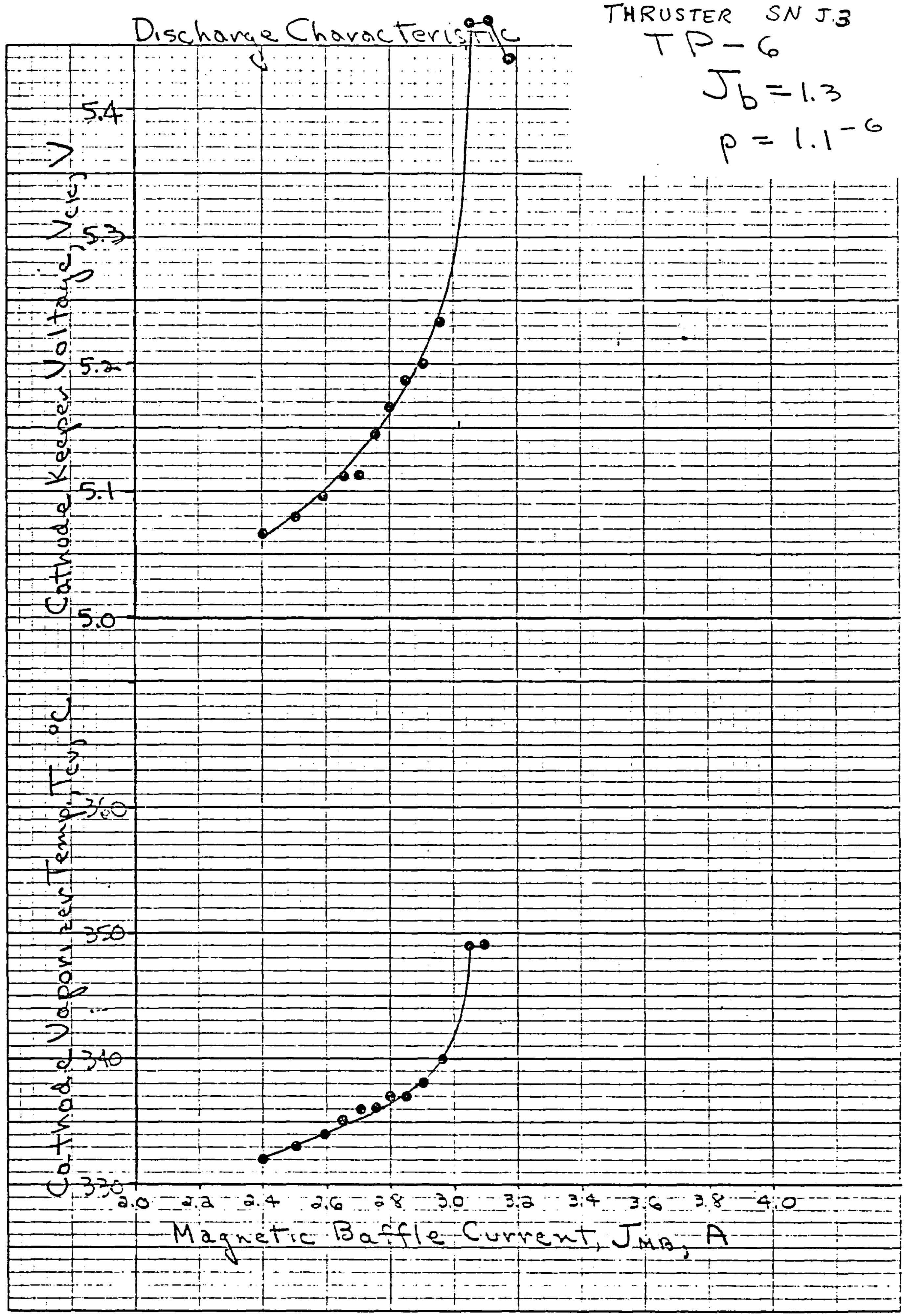
Thruster J3


Selected Magnetic Baffle Currents
Magnetic Baffle Current, J_{MB}, A
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
4/23/80
4/16/80
Beam Current, J_b, A

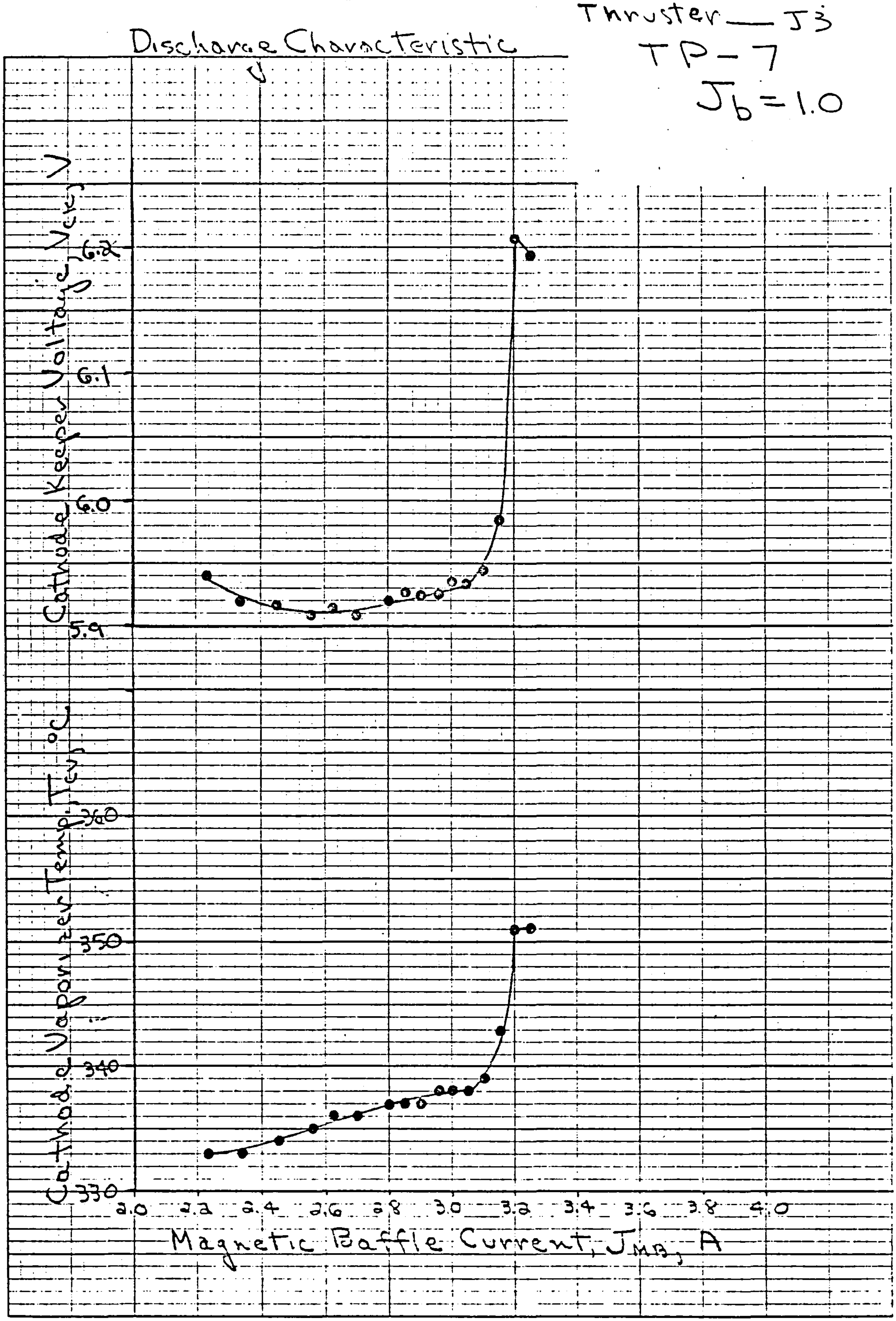

Thruster J3
TP-1
J_b=2.0 A
IV-C SN 825
Cathode Keeper Voltage, V_{CK}, V
4.9
4.8
4.7
4.6
Cathode Vaporizer Temp, T_{CV}, °C
360
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A

Thruster J3
TP-4
$J_b = 1.6$

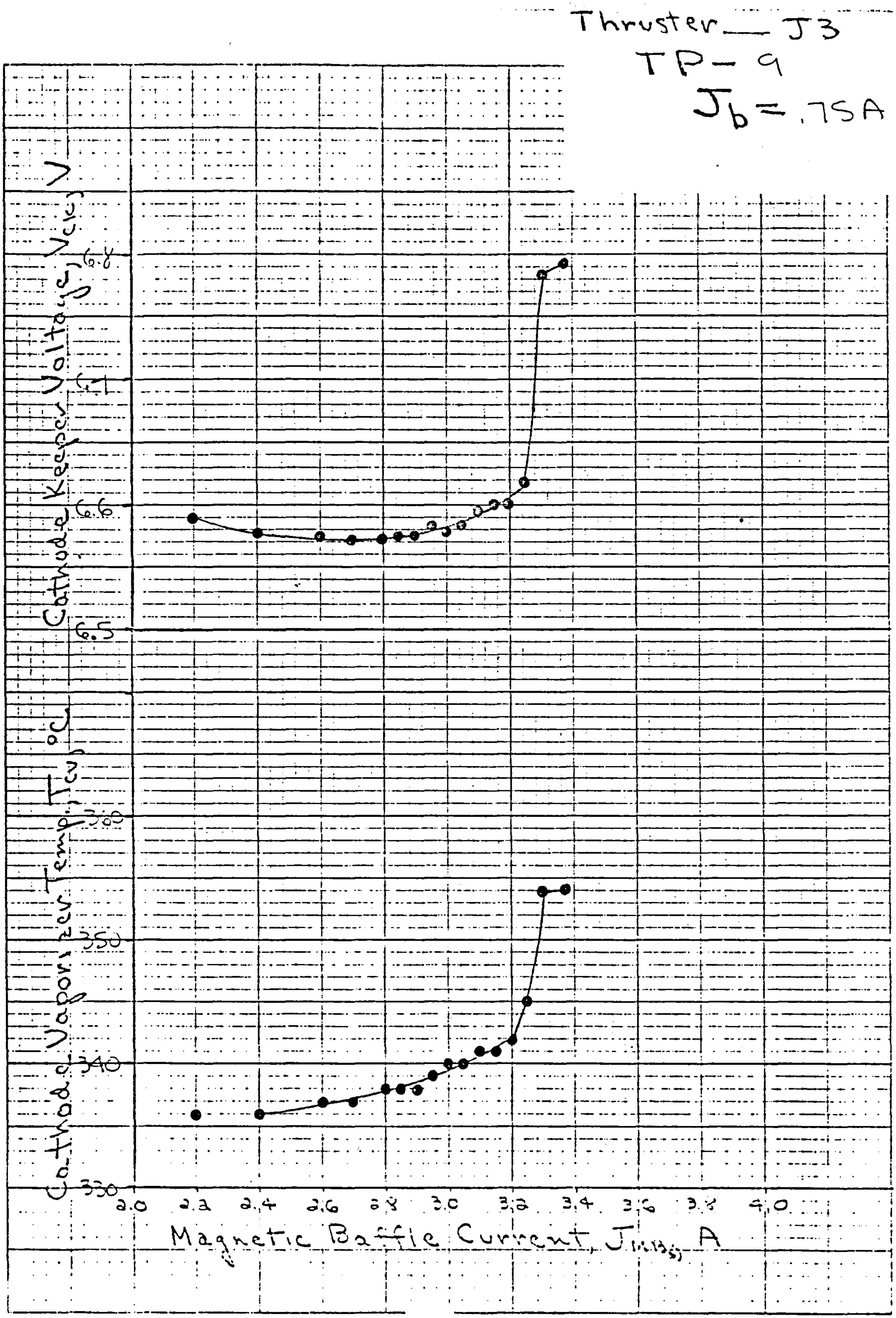




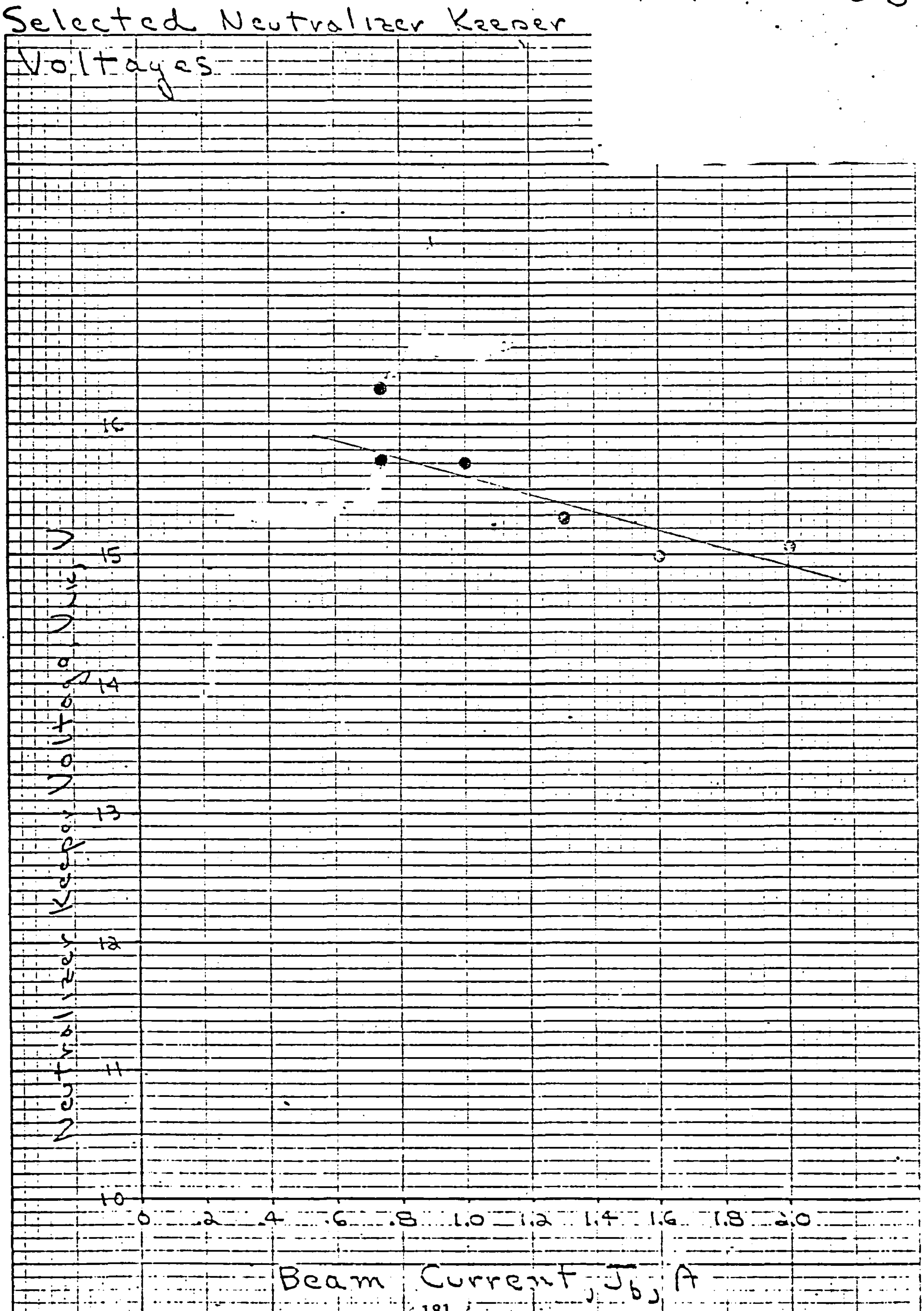
Discharge Characteristic
THRUSTER SN J.3
TP-6
$J_b = 1.3$
$p = 1.1^{-6}$
Cathode Keeper Voltage, V_{CK}, V
5.4
5.3
5.2
5.1
5.0
Cathode Vaporizer Temp., T_{CV}, °C
360
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A



Thruster — J3
TP-7
Jb = 1.0
Discharge Characteristic
Cathode Keeper Voltage, Vck, V
6.2
6.1
6.0
5.9
Cathode Vaporizer Temp, Tcv, °C
360
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, JMB, A


Thruster — J3
TP-9
J_b = .75A
Cathode Keeper Voltage, V_{CK}, V
6.8
6.7
6.6
6.5
Cathode Vaporizer Temp, T_{CV}, °C
360
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A

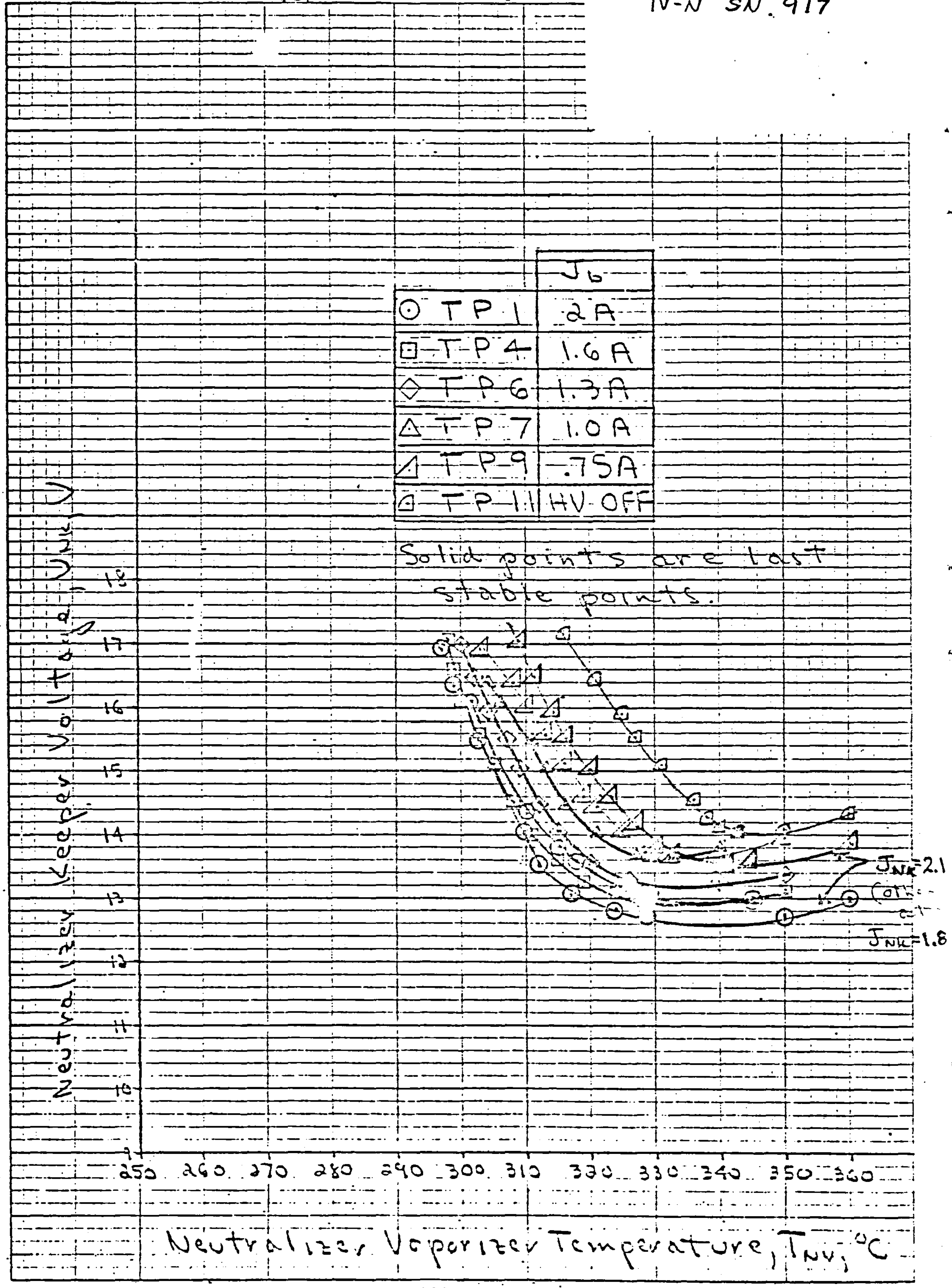
Thruster J3



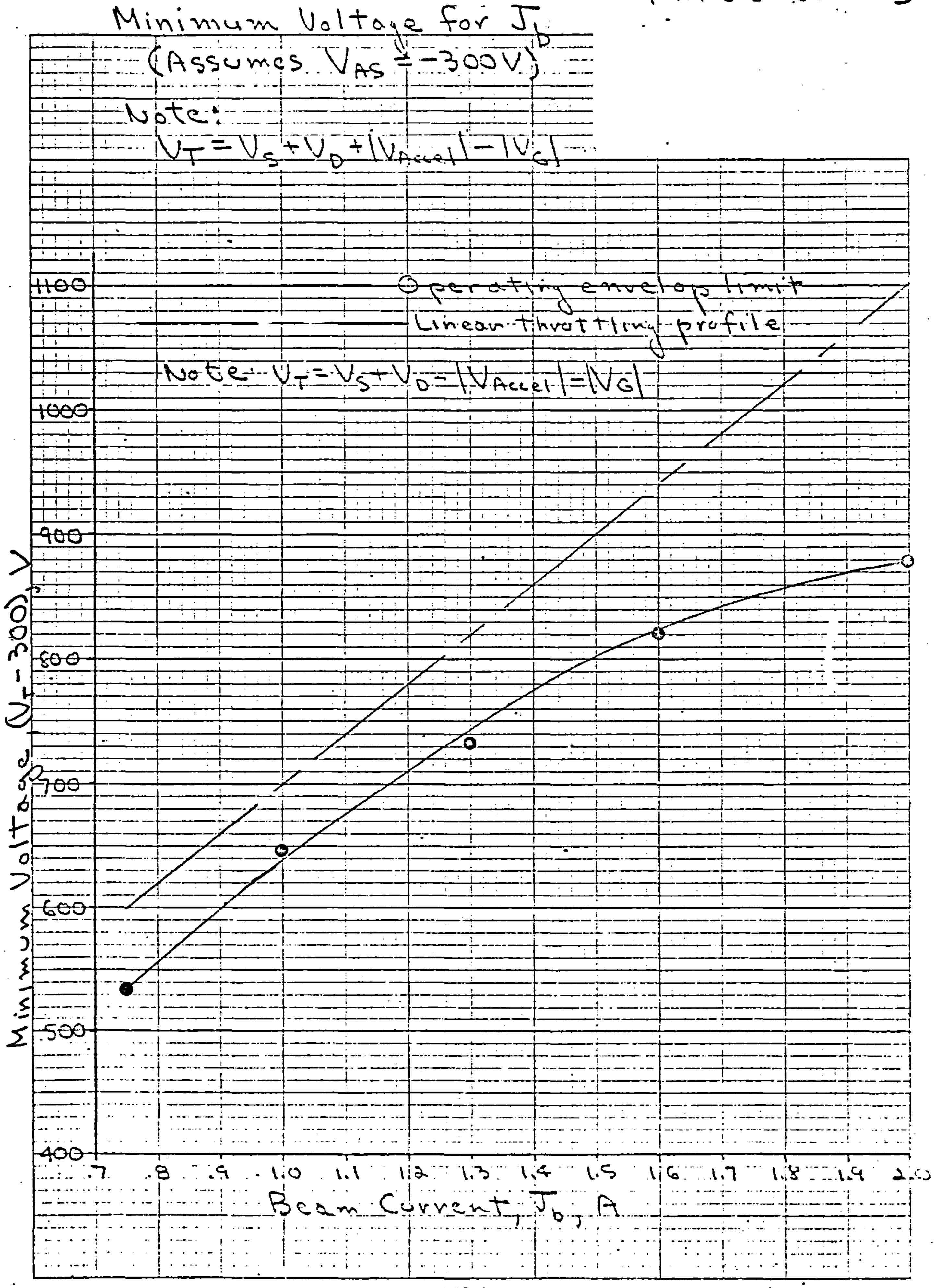
Selected Neutralizer Keeper Voltages
Neutralizer Keeper Voltage, V
16
15
14
13
12
11
10
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Beam Current, Jb, A

Thruster J3
IV-N SN. 917

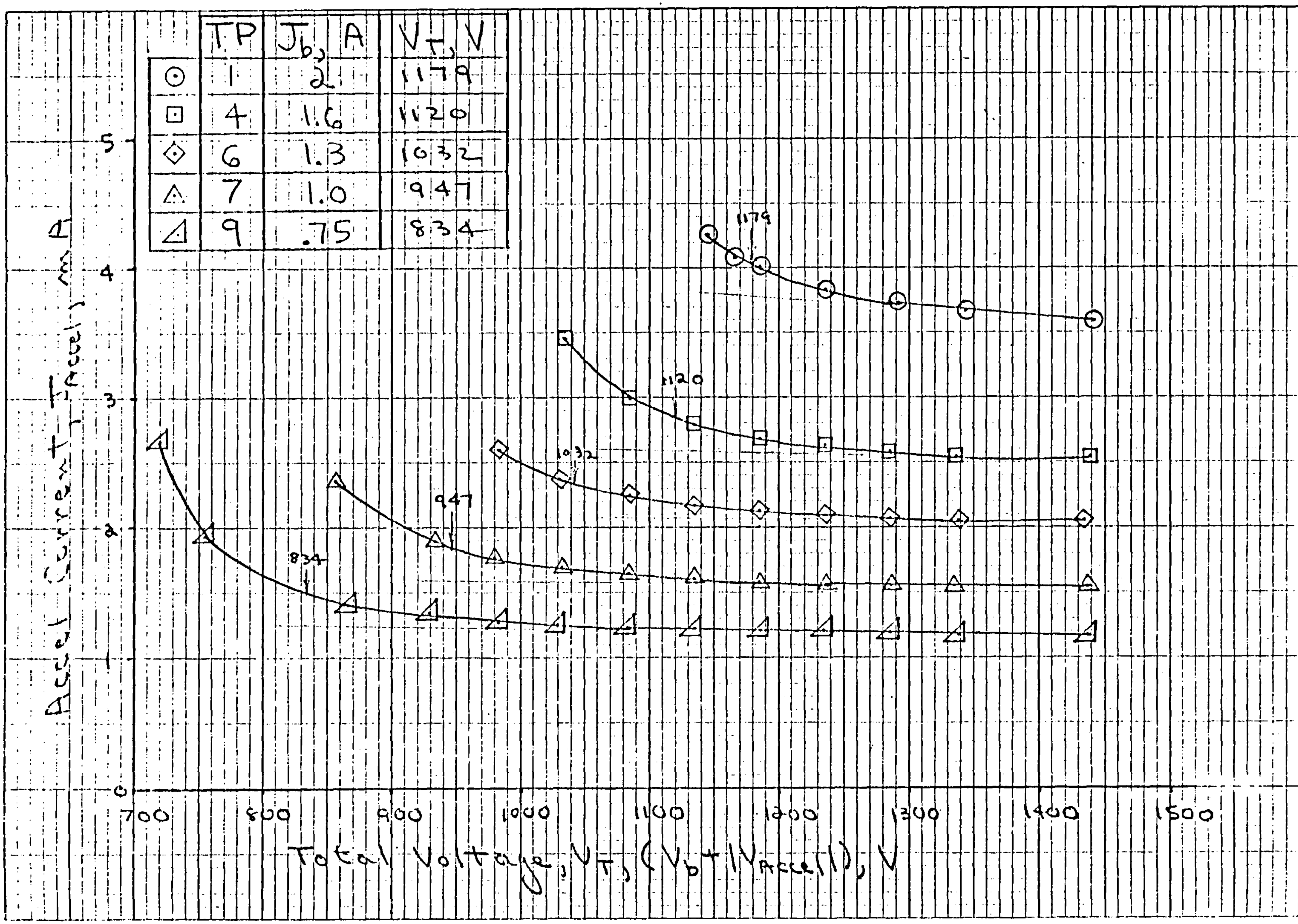
Neutralizer Characteristics



Thruster J3



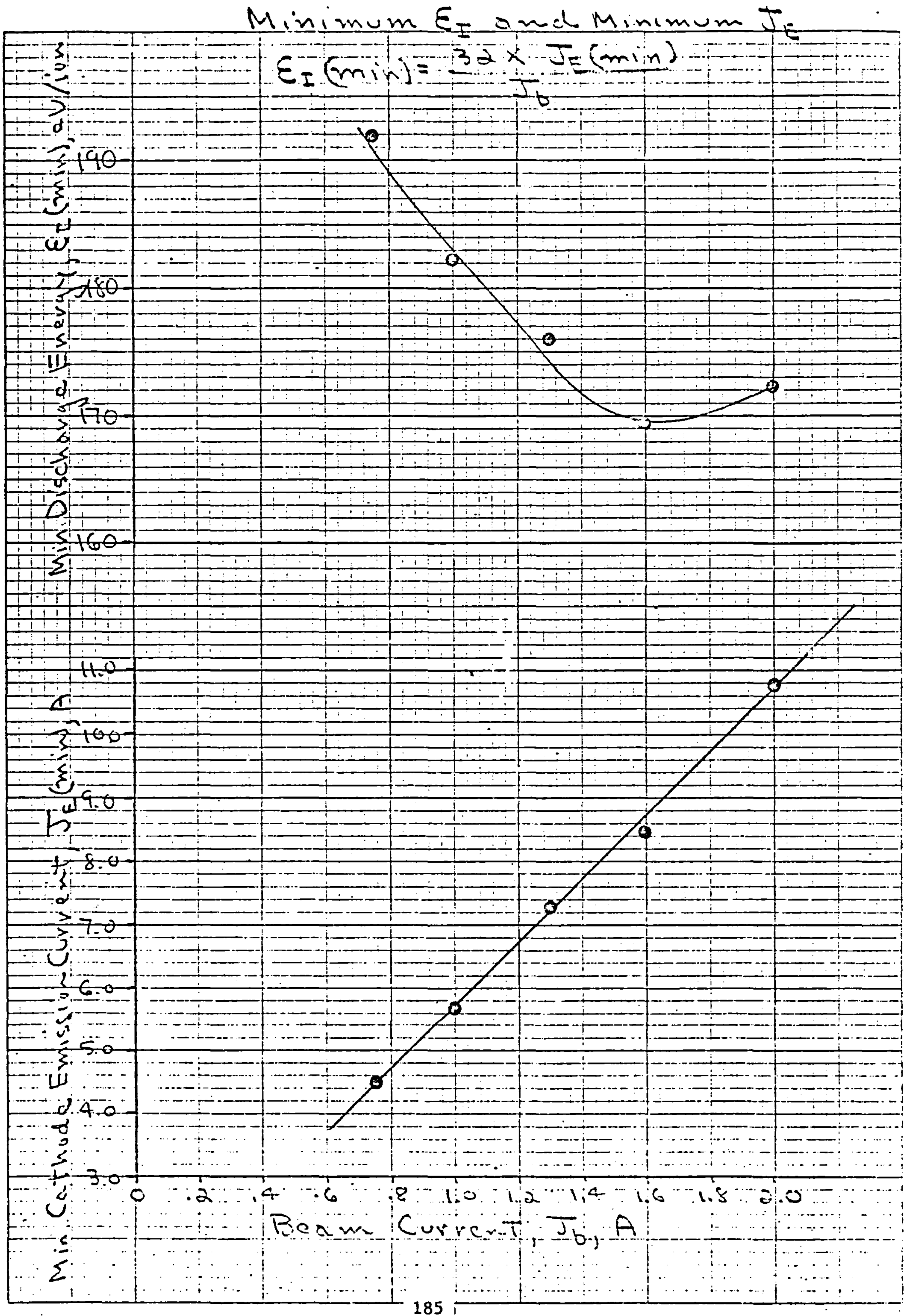
Minimum Voltage for J_b
(Assumes $V_{AS} \doteq -300V$)
Note:
$V_T = V_S + V_D + |V_{Accel}| - |V_G|$
Operating envelop limit
Linear throttling profile
Note: $V_T = V_S + V_D - |V_{Accel}| = |V_G|$
Minimum Voltage (V_T - 300), V
1100
1000
900
800
700
600
500
400
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Beam Current, J_b, A



TP | J_b, A | V_T, V
1 | 2 | 1179
4 | 1.6 | 1120
6 | 1.3 | 1032
7 | 1.0 | 947
9 | .75 | 834
1179
1120
1032
947
834
Accel Current, J_{accel}, mA
Total Voltage, V_T, (V_b + |V_{accel}|), V
0
1
2
3
4
5
700
800
900
1000
1100
1200
1300
1400
1500
Perveance

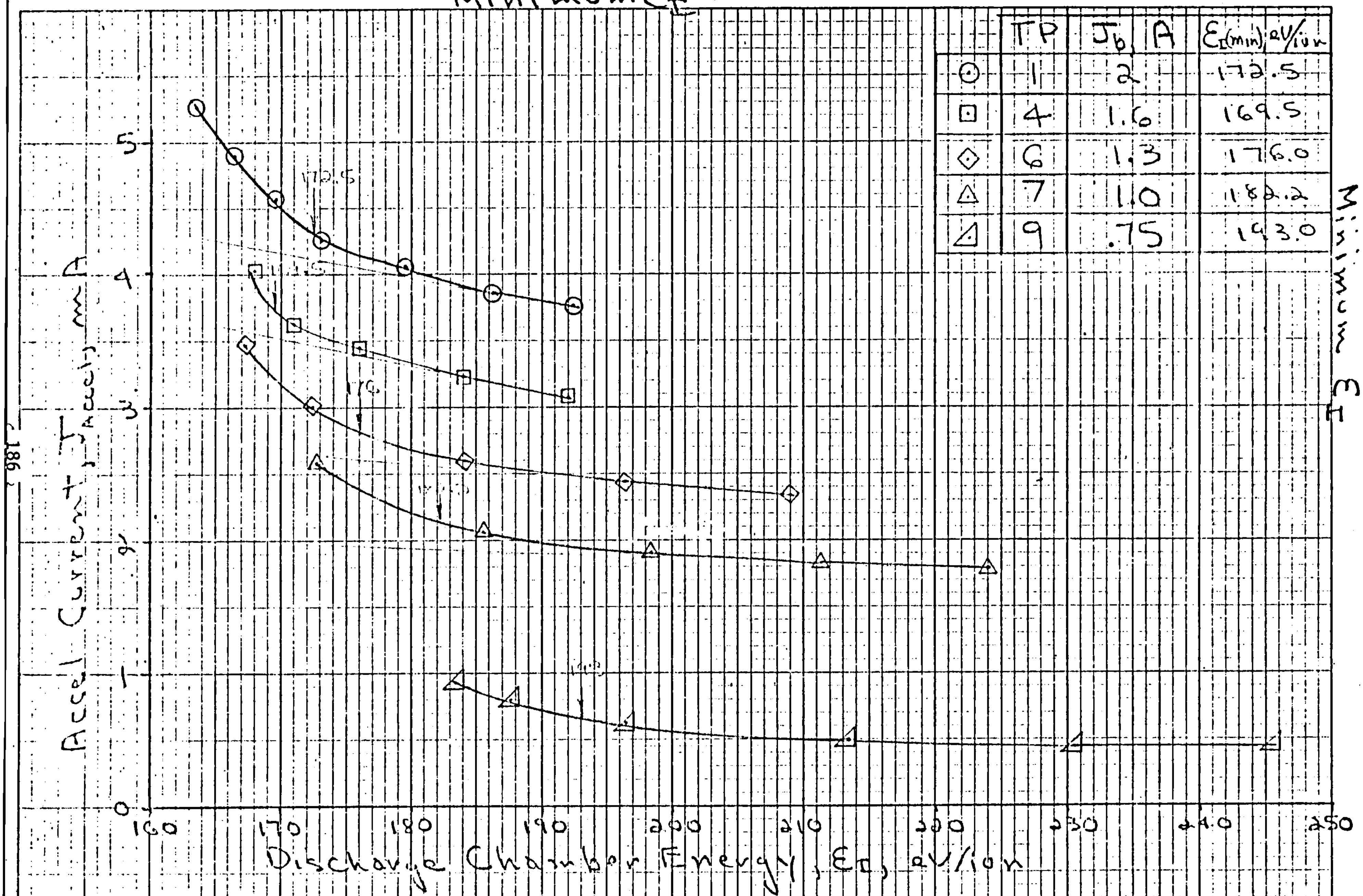
THRUSTER J-3

Thruster J3



Minimum E_I and Minimum J_E
$E_I(min) = \frac{32 \times J_E(min)}{J_b}$
Min Discharge Energy, E_I(min), eV/ion
190
180
170
160
Min Cathode Emission Current, J_E(min), A
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Beam Current, J_b, A

Minimum $\mathcal{E}_I$



TP	J_b, A	$\mathcal{E}_{I(min)}$ eV/ion
⊙ 1	2	172.5
⊡ 4	1.6	169.5
◇ 6	1.3	176.0
△ 7	1.0	182.2
◺ 9	.75	193.0

Thruster J3

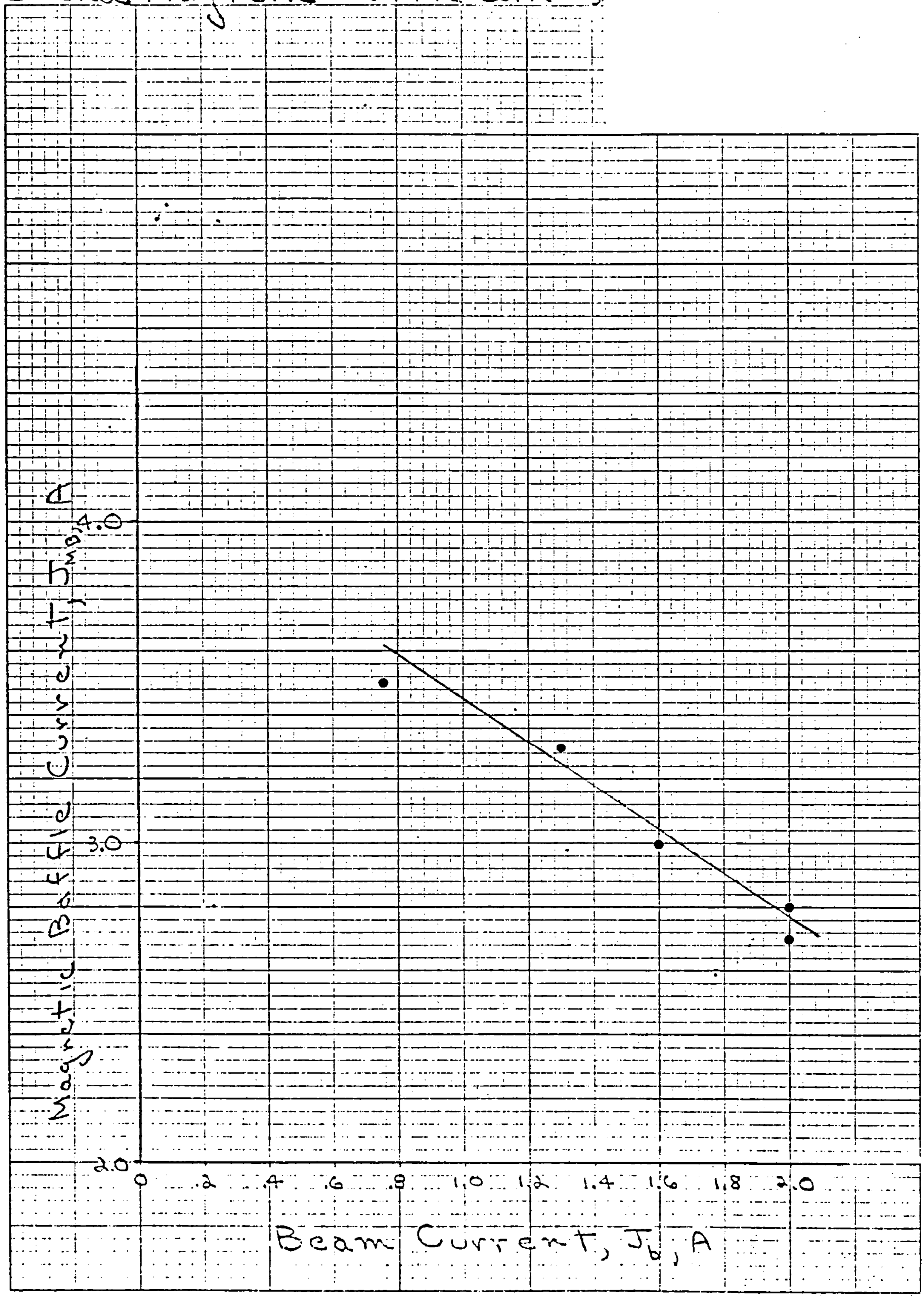
THRUSTER J4

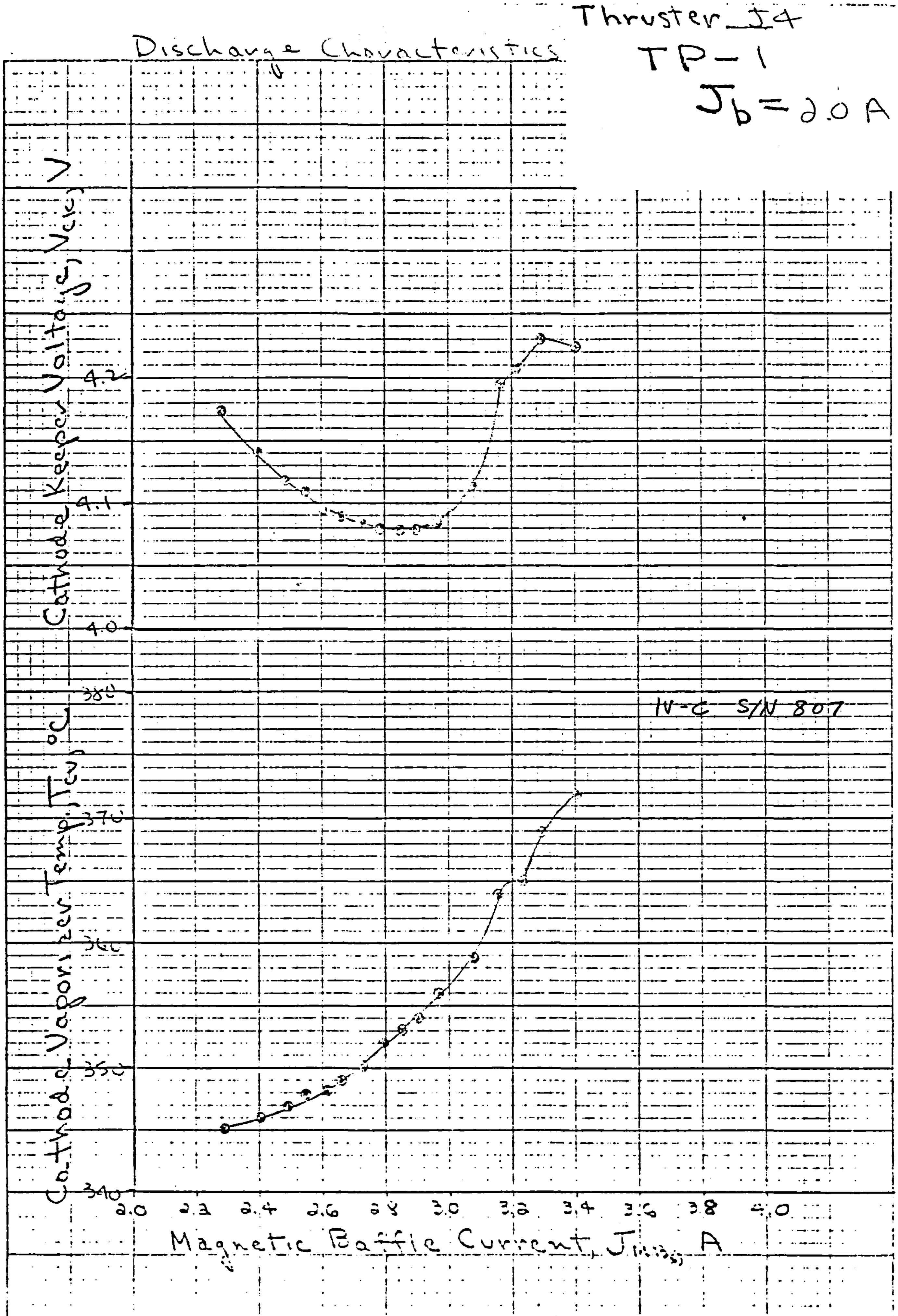
ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

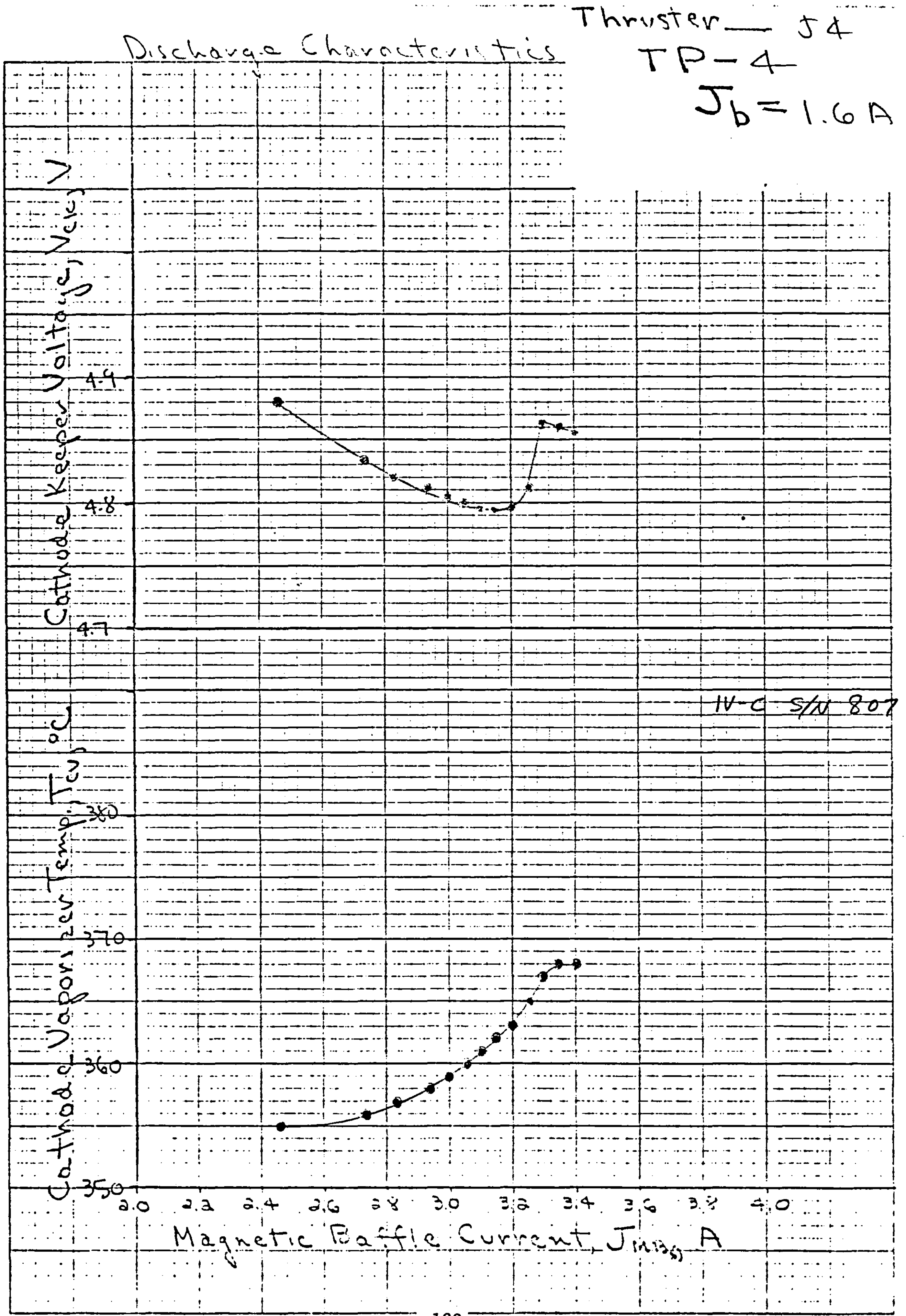
	TEST POINT		1	2	3	4	5	6	7	8	9	10
OPERATING PARAMETERS	V_b	V	1103	1103	1103	943	1101	820	701	1100	600	599
	J_b	A	2.005	2.003	2.005	1.60	1.299	1.3	1.0	.751	.75	.751
	V_D	V	32.0	31.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	31.0
	J_D	A	14.0	14.0	13.4	11.6	9.8	9.8	8.0	6.5	6.51	6.49
	J_E	A	12.0	12.0	11.4	10.0	8.5	8.5	7.0	5.76	5.76	5.74
	J_{MB}	A	2.71	2.80	2.80	3.0	3.3	3.40	3.40	3.5	3.50	3.40
	V_{CK}	V	3.92	4.08	4.12	4.60	5.06	5.15	5.82	6.52	6.67	6.76
	J_{CK}	A	.934	.955	.953	.952	.951	.952	.950	.951	.932	.954
	V_{Accel}	V	-338	-338	-339	-335	-338	-332	-329	-337	-326	-325
	J_{Accel}	mA	4.02	4.07	3.92	2.95	2.07	2.47	1.84	1.08	1.39	1.41
	V_{NK}	V	12.99	13.03	13.03	13.10	13.21	13.09	13.20	13.31	13.33	13.31
	J_{NK}	A	1.82	1.81	1.80	1.81	1.81	1.81	1.81	1.80	1.81	1.81
	V_G	V	9.39	9.57	9.59	9.51	9.68	9.52	9.69	9.99	9.77	9.79
FLOWS	T_{MV}	°C	297	298	296	288	281	281	273	263	264	264
	T_{CV}	°C	348	353	345	356	359	361	363	367	368	370
	T_{NV}	°C	245	296	295	300	300	303	308	310	310	313
	$\dot{m}_{MV}$	eq. A	1.967	2.022	2.017	1.580	1.292	1.283	1.000	.755	.758	.762
	$\dot{m}_{CV}$	eq. A	.075	.080	.070	.083	.101	.102	.104	.116	.116	.113
	$\dot{m}_{NV}$	eq. A	.027	.025	.028	.026	.035	.035	.039	.045	.043	.040
	$\dot{m}_t$	eq. A	2.069	2.127	2.115	1.689	1.428	1.420	1.143	.916	.917	.915
	η_{mD} (unc)	%	98.2	95.3	96.1	96.2	93.3	93.8	90.2	86.2	85.8	85.8
	η_{mD}	%										
	η_m (unc)	%	96.9	94.2	94.8	94.7	91.0	91.5	87.1	82.0	81.8	82.1
POWER	P_b	W	2212	2209	2212	1509	1430	1065	698	826	450	450
	P_V	W	11.6	11.9	11.1	12.6	12.0	13.2	13.7	14.3	14.5	14.5
	P_t	W	2663	2646	2641	1840	1760	1406	979	1066	681	684
	η_e	%	83.1	83.5	83.8	79.8	81.3	75.7	71.3	77.5	66.1	65.8
BEAM	α		.9643	.9718	.9699	.9717	.9784	.9782	.9834	.9879	.9911	.9929
	F_T		.9818	.9785	.9782	.9771	.9767	.9778	.9774	.9773	.9771	.9779
	γ		.9467	.9509	.9482	.9494	.9556	.9565	.9612	.9654	.9684	.9719
	β		.9390	.9519	.9478	.9517	.9631	.9627	.9717	.9793	.9848	.9879
	J_b^{++}/J_b^{+}		.1389	.1064	.1165	.1070	.0796	.0805	.0601	.0431	.0313	.0248
MISC.	η_T	%	72.2	71.2	71.4	68.1	67.6	67.6	57.4	59.2	50.7	51.0
	F	mN	128.5	129.0	128.7	95.1	84.0	72.6	51.9	49.0	35.6	36.4
	I_{sp}	s	3049	2976	2988	2764	2887	2510	2228	2627	1941	1954
	P_{tank}	pa	1.9^{-4}	1.2^{-4}	1.4^{-4}	1.2^{-4}	6.6^{-5}	1.1^{-4}	5.3^{-5}	3.2^{-5}	4.5^{-5}	3.3^{-5}

Thruster J4.

