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8,000-HOUR LIFE TEST OF AN ELECTRON BOMBARDMENT MERCURY ION THRUSTER SYSTEM FOR SERT II

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - EAST

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract No. NAS 3-11521
Raymond R. Nicholls, Project Manager

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FINAL REPORT

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20 NOVEMBER 1970

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NASA Lewis Research Center
Cleveland, Ohio
Raymond R. Nicholls, Project Manager
Spacecraft Technology Division

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FOREWORD

The work described herein was conducted by the McDonnell Douglas Corporation under NASA Contract NAS3-11521 with Mr. Raymond R. Nicholls, Spacecraft Technology Division, NASA-Lewis Research Center, as Project Manager.

TABLE OF CONTENTS

(Cont'd)

(Cont'd)

TABLE OF CONTENTS

ABSTRACT

The operational performance of an electron bombardment mercury ion thruster system was monitored during approximately 8000 hours of life testing in a space simulation chamber at the McDonnell Douglas Corporation. The thruster system consisted of a NASA flight-type 15-cm Kaufman thruster and power conditioning unit. The thruster system and space simulation facility achieved nearly a year of operation without removal of the system from the simulated space environment. The test was completed when the thruster propellant supply was exhausted.

SUMMARY

An electron bombardment mercury ion thruster system, consisting of a flight-type 15-cm Kaufman thruster and power conditioning unit, was subjected to approximately 8000 hours of life testing in a space simulation chamber at the McDonnell Douglas Corporation's Space Systems Laboratory in St. Louis, Missouri. The thruster system, developed by NASA-Lewis Research Center, is of the kind being developed for orbit transfer, attitude control, station keeping purposes, and interplanetary spacecraft propulsion. The simulated space environment ground test was begun in advance of NASA's SERT II orbital flight test, which started in February 1970, to determine potential operating problems and provide solutions before and during the flight test. The ground test continued until the mercury propellant was depleted. The thruster system appeared to be in good condition after the life test.

1.0 INTRODUCTION

1.1 OBJECTIVE. A long-duration life test was performed to determine the operational characteristics of an electron bombardment mercury ion thruster system under conditions simulating Earth orbital operation. Results were obtained during ground testing to provide greater confidence during flight testing of a pair of thruster systems which were launched into Earth orbit in February 1970.

1.2 RELATED PREVIOUS WORK. The life test was part of a comprehensive program directed by NASA-Lewis Research Center (LeRC), in its own and in contractor laboratories, to develop electrical propulsion systems for orbit transfer, attitude control, station keeping purposes, and for interplanetary exploration vehicle propulsion.[1-4*]

The experience gained on previous long-duration test programs at McDonnell Douglas Corporation (MDC) was employed in the design and operation of the facility used for the mercury ion thruster system life test. Prior MDC experience in conducting thruster system tests and in designing and operating cryogenic and vacuum systems was also beneficial in designing and operating the facility.

1.3 PERIOD AND PLACE OF PERFORMANCE. The thruster system life test program was conducted in the MDC Space Systems Laboratory, General Engineering Division, Building 102, St. Louis, Missouri, during the period September 1968 to September 1970. A chronological record of significant events is presented in Appendix A.

*Superscripts refer to references at end of this report.

2.0 CONCEPT

2.1 GENERAL. Long-duration testing required a reliable facility with excess performance capability to compensate for normal degradation, pump redundancy to minimize interruptions due to single failures, maintainability to permit adjustments and repairs rapidly with the facility operating, and automatic alarms and safety features to permit economical unattended operation. Schedule and budget considerations required that an existing facility be utilized with only minor additions and modifications to tailor the facility to the test article. These factors were all taken into consideration in the selection of the facility and design of hardware for the test. Specific concepts considered in selecting the vacuum, mechanical, and thermal equipment and instrumentation and power control systems are described in the following sections.

2.2 SPACE SIMULATION VACUUM FACILITY. The thruster required testing with its exhaust plume expanding into a cylindrical test volume approximately 4.5 ft (1.37 m) in diameter and 5 ft (1.52 m) long, concentric with the thruster. The thruster required a volume 18 in. (0.46 m) long and 16 in. (0.41 m) in diameter, and the power conditioning unit (PCU) required a 2 x 2 x 1-ft (0.61 m x 0.61 m x 0.31 m) volume. The test zone pressure was required to remain below 5×10^{-6} torr during thruster system operation.

Several chambers and arrangements were considered. For example, a horizontal 5.5-ft (1.68 m) diameter, 10-ft (3.04 m) long chamber could have been remounted with its centerline vertical. This would have been relatively expensive, and the chamber had only one diffusion pump. An available 8-ft (2.43 m) diameter, 15-ft (4.57 m) long horizontal stainless steel space simulation chamber with two 50,000-liter/sec diffusion pumps was available that provided all the basic features and redundancy needed for the test. This chamber was large enough to permit mounting the thruster with its centerline vertical or horizontal. Its pumping system, utilizing DC-704 silicone pumping fluid, was capable of providing ultrahigh vacuum relatively free from contaminants. A foreline crossover pipe and valves provided mechanical vacuum pump redundancy consisting of two 530-cfm (0.25 m^3/sec) and one 50-cfm (0.024 m^3/sec) pumps. Evaluation of the chamber residual atmosphere with a quadrupole mass spectrometer demonstrated that the vacuum remained adequately uncontaminated when cooling water, instead of liquid nitrogen, was used in the optically-tight anti-backstreaming baffles; hence, water was selected for economy. Furthermore, diffusion pump fluid does not freeze and collect on a water-cooled baffle, but returns to the pump, permitting longer continuous operation without depletion of pump fluid. As a further precaution, sight gauges were added to the diffusion pumps to permit monitoring their fluid levels during operation. Valves were also added to permit fluid addition if required. The chamber was equipped with all necessary pass-through ports and viewports, except for one small hole added for mercury system lines.

2.3 MECHANICAL AND THERMAL EQUIPMENT. To simulate the space environment, in which only a little mercury exhausted by the thruster would return to the thruster and PCU, it was necessary to line the exhaust plume test zone with surfaces which would collect the mercury. Since the mercury leaving the thruster in the general direction of the thruster centerline has sufficient energy to sputter and erode a metal surface, and since contamination of the thruster by metals other than mercury could be detrimental to the thruster, a circular collector was required to be surfaced with mercury. For maximum collection effectiveness, solid mercury at approximately -100°F (-73°C) or lower was desired. Since some of the mercury in the exhaust plume flares out away from the thruster centerline, and since some mercury sputters off the collector, a liner is necessary to enclose the sides of the test zone. For these reasons, a 4.5-ft (1.37-m) diameter pool of frozen mercury was maintained on a cryogenic collector, and cryogenically cooled panels were used to enclose the 5-ft (1.52 m) long cylindrical test zone.

