AD NUMBER

AD854589

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; May 1969. Other requests shall be referred to Air Force Aero Propulsion Lab., Wright-Patterson AFB, OH.

AUTHORITY

AFAPL ltr, 12 Apr 1972

AFAPL-TR-69-8

LIFE TESTING OF A COLLOID THRUSTOR SOURCE

W. C. BURSON

TECHNICAL REPORT AFAPL-TR-69-8

MAY 1969

AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio.

Distribution of this report is restricted to protect technical know-how pertaining to military weapon systems.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

100 - June 1969 - CO455 - 80-1774

AFAPL-TR-69-8

LIFE TESTING OF A COLLOID THRUSTOR SOURCE

W. C. BURSON

FOREWORD

This work was performed as an in-house effort by the author for the Aerospace Power Division, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio. The work was accomplished under Task No. 314102, Project No. 3141, "Electric Propulsion Technology."

This effort was conducted between November 1967-October 1968. The report was submitted by the author in January 1969.

The author wishes to express his appreciation to Mr. E. Francescone, technician, from the Air Force Aero Propulsion Laboratory, for his assistance.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Philip E Stover

PHILIP E. STOVER
Chief, Propulsion and Power Branch
Aerospace Power Division

ABSTRACT

Thrustors capable of high exhaust velocity (specific impulse) and efficiency are desirable for space propulsion. During the past few years, research to achieve these goals has been in progress on the formation and acceleration of charged liquid droplets. To date this research has led to the development of charged particle sources in the 10 to 500 μ lb thrust range, with specific impulse values on the order of 600 to 1[illegible]00 seconds, which appears to offer greater promise in space applications.

Since mission lifetimes of 30,000 hours and higher are anticipated, it is desirable to obtain some indication of the lifetime that can be expected from the metal capillary needles which generate the charged liquid droplets. Life tests totalling 3687 hours were performed on a three-needle colloid source. After these tests, the platinum capillary needles appeared to be in excellent condition, which indicates that needle life should satisfy mission requirements.

(This abstract is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with the prior approval of the Air Force Aero Propulsion Laboratory, APIE-1, Wright-Patterson Air Force Base, Ohio.)

TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (CONTD)

SECTION I
INTRODUCTION

By establishing an intense electric field on the surface of a conducting fluid at the tip of a metallic capillary tube, the electrical forces on the charge carriers overcome the surface tension forces and cause the liquid surface to rupture, which results in the formation of small charged droplets (colloids). The droplets, depending upon their charge and mass, can acquire an appreciable velocity as they pass from the region of high electric field intensity. The spraying process can be controlled by varying the capillary potential and propellant feed pressure. The schematic of a laboratory colloid source is shown in Figure 1.

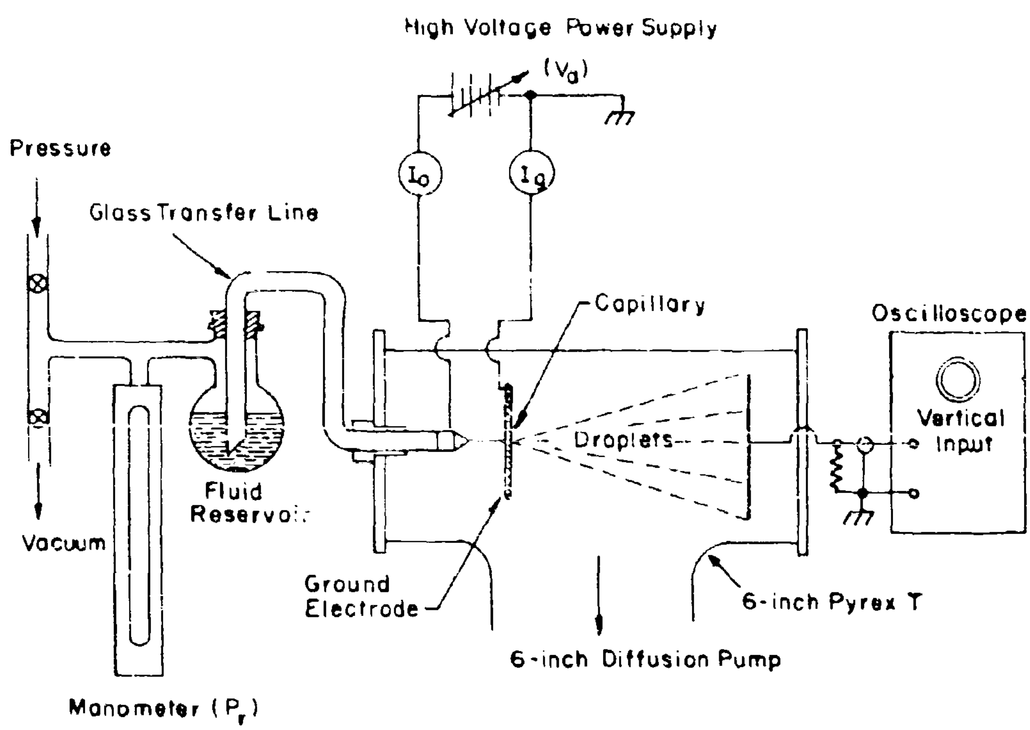


Figure 1. Electrohydrodynamic Spraying Apparatus

A three-needle colloid flight-qualified thrustor system being developed under AF Contract 33(615)-1141 by Thompson Ramo Wooldrige Systems Inc., is shown in Figure 2. This system is designed to the following parameters:

a. 4 micropounds thrust at 600 seconds specific impulse and 8 micropounds thrust at 900 seconds specific impulse.

b. Maximum power requirements of 5 watts.

c. System weight (dry) of 9 pounds.

d. Neutralization accomplished with a hot wire.

e. Maximum needle voltage of 8 KV.

f. Thrust levels sufficient to provide attitude control and East- [illegible] station keeping for a satellite in a synchronous or[illegible]

A three-needle colloid source developed under this contract was delivered to AFAPL in August 1967 for life testing; this source is shown in Figure 3. These life tests were conducted to indicate whether or not the capillary needle life is critical to the system operation. This report presents the results of these life tests.