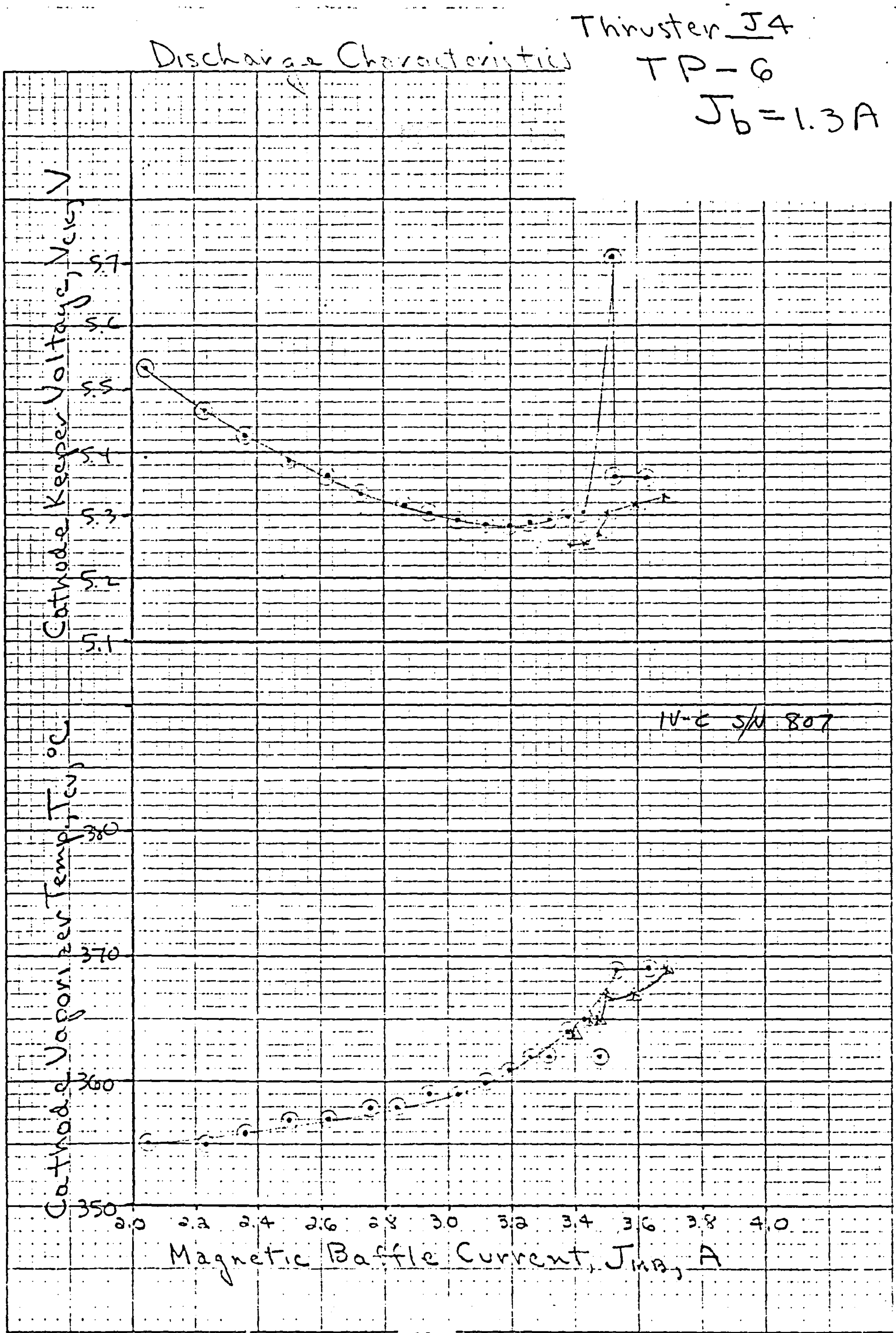
Selected Magnetic Baffle Currents




Discharge Characteristics
Thruster J4
TP-1
J_b = 2.0 A
Cathode Keeper Voltage, V_{CK}, V
4.2
4.1
4.0
380
370
360
350
340
Cathode Vaporizer Temp, T_{CV}, °C
IV-C S/N 807
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A



Discharge Characteristics
Thruster J4
TP-4
J_b = 1.6 A
Cathode Keeper Voltage, V_{CK}, V
4.9
4.8
4.7
IV-C S/N 807
Cathode Vaporizer Temp, T_{CV}, °C
380
370
360
350
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A

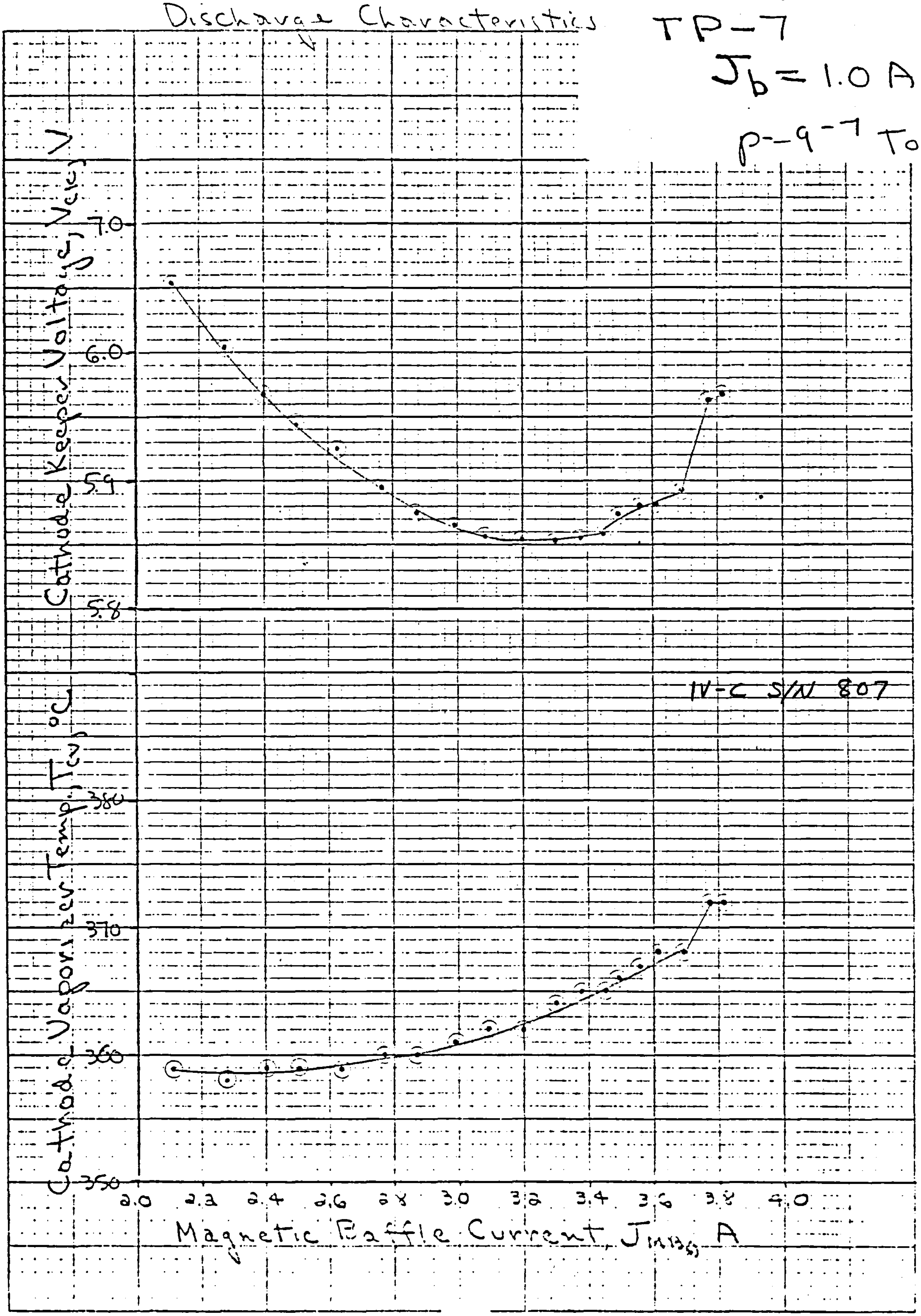

Discharge Characteristics
Thruster J4
TP-6
Jb=1.3A
Cathode Keeper Voltage, Vck, V
5.7
5.6
5.5
5.4
5.3
5.2
5.1
IV-C S/N 807
Cathode Vaporizer Temp, Tcv, °C
380
370
360
350
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, JMB, A

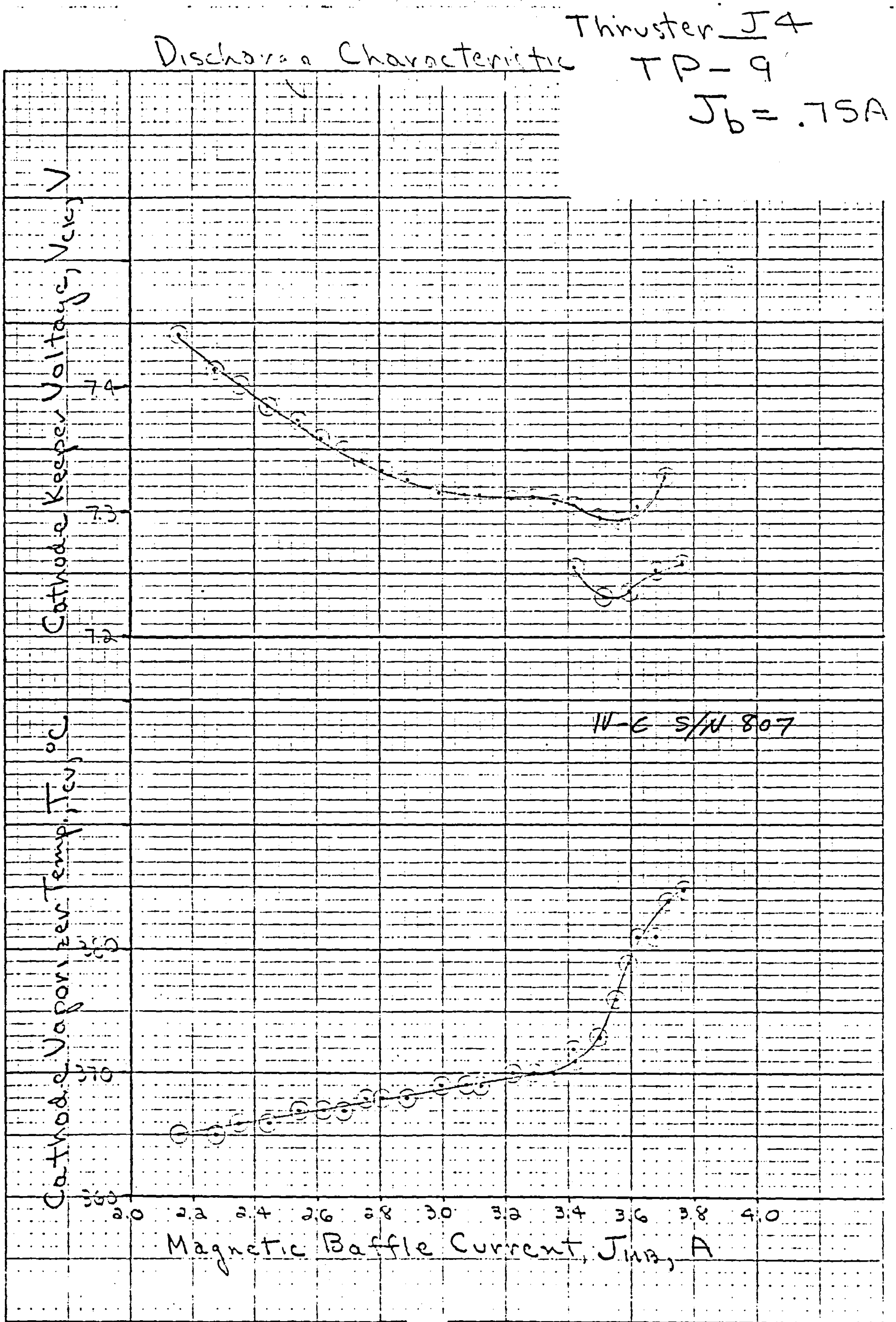
Thruster J4

TP-7

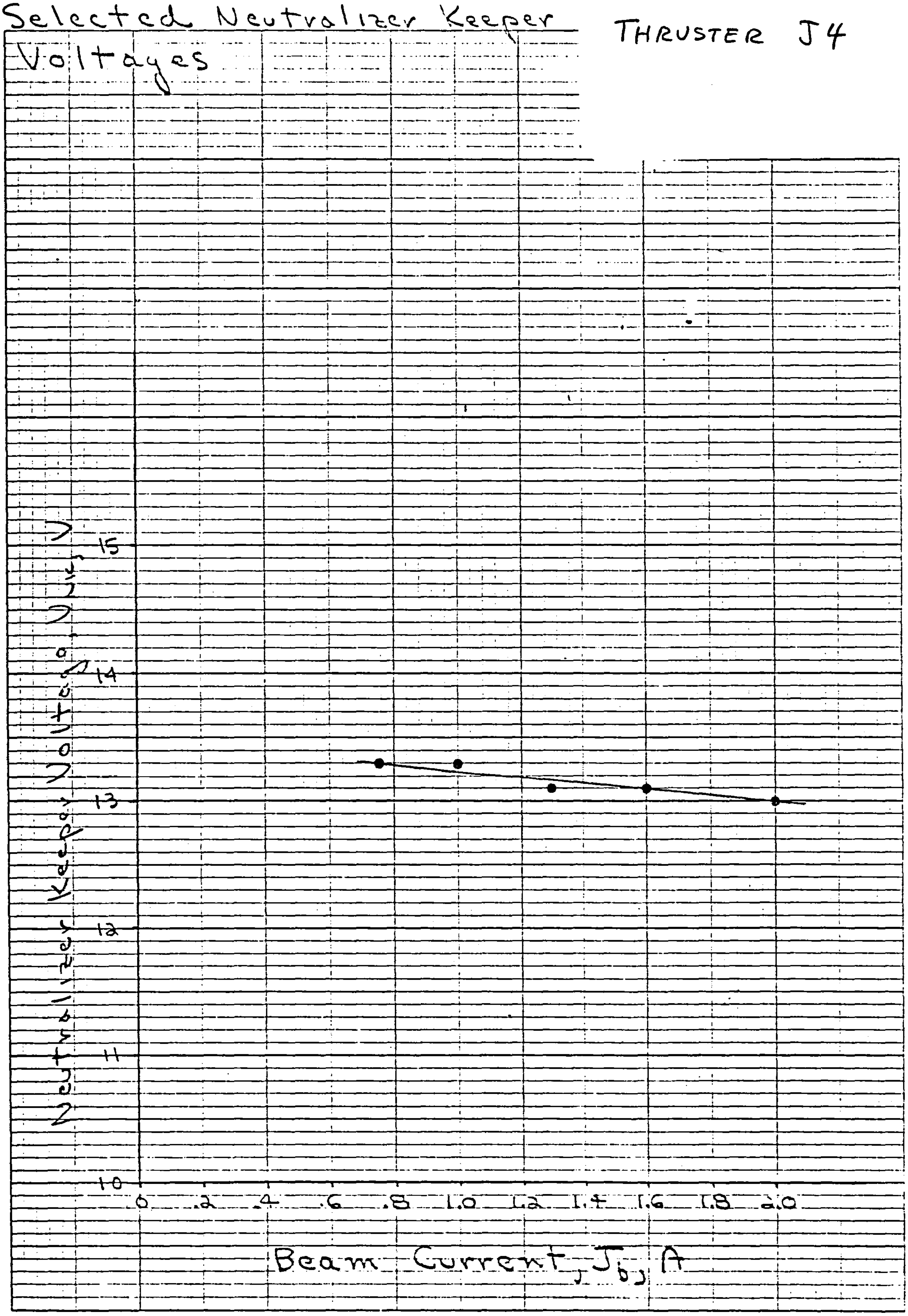
$J_b = 1.0$ A

$p \sim 9^{-7}$ Torr



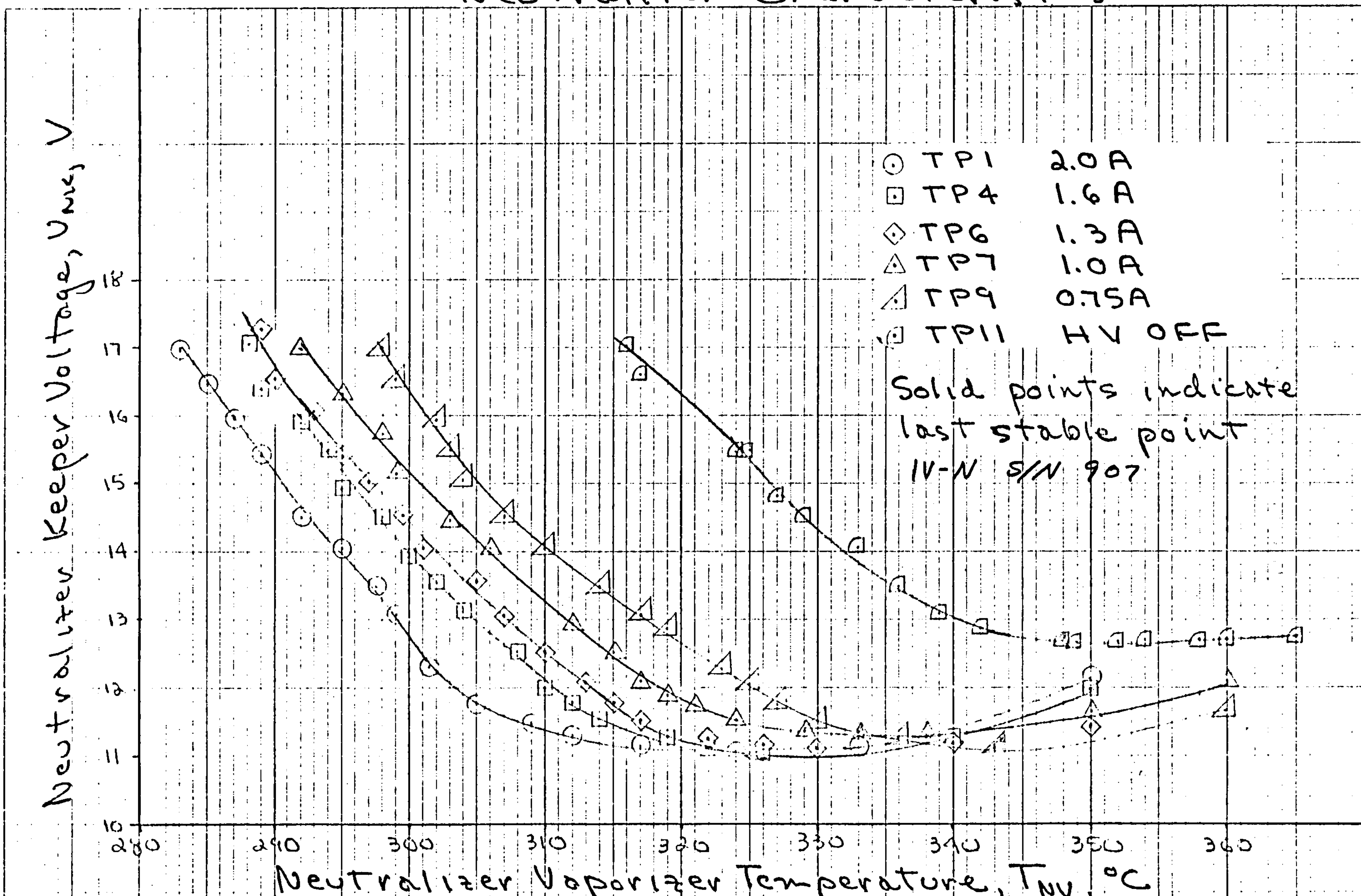


Thruster J4
TP-9
J_b = .75A
Discharge Characteristic
Cathode Keeper Voltage, V_{CK}, V
Cathode Vaporizer Temp., T_{CV}, °C
7.4
7.3
7.2
380
370
360
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A
IV-C S/N 807



Selected Neutralizer Keeper Voltages
THRUSTER J4
Neutralizer Keeper Voltage, VNK, V
15
14
13
12
11
10
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Beam Current, Jb, A

Neutralizer Characteristics



Summary of neutralizer keeper voltage characteristics obtained in acceptance test of thruster J4.

Neutralizer Characteristics

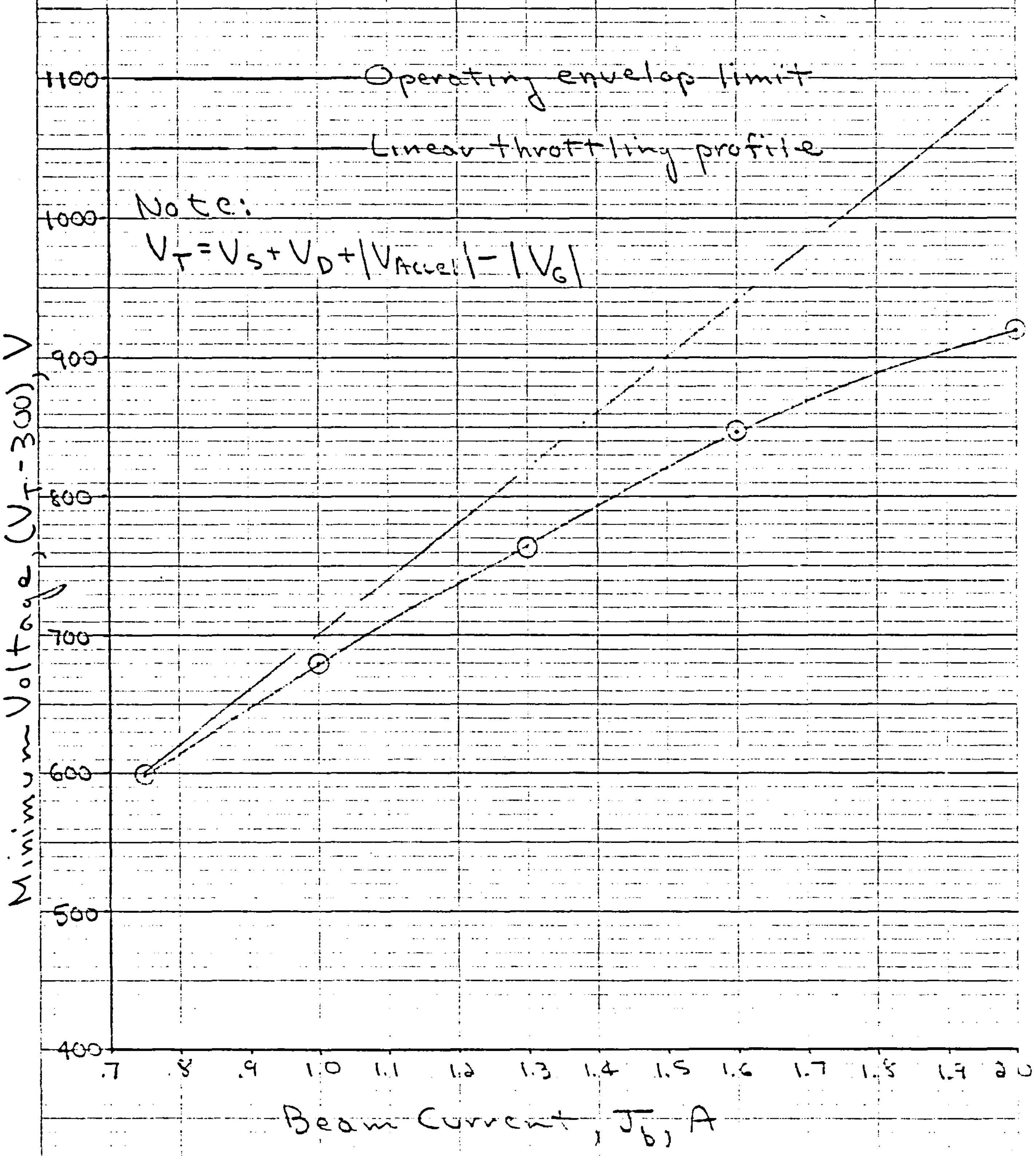
THRUSTER S/N J4

195 1/2

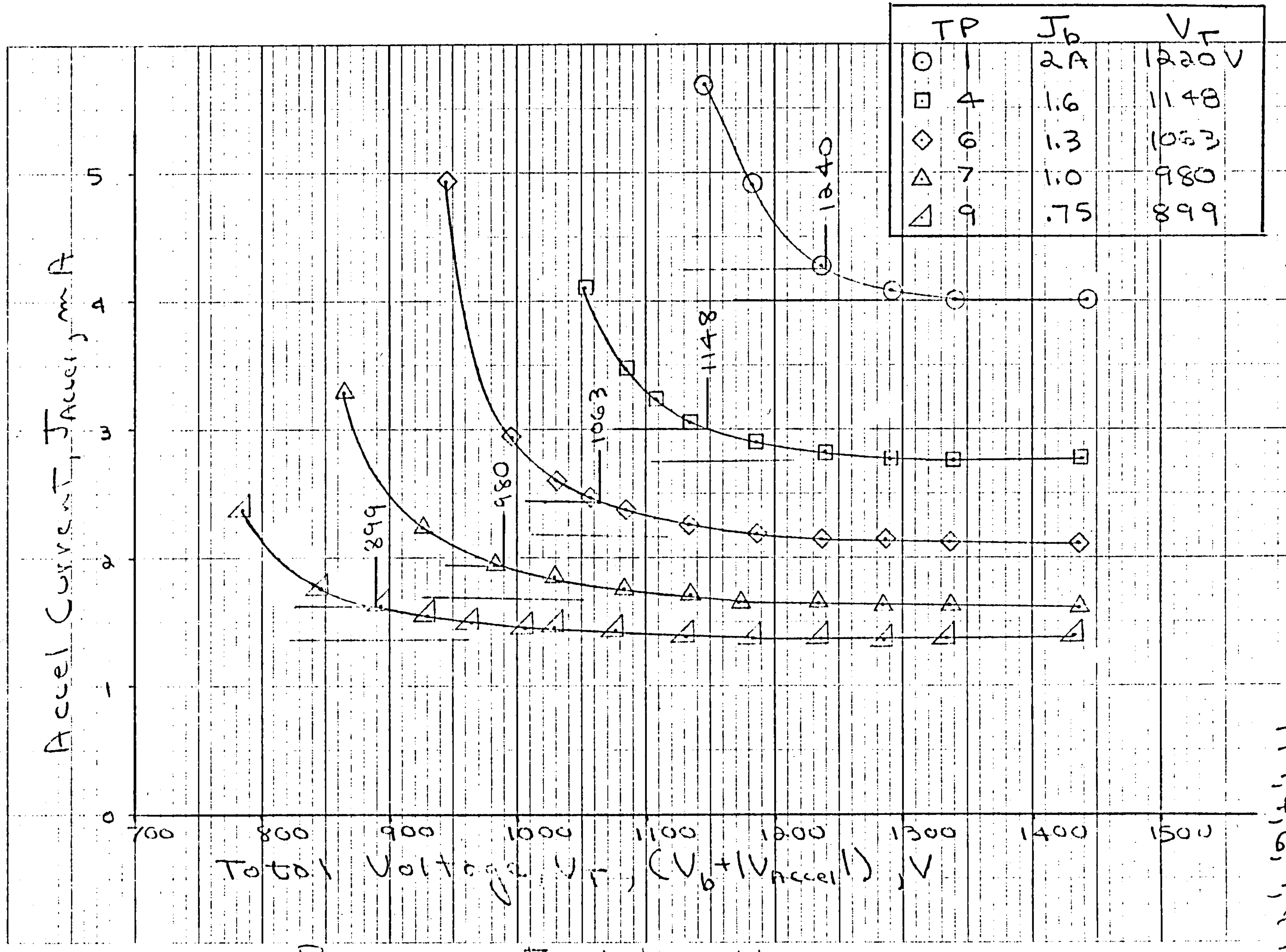
THRUSTER J4

Minimum Voltage for J_b
(Assumes V_{AS} = 300 V)

TP 1, 4, 6, 7, 8, 9



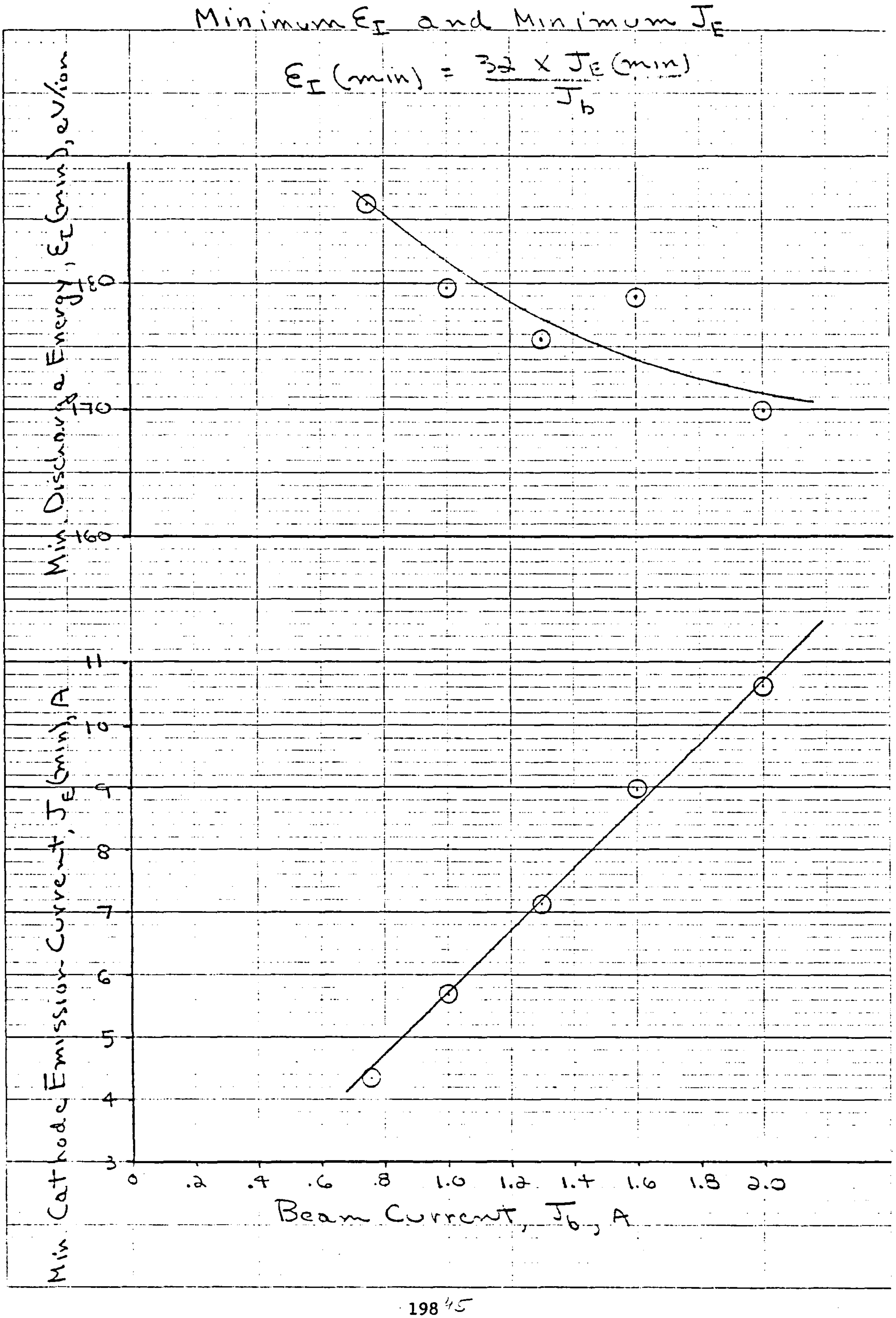
46 0780



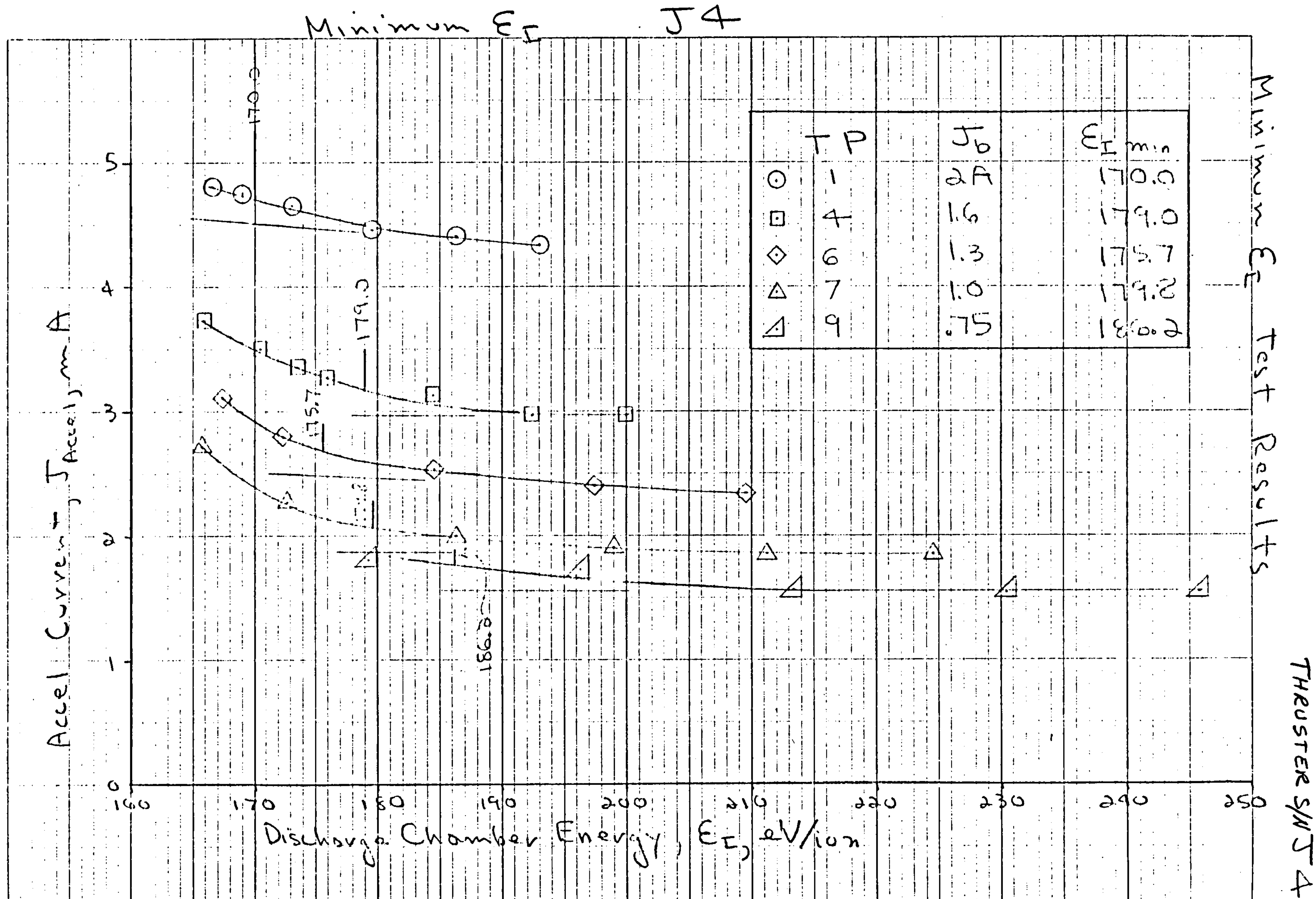
THRUSTER S/N J4
TP 1, 4, 6, 7, 9

197

THRUSTER S/N J4



46 0780



Minimum $\mathcal{E}_I$ J4
Minimum $\mathcal{E}_I$ Test Results
THRUSTER S/N J4
TP | J_b | $\mathcal{E}_{I\,min}$
1 | 2A | 170.0
4 | 1.6 | 179.0
6 | 1.3 | 175.7
7 | 1.0 | 179.8
9 | .75 | 186.2
170.0
179.0
175.7
186.0
Accel Current, J_{Accel}, mA
Discharge Chamber Energy, $\mathcal{E}_I$, eV/ion
0
1
2
3
4
5
160
170
180
190
200
210
220
230
240
250

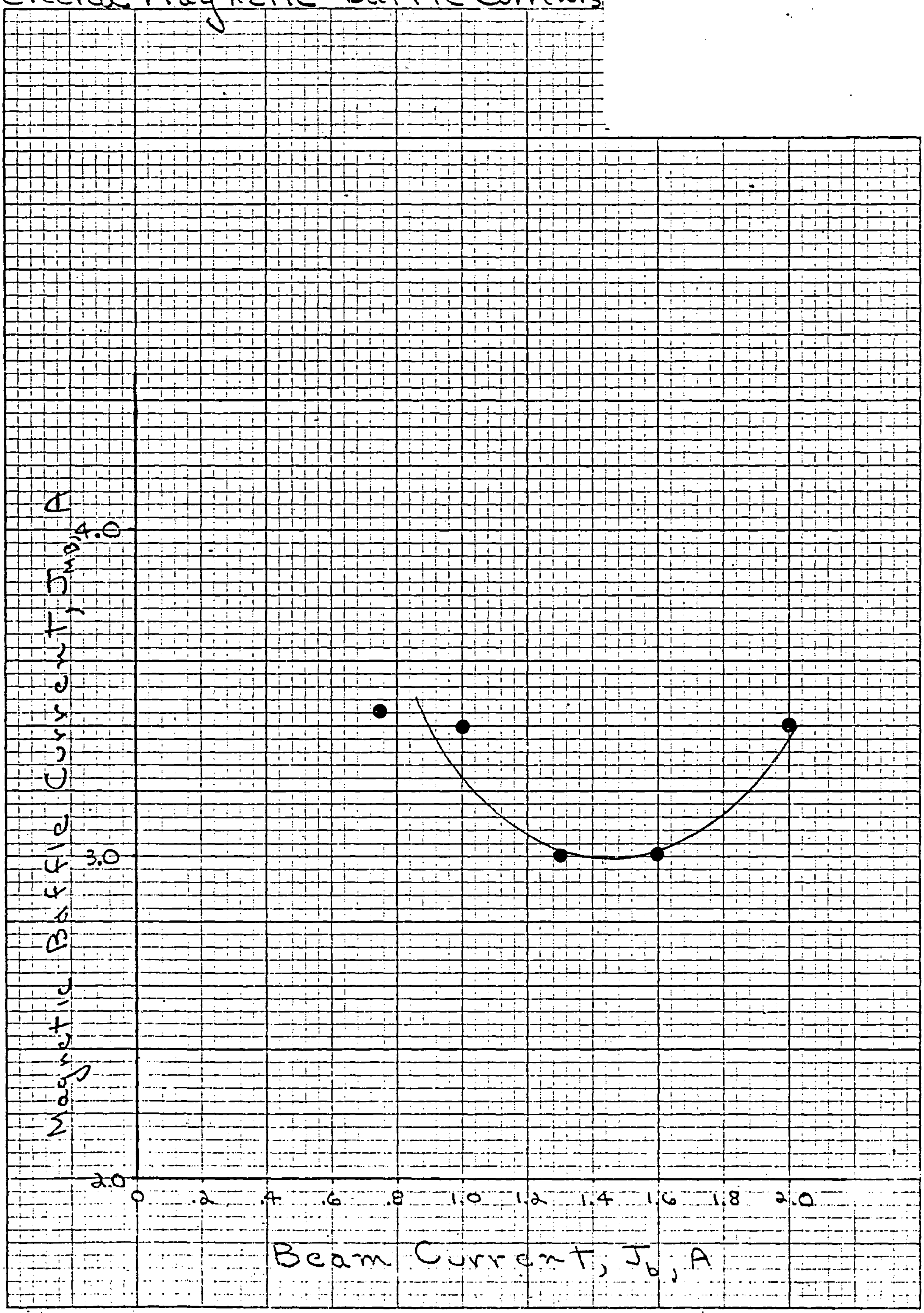
ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

THRUSTER S/N J5

	TEST POINT		1	2	3	4	5	6	7	8	9	10	
OPERATING PARAMETERS	V_b	V	1087	1085	1086	940	1094	822	698	1098	605	604	
	J_b	A	2.00	2.00	1.99	1.60	1.30	1.30	1.00	0.75	0.75	0.75	
	V_D	V	32.0	31.0	32.1	32.0	32.0	32.0	32.0	31.9	32.0	31.0	
	J_D	A	14.0	14.0	13.5	11.6	9.8	9.8	8.0	6.5	6.5	6.5	
	J_E	A	12.0	12.0	11.46	10.0	8.5	8.5	7.0	5.75	5.75	5.8	
	J_{MB}	A	3.4	3.4	3.4	3.0	3.2	3.0	3.4	3.4	3.45	3.4	
	V_{CK}	V	4.0	4.0	4.0	4.3	4.8	4.8	5.5	6.3	6.3	6.3	
	J_{CK}	A	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.86	0.86	0.86	
	V_{Accel}	V	338	338	338	334	334	334	331	327	327	327	
	J_{Accel}	mA	5.3	5.3	5.3	4.2	2.7	2.7	2.0	1.6	1.6	1.6	
	V_{NK}	V	15.3	15.3	15.2	15.0	15.0	15.0	14.7	14.7	14.7	14.7	
	J_{NK}	A	1.80	1.80	1.80	1.80	1.80	1.80	1.81	1.81	1.81	1.81	
	V_G	V	10.6	10.6	10.6	10.6	10.7	10.7	10.8	11.0	11.0	11.0	
FLOWS	T_{MV}	°C	308	309	310	300	293	294	284	275	275	276	
	T_{CV}	°C	349	330	322	327	330	328	336	341	341	344	
	T_{NV}	°C	316	316	315	318	324	325	331	337	338	337	
	$\dot{m}_{MV}$	eq. A	1.943	2.090	2.100	1.610	1.317	1.350	1.053	0.788	0.777	0.807	
	$\dot{m}_{CV}$	eq. A	0.094	0.069	0.053	0.052	0.056	0.065	0.086	0.087	0.083	0.092	
	$\dot{m}_{NV}$	eq. A	0.023	0.027	0.028	0.031	0.026	0.033	0.042	0.049	0.038	0.046	
	$\dot{m}_t$	eq. A	2.060	2.186	2.181	1.693	1.399	1.448	1.181	0.924	0.898	0.945	
	η_{mD} (unc)	%	98.2	92.6	92.4	96.3	94.7	91.9	87.7	85.7	87.2	83.4	
	η_{mD}	%	92.7	87.4	86.4	87.3	90.1	86.6	83.8	82.7	84.0	78.4	
	η_m (unc)	%	97.1	91.5	91.2	94.5	92.9	89.8	84.7	81.2	83.5	79.4	
POWER	P_b	W	2.174	2170	2161	1504	1422	1069	698	823	454	453	
	P_V	W	12.4			14.3		10.0	9.7		14.9		
	P_t	W	2626	2608	2595	1889	1751	1398	977	1061	696.	689	
	η_e	%	82.8	83.2	83.3	79.6	81.2	76.4	71.4	77.6	65.2	65.7	
BEAM	α		.9671	.9670	.9616	.9454	.9715	.9667	.9733	.9797	.9784	.9647	
	F_T		.9818	.9813	.9815	.9830	.9820	.9822	.9825	.9824	.9826	.9833	
	γ		.9495	.9489	.9438	.9293	.9540	.9495	.9563	.9625	.9614	.9486	
	β		.9439	.9437	.9344	.9068	.9513	.9432	.9545	.9654	.9632	.9398	
	J_b^{++}/J_b^{+}		.1263	.1270	.1510	.2292	.1079	.1281	.1001	.0744	.0794	.1368	
MISC.	η_T	%	72.5	68.5	67.7	65.0	68.7	61.9	55.3	58.4	50.3	46.9	
	F	mN	127.7	127.5	126.2	93.0	83.6	72.2	51.5	48.8	36.2	35.7	
	I_{sp}	s	3043	2863	2839	2695	2934	2447	2142	2592	1977	1853	
	P_{tank}	pa											