Preliminary information from NASA indicated that the mercury might be eroded in some areas to a depth of up to 1/2 in. (0.013 m) in an 8000-hour test. Hence, the collector was designed to contain mercury 3/4 in. (0.019 m) deep, which required approximately 1000 pounds (454 kg) of mercury. One of the factors considered during selection of the chamber was the orientation of the thruster, collector, and liner. Use of a 5.5-ft (1.68 m) diameter horizontal chamber would have required operating the thruster with its centerline horizontal and the collector surface in a vertical plane. The mercury would have had to be frozen while in a horizontal plane; then the collector would have had to be rotated, in vacuum, to a vertical plane. Adhesion of mercury to a vertical collector was evaluated, and means were developed which would prevent mercury from falling off a vertical collector, but the additional cost and schedule delay which would result from a requirement for vacuum-compatible actuators to rotate the collector was considered undesirable. Various metals were considered for fabrication of the collector and liner, and Type 304 stainless steel was selected for its mercury corrosion resistance and vacuum compatibility.

A comparison was made of two-stage freon refrigeration and liquid-nitrogen cooling of the collector and liner. The liquid nitrogen system was chosen for several reasons. The laboratory was equipped with a 15,000-gallon (56.7 m^3) supply tank, cryogenic lines, pumps, separator, etc., with recirculating LN_2 piped directly to the 8-ft (2.43 m) diameter chamber; hence, no additional refrigeration equipment was needed. The liquid nitrogen, at -320°F (-196°C), provided a wide margin of safety to prevent melting of mercury at what might have become "hot spots" in a -100°F (-73°C) freon system. Reliability of the 3-pump LN_2 system had been demonstrated in previous test programs in the laboratory. No additional floor space was required for the LN_2 system.

A water-cooled PCU cold plate, maintained at 100°F ± 20°F (38°C ± 11°C), was required to absorb up to 300 watts of heat from the PCU. The cold plate also was required to be suitable for baking out the PCU at 163°F ± 5°F (73°C ± 3°C) by circulation of heat transfer fluid through the cold plate. Bakeout of the PCU was required in order to reduce outgassing and the likelihood of glow discharge and arcing within the PCU during high voltage operation. Also, to reduce the contamination of the PCU by mercury sputtered off the collector surface, baffles were required surrounding the PCU region. To prevent undesirable cooling of the thruster during standby operation which included collector and liner cooldown prior to thruster startup, heat lamps were required around the thruster.

The collector, liner, PCU cold plate, and space chamber were required to be thermally isolated from each other and were also required to be electrically isolated from each other at potentials as high as 5000 volts DC. This required the design of Teflon insulators which would not be degraded by conductive coatings, such as mercury, on their outer surfaces. This also required the use of a Delrin passthrough plate and Teflon line assemblies for the fluid lines which could be at various potentials. To avoid electrical problems due to moisture and frost formation on the coolant lines outside the chamber, enclosure of the Teflon line assemblies and valves in cryogenic insulation was required. To keep the passthrough plate and exposed metallic portions of the coolant lines from condensing moisture from the air, forced circulation of air, by means of a small blower, was selected as the most practical technique.

2.4 <u>INSTRUMENTATION AND POWER CONTROL</u>. The console required to command and power the thruster system and the consoles needed to monitor and record thruster system operational parameters were furnished by LeRC. Consoles for operating the facility, for monitoring and recording facility and environmental parameters, and for performing automatic alarm and shutdown functions were designed and built by MDC to function in harmony with the LeRC items. In general, the concept was to provide redundant instrumentation for critical parameters and to provide fail-safe automatic alarm and shutdown capabilities to protect the thruster system in the event of any one of the following occurrences:

a. A rise in vacuum chamber pressure above 2×10^{-5} torr for longer than 15 minutes.

b. Failure of the laboratory electrical power.

c. Rise in temperature of the collector or liner above the set-point limit, usually -150°F (-101°C).

d. Power conditioning unit cold plate temperatures outside the upper or lower set-point limits, 100°F ± 20°F (38°C ± 11°C).

In addition to monitoring with electrical instrumentation, visual surveillance of the thruster and collector were desired.

3.0 DESCRIPTION OF TEST SPECIMENS

Test specimens consisted of 15-cm diameter Kaufman thrusters with their PCU's. The thruster system has a nominal input power of one kilowatt and delivers a nominal 250-milliampere mercury ion beam at a nominal effective specific impulse of 4380 seconds.

Various combinations of thrusters, PCU's and test consoles were used in the life test program, and they are listed below:

Run No.	Ion Thruster No.	PCU No.	Test Console No.
1	P-4	Included in Console	GE-B
2	P-4	Included in Console	GE-B
3	P-20	EX-1	LTC-1
4	P-20	EX-1	LTC-1
5	P-20	PT-1	LTC-1
6	P-20	PT-1	LTC-1
7	P-15	PT-1	LTC-1
8	P-15	PT-1	LTC-1
9	P-20	PT-1	LTC-1

A cutaway drawing of the thruster is shown in Figure 1. Thruster P-4 prior to Run No. 1 and PCU PT-1 prior to Run No. 5 are shown in Figure 2. The thruster is shown mounted on the lid of its shipping container, which was removed before testing. The PCU, which is identical to the flight PCU's, is shown after repair of the terminal damaged in Run No. 4.[4] The thermocouple taped to its upper surface was used to monitor operating temperature.

The thruster features a hollow cathode neutralizer to neutralize the main ion beam by injecting an equal current of electrons. Without neutralization, the thruster would build up a negative electrical charge which would prevent the exhaust ions from leaving the thruster.

4.0 TEST SETUP

4.1 GENERAL. The test setup incorporated GFE consoles and MDC fixtures built in accordance with drawings, listed in Table 1, approved by LeRC. For convenience, the following description of equipment is divided into three sections: space simulation vacuum facility, mechanical and thermal equipment, and instrumentation and power control.

4.2 SPACE SIMULATION VACUUM FACILITY. The space simulation chamber selected for ion thruster system life testing is shown, before the test program, in Figure 4. Its internal cylindrical volume is 8 ft (2.43 m) in diameter and 15 ft (4.57 m) long and is entirely free from obstructions which would interfere with an ion thruster test setup. The chamber is of Type 304 stainless steel and incorporates strip heaters, insulating blankets, cooling tubes, and water-cooled Viton-A and Buna-N O-rings, for bakeout, cooldown, and ultrahigh vacuum operation. The horizontal chamber and door dolly provide easy access to a test article in the chamber. Several large passthroughs and viewports provide access for electrical and fluid lines and for visual observation. In two hours, the system can reach 6.3×10^{-9} torr with LN_2-cooled baffles and liner and 8×10^{-7} torr with water-cooled baffles and LN_2-cooled liner and collector, as shown in Figure 5.