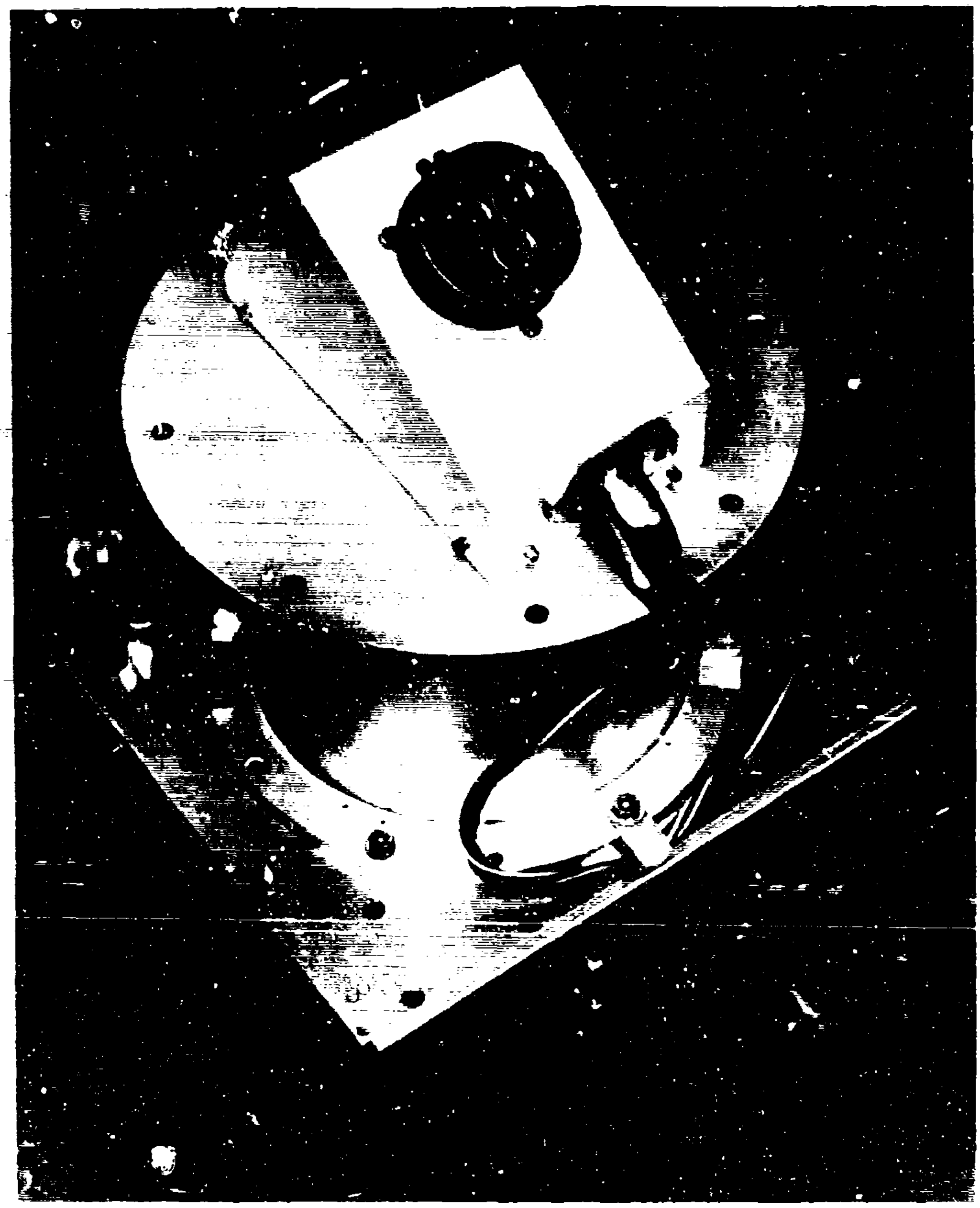


Figure 2. Colloid Microthrustor Experimental System

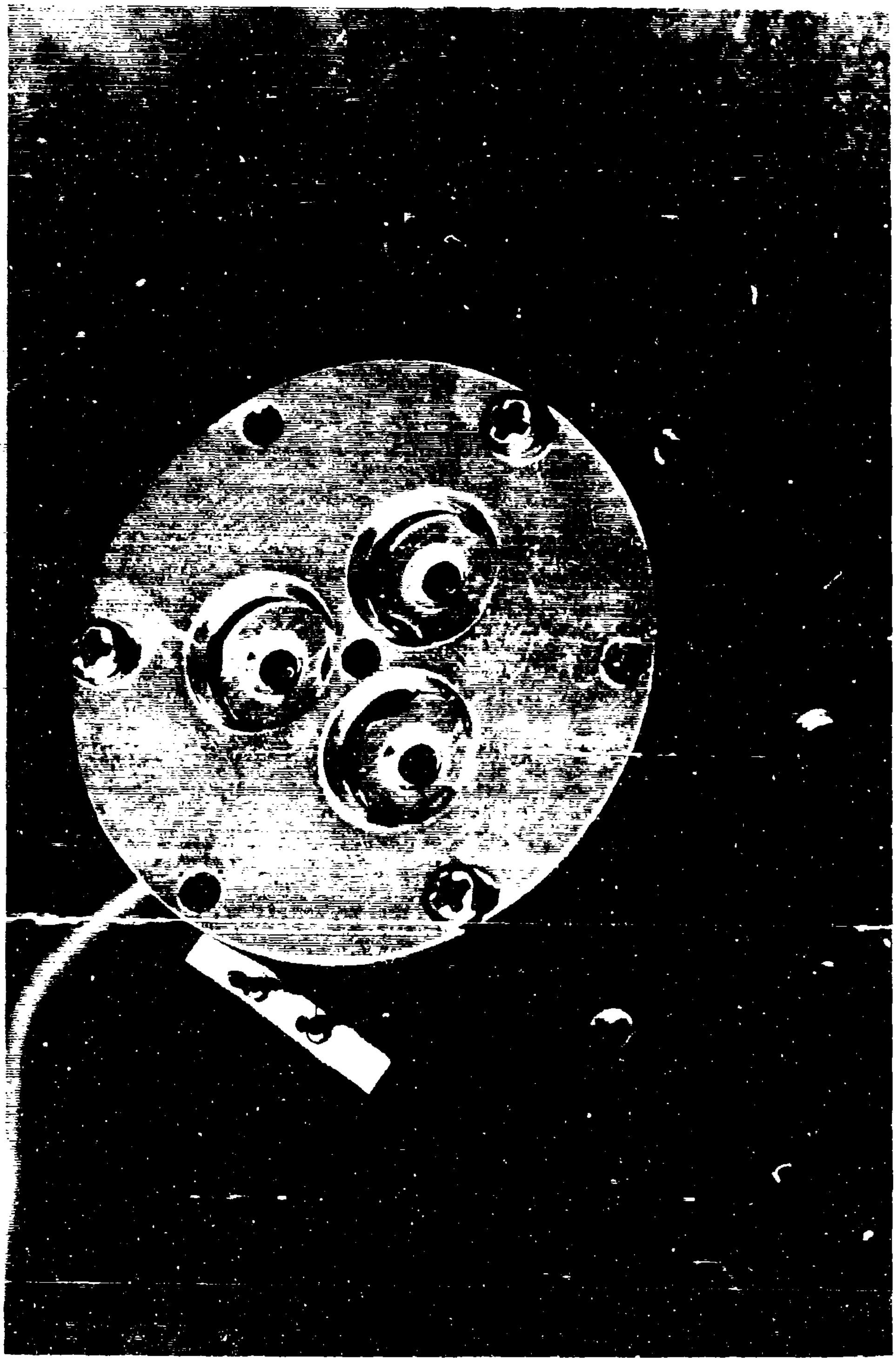


Figure 3. Three-Needle Colloid Source

SECTION II
TEST SETUP

The three-needle colloid source was installed in a bell jar vacuum facility for the life tests, as shown in Figure 4. Pumping was provided by two 6-inch diffusion pumps with cold traps and the necessary forepumps. Chamber pressure was held on the 10^{-6} mm Hg scale during source operation. Two 50-gallon liquid nitrogen dewars were used to operate the cold traps; they were filled approximately every 2-1/2 days. Positive needle voltage was supplied by a 60 KV laboratory voltage source; the extractor was held at -200 volts bias with a 500 volt power supply.

If the pressure increased to 10^{-4} mm Hg during operation, due to a leak or pumping failure, the pump gate valves would close and the voltage supplies would shut down so as to prevent arcing damage to the colloid source. No back-up capability was available in case of a power failure.

The colloid source was mounted 15 inches above a time-of-flight (TOF) collector, with the beam directed downward, as shown in Figure 5. The propellant reservoir was made of copper and mounted outside the vacuum chamber, with a copper feed line to the source. Gas pressure was used to force the propellant (15 gm of sodium iodide in 100 ml glycerol) to the source. The TOF collector was used for determining the propulsion parameters. After a few days operation, however, the beam spread was so wide that most of the beam current was missing the collector and TOF information could not be obtained.