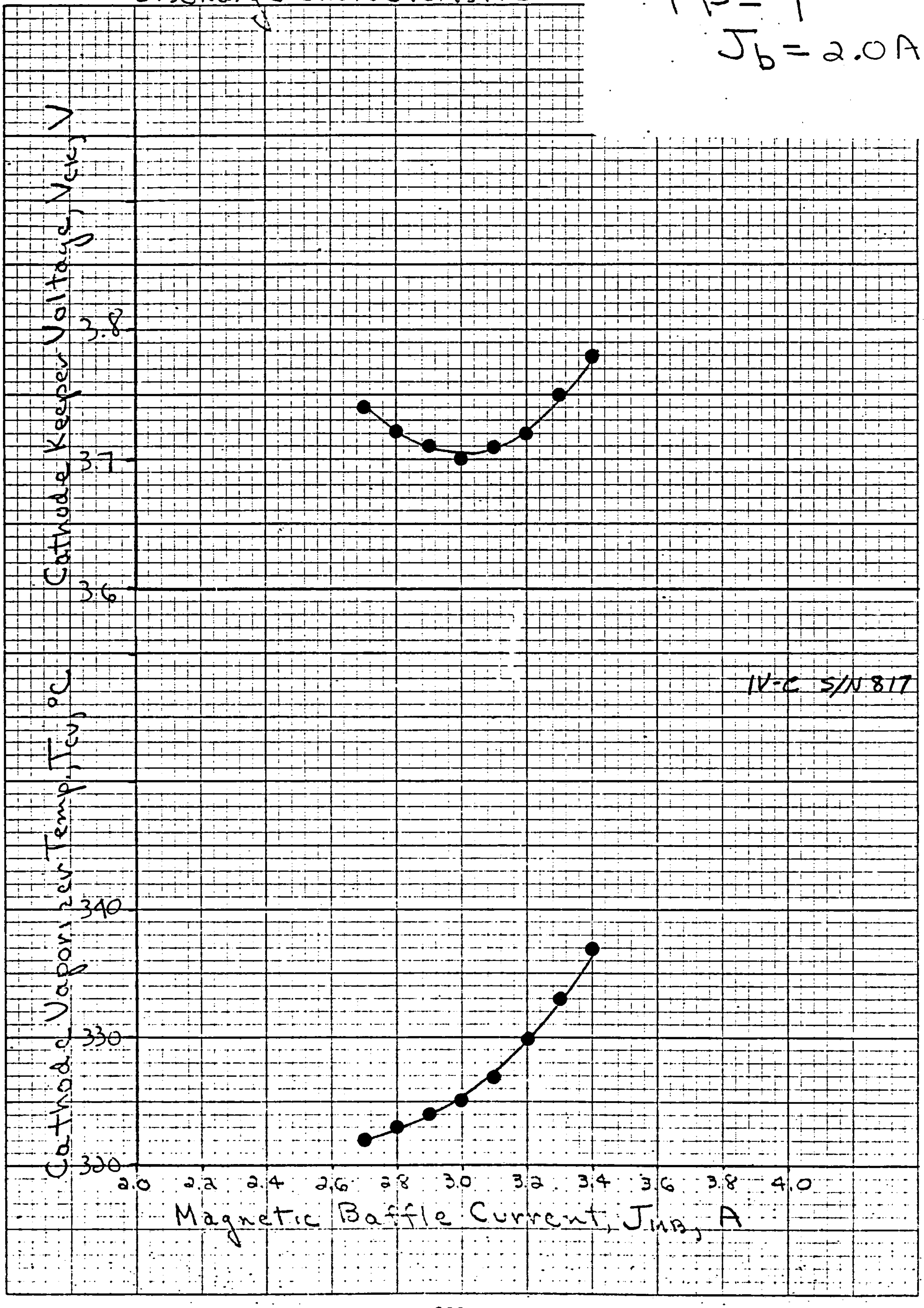
Thruster J-5

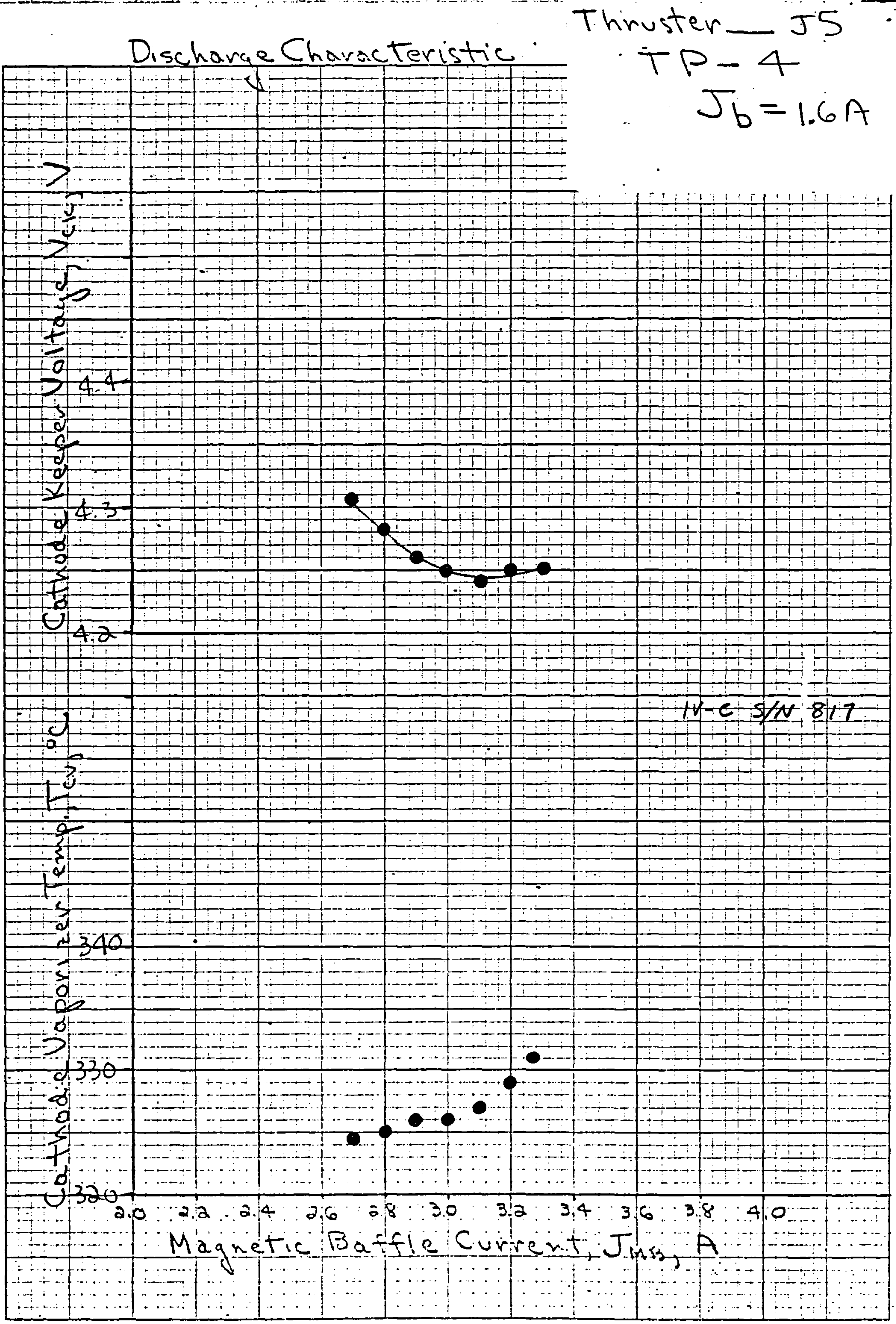
Selected Magnetic Baffle Currents



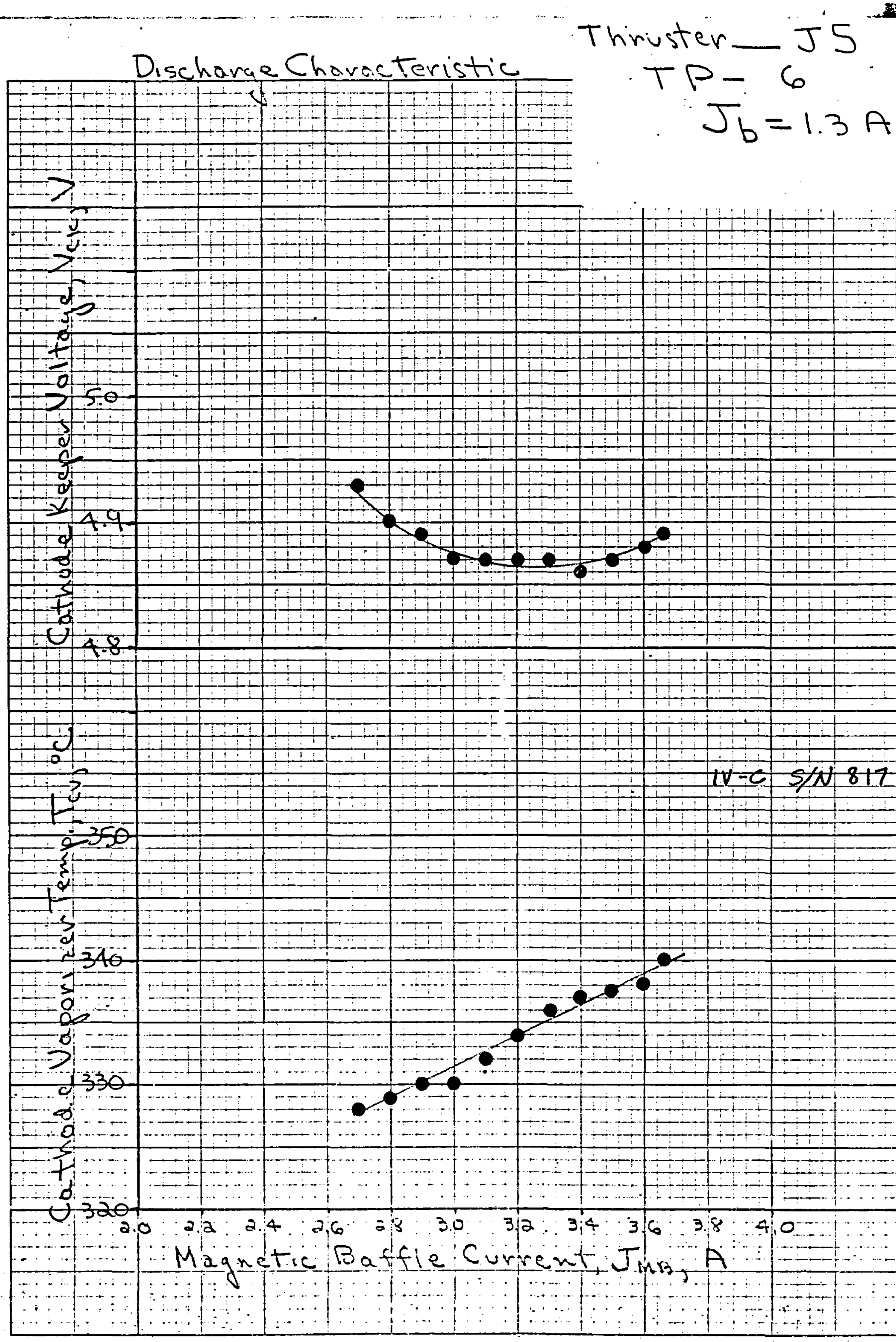
Thruster J5
TP-1
$J_b = 2.0A$

Discharge Characteristic

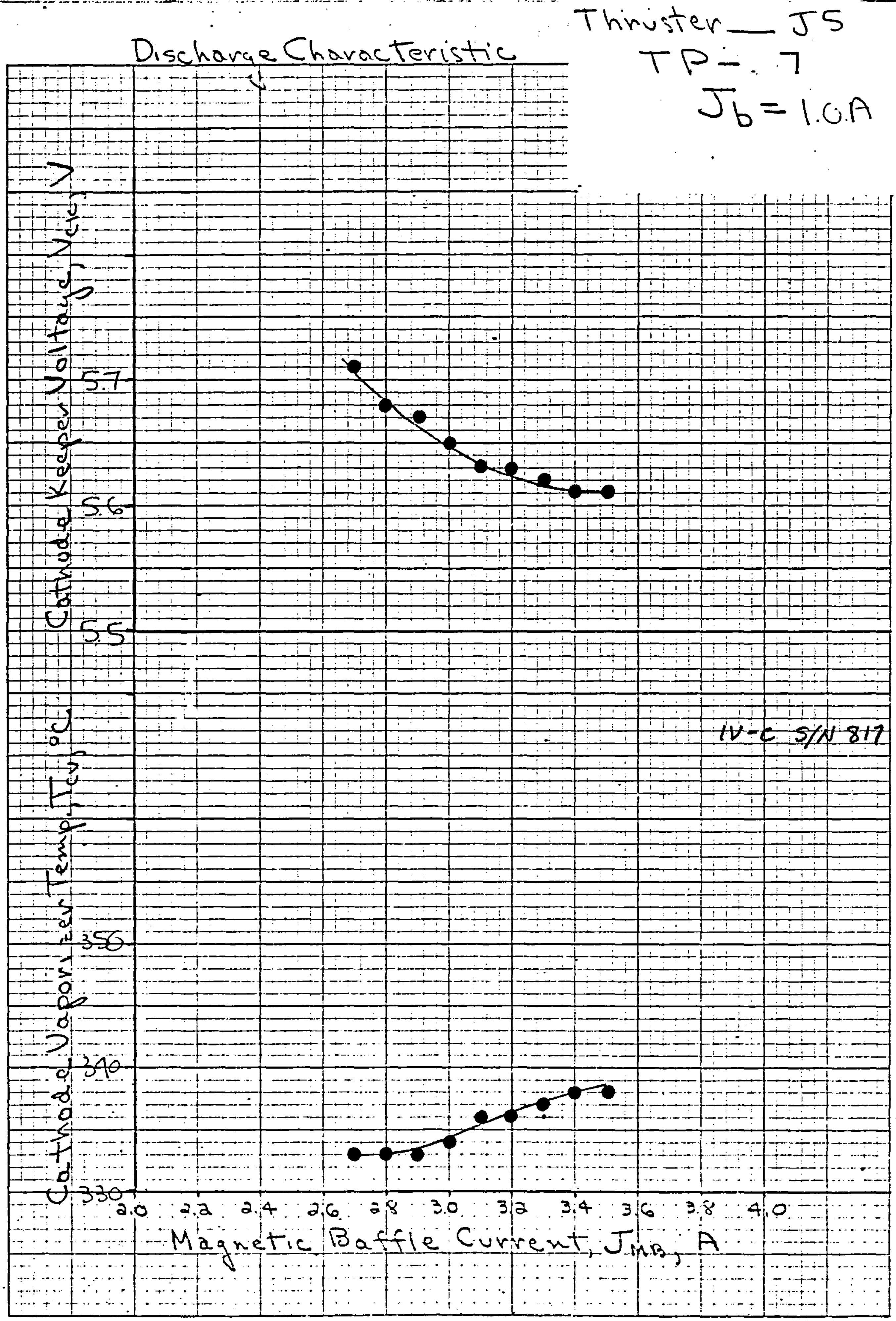


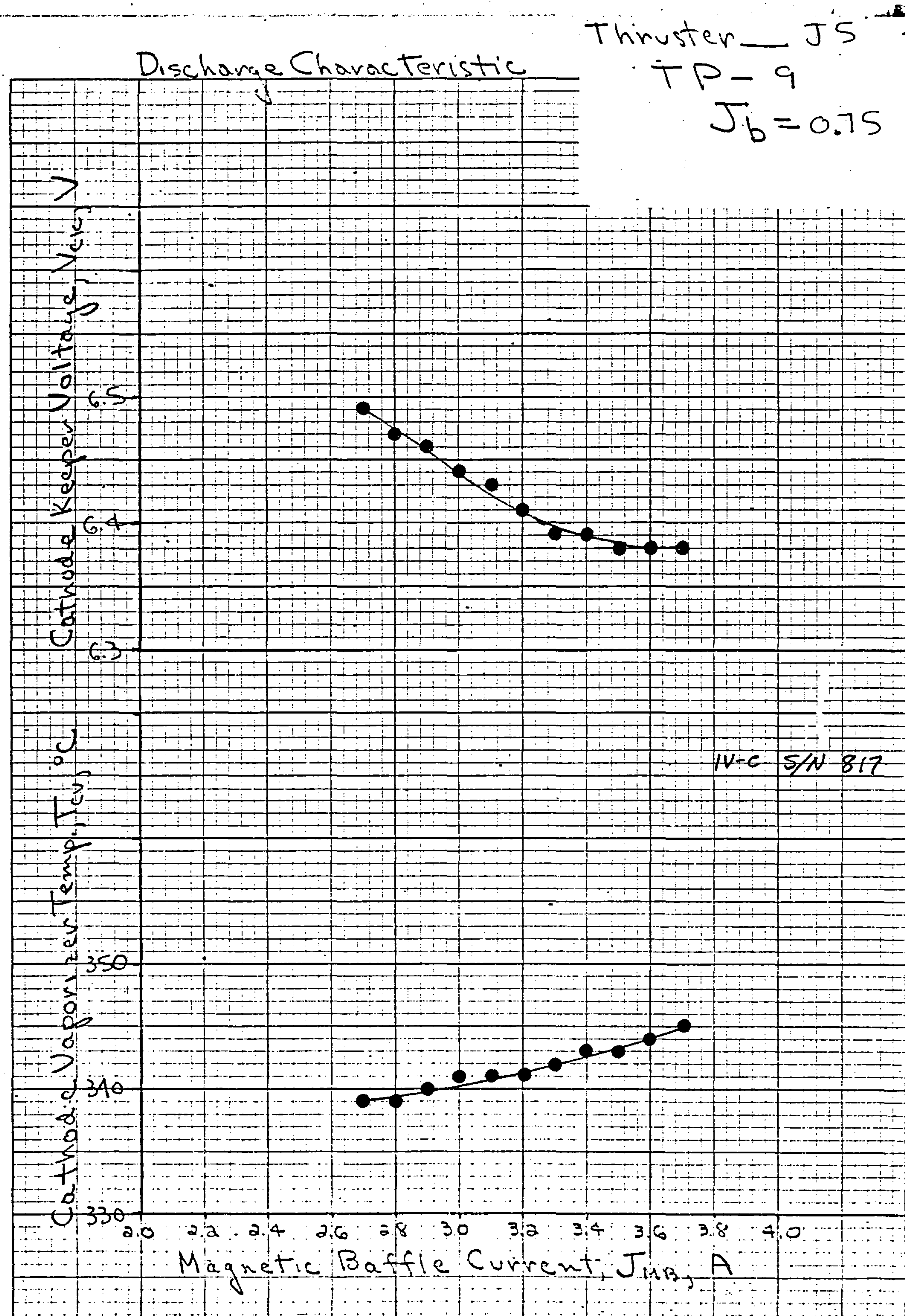


Discharge Characteristic
Thruster __ J5
TP-4
Jb=1.6A
Cathode Keeper Voltage, Vck, V
4.4
4.3
4.2
IV-C S/N 817
Cathode Vaporizer Temp, Tcv, °C
340
330
320
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, JMB, A



Thruster J5
TP-6
J_b = 1.3 A
Discharge Characteristic
Cathode Keeper Voltage, V_{CK}, V
5.0
4.9
4.8
IV-C S/N 817
Cathode Vaporizer Temp, T_{CV}, °C
350
340
330
320
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A

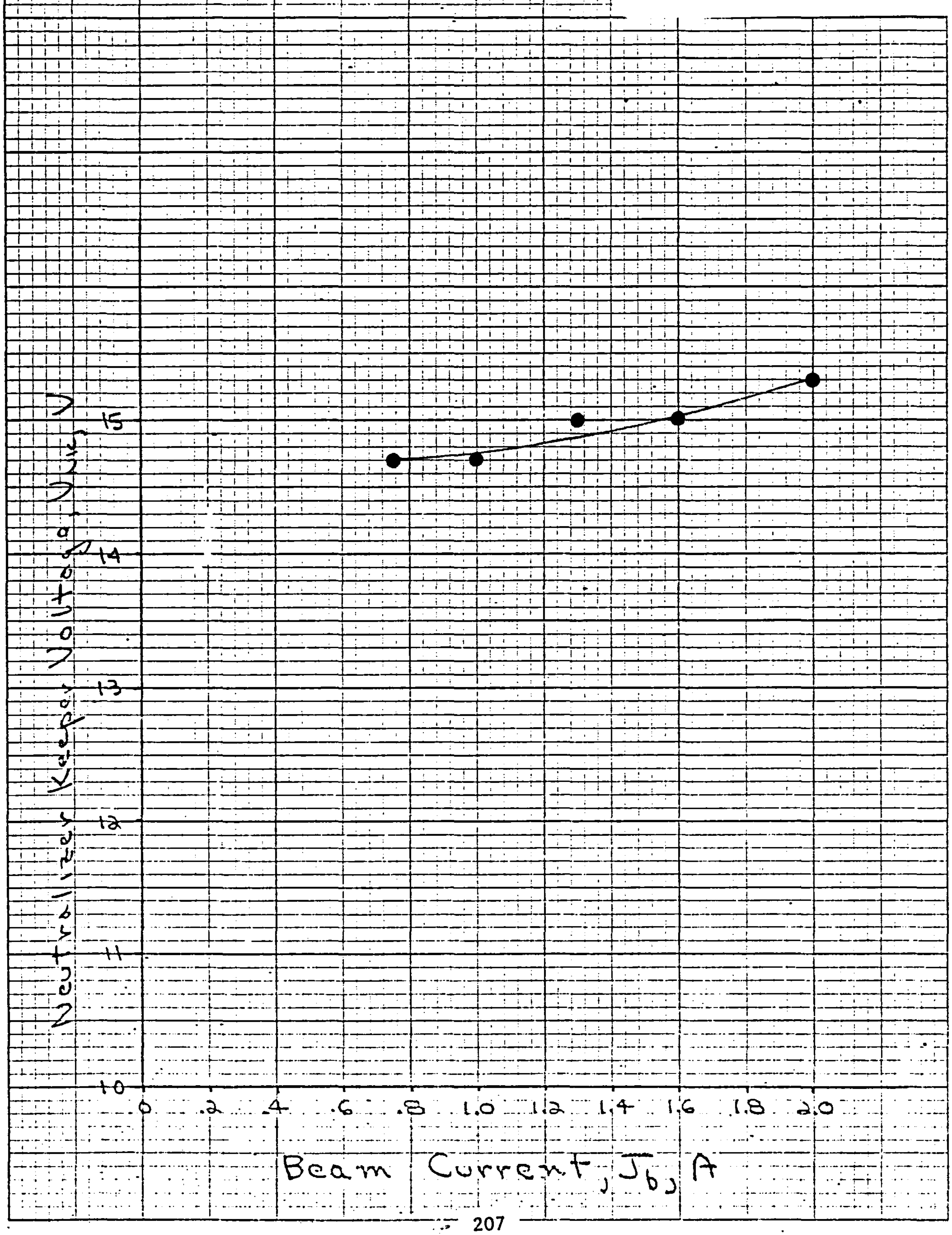

Discharge Characteristic
Thruster — J5
TP - 7
J_b = 1.0A
Cathode Keeper Voltage, V_{CK}, V
Cathode Vaporizer Temp, T_{CV}, °C
5.7
5.6
5.5
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{MB}, A
IV-C S/N 817



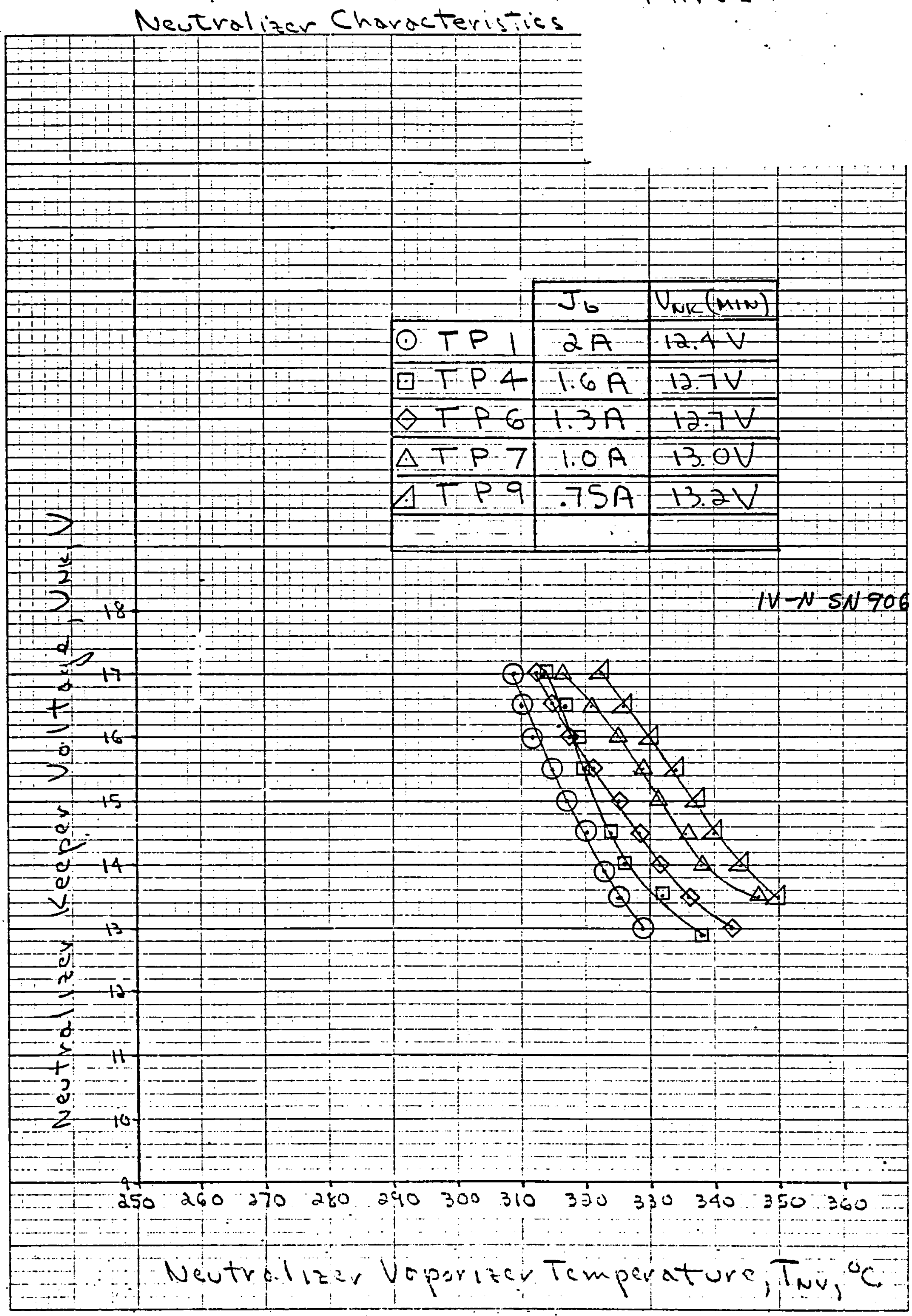
Discharge Characteristic
Thruster __ J5
TP - 9
Jb = 0.75
Cathode Keeper Voltage, Vck, V
Cathode Vaporizer Temp, Tcv, °C
6.5
6.4
6.3
350
340
330
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, JMB, A
IV-C S/N 817

Thruster J-5

Selected Neutralizer Keeper Voltages



Thruster J-5



	J_b	V_{NK}(MIN)
⊙ TP 1	2A	12.4V
⊡ TP 4	1.6A	12.7V
◇ TP 6	1.3A	12.7V
△ TP 7	1.0A	13.0V
◺ TP 9	.75A	13.2V

46 0780

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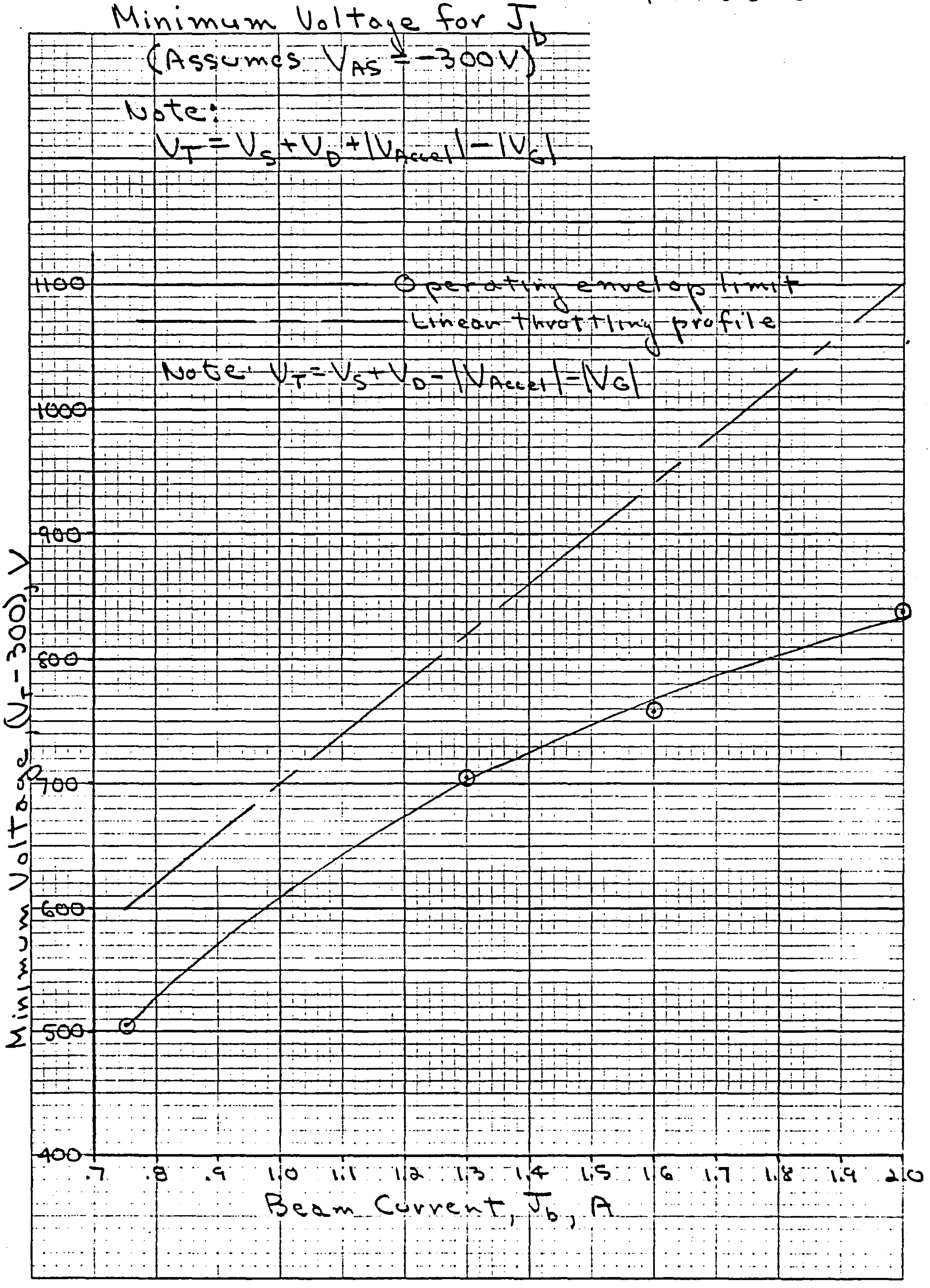
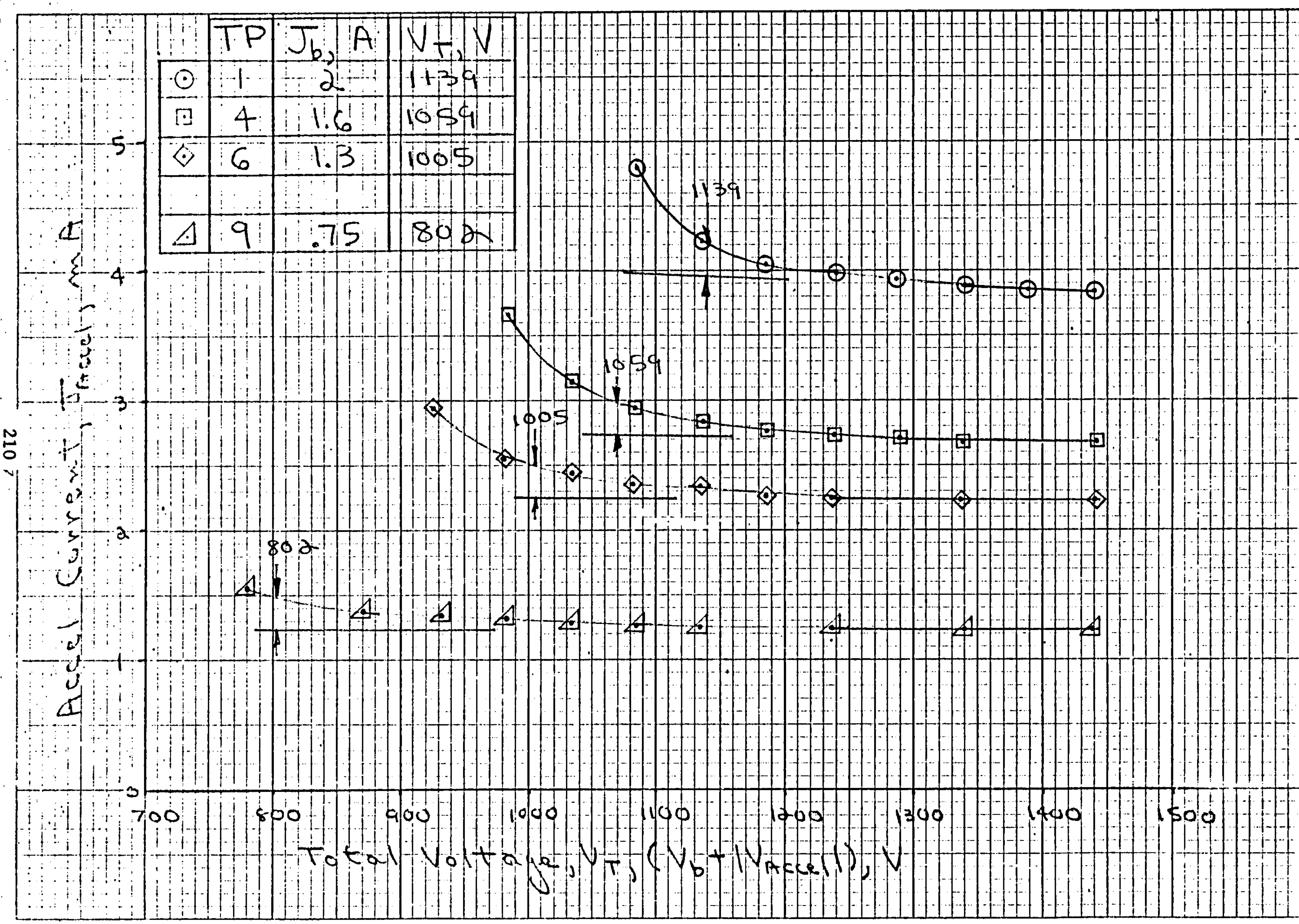
Thruster J-5


Minimum Voltage for J_b
(Assumes $V_{AS} \doteq -300V$)
Note:
$V_T = V_S + V_D + |V_{Accel}| - |V_G|$
⊙ Operating envelop limit
Linear throttling profile
Note: $V_T = V_S + V_D - |V_{Accel}| - |V_G|$
1100
1000
900
800
700
600
500
400
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Beam Current, J_b, A
Minimum Voltage (V_T - 300), V



	TP	J_b, A	V_T, V
⊙	1	2	1139
⊡	4	1.6	1059
◈	6	1.3	1005
◺	9	.75	802

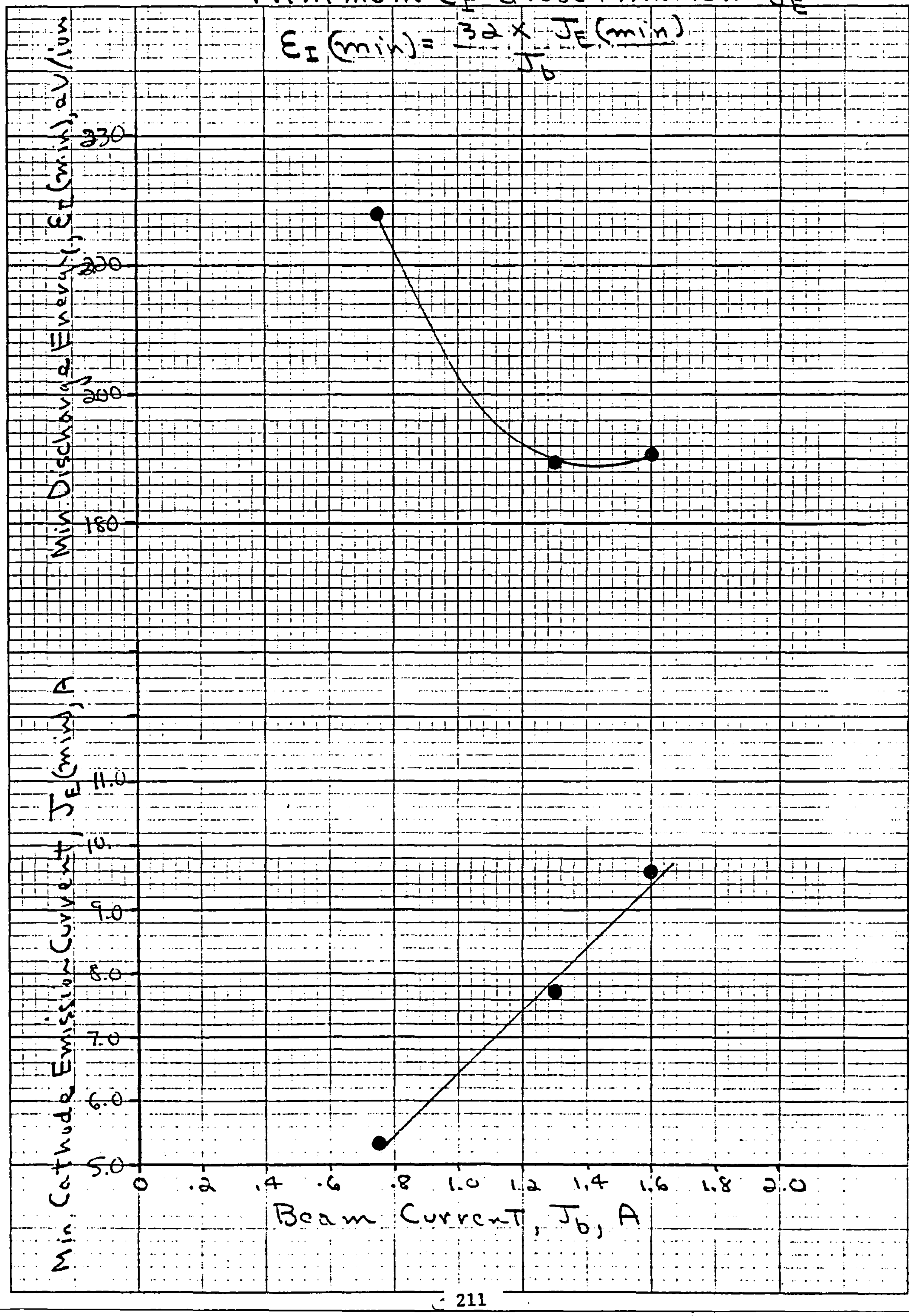
Perveance

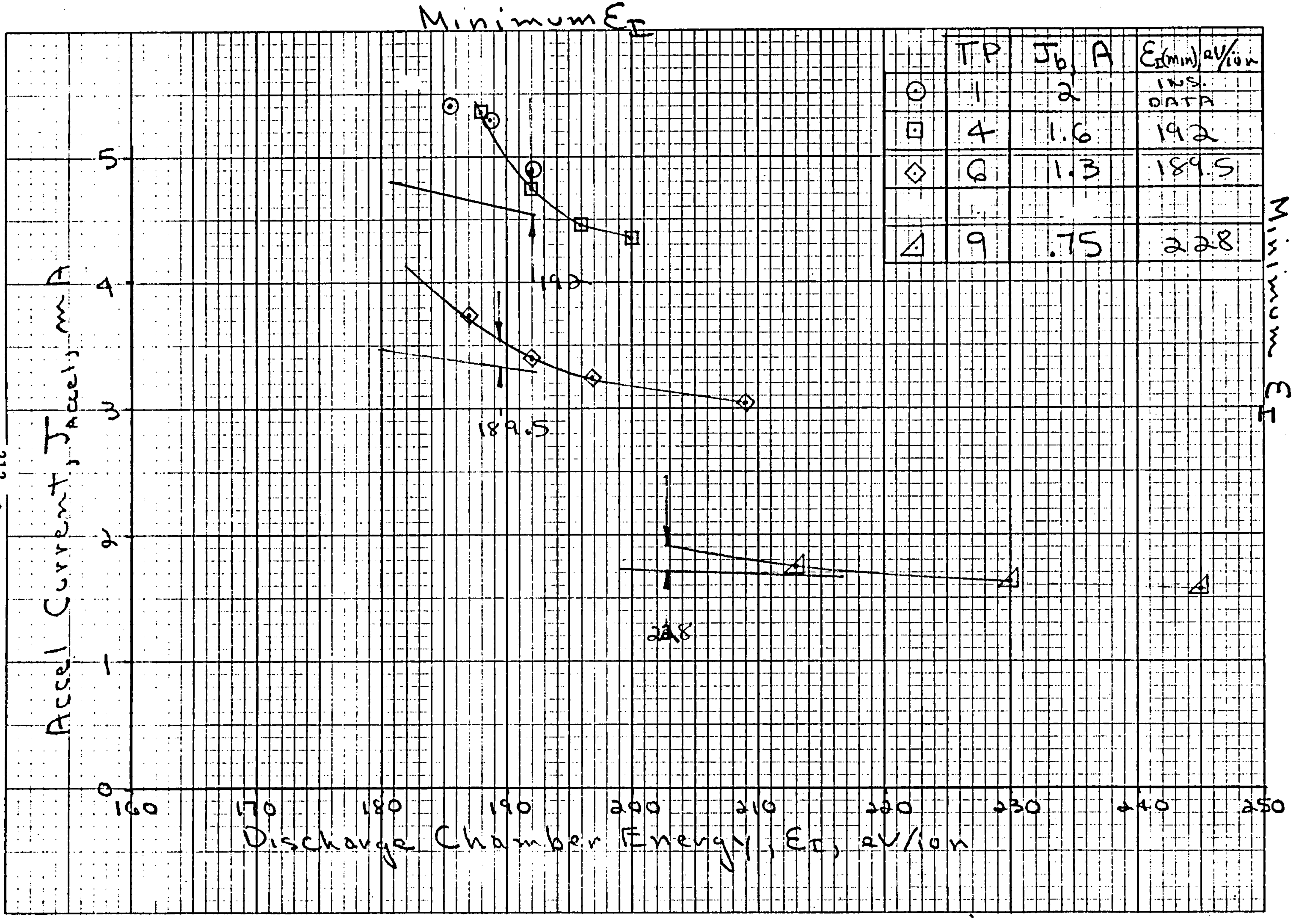
Thruster J-5

210

Thruster J-5

Minimum $\mathcal{E}_I$ and Minimum J_E




Minimum $\mathcal{E}_I$
TP | J_b, A | $\mathcal{E}_{I(min)}$ eV/ion
1 | 2 | INS. DATA
4 | 1.6 | 192
6 | 1.3 | 189.5
9 | .75 | 228
192
189.5
228
Minimum $\mathcal{E}_I$
Accel Current, J_{accel}, mA
Discharge Chamber Energy, $\mathcal{E}_I$, eV/ion
0
1
2
3
4
5
160
170
180
190
200
210
220
230
240
250

Thruster J-5

ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

THRUSTER J6

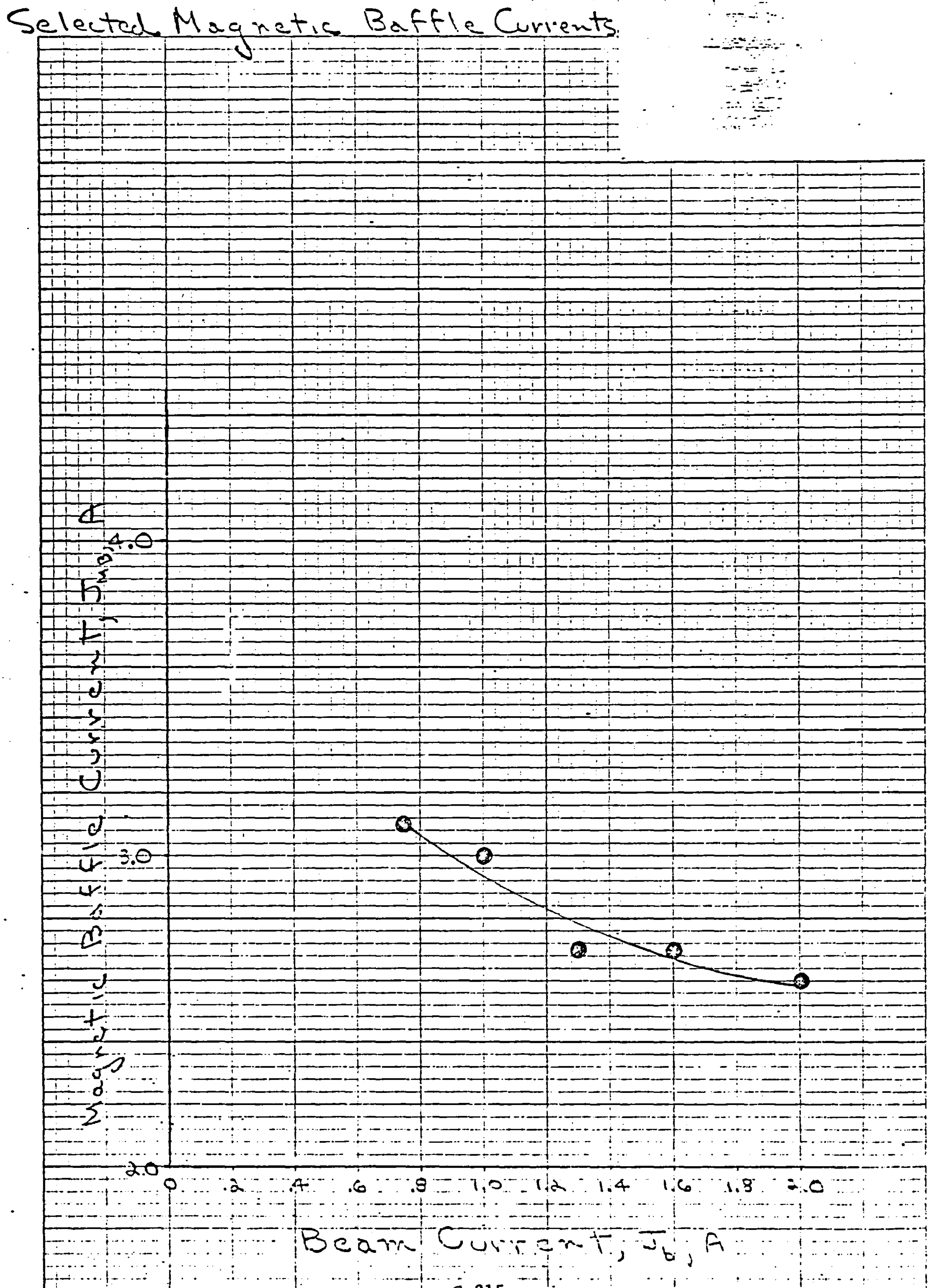
	TEST POINT		1	2	3	4	5	6	7	8	9	10
OPERATING PARAMETERS	V_b	V	1107	1106	1106	943	1101	820	703	1098	602	599
	J_b	A	2.0	2.0	2.0	1.61	1.30	1.30	1.0	.75	.75	.75
	V_D	V	32	31	32	32	32	32	32	32	32	31
	J_D	A	14.06	14.0	13.4	11.81	9.84	9.82	7.98	6.51	6.49	6.51
	J_E	A	12.06	12.0	11.4	10.20	8.54	8.52	6.98	5.76	5.74	5.76
	J_{MB}	A	2.59	2.60	2.60	2.80	2.88	2.88	3.30	3.40	3.39	3.40
	V_{CK}	V	4.20	4.30	4.34	5.32	5.28	5.31	6.04	6.81	6.85	7.15
	J_{CK}	A	.983	.980	.981	.956	.981	.973	.979	.981	.979	.981
	V_{Accel}	V	-340	-339	-340	-335	-339	-335	-331	-338	-330	-328
	J_{Accel}	mA	3.54	4.00	3.76	2.20	1.93	2.41	1.54	1.18	1.14	1.34
	V_{NK}	V	13.59	13.58	13.59	13.60	13.64	13.41	13.48	13.98	13.14	13.99
	J_{NK}	A	1.81	1.80	1.82	1.81	1.82	1.81	1.82	1.82	1.82	1.82
	V_G	V	-10.36	-10.39	-10.31	-10.16	-10.52	-10.59	-10.75	-10.84	-11.32	-10.76
FLOWS	T_{MV}	°C	320	315	315	306	301	306	289	281	279	278
	T_{CV}	°C	302	281	307	309	292	284	287	306	318	326
	T_{NV}	°C	292	293	292	306	303	302	306	311	322	310
	$\dot{m}_{MV}$	eq. A	1.929	1.945	1.954	1.563	1.252	1.290	.950	.761	.759	.700
	$\dot{m}_{CV}$	eq. mA	65.1	71.3	43.4	76.5	76.3	79.9	88.2	100.2	99.6	156.3
	$\dot{m}_{NV}$	eq. mA	33.4	20.4	30.5	39.9	34.9	48.9	40.9	54.1	~75	51.1
	$\dot{m}_t$	eq. A	2.028	2.037	2.028	1.679	1.363	1.419	1.079	.915	.934	.907
POWER	$\eta_{D(unc)}$	%	100.3	99.2	100.1	98.2	97.9	94.9	96.3	87.1	87.4	87.6
	η_D	%	97.2	95.0	95.4	93.5	95.1	91.1	94.4	86.1	86.3	86.8
	$\eta_{t(unc)}$	%	98.6	98.2	98.6	95.9	95.4	91.6	92.7	82.0	80.2	82.7
	P_b	W	2214	2212	2212	1518	1429	1066	701	824	452	450
	P_V	W	7.29	9.42	7.91	9.92	10.38	8.65	8.76	10.30	11.57	11.96
	P_t	W	2657.5	2645.1	2636.2	1861.3	1758.4	1393.9	977.8	1062.0	689.0	683.4
	η_e	%	83.3	83.6	83.9	81.6	81.3	76.4	71.7	77.6	65.6	65.8
BEAM	α		.9820	.9753	.9723	.9718	.9834	.9765	.9882	.9935	.9925	.9946
	F_T		.9857	.9851	.9845	.9862	.9837	.9847	.9836	.9839	.9843	.9838
	γ		.9680	.9608	.9572	.9584	.9674	.9616	.9720	.9775	.9769	.9785
	[illegible]		.9693	.9579	.9526	.9518	.9718	.9599	.9798	.9890	.9872	.9909
	J_b^{++}/J_b^{+}		.0653	.0920	.1046	.1066	.0599	.0872	.0421	.0226	.0263	.0186
MISC.	η_T	%	77.0	75.8	75.8	71.9	73.2	64.7	62.8	60.8	50.2	52.1
	F	mN	131.3	130.3	129.8	96.6	85.1	73.0	52.6	49.5	36.7	36.6
	I_{sp}	s	3179	3140	3141	2824	3064	2525	2390	2657	1926	1981
	P_{tank}	pa	1.4^{-4}	1.1^{-4}	1.6^{-4}	1.3^{-4}	1.3^{-4}	1.3^{-4}	5.1^{-5}	1.0^{-4}	1.06^{-4}	8.7^{-5}

ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

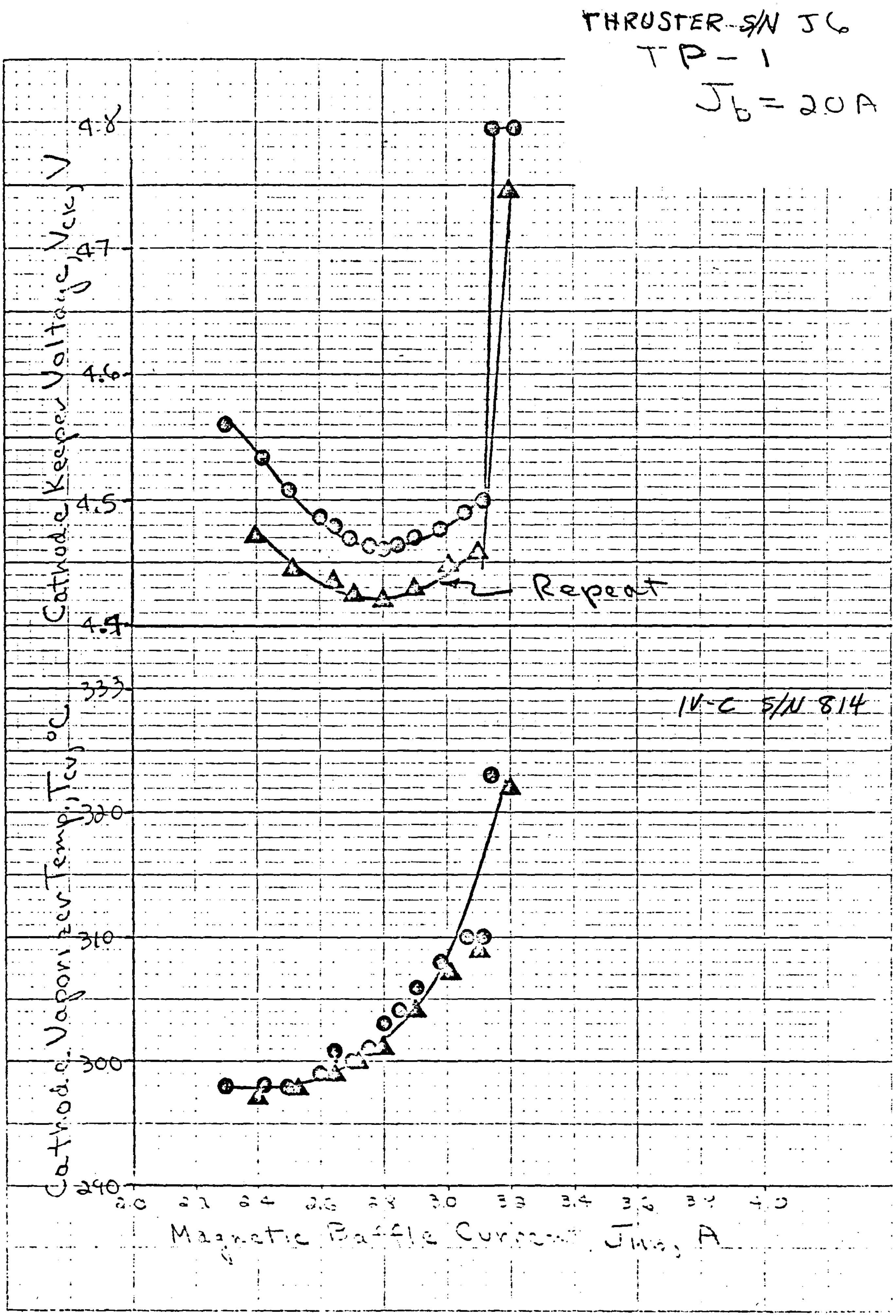
THRUSTER J G

	TEST POINT		1	2	3	4	5	6	7	8	9	10
OPERATING PARAMETERS	V_b	V	1099			939		820	701		598	
	J_b	A	2.001			1.598		1.299	.997		.750	
	V_D	V	32.0			32.0		32.0	32.02		32.0	
	J_D	A	13.98			11.60		9.80	8.0		6.51	
	J_E	A	11.98			10.0		8.5	7.0		5.76	
	J_{MB}	A	2.6			2.7		2.7	3.0		3.10	
	V_{CK}	V	4.36			4.93		5.55	6.33		7.16	
	J_{CK}	A	1.02			1.00		.999	1.03		1.03	
	V_{Accel}	V	-307			-304		-301	-299		-296	
	J_{Accel}	mA	4.16			3.09		2.40	1.85		1.48	
	V_{NK}	V	13.90			14.01		14.3	14.35		14.90	
	J_{NK}	A	1.81			1.80		1.80	1.80		1.80	
	V_G	V	10.12			10.10		10.12	10.20		10.23	
FLOWS	T_{MV}	°C	316			309		302	292		283	
	T_{CV}	°C	296			302		305	311		315	
	T_{NV}	°C	288			291		295	298		299	
	$\dot{m}_{MV}$	eq. A	2.010			1.613		1.312	1.025		.773	
	$\dot{m}_{CV}$	eq. A	.054			.062		.065	.075		.083	
	$\dot{m}_{NV}$	eq. A	.029			.031		.033	.036		.036	
	$\dot{m}_t$	eq. A	2.093			1.706		1.410	1.136		.892	
	η_{mD} (unc)	%	96.9			95.4		94.3	90.6		87.6	
	η_{mD}	%										
	η_m (unc)	%	95.6			93.7		92.1	87.8		841	
POWER	P_b	W	2199			1501		1065	699		449	
	P_V	W	8.56			8.72		9.29	10.62		11.76	
	P_t	W	2647			1882		1395	980		690	
	η_e	%	83.1			79.8		76.3	71.3		65.1	
BEAM	α											
	F_T											
	γ											
	β											
	$J_b{}^{++}/J_b{}^{+}$											
MISC.	η_T	%										
	F	mN										
	I_{sp}	s										
	P_{tank}	pa	1.2^{-4}			93^{-5}		9.0^{-5}	6.3^{-5}		6.0^{-5}	

Thruster J6

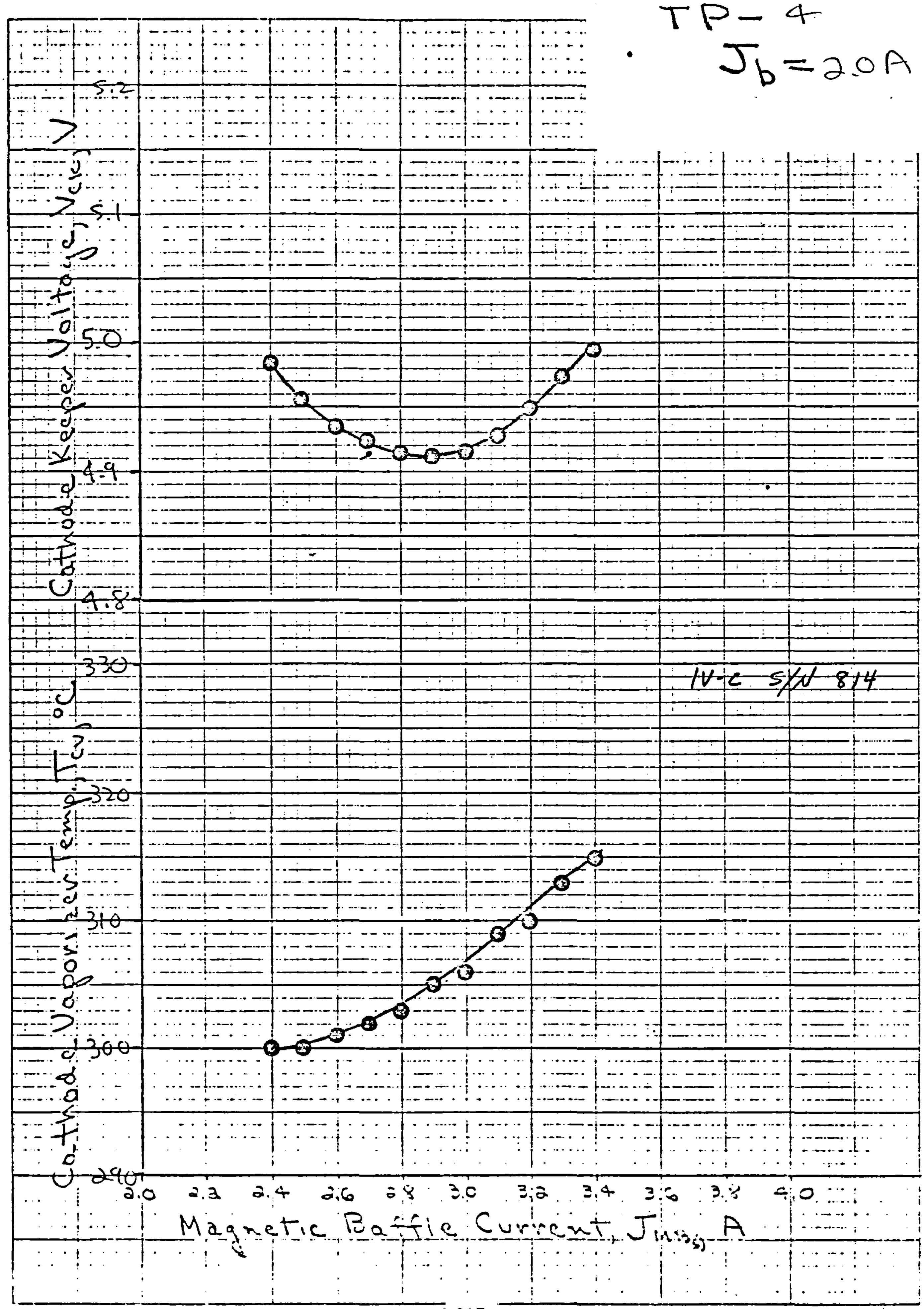


Selected Magnetic Baffle Currents
Magnetic Baffle Current, J_{MB}, A
4.0
3.0
2.0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Beam Current, J_b, A

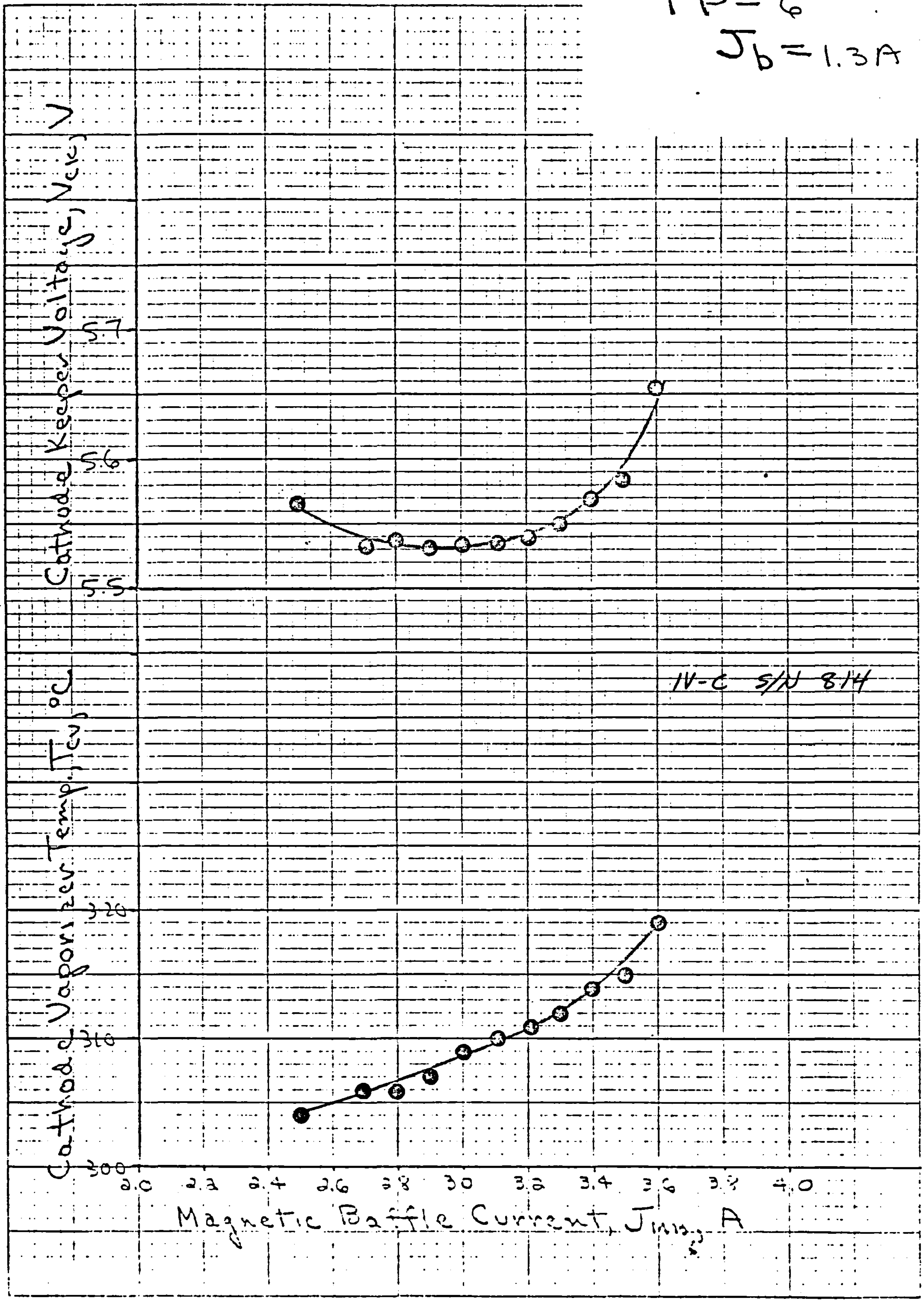


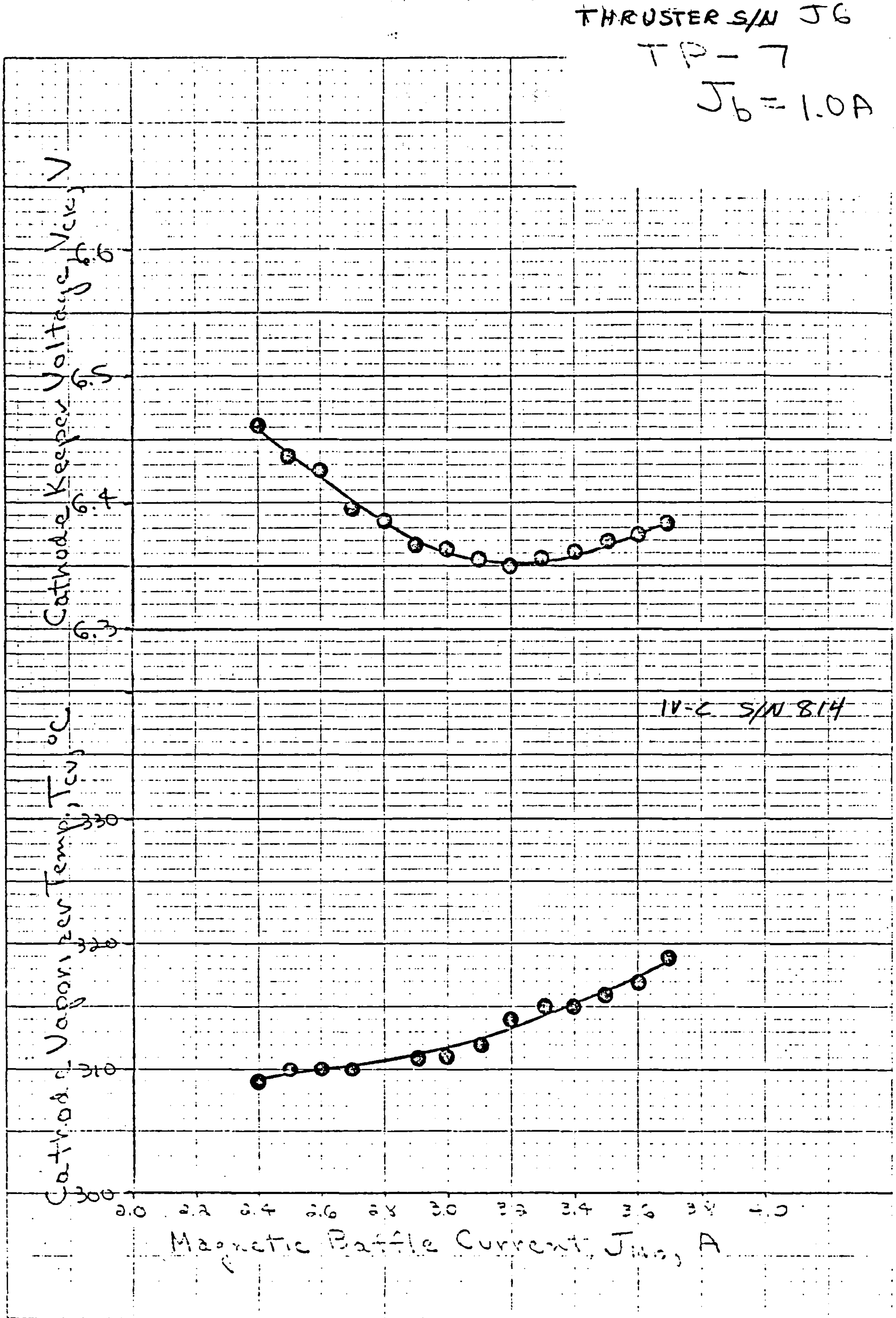
THRUSTER S/N J6
TP-1
J_b = 20A
Cathode Keeper Voltage, V_{ck}, V
4.8
4.7
4.6
4.5
Repeat
333
IV-C S/N 814
Cathode Vaporizer Temp, T_{cv}, °C
320
310
300
290
2.0
2.4
2.6
2.8
3.0
3.2
3.4
3.6
4.0
Magnetic Baffle Current J_{mb}, A

Thruster J6
TP-4
$J_b = 2.0A$

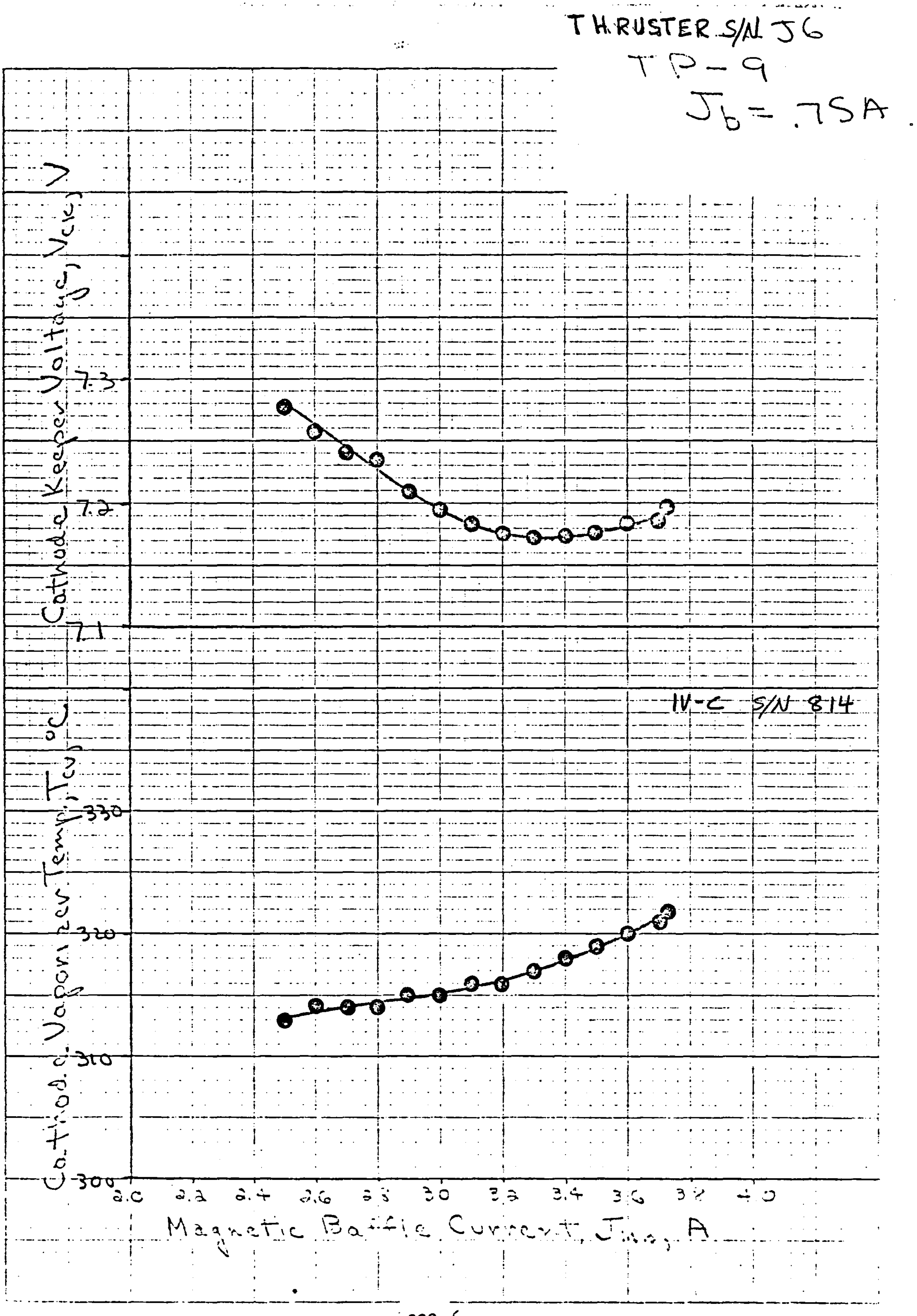


THRUSTER S/N J6
TP-6
$J_b = 1.3A$



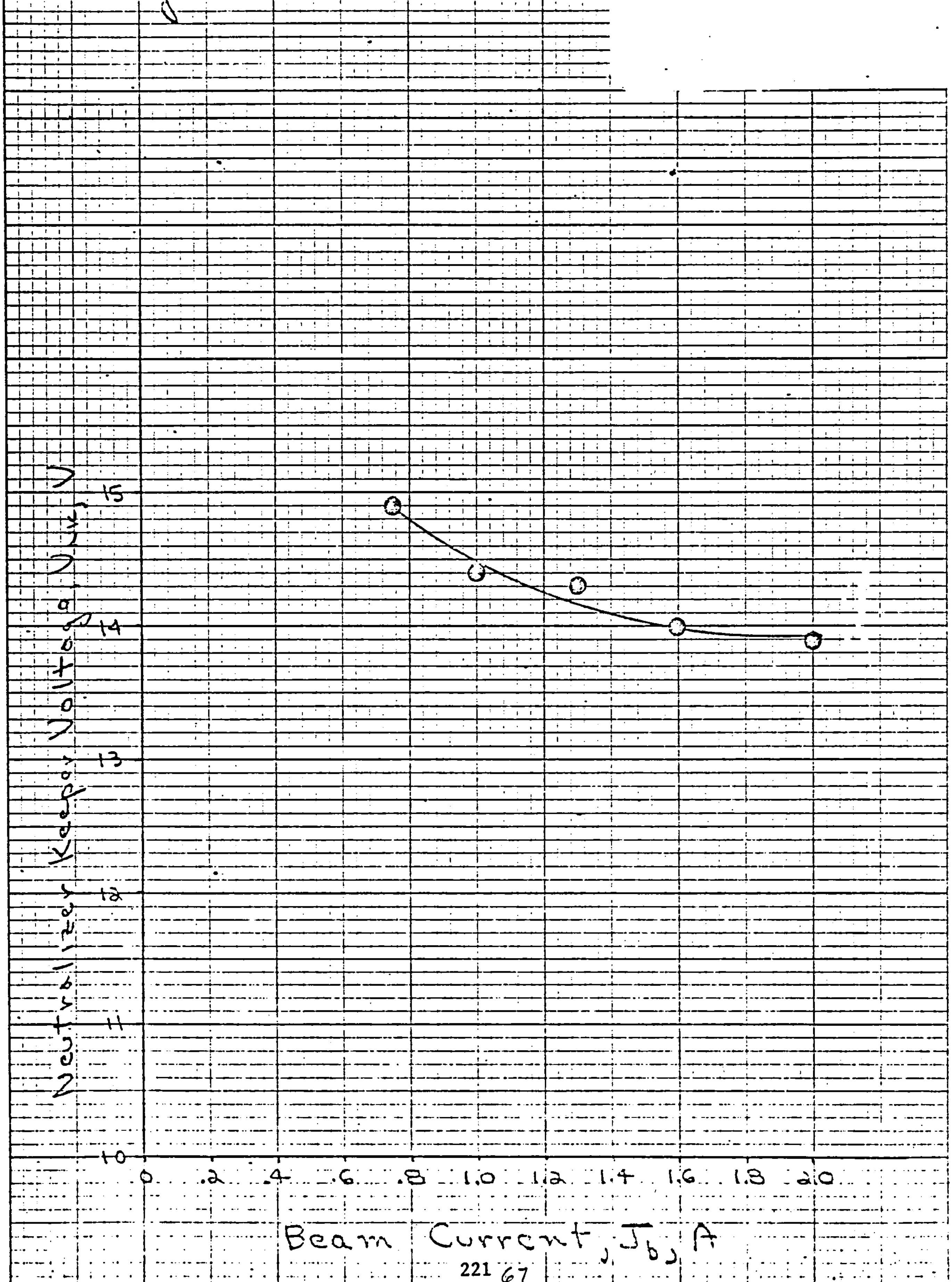


THRUSTER S/N J6
TP-7
Jb=1.0A
Cathode Keeper Voltage, Vck, V
6.6
6.5
6.4
6.3
IV-C S/N 814
Cathode Vaporizer Temp, Tcv, °C
330
320
310
300
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, Jmb, A


THRUSTER S/N J6
TP-9
Jb = .75A
Cathode Keeper Voltage, Vck, V
7.3
7.2
7.1
IV-C S/N 814
Cathode Vaporizer Temp, Tcv, °C
330
320
310
300
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, Jmb, A

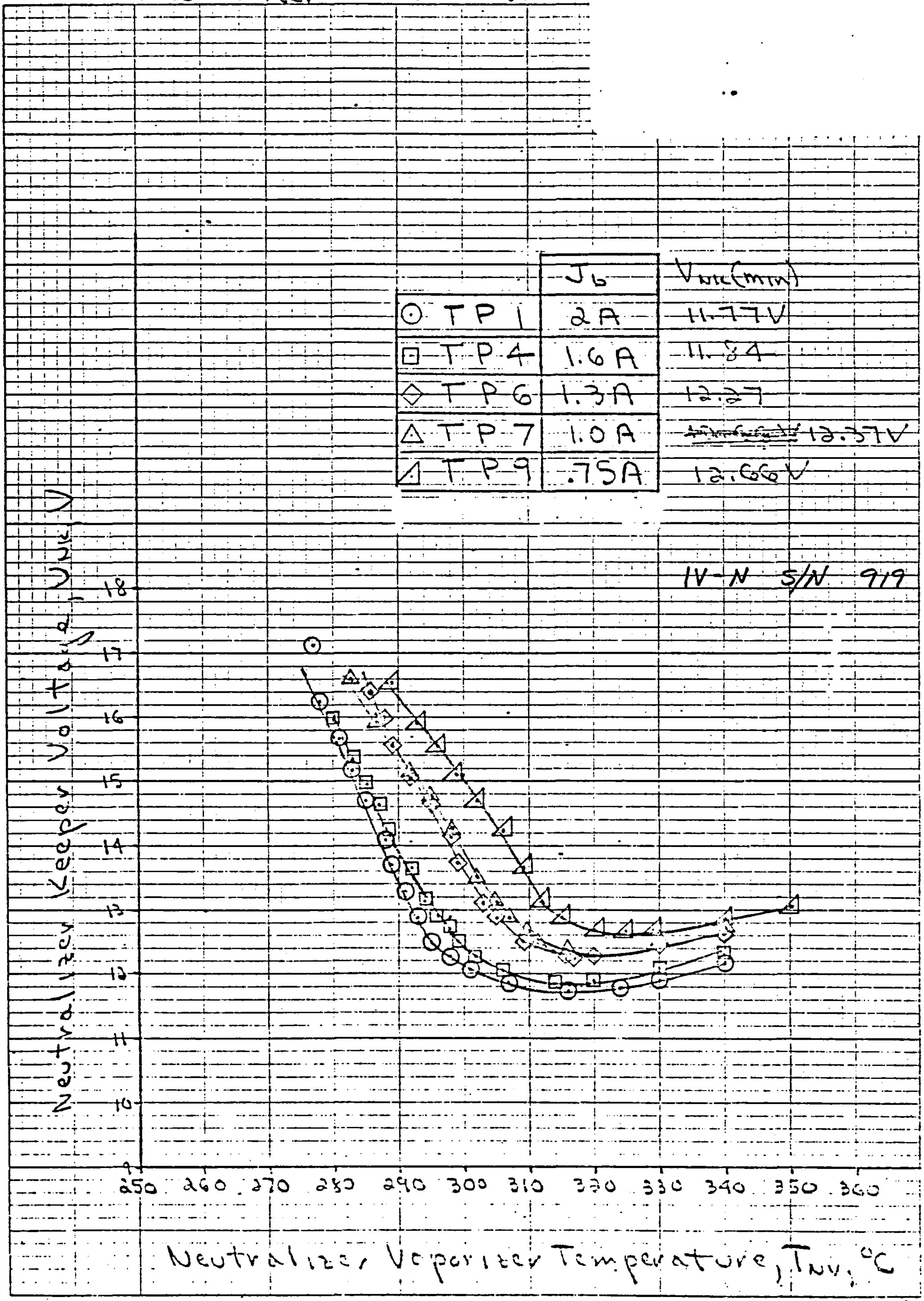
Thruster J6

Selected Neutralizer Keeper Voltages

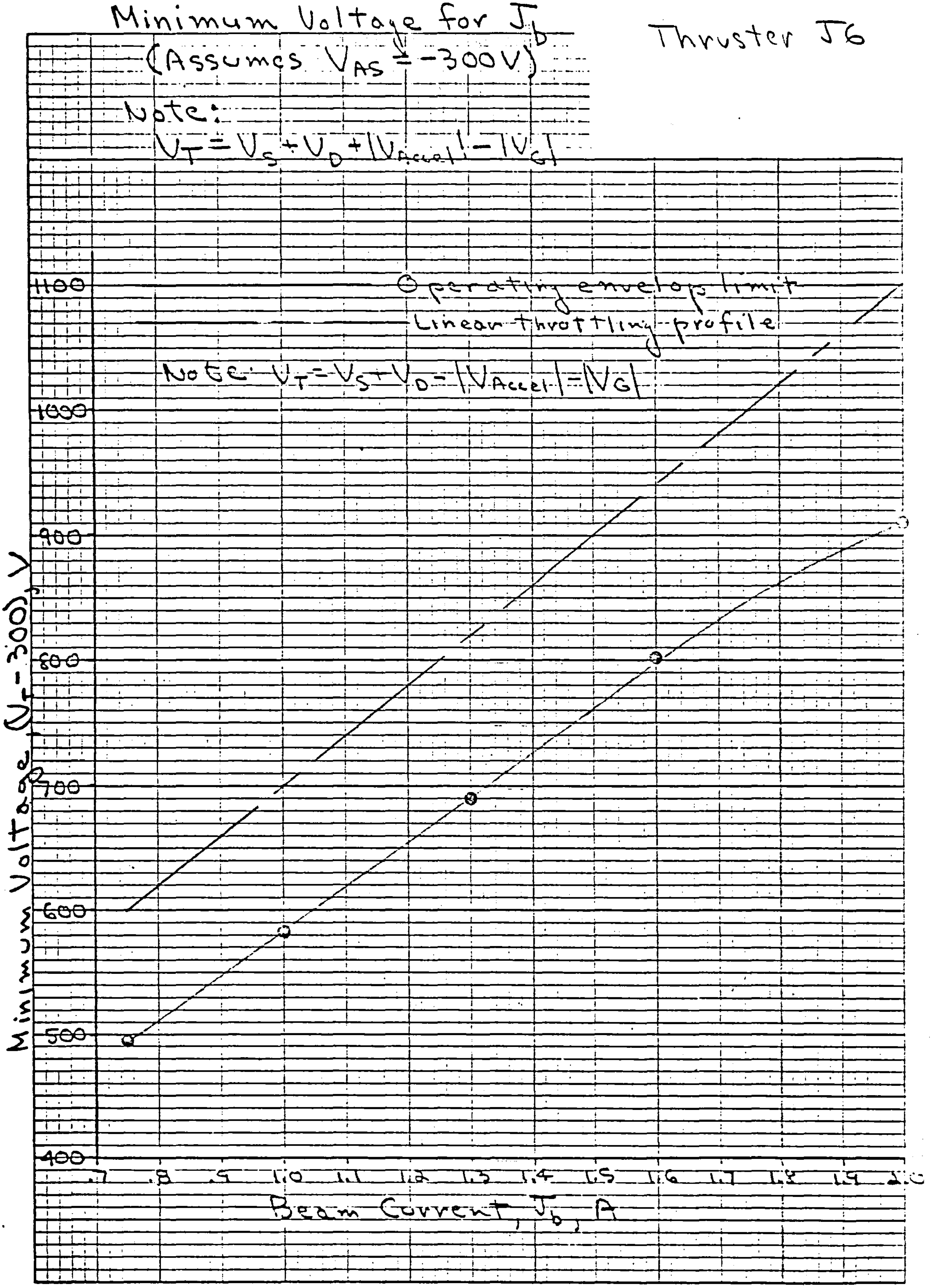


Thruster J6.

Neutralizer Characteristics

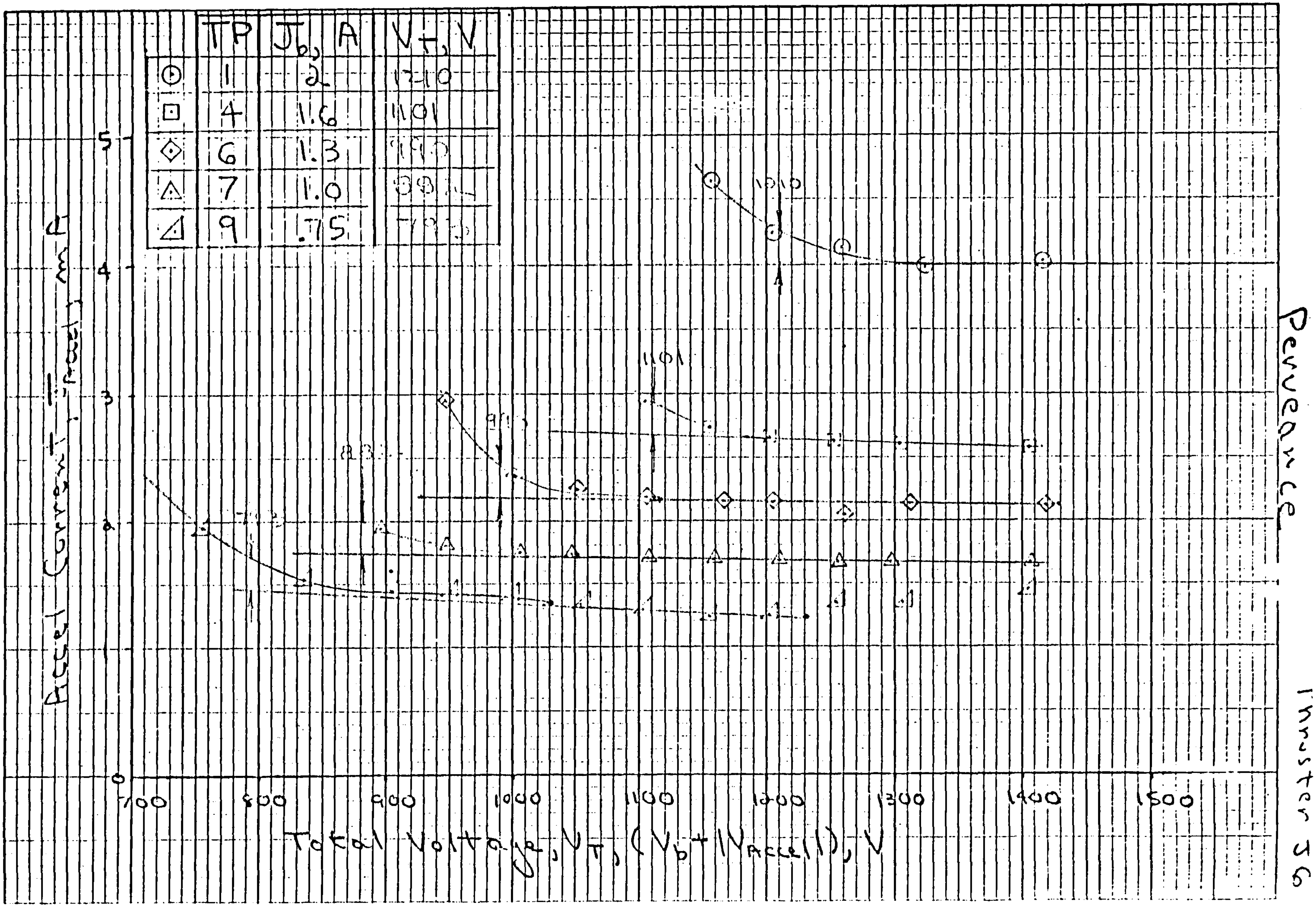


Thruster J6



Minimum Voltage for J_b
(Assumes $V_{AS} \cong -300V$)
Note:
$V_T = V_S + V_D + |V_{Accel}| - |V_G|$
Operating envelope limit
Linear throttling profile
Note: $V_T = V_S + V_D - |V_{Accel}| = |V_G|$
1100
1000
900
800
700
600
500
400
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Minimum Voltage (V_T - 300), V
Beam Current, J_b, A

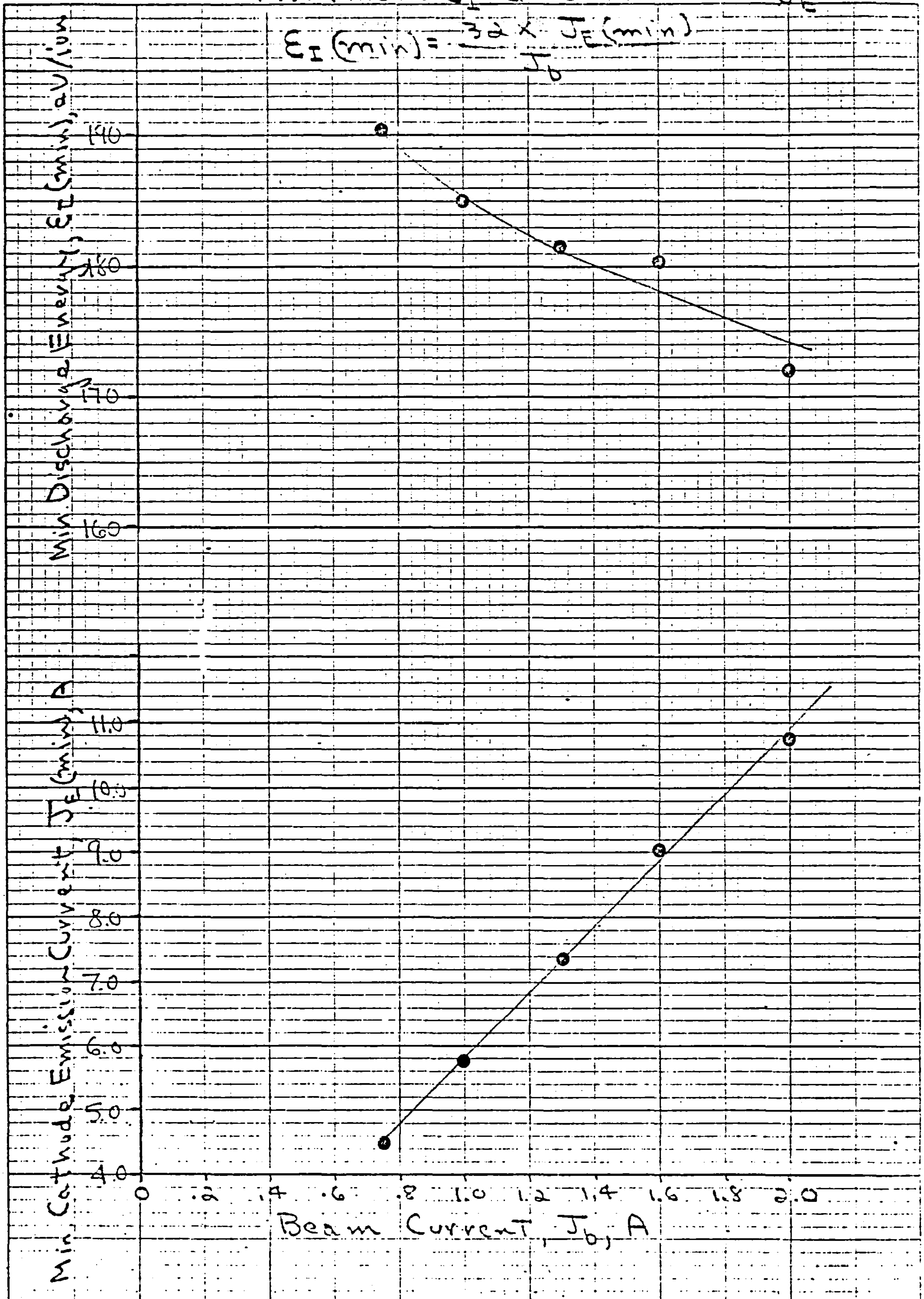
C 224



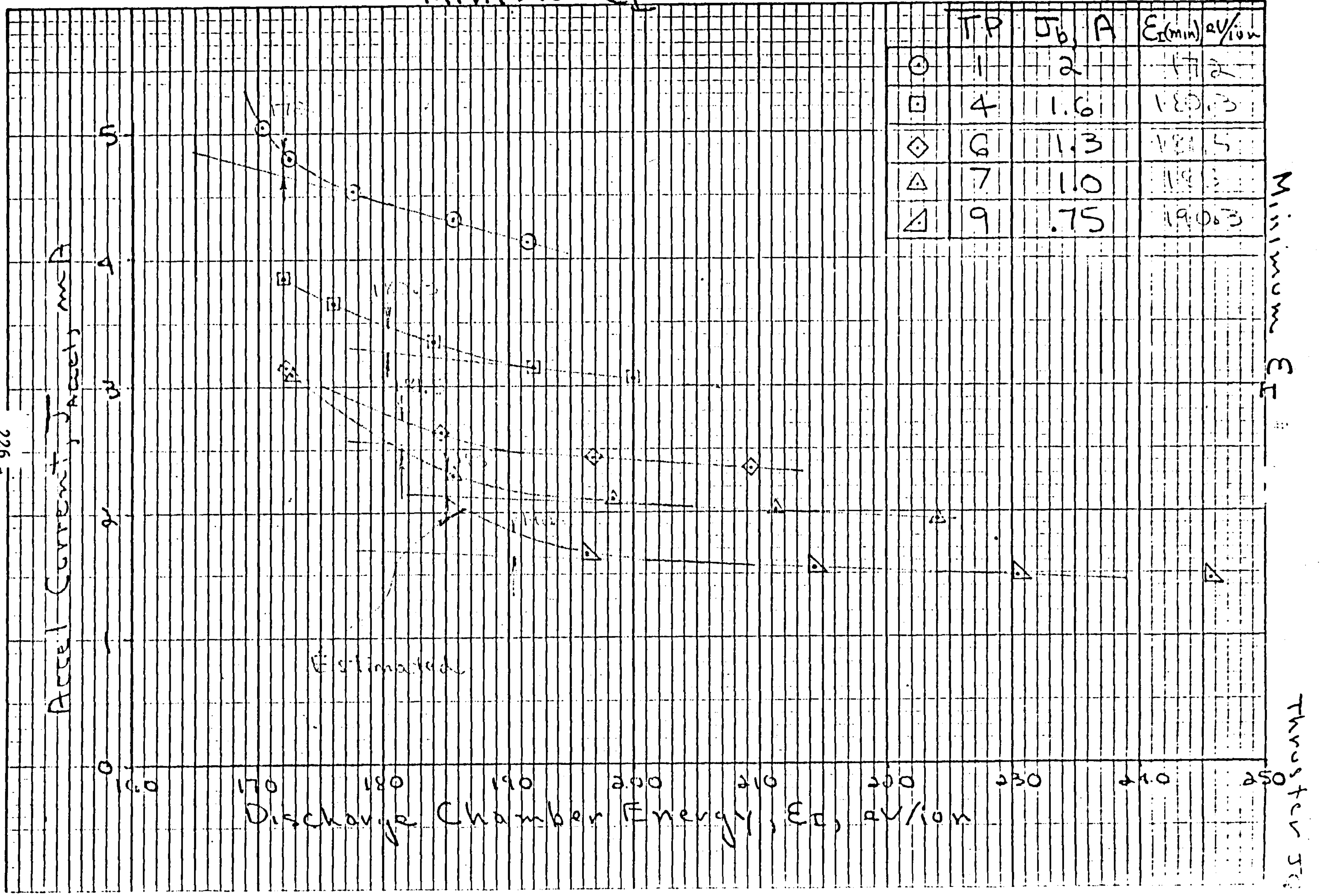
TP | Jb, A | VT, V
1 | 2 | 1210
4 | 1.6 | 1101
6 | 1.3
7 | 1.0
9 | .75
1210
1101
0
4
5
700
800
900
1000
1100
1200
1300
1400
1500
Total Voltage, VT, (Vb+|Vaccel|), V
Perveance
Thruster J6

Thruster J...