4.3 MECHANICAL AND THERMAL EQUIPMENT. The cryogenic liner and collector are shown during installation in the 8-Ft (2.43 m) Chamber, prior to the Facility Demonstration Test, in Figure 6A. This view, looking into the chamber, shows the inside of four of the six curved stainless steel panels comprising the liner. The embossed coolant passages can be seen on the outer surface of the panels which had not yet been bolted into place. These commercially procured panels were formed by resistance welding two sheets of Type 304 stainless steel along parallel strips, then hydraulically inflating the spaces between welds to form a coolant channel, as shown in Figure 6B. The panels were also edge welded to provide a vacuum-tight seal. Below the liner is the square collector with a circular dam to contain mercury. The collector and liner were supported on a frame resting on two rails welded to the chamber. Above the liner is another frame, on which the thruster and PCU were mounted. Substantially all hardware, including the flexible metal hoses used to supply LN_2 to the liner, were of stainless steel. The general arrangement of test fixtures in the chamber is shown, schematically, in Figure 7.

An interior view of the collector and the lower end of the liner is shown in Figure 8. Thermocouples, installed in a line along a diameter of the collector, were used to measure mercury temperatures during the Facility Demonstration Test. The collector was electrically isolated from ground (the chamber support rail and wall) and the liner was electrically isolated from the collector and ground by high-voltage insulators, shown in Figure 9. This was done to permit operation of the collector and liner at a high voltage, up to 5000 volts, with respect to ground. The cylindrical insulators, made of Teflon, were designed to prevent loss of electrical resistance due to mercury or other conducting films. Means were provided, outside the chamber, to bypass the insulators so that the collector and liner could be grounded.

Similar insulators were provided for mounting the thruster and PCU cold plate, as shown in Figure 10. This figure also shows the copper bus bars which supplied power to the electron bombardment device during the Facility Demonstration Test. The vacuum gauge shown in the background was mounted on a hollow spherical baffle with an opening viewing the mercury collector surface and the interior of the liner. The baffle was used to prevent sputtered mercury from contaminating the interior of the gauge. The bracket and wiring shown in the right foreground were used for the vacuum gauge which directly viewed the collector surface and the interior of the liner.

Water and LN_2 lines entered the chamber through the passthrough shown in an initial setup in Figure 11A. The final arrangement is shown in Figure 11B. To maintain electrical isolation of the collector, liner, and PCU cold plate, their fluid lines incorporated Teflon fittings and a Delrin passthrough plate. Control valves were installed on the electrically grounded side of the lines. The cryogenic lines, valves, and insulated fittings were later encapsulated in cryogenic insulation to avoid condensation of moisture and formation of frost on the parts. Only the vacuum-jacketed portions of the lines, near the pass-through plate, were not encapsulated. They were kept dry by forced convection of ambient air from a small fan. The inside of the passthrough is shown in Figure 12. Teflon tubes and caps were used to ensure electrical isolation of the fluid lines.

The mercury fill and drain system, shown in Figure 13, was capable of transferring mercury to and from the collector with the chamber evacuated or at ambient pressure. A cooling coil in the insulated tank was installed to permit cold nitrogen gas to be used to chill the mercury to approximately 0°F (-18°C) to reduce the vapor pressure. Three electrical probes in the collector were employed to sense the mercury surfaces when the depth reached the desired 3/4 inch (0.019 m).

Heat lamps, controlled by a variable transformer, were used to prevent excessive cooling of the thruster during standby operations.

4.4 INSTRUMENTATION AND POWER CONTROL. The instrumentation consoles utilized in the major portion of the life test are shown in Figure 14. The pair of consoles in the center of the picture contain the command circuits, power supplies, and instrumentation supplied by NASA-LeRC to operate and monitor the thruster system. Included are two strip chart recorders, telemetry output meters, digital voltmeters, and elapsed time meters. The tall console at the right contains vacuum and thermal instrumentation and part of the emergency alarm system. The shorter console at the right, the X-Y plotter at the left, and an oscilloscope (not shown), were used on occasion, for diagnostic purposes. The console at the extreme left is not part of this system but is similar to the one (not shown) used to monitor the vacuum system chamber and foreline pressures and to operate the chamber over-pressure alarm system.

Power was brought into the chamber through the high-voltage insulators shown in Figure 15. The ends of these insulators inside the chamber were protected from contamination by mercury or other conductive films by a Teflon sheet and a metal screen, as shown in Figure 16. This picture also shows the vacuum gauge (at the right) which directly viewed the collector surface and the interior of the liner. The sheet metal baffle which shielded the PCU from excessive mercury from the thruster, collector, and liner, can be seen in the center foreground. A second passthrough, for thermal and vacuum instrumentation, was also protected from contamination by a Teflon sheet and metal screen, as shown in Figure 17. This picture shows the thruster, PCU, liner, and collector installed prior to Run No. 4. The vacuum gauge and spherical baffle used to indirectly view the collector surface and interior of the liner is shown in Figure 18.

The four vacuum gauges used in the life test were designated as follows:

Designation	Type	Location
Pressure Veeco Thruster	Veeco RG-75 Bayard-Alpert	In front of thruster, viewing collector and liner directly.
Pressure NRC Thruster	NRC 751 Nottingham	Behind thruster, viewing collector and liner through spherical baffle.
Pressure Veeco PC	Veeco RG-75 Bayard-Alpert	Above and viewing the PCU.
Pressure NRC Outside	NRC 751 Nottingham	On top of chamber, viewing chamber interior through valve.

In addition to the four vacuum gauges used for measuring pressures at various locations in the chamber, a quadrupole mass spectrometer residual gas analyzer (RGA) was installed to analyze the chamber residual atmosphere. To prevent unnecessary contamination of the instrument, especially during the long periods between measurements, the sensing head was installed in a separate enclosure attached to a chamber passthrough port by means of a vacuum valve. Except when the instrument was in use, the valve was closed. This method also permits removal of the sensing head for servicing without interfering with chamber operation. One of the chamber vacuum gauges was similarly installed to permit its replacement in the event of contamination or malfunction during long-duration chamber operation.

The safety alarm and emergency shutdown system was installed to provide an annunciator signal if the chamber pressure, as indicated by a strip chart recorder, exceeded 2.0×10^{-5} torr. In the event that the pressure remained above the alarm set point for 15 minutes, an automatic timer switch was set to shut off the main power to the thruster system. Collector or liner temperature above a set point, usually -150°F, (-101°C) or PCU cold plate temperature outside the range 100°F ± 20°F (38°C ± 11°C) also were incorporated as signals to shut off the main power to the thruster system. The safety system was designed to shut off main power in the event of even a momentary laboratory power interruption. The safety system incorporated a battery-powered alarm in the laboratory and at a security guard station that was always manned, to warn of loss of main power to the thruster.

A mercury vapor detector was provided to warn of hazardous concentrations of mercury during loading, unloading, and cleanup operations. The detector was capable of indicating concentrations from 0.005 to 3.0 mg/m^3.

5.0 TEST PROCEDURE

5.1 FACILITY DEMONSTRATION TEST. The Facility Demonstration Test, conducted over a 3-day period, was witnessed by NASA-LeRC personnel. The test consisted of the following steps:

(a) A timed evacuation ("pumpdown") of the chamber from ambient pressure to 1×10^{-6} torr or less, followed by continuous operation of the chamber system for 50 hours, minimum.