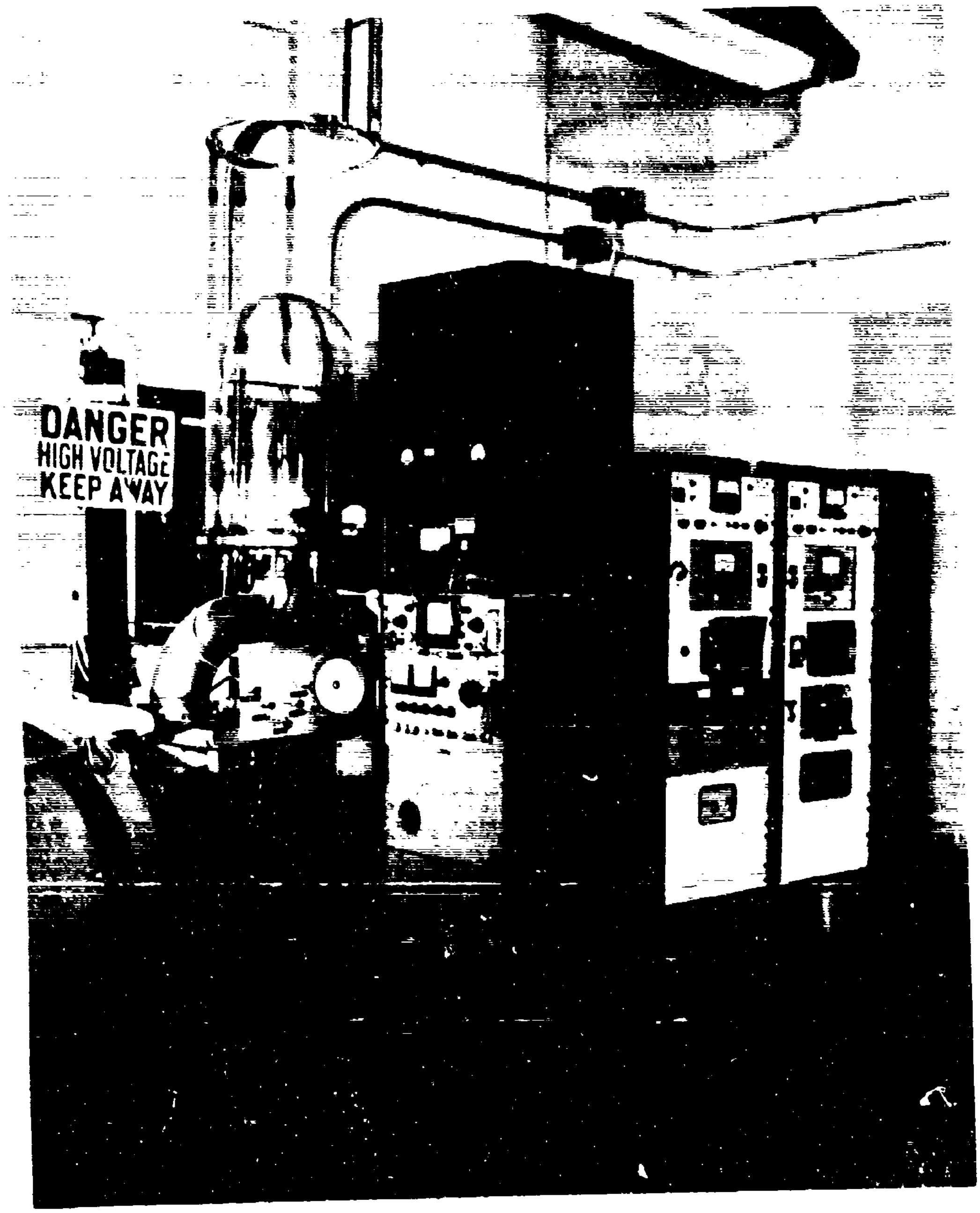


Figure 4. Test Setup

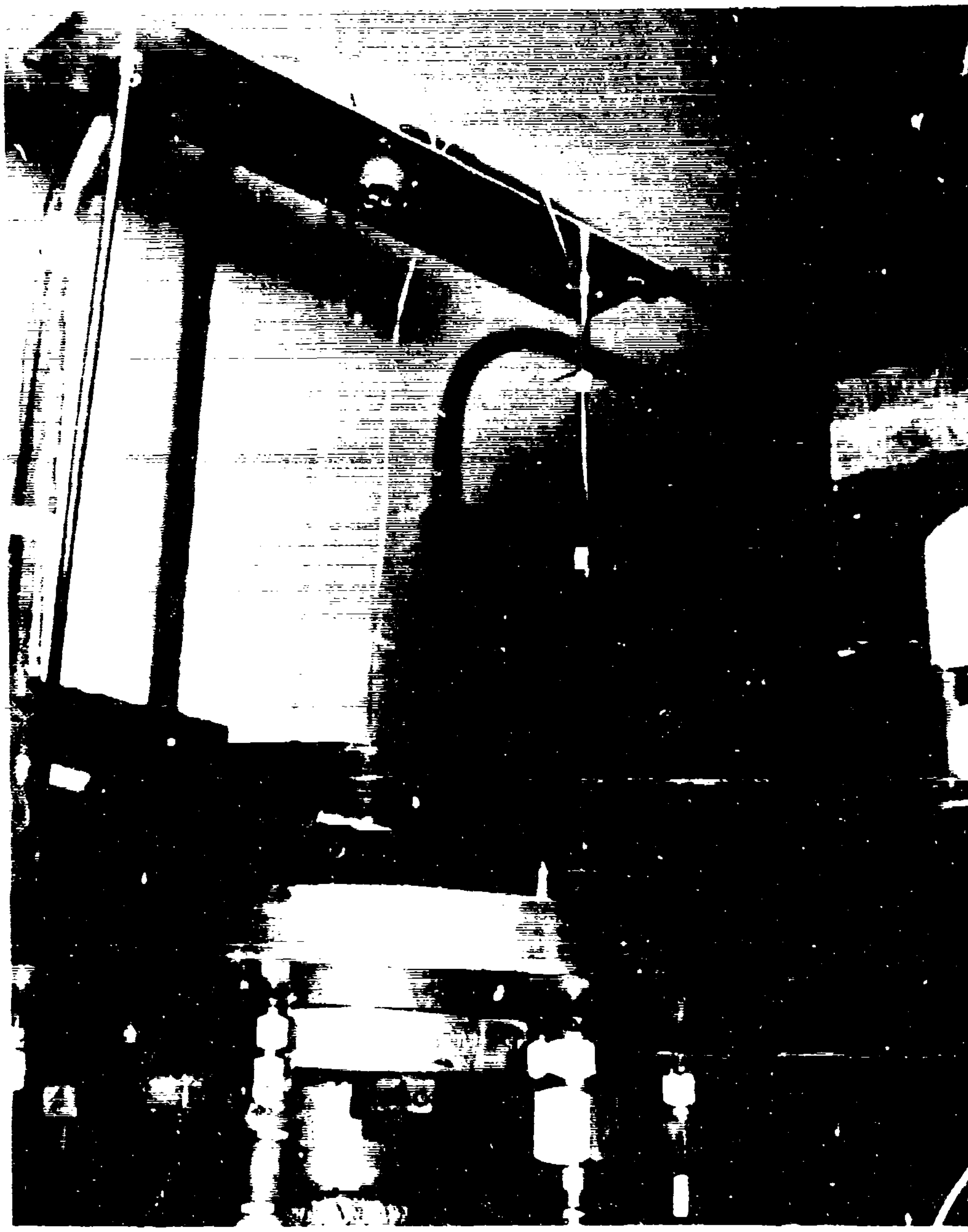


Figure 5. Source Mount

SECTION III

TEST RESULTS

The first life test lasted for 1293 hours. It was terminated when a power failure permitted the propellant to form a droplet between the capillary needle and the extractor and cause a short circuit. The excess propellant could not be burned off by applying voltage, so the vacuum chamber had to be opened and the source examined. The needles themselves looked very good and clean, but the extractor appeared to have deposits from back-sputtering and areas with evidence of beam interception, as shown in Figures 6, 7, 8, and 9. These needles are platinum with a 6 mil ID and a 10 mil OD. The extractor and ground plane are made of stainless steel.

From these tests, recorded values for needle current, needle voltage, feed pressure, and temperature vs. time are plotted in Figures 10, 11, 12, and 13. The current varied widely; part of this variation is due to temperature variations, since the propellant viscosity is sensitive to changes in temperature. Other factors contributing to the current variation are probably back sputtering of neutrals and the formation of secondary electrons from the extractor due to beam impingement.

Extractor current was not monitored on this test. A wire screen was wrapped around the propellant feed line inside the vacuum chamber and held at the same negative bias as the extractor to prevent electron current from reaching the feed line. Thus, any beam impingement on the screen would have shown as part of the extractor current, but it should have been no more than a small percentage. The extractor current, however, was monitored on the second life test.

It was thought that the excessive beam spread might be due partly to the propellant feed pressure being too high. On the second life test, using the same source, the feed pressure was lowered and the extractor current was monitored. This test lasted 2393.3 hours and was stopped when all the beam current was reaching the extractor.