Minimum E_I and Minimum J_E



Minimum E_I



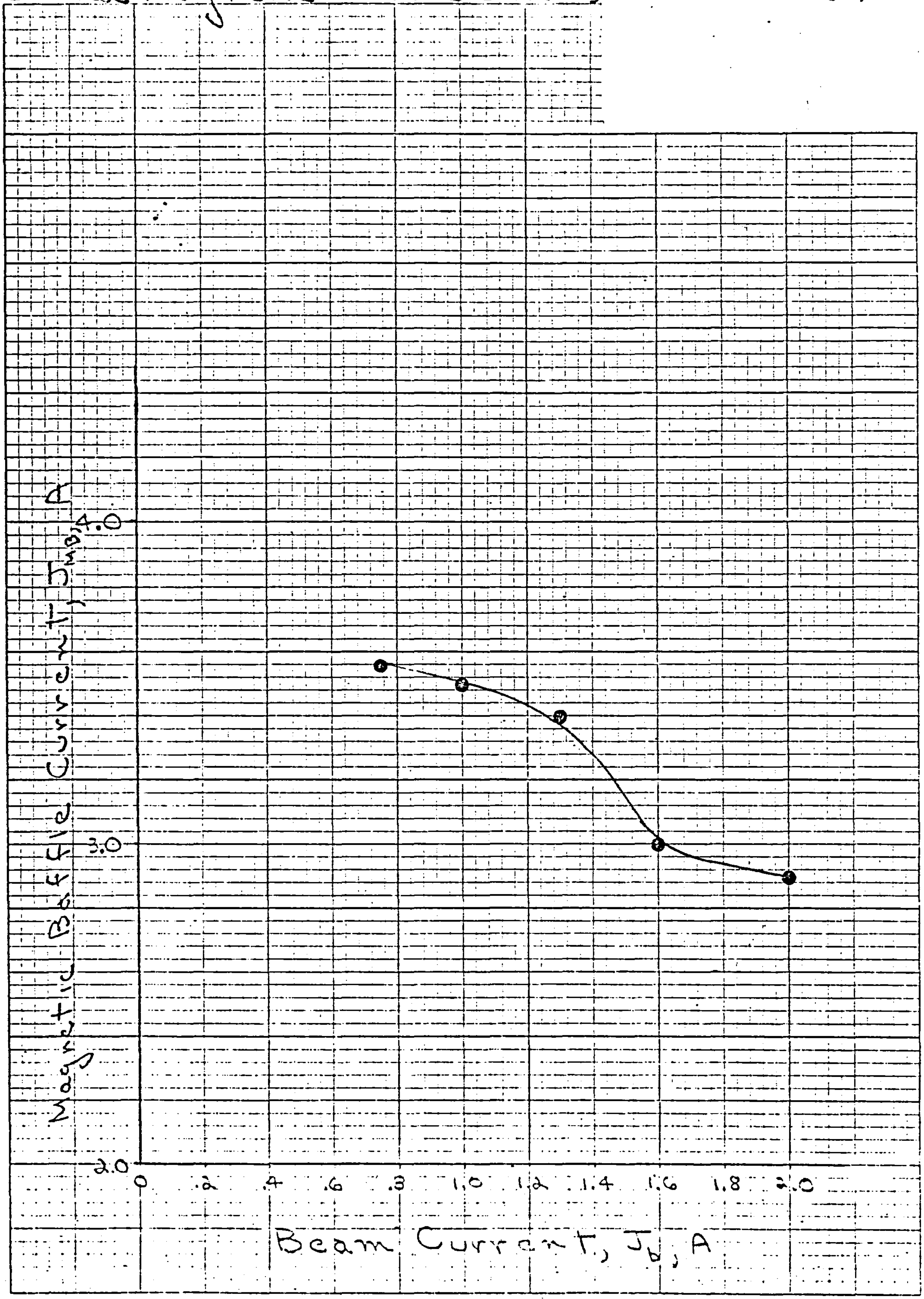
226

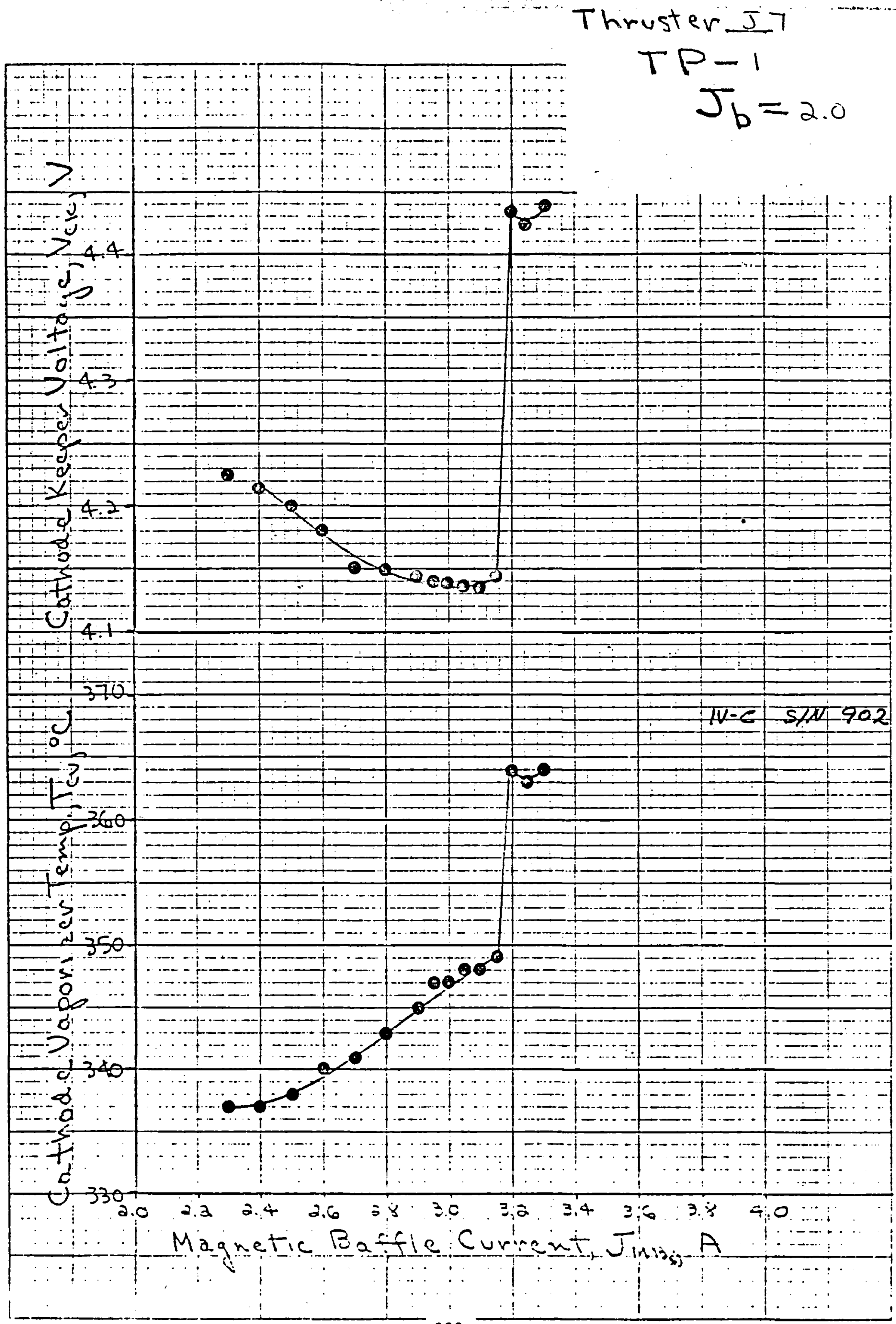
ACCEPTANCE TEST
DATA/PERFORMANCE SUMMARY

THRUSTER J-7

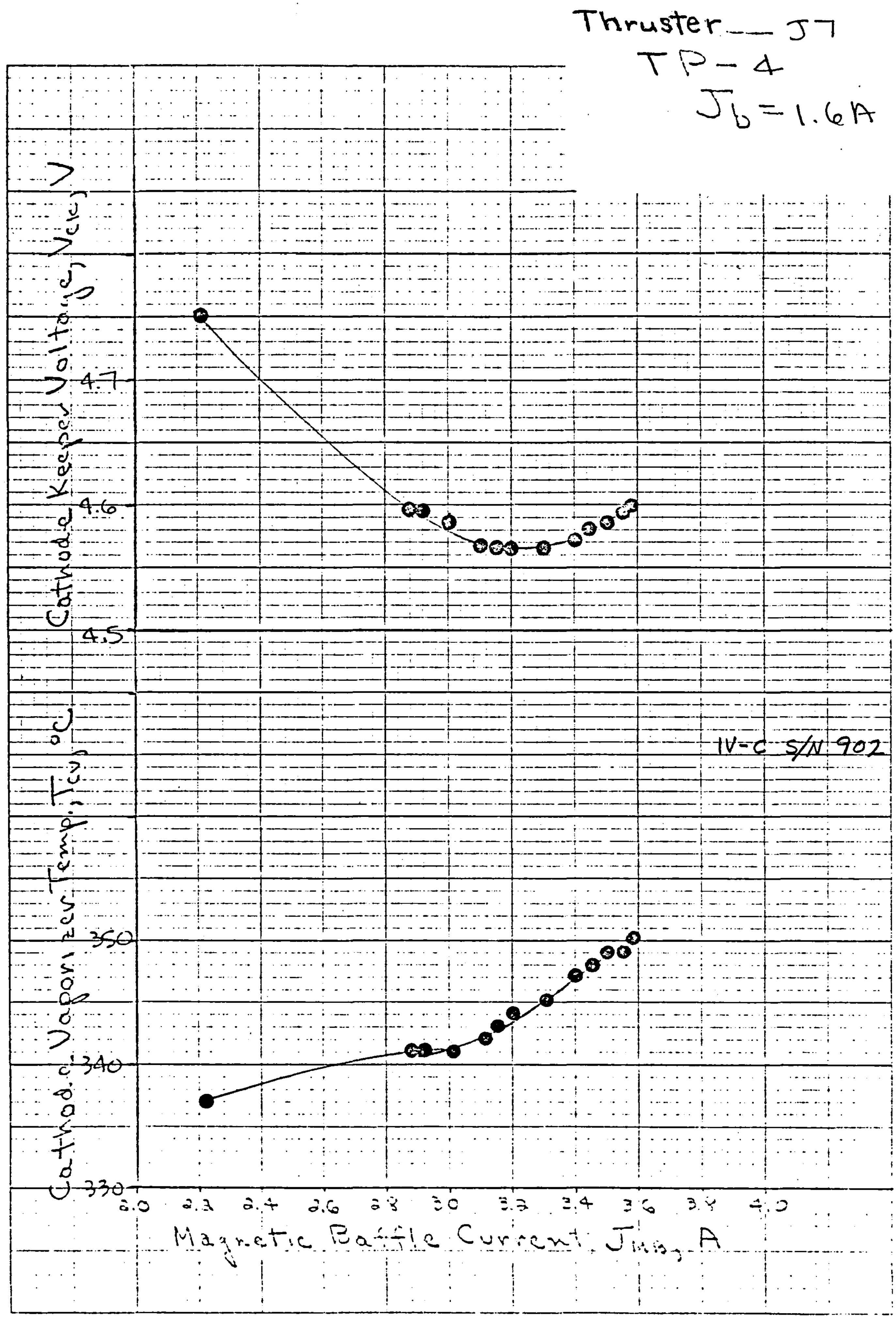
	TEST POINT		1	2	3	4	5	6	7	8	9	10
OPERATING PARAMETERS	V_b	V	1100	1097	1100	939	1101	817	697	1100	596	595
	J_b	A	2.004	2.000	2.002	1.602	1.300	1.299	.998	.751	.752	.752
	V_D	V	32.05	31.0	32.03	32.0	31.96	31.95	31.95	31.96	32.0	310
	J_D	A	14.02	14.0	13.40	11.6	9.80	9.50	8.0	6.49	6.49	6.49
	J_E	A	12.02	12.0	11.40	10.0	8.5	8.50	7.0	5.74	5.74	5.74
	J_{MB}	A	2.90	2.90	2.90	3.00	3.40	3.40	3.5	3.55	3.55	3.55
	V_{CK}	V	4.12	4.11	4.20	4.45	5.12	5.14	5.71	6.50	6.97	6.55
	J_{CK}	A	1.02	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03
	V_{Accel}	V	-311	-311	-310	-306	-308	-303	-301	-307	-298	-299
	J_{Accel}	mA	4.32	4.50	4.46	1.602	2.43	2.70	1.97	1.31	1.58	1.55
	V_{NK}	V	15.83	14.64	15.99	15.99	16.07	16.07	16.48	16.85	16.83	16.85
	J_{NK}	A	1.82	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
	V_G	V	11.73	11.78	11.67	11.63	11.75	11.80	11.75	12.09	12.01	12.01
FLOWS	T_{MV}	°C	347	347	346	337	329	329	319	309	309	310
	T_{CV}	°C	346	347	337	341	350	344	349	354	354	354
	T_{NV}	°C	299	295	294	286	289	294	292	277	281	276
	$\dot{m}_{MV}$	eq. A	1.933	1.978	1.952	1.568	1.281	1.301	.994	.750	.759	.764
	$\dot{m}_{CV}$	eq. A	.077	.083	.069	.069	.085	.083	.081	.090	.090	.091
	$\dot{m}_{NV}$	eq. A	.028	.032	.027	.026	.030	.032	.031	.034	.035	.034
	$\dot{m}_t$	eq. A	2.038	2.093	2.048	1.663	1.396	1.416	1.106	.874	.884	.889
	η_{mD} (unc)	%	99.7	97.0	99.1	97.9	95.2	93.9	92.8	89.4	88.6	88.0
	η_{mD}	%	92.6	91.7	93.2	93.2	91.4	89.6	89.8	86.9	87.1	80.2
	η_m (unc)	%	98.3	95.6	97.8	96.3	93.1	91.7	90.2	85.9	85.1	84.6
POWER	P_b	W	2204	2194	2202	1504	1431	1061	696	826	448	447
	P_V	W	11.0	11.7	10.9	10.7	11.9	12.0	11.6	12.0	12.1	12.1
	P_t	W	2664	2639	2642	1890	1770	1399	982	1072	694	687
	η_e	%	82.7	83.1	83.7	83.1	80.8	75.8	70.9	77.1	64.6	65.1
BEAM	α		.9583	.9676	.9650	.9724	.9766	.9733	.9811	.9836	.9901	
	F_T		.9893	.9867	.9864	.9846	.9856	.9827	.9860	.9807	.9891	
	γ		.9480	.9547	.9519	.9571	.9625	.9565	.9674	.9646	.9793	
	B		.9288	.9457	.9402	.9521	.9600	.9545	.9677	.9734	.9831	
	J_b^{++}/J_b^{+}		.1661	.1169	.1358	.1069	.0869	.1001	.0690	.0575	.0351	
MISC.	η_T	%	73.1	72.4	74.2	73.3	70.0	63.6	59.9	61.6	52.7	
	F	mN	128.5	129.0	128.9	95.8	84.7	72.4	52.0	44.0	36.7	
	I_{sp}	s	3094	3024	3089	2828	2976	2510	2306	2751	2035	
	P_{tank}	pa	1.3^{-4}	1^{-4}	1.1^{-4}	7^{-5}	8^{-5}	7.7^{-5}	5.3^{-5}	5.3^{-5}	6^{-5}	

Selected Magnetic Baffle Currents THRUSTER J7

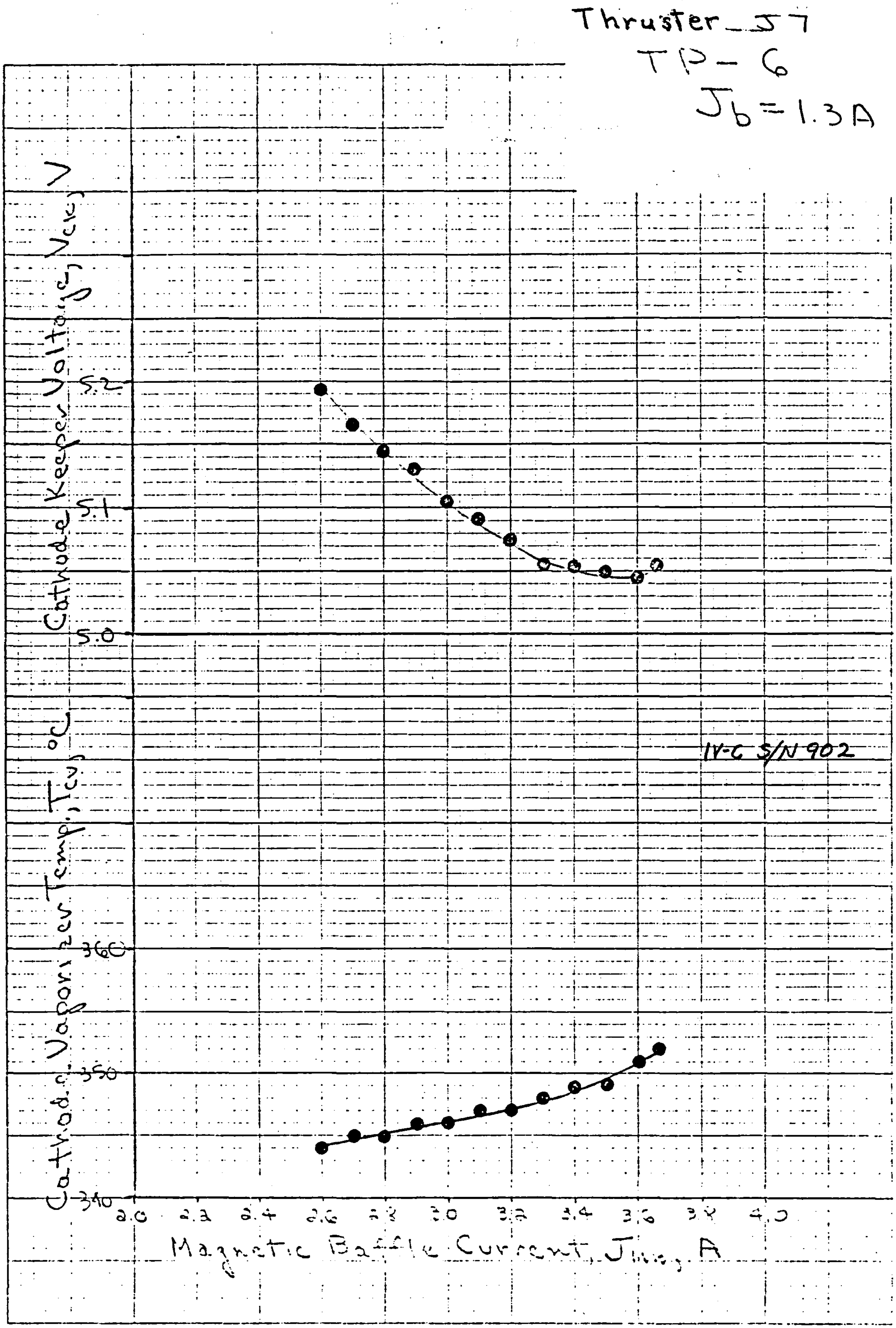




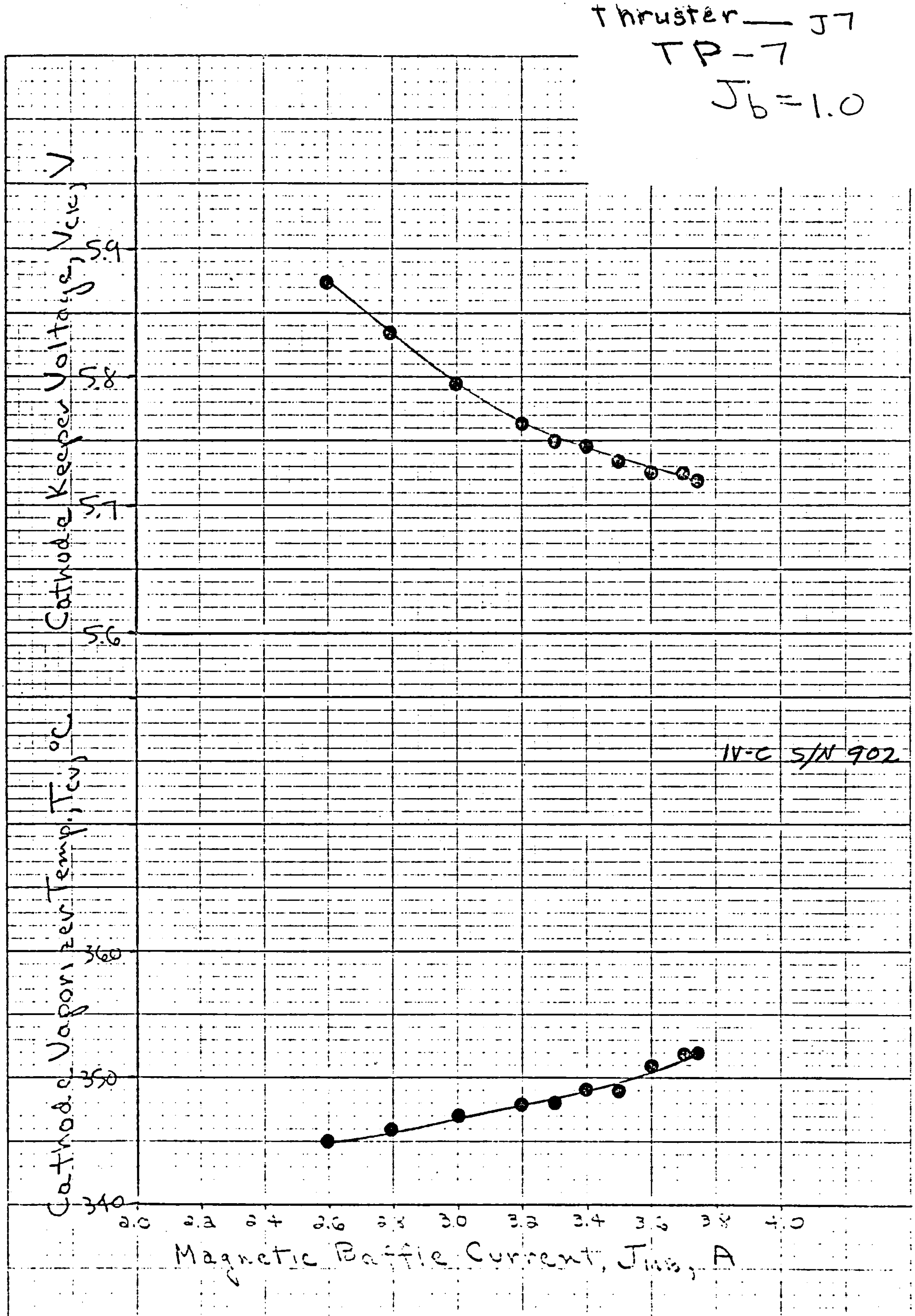
Thruster J7
TP-1
$J_b = 2.0$
Cathode Keeper Voltage, V_{ck}, V
4.4
4.3
4.2
4.1
370
360
350
340
330
Cathode Vaporizer Temp, T_{cv}, °C
IV-C S/N 902
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{mb}, A



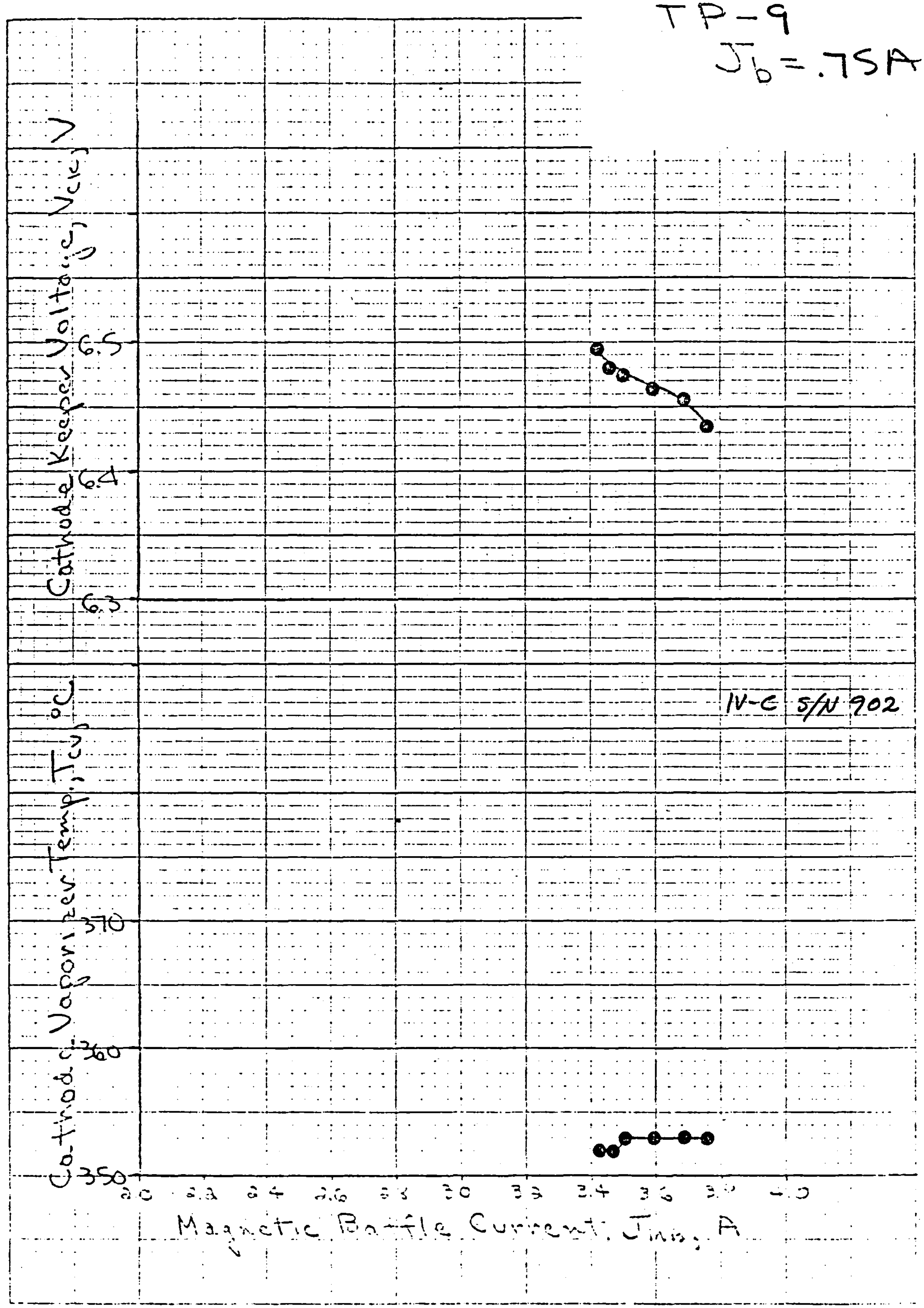
Thruster J7
TP-4
J_b=1.6A
Cathode Keeper Voltage, V_{ck}, V
4.7
4.6
4.5
Cathode Vaporizer Temp, T_{cv}, °C
350
340
330
IV-C S/N 902
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, J_{mb}, A



Thruster J7
TP-6
Jb=1.3A
Cathode Keeper Voltage, Vck, V
Cathode Vaporizer Temp, Tcv, °C
5.2
5.1
5.0
360
350
340
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
IV-C S/N 902
Magnetic Baffle Current, Jmb, A

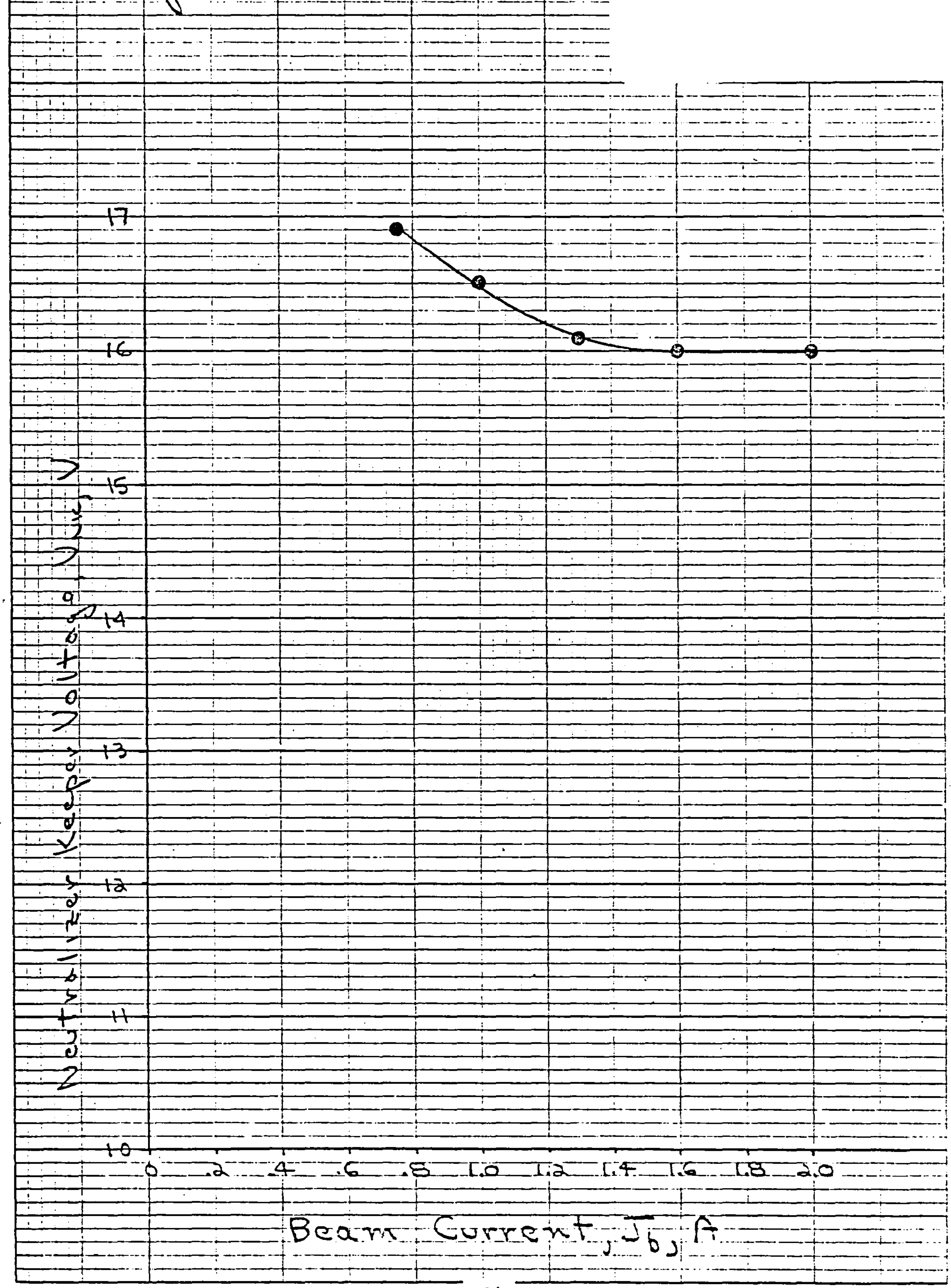

Thruster J7
TP-7
Jb=1.0
IV-C S/N 902
Cathode Keeper Voltage, Vck, V
Cathode Vaporizer Temp, Tcv, °C
5.9
5.8
5.7
5.6
360
350
340
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
Magnetic Baffle Current, Jmb, A

Thruster J7
TP-9
$J_b = .75A$

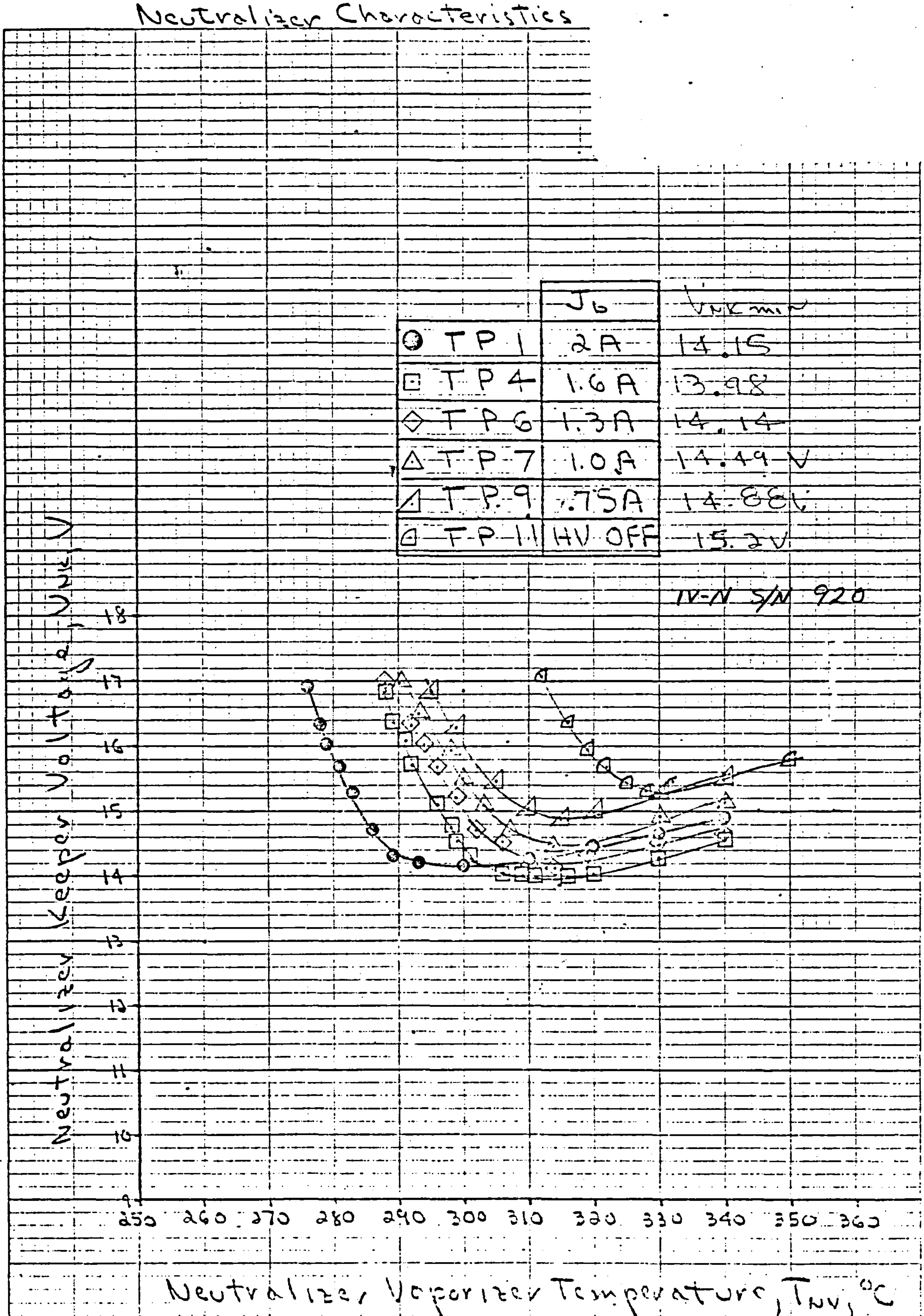


Thruster J7

Selected Neutralizer Keeper Voltages

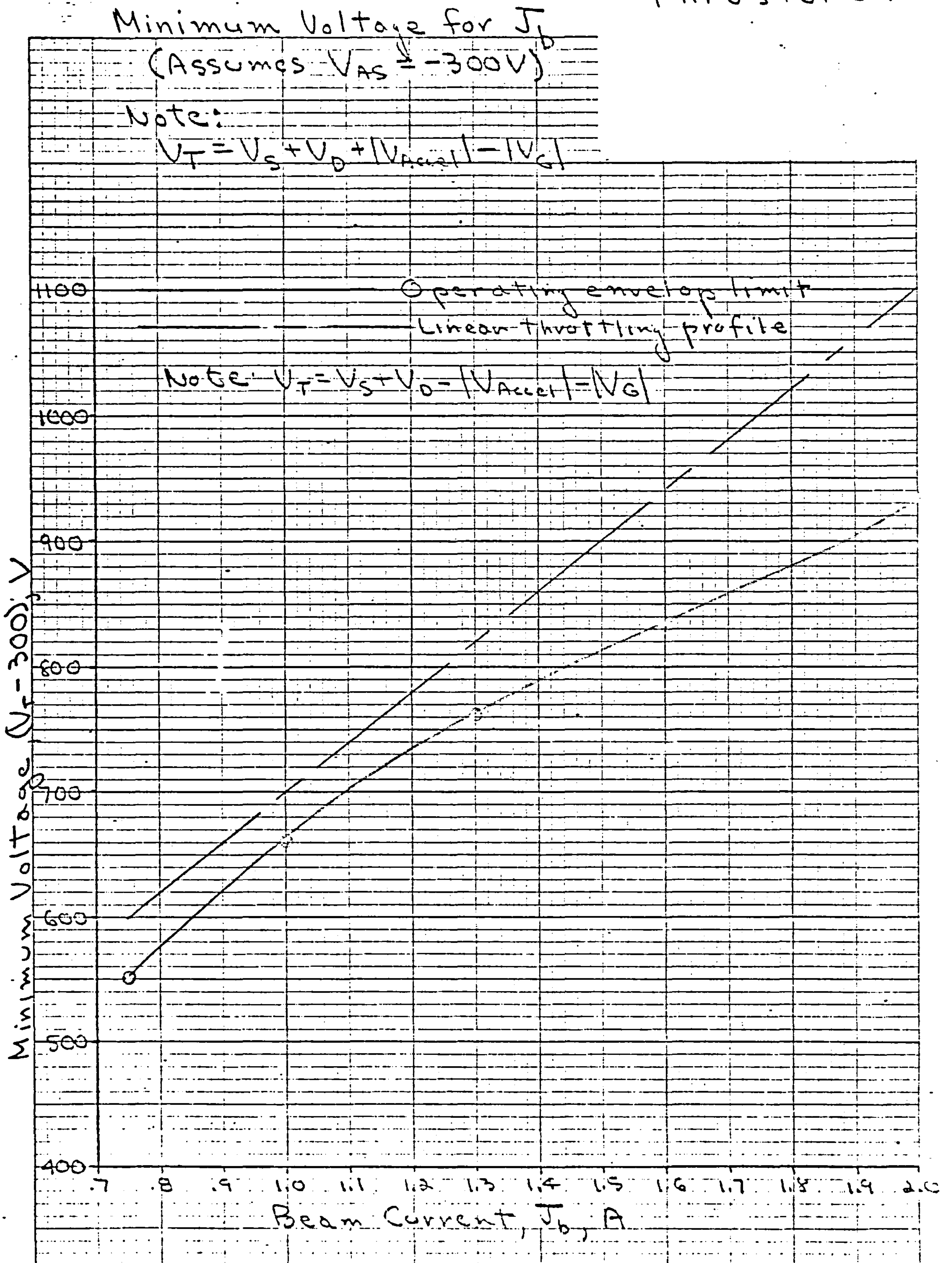


Thruster J7



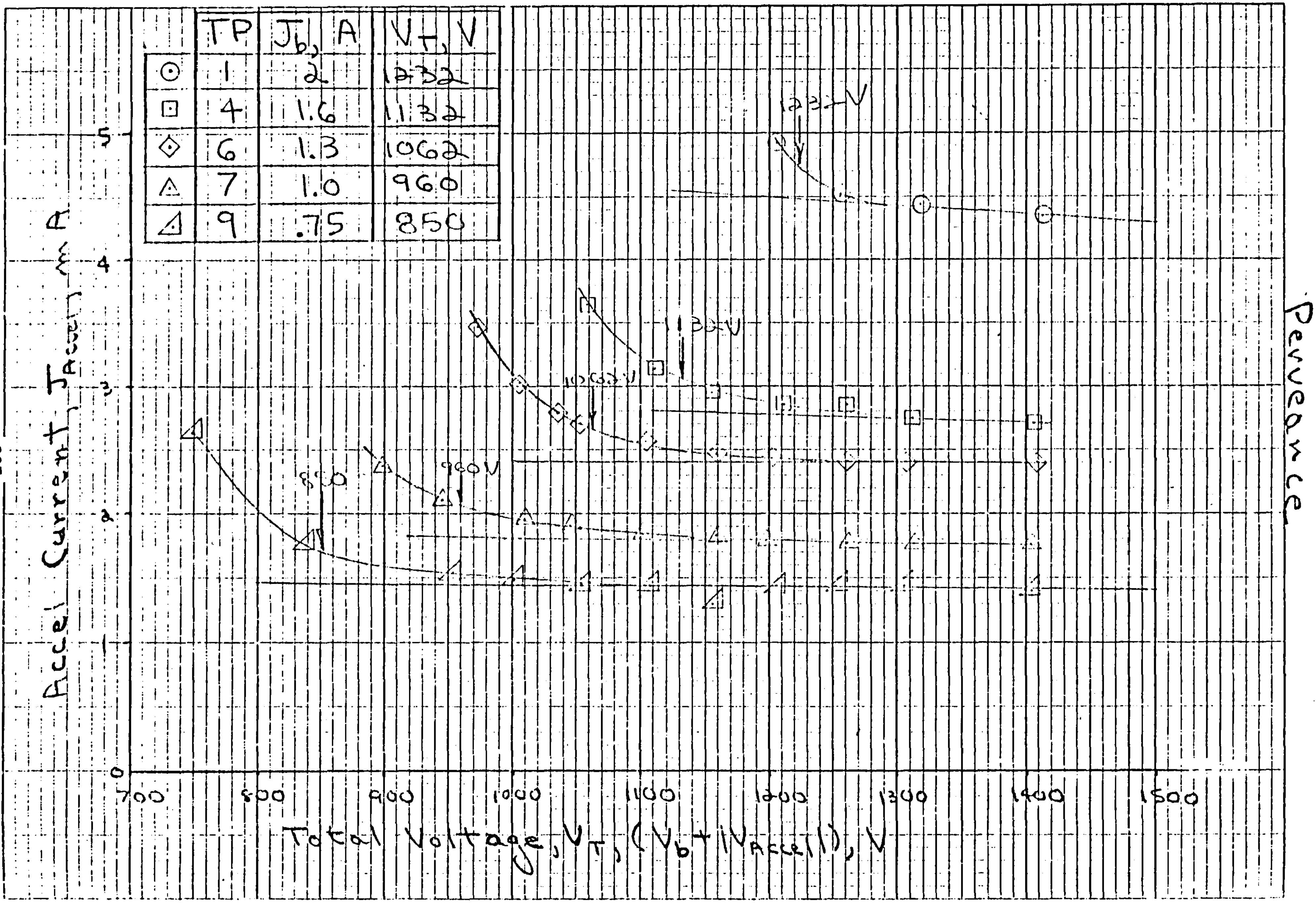
	J_b	$V_{NK\,min}$
● TP 1	2A	14.15
□ TP 4	1.6A	13.98
◇ TP 6	1.3A	14.14
△ TP 7	1.0A	14.49 V
◺ TP 9	.75A	14.88 V
◿ TP 11	HV OFF	15.2V

Thruster J7



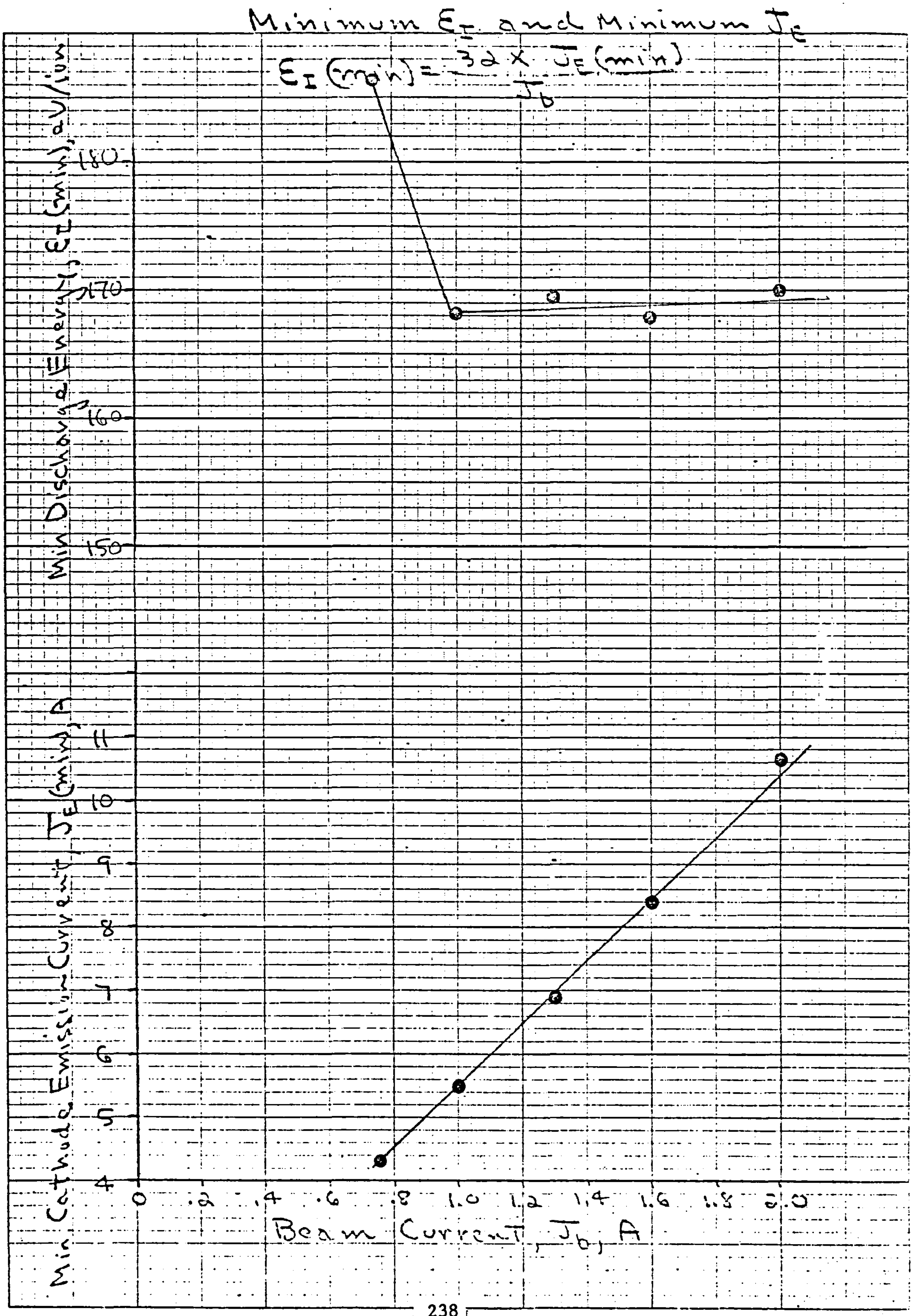
Minimum Voltage for J_b
(Assumes $V_{AS} \approx -300V$)
Note:
$V_T = V_S + V_D + |V_{Accel}| - |V_G|$
Operating envelop limit
Linear throttling profile
Note: $V_T = V_S + V_D - |V_{Accel}| = |V_G|$
1100
1000
900
800
700
600
500
400
Minimum Voltage $(V_T - 300)$, V
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Beam Current, J_b, A

46 0780

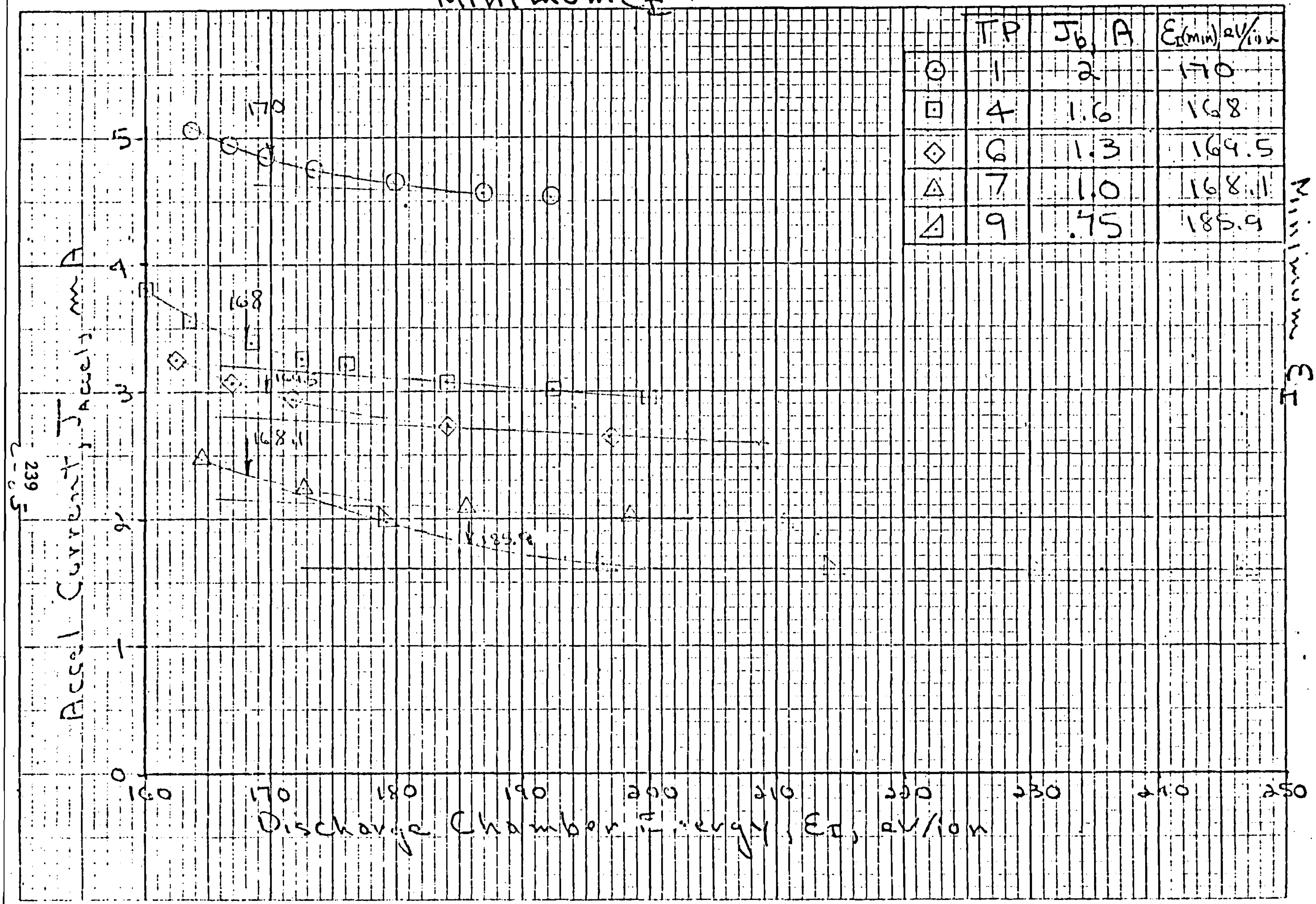


Thruster J7

Thruster J-7


Minimum E_I and Minimum J_E
$E_I(min) = \frac{32 \times J_E(min)}{J_b}$
Min Discharge Energy, $E_I(min)$, eV/ion
180
170
160
150
Min Cathode Emission Current, $J_E(min)$, A
11
10
9
8
7
6
5
4
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Beam Current, J_b, A

Minimum ε_I



	TP	J_b, A	ε_I(min) eV/ion
⊙	1	2	170
⊡	4	1.6	168
◇	6	1.3	169.5
△	7	1.0	168.1
◺	9	.75	185.9

Thruster J-7

APPENDIX D

APPENDIX D

The thrust produced by an ion thruster is typically calculated from the measured ion beam current, J_b, and voltage, V_b, using the expression

$$F_c = J_b \frac{2m}{e} V_b^{\ 1/2} , \qquad (1)$$

where m and e are the charge and mass of the beam ions, respectively. The measured ion beam current contains contributions from doubly charged ions, but not all ion trajectories are paraxial. Consequently, the calculated thrust, F_c, has to be modified to account for these so-called thrust losses. The technique employed by Hughes makes use of a collimating mass spectrometer to measure the distribution of singly and doubly charged ions as functions of angle with respect to the thruster axis. This enables computation of the correction factors, α and F_t, used to correct the measured beam current for contributions of doubly charged ions and non-axial velocity components. Hence,

$$F = \alpha F_t F_c \quad ,$$

where F is the true thrust computed from the calculated thrust. The accuracy of determining α, F_t, and F_c depends on both experimental and computational error that is inherent in the measurement technique. An investigation has been performed recently under NASA contract NAS 3-21943 to assess, quantitatively, the magnitude of the inherent error. This appendix summarizes this analysis and its results (a more detailed description will be found in the final report for contract NAS 3-21943).

A. EXPERIMENTAL PROCEDURE

Determination of the thrust-loss factors, α and F_t, requires a probing technique that can determine the singly and multiply charged ion beam current-density vectors as a function of the polar coordinates, r and θ, defined in Figure D-1. Assumption of symmetry about the thruster axis simplifies the measurement by eliminating the variable, θ, and the problem is reduced to that of

11268–1

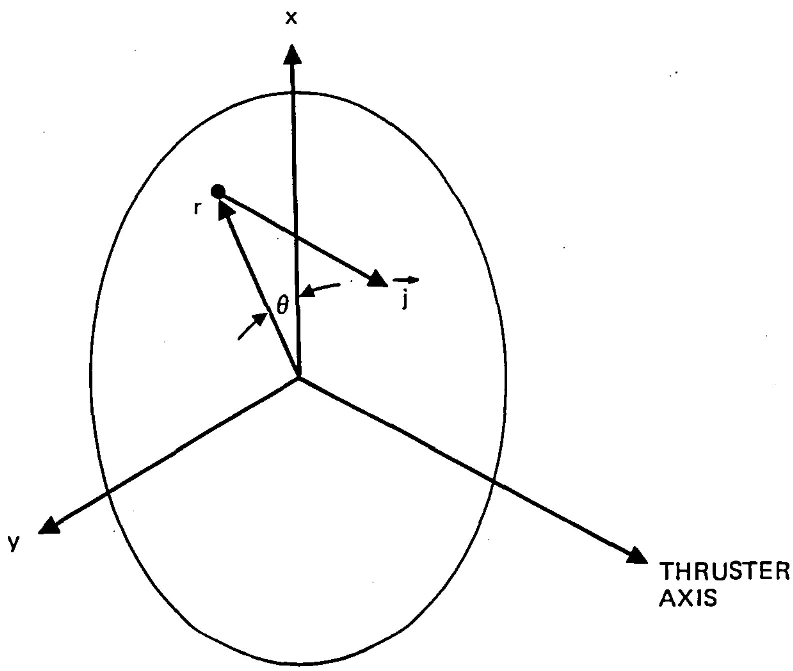


Figure D-1. Definition of polar coordinate system in relation to the thruster axis.

determining the current-density corresponding to each ionic species as a functionial coordinate r. This measurement is accomplished through the use of an articulating probe that can view a small region of the accelerator system from different angles, ϕ_p, and separate the total current leaving this region according to charge. This yields the currents, i_n (r, ϕ_p), where the index n is used to denote the charge state. Integration of these currents over the angle, ϕ_p, gives the current-density vector, $\vec{j}(r)$, and the angle, ϕ, that this vector makes with respect to the thruster axis; Figure D-2 illustrates the geometry. A complete description of the technique used to determine the currents, $i_n(r, \phi_p)$, is presented below.