(b) Operation of the cryogenic collector and liner so as to freeze a pool of mercury 3/4 in. (0.019 m) deep and maintain the frozen state during the 50 hours of the chamber system test.

(c) Operation of an electron bombardment device, to simulate the heat load of the thruster on the frozen mercury, during the 50 hours of the chamber system test.

(d) Analysis of the chamber residual atmosphere gas species from 1 to 200 AMU at a chamber pressure of 1×10^{-6} torr or less, with the collector and liner cold and the mercury frozen during the 50-hour test.

(e) A timed warming of the collector and liner to near room temperature, followed by analysis of the chamber residual gas species.

(f) Repressurization, opening, resealing, and re-evacuation of the chamber to a pressure of 1×10^{-6} torr or less, following the 50-hour test.

The test setup used for the Facility Demonstration Test employed an electron bombardment device (the U-shaped device in Figure 6) to apply a simulated thruster heat load, with the NASA-specified heat flux distribution, to the frozen mercury surface. The locations of thermocouples in the mercury and on the liner are shown in Figure 19, along with the positions occupied later by the thruster and PCU. Eight thermocouples were located in the mercury and six were attached to the inner surface of the liner.

A prototype electron bombardment device, used to determine operating parameters and distance to the collector, is shown in Figure 20. The prototype unit is shown with a dummy collector in a 5.5-ft (1.68 m) diameter chamber. The center circular zone is electrically insulated from the surrounding annular zone to permit measuring power input to each zone separately. Heat flux sensors (small square devices) were installed in the dummy collector, as shown.

5.2 <u>INSTALLATION OF THRUSTER AND POWER CONDITIONING UNIT</u>. The initial life test installation, Figure 21, shows Thruster P-4 installed along with a terminal board which joined the thruster electrical leads to the chamber passthrough leads, with LeRC-furnished insulators mounted to simulate PCU output terminals. This thruster, with the PCU installed in the test console outside the chamber, was used in Run Nos. 1 and 2. The thruster and terminal board are shown, after Run No. 1, in Figure 22. The terminal board was not used after Run No. 1. In Run No. 2 the thruster leads were spliced directly to the chamber passthrough leads. The installation shown in Figures 16 and 17 is typical of the arrangement used for most of the life test program and shows the system installed prior to Run Nos. 3 and 4.

The equipment to be installed in the chamber was handled with white Nylon or plastic gloves to avoid contamination of critical surfaces. All test fixtures were cleaned to minimize outgassing in vacuum and to avoid electrically conductive deposits on electrical insulators. Two electrically-powered fork lifts were used, with holding brackets designed for the purpose, to carefully insert the test article in the chamber without risk of damaging them. The work outline used during installation of the thruster system is shown in Table 2.

5.3 NORMAL TEST PROCEDURE. After installation and checkout of a thruster system and after instrument calibration and functional checkout specified by the NASA Project Manager, the PCU was baked out at 163°F ± 5°F (73°C ± 3°C) for 12 hours in vacuum prior to operation of the PCU (all runs after Run No. 2). This was done to remove moisture and volatile materials that could cause glow discharge and electrical arcing during initial operation in vacuum. Then the collector and liner were cooled to approximately -320°F (-196°C) with LN_2 at 40 psig ($2.76 \times 10^5 N/m^2$). Higher LN_2 flow rates were available at 80 psig ($5.52 \times 10^5 N/m^2$) if needed. After the desired chamber test conditions were obtained, the thruster system was started.

The normal startup, operating, and shutdown procedures for the test facility are presented in Table 3, and the corresponding schematic diagrams which identify the system components are shown in Figures 23-26. The detailed procedure for startup, operation, and re-start of Thruster P-20 and PCU PT-1 is presented in Table 4, and the corresponding photographs which identify the switches and meters are Figures 27 and 28. Test parameters are identifed and nominal operating values (for AAA Mode with I5 = 250 ma and 66-volt input voltage) are listed in Table 5.

To supplement the recorders and to provide a check of system operation at night and on weekends and holidays, test personnel manually recorded data once each eight hours during test runs.

5.4 FAILURES AND EMERGENCY PROCEDURES. In the event of excessively high chamber pressure, (over 2.0×10^{-5} torr) for longer than 15 minutes, collector or liner temperatures above the set point, usually -150°F (-101°C), PCU cold plate temperature outside the set point range, 100°F ± 20°F (38°C ± 11°C), or laboratory power interruption, the thruster main power was shut off automatically and an alarm sounded in the laboratory and in the security guard station. On second and third shift and on weekends and holidays, the guard called the assigned standby test personnel to take remedial action. Test specimen or facility malfunctions which could damage the test specimen, conditions which would lead inevitably to an automatic shutdown, or instructions from the NASA Project Manager were cause for instituting manual shutdown.

The procedure followed as soon as possible after automatic shutdown, the procedure for manual shutdown, and the detailed re-start procedure are included in Table 4.

5.5 REMOVAL OF THRUSTER AND POWER CONDITIONING UNIT. Run Nos. 1-7 required removal of little or no test hardware, so the complete removal of equipment after Run No. 9 will be described in this section. Following the completion of the life test, NASA-LeRC personnel desired to view the thruster system, frozen mercury surface, and liner surfaces. This required maintaining the cryogenic surfaces at a temperature that produced copious quantities of frost in the ambient air. The frost and mercury deposits can be seen on a liner section, in Figure 29, after some of the material had flaked off. Part of the frozen mercury surface and the cold liner are shown in Figure 30. The vertical line is the boundary between two adjacent liner panels which warmed up at different rates and collected different amounts of frost when exposed to air.

After initial examination and photographs were made, the thruster and PCU were removed from the chamber for closer examination by NASA-LeRC and MDC personnel. The removal operations were conducted by MDC personnel wearing appropriate safety equipment including respirators (outside the chamber), self-contained breathing equipment (inside the chamber), plastic coveralls, disposable shoes, and plastic gloves. The work was performed over a plastic sheet to collect any spilled mercury. MDC Health and Safety Department personnel monitored the mercury vapor level and the compliance with the prearranged procedures. Calcium polysulfide was applied to spilled mercury to reduce the evaporation of mercury and to aid in mercury cleanup using an approved vacuum device. After examination, the thruster was cleaned, sealed into its shipping container and was turned over to NASA-LeRC personnel who returned it to LeRC. The GFE test consoles, mercury, and PCU were packed and shipped to LeRC.

5.6 REMOVAL AND DISPOSITION OF TEST FIXTURES. Following the removal of the thruster and power conditioning unit, disassembly and removal of test fixtures was initiated. Promptly after removal of test fixtures, the fixtures were scrubbed in a large vat of alcohol to remove all accessible mercury. Then the parts were wrapped in two layers of heavy clear plastic film to minimize the escape of any residual mercury. Parts to be scrapped were wiped with alcohol-soaked cloth to remove most of the mercury. Then they were double-wrapped in plastic for disposal at a site approved by the Health and Safety Department. The chamber, pumps, and vacuum lines were disassembled sufficiently to permit thorough removal of mercury.