Figure 6. Source After 1293 Hours of Testing

Figure 7. Tip of Needle 1 After 1293 Hours

Figure 8. Tip of Needle 2 After 1293 Hours

Figure 9. Tip of Needle 3 After 1293 Hours

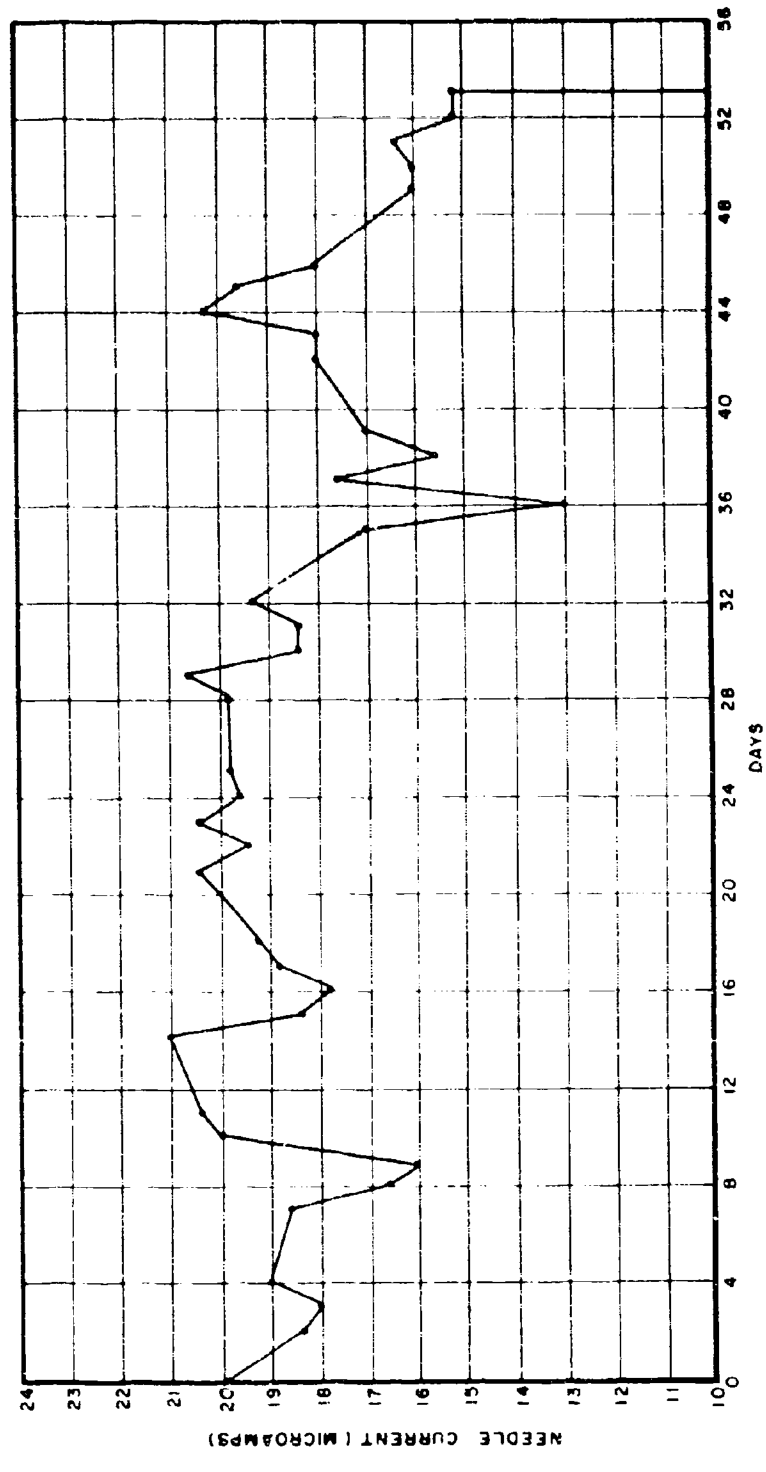


Figure 10. Needle Current Versus Time, 1293-Hour Test

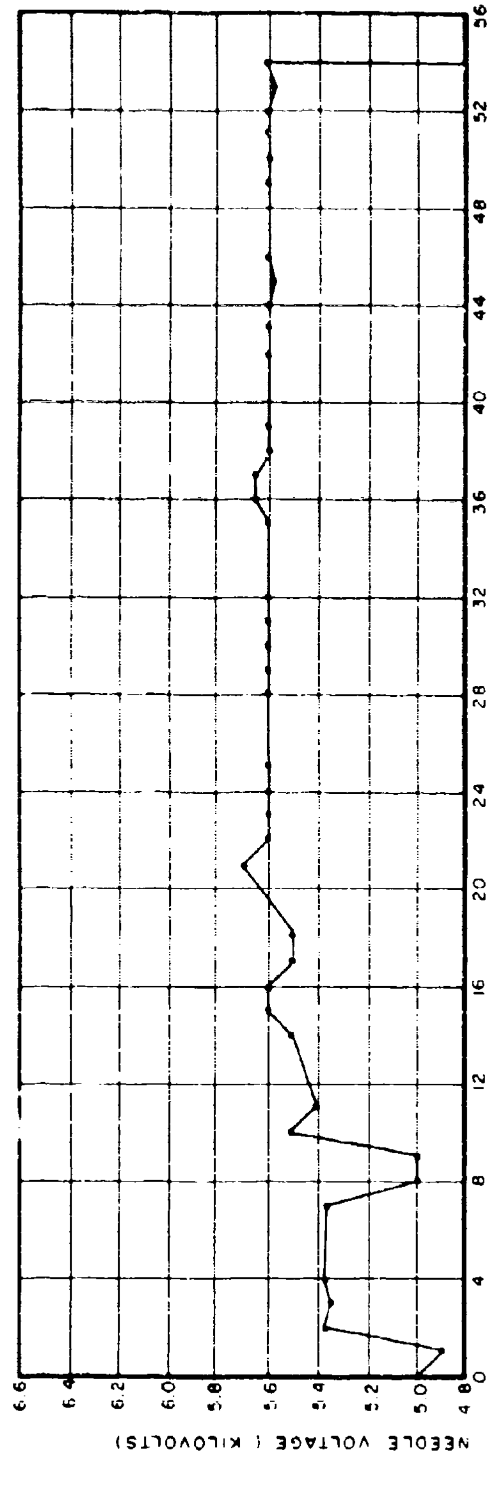


Figure 11. Needle Voltage Versus Time, 1293-Hour Test

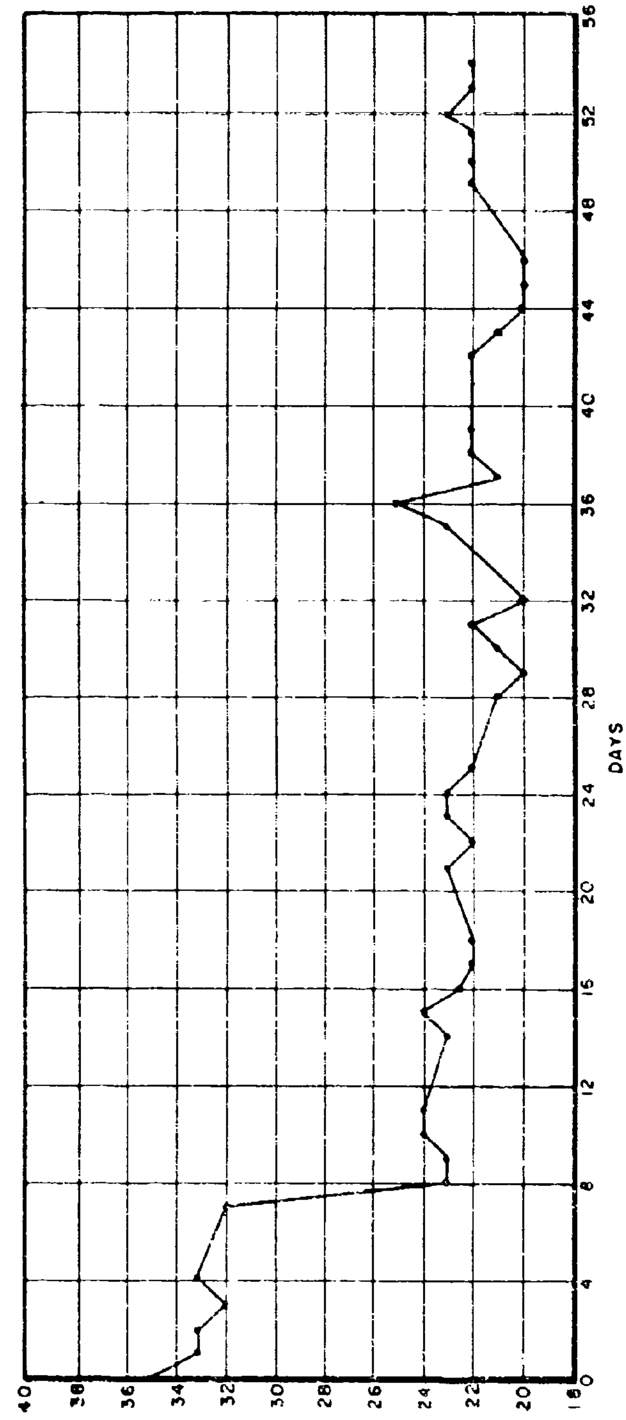


Figure 12. Propellant Feed Pressure Versus Time, 1293-Hour Test

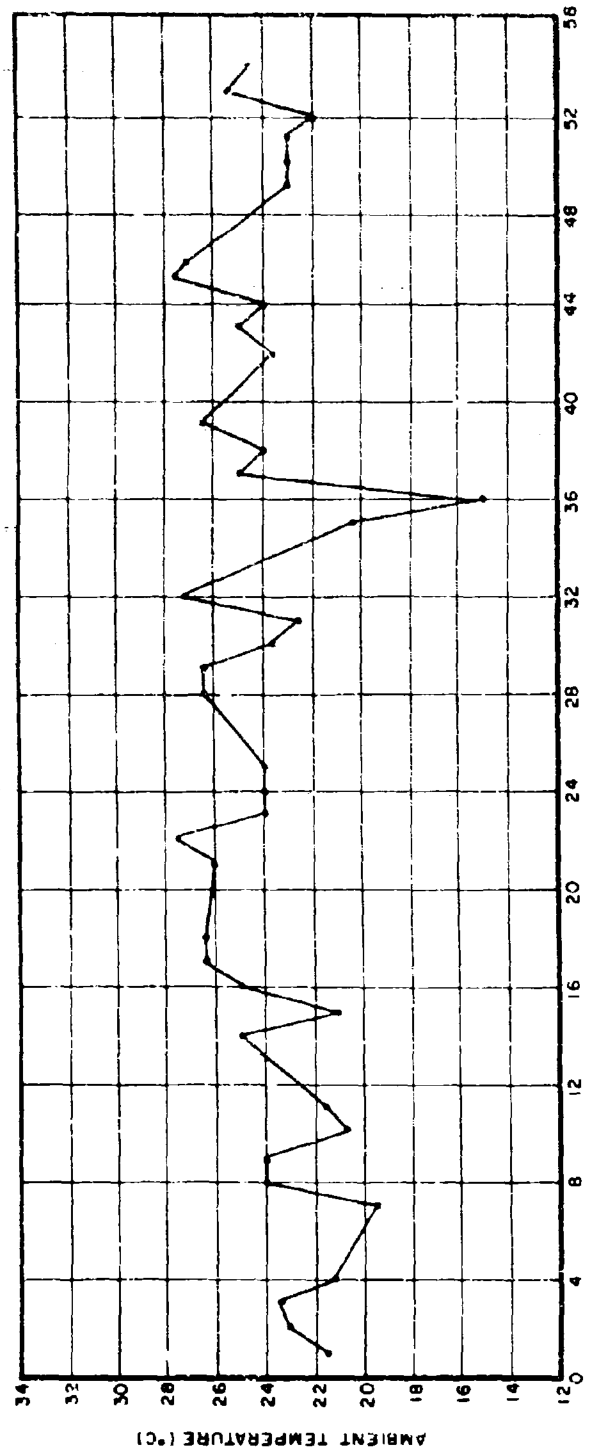


Figure 13. Ambient Temperature Versus Time, 1293-Hour Test

Two power failures occurred during this 2400-hour run, but the source was restarted after both of these failures. Operation was more erratic after these failures, however, probably because the propellant had worked its way around the tip of the needle while the power was off. A glycerol film formed on the needles, which when bombarded by electrons from the extractor or other source, turned into a tar-like deposit. As the tar deposit increased, the current decreased and the spread in the beam became excessive. Thus, the test had to be terminated. After the test, the needles were examined. One needle, the one with the highest flow impedance of the three, had no tar deposit. The higher flow impedance of this needle prevented the glycerol from working its way around the needle tip as easily as in the other two; thus, no tar was built up. The beam spread may have been enhanced also by neutral particles in the chamber being deposited on the needle tips and wetting them, thus enabling the glycerol to work itself further around the tip of the needles.