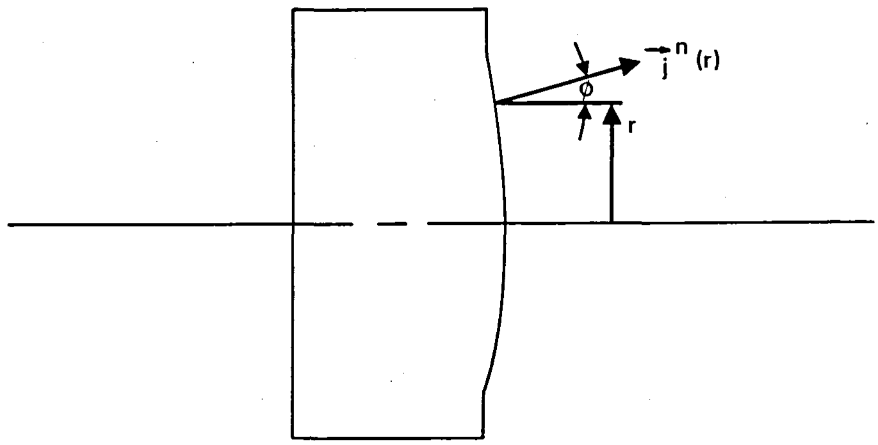


Figure D-2. Illustration of geometric variables for current density at the accelerator grid.

1. Velocity-Analyzer Probe

Separation of the total current emanating from the active region of the accelerator system into the current components, $i_n(r, \phi_p)$, is accomplished using a series-arrangement of a collimator and velocity filter. The collimator restricts the viewing area and transmits a highly collimated beam to the velocity filter. The transmission of the collimator is illustrated in Figure D-3, which shows the response of the collimator to a parallel beam inclined at an angle, ϕ_o. The transmission is unity when the collimator is aligned with the beam ($\phi_p = \phi_o$), and drops rapidly to zero for angles $\pm\psi$ at about ϕ_o. The angle, ψ, is the acceptance half-angle, which is small enough ($\psi < 0.3°$) to enable the probe response at any angle, ϕ_p, to be interpreted as the response due to particles which leave the viewing area and follow straight-line trajectories inclined at an angle, ϕ_p, with respect to the thruster axis. The velocity filter is composed

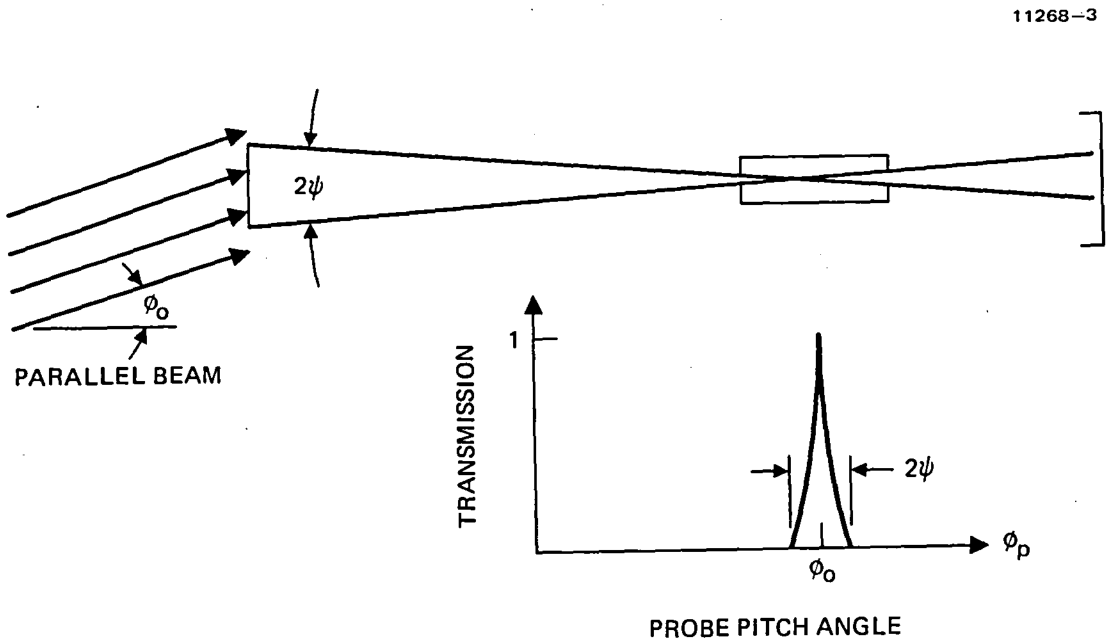


Figure D-3. Angular response of the collimator.

of orthogonal electric and magnetic fields ($\vec{E}$ and $\vec{B}$, as shown in Figure D-4) and transmits only those particles having velocity equal in magnitude to E/B. All other particles are "filtered out" by an imbalance in the electric and magnetic forces which deflects the particle trajectories into the upper or lower electric-field plates, depending upon whether the particle speed is greater-than or less-than the ratio, E/B. The series arrangement of the collimator and velocity filter results in a probe whose output is restricted to those particles having velocity vectors with magnitude, E/B, and direction in the range, $\phi_p - \psi \leq \phi \leq \phi_p + \psi$.

A schematic of the velocity-analyzer, or ExB probe, developed by Hughes for performing the measurements of $i_n(r, \phi_p)$ is presented in Figure D-5. The probe assembly consists of a collimator, drift tube, separation aperture, and current collector. The collimator apertures have a diameter of 0.25 mm, resulting in a viewing half-angle of $\psi = 0.29°$. With this geometry, and with the probe positioned 38 cm downstream of the accelerator grid, the viewing area is 0.13 cm^2, or about three accelerator apertures for the J-series-thruster electrode design.

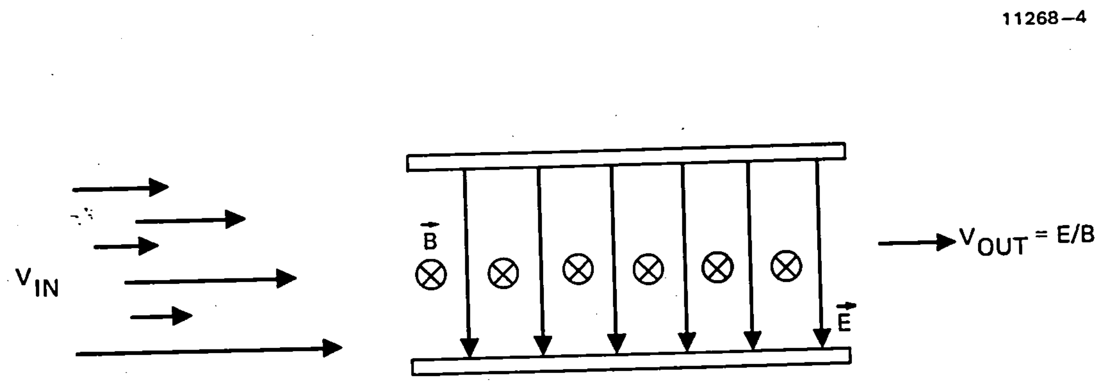


Figure D-4. Configuration of velocity filter for separating singly and and doubly charged ions.

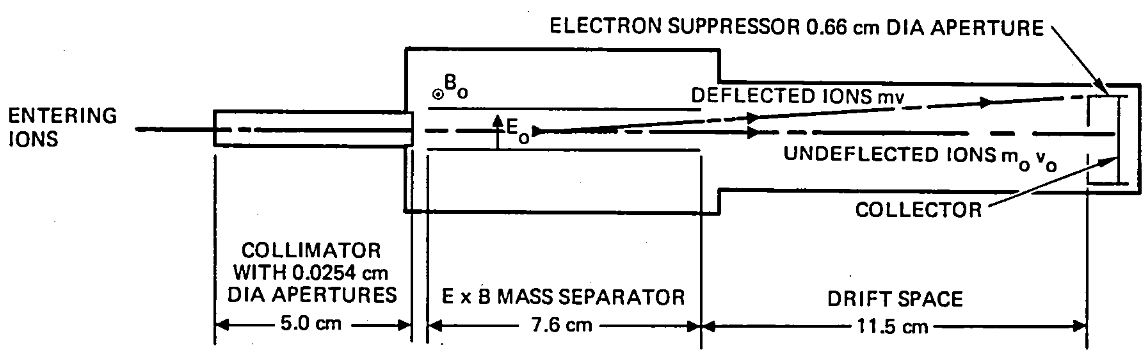


Figure D-5. Configuration of collimating ExB probe.

The separator provides orthogonal electric and magnetic fields E and B, which prevent all ions from reaching the collector except those having velocities of magnitude E/B. The magnetic field is provided by a permanent magnet, while the electric field is provided by the potential applied to parallel plates. Varying the plate potential changes the ratio, E/B, allowing ions of different velocities to traverse the separator undeflected and reach the collector. Figure D-6 presents a typical variation of collector current with plate voltage and demonstrates

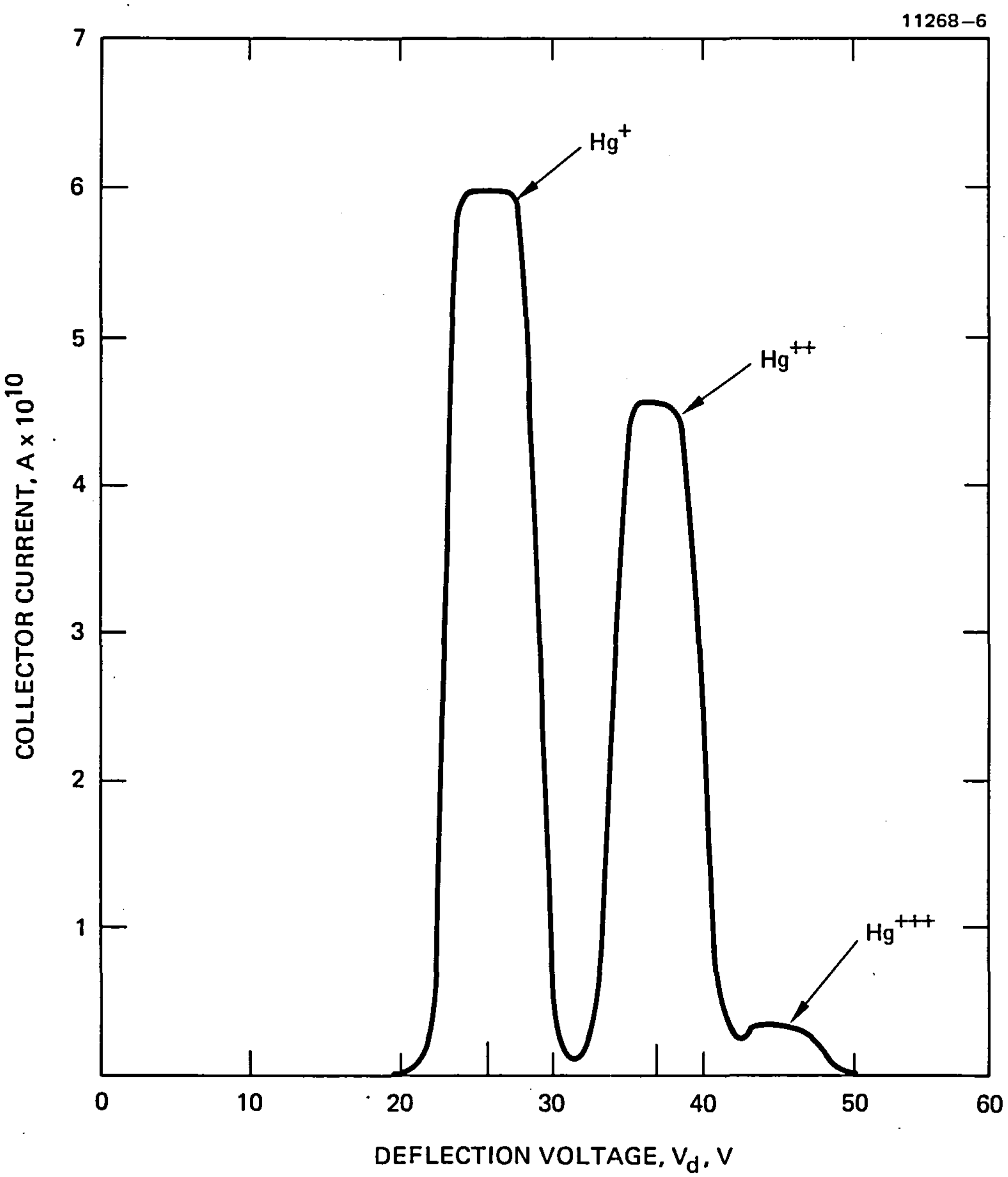


Figure D-6. Example of current output of probe as function of deflection plate voltage (probe measuring in thruster beam).

the ability of the probe to resolve the peaks associated with singly and doubly charged ions.* The nearly rectangular shape of the peaks enables the height to be used as an indication of the total current of each species, which simplifies the data acquisition and analysis requirements. The dimensions of the collimator result in a viewing area that is small, but still large enough to provide a readily measurable current ($\approx 10^{-9}$ A). The drift-tube length and collector aperture diameter ensure collection of the entire collimated and undeflected beam of the ion species of interest. The collector aperture is biased 45 V negative of the probe assembly to repel beam electrons and to return secondary electrons to the collector.

2. Test Facility

A sketch of the probe setup used in the Hughes 9 ft diameter vacuum chamber is presented in Figure D-7. The probe is moved vertically in or out of the thrust beam using a precision stepping motor located on the top of the vacuum chamber to vary the coordinate, r. The pitch angle, ϕ_p, is controlled using a precision stepping motor located inside the chamber. A precision potentiometer and digital readout provide a visual display of the probe pitch angle. The probe yaw angle, Ω, can be adjusted to position the probe axis parallel to the thruster axis. The vacuum feedthrough is located off-center in the flange shown in Figure D-7 so that the lateral position of the probe can be adjusted, enabling the vertical axis of the probe to be positioned on the thruster axis. The only maintenance requirement of the probe system is an occasional replacement of the collimator aperture, which eventually disintegrates as a result of on sputtering. The loss of the collimating aperture is detected by the operator in the form of an increase in collector current and the inability to resolve the peaks corresponding to the various ion species.

*The probe can also resolve the peak associated with triply charged ions.

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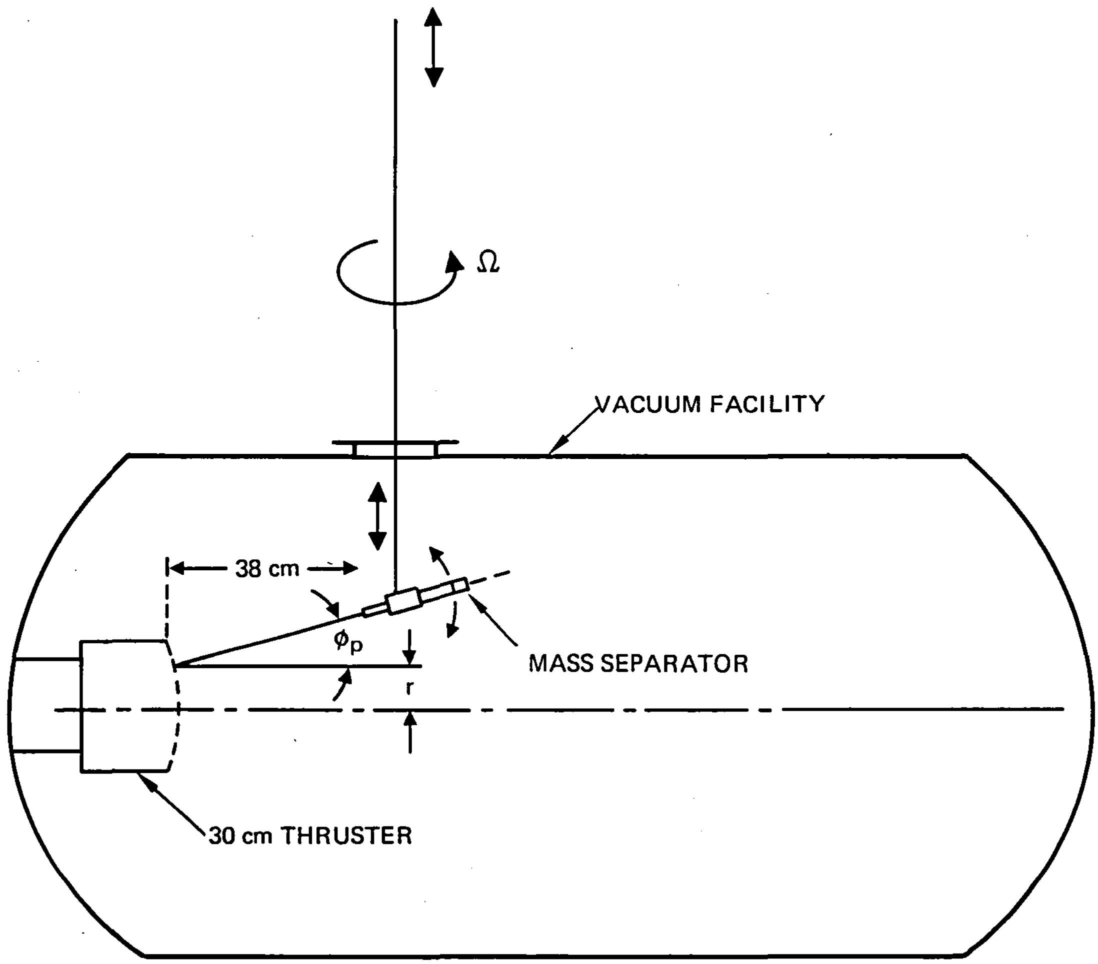

Figure D-7. Coordinates (r, ϕ_p, Ω) for defining probe position with respect to the thruster (as located in the test facility.

3. Thruster Alignment

The probe-to-thruster alignment is accomplished by aligning both the thruster and the probe with the tank axis. This approach minimizes setup time since the probe-to-tank alignment is required only after removal and reinstallation of the probe. The thruster-to-tank alignment is accomplished by aligning the thruster with respect to the axis of the vacuum enclosure flange, as shown in Figure D-8.

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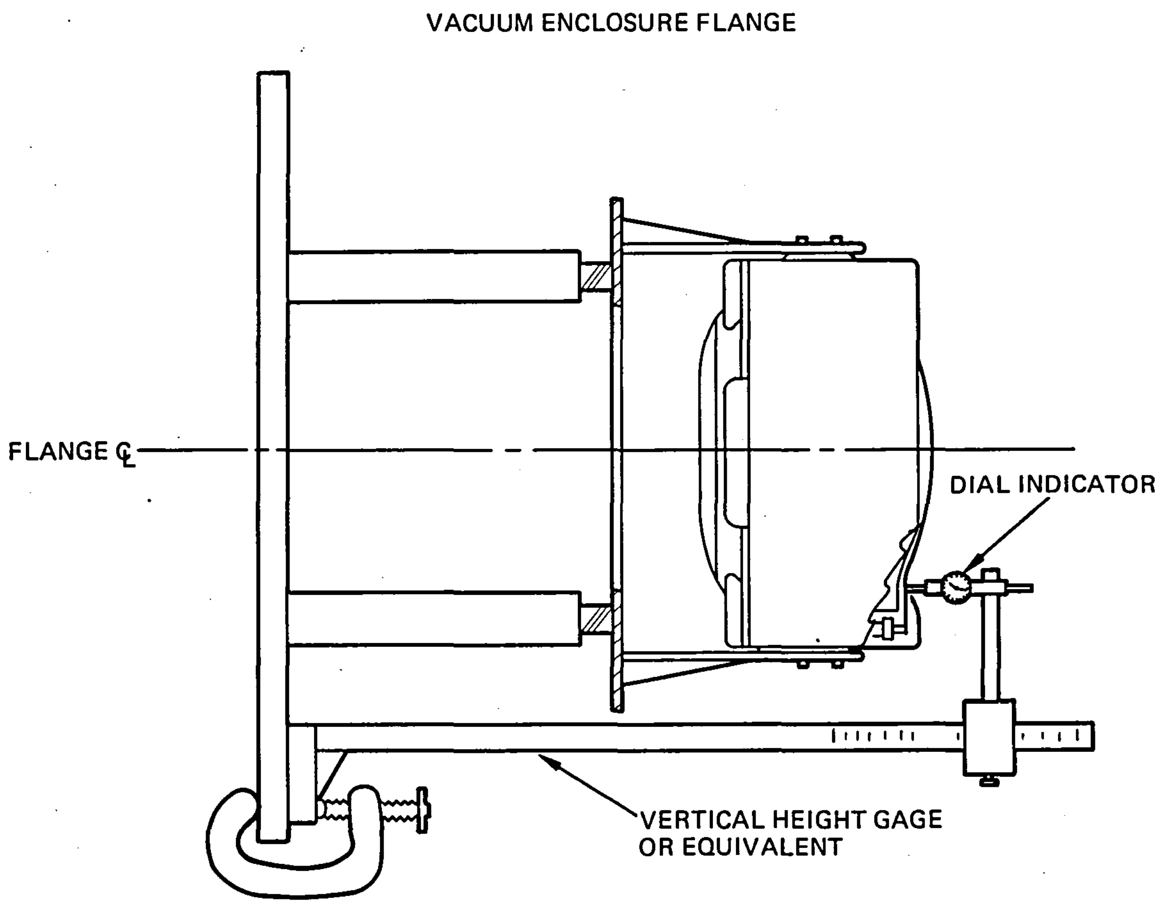

Figure D-8. Illustration of procedure used for aligning thruster with the the vacuum chamber axis.

The thruster support and vacuum enclosure flange position the thruster with respect to the tank axis, and the angular alignment is accomplished using the dial indicator to locate the edge of the accelerator grid at 90° intervals. In order to ensure that the angle between the thruster and flange axis is less than 1°, the difference between the readings obtained 180° apart must not exceed 0.5 cm. If the difference is greater, the mounting fasteners are loosened and the thruster is shifted to obtain the necessary tolerance.

4. Data Acquisition

The probe-positioning and data-acquisition system is semi-automated, requiring the operator to select the probe pitch angle, locate the beam edge, and determine the plate potentials corresponding to the various ion species.* The first step the operator performs in conducting a beam scan is to set the probe pitch angle at $\phi_p = 0$, and then drive the probe down towards the beam until a collector current is detected. This locates the edge of the beam at the plane of the accelerator grid and provides a reference for subsequent movement of the probe into the beam a distance equal to one-half the diameter of the active region of the electrodes. If either the thruster or probe have been removed from the test facility since the last probe measurements were performed, the probe-to-thruster alignment is checked by varying the probe yaw angle, Ω, until maximum probe current is detected. With the probe-travel axis and thruster axis aligned, this step ensures that the viewing axis of the probe is coincident with the thruster axis. The operator then varies the output of the electric-field power supply to determine the voltages, V_+ and V_{++}, corresponding to the peaks of the i_+ and i_{++} current profiles (see Figure D-4). These voltages are then input to the data-acquisition system via potentiometers located on the control panel. Next, the probe is driven up and out of the beam, and the pitch angle, ϕ_p, is set to the maximum negative value to be sampled (usually -15°). The probe is then driven down to locate the beam edge. The beam edge is always located by moving the probe in the downward direction, eliminating any position error that could be caused by hysteresis in the positioning mechanism. At this point, the operator places the system in the auto mode, which executes the following steps:

*The normal operating conditions of the 8- and 30-cm thrusters result in a negligible population of triply charged ions; therefore, the standard practice has been to measure only the singly and doubly charged ion currents. However, the probe system located in the Hughes 9 ft vacuum chamber also has the capability of measuring triply charged ions, which may not be negligible in thrusters operating at high beam currents.

1. The probe is driven downward to a distance equal to one-fourth the radius of the active region of the electrodes.

2. Any vibration of the probe caused by the directed motion is allowed to dampen out.

3. The currents, i_+ and i_{++}, are sampled and recorded on paper tape.

4. Steps 1-3 are automatically repeated a total of four times, with the last measurement performed on the thruster axis.

Next, the operator drives the probe up and out of the beam, increases the pitch angle, ϕ, by 5°, locates the beam edge, and resets the auto mode.

In developing the computer program used for analyzing the probe data, one of the primary objectives was to minimize the number of input data points subject to the constraint that the accuracy of the reduced data should be at least comparable to that of the raw probe data (±2% of full scale based on the manufacturers specifications on the accuracy of the electrometer). Minimizing the data-collection time ensures that the thruster operating conditions remain nearly constant during the data scan and also relieves the operator of the time-consuming task of taking more data than is necessary. After the initial installation of the probe, scans having a different number of data points were taken, and it was found that four equally spaced radial values and seven equally spaced angular values were near optimum. A larger number of radial data points produced essentially the same results, while a smaller number produced discontinuous-appearing curves. While six angular values for each radial value were usually satisfactory, seven were better for more divergent beams. The final technique chosen was to use four radial values and seven angular values, resulting in a total of 56 data points per scan (28 each for i_+ and i_{++}). In practice, the operator may conduct the scan using as many as nine pitch angles so that the symmetry of the angular dispersion profiles can be checked, enabling the most symmetrical data to be used as input to the data-analysis routine.

B. DATA ANALYSIS PROCEDURE

The paper tape generated during the data acquisition contains 28 pairs of probe currents (i_+ and i_{++}) corresponding to the measurements conducted while viewing the four radial locations on the accelerator grid from seven discrete angles. After completing a beam scan, this tape is input to a DEL PDP-170 computer which performs the data analysis according to the procedure described below.

The probe collector current, i, corresponding to species, n, is given by the expression,

$$i_n(r, \phi_p) = \iint I_n(r, \phi) \cos(\phi - \phi_p)\{u[\phi - (\phi_p - \psi)] - u[\phi - (\phi_p + \psi)]\}T(\phi - \phi_p)d\omega dA_p, \tag{3}$$

where I_n is the intensity of the ion flux, r and ϕ are the coordinates, ϕ_p is the probe angle, ψ is the acceptance half-angle of the collimator, u is the unit step function, T is the transmission of a cylindrical collimator, ω is the solid angle, and A_p is the aperture area. The combination of the transmission and unit step functions in Equation (3) effectively "collimates" the incoming flux (as illustrated in Figure D-9), allowing only a fraction of those ions having angles in the range $\phi_p \pm \psi$ to reach the velocity filter. In practice, the operator selects the ion species of interest by varying the ratio, E/B, to match the particle speed. The narrow acceptance angle (2ψ) of the collimator permits the intensity in Equation (3) to be replaced by the value corresponding to the probe angle, ϕ_p. Since the collimator restricts the angle difference to $\phi - \phi_p \leq \psi$, the cosine can be replaced by unity, and Equation (3) can be written as

$$i_n (r, \phi_p) = \iint I_n(r, \phi_p)Td\omega dA_p \quad . \tag{4}$$

The narrow field-of-view of the collimator and the small size of the entrance aperture permits us to assume that the ion flux is homogeneous over the aperture area, and isotropic within the field-of-view. This enables the intensity to be expressed as

$$I_n = \frac{J_n}{\Omega} \quad , \tag{5}$$

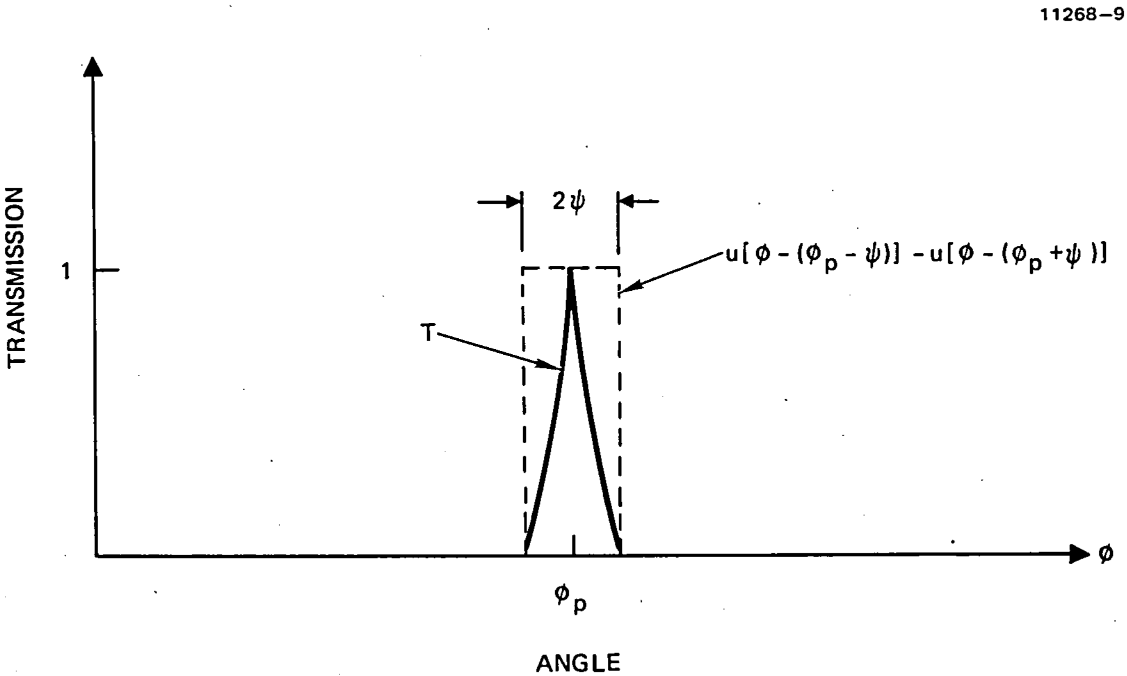

Figure D-9. Transmission of a cylindrical collimator inclined at angle ϕ_p. The step functions filter out all angles except those of bandwidth 2ψ centered at ϕ_p. The function, T, is the transmission of cylindrical apertures viewing a parallel beam inclined at angle ϕ_p.

where J is the current density, and Ω is the solid angle subtended by the collimator. Reference to Figure D-10 shows that the solid angle, Ω, is given by

$$\Omega = \frac{A_p}{\ell^2} , \tag{6}$$

where the aperture area, A_p, is given by

$$A_p = \pi \ell^2 \psi^2 . \tag{7}$$

The differential solid angle, $d\omega$, is given by

$$d\omega = \frac{dA}{\ell^2} , \tag{8}$$

$$= \frac{2\pi r dr}{\ell^2} . \tag{9}$$

For small angles, $r = \ell\varepsilon$, and the expression above can be written as

$$d\omega = 2\pi\varepsilon d\varepsilon \quad . \tag{10}$$

Combining Eqautions (4), (5), (6), and (10), and performing the integration over dA_p, results in

$$i_n(r,\ \phi_p) = \frac{2J_n(r,\ \phi_p)A_p}{\psi^2} \int_0^{\psi} \varepsilon T d\varepsilon \quad , \tag{11}$$

which can be solved for the current density, J_n,

$$J_n(r,\ \phi_p) = \frac{\psi^2}{2\int_0^{\psi} \varepsilon T d\varepsilon} \ \frac{i_n(r,\ \phi_p)}{A_p} \quad . \tag{12}$$

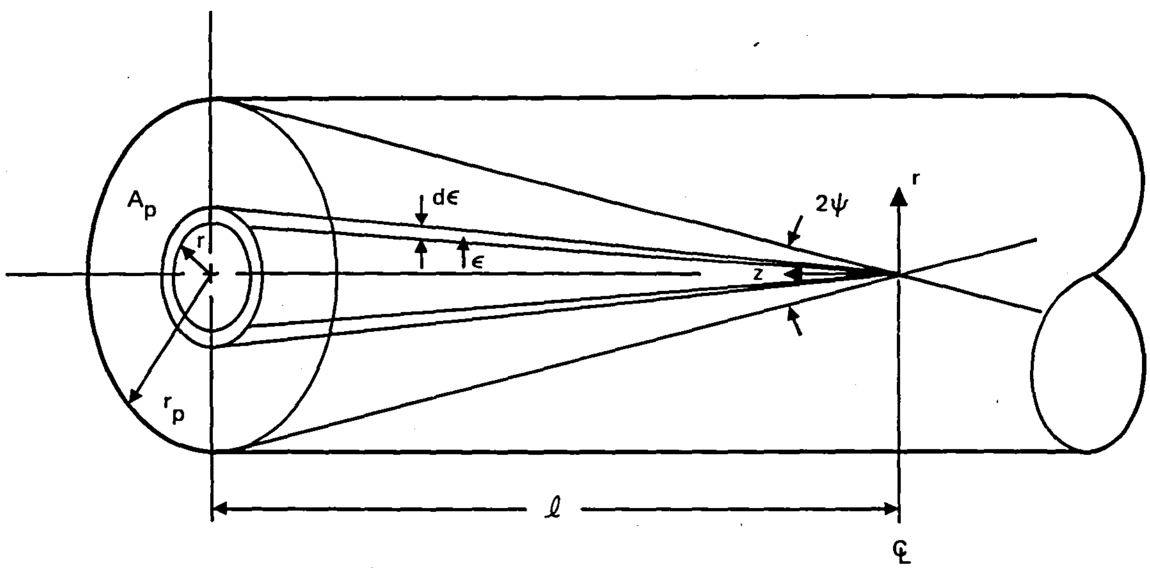

Figure D-10. Definition of variables used in analysis of the response of a cylindrical collimator.

The transmission of the cylindrical collimator is given by

$$T = 1 - \frac{2}{\pi}\left\{\frac{1+s}{2}\left[1 - \left(\frac{1+s}{2}\right)^2\right]^{1/2} + \sin^{-1}\left(\frac{1+s}{2}\right)\right\} \quad , \tag{13}$$

where (for small angles ε)

$$\frac{1+s}{2} = \frac{\ell\varepsilon}{r_p} = \frac{\varepsilon}{\psi} \quad . \tag{14}$$

The transmission represents the fractional overlap of the circular areas of the entrance and exit apertures (as shown in Figure D-11), and therefore represents the response of the collimator to a parallel beam. Combining Equations (13) and (14) gives

$$T = 1 - \frac{2}{\pi}\left\{\frac{\varepsilon}{\psi}\left[1 - \left(\frac{\varepsilon}{\psi}\right)^2\right]^{1/2} + \sin^{-1}\left(\frac{\varepsilon}{\psi}\right)\right\} \quad . \tag{15}$$

Evaluation of the integral appearing in Equation (12) is simplified by making the substitution,

$$x = \frac{\varepsilon}{\psi} \quad , \tag{16}$$

which results in

$$\int_0^{\psi} \varepsilon T(\varepsilon) d\varepsilon = \psi^2 \int_0^1 x - \frac{2}{\pi}\left[x^2\sqrt{1-x^2} + \sin^{-1}x \quad dx\right] . \tag{17}$$

The integration can be performed using standard techniques to evaluate the following integrals:

$$\int_0^{\psi} x dx = \frac{1}{2} \quad , \tag{18}$$

$$\int_0^1 x^2\sqrt{1-x^2}\, dx = \frac{\pi}{16} \quad , \tag{19}$$

$$\int_{o}^{1} x \sin^{-1} x dx = \frac{\pi}{8} \quad . \tag{20}$$

Substituting these result into Equation (15) gives

$$\int_{o}^{\psi} \varepsilon T(\varepsilon) d\varepsilon = \psi^2 \left[\frac{1}{2} - \frac{2}{\pi}\left(\frac{\pi}{16} + \frac{\pi}{8}\right)\right]$$

$$= \frac{\psi^2}{8} \quad . \tag{21}$$

Combining Equation (12) and (21) gives the relationship between the current density at the probe aperture and the collector current,

$$J_n(r, \phi_p) = 4 \frac{i_n(r, \phi_p)}{A_p} \quad . \tag{22}$$

The relationship between the current density at the accel electrode and the collector current can be derived using the geometric variables defined in Figure D-12. The small area, A_o, of the accelerator electrode is "viewed" from different angles, ϕ_p, resulting in a current-density dispersion profile similar to the one shown. This profile represents the current density* at the measurement plane due to ion flow from the area, A_o. The total current from A_o is obtained by integrating this current density over the measurement plane,

$$I_n = \int \vec{J}_n \cdot \hat{n} dA \quad , \tag{23}$$

*Note that the current density, J, is not necessarily the total current density at the measurement plane, since the collimator restricts the probe viewing area to A_o. For this reason, the total current from the accelerator system cannot be found by integrating the current density at the measurement plane.

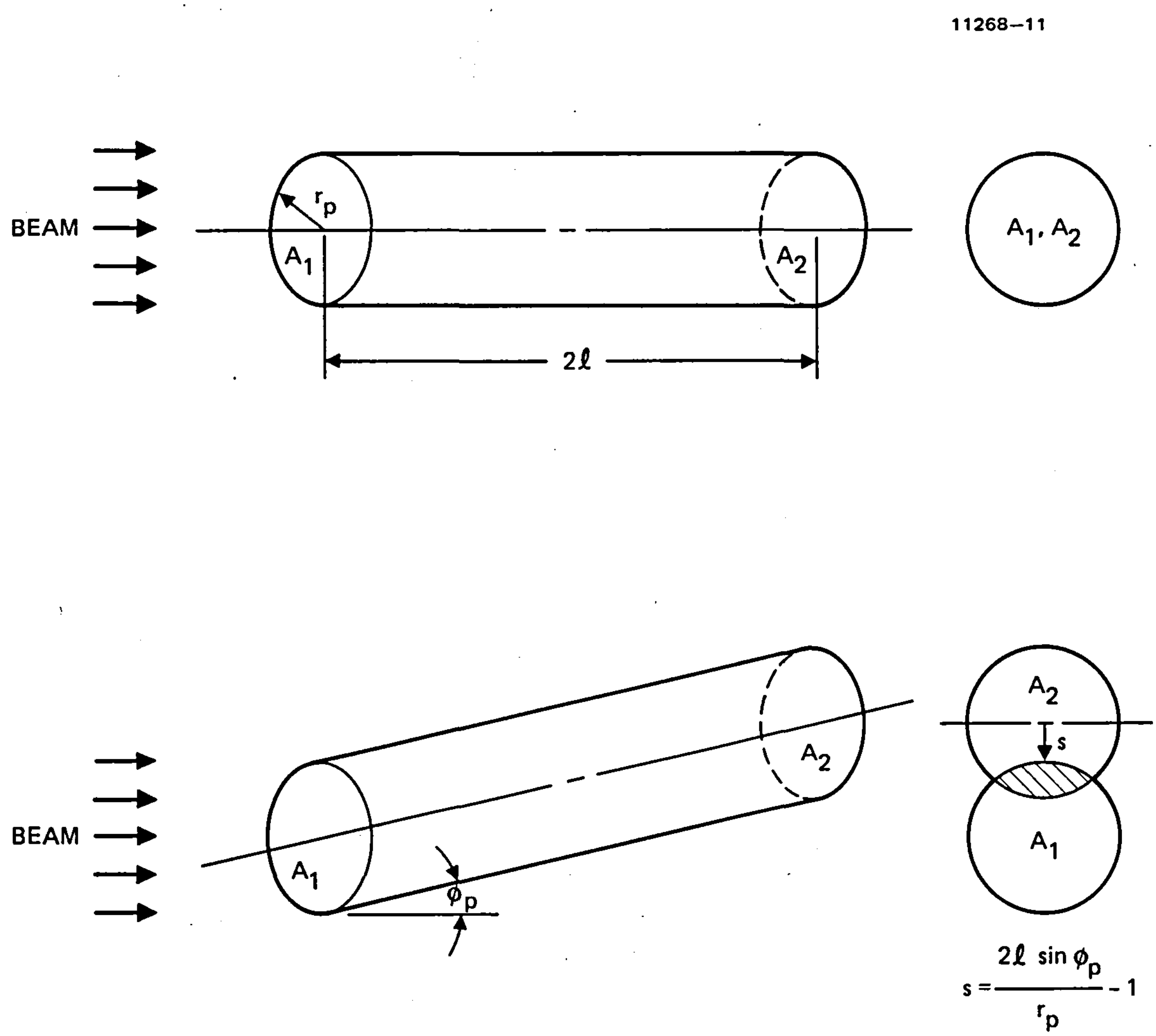

Figure D-11. Definition of variables used in analysis of the response of a cylindrical collimator.

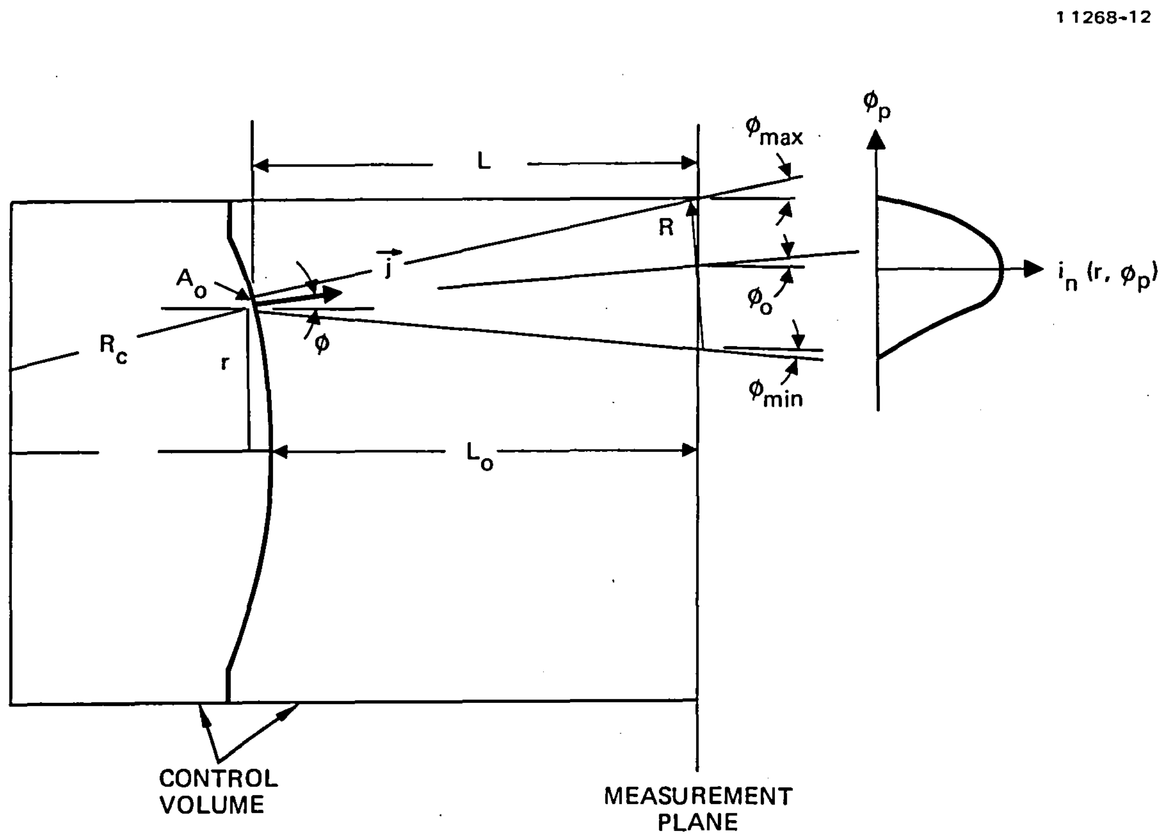

Figure D-12. Definition of variables used in analysis of probe collector current.

The scalar product is given by

$$\vec{J} \cdot \hat{n} = J \cos \phi_p \quad . \tag{24}$$

The area element, dA, is given by the expression

$$dA = \frac{dA_\perp}{\cos\phi_o} \quad , \tag{25}$$

which is obtained by projecting the area element, dA, onto a plane normal to the direction defined by the angle, ϕ_o, and corresponding to the peak of the current-density distribution. In this plane, the current density is assumed symmetrical about the radii defined by the angles, ϕ_{min} and ϕ_{max}, of Figure D-12. Under this assumption, the area element $dA_\perp$ is given by

$$dA_{\perp} = \pi R dR \quad , \tag{26}$$

where the coordinate R is given by

$$R = L \sec \phi_o \tan(\phi_p - \phi_o) \quad , \tag{27}$$

and

$$dR = L \sec \phi_o \sec^2 (\phi_p - \phi_o) d\phi_p \quad . \tag{28}$$

The distance, L, from the measurement plane to the accelerator grid is given by

$$L = L_o + R_c(1 - \cos\gamma) \quad , \tag{29}$$

where L_o is the distance from the probe to the accelerator electrode on the thruster axis, and R_c is the radius of curvature of the electrodes (as shown, R_c is positive for electrodes dished outward). The angle, γ, is given by

$$\gamma = \sin^{-1} \left(\frac{r}{R_c}\right) \quad . \tag{30}$$

Combining Equations (22) through (28) gives the desired expression for the current through the measurement plane,

$$I_n = \frac{4\pi L^2 \sec^3 \phi_o}{A_p} \int_{\phi_{min}}^{\phi_{max}} i_n \cos\phi_p \sec^2 (\phi_p - \phi_o) \left|\tan (\phi_p - \phi_o)\right| d\phi_p \quad . \tag{31}$$

This is also the current through the area, A_o, of the accelerator grid, which can be written as

$$I_n = j_n \cos(\gamma - \phi)A_o \quad , \tag{32}$$

where j_n is the current density at the accelerator electrode. Combining Equations (31) and (32) gives the desired expression relating the current density at the electrodes to the probe current,

$$j_n(r) = \frac{4\pi L^2 \sec^3\phi_o}{A_o A_p \cos(\gamma - \phi)} \int_{\phi_{min}}^{\phi_{max}} i_n(r, \phi_p) \cos\phi_p \sec^2(\phi_p - \phi_o) \left|\tan(\phi_p - \phi_o)\right| d\phi_p \ . \tag{33}$$

An expression for the angle ϕ can be derived by applying the momentum equation to the control volumes of Figure D-6. Using the measurement plane as the control surface, the net thrust is given by

$$F_{net}(r) = \frac{mv_+}{e} \iint \left[j_+(r) + \frac{\sqrt{2}}{2} j_{++}(r) \cos(\gamma - \phi) \right] \cos\phi_p dA \ . \tag{34}$$

Using the accelerator electrode as the control surface, the net thrust is given by

$$F_{net}(r) = \frac{mv_+}{e} \left[j_+(r) + \frac{\sqrt{2}}{2} j_{++}(r) \right] \cos(\gamma - \phi) \cos\phi A_o \ . \tag{35}$$

Equating the two expressions for net thrust and solving for the angle ϕ results in

$$\phi(r) = \cos^{-1} \frac{\iint \left[J_+(r, \phi_p) + \frac{\sqrt{2}}{2} J_{++}(r, \phi_p) \right] \cos^2 \phi_p dA}{\left[j_+(r) + \frac{\sqrt{2}}{2} j_{++}(r) \right] \cos(\gamma - \phi) A_o} \ . \tag{36}$$

Substituting Equations (22), (25), through (28), and (33) into Equation (36) gives the desired expression for the angle ϕ:

$$\phi(r) = \cos^{-1} \frac{\int_{\phi_{min}}^{\phi_{max}} i(r)_+ + \frac{\sqrt{2}}{2} i(r)_{++} \cos^2\phi_p \sec^2(\phi_p - \phi_o) \tan(\phi_p - \phi_o) \, d\phi_p}{\int_{\phi_{min}}^{\phi_{max}} i(r)_+ + \frac{\sqrt{2}}{2} i_{++}(r) \cos\phi_p \sec^2(\phi_p - \phi_o) \tan(\phi_p - \phi_o) \, d\phi_p} \ . \tag{37}$$

The thrust-loss factors, α and F_t, are calculated using the expressions

$$\alpha = \frac{J_+ + \frac{\sqrt{2}}{2} J_{++}}{J_+ + J_{++}} \quad , \tag{38}$$

and

$$F_t = \frac{\int_{A_g} j_+ + \frac{\sqrt{2}}{2} j_{++} \quad \cos(\gamma - \phi) \cos\phi dA}{\int_{A_g} j_+ + \frac{\sqrt{2}}{2} j_{++} \quad \cos(\gamma - \phi) dA} \quad , \tag{39}$$

where the total current of species n, and J_n, is determined by

$$J_n = \int_{A_g} j_n \cos(\gamma - \phi) \frac{2\pi r dr}{\cos \gamma} \quad . \tag{40}$$

The integrations of Equations (33), (37), (39), and (40) are performed using the trapezoidal rule, with the integrands evaluated at the midpoints of the probe-angle intervals using a second-order interpolation routine. The probe current is set equal to zero at the integration limits, ϕ_{min} and δ_{max}, where these limits are defined as 5° less than the minimum input angle, and 5° greater than the maximum input angle, respectively.

APPENDIX E

APPENDIX E

The work performed under this program to upgrade the drawings and fabrication control documents for the J-series thruster is best summarized by the indentured parts list that catalogs these documents. The latest revision of this parts list is included here.