6.0 RESULTS AND DISCUSSION OF RESULTS

6.1 FACILITY DEMONSTRATION TEST. The results of the Facility Demonstration Test are presented in Appendix B. The timed evacuation of the chamber from ambient pressure to 1 x 10^{-6} torr was accomplished in less than seven hours, using cooling water in the anti-backstreaming baffles. The pressure-time history for the initial evacuation, 50-hour facility test, chamber repressurization, chamber opening, resealing, and re-evacuation is shown in Figure B-1 in Appendix B. The data are based on compensated vacuum gauge readings, (nulled to cancel electrical noise), and show that the facility achieved and maintained the desired pressure level for thruster system testing even with a simulated thruster heat load of 2000 watts applied to the cryogenic mercury and liner surfaces with the heat flux distribution shown in Figure B-2. The mercury remained completely frozen, as shown by the low temperatures along a diameter of the collector, in Figure B-3. The liner also remained at a temperature well below the melting point of mercury, as shown in Figure B-4. The coolant inlet and outlet line temperatures, in Figure B-5, confirm that the collector, liner, and LN_2 supply system were able to absorb the imposed heat load in addition to stray heat leaks (e.g., thermal radiation from the chamber walls). Residual gas analyses, made with the collector and liner at cryogenic temperature and at ambient temperature are shown in Figures B-6 through B-15. The data all demonstrated that the facility was suitable for thruster system testing.

The only problem encountered during the test was pressure measurement. The vacuum gauge designated "Pressure NRC Outside" had a broken collector element, and the vacuum gauge designated "Pressure NRC Thruster" was affected by operation of the electron bombardment device. The latter gauge was, subsequently, supplied with an electronic null signal to compensate for the interference from the electron bombardment device. Later, the gauge leads were shielded to circumvent the problem. An operational evaluation was performed, which proved that the original compensated pressure data were correct. The validity of the Facility Demonstration Test was established to the satisfaction of the NASA Project Manager.

6.2 PERFORMANCE OF THE THRUSTER SYSTEM. During Runs 1-8, a number of operational problems were investigated and solutions were provided, as described in Appendix A, using various thrusters and power conditioning units. As shown in Table 6, a total of 1228.4 hours of operation were accumulated during Runs 1-8, including 1166.7 hours of Thruster P-20 operation and 1171.2 hours of PCU PT-1 operation. The Thruster P-20 Neutralizer System had been operated 1209.4 hours in the AAA Mode before Run No. 9, including operating time at LeRC. Examination of Thruster P-20 grid and neutralizer after 764.1 hours of operation, Figure 32, revealed no signs of erosion and only slight deposits (mostly mercury).

During Run No. 9, 6742.9 hours of thruster system operation were performed in a continuous thermal vacuum environment simulating Earth orbit, with only minor operational problems described in Appendix C. During Run No. 9, the thruster system was operated 2737.6 hours in the AAA Mode ($I5 = 250$ ma) and 4005.3 hours in the BAA Mode ($I5 = 200$ ma). The thruster system operating mode was changed from AAA to BAA because the neutralizer vaporizer control loop became unstable in the AAA Mode. The life test was concluded after the thruster system mercury propellant supply was exhausted and after final operational checks were completed. During Runs 1-9, a total operating time of 7971.3 hours was accumulated, not including 38.6 hours in the Preheat Mode. The Thruster P-20 Neutralizer System had been operated a total of 7952.3 hours in the AAA and BAA Modes, including operating time at LeRC.

The major events during Run No. 9, indicated on a chart of Operating Hours versus Calendar Time, Figure A-1 in Appendix A, are:

1. Thruster P-20 and PCU PT-1 received from LeRC.
2. Run No. 9 started in AAA Mode.
3. Momentary electrical power interruption in laboratory.
4. Slight rise in chamber pressure due to pump switch failure.
5. Thruster system operation became unstable in AAA Mode. Operation in BAA Mode started.
6. Various operating modes evaluated. Operation in BAA Mode resumed.
7. Warming of collector and liner above -150°F (-101°C) due to depletion of LN_2.
8. Momentary electrical power interruption in laboratory.
9. Various operating modes evaluated and 30-volt zener diode safety clamp between V1 and ground replaced with 100-volt unit. Operation in BAA Mode resumed.
10. Slight rise in chamber pressure due to opening of fuse in power supply to one diffusion pump.
11. Momentary electrical power interruption in laboratory.
12. Thruster beam current I5 dropped to approximately zero, due to depletion of mercury supply.
13. Thruster system operational evaluation begun by LeRC personnel at MDC.
14. Thruster system operational evaluation completed and Run No. 9 terminated. Thruster System Life Test completed.

After the life test was completed, the thruster system was examined. As shown in Figure 33, the PCU and upper part of the thruster were quite clean and free from deposits, which indicates that a good simulated space vacuum was maintained throughout the test. The thruster grid and neutralizer after the life test are shown in progressively closer views, Figures 34, 35, and 36. Some erosion of the grid can be seen in the vicinity of the neutralizer. Deposits (chiefly mercury) are prominent on the grid and neutralizer. Generally, the thruster system appeared to be in good condition.

The range of values for Neutralizer Tank Pressure Telemetry Voltage, Neutralizer Keeper Electrode Supply Voltage (V8), Discharge Chamber Supply Current (I4), and Neutralizer Cathode and Vaporizer Heater Current (I7) are shown for Run No. 9 in Figure 37. The Neutralizer Tank Pressure decreased steadily throughout the test, as expected. The Neutralizer Keeper Electrode Supply Voltage was nearly constant for more than six months, except for a few "spikes." During the final three months, it was unstable and oscillated between various upper and lower limits. (The ranges shown in Figure 37 are the week-by-week maxima and minima.) The discharge Chamber Supply Current (I4) was nearly constant within its nominal range during AAA Mode operation. After more than four months of operation in the BAA Mode, slight fluctuations were observed. Neutralizer Cathode and Vaporizer Heater Current was within its nominal range during the first two months of operation but dropped to slightly below the nominal range for the remainder of AAA Mode operation and the first two months of BAA Mode operation. It became very unstable, fluctuating greatly during the remainder of the BAA Mode operation.

At the request of the NASA Project Manager, an examination was made of the mercury in the collector after the life test. The primary purpose was to attempt to find any small pieces of thruster grid or screen material which might have become detached from the thruster during operation. It was suspected that small filaments or "whiskers" of screen or grid material, of the order of 0.005-in. (0.0001 m) diameter, 0.1-in. (0.003 m) long, might have caused a screen-to-grid short circuit and consequent early automatic shutdown of a thruster system in the Earth orbit flight test. If such "whiskers" could be found in or on the mercury collector in the chamber, it would be reasonable to suspect that they had fallen from the thruster after the thruster system was shut down and the electrostatic fields collapsed. In space, the "whiskers" might remain in place, since there is no gravitational effect to cause them to fall out of the thruster. The secondary purpose of the examination was to determine how much the frozen mercury surface had been eroded by impingement of the high energy mercury exhaust plume from the thruster.