Beam current, needle voltage, temperature, extractor current, and feed pressure vs. time are plotted in Figures 14, 15, 16, 17, and 18. Source operation was obviously degraded after the power failures. A TOF trace shown in Figure 19 was taken at the start of the test and the following parameters were obtained:

Thrust — 17 micropounds; efficiency — 75%; and specific impulse — 200 seconds.

Figures 4, 5, 20, 21, and 22 show the spray pattern of the beam, which indicates a hollow conical beam. The clean areas are where the beam was impinging. The needles with and without tar deposits are shown in Figures 23, 24, and 25. Figure 26 shows the same needles after cleaning. The capillary needle tips appeared to be in good condition after the test. The color of the deposits on the source and vacuum chamber was a gold-brown, which indicates that iodine probably came out of solution when the beam hit a surface.

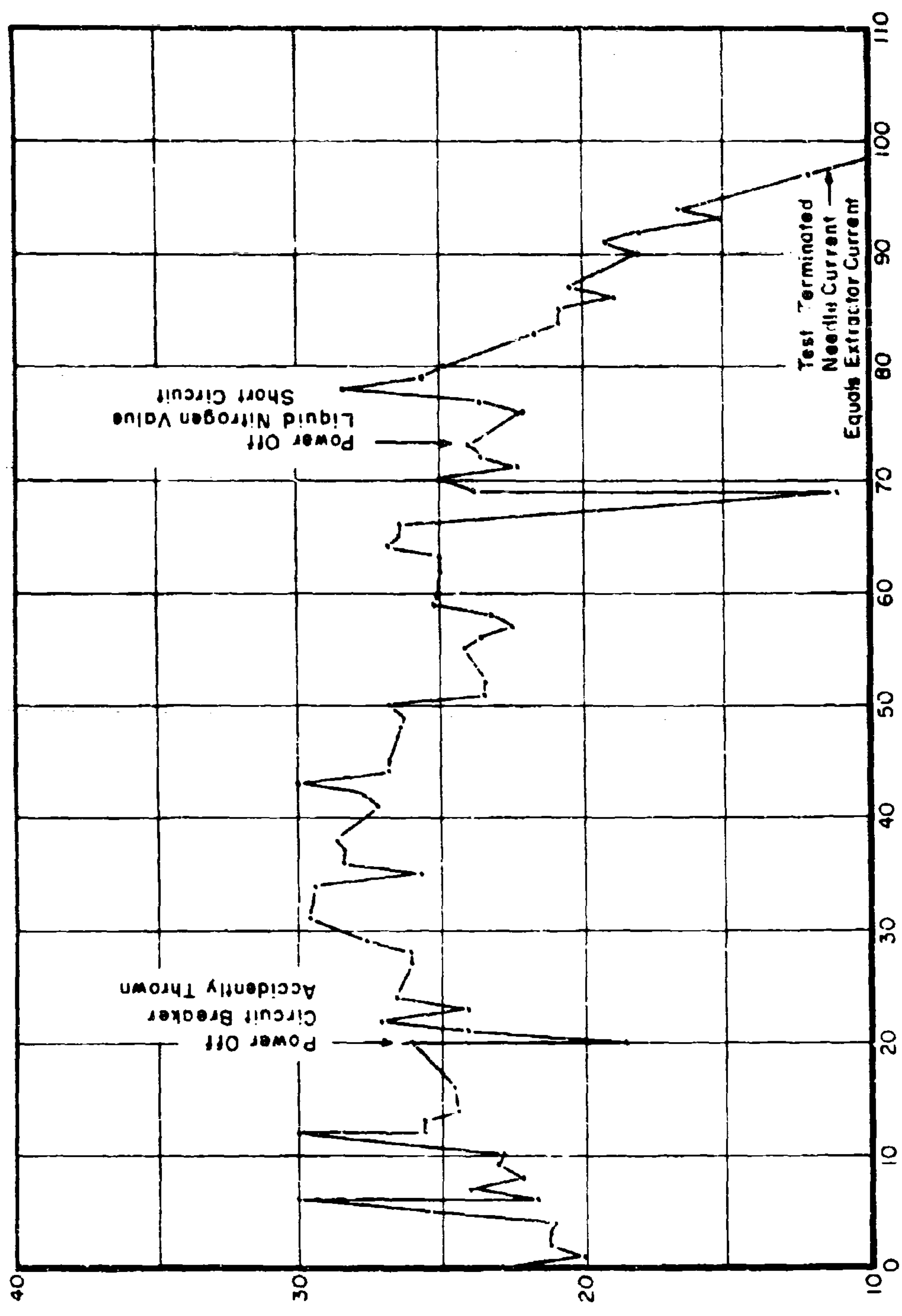


Figure 14. Needle Current Versus Time, 2409-Hour Test

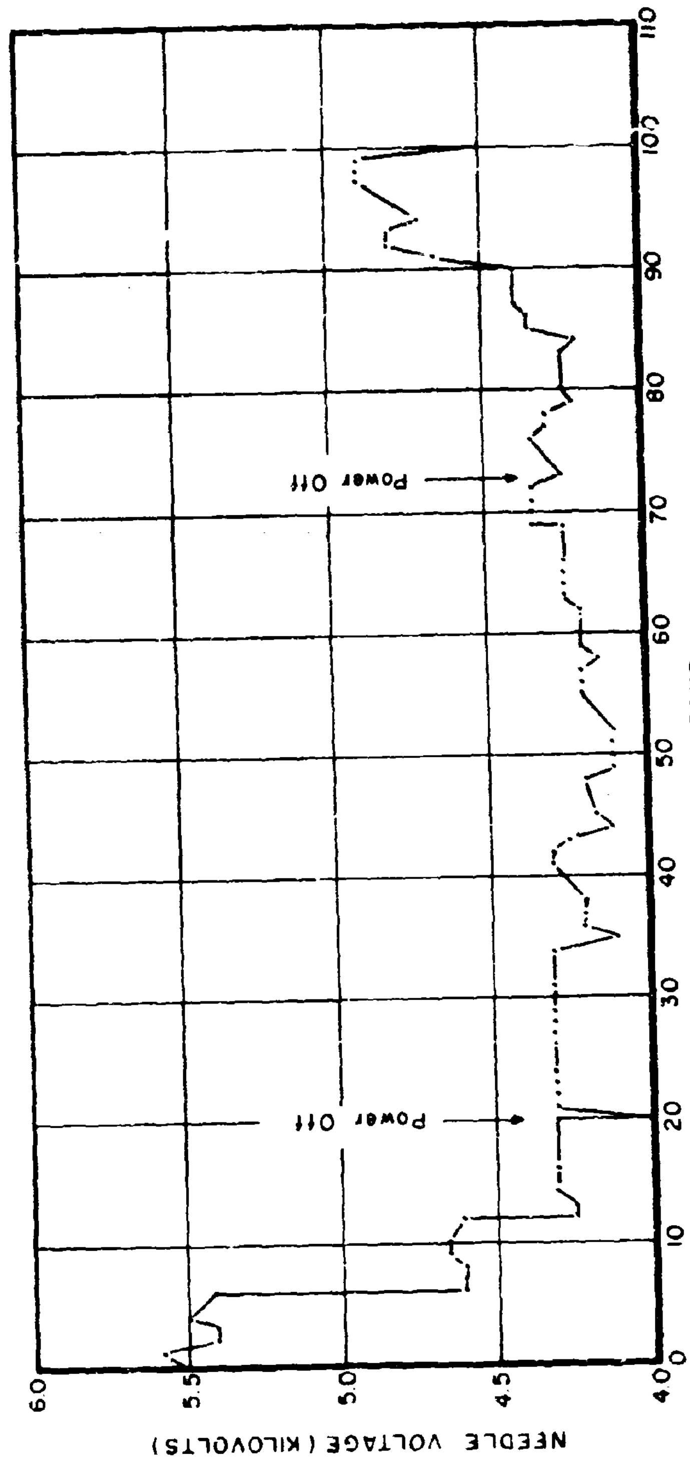


Figure 15. Needle Voltage Ver us Time, 2400-Hour Test

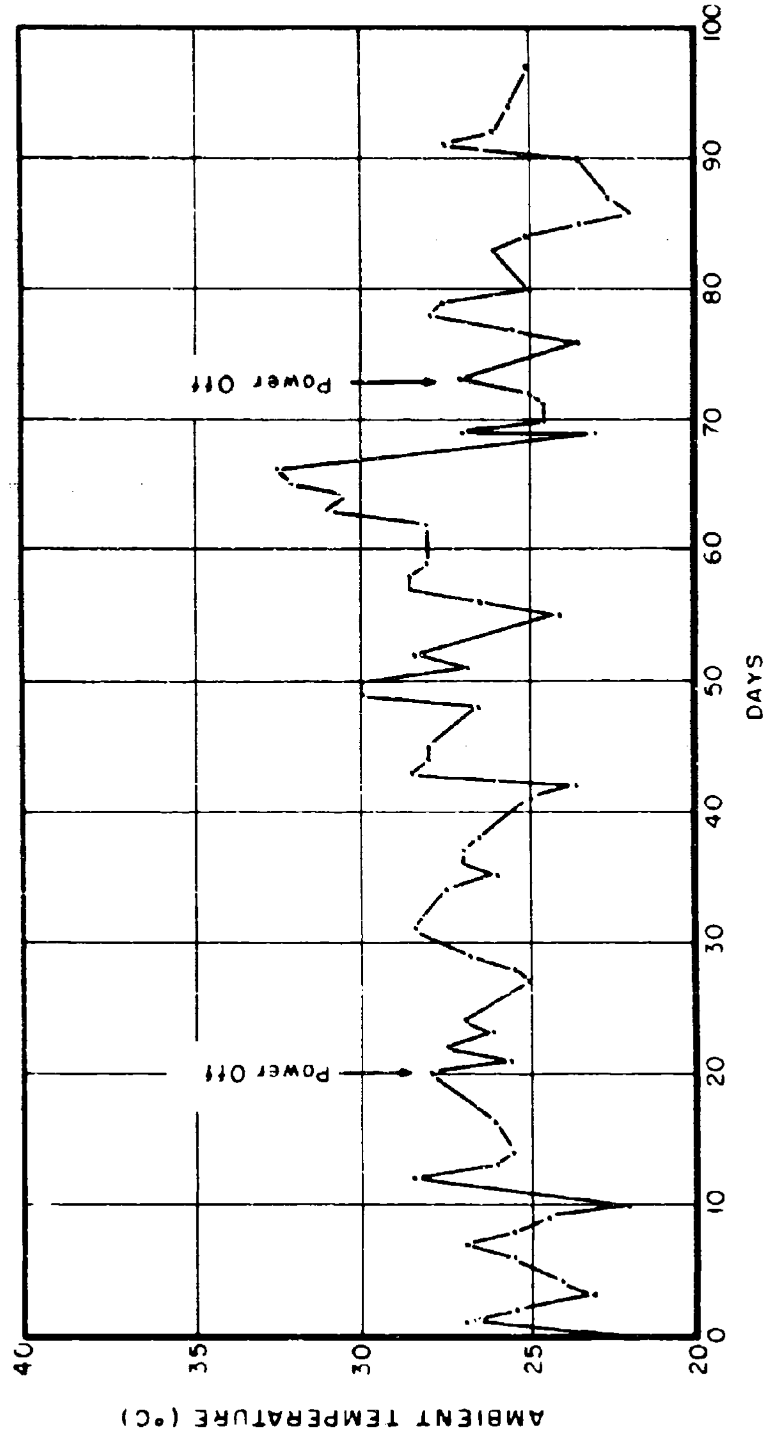


Figure 16. Ambient Temperature Versus Time, 2400-Hour Test

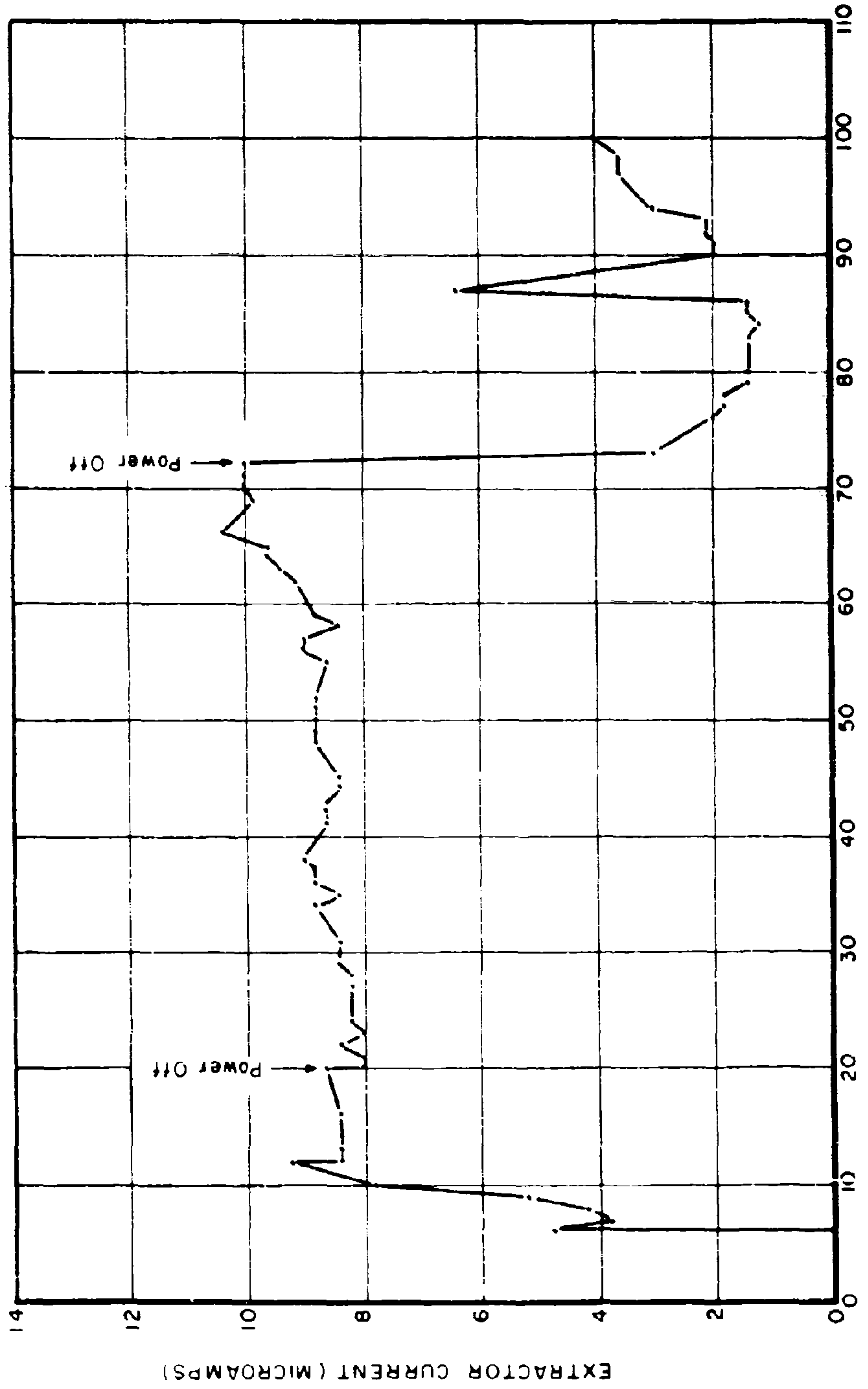


Figure 17. Extractor Current Versus Time, 2400-Hour Test

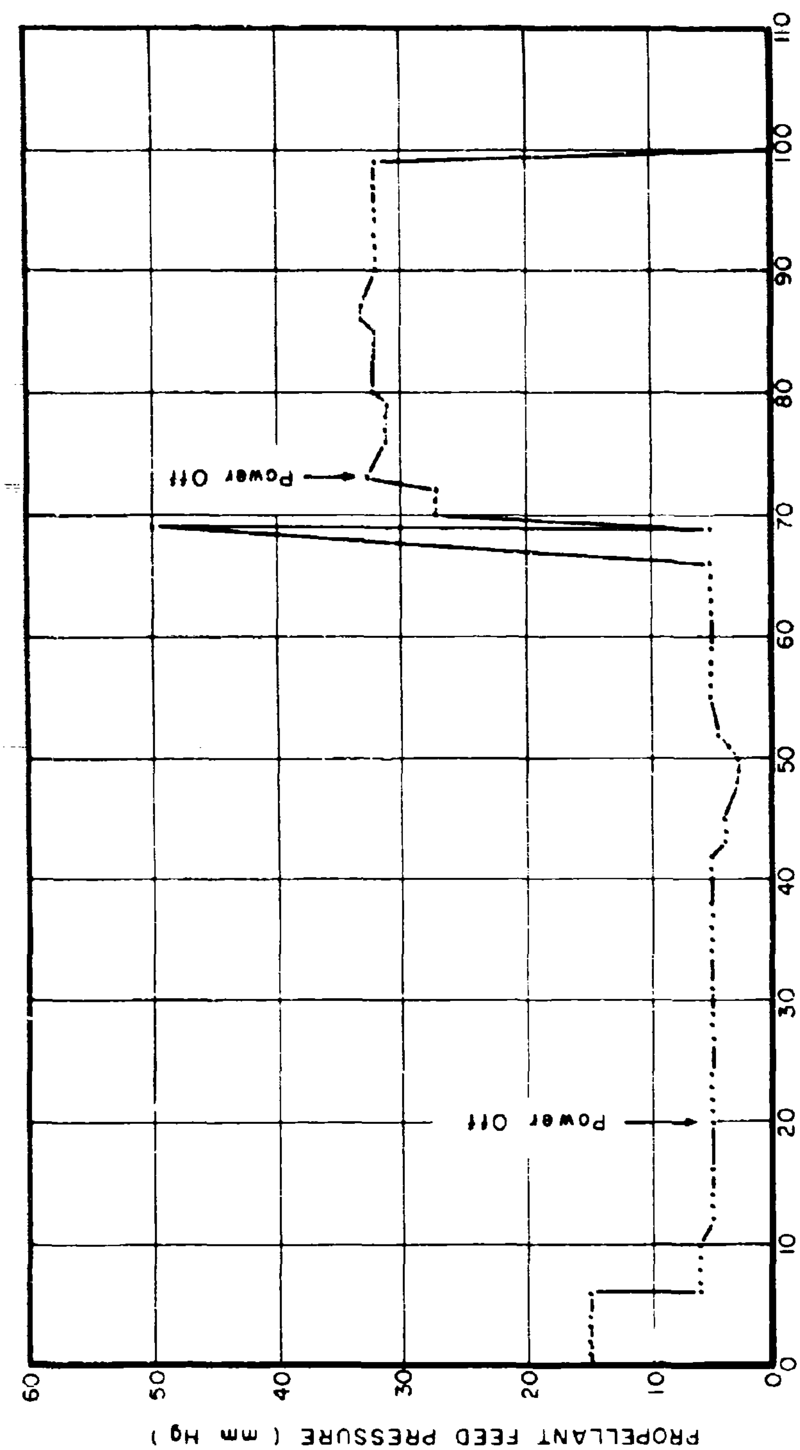
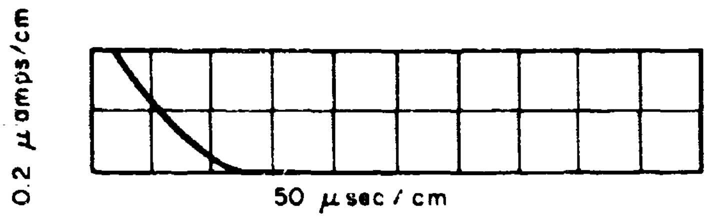