PARTS LIST	TITLE 30-cm J-SERIES ION THRUSTER E1026510 REV G Revision Status by Page No.	DATE	REV	NEXT ASS'Y
		BY	SHEET 1	OF 57 SHEETS

PAGE	CHANGE	DATE REV.	PAGE	CHANGE	DATE REV.	PAGE	CHANGE	DATE REV.
1	B	5-29-81	18	A	2-16-81	35		3-25-80
2	B	5-29-81	19	A	2-16-81	36	A	2-16-81
3	B	5-29-81	20	A	2-16-81	37	A	2-16-81
4	B	5-29-81	21	B	2-16-81	38		2-16-81
5		5-21-81	22	A	2-16-81	39	A	2-16-81
6		5-21-81	23	A	2-16-81	40	A	2-16-81
7		5-21-81	24	A	2-16-81	41	A	2-16-81
8		5-21-81	25	A	2-16-81	42	A	2-16-81
9		5-21-81	26	A	2-16-81	43	A	2-16-81
10		5-21-81	27	A	2-16-81	44	A	2-16-81
11		5-21-81	28	A	2-16-81	45	A	2-16-81
12		5-21-81	29	A	2-16-81	46	A	2-16-81
13		5-21-81	30	A	2-16-81	47	A	2-16-81
14	A	5-21-81	31	A	2-16-81	48	A	2-16-81
15	A	2-16-81	32	A	2-16-81	49	A	2-16-81
16	A	2-16-81	33	A	2-16-81	50	B	2-16-81
17	A	2-16-81	34		3-25-80	51	A	2-16-81
						52	B	2-16-81
						53	A	2-16-81
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						55	A	2-16-81
						56	A	2-16-81
						57	A	2-16-81

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B1024208	33,38				
216	33,38				
B 226-98	14				
B -99	14				
B 529	30,33,34,39				
B 914	37				
B 917	37				
B 919-2	33,38				
B 920	33,38				
B1024925	32,47				
B1025262	30,44				
B 266-1	26				
B -2	16,27				
B -3	28				
B 267-1	26				
B -2	16				
B 268	16,27				
B 270	27				
B 311	43,54				
E1025316	7,56				
-97	56				
-99	56				
B 317	15,54				
B 318	17,21,53				
D 320	15,24				
D 320-96	24				
D -97	24				
D -98	24				
D -99	24				
D 324	14,21				
B 330	39				
C 352	14				
E1025353	14,24				
E -99	24				
B 357	25				
D 381	22				
C 383	23				
D 384	23				
B 422	27				
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C 424	26				
B 425	25				
B 431	44				
B 433-1	44				
B -2	30				
C 498-2	33,38				
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B1025645	45				

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B -99	43				
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B 086	44				
B 089-1	48				
B -2	48				
B 090	48				
B 091	48				
B 093	38				
C 136	54				
D 137-91	53				
D 138-91	54				
B 194	21				
B 370	30				
C 371	30				
B1026374	30,44				
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D 452-1	21				
D -2	21				
D 462	17,56				
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D 485	15,29				
D 488	15				
E 498	21				
D1026501	23				
C 502	46				
C 503	42				
B 504	46				
B -99	46				
C 505	50				
C 508-1	14				
C -2	14				
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E 518-1	39				
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B -99	35,41				
B 541	34,40				
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B1026601	15				
B 602	34				
B 603	25				
B 604	30				
D 605	25				
D -99	25				
B 606	34				
C 611	33				
C 624	15,30				
C 633	46				
C 634	50				
B 635-1	30				
B -2	31				
B 637	31,45				
B 809	17				
B 882	46				
B 920	35,40,41				
B1026921	35,40,41				
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B 344	29				
B 345	29				
B 360	43				
C 364	42				
B 366	50				
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B 398	17				
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B 009	17				
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B -2	32				
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B 095	14				
B 097	29				
D1095121	17				

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B	-97	43
B	-99	43
B	293-97	49
B	-99	43
B	294-97	49
B	-99	44
B	295	46
B	296	43
B	297	43
B	397	48,36,39
B	418	49,36,39
B	419-1	49,36,39
B	-2	49,36,39
B	421	55
B	426	43
B	428	15
D	429	15
B	461	32,37,47,57
B	590-1	31
B	-2	45
B	-97	45,31
B	-98	31
B	-99	45
C	592	42
C	593	42
D	682	55
C1095683		16,55

DWG/PT NO.		Pg
C1095683-99		55
B	684-1	18
B	-2	18
B	685	57
C	686	18,57
C	-1	57
C	687	11,57
C	-1	57
B	706	57
B	708	18
B	709	17
B	712	15,21,29
B	-1	21,29
B	713-1-08	30
B	-2-04	33,34,39
B	714	27
C	715	27
B	716	27
B	717	25
B	718	28
D	719	15,25
C	721	34
B	723	16
B	724	16
B	729	43
B	733	17
B	738	36,40,48
C	747	53
B	751	53
E	752	16,53
E	-99	53
B	754	17,23,54
C	755	16,37
B	756	37
C	757	37
B	758	37
B	759	37
C	760-1	33
C	-2	38
C	761	47
B	762	48
D	763	15,32
B	764	32,47
B	765	32,47
B	766	32
B	767	32,47
B	769	34,39
B1095770		37

DWG/PT NO.		Pg
B1095771		32,47
C	772-98	53
C	-99	54
D	773	16,42
B	778-98	53
B	-99	15,22
C	808	46
C	809	42
B	810	26
B	811	26
D	845	50,17,14,16,28
C	850	15
D	851	23
B	857	25
B	862	43
B	909	
B	910	
HA		
MS16995-2		35,40,41
MS20426AD3-3		46,56
MS20426AD3-5		42
MS20427F2-2		52
	-3	42
MS20427F3-3		24,24
MS21060-06		56
MS21070-06		24,46,56
MS21076-06		46

DWG/PT NO.	Pg	Pg	Pg	Pg	Pg
MS21076-L06		42	56		
MS24673-1		19	22		
" -3		19			
MS24673-5		85			
MS24674-1		19	50		
MS24674-2		19			
" " -3		19			
MS24693-C4		43			
MS24693-C31		19			
MS24693-C270		43			
MS35275-18		55	52		
MS35649-244	35	35	40	41	
MS51957-13	19				
MS51957-17		19			
MS51957-21		19	50		
MS51957-26		19			
-27			52		
MS51957-28		19			
-30		19			
MS51957-125		19			

DWG/PT NO.	Pg	Pg	Pg	Pg	Pg
AN340-C4			52	20	
AN340-C8			28		
AN345-C0		36	20	51	41
AN960-C2			51		
AN960-C4			49	28	
AN960-C6			20	50	
AN960-C8			51	28	
AN960-C10			20		
AN960-C10L			20		
NAS509 C8			20		
NAS620 C0			36	41	50
NAS620 C4			20		
NAS620 C6			20		
NAS671 C0		20	36	41	52
NAS698 C06			36		
NAS1291 C3			20		
NAS1291 C04			20	55	50
NAS1291 C06			20		
NAS1291 C08				51	
NAS1352 C04H			51		
NAS1352 C04-			28		
" " " -			20		
NAS1352 C08-			51		
NAS1395 C3L			21	29	
NAS1395 C08L			45		

DWG/PT NO.	Pg	Pg	Pg	Pg	Pg
MISCELLANEOUS HARDWARE					
.020/25 LOCKWIRE QQ-W-423		18	22	52	55
R44671-IP (RESISTOFLX)			36	39	48
R44223-ZP-CZ(")			"	"	"
PARKER 2-006 VITON O-RING		18			
PRS-SCI C-SEAL 632-U55-0002-2		18			
146FB200(RSMT)			36	40	49
SCREW, PN HD CRES 0-80 x .62 L			36	40	
CT250 (ALBEROX)			25		
C-3 DYLON SUPERBOND			36	40	49
321883 (Amp #2)				18	
321884 (Amp #4)				18	
CLOTH, CRES (304L) .0035 x 94 SQ MESH			26	26	27
322872 (Amp #6)			18		
321895 (Amp #8)			18		
WIRE, 16 & 20 AWG (Stranded)					
HMS 2-1820-16-B-9			18		
-20-B-9			18		
OFHC COPPER WIRE .009/.010 ⌀				16	
TEFLON TAPE, INSUL 1.0 x .004				17	
LACING TIE (BEN HAR) HMS 20 1924					17
BEAD, CERAMIC				18	
TANTALUM FOIL 2 x .12 x .005				26	

PARTS LIST	TITLE 30-CM TOOLS AND FIXTURES	DATE 5/21/81	REV	NEXT ASS'Y
		BY	SHEET 5 OF SHEETS 57	

FIXTURE NUMBER	DESCRIPTION	USED ON	LOCATION	
T-1001	RING STRUCTURE DRILLING AND ASSEMBLY FIXTURE	E1024698	BLDG. 253 RM 711	
T-1002	RING STRUCTURE STRESS RELIEF FIXTURE	E1026498	BLDG. 253 RM 711	
T-1004	REED TUBE CONNECTOR ASSEMBLY BRAZING FIXTURE	B1026611	BLDG. 253 RM 711	
T-1005	THRUSTER ASSEMBLY & GIMBAL DRILLING FIXTURE	D1025324		
T-1006	REAR BRACE WELD FIXTURE	D1026485		
T-1007	BACK SUPPORT BEAM FIXTURE	D1026485		
T-1008	30-CM OPTICS DRILL FIXTURE	E1095752		
T-1011	HEATER TERMINAL LOCATING FIXTURE	C1025275 C1026622	BLDG. 253 RM 711	
T-1012	MIV PLATING PROTECTION FLANGE	C1025275		
T-1013	CIV PLATING PROTECTION RANGE	C1026622		
T-1014	EBW MANDREL - SHIELD INNER - SHIELD SEGMENT - 98	B1026541 B1026538-98	2130	
T-1015	EBW MANDREL - SHEILD OUTER - 99	B1026538	2130	
T-1016	45^{0} ANGLE FORMING FIXTURE	B1026538-1	7111	

PARTS LIST	TITLE 30-CM TOOLS AND FIXTURES	DATE 5/21/81	REV	NEXT ASS'Y
		BY	SHEET 6 OF SHEETS 57	

FIXTURE NUMBER	DESCRIPTION	USED ON	LOCATION	
T-1017	EXPANDING MANDREL	B1026538-98 B1026541	7111	
T-1018	45° ANGLE FORMING FIXTURE	B1026538-99	7111	
T-1019	COPPER SPOT WELD FIXTURE	B1026538	7111	
T-1020	FORMING STRUCTURE - STIFFENING GROOVES	B1026538-99	7111	
T-1021	FORMING FIXTURE - STIFFENING GROOVES	B1026541	7111	
T-1022	MISCELLANEOUS TOOLING AIDS	B1026538 B1026541	7111	
T-1023	BENDING FIXTURE - FEED TUBE	B1026606	7111	
T-1024	BAFFLE SUPPORT COVER FORMING PUNCH	B1026608	7111	
T-1025	ANODE-WIRE MESH EBW FIXTURE	D1095246	7111	
T-1026	ANODE DRILLING & GRIT BLAST FIXTURE	D1095246	7111	
T-1027	NEUTRALIZER MOUNTING BRACKET ALIGNMENT FIXTURE	D1026506		
T-1028	DRILL BUSHING FIXTURE MAIN KEEPER ASSEMBLY	C1095033	7111	
T-1029	PLASMA SPRAY FIXTURE END PLATE 2.125 DIA.	C1095080	7111	

PARTS LIST

TITLE 30-CM TOOLS AND FIXTURES

DATE 5/21/81 | REV | NEXT ASS'Y | BY | SHEET 7 OF SHEETS 57

FIXTURE NUMBER	DESCRIPTION	USED ON	LOCATION	
T-1030	PLASMA SPRAY FIXTURE END PLATE 3.705 DIA.	C1095080	7111	
T-1031	PLASMA SPRAY MASK - TANTALUM TOP	B1095088	7111	
T-1032	WELDING FIXTURE - DRILLING FIXTURE - RING STRUCTURE	E1026498	7111	
T-1033	STRESS RELIEVING FIXTURE - RING STRUCTURE	E1026498	7111	
T-1034	WELDING BOX - ARGON ATMOSPHERE FOR TITANIUM	E1026498 C1026509 B1026504 D1026506	7230	
T-1053	30-CM STRESS RELIEVING FIXTURE	E1026498	7111	
T-1054	EPOXY FORMING ROLLERS	D1095246 D1025381	7111	
T-1055	STRESS RELIEVE FIXTURE #1	1026137 6138	7250	
T-1056	STRESS RELIEVE FIXTURE	D1026137 D1026138	7250	
T-1059	HEAT SINK FOR RESISTOFLEX FITTING	C1095430	7111	
T-1066	MAGNET TESTING FIXTURE	B1095044		
T-1071	30-CM EMT MOUNTING U N			
T-1074 -1 to -3	SCREEN ELECTRODE SIZING FIXTURE	1026137	7111	

PARTS LIST	TITLE 30-CM TOOLS AND FIXTURES	DATE 5/21/81	REV	NEXT ASS'Y
		BY	SHEET 8 OF SHEETS 57	

FIXTURE NUMBER	DESCRIPTION	USED ON	LOCATION	
T-1076	EBW FIXTURE FOR KEEPER ASSEMBLY	C1095715	7111	
T-1077	OXIDIZING HEADER FOR VAPORIZERS	ALL VAPORIZERS	7111	
T-1078	POROUS PLUS WASHING FIXTURE	8CM & 30 CM		
T-1079	30-CM OPTIC SR FIXTURE	30 CM E1095752		
T-1080	30-CM RING STRUCTURE MACHINING FIXTURE	30 CM E1026498		
T-1090	MANIFOLD LOCATING FIXTURE 30 CM	30 CM C1095683		
T-1091	WRENCH - RESISTOFLEX FITTING B1095397	B1095397		
T-1093	MASK TO GRID SPACING BARS	30 CM D1026462	7111	
T-1094	SPECIAL DEPTCH MICROMETER	E1026510	7111	
T-1095	FORMING FIXTURE NEUTRALIZER BRACKET 1027364	30 CM 1027364	7111	
T-1097	PIN ALIGNMENT FIXTURE FOR DISHING 30 CM ELECTRODES	D1026137 30 CM D1026138	7111	
T-1100	SHOE HORN - ANODE	D1025246 30 CM	7111	
T-1103	RIVET GO-NO GO GAUGE	E1095752 30 CM		

SPEC. NO. IPD-PR-	TITLE	DATE OF ISSUE	REVISION LETTER DATE	REQUESTOR
010	CLEANING PROCEDURE - ION THRUSTER PARTS (METAL) HAVING COMPLEX CONFIGURATION (CAVITIES, THREADS, ETC.)	Jan. '64	"B" REV 5/29/81	W. D. Meyers
016	CLEANING & FIRING OF CERAMIC PARTS	Mar.'64	"B" REV 7/24/79	Prepared by: W. Perkins W. D. Meyers
017	BRIGHT DIPPING TITANIUM PROCEDURE	Nov.'74	"B" REV 9/11/80	Prepared by: R. Olney W. D. Meyers
043	FLASH NICKEL PLATING, ION THRUSTER MILD STEEL PARTS	Jul.'71	"B" REV 5/21/79	T. Packman
050	SHIELD-INNER FABRICATION B1026541	Oct.'73	"B" REV 7/14/80	Prepared by: B. Reeves D. Schnelker
051	SHIELD-OUTER FABRICATION	Oct.'73	"B" REV 7/14/80	Prepared by: B. Reeves D. Schnelker
052	FIELD TUBE CONNECTOR ASSEMBLY B1026611	Oct.'75	"E" REV 7/15/80	Prepared by: B. Reeves D. Schnelker
053	CATHODE ASSEMBLY C1026624	Oct.'75	"D" REV 9/12/80	D. Schnelker
054	BAFFLE AND POLE ASSEMBLY D1095719	Oct.'75	"C" REV 8/26/80	D. Schnelker
055	ASSEMBLY PROCEDURE FOR 30-CM PLENUM ASSEMBLY 1025320	Jul.'79	"A" REV 7/16/80	S. Kami
062	ASSEMBLY PROCEDURE FOR RING STRUCTURE E1026496	Dec.'75	"B" REV 8/4/80	Prepared by: B. Reeves D. Schnelker
064	30 CM THRUSTER ASSEMBLY E1026510	Jun.'76	"C" REV 9/12/80	D. Schnelker
065	GRIT-BLAST PROCEDURE FOR ION THRUSTER PORTS	Oct.'73	"A" REV 8/2/76	Prepared by: H. McNulty D. Schnelker
069	FINAL ASSEMBLY OF MASK D1026462	Nov.'75	"B" REV 9/10/80	Prepared by: C. Fibuzian D. Schnelker
070	FINAL ASSEMBLY OF REAR SHIELD E1025216	Nov.'75	"A" REV 9/2/80	D. Schnelker

PARTS LIST	TITLE 30-CM ASSEMBLY PROCEDURES	DATE 5/21/81	REV	NEXT ASS'Y
		BY	SHEET 10	OF SHEETS 57

SPEC. NO. IPD-PR-	TITLE	DATE OF ISSUE	REVISION LETTER DATE	REQUESTOR
071	ANODE FABRICATION D1095246	Jan.'76	"D" REV 9/10/80	D. Schnelker
074	HELIUM LEAK DETECTION	Oct.'75		Prepared by: R. Olney D. Schnelker
075	MAGNETIZATION 30-CM ION THRUSTER MAGNETS B1095074 & B1095095	Nov.'74	"A" REV 10/20/75	Prepared by: R. Olney D. Schnelker
092	30 CM ION OPTICS FORMING PROCEDURE P/Ns D1026137 & D1026138	Oct.'75	"A" REV 9/10/80	B. J. Reeves
093	CATHODE ASSEMBLY-NEUT. P/N C1095283	Oct.'75	"C" REV 9/10/80	D. Schnelker
094	CALIBRATION OF 30 CM ION THRUSTER RADIAL MAGNETS P/N B1095095	Oct.'75	"A" REV 9/15/80	Prepared by: R. Olney D. Schnelker
095	CALIBRATION OF 30 CM ION THRUSTER AXIAL MAGNETS P/N B1095094	Oct/75	"A" REV 9/15/80	D. Schnelker
098	DYE PENETRANT TEST FOR ALL FORMED SHEET METAL PARTS	Jan.'76	"A" REV 4/14/81	S. Kami
133	INTRUSION TEST AND FLOW FABRICATION PROCEDURE	Aug.'77	"A" REV 5/10/78	S. Kami
138	30 CM THRUSTER ACCEPTANCE TEST PROCEDURE		"A" REV 3/1/80	Prepared by: C. Dulgeroff
139	THRUSTER TEST FACILITY	Jul.'79		Prepared by: R. Poeschel
140	30 CM THRUSTER POWER PROCESSOR SPECIFICATION	Jul.'79		R. Poeschel
141	INSTRUMENTATION AND CALIBRATION	Jul.'79		Prepared by: R. Poeschel
142	PRELIMINARY THRUSTER PREPARATION	Jul.'79		Prepared by: R. Poeschel
143	DATA FORMATS FOR THRUSTER DOCUMENTATION		"A" REV 3/1/80	Prepared by: C. Dulgeroff

PARTS LIST	TITLE 30-CM ASSEMBLY PROCEDURES	DATE 5/21/81	REV	NEXT ASS'Y
		BY	SHEET 11 OF SHEETS 57	

SPEC. NO. IPD-PR-	TITLE	DATE OF ISSUE	REVISION LETTER DATE	REQUESTOR
146	30 CM ELECTRODE STRESS RECEIVING PROC. P/N D1026137 & D1026138	Mar.'78	"B" REV 7/15/80	G. J. Reeves
151	VAPORIZER POROUS PLUG - HOUSING; ASSEMBLY AND PROCESSING PROCEDURE 30 CM	Jul.'79		Prepared by: S. Kami
152	MAIN ISOLATER VAPORIZER ASSEMBLY C1095755	Mar.'80	"A" REV 9/10/80	Prepared by: S. Kami
153	30 CM OPTICS ASSEMBLY PROCEDURE 1095752	Jul.'79		Prepared by: S. Kami
154	CATHODE-ISOLATOR VAPORIZER ASSEMBLY 1095763	Jul.'79	"A" REV 9/10/80	Prepared by: S. Kami
155	NEUTRALIZER ASSEMBLY 1095773	Sep.'79	"A" REV 9/12/80	Prepared by: S. Kami
156	NEUTRALIZER VAPORIZER ASSEMBLY 1095761	Jul.'79		Prepared by: S. Kami
159	PREP. OF THRUSTER DELIVERY PACKAGE	?	"A" REV 6/2/80	Prepared by: R. Poeschel
165	VAP HEATER TEMP CYCLE	Mar.'80		Ray Maheux
166	CATHODE HEATER TEMP CYCLE	May.'80		R. Jones

PARTS LIST

TITLE	DATE	REV	NEXT ASS'Y
30-CM MATERIALS LIST	5/21/81		
	BY	SHEET 12	OF SHEETS 57

NO.	MATERIAL AND USE	QTY PER THR.
1.	MOLYBDENUM FOR ION OPTICS	
	a. .015" ARC-CAST SHEET	2.25 kg
	b. .075" POWDER-MET. SHEET	4.18 kg
	c. .160" POWDER-MET. SHEET	4.91 kg
	d. ½" ARC-CAST PLATE	1.84 kg
2.	TANTALUM FOR CATHODES AND POLE-PIECE SHIELDS	
	a. ¼" DIA ROD	.42 lb
	b. 5/16" DIA ROD	.46 lb
	c. 2/16" DIA ROD A	.09 lb
	d. ½" DIA ROD	.68 lb
	e. 3/4" DIA ROD	1.59 lb
	f. .125" THICK SHEET	2.40 lb
	g. 3/16" THICK SHEET	3.50 lb
	h. ¼" THICK SHEET	1.66 lb
	i. .010 THICK SHEET	.036 lb
	j. .016 THICK SHEET A	.096 lb
	k. .032 THICK SHEET B	.46 lb
	l. .090 THICK SHEET C	.54 lb
	m. ¼" DIA x .010 WALL TUBE	.5 ft
	n. .0005" THICK FOIL	.009 lb
	A 25 lb. Min. Order	
	B 35 lb. Min. Order	
	C 50 lb. Min. Order	
3.	CERAMIC INSULATORS MISCELLANEOUS ASSEMBLY	147 parts
4.	POROUS TUNGSTEN (VAPORIZERS) 3 VAPORIZERS (YIELD ¼)	12 parts
5.	IMPREGNATED POROUS W INSERT 2 CATHODES (YIELD 2/3)	3
6.	HEATERS	
	a. CATHODE (Ta)	4 to get 2
	b. VAPORIZER ( )	6 to get 3
	c. ISOLATOR ( )	4 to get 2
7.	TITANIUM	
	a. .020" THICK SHEET	2.0 lb
	b. .032" SHEET	2.0 lb
	c. .08"	2.0 lb
	d. 3/8" DIA ROD	.9 lb
	e. ½" DIA ROD	.016 lb
	f. 1½" THICK PLATE	63
8.	MAGNETS	
	a. 12 AXIAL	15
	b. 12 RADIAL	15
9.	VESPEL	
	a. ¼" SHEET	4 sq.in.
	b. ½" SHEET	4 sq.in.
	c. 3/4" ROD	14 in.
10.	RESISTOFLEX FITTINGS	5

PARTS LIST

TITLE	DATE	REV	NEXT ASS'Y
30-CM MATERIALS LIST	5/21/81		
	BY	SHEET 13	OF SHEETS 57

NO.	MATERIAL AND USE	QTY PER THR.	NO.	MATERIAL AND USE	QTY PER THR.
11.	302/304				
	a. .003 THICK SHEET	144 $(in)^2$			
	b. .005 THICK SHEET	4 $(in)^2$			
	c. .010 THICK SHEET	1233 $(in)^2$			
	d. .015	18 $(in)^2$			
	e. .016	3 $(in)^2$			
	f. .025	8 $(in)^2$			
	g. .060	1"x4"			
	h. 3/16" PLATE	1"x4"			
	i. 1" $(in)^2$ BAR	3" LG.			
	j. .187 DIA	7"			
	k. .375 DIA	8"			
	l. .500 DIA	4"			
	m. 1.500 DIA	5"			
	n. 2.250 DIA	3"			
	o. .090 x .016 WALL TUB	6"			
	p. .062 x .010 WALL	6 ft			
12.	a. 165 x 800 302/304 SINTERED MESH	240 $(in)^2$			
	b. 165 x 800 MESH	250 $(in)^2$			
	c. 165 x 1400	36 $(in)^2$			
	d. 23 MICRON	12 $(in)^2$			
	e. 94 MESH	46 $(in)^2$			
13.	KOVAR SHEET .020	36 $(in)^2$			
14.	ALUM a. .020	50 $(in)^2$			
	b. .025	40 $(in)^2$			
	c. .030	510 $(in)^2$			
	d. 1" DIA	2" LG			
15.	1010/1018 C.R.S.				
	a. .010 SHEET	36 $(in)^2$			
	b. .024 SHEET	450 $(in)^2$			
	c. .030 SHEET	6 $(in)^2$			
	d. 1" DIA	2" LG			
	e. 3" O.D.x.050 WALL TUBE	1½" LG			
16.	OFHC COPPER .010 DIA	50"			
17.	2% THOR TUNGSTEN ¼" DIA	1"			
18.	CLASS 200 NICKEL SHEET	2 $(in)^2$			
19.	TA. MESH 50 x 700	2 $(in)^2$			
20.	GRAPHITE .050	3"x10"			

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER
E1026510
REF IPD-PR-004 [illegible] ASSY

DATE 2/16-84 | REV A | NEXT ASS'Y
BY RJ | SHEET 14 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO	PAGE	IPD PR –	TOOL T–	MATERIAL
D	OUTER HOUSING ASSEMBLY 1025324	F	1	1	1	1	21	064	1094 109[illegible]	
B	INSULATOR-SPACER MALE 1024226-98	G	2	12	12	2		–		,313 O.D X .156 I.D. X .3[illegible] Lg AL 300 ALU[illegible] WESTRN GOLD & PLAT.
B	SHIELD, TUBE 1026081-1	B	9	12	49	3		–		1.2 DIA X .01 THK BLANK 302/304 CRES QQ-S-766
D	WIRE MESH ANODE 1095246	E	1	1	5	4		071	1059 1025 1026 1100	11.82 X 4.9, 165X[illegible] MESH 304 L CRES [illegible] BOND'D TO .003/.005 304L CRES SHEET
B	INSULATOR-SPACER, FEMALE 1024226-99	G	9	12	13	5		–		,313 O.D X .12[illegible] I.D. X .251 Lg AL 300 ALUMINA, WSTRN GLD & PLAT
B	SHIELD, INSULATOR 839299	D	2	12	14	6		–		.50 DIA X .22 Lg 302/304 CRES B[illegible] QQ-S-763
D	WIRE ASSY, ANODE 1095845-04	G	5	5	56	7		167		
D	WIRE ASSY, ANODE 1095845-05	G	3	3	56	8		167		
D	WIRE ASSY, ANODE 1095845-03	G	1	1	56	9		167		
D	WIRE ASSY, ANODE 1095845-02	G	1	1	56	10		167		
E	BACK PLATE ASSEMBLY 1025353	F	1	1	8	11	18	–		
C	RETAINER, RADIAL MAGNET 1026508-1	B	8	8	9	12		–		3.3 X .78 X .008 THK COM'L PURE TITANIUM AMS 4[illegible]/490[illegible]
C	RETAINER, RADIAL MAGNET 1026508-2	B	2	2	10	13		–		"
C	RETAINER, RADIAL MAGNET 1026508-3	B	2	2	11	14		–		"
C	RETAINER, MAGNET, INNER 1025352	C	1	1	23	15		–		5.2 [illegible] X .01[illegible] THK AISI 1010/1019 STEEL
B	MAGNET, RADIAL 1025995	A	12	12	3	16		075	[illegible]	.30 X .14[illegible] X 3.8 Lg ALNICO V

16583 RL MAY 1980

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER

DATE 2/16-81 | REV A | NEXT ASS'Y

BY RJ | SHEET 15 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO	[illegible]	IPD PR —	TOOL T-	
D	RETAINER, MAGNET, OUTER 1026488	C	1	1	6	17		043		
C	RETAINER, FORMED BLANK 1095850	[illegible]	1	1	(1)	(1)		—		14.0 O.D. x 11.5 I.D. x .024 THK BLANK AISI 1010/1018 STEEL
B	MAGNET, AXIAL 1095094	A	12	12	18	18		075 095	1066	.140 DIA x 5.3 Lg ALNICO V
D	PLENUM ASSEMBLY 1025320	J	1	1	15	19	18	055		
D	SHIELD, MESH 1095429	A	1	1	50	20		—		165 X 800 DUTCH TWILL 304L CRES-TETCO, INC 14.0 DIA
D	BAFFLE & POLE ASSEMBLY 1095719	B	1	1	52	21	19	054		
B	MESH, CIV 1095428	B	1	1	51	22		—		165 X 800 DUTCH TWILL 304 L CRES-TETCO, INC 4.0 DIA
B	SHIELD, OUTER, INSULATOR 1025317	B	14	[illegible]	22	23		—		18-8 TYPE 302 CRES COND A, QQ-S-766 1.8 DIA x .010 THK
B	INSULATOR (CERAMIC) 1095778-99	A	2	24	19	24		—		96% PURE AL_2O_3, & KOVAR OR EQ PER ASTM F-15. CERAMASEAL PT # 809[illegible]
B	INSULATOR, ASSEMBLY - VESPEL 1095712	—	2	14	30	25	23	—		VESPEL SP-1 DU PONT DE NEMOURS
D	REAR BRACE ASSEMBLY 1026485	H	1	1	17	26	23	164		TITANIUM, COM'L PURE, AMS 4900/01
C	CATHODE ASSEMBLY-CIV 1026624	G	1	1	36	27	24	053		
B	SEAL, CATHODE 1026601	A	1	1	53	28				COM'L PURE TA .005 x 1.5 DIA
D	ISO-VAP ASSEMBLY, CATHODE 1095763	A	1	1	42	29	26	154	1013 1011	
B	COVER, BAFFLE, UPSTREAM 1095239	D	1	1	55	30		—		.014/.016 COM'L PURE TA, 2.3 DIA
B	BAFFLE 1025423	G	1	1	18	31				1010 AISI STEEL 2.125 DIA x .03 THK QQ-S-698

16583 RL MAY 1980

PARTS LIST

TITLE	DATE	REV	NEXT ASS'Y	BY	SHEET
30 CM J-Series Ion Thruster Standard Hardware	2/16/91	A		REJ	16 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO	PAGE	IPD PR –	TOOL T-	
B	COVER, BAFFLE, DOWNSTREAM 1095238	E	1	1	54	32		—		2.200 DIA X.084 Lg TA COM'L PURE
B	SCREW, BAFFLE 1095241	A	3	3	37	33		—		.250 DIA X.250 Lg TA COM'L PURE
C	ISO-VAP ASSEMBLY, MAIN 1095755	A	1	1	35	34	31	074 152	1012 1011	
D	NEUTRALIZER ASSEMBLY 1095773	B	1	1	41	35	36	074 155		
E	30CM OPTICS ASSEMBLY 1095752	B	1	1	40	36	47	153		
D	JUMPER WIRE, ACCEL 1095845-01	G	1	1	57	37		167		
B	SHIELD 1026447-1	B	19	23	46	38		098		.010 THK X 1.7 DIA TYPE 304 CRES PER QQ-S-766, COND A
B	INSULATOR, KEEPER, MALE 1025268	E	19	22	47	39				.375 DIA X Lg AL 300, WESTERN GOLD & PLATINUM CO.
B	INSULATOR, KEEPER, FEMALE 1025267-2	C	19	20	48	40				"
B	SHIELD, KEEPER 1025266-2	C	38	42	45	41		098		.010 TK 18-8 TYPE 304 CRES PER QQ-S-766, COND A
B	PLATE, FEEDLINE SUPPORT 1095723	-	1	1	31	42				.025 TK X 3.4 X 1.34 TYPE 304 CRES PER QQ-S-766 COND A
-	OFHC COPPER WIRE (ANNEALED) .009/.010 Dia	—	A/R	A/R	65	43				20.0 Lg (2 WRAPS)
B	CLAMP, FEEDLINE SUPPORT 1095724	-	2	2	32	44				.016 TK 18-8 TYPE 304 CRES PER QQ-S-766 COND A 1.1 X .62 X .016 THK
C	MANIFOLD ASSEMBLY, THRUSTER 1095683	-	1	1	25	45	49	074	HEAT SINK	
D	JUMPER WIRE, MAG BAFFLE 1095845-08	G	1	1	59	46		167		
D	JUMPER WIRE, MAG BAFFLE 1095845-09	G	1	1	60	47		167		

PARTS LIST

TITLE	DATE	REV	NEXT ASS'Y
30CM J-SERIES ION THRUSTER STANDARD HARDWARE	2/16/81	A	
	BY REJ	SHEET 17 OF 57 SHEETS	

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO	PAGE	IPD PR	TOOL T-	
D	JUMPER WIRE, CATHODE HEATER 1095845-06	G	1	1	58	48		167		
B	CLAMP, GUIDE, CABLE 1095709	–	4	4	4	49				.015 TKX1.7X.38 301 CRES PER QQ-S-766 COND. 1/4 HRD
D	JUMPER WIRE, THERMISTER 1095845-41	G	1	1	61	50		167		–
D	WIRING & HARNESS ASSEMBLY 1095845-16 thru 40 & -42	G	1 ea	1 ea	44	51		167		
B	INSULATOR,WIRE CLAMP 1095009	A	2	2	39	52		—		.020 TK TEFLON MIL-P-22241 1.32 X .5
B	WIRE CLAMP (STRAP) 1095008	A	2	2	38	53		—		.005 TK X 1.1 X .41 TYPE 304 CRES PER QQ-P-766 COND A
	TAPE, INSULATION .004 x 1.0 (TEFLON)	–	A/R	A/R	70	54		–		MIL-P-22241
B	GUIDE-HARNESS 1027398	E	4	4	33	55		—		VESPEL SP-1 DU PONT DE NEMOURS 1.3X1.4X.38
-	LACING TIE, WIRE (BEN HAR) HMS 20-1924	-	A/R	-	62	56		—		———
B	SHIELD, INNER, INSULATOR 1025318	B	4	38	21	57		098		.010 THK X 2.5 DIA TYPE 304 CRES PER QQ-P-766 COND A
E	REAR SHIELD ASSEMBLY 1025316	T	1	1	7	58	50	070		
B	COVER 1026809	B	1	1	20	59		—		.020 TK X 4.6 DIA 6061-T4 ALUMINUM ALLOY QQ-A-250/11
B	BRACKET, MOUNTING, NEUTRALIZER 1095733	A	1	1	34	60				.032 TK TITANIUM SHEET, AMS 4900/01 COM'L PURE 1.5X1.75
D	MASK ASSEMBLY 1026462	C	1	1	16	51	50	069	1093	.016 TK "
B	SHIM, MOUNTING 1095754	–	A/R	A/R	[illegible]	62		–		.002 THRU .040 TK 18-8 TYPE 302/304 CRES, COND A, QQ-S-766 .44 DIA.
D	SHIELD, OUTER, SEGMENT A 1095121	D	1	1	27	63		-		.030 TK 6061-T4 ALUM, QQ-A-250/11 10.1 X 7.5
D	SHIELD, OUTER, SEGMENT B 1095122	E	1	1	28	64		–		" 22.2 X 7.5

PARTS LIST

TITLE	DATE	REV	NEXT ASS'Y
30CM J-SERIES ION THRUSTER STANDARD HARDWARE	2/16/81	A	
	BY REJ	SHEET 18 OF 57 SHEETS	

SIZE	NOMENCLATURE / DRAWING NUMBER (1 2 3 4 5 6 7 8 9 10 11 12)	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO	PAGE	IPD PR –	TOOL T–	
	SHIELD, OUTER, SEGMENT C									.030 TK 6061-T4 ALUM. QQ-A-250/11
D	1095123	E	1	1	29	65		–		18.3 X 7.5
	PLT ASSEMBLY, HDR, MAN, 3-INLET							074	1090	
C	1095686 (Optional)	A	1	1	34	66	51	Ground Test Version		
	PLT-SPACER, MANIFOLD SEAL									.051 X 1 X 2.0 TYPE 304 CRES COND A, QQ-S
B	1095684-1	B	1	1	24	67	-	Ground Test Version		-766
	O-RING (VITON)									V-747-75 VITON
-	PARKER #2-006	-	3	3	54	68	-	Ground Test Version		
	PLT ASSEMBLY, HDR, MAN, 1-INLET							074	1090	
C	1095687	A	1	1	26	69	51	Flight Version		
	PLT SPACER, MANIFOLD SEAL									.057 TK X 1 X 2 TYPE 304 CRES, COND A, QQ-S
B	1095684-2	B	1	1	54	70	-	Flight Version		-766
	C-SEAL (PRESS SCI)									
-	632-U55-0002-2	-	3	3	66	71	-	Flight Version		
	LOCKWIRE .020/.025 CRES		A	A						
-	QQ-W-423		/R	/R	69	72		–		
	INTERFACE ENGR MODEL									
E	1095023 (ref)	D	-	-	43	73		–		
	WIRING & HARNESS ASSY (REF)									
D	1095845	G	–	–	–	74		167		
	WIRE, ELECT, STRANDED, 16 AWG		A/							KFT-5001-4 (GORE) 235 FT
	HMS-2-18202089	–	R	–	(1)	(1)		–		
	WIRE, ELECT, STRANDED, 20 AWG		A/							KFT-5001-3 (GORE) 125 FT
	HMS-2-18201689	–	R	–	(2)	(2)		–		
	GUIDE, CABLE, INSULATED									.235 DIA X .625 Lg AL2[illegible] AL-300
B	1095708		4	4	(3)	(3)		–		[illegible]
	BEAD, CERAMIC (FISH SPINE)		40 TO	40 TO						ALUMINA
	COMMERCIAL	–	45	45	(4)	(4)		–		
	TERMINAL LUG (AMP #2)									Ni CLASS [illegible]
	321883	–	6	6	[illegible]	[illegible]		–		
	TERMINAL LUG (AMP #4)									Ni " "
	321[illegible]4	–	6[illegible]	[illegible]	[illegible]	(6)		–		
	TERMINAL LUG (AMP #6)									Ni " "
	322[illegible]72	–	25	25	(7)	(7)		–		
	TERMINAL LUG (AM[illegible] #8)									Ni " "
	321885	–	3	3	(8)	(8)		–		

16583 RL MAY 1980

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER
E1026510
Standard Hardware

DATE 2/16/81 | REV A | NEXT ASS'Y
BY [illegible] | SHEET 19 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO
E	MISCELLANEOUS HARDWARE 1026510-99	G	–	–	–	75
	SCREW, CAP, SOC HD, 10-32, CRES x.38 Lg MS 24673-1	–	22		102	(1)
	SCREW, CAP, SOC HD, 10-32, CRES x.62 Lg MS24673-3	–	6		112	(2)
	SCREW, CAP, SOC HD, 6-32, CRES x.25 Lg MS 24674-1	–	36		110	(3)
	SCREW, CAP, SOC HD, 6-32, CRES x.38 Lg MS 24674-2	–	16		106	(4)
	SCREW, CAP, SOC HD, 6-32, CRES x.88 Lg MS24674-3		1		125	(5)
	SCREW, FLT HD, CROSS REC, 6-32, CRES MS 24693-C31	–	4		124	(6)
	SCREW, PAN HD, 4-40, CRES x.25 Lg MS 51957-13	–	1		114	(7)
	SCREW, PAN HD, 4-40, CRES x.5 Lg MS 51957-17	–	6		118	(8)
	SCREW, PAN HD, 4-40, CRES x 1.0 Lg MS 51957-21	–	9		103	(9)
	SCREW, PAN HD, 6-32, CRES x .25 Lg MS 51957-26	–	6		113	(10)
	SCREW, PAN HD, 6-32, CRES x .38 Lg MS 51957-28	–	32		115	(11)
	SCREW, PAN HD, 6-32, CRES x .5 Lg MS 51957-30	–	6		109	(12)
	SCREW, PAN HD, 6-32, CRES x 1.38 Lg MS 51957-125	–	22		11[illegible]	(13)

16583 RL MAY 1980

PARTS LIST	TITLE 30CM J-SERIES ION THRUSTER E1026510 Standard Hardware	DATE 2/16/91	REV A	NEXT ASS'Y
		BY RL	SHEET 20 OF 57 SHEETS	

SIZE	NOMENCLATURE DRAWING NUMBER	CHG LTR	QTY/ASSY	QTY/TOT	FIND NO	ASSY NO				
	NUT, HEX, PLAIN, 4-40, CRES AN 340-C4	–	27		120	(14)				
	NUT, HEX, PLAIN, 0-80 CRES AN 345-C0	–	8		117	(15)				
	WASHER, FLAT, NO. 4, CRES AN 960-C4	–	14		123	(16)				
	WASHER, FLAT, NO. 6, CRES AN 960-C6	–	103		107	(17)				
	WASHER, FLAT, NO. 10 CRES AN 960-C10	–	12		101	(18)				
	WASHER, FLAT, NO. 10 (THIN) CRES AN 960-C10L	–	22		116	(19)				
	NUT, HEX, PLAIN, 8-32 (DRLD) CRES NAS 509 C8	–	3	3	121	(20)				
	WASHER, FLAT, NO. 4 (SM. O.D.) CRES NAS 620 C4	–	39		104	(21)				
	WASHER, FLAT, NO 6 (SMALL O.D.) CRES NAS 620-C6		16		126	(22)				
	NUT HEX, PLAIN 0-80 CRES NAS 671 C0		8		–	–				ALTERNATE TO (15)
	NUT, SELF-LOCKING, 4-40 CRES NAS 1291 C04	–	36		105	(23)				
	NUT, SELF-LOCKING, 6-32, CRES NAS 1291 C06	–	59		10[illegible]	(24)				
	NUT, SELF-LOCKING, 10-32, CRES NAS 1291 C3	–	6		111	(25)				
	SCREW, SOC HD CAP, 4-40, CRES x 1.0 Lg NAS 1352C04-16		20		122	(26)				

16583 RL MAY 1960

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510

D1025324 OUTER HOUSING ASSEMBLY [1]

(Page 1 of 3)

DATE 2/16/81 | REV B | NEXT ASS'Y | BY REJ | SHEET 21 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPO PR	TOOL T-	MATERIAL
D	OUTER HOUSING ASSEMBLY 1025324	F	1	1	[1]	[1]		064	1094 1005	
E	RING STRUCTURE 1026498	F	1	1	1	1		164 062	1002 1032 1033 1034 1001	
D	RING, THRUSTER SUPPORT 1026452-2	A	1	1	(2)	(1)		164 062	1080 1053	.050 THK COM'L PURE Ti, AMS 4900/01
C	UPRIGHT, RING SUPPORT 1026451-1	B	4	4	(3)	(2)		164 062		.020 THK "
C	UPRIGHT, RING SUPPORT 1026451-2	B	4	4	(4)	(3)		164 062		"
C	UPRIGHT, RING SUPPORT 1026451-3	B	4	4	(5)	(4)		164 062		"
D	RING, THRUSTER SUPPORT 1026452-1	A	1	1	(6)	(5)		164 062		.050 THK "
B	TUBE, MAG RETAINING 1026194	C	12	12	(7)	(6)		164 062		.189/.191 O.D X .150 I.D. Ti AMS 4900/01
B	SHIELD, INNER INSUL 1025318	B	22	38	3	2		098		.010 SHEET TYPE 302/304 CRES 1.6 DIA
B	INSULATOR ASSEMBLY - VESPEL 1095712	—	12	14	2	3		—		.685 DIA X .763 L VESPEL SP-1 E.I. DUPONT
B	INSULATOR-VESPEL 1095712-1	—	1	14	(1)	(1)		—		"
-	INSERT, SELF-LOCKING NAS 1395 C3L	—	2	28	(2)	(2)		—		—

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510

D1025324 OUTER HOUSING ASSEMBLY [1]

DATE 2/16/81 | REV A | NEXT ASS'Y

BY REJ | SHEET 22 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
B	INSULATOR (CERAMIC) 1095778-99	A	10	24	4	4				CERAMASEAL PT# 809B9797-1
B	SHIELD, OUTER, INSUL. 1025317	B	12	26	5	5		098		TYPE 302/304 CRES COND A, QQ-S-766
-	SCREW, CAP, HEX SOC, DRLD, 10-32, CRES MS 24673-1	-	40	56	6	6		—		—
-	LOCKWIRE, .020-.025 (302) QQ-W-423		A/R	-	7	7		—		—
D	OUTER SHELL 1025381	F	1	1	8	8		—	1054	.008 THK Ti SHEET PER AMS 4900/01 6AL 4V TYPE

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510

D1025324 OUTER HOUSING ASSEMBLY [1] (Page 3 of 3)

DATE 2/16/81 REV A NEXT ASS'Y

BY REJ SHEET 23 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL	
C	GIMBAL BRACKET, ASSEMBLY 1026509	E	2	2	9	9		164	1034		
C	PLATE, FRONT 1026509-99	E	1	1	(1)	(1)				.080 THK COM'L PURE Ti PER AMS 4900/01	
C	PLATE, TOP 1026509-98	E	1	1	(2)	(2)				"	
C	PLATE, BOTTOM 1026509-96	E	1	1	(3)	(3)				"	
C	GUSSET 1026509-97	E	2	2	(4)	(4)				"	
B	INSERT, THREADED 1026520	B	4	4	(5)	(5)				"	
											IN COMPUTER TO HERE
B	SHIM, MOUNTING 1095754	—	A/R	-	10	10				.002 THRU .040 THK TYPE 302/304 CRES PER QQ-S-766 COND A	
D	RING, DOWNSTREAM 1025384	E	1	1	11	11		043		24 GA(.024) SHEET AISI 1010/1018 PER QQ-S-698	
C	POLE 1025383	C	1	1	12	12		043		"	
D	RING, UPSTREAM 1026501	C	1	1	13	13				"	
D	RING, FORMED, BLANK 1095851	—	1	1	(1)	(1)				"	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
E1025353 - BACKPLATE ASSEMBLY [11]
D1025320 - PLENUM ASSEMBLY [19]
(Page 1 of 1)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 24 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
E	BACKPLATE ASSEMBLY 1025353	F	1	1	[8]	[11]		—		
E	BACKPLATE 1025353-99	F	1	1	1	1				.020 THK SHEET COM'L PURE Ti AMS 4900/4901
-	NUTPLATE, SLF-LKG, 6-32, FXD MS21070-06	—	8	39	2	2		—		—
-	RIVET, CSK HD,093, CRES MS20427-F3-3	—	16	32	3	3		—		—
D	PLENUM ASSEMBLY 1025320	J	1	1	[15]	[19]		055		—
D	PLENUM 1025320-99	J	1	1	1	1				.016 THK SHEET COM'L PURE Ti AMS 4900/4901
D	MESH, 165x800, CRES 1025320-97	J	12	12	3	2				302/304 CRES 23 MICRON
D	DEFLECTOR 1025320-98	J	1	1	2	3				.016 THK SHEET COM'L PURE Ti AMS 4900/4901
	TAB, SUPPORT 1025320-96	J	4	4	1	4				" " 3/16 x 3/8 x .01
-	NUTPLATE, SLF-LKG, 6-32, FXD MS21070-06	—	8	39	4	5				—
-	RIVET, CSK HD, .093, CRES MS 20427 F3-3	—	16	32	5	6				—

8818 RL DEC 1973

PARTS LIST

TITLE: 30CM J-SERIES ION THRUSTER E1026510
D1095719 BAFFLE & POLE ASSEMBLY [21]
(Page 1 of 4)

DATE: 2/16/81 | REV: A | NEXT ASS'Y: | BY: REJ | SHEET 25 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR –	TOOL T–	MATERIAL
D	BAFFLE & POLE ASSEMBLY 1095719	B	1	1	[52]	[21]		054		
D	CATHODE POLE ASSEMBLY 1026605	G	1	1	1	1		054		
B	FLANGE, CIV 1026521	F	1	1	(1)	(1)		—		
B	POLE, CATHODE 1025357	F	1	1	(3)	(2)		—		
B	FLANGE, CATHODE 1026603	B	1	1	(4)	(3)		—		TYPE 304L CRES QQ-S-763 1.5 DIA X 1.0 LNG
B	COVER, REAR 1095245	B	1	1	(5)	(4)		—		94 SQ MESH 304L CRES CLOTH .0035 WIRE
D	COVER, COLUMN 1026605-99	G	4	4	(11)	(5)		—		.625 X .775 X .010 TANTALUM, COM'L PURE
B	SUPPORT, BAFFLE 1025425	G	1	1	(2)	(6)		—		1.0 DIA X .800 I.D. X 1.407 LNG AISI 1010/1018 SEAMLESS TUBING
B	COLLAR, TERMINAL 1095717	—	3	3	(6)	(7)		—		.438 DIA X .125 LG BAR TYPE 304L CRES COND A PER QQ-S-763
B	TERMINAL-FEEDTHRU, MODIFIED 1095857	—	3	3	(10)	(8)		—		————
	TERM., FEEDTHRU CT250 (ALBEROX)	—	1	1	-1-	-1-		—		PURCHASED PART ————
B	COVER, FLANGE 1095242	B	1	1	(7)	(9)				.032 THK SHEET TANTALUM, COM'L PURE

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095719 BAFFLE & POLE ASSEMBLY 21