To facilitate examination of the frozen mercury surface, the chamber was repressurized with dry nitrogen gas which prevented condensation of moisture, carbon dioxide, and oxygen on the cold mercury and liner surfaces. As soon as the chamber was opened, a large clear plastic sheet was draped over the end of the chamber and test personnel wearing self-contained breathing equipment and special protective clothing entered the chamber to examine the frozen mercury. The liner was kept cold to prevent liner deposits from falling on the collector. No large particles were observed, and the irregularities in the mercury surface prevented a good visual examination for very small particles. While the cold surfaces were being photographed, air entered the chamber, unavoidably, and the cold surfaces became obscured by frost. The mercury showed no measurable erosion when checked with a straightedge laid along a diameter of the frozen surface.

After examination of the cold surfaces, the chamber was closed and the collector and liner were warmed to ambient temperature. The thruster and PCU were removed from the chamber. Then, most of the mercury was drained into the mercury reservoir through a trap designed to collect any lighter particles. When the mercury depth in the collector reached approximately 1/8 in. (0.003 m), the chamber was opened and the remaining mercury was removed from the collector by a vacuum device which incorporated a double trap to collect all the residue from the surface of the liquid mercury. Trap No. 1 was emptied into a strainer to concentrate the residue, of which several pounds was collected. Trap No. 2 contained a little material, including a few small heavy particles. The residue was given to the NASA Project Manager for analysis by LeRC, and no pieces of thruster grid or screen material were found.

6.3 PERFORMANCE OF THE TEST FACILITY. The test facility maintained a safe vacuum and thermal environment for the thruster system throughout the life test. During nearly ten months of continuous space simulation exposure, the automatic alarm system was actuated only four times and the problems were corrected before they had any significant effect on the thruster system. The performance was excellent for a large thermal-vacuum system, particularly when operated continuously without 3-shift 7-day-per-week attendance of test personnel.

Examination of the facility after the life test showed that it had not been significantly degraded by the long continuous operation. The unshielded and shielded vacuum gauges were all free from mercury contamination and were functioning properly. The diffusion pumps were operating normally, and the pumping fluid (DC-704) was at the normal operating level and reasonably clean. Although condensed mercury was found in the mechanical pumps and in the foreline between the diffusion and mechanical pumps, no degradation of performance occurred and no equipment damage resulted. The diffusion pump heaters showed normal aging but appeared to have several thousand hours of useful life remaining. With two diffusion pumps, one pump at a time could have been shut down to change heaters if required, without loss of an adequate vacuum environment for thruster system operation.

The liquid nitrogen system operated without failure, although human error resulted in brief depletion of LN_2 during a 3-day weekend. During that weekend, an unusually large number of vacuum and cryogenic systems were operating in the laboratory, and the LN_2 usage rate exceeded the anticipated rate. More frequent monitoring of the LN_2 supply was initiated to prevent a recurrence.

Facility cleanup, following the life test, required considerable effort because all the test hardware was contaminated with mercury, a potentially hazardous toxic material. MDC fixtures were cleaned, wrapped, and stored or scrapped as appropriate. Cleaning, performed by MDC personnel wearing appropriate protective clothing and breathing equipment, included washing of hardware in isopropyl alcohol. The chamber was cleaned by wiping with squeegees and alcohol-soaked cloths. Some of the chamber surfaces were also sanded to remove a thin layer of stainless steel which had combined with mercury. The chamber system was completely disassembled to remove mercury from baffles, pumps, lines, and valves. Examination showed that none of the facility items had been damaged by mercury.

Even the viewport and mirror, used to observe the thruster system and collector had functioned well throughout the test.

The collector and liner had functioned flawlessly during the test and showed no signs of damage due to bombardment by high energy mercury. The thermal design, using LN_2 as a coolant, would have been able to handle even greater heat loads if desired.

The facility demonstrated considerable thermal and vacuum reserve capacity and would be suitable for testing even larger thruster systems for even longer test durations. The temperature and vacuum instrumentation showed no degradation during the test and did not experience the mercury contamination effects that had been allowed for (by the use of a baffled ion gauge, for example). The PCU and upper part of the thruster showed no contaminating deposits, thus substantiating the mass spectrometer (RGA) demonstration of adequate vacuum cleanliness for long duration simulated space testing.

6.4 SUMMARY OF FAILURES. The test specimen failures which occurred were in the:

(a) High voltage screen power supply in PCU PT-1 (Run No. 5, Failure Report No. 1).

(b) Thruster cathode and isolator heater circuit of PCU PT-1 (Run No. 7, Failure Report No. 2).

(c) Thruster system (Thruster P-15 and PCU PT-1) anode circuit (Run No. 8, Failure Report No. 4).

(d) Mercury propellant depletion in Thruster P-20 (Run No. 9, Failure Report No. 15).

The GFE recorders in Life Test Console LTC No. 1 experienced the following failures:

(a) Recorder No 1 recorded zero on several channels, and Recorder No. 2 pens tended to come off when transient data were being recorded. The ink supply in Recorder No. 2 failed frequently. (Run No. 8, Failure Report No. 3).

(b) Recorder No. 1 repeated Channel 1-12 data on Channels 13-24 (Run No. 9, Failure Report No. 7).

(c) Recorder No. 1 chart drive malfunctioned (Run No. 9, Failure Report Nos. 9, 11, and 12).

The facility failures which caused interruption of testing were as follows:

(a) Momentary (up to one or two seconds) electrical power interruption in the laboratory (Run No. 9, Failure Report Nos. 5, 10, and 14).

(b) Zero-speed switch failure on mechanical foreline pump (Run No. 9, Failure Report No. 6).

(c) Depletion of LN_2 supply (Run No. 9, Failure Report No. 8).

(d) Diffusion pump heater fuse opening (Run No. 9, Failure Report No. 13).

6.5 RECOMMENDATIONS. The practicability of performing long-duration life tests of an operating thruster system in a simulated space environment has been demonstrated, and it is recommended that all future thruster systems be subjected to similar tests. To avoid thruster system shutdowns due to momentary interruptions of electrical power, a time delay circuit is recommended to restart the thruster system automatically. More reliable recorders and indicating command-switch lamps are recommended for use in the GFE test consoles. Since liquid nitrogen provides simple and reliable refrigeration of the collector and liner and also provides a large temperature margin below the maximum desired operating temperature, liquid nitrogen is recommended as the coolant for future mercury ion thruster system tests.

7.0 CONCLUSIONS

The ion thruster system life test was concluded after an accumulated total test time of 7971.3 hours, at which time the mercury propellant was depleted. The thruster system appeared to be in good condition after the test and showed only a little erosion of its grid. After several modifications of the thruster system to alleviate problems observed in the early part of the test program, the final thruster system configuration was tested for 6742.9 hours without removal from the simulated space environment. The test facility performed well during the long-duration test with only a few minor malfunctions. Information obtained during the test program was utilized in preparation of the flight test thruster systems which were launched into Earth-orbit by NASA in February 1970.