Figure 18. Propellant Feed Pressure Versus Time, 2400-Hour Test



Needle Voltage — 5.5 KV

Extractor Voltage — 200 Volts

Needle Current — 4 Microamps

Extractor Current — 0

Feed Pressure — 30 mm Hg

Figure 19. Time of Flight Trace at Start of 2400-Hour Test

Figure 20. Beam Spray Pattern

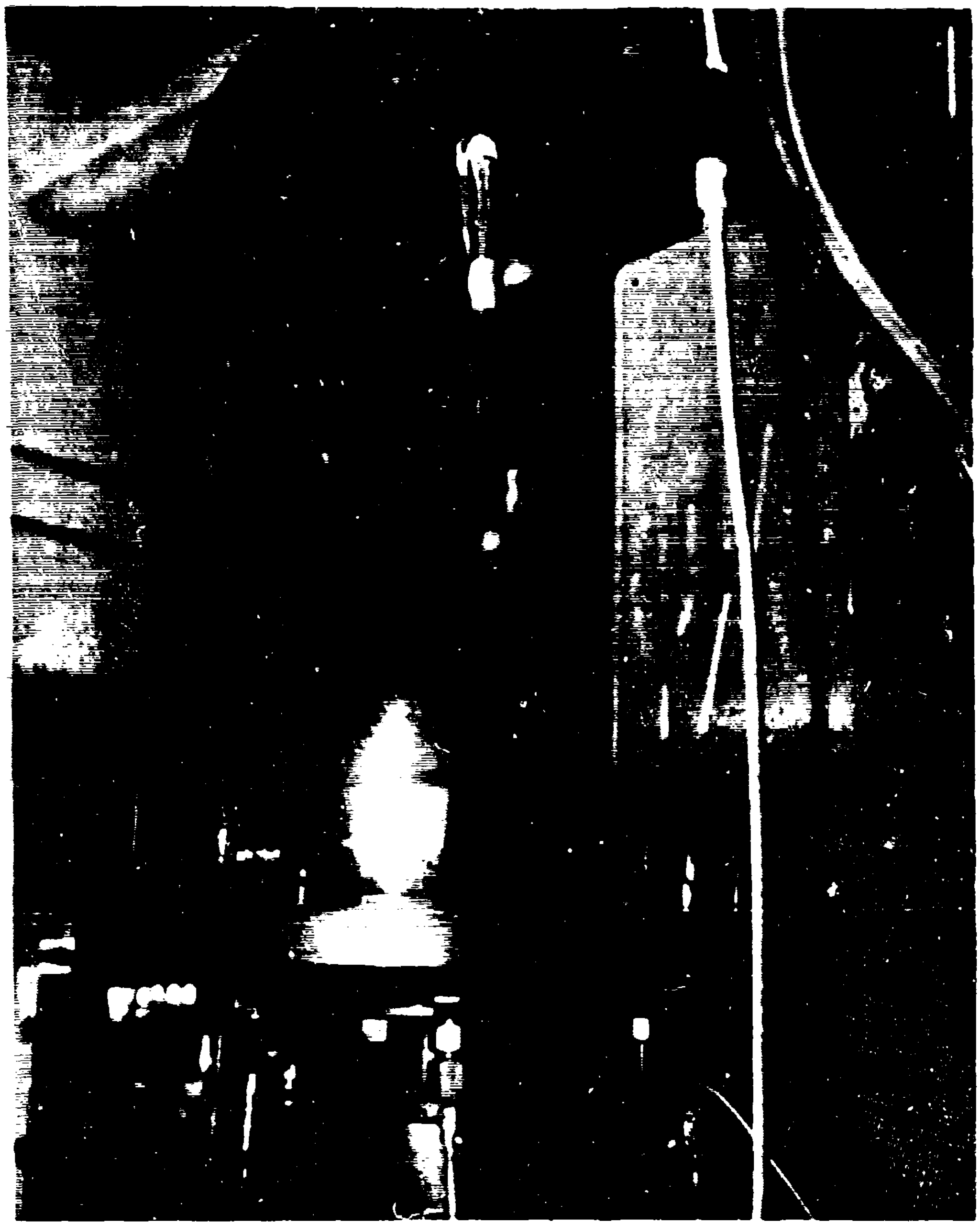


Figure 21. Beam Spray Pattern, Opposite Side From Figure 20

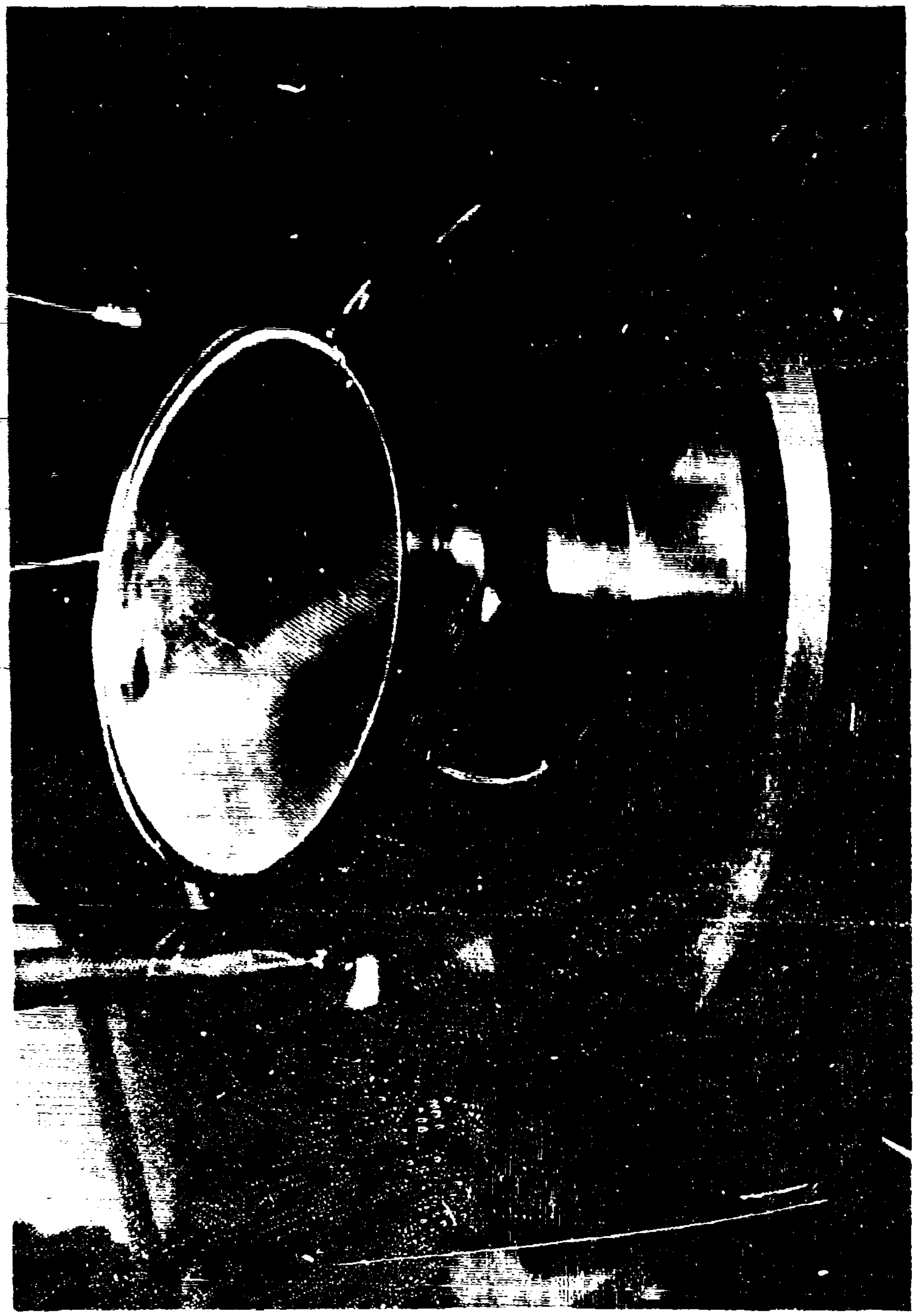


Figure 22. Beam Spray Pattern on Base Plate of Vacuum Chamber

Figure 23. Tar Deposit on Tip of Needle 1

Figure 24. Tar Deposit on Tip of Needle 2

Figure 25. Tip of Needle 3
(No tar deposit)