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ |

SIZE	NOMENCLATURE DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR—	TOOL T-	MATERIAL	
B	COVER, POLE PC, OUTER 1095243	B	1	1	(9)	(10)				.032 X 3.9 DIA TANTALUM, COM'L PURE	
B	COVER, POLE PC, INNER 1095244	B	1	1	(8)	(11)				2.940 O.D. 2.785 I.D. x 1.4 Lg TANTALUM COM'L PURE	
B	COIL, MAGNETIC BAFFLE 1025424	G	1	1	19	2				PURCHASE FROM SEMCO INC. COAX COPPER - MGO-CU	
–	TANT. FOIL STRIP 2X .12 X .005	–	3	3	1	(1)				COM'L PURE	
-	CLOTH, CRES (COIL COVER) .0035x94 SQR MESH (304L)	–	A/R	-	20	3				4.0 X .50 RECT.	
B	SHIELD ASSEMBLY, INNER 1095811	A	2	2	10	4				——	
B	SHIELD, KEEPER 1025266-1	C	1	2	(1)	(1)				.010 SHEET 18-8 TYPE 304 CRES COND A QQ-S-766	
-	CLOTH, CRES (SHIELD COVER) .0035x94 SQ MESH (304L)	–	A/R	-	(2)	(2)				.610 X 2.0 AND .525 DIA. PIECES	
B	INSULATOR, KEEPER, FEMALE 1025267-1	C	2	2	8	5				.375 O.D. X .205 I.D. X .661 AL 300 ALUMINA. WESTERN GOLD & PLAT.	
B	SHIELD ASSEMBLY, OUTER 1095810	-	2	2	9	6				——	
B	SHIELD 1026447-1	S	1	23	(1)	(1)				.010 THK 18-8 TYPE 304 CRES COND A QQ-S-766	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095719 BAFFLE & POLE ASSEMBLY [21]

DATE 2/12/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 27 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T-	MATERIAL
-	CLOTH, CRES (SHIELD COVER), .0035x94 SQ MESH (304L)	—	A/R	-	(2)	(2)				.184 X 2.0 AND .625 DIA PIECES
C	KEEPER ASSEMBLY 1095715	A	1	1	12	7		054	1076 1075 1028	———
B	KEEPER 1025270	C	1	1	(1)	(1)				.062 THK X .312 X 2.312 ARC CAST MOLY PER AMS 7801
B	BUSHING, KEEPER 1095714	B	2	2	(2)	(2)				.195 DIA X .438 L ARC CAST MOLY AMS 7800/01
B	COVER-MESH, KEEPER 1095716	A	2	2	(3)	(3)				7/8 X 1/2 STRIP 94 SQ MESH .0035 WIRE 304 CRES CLOTH
E	INSULATOR, KEEPER, MALE 1025268	E	2	22	7	8				.094 I.D. X .375 O.D. AL 300 ALUMINA WESTERN GOLD & PLATINUM CO.
B	SHIELD, KEEPER 1025266-2	C	2	42	16	9				.010 THK X 1.5 DIA BLANK 304 CRES COND A QQ-S-766
B	FLANGE, BAFFLE 1025422	D	1	1	5	10				1.280 O.D X .062 THK AISI 1010/1018 STEEL BAR QQ-S-698

8818 RL DEC 1973

PARTS LIST

TITLE: 30CM J-SERIES ION THRUSTER E1026510
D1095719 BAFFLE & POLE ASSEMBLY [21]
(Page 4 of 4)

DATE: 3-16-80 | REV: – | NEXT ASS'Y:
BY: REJ | SHEET 28 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR –	TOOL T–	MATERIAL
B	SHIELD, KEEPER 1025266-3	C	3	3	11	11				.010 THK X 2.3 DIA BLANK 304 CRES COND A, QQ-S-766
B	COVER, COIL END 1095718	A	2	2	15	12				.015 X .144 DIA BLANK (FOR 4 PCS) 304L CRES COND A QQ-S-766
-	WASHER, #4 AN 960-C4	–	2	30	14	13				—
	JUMPER WIRE, CATHODE KEEPER 1095845-07	G	1	1		14		167		—
-	SCREW, SOC HD, 4-40 NAS1352C04-14	–	2	2	13	15				—
-	WASHER, #8 AN 960-C8	–	6	16	17	16				—
-	NUT, HEX, PLAIN, 8-32 AN 340-C8	–	3	3	18	17				—
										—

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
B1095712 INSULATOR ASSEMBLY, VESPEL [25] (Page 1 of 1)
D1026485 REAR BRACE ASSEMBLY [26] (Page 1 of 1)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 29 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR –	TOOL T-	MATERIAL
B	INSULATOR ASSEMBLY - VESPEL 1095712	–	2	14	30	25				—
B	INSULATOR - VESPEL 1095712-1	–	1	14	1	1				.75 DIA X .763 Lg VESPEL SP-1 DU PONT -
-	INSERT, SELF-LOCKING NAS 1395-C3L	–	2	28	2	2				—
D	REAR BRACE ASSEMBLY 1026485	H	1	1	17	26		164	1006	—
B	BEAM 1027343	B	2	2	1	1				.032/5 THK Ti SHEET AMS 4900/01
B	BEAM, CURVED 1027367	A	2	2	6	2				"
B	BEAM, STEPPED 1027368	A	4	4	5	3				"
B	BRACKET, TERMINAL 1027345	A	4	4	4	4				"
B	GUSSET 1095097	A	8	8	2	5				"
B	INSERT 1027344	A	22	22	3	6				.375 DIA X 1.08 Lg TITANIUM COM'L PURE AMS 4900/01

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510

C1026624 CATHODE ASSEMBLY, CIV 27 (Page 1 of 2)

DATE 2/16/91 | REV A | NEXT ASS'Y

BY REJ | SHEET 30 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR –	TOOL T–	MATERIAL
C	CATHODE, ASSEMBLY, CIV 1026624	G	1	1	36	27		053		
B	TUBE 1025433-2	D	1	1	1	1				.260 O.D X .010 WALL X 1.7 Lg TA COM'L PURE SEAMLESS TUBING
B	DISK, ORIFICE 1026370	A	1	1	4	2				.235 DIA X .06 Lg 2% THORIATED TUNGSTEN
C	FLANGE 1026371	B	1	1	3	3				.668 DIA X .04 Lg TA ROD, COM'L PURE
B	HEATER, CATHODE 1025262	E	1	2	13	4		166		COAX TA-MGO-TA PURCHASED PART
B	CLAMP 1026374	C	1	2	12	5				.285 X .370 X .135 TA BAR, COM'L PURE
B	MOUNT, CATHODE 1026604	B	1	1	2	6				1.5 DIA X .250 Lg TA BAR COM'L PURE
B	INSULATOR, HEATER TERM 1024529	J	1	5	8	7				.094 O.D. X .04 I.D. X .094 Lg AL 300 ALUMINA - WESTERN GOLD & PLATINUM
B	TERMINAL, COAX HTR. 1095713-1-08	C	1	1	7	8				.156 X .312 X .61 TA BAR COM'L PURE
B	STRAP 1026635-1	B	3	3	5	9				.010 X .035 X 1.0 Lg TA STRIP, COM'L PURE

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
C1026624 CATHODE ASSEMBLY, CIV 27
(Page 2 of 2)

DATE 2/16/91 | REV A | NEXT ASS'Y
BY REJ | SHEET 31 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	LPD PR-	TOOL T-	MATERIAL	
B	STRAP 1026635-2	B	1	1	6	10				.010X.035X.93 Lg TA STRIP COM'L PURE	
B	SHIELD, RADIATION 1026637	B	1	2	14	11				.800 X 8.5 Lg X .0005 THK TA FOIL, COM'L PURE	
B	INSERT, CATHODE 1095590-1	A	1	1	11	12				PURCHASED PART FROM SPECTRA-MAT WATSONVILLE CA	
B	INSERT, IMPREGNATED 1095590-97	A	1	2	(1)	(1)				POROUS TUNGSTEN W/BA-CA-AL IMPREG 4:1:1 RATIO	
B	WIRE, RHENIUM, .020 Dia. 1095590-98	A	A/R	-	(2)	(2)				.020 DIA X .92 Lg	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510

D1095763 ISO-VAP ASSEMBLY, CATHODE [29]

DATE 2/16/91 | REV A | NEXT ASS'Y

BY REJ |

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR	TOOL T-	MATERIAL
D	ISOLATOR-VAPORIZER ASSY, CATHODE 1095763	A	1	1	42	29		154	1013 1011	———
B										
B	PLUG, POROUS 1095771	—	1	2	3	(1)			1078	———
B	PLUG, POROUS, BLANK 1024925	H	1	2	(1)	-1-				.185 DIA X.05 THK 80% DENSE POROUS TUNGSTEN PURCHASED PART
B	HOUSING, PLUG, VAPORIZER 1095764	—	1	2	2	(2)				.270 DIA X.35 Lg TA BAR COM'L PURE
B	MOUNT, VAPORIZER, CATHODE 1095766	A	1	1	4	2				.269 DIA X.233 Lg TA BAR, COM'L PURE
B	HEATER, VAPORIZER 1095135	E	1	2	14	3		165		PURCHASED PART COAX INCONEL-MGO-NICHROME V
B	HOUSING, VAPORIZER (RT. ANGLE) 1095765	A	1	2	1	4				.269 DIA X.57 Lg TA ROD, COM'L PURE
B	MOUNT, RTD 1095767	A	1	2	16	5				.364 X.19 X.43 TA BAR COM'L PURE
B	TRANSITION, TUBING 1095461	C	2	7	15	6				.168 DIA X.35 Lg 304 CRES ROD COND A QQ-A-763
B	FEED TUBE (.06) 1095016-2	C	1	1	28	7				.062 O.D X.010 WALL 321 CRES TUBE 10.5 LNG MIL-T-8808 COND A

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095763 ISO-VAP ASSEMBLY, CATHODE 29
(Page 2 of 5)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 33 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
B	TERMINAL, COAX HEATER 1095713-2-04	C	1	4	19	8				.312 X .15 X .61 Lg 200 NICKEL BAR
B	INSULATOR, HEATER TERM 1024529	J	1	5	20	9				.094 O.D X .040 I.D AL 300 ALUMINA, WESTERN GOLD & PLATINUM
C	PLATE, ISOLATOR-VAPORIZER 1095760-1	—	1	1	5	10				1.5 DIA X .25 Lg 321 CRES BAR QQ-S-766 COND A
C	ISOLATOR ASSEMBLY 1025498-2	C	1	2	6	11				VENDOR BRAZED HRL SUPPLIES BODY & KOVAR RINGS
B	BODY, ISOLATOR 1024208	H	1	2	3	(1)		098		1.38 O.D. X 1.135 I.D X .905 Lg AL 300 ALUMINA WSTRN GOLD & PLAT
B	RING, ISOLATOR BODY 1024919-2	E	2	4	1	(2)		098		3.0 DIA X .02 THK BLANK KOVAR OR EQUIV. (FORM'D PART)
B	RING, BACK-UP 1025499-2	C	2	4	2	(3)		098		1.38 O.D. 1.14 I.D. X .05 THK AL 300 ALUMINA-WESTRN GOLD & PLATINUM
B	RING, ISOLATOR 1024920	E	7	14	7	12		098		1.135 O.D. X .870 I.D. X .125 Lg AL 300 ALUMINA, WESTRN GOLD & PLAT
B	MESH, ISOLATOR 1024216	E	8	16	8	13		010		1.13 DIA DISK-165 X 1400 (17 M FILTER CLOTH) 302/304 CRES (KRESSILK PR)
C	CONNECTOR ASSY, FEED TUBE 1026611	H	1	1	10	14		052		—

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095763 ISO-VAP ASSEMBLY, CATHODE [29]
(Page 3 of 5)

DATE 3-25-90 | REV — | NEXT ASS'Y
BY REJ | SHEET 34 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T-	MATERIAL	
B	FLANGE, ISOLATOR OUTLET 1026519-1	A	1	1	(1)	(1)				1.5 DIA X .51 Lg TYPE 304 L CRES COND A, QQ-S-766	
C	HEATER, ISOLATOR, CATHODE 1095721	A	1	1	(4)	(2)		165		PURCHASED PART COAX INCONEL-MgO-NICHROME V	
B	FEED TUBE (.09) 1026606	D	1	1	(2)	(3)		052	1023	.094 O.D. X .016 WALL 321 CRES TUBE MIL-T8606 4.7 Lg (APPROX)	
B	CONNECTOR, FEED TUBE 1026602	A	1	1	(3)	(4)				1.5 DIA X .18 Lg 304L CRES QQ-S-766	
B	TERMINAL, COAX HEATER 1095713-2-04	C	1	4	(5)	(5)				.312 X .15 X .6 Lg 200 NICKEL BAR	
B	INSULATOR, HEATER TERMINAL 1024529	J	1	5	(6)	(6)				.094 O.D. X .041 I.D. AL 300 ALUMINA WESTERN GOLD & PLATINUM	
B	FLANGE, ISOLATOR MOUNTING 1026518-2	A	1	1	9	15				2.25 DIA X .25 Lg 304L CRES BAR QQ-S-766 COND A	
B	BRACKET, TERMINAL 1095769	—	1	3	18	16				1.5 DIA X .506 Lg 304L CRES BAR QQ-S-763 COND	
B	SHIELD, INNER 1026541	B	1	2	12	17		050	1022 1021 1017 1014		
B	SHIELD 1026541-99	B	1	2	(1)	(1)				5.0 X 1.04 X .003 THK TYPE 302/304 CRES COND A MIL-S-5059	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095763 ISO-VAP ASSEMBLY, CATHODE 29 (Page 4 of 5)

DATE 3-25-80 | REV — | NEXT ASS'Y
BY REJ | SHEET 35 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR	TOOL T-	MATERIAL	
B	SHIELD CLAMP, L.H. 1026920	A	1	4	(2)	(2)				.90 X .19 X .012/.015 THICK 304 CRES STRIP, COND A QQ-S-766	
B	SHIELD CLAMP, R.H. 1026921	A	1	4	(3)	(3)				"	
-	SCREW, CAP, 2-56, CRES MS 16995-2	—	1	4	(4)	(4)				———	
-	NUT, HEX, 2-56, CRES MS 35649-244	—	1	4	(5)	(5)				———	
B	SHIELD, OUTER 1026538	B	1	2	11	18		051	1019 1022		
B	SHIELD 1026538-99	B	1	2	(1)	(1)			1020 1018 1015	5.5 X .73 X .003 THICK 302/304 CRES STRIP COND A MIL-S-5059	
B	SHIELD 1026538-98	B	1	2	(2)	(2)			1017 1016 1014	4.9 X .36 X .003 THICK 302/304 CRES STRIP COND A MIL-S-5059	
B	SHIELD CLAMP, LH 1026920	A	1	4	(3)	(3)				.90 X .19 X .012/.015 THICK 304 CRES STRIP COND A QQ-S-766	
B	SHIELD CLAMP, RH 1026921	A	1	4	(4)	(4)				"	
-	SCREW, CAP, 2-56, CRES MS 16995-2	—	1	4	(5)	(5)				———	
-	NUT, HEX, 2-56, CRES MS35649-244	—	1	4	(6)	(6)				———	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095763 ISO-VAP ASSEMBLY, CATHODE [29]

DATE 2/18/71 | REV A | NEXT ASS'Y
BY REJ | SHEET 36 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR-	TOOL T-	MATERIAL
B	INSULATOR, THERM TERM 1095419-1	B	2	6	21	19				.125 O.D. x .062 I.D x .177 Lg AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	INSULATOR, THERM. TERM 1095419-2	B	2	6	22	20				DITTO EXCEPT .127 Lg
B	SHIELD, THERM. TERM 1095418	A	4	10	23	21				.190 DIA X .095 Lg TYPE 304 CRES COND A QQ-S-763
	NUT, SHOULDER (RESISTOFLEX) R44228-2P-02	—	1	3		22			1091	PURCHASED PART SHIPPED WITH ASSY NO 23 BELOW
B	SHOULDER, MODIFIED 1095397	B	1	3	27	23			1091	PURCHASED PART MADE TO ORDER BY RESISTOFLEX INC.
-	SHOULDER (RESISTOFLEX) R 44671-1P	—	1	3	(1)	(1)				PURCHASED PART MADE INTO ASSY NO 23 BY RESISTO-FLEX INC.
-	BONDING AGENT (DYLON) C-3 (SUPERBOND)	—	A/R	-	29	24				——
B	SLEEVE, SENSOR 1095738	A	1	3	13	25				.125 O.D X .061 I.D. X .312 Lg AL 300 ALUMINA, WESTERN GOLD & PLATINUM
-	SENSOR, TEMPERATURE 146FB-200 (ROSEMOUNT)	—	1	3	17	26				PURCHASED PART
-	SCREW, PAN HD, 0-80, CRES x .62 Lg COMMERCIAL	—	2	6	24	27				——
-	WASHER, FLAT, #0 NAS 620 CO	—	2	8	25	28				——
-	NUT, HEX, 0-80 NAS 671 CO / AN 345-CO	—	2	8	26	29				——

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
C1095755 ISOLATOR VAPORIZER ASSEMBLY, MAIN [34]
(Page 1 of 5)

DATE	REV	NEXT ASS'Y
[illegible]	A	
BY: REJ	SHEET 37 OF 57 SHEETS	

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR –	TOOL T-	MATERIAL	
C	ISOLATOR-VAPORIZER ASSEMBLY, MAIN 1095755	A	1	1	35	34		152	1012 1011	—	
B										—	
B	PLUG, POROUS, MAIN VAPORIZER 1095770	–	1	1	3	(1)		151	1078	—	
B	PLUG, POROUS, BLANK, MAIN 1024914	H	1	1	(1)	-1-		151		.630 DIA x .06 THK 73% DENSE POROUS TUNGSTEN PURCHASED PART	
B	HOUSING, PLUG, MAIN VAPORIZER 1095756	A	1	1	2	(2)				.717 O.D x .601 I.D. TANTALUM, COM'L PURE	
B	MOUNT, MAIN VAPORIZER 1095758	A	1	1	4	2				.717 DIA x .391 Lg TANTALUM, COM'L PURE	
B	HEATER, MAIN VAPORIZER 1024917	F	1	1	5	3		165		PURCHASED PART - COAX INCONEL-MGO -NICHROME V	
B	STRAP, HEATER RETAINER 1095027	C	4	4	27	4				.1 x .63 x .003 THK STRIP, 302/304 CRES MIL-S-5059	
C	HOUSING, MAIN VAP. (RT. ANGLE) 1095757	A	1	1	1	5				.717 DIA x .54 Lg TANTALUM, COM'L PURE	
B	MOUNT, RTD, MAIN VAP 1095759	–	1	1	21	6				.23 DIA x .34 Lg, TANTALUM, COM'L PURE	
B	TRANSITION, TUBING 1095461	C	2	7	16	7				.168 DIA x .35 Lg 304 CRES COND A QQ-S-763	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
C1095755 ISO-VAP ASSEMBLY MAIN [34]

(Page 2 of 5)

DATE: 3-25-80 | REV: — | NEXT ASS'Y:
BY: REJ | SHEET 38 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR –	TOOL T–	MATERIAL
B	FEED TUBE (06) 1095016-3	C	1	1	25	8				.062 O.D X .010 WALL 321 CRES TUBE, MIL-T-8808 COND A, 5.5 Lg
C	PLATE, ISOLATOR-VAPORIZER 1095760-2	—	1	1	6	9				1.5 DIA X .25 Lg TYPE 321 CRES BAR COND A QQ-S-766
C	ISOLATOR ASSEMBLY 1025498-2	C	1	2	7	10				VENDOR BRAZED HRL SUPPLIES BODY & KOVAR RINGS
B	BODY, ISOLATOR 1024208	H	1	2	(3)	(1)				1.38 O.D. X 1.135 I.D. X .905 Lg AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	RING, ISOLATOR BODY 1024919-2	E	2	4	(1)	(2)				3.0 DIA X .02 THK BLANK KOVAR OR EQIV (FORMED PART)
B	RING, BACK-UP 1025499-2	C	2	4	(2)	(3)				1.38 O.D., 1.14 I.D X .05 THK AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	RING, ISOLATOR 1024920	E	7	14	8	11				1.135 O.D. X .87 I.D. X .125 Lg AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	MESH, ISOLATOR 1024216	E	8	16	9	12				1.13 DIA DISK – 165 X 1400 (17 M, FILTER CLOTH) 303/304 CRES (KRESSILK PROD)
B	FLANGE, ISOLATOR OUTLET 1026519-2	A	1	1	11	13				1.5 DIA X .51 Lg 304L CRES COND A BAR, QQ-S-766
B	MESH, END CAP 1026093	A	1	1	12	14				200 X 600 RECT MESH (23 MICRON) 304L CRES .8 DIA

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
C1095755 ISO-VAP ASSEMBLY, MAIN [34]
(Page 3 of 5)

DATE 2/16/81 | REV 1 | NEXT ASS'Y
BY REJ | SHEET 39 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
B	HEATER, ISOLATOR 1025330	D	1	1	15	15		165		PURCHASED PART COAX INCONEL-MgO -NICHROME V
B	FLANGE 1026518-1	A	1	1	10	16				2.25 DIA X .26 Lg 304L CRES BAR COND A QQ-S-766
B	BRACKET, TERMINAL 1095769	—	2	3	17	17				1.48 DIA X .52 Lg (MAKES 5-6 PARTS) 304L CRES, QQ-S-763
B	INSULATOR, TERMINAL 1024529	J	2	5	24	18				.094 O.D. X .04 I.D. AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	TERMINAL, COAX, HTR 1095713-2-04	C	2	4	23	19				.312 X .15 X .61 Lg 200 NICKEL
B	INSULATOR, THERMAL TERM. 1095419-1	B	2	6	18	20				.125 O.D X .062 I.D. X .177 Lg AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	INSULATOR, THERMAL TERM. 1095419-2	B	2	6	19	21				.125 O.D. X .062 I.D. X .127 Lg AL 300 ALUMINA, WESTERN GOLD & PLATINUM
B	SHIELD, THERMAL TERM 1095418	A	4	10	20	22				.187 DIA X .095 Lg 304 CRES COND A QQ-S-763
	NUT, SHOULDER (RESISTOFLEX) R44228-2P-02	—	1	3		23			1091	PURCHASED PART SHIPPED WITH # 24 BELOW
B	SHOULDER, MODIFIED 1095397	B	1	3	26	24			1091	PURCHASED PART MADE TO ORDER BY RESISTOFLEX INC.
-	SHOULDER R44671-1P (RESISTOFLEX)	—	1	3	(1)	(1)				PURCHASED PART MADE INTO #24 BY RESISTOFLEX INC.

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
C1095755 ISO-VAP ASSEMBLY, MAIN [34]
(Page 4 of 5)

DATE [illegible] | REV A | NEXT ASS'Y
BY REJ | SHEET 40 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL	
-	BONDING AGENT (DYLON) C-3 (SUPERBOND)	—	A/R	-	32	25				———	
B	SLEEVE, SENSOR 1095738	A	1	3	28	26				.125 O.D. X .06 I.D X .312 Lg AL300 ALUMINA WESTRN GOLD & PLAT	
-	SENSOR, TEMP 146FB200 (ROSEMOUNT)	—	1	3	22	27				PURCHASED PART	
B	SHIELD, INNER 1026541	B	1	2	13	28		050	1022 1021 1017 1014	———	
B	SHIELD 1026541-99	B	1	2	(1)	(1)				5.0 X 1.04 X .003 THK TYPE 302/304 CRES COND A MIL-S-5059	
B	SHIELD CLAMP, LH 1026920	A	1	4	(2)	(2)				.90 X .18 X .012/.015 THICK 304 CRES STRIP COND A QQ-S-766	
B	SHIELD CLAMP, RH 1026921	A	1	4	(3)	(3)				"	
-	SCREW, CAP, 2-56, CRES MS16995-2	—	1	4	(4)	(4)				———	
-	NUT, HEX, 2-56, CRES MS 35649-244	—	1	4	(5)	(5)				———	

8818 RL DEC 1973

PARTS LIST	TITLE 30CM J-SERIES ION THRUSTER E1026510 C1095755 ISO-VAP ASSEMBLY, MAIN 34 (Page 5 of 5)	DATE 2/16/91	REV A	NEXT ASS'Y
		BY REJ	SHEET 41 OF 57 SHEETS	

SIZE	NOMENCLATURE DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
B	SHIELD, OUTER 1026538	B	1	2	14	29		051	1019 1022	—
B	SHIELD 1026538-99	B	1	2	(1)	(1)			1020 1018 1015	5.5 X .73 X .003 THK 302/304 CRES STRIP COND A MIL-S-5059
B	SHIELD 1026538-98	B	1	2	(2)	(2)			1016 1017 1014	4.9 X .36 X .003 THK 302/304 CRES STRIP COND A MIL-S-5059
B	SHIELD CLAMP - LH 1026920	A	1	4	(3)	(3)				.012/.015 X .19 X .90 304 CRES STRIP, QQ-S-766
B	SHIELD CLAMP - RH 1026921	A	1	4	(4)	(4)				"
-	SCREW, CAP 2-56, CRES MS16995-2	—	1	4	(5)	(5)				—
-	NUT, HEX, 2-56 CRES MS35649-244	—	1	4	(6)	(6)				—
-	SCREW, PAN HD, 0-80, CRES COMMERCIAL	—	2	6	31	30				—
-	WASHER, FLAT, CRES, #0 NAS 620 C0	—	2	8	29	31				—
-	NUT, HEX, 0-80, CRES NAS 671 C0 / AN 345-C0	—	2	8	30	32				—

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
E1095773 NEUTRALIZER ASSEMBLY [35]
(Page 1 of 11)

DATE 2/16/81 REV A NEXT ASS'Y

BY REJ SHEET 42 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR-	TOOL T-	MATERIAL
D	NEUTRALIZER ASSEMBLY 1095773	B			41	35		155	1027	———
C	BRACKET, NEUTRALIZER 1027364	C	1	1	2	1			1095	———
C	BRACKET, FLAT PATTERN, NEUTRL 1095593	A	1	1	(1)	(1)				4.95 X 9.16 X .032 THK TITANIUM SHEET, AMS 4900/01
C	BRACKET, MAIN SUPPORT 1026503	H	1	1	6	2				———
C	BRACKET, FORMED, MAIN SUPPT. 1095809	—	1	1	(1)	(1)				———
C	BRACKET, FLT. PATT, MN. SUPP. 1095592	B	1	1	-1-	-1-				3.37 X 4.7 X .032 THK TITANIUM SHEET, AMS 4900/01
-	NUTPLT, SLF-LKG, 6-32, COR NAS 698 C06	—	2	2	(2)	(2)				———
-	RIVET, CSK HD, 100°, .062, CRES MS 20427 F2-3	—	4	4	(3)	(3)				———
-	NUTPLATE, SLF-LKG, FLTG, 6-32 MS 21076-L06	—	2	14	(4)	(4)				———
-	RIVET, CSK HD, 100° .094 Al MS 20426 AD3-5	—	4	4	(5)	(5)				———

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY [35]

(Page 2 of 11)

DATE 2/16/9· | REV A | NEXT ASS'Y
BY REJ | SHEET 43 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T-	MATERIAL
B	GRAPHITE COVER, BOTTOM 1095296	A	1	1	17	3				1.5 X 2.1 X .05 THK GRAPHITE TYPE HPD-1 (POCO GRAPH)
B	GRAPHITE COVER, INNER 1095297	A	2	2	16	4				1.9 X .51 X .05 THK GRAPHITE TYPE HPD-1 (POCO)
B	GRAPHITE COVER, OUTER 1095426	A	2	2	18	5				1.19 X 1.55 X .05 TK GRAPHITE TYPE HPD-1 (POCO GRAPH)
B	BRACKET, TERM MTG 1095729	A	1	1	12	6				.85 X .70 X .032 THK TITANIUM COM'L PURE AMS 4900/4901
B	KEEPER, ORIFICE 1027360	C	1	1	5	7				1.25 X .98 X .38 ARC CAST MOLY AMS 7801
B	TERMINAL-LINK 1026083-99	B	1	1	20	8				.63 X .31 X .015 THK NICKEL 200
B	SHIELD, OUTER 1095291-99	A	6	6	32	9				1.8 DIA X .01 THK 304 CRES SHEET QQ-S-766
B	INSULATOR, OUTER 1095293-99	B	6	6	28	10				.274 O.D. X .187 I.D. X .307 Lg AL 300 97% PURE WESTERN GOLD & PLATINUM
B	SHIELD, INNER 1095292-99	A	6	6	31	11				1.8 DIA X .01 THK BLANK 304 CRES QQ-S-766
B	SHIELD, INNER 1095292-97	A	8	6	30	12				1.6 DIA X .01 THK BLANK 304 CRES QQ-S-766
B	SHIM, NEUTRALIZER 1095862	A	A/R	A/R	9	13				.30 DIA X .002, 3, .005 & .010 THK 302/304 CRES QQ-S-766

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY 35
(Page 3 of 11)

DATE 2/11/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 44 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR	TOOL T-	MATERIAL
B	SHIELD, OUTER 1095291-97	A	2	2	29	14				1.6 DIA X.01 THK BLANK 304 CRES QQ-S-766
B	INSULATOR, INNER 1095294-99	A	6	6	27	15				.274 O.D. X .115 I.D. X .38 Lg 97% P AL 300 ALUMINA WESTRN GLD & PLAT
B	SHIELD, OUTER 1095291-95	A	6	6	33	16				1.7 DIA X.01 THK BLANK 304 CRES QQ-S-766
C	CATHODE ASSEMBLY, NEUTRALIZER 1095283	C	1	1	3	17		093		———
B	END CAP 1095290	B	1	1	(9)	(1)				.38 DIA X.16 Lg TANTALUM BAR COM'L PURE
B	DISK, ORIFICE 1025431	C	1	1	(3)	(2)				.235 DIA X .052 THK 2% THORIATED TUNGSTEN
B	TUBE 1025433-1	D	1	1	(2)	(3)				.250 O.D X .010 WALL SEAMLESS TA TUBING, 3 Lg COM'L PURE
B	HEATER, CATHODE 1025262	E	1	2	(8)	(4)		166		PURCHASED PART COAX TA-MgO-TA
B	CLAMP 1026374	C	1	2	(7)	(5)				.37 X .29 X .125 TA BAR COM'L PURE
B	SUPPORT, TUBE 1026086	D	2	2	(1)	(6)				.375 X .250 X1.25 TA BAR COM'L PURE

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY [35]
(Page 4 of 11)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 45 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
	FLANGE, TUBE, NEUTRALIZER 1095285	C	1	1	(6)	(7)				.440 DIA X.21 Lg TA BAR COM'L PURE
B	SHIELD - RADIATION 1026637	B	1	2	(10)	(8)				.8 X 8.5 X.0005 THK. TA FOIL COM'L PURE
B	INSERT, CATHODE 1095590-2	A	1	1	(4)	(9)				PURCHASED PART FROM SPECTRAMAT WATSONVILLE, CA
B	INS. IMPREGNATED 1095590-97	A	1	1	-1-	-1-				POROUS TUNGSTEN W/Ba-Ca-Al IMPREG 4:1:1 RATIO
B	WIRE, Re, .020 DIA. 1095590-99	A	3	3	-2-	-2-				.020 DIA X 2.16 Lg
B	BAFFLE, NEUTRALIZER 1025645	B	1	1	(5)	(10)				————
B	PLATE, SUPPORT 1025645-1	B	1	1	1	-1-				1.7 X .06 X .005 THK TA COM'L PURE
B	PLATE, END 1025645-2	B	2	2	2	-2-				.228 X .120 X .010 THK TA COM'L PURE
C	BRACKET, INSULATION ASSEMBLY 1026084	E	2	2	15	18				————
C	BRACKET - VESPEL 1026084-1	E	1	2	(1)	(1)				1.561 X .62 X .46 VESPEL SP-1 DU PONT DE NEMOURS
—	INSERT, SELF-LOCKING, 8-32 NAS 1395 C08L	—	2	4	(3)	(2)				————

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY 35

DATE 2/16/81 | REV — | NEXT ASS'Y

BY REJ | SHEET 46 OF 57 SHEETS

SIZE	NOMENCLATURE DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL	
C	BRACKET - VESPEL 1026084-2	E	1	2	(2)	(3)				1.561 X .62 X .19 VESPEL SP-1 DU PONT DE NEMOURS	
B	SHIELD, BRACKET 1095295	A	1	1	7	19				3.7 X 3.72 X .005 THK TITANIUM SHEET AMS 4901	
B	GROMMET 1026882	B	1	1	26	20				.64 DIA X .19 Lg DU PONT TEFLON	
C	HOUSING, NEUTRALIZER 1026502	D	1	1	1	21				———	
C	HOUSING, FORMED, NEUTRALIZER 1095808	—	1	1	(1)	(1)				———	
C	HOUSING, FLT PATT, NEUTR. 1026633	D	1	1	-1-	-1-				5.92 X 9.58 X .02 THK 6061-T4 ALUM QQ-A 250/11	
-	NUTPLATE, SELF-LOCKING, FXD MS21070-06	—	14	39	(2)	(2)				———	
-	RIVET, CSK HD, .094, ALUM MS 20426 AD3-3	—	28	102	(3)	(3)				———	
B	BRACKET ASSEMBLY, SUPPORT 1026504	C	2	2	11	22		164	1034	———	
B	BRACKET, SUPPORT 1026504-99	C	1	2	(1)	(1)				5.3 X 1.5 X .03 THK TITANIUM AMS 4900/01	
-	NUTPLATE, SELF-LOCKING, FLTG MS 21076-06	—	2	4	(2)	(2)				———	
-	RIVET, CSK HD, .094, ALUM MS 20426 AD3-3	—	4	102	(3)	(3)				———	

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY [35]
(Page 6 of 11)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 47 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
C	VAPORIZER ASSEMBLY, NEUTRALIZER 1095761	A	1	1	4	23		156		———
B										———
B	PLUG, POROUS 1095771	—	1	2	(7)	-1-			1078	———
B	PLUG, POROUS, BLANK 1024925	H	1	2	-1-	<1>				.185 DIA X .05 THK 80% DENSE POROUS TUNGSTEN PURCHASED PART
B	HOUSING, PLUG, VAPORIZER 1095764	—	1	2	(8)	-2-				.275 DIA X .358 Lg TA BAR COM'L PURE
B	HOUSING, VAPORIZER (RT ANGLE) 1095765	A	1	2	(10)	(2)				.270 DIA X .575 Lg TA ROD COM'L PURE
B	TRANSITION, TUBING 1095461	C	2	7	(11)	(3)				.168 DIA X .35 Lg 304 CRES COND A QQ-S-763
B	FEEDTUBE (.06) 1095016-1	C	1	1	(12)	(4)				.062 O.D. X 010 WALL 321 CRES TUBE COND A, 21 Lg MIL-T-8808
B	MOUNT, RTD 1095767	A	1	2	(13)	(5)				.364 X .43 X .187 THK TA BAR COM'L PURE
B	HEATER, VAPORIZER 1095135	E	1	2	(9)	(6)				PURCHASED PART COAX INCONEL-MgO-NICHROME V

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY [35]

(Page 7 of 11)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 48 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR	TOOL T-	MATERIAL
B	MOUNT, NEUTRALIZER-VAPORIZER 1095762	A	1	1	(5)	(7)				.39 DIA X 36 Lg TA ROD COM'L PURE
B	TUBE, INSULATOR 1026090	C	1	1	(4)	(8)				.375 O.D X .125 I.D X .3 Lg AL 300 ALUMINA WESTRN GLD & PLAT
B	SHIELD 1026091	C	1	1	(3)	(9)				.50 DIA X .51 Lg TA BAR COM'L PURE
B	SCREEN 1026089-1	C	1	1	(2)	(10)				.194 DIA 50X700 TA MESH DUTCH WEAVE (UNIQUE WIRE)
B	SCREEN 1026089-2	C	1	1	(6)	(11)				.164 DIA - OTHERWISE SAME AS ABOVE
B	FLANGE, VAPORIZER 1095286	B	1	1	(1)	(12)				.44 DIA X .217 Lg TA BAR COM'L PURE
	NUT, SHOULDER (RESISTOFLX) R44228-2P-02	–	1	3		(13)			1092	PURCHASED PART SHIPPED WITH NO. (14) BELOW
B	SHOULDER, MODIFIED 1095397	B	1	3	(14)	(14)			1059 1092	PURCHASED PART MADE TO ORDER BY RESISTOFLEX INC.
-	SHOULDER (RESISTOFLEX) R44671-1P	–	1	3	-1-	-1-				PURCHASED PART MADE INTO ASSY NO (14) BY RESISTOFLEX INC.
B	CLAMP, NEUTRALIZER 1095281	C	1	1	13	24				1.0 X .55 X .25 MOLY BAR, ARC CAST AMS 7801
B	TERMINAL-LINK 1026083-97	B	1	1	19	25				.312 X .625 X .015 THK NICKEL 200

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY [35]

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ |

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL	
B	SEAL, NEUTRALIZER 1095282	B	1	1	14	26				.250 O.D. X .187 I.D. X .105 Lg TA COM'L PURE	21
B	SHIELD, INNER 1095292-95	A	2	2	35	27				1.7 DIA X .01 THK 304 CRES BLANK QQ-S-766	21
B	SHIELD, OUTER 1095291-93	A	2	2	36	28				1.8 DIA X .01 THK 304 CRES BLANK QQ-S-766	21
B	INSULATOR, INNER 1095294-97	A	2	2	34	29				.274 O.D X .115 I.D. X .44 Lg AL 300 ALUMINA, WESTRN GOLD & PLATINUM	35
B	INSULATOR, OUTER 1095293-97	B	2	2	37	30				.274 O.D X .187 I.D. X .185 Lg AL 300 ALUMINA 97% PURE WESTRN GLD & PLAT.	35
B	INSULATOR, THERM TERM 1095419-1	B	2	6	22	31				.125 O.D X .062 I.D. X .177 Lg AL 300 ALUMINA WESTRN GLD & PLAT.	35
B	INSULATOR, THERM TERM 1095419-2	B	2	6	24	32				(EXCEPT " .125 Lg)	35
--	BONDING AGENT (DYLON) C-3 (SUPERBOND)	—	A/R	-	48	33				————	
B	SLEEVE, SENSOR 1095738	A	1	3	47	34				.125 O.D. X .063 I.D. X .312 Lg AL 300 ALUMINA WESTERN GOLD & PLATINUM	35
-	SENSOR, TEMP 146FB-200 (ROSEMOUNT)	—	1	3	46	35				PURCHASED PART	126
B	SHIELD, THERM TERM 1095418	A	2	10	25	36				.190 DIA X .095 Lg 304 CRES COND A QQ-S-763	21

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY 35

(Page 9 of 11)

DATE 2/16/81 | REV B | NEXT ASS'Y
BY REJ | SHEET 50 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL	
C	COVER, NEUTRALIZER 1026505	A	1	1	8	37				——	
C	COVER, FLAT PATTERN, NEUTRL. 1026634	B	1	1	(1)	(1)				1.692 X 11.348 Lg X.020 THK ALUM 6061-T4, QQ-A-250/11	
B	SHIELD, KEEPER 1027366	A	1	1	10	38				2.14 X 1.692 X .020 TITANIUM AMS 4900/01	
D	WIRE ASSY (S) NEUTR 1095845 -10 THRU -15	F	1 EA		56	39					
								Standard Hardware			
-	SCREW, PAN HD, 4-40 × 1.0 Lg MS 51957-21 / 35233-21	—	8	36	38	40					
-	WASHER, FLAT, #4 CRES AN960-C4	—	16	26	39	41					REMOVE[illegible] 4 WASH [illegible] SHLDR INTERFERENCE
-	NUT, SELF-LOCKING, #4-40 CRES NAS 1291 C04	—	10	40	40	42					
-	SCREW, SOC HD, DRLD, 6-32 × .25 Lg MS 24674-1	—	6	22	41	43					
-	WASHER, FLAT, #6 CRES AN 960-C6	—	6	83	42	44					

8918 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
D1095773 NEUTRALIZER ASSEMBLY [35]
(Page 10 of 11)

DATE 2/16/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 51 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #
-	NUT, SELF-LOCKING, #8-32 CRES NAS 1291 C08	–	6	6	43	45	
-	SCREW, HEX SKT HD, 4-40 x.25 Lg NAS 1352 C04 H4	–	2	2	44	46	
-	SCREW, PAN HD, 0-80, x.62 Lg COMMERCIAL	–	2	6	45	47	
-	WASHER, FLAT, #0 CRES NAS 620 C0	–	4	8	49	48	
-	WASHER, FLAT, #2 CRES AN 960 - C 2	–	2	2	50	49	
-	NUT, HEX, #0-80 CRES NAS 671 C0 / AN 345-C0	–	4		51	50	
-	SCREW, SOC HD, 8-32 x.5 Lg NAS1352C08-8	–	4	4	52	51	
-	WASHER, FLAT, #8 CRES AN 960-C8	–	4	16	53	52	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER
D1095773 NEUTRALIZER ASSEMBLY 35

E1026510
(Page 11 of 11)

DATE	REV	NEXT ASS'Y
2/16/91	B	
BY REJ	SHEET 52 OF 57 SHEETS	

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #
-	SCREW, PAN HD, 6-32, x.31 Lg MS 51957-27	—	16	16	54	53	
-	RIVET, CSK HD, .062, CRES MS 20427 F2-2	—	2	2	55	54	
-							
-	LOCK WIRE, .020-025 (302) CRES QQ-W-423	—	A/R	-	57	55	
-	SCREW, PHIL HD, SLTD, DRLD 4-40x .56 Lg MS 35275-18	—	2	2	59	56	
-	NUT, HEX, PLAIN, 4-40 CRES AN 340-C4	—	2	11	60	57	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
E1095752 30CM OPTICS ASSEMBLY 36

(Page 1 of 3)

DATE 2/11/91 | REV A | NEXT ASS'Y
BY REJ | SHEET 53 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T-	MATERIAL
E	30CM OPTICS ASSEMBLY 1095752	B	1	1	40	36		153	1008	———
D	RING, OPTICS MOUNTING 1027457	D	1	1	5	1			1080	———
C	RING, BLANK, OPT MTG. 1095093	B	1	1	(1)	(1)				15.3 O.D. X 12.0 I.D. X 1.5 Lg TITANIUM AMS 4900/4901
B	RIVET, ELECTRODE 1095751	B	48	48	10	2				PURCHASED PART - CUSTOM MADE - OF MOLY PER AMS 7800 .156 DIA X .156 LG
C	RING, SUPPORT, SCREEN ELECTRODE 1095747	A	1	1	2	3				———
C	RING, BLANK, ELECTRD. SUPPT. 1095772-98	A	1	1	(1)	(1)				13.685 O.D. X 11.81 I.D. X .100 THK MOLY PER AMS 7800 (PRESSED & SINTERED)
E	COVER, ALIGNMENT HOLES 1095752-99	B	8	8	16	4				.25 X .25 X .001 304 CRES QQ-S-766
D	ELECTRODE, SCREEN 1026137-91	J	1	1	1	5		092 146	1079 1074 1056 1055	12.625 DIA X .015 THK ARC CAST MOLY AMS 7801
B	SHIELD, INNER, INSUL. 1025318	B	12	38	8	6			1053 1097	2.5 DIA X .01 THK BLANK 302/304 CRES QQ-S-766
B	INSULATOR (CERAMIC) 1095778-98	A	12	24	6	7				PURCHASED PART ALUMINA-KOVAR (CERAMASEAL INC)

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
E1095752 30CM OPTICS ASSEMBLY [36]

(Page 2 of 3)

DATE 2/16/81 | REV A | NEXT ASS'Y

BY REJ | SHEET 54 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T-	MATERIAL
B	SHIELD, OUTER, INSUL, 1025317	B	12	38	7	8		098		2.0 DIA X .01 THK 302 CRES COND A QQ-S-766
B	SPACER 1025311	G	12	12	9	9				.375 O.D. X .204 I.D. X .553 Lg 302/304 CRES QQ-S-763 COND A
B	SHIM, MOUNTING 1095754	—	A/R	-	11	10				.438 O.D X .201 I.D X .002, .003, .005, .015, .015 & .040 302/4 CRES COND A QQ-S-766
C	RING, ACCEL STIFFNG 1026136	F	1	1	4	11				———
C	RING, BLANK, ACCEL STFNG. 1095772-99	A	1	1	(1)	(1)				14.825 O.D. X 11.80 I.D. X .075 THK MOLY PRESSED & SINTERED PER AMS 7800
D	ELECTRODE, ACCEL 1026138-91	H	1	1	3	12		092 146	1053 1079 1056 1055 1097	12.625 DIA X .015 THK ARC CAST MOLY AMS 7801
	SCREW, FLT HD, 100°, 10-32 CRES MS24693-C270	—	12	12	13	13				———
	SCREW, FLT HD, 100°, 4-40 CRES MS24693-C4	—	12	12	14	14				———

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
E1095752 30CM OPTICS ASSEMBLY [36] (Page 3 of 3)
C1095683 MANIFOLD ASSY, THRUSTER (Page 1 of 1) [45]

DATE 2/11/81 | REV A | NEXT ASS'Y
BY REJ | SHEET 55 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TCT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T-	MATERIAL	
	SCREW, CAP, HEX SOC, 10-32 CRES MS24673-5	—	12	12	15	15				———	
	NUT, SELF-LOCKING, 4-40 CRES NAS1291 C04	—	12	40	12	16				———	
	LOCKWIRE, .020-.025 Dia (302) QQ-W-423	—	A/R	-	17	17				———	
C	MANIFOLD ASSEMBLY, THRUSTER 1095683	—	1	1	[25]	[45]		074			
D	MANIFOLD, PROPELLANT 1095682	B	1	1	1	1				2.6 X .89 X .81 BAR 304L CRES COND A QQ-S-766	
B	FITTING, MANIFOLD 1095421	—	3	3	2	2				PURCHASED PART #R44672 REF. (RESISTOFLEX INC)	
C	PIN, .045 DIA, CRES 1095683-99	—	2	2	3	3				.125 Lg 304 CRES QQ-S-763	

8818 RL DEC 1973

PARTS LIST

TITLE 30CM J-SERIES ION THRUSTER E1026510
E1025316 REAR SHIELD ASSEMBLY 58 (Page 1 of 1)
D1026462 MASK ASSEMBLY 61 (Page 1 of 1)

DATE 2/16/71 | REV A | NEXT ASS'Y
BY REJ | SHEET 56 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
E	REAR SHIELD ASSEMBLY 1025316	T	1	1	7	58		070		
E	REAR SHIELD 1025316-99	T	1	1	1	1				18.0 DIA OR SQR X .025 THK 6061 -T4 QQ-A-250/11 (BLANK) ALUM
E	DISK 1025316-97	T	8	8	2	2				1.0 DIA X .025 THK 6061-T4 ALUM, QQ-A-250/11
-	NUTPLATE, SLF-LOCKING, FLTG, 6-32 MS21076-L06	—	12	14	3	3				—
-	RIVET, CSK HD, .094, ALUM MS20426 AD3-3	—	38	102	4	4				—
-	NUTPLATE, SELF-LKG, FXD, 6-32 MS21070-06	—	7	39	5	5				—
D	MASK ASSEMBLY 1026462	C	1	1	16	61		69		
D	MASK 1026462-99	C	1	1	1	1				18.5 O.D. X 11.0 I.D. X .016 THK (BLANK) TITANIUM AMS 4900/01
-	NUT PLT, SELF-LOCKING, FLTG, 6-32 MS21060-06	—	12	12	2	2				—
-	NUT PLT, SLF-LOCKING, FXD, 6-32 MS21070-06	—	2	39	3	3				—
-	RIVET, CSK HD, .094 ALUM MS20426 AD3-3	—	28	102	4	4				—

8818 RL DEC 1973

PARTS LIST

TITLE: 30CM J-SERIES ION THRUSTER E1026510
C1095686 PLT. ASSY HDR MAN. 3-INLET 66
C1095687 PLT. ASSY HDR MAN. 1-INLET 69 (Page 1 of 1)

DATE: 2/16/81 | REV: A | NEXT ASS'Y: | BY: REJ | SHEET 57 OF 57 SHEETS

SIZE	NOMENCLATURE / DRAWING NUMBER	CHG LTR	QTY/ASSY	QT/TOT	FIND #	ASSY #	PAGE #	IPD PR —	TOOL T—	MATERIAL
C	PLATE ASSY, HDR MANIFOLD, 3-INLET 1095686 (OPTIONAL)	A	1	1	34	66		074		—
C	TUBING, .06 x .01, CRES 1095686-1	A	1	1	3	1				18.0 Lg 321 CRES SEAMLESS TUBING .010 WALL MIL-T-8808 TYPE I
B	TRANSITION, TUBING 1095461	C	1	7	2	2				.168 DIA x .35 Lg 304 CRES ROD COND A QQ-S-763
B	PLATE, HEADER MANIFOLD 1095685	C	1	1	1	3				1.93 x .812 x .175 THK 304L CRES PLT. COND A QQ-S-766
C	PLATE ASSY, HDR MANIFOLD 1-INLET 1095687	A	1	1	26	69		074		
C	TUBING, .06 x .01, CRES 1095687-1	A	1	1	3	1				LENGTH TO BE DET .010 WALL SEAMLESS 321 CRES MIL-T-8808 TYPE I
B	TRANSITION, TUBING 1095461	C	1	7	2	2				.168 DIA X .35 Lg 304 CRES ROD COND A, QQ-S-763
B	PLATE, HEADER MANIFOLD 1095706	C	1	1	1	3				1.93 x .812 x .175 THK 304L CRES PLATE COND A QQ-S-766

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