TABLE 1 - DESIGN DRAWINGS

TITLE	DRAWING NUMBER
Main Assembly	T-054352
Upper Support Frame	T-054353
Lower Support Frame	T-054354
Mounting Angle	T-054355
Collector & Liner Insulator Mounts	T-054356
LN_2 Lines to Liner & Collector	T-054357
Collector Panel	T-054358
Passthrough Plate	T-054359
High Voltage Passthrough Plate	T-054360
Window Passthrough	T-054361
Instrumentation Passthrough	T-054362
Liner Cryopanel	T-054363
RGA Support	T-054364
Power Conditioner Cold Plate	T-054365
Ion Gauge Mount	T-054366
Mirror Mount	T-054367
Water Passthrough	T-054368
LN_2 Passthrough	T-054369
LN_2 Line Insulator	T-054370
Water Line Insulator	T-054371
Electrical Alarm Schematic	T-054378
Mercury Tank Base Plate	T-054379
Mercury Fill System	T-054380
Mercury Shield	T-054382
Liner Shield	T-054383
Thermocouple Installation	T-054384
Mercury Level Sensors	T-054385
Mercury Reservoir	T-054387

TABLE 2 - WORK OUTLINE PROCEDURE FOR TEST SETUP OF ION THRUSTER SYSTEM - 8-FT CHAMBER

	ITEM	INITIAL
1.	Obtain all required equipment such as the mercury vapor detector tools, work benches, Helium Leak Detector, prior to the backfill of the 8-ft test chamber to atmospheric pressure.	________
2.	Perform the necessary steps to place the mercury vapor detector in operation.	________
3.	Remove the ion thruster engine and power conditioning unit (PCU) from their respective shipping containers. White Nylon or plastic gloves are to be used whenever handling the above mentioned units.	________
4.	Perform "Dummy Load" test on the PCU.	________
5.	Mount the ion thruster engine into the test fixture. CAUTION - never place the ion thruster engine test fixture on a table or any other similarly flat surface when the engine is mounted without a 4" x 4" shim block under each leg of the fixture.	________
6.	After mounting the PCU on the cold plate, torque the mounting bolts to 30 $\pm$ 3 in.-lb.	________
7.	Remove the electrical lead cover on the PCU and connect electrical leads from the ion thruster engine to the PCU. Torque nuts securing electrical leads to 14 $\pm$ 2 in.-lb. Replace the electrical lead cover on the PCU.	________
8.	Mount handling tooling on both battery operated fork lifts.	________
9.	Lock 4 wheel swivels on the 8-ft test chamber door dolly, and then roll door dolly back far enough from the chamber to allow for proper positioning of fork lifts	________
10.	Properly position fork lifts in front of 8-ft test chamber.	________
11.	Check on the operation of the Helium Leak Detector which will be used to leak check cold plate coolant circuit.	________
12.	Start pump cart and initiate preheat of the fluid to approximately 150°F. This pump cart will be used for bakeout of the PCU.	________

(Cont'd)

(Cont'd)

TABLE 2 - WORK OUTLINE PROCEDURE FOR TEST SETUP OF ION THRUSTER SYSTEM - 8-FT CHAMBER

ITEM	INITIAL
13. Move the workbench holding the ion thruster engine and the PCU in front of the 8-ft test chamber and load the ion thruster and PCU on handling tooling. Remove workbench from the area.	______
14. Simulataneously place the ion thruster and PCU in the 8-ft test chamber and mount with four (4) bolts each. CAUTION - make sure that electrical leads from the ion thruster and PCU are not damaged.	______
15. Mount ionizations gauges in the ion thruster and PCU areas and connect them to their respective wire bundles. Carefully recheck to make sure the gauge leads are properly connected.	______
16. Perform resistance check of high-voltage insulators between the ion thruster and PCU mounts to chamber ground.	______
17. Install shield over coolant lines to the PCU cold plate.	______
18. Perform a helium leak check on the cold plate coolant circuit. Zero detectable leakage required ($<10^{-9}$ std cc/sec of He).	______
19. Connect pump cart to the PCU cold plate coolant circuit and start heating PCU unit to approximately 150°F. Hold at this temperature until-8-ft test chamber evacuation is started, then increase to the desired PCU bakeout temperature.	______
20. Connect two (2) thermocouples from the PCU cold plate to the 8-ft test chamber passthrough.	______
21. Connect wire bundles E2J1 Solar Array, E2J2 Thermistor, E2J3 Telemetry and E2J4 Command from the 8-ft chamber passthrough to the PCU.	______
22. Connect ground wires to the ion thruster and PCU.	______
23. Mount the ion thruster heat lamps.	______
24. Recheck the following: electrical connections to the PCU, three (3) ionization gauges, thermocouple instrumentation, heat lamps and mercury level sensors.	______

(Cont'd)

(Cont'd)

TABLE 2 - WORK OUTLINE PROCEDURE FOR TEST SETUP OF ION THRUSTER SYSTEM - 8-FT CHAMBER

	ITEM	INITIAL
25.	Check the general setup, coolant lines, wire bundles viewport shields, Teflon shields and insulators, etc.	________
26.	Clean mirrors and viewport with alcohol.	________
27.	Roll 8-ft test chamber door dolly forward to close the chamber, and initiate detailed "Operating Procedure".	________

TABLE 3 - FACILITY OPERATING PROCEDURE*
(Revision A, 1 December 1969)

1.0 STARTUP	Initial	Time	Date
Chamber Pumpdown			
1.1 Close and secure chamber door	______	______	______
1.2 Close air release valve V-7, Figure 23	______	______	______
1.3 Close valve V-8, Figure 23	______	______	______
1.4 Close shutoff valve V-4, Figure 23	______	______	______
1.5 Open variable leak valve V-5, Figure 23, to a setting of 40	______	______	______
1.6 Close fine control air admittance valve V-6, Figure 23	______	______	______
1.7 Open Alphatron pressure gauge isolation valve V-3, Figure 23	______	______	______
1.8 Turn Alphatron gauge control switch to "Warm" position	______	______	______
1.9 Open mechanical pump cooling water valve V-23, Figure 23	______	______	______
1.10 Open manual oil valve on mechanical pump	______	______	______
1.11 Open mechanical pump isolation foreline valve V-58, Figure 23	______	______	______
1.12 Close main electrical disconnect switch on power control panel	______	______	______
1.13 Depress and release valve reset switch on power control panel	______	______	______
1.14 Open main water solenoid valve V-24, Figure 24, by turning switch on power control panel to open position	______	______	______

*See Figures 23-26 for schematic drawings identifying valves, etc. in this procedure.