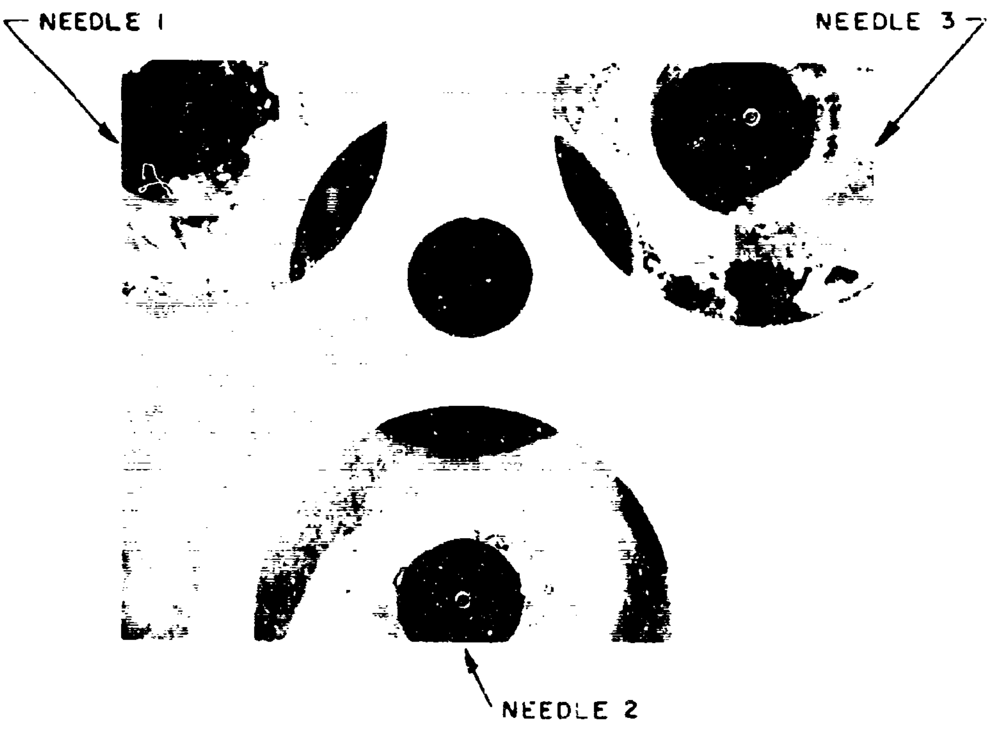


Figure 26. Needle Tips After Cleaning

SECTION IV
CONCLUSIONS

The long lifetime necessary for space propulsion devices to provide satellite attitude control and station-keeping prompted an investigation to determine the lifetime of the metal capillary needles used in colloid thrustors. A three-needle capillary source was subjected to two life tests totalling 3687. 3 hours. After these tests, the capillary needle tips were in excellent condition, which indicates the needles will meet mission life requirements.

In these tests, failure occurred when the beam spread until most of the beam current hit the extractor plate. This beam spreading was due to the propellant working itself around the tip of the needle and spraying sideways. This phenomenon could be caused by excessive feed pressure, power failure, neutral deposition on the needle tip by back sputtering, or a combination of these factors. Once the beam hit the extractor, secondary electrons bombarded the needle tip and turned the glycerol into a tar-like substance; this tarry substance further aggravated the beam spread.

It appears from these tests that the lifetime of a colloid source will be substantial if glycerol is prevented from working itself around the needle tip, the needles are shielded from electrons, and neutrals in the vacuum chamber are prevented from depositing themselves on the needle tips. These findings can be confirmed by flight test or possibly by testing in a large vacuum facility where neutral deposition can be made negligible.

BIBLIOGRAPHY

1. Carson, R. S. Electrical Spraying of Macroscopic Liquid Particles Under Pulsed Conditions, Report No. CPRL-1-64. Engineering Experiment Station, University of Illinois. 1964.

2. Cohen, E. Research on Charged Colloid Generation. APL TDR 64-75. June 1964.

3. Cohen, E. Research on the Electrostatic Generation and Acceleration of Submicron-Size Particles. ARL-63-88, OAR. 1963.

4. Cohen, E., Somol, C. J., and Gordon, D. A. A 100 Kv, 10-Watt Heavy Particle Thrustor. AIAA Paper No. 65-377. 1965.

5. Gignoux, D., et al. Further Development of a Charged Liquid Colloid Source for Electrostatic Propulsion. NASA CR 54642. 1965.

6. Hendricks, C. D. and Pfeifer, R. J. Parametric Studies of Electrohydrodynamic Spraying. AIAA Paper No. 66-252. 1966.

7. Hogan, J. J. Parameters Influencing the Charge-to-Mass Ratio of Electrically Sprayed Liquid Particles. Report No. CPRL-2-63. Engineering Experiment Station, University of Illinois. 1963.

8. Hogan, J. J., Carson, R. S., and Schneider, J. M. Factors Influencing Electrically Sprayed Liquids. AIAA Paper 64-12, pp 3. 1964.

9. Hunter, R. E. [illegible] the Feasibility of the Electrodeless Colloid Thrustor, (Appen[illegible]). PhD Dissertation, the Ohio State University. 1965.

10. Hunter, R. E. and Wineland, S. H. "Charged Colloid Generation Research." Space Electronics Symposium, Vol. 6, AAS Science and Technology Series, Eric Burgess, Ed. 1965.

11. Hunter, R. E. and Wineland, S. H. "Exploration of the Feasibility of an Electrodeless Colloid Thrustor Concept." Sixth International Symposium on Space Science and Technology. Tokyo, Japan. 1965.

12. Pfeifer, R. J. Parametric Studies of Electrohydrodynamic Spraying. Report No. CPRL-4-65. Engineering Experiment Station, University of Illinois. 1965.

13. Stark, S. W., and Allan, S., Research and Development in Needle and Slit Colloid Thrustors, GSFC X-734-68-460. November 1968.

14. Wineland, S. H. and Burson, W. C. "Electrodeless Heavy Particle Thrustor." RTD Brief. December 1966.

BIBLIOGRAPHY (CONTD)

15. Wineland, S. H., Burson, W. C., and Hunter, R. E. The Electrohydrodynamic Generation of Charged Droplet Beams, AFAPL-TR-66-72. Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio. August 1966.

16. Wineland, S. H. and Hunter, R. E. Negatively Charged Colloid Generation Research. AIAA Paper No. 66-251. 1966.

17. Burson, W.C., Jr., Research on Electrohydrodynamic Charged Droplet Beams, AFAPL-TR-67-109, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, October 1967.

18. Huberman, M.N., P.W. Kidd, Charged Particle Electrostatic Thrusters, AFAPL-TR-69-14, TRW Systems, Redondo Beach, California, March 1969.

19. Perel, J., A.Y. Yahiku, and J. F. Mahoney, Research on Charged Particle Electrostatic Thrusters, AFAPL-TR-69-25, Electro-Optical Systems, Pasadena, California, April 1969.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Aero Propulsion Laboratory Wright-Patterson Air Force Base, Ohio	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

LIFE TESTING OF A COLLOID THRUSTOR SOURCE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

W. C. Burson

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1969	39	

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 3141 c. Task No. 314102 d.	9a. ORIGINATOR'S REPORT NUMBER(S) AFAPL-TR-69-8 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Aero Propulsion Laboratory Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

Thrustors capable of high exhaust velocity (specific impulse) and efficiency are desirable for space propulsion. During the past few years, research to achieve these goals has been in progress on the formation and acceleration of charged liquid droplets. To date this research has led to the development of charged particle sources in the 10 to 500 μ lb thrust range, with specific impulse values on the order of 600 to 1500 seconds, which appears to offer greater promise in space applications.

Since mission lifetimes of 30,000 hours and higher are anticipated, it is desirable to obtain some indication of the lifetime that can be expected from the metal capillary needles which generate the charged liquid droplets. Life tests totalling 3687 hours were performed on a three-needle colloid source. After these tests, the platinum capillary needles appeared to be in excellent condition, which indicates that needle life should satisfy mission requirements.

(This abstract is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with the prior approval of the Air Force Aero Propulsion Laboratory, APIE-1, Wright-Patterson Air Force Base, Ohio.)

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electrostatic Propulsion						
Colloids						
Electrohydrodynamic Spraying						