(Cont'd)

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TABLE 3 - FACILITY OPERATING PROCEDURE

1.0 STARTUP (CONTINUED)	Initial	Time	Date
1.15 Check that foreline valves V-1, V-2, and air release valve V-9, Figure 23, are in the closed position by checking switches on the control panel	______	______	______
1.16 Turn Alphatron gauge control switch to "on" position	______	______	______
1.17 Turn T/C pressure gauge control switch to T/C No. 1 position	______	______	______
1.18 Turn recorder switch to 530 position	______	______	______
1.19 Turn recorder chart switch (inside case) to "on"	______	______	______
1.20 Open mechanical pump air release valve V-9, Figure 23, by turning switch on power control panel	______	______	______
1.21 Depress mechanical pump start switch on power control panel	______	______	______
1.22 Close mechanical pump air release valve V-9, Figure 23	______	______	______
1.23 Check mechanical pump blank off pressure (approximately 100 micron) by reading T/C No. 1	______	______	______
1.24 Open foreline valves V-1 and V-2, Figure 23, by turning switches on power control panel to "open" position	______	______	______
1.25 Evacuate chamber to 5 x 10^{-1} torr or less using mechanical pump	______	______	______
1.26 Check cooling water valves V-25 through V-34, Figure 24, for open position	______	______	______
1.27 Check manual quick cool valves, V-37 and V-38, Figure 23, for closed position	______	______	______

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

1.0 STARTUP (CONTINUED)		Initial	Time	Date
1.28	Check for closed position of quick cool solenoid valve switch on power control panel			
1.29	Open manual quick cool drain valves V-39 and V-40, Figure 23, on diffusion pumps			
1.30	Confirm cooling water flow by inspection of open drain. (Keep thruster temperature at approximately 100°F with heat lamps.) Hold PCU base plate near bakeout temperature			
1.31	Continue evacuation of chamber for approximately 30 minutes after obtaining a chamber pressure of 5×10^{-1} torr			
1.32	When chamber pressure reaches approximately 1×10^{-1} torr initiate diffusion pump startup			
1.33	Check to see that baffle water valves, V-60 and V-61, Figure 26, are in the closed position			
1.34	Start water flow to the baffle by opening supply valve V-62 and water return valve V-63, Figure 26			
1.35	Depress diffusion pump start switches 1 and 2 on power control panel			
1.36	Initiate GN_2 sweep through the chamber to reduce backstreaming			
1.37	Open air release valve V-7, GN_2 supply valve V-11 and slowly open fine control valve V-6, Figure 23			
1.38	Close valves V-6, V-7, and V-11, Figure 23, approximately one hour after opening them			

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

1.0 STARTUP (CONTINUED)

1.39 Initiate bakeout of PCU per detailed procedure supplied by NASA-maintain thruster at 110 $\pm$ 10°F. Also start precool of Hg to 0°F.

SPECIFICATION FOR STARTUP OF THE PCU AFTER EXPOSURE TO ANY AMBIENT ENVIRONMENT OR SOURCE OF CONTAMINATION

Prior to applying any power to the PCU, the following procedure must be followed:

1. Raise the base plate temperature to 163 $\pm$ 5°F.
2. Allow all temperatures to stabilize where stabilization is defined as occurring when all thermocouple or thermistor readings do not vary more than 1°F per hour.
3. Bake at this temperature for 12 hours.
4. Reduce the base plate to test temperatures.
5. Preheat for 1/2 hour or more.
6. Turn on high voltage and reset the base plate to test temperatures.

Mercury Transfer to Collector

(CAUTION - Turn off ion gauges - start Hg fill at 5 psi until Hg has covered fill holes then increase to 10 psi.)

		Initial	Time	Date
1.40	Initiate filling of the collector with mercury to a depth of 3/4-inch	______	______	______
1.41	Close valves V-1 through V-6, Figure 25	______	______	______
1.42	Open pressure gauge shutoff valve V-7, Figure 25	______	______	______
1.43	Set pressure regulator PR-1, Figure 25, at 10 psig	______	______	______
1.44	Open GN_2 shutoff valve V-2, Figure 25	______	______	______

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

1.0 STARTUP (CONTINUED)	Initial	Time	Date
1.45 Slowly open mercury fill valve V-1, Figure 25			
1.46 Adjust pressure regulator PR-1, Figure 25, as required			
1.47 Close mercury fill valve, V-1, Figure 25, when mercury level indicator lights come on			
1.48 Close GN_2 shutoff valve V-2, Figure 25			
1.49 Start vacuum pump, Figure 25			
1.50 Open vacuum valves V-8 and V-9, Figure 25			
1.51 Fill LN_2 trap, Figure 25			
1.52 Slowly open vacuum valve V-4, Figure 25, and evacuate mercury reservoir			
1.53 Close vacuum valve V-4, Figure 25			
1.54 Open valve V-3, Figure 25			
1.55 Open GN_2 shutoff valve V-2, Figure 25, and increase reservoir pressure to approximately 5 psig			
1.56 Close valve V-2, Figure 25			
1.57 Check resistance across T-054371-3 insulator, Figure 25			
Collector And Liner Cooldown			
1.58 Initiate cooldown of the collector and liner			
1.59 Close manual shutoff valves V-49, V-52, V-53, and V-54, Figure 26			

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

1.0 STARTUP (CONTINUED)	Initial	Time	Date
1.60 Open manual shutoff valves V-51, V-55, V-56, V-57, V-58, and V-59, Figure 26	______	______	______
1.61 Open LN_2 return valve CV-17 Figure 26, by turning switch on the control panel	______	______	______
1.62 Open manual LN_2 shutoff liner and collector supply valves V-64, V-65 V-66, V-67, V-68 and V-69, Figure 26	______	______	______
1.63 Open LN_2 supply valves CV-18 and close "purge GN_2 out" valve CV-19, Figure 26, by turning switch on the control panel to the "open" position. This step should be performed approximately 15 minutes after Step 1.58	______	______	______
1.64 When Hg is frozen stop bakeout of PCU	______	______	______
1.65 Adjust H_2O flow for PCU temperature of 100 ± 20°F when PCU is operating	______	______	______
1.66 When a chamber pressure of 1×10^{-6} torr or less is obtained, initiate thruster operation per detailed test procedure supplied by NASA (See Table 4)	______	______	______
2.0 SHUTDOWN			
Stop Thruster Operation			
2.1 Discontinue thruster operation per detailed test procedure supplied by NASA	______	______	______
Collector and Liner Warmup			
2.2 Initiate purge of LN_2 from the liner and collector	______	______	______

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

2.0	SHUTDOWN	Initial	Time	Date
2.3	Open CV-19, Figure 26, purge GN_2 out by turning the switch on the control panel to "open"	______	______	______
2.4	Close valves CV-17 and CV-18, Figure 26	______	______	______
2.5	Open valve SOV-14, Figure 26	______	______	______
2.6	Initiate warmup of the liner and collector	______	______	______
2.7	Close "purge GN_2 out" valve CV-19, Figure 26	______	______	______
2.8	Open "warmup GN_2 out" valve SOV-15, Figure 26	______	______	______
2.9	Initiate shutdown of the diffusion pumps	______	______	______
2.10	Close diffusion pump quick cool drain valves V-39 and V-40, Figure 24	______	______	______
2.11	Open quick cool solenoid valve by turning switch on power control panel to the "open" position	______	______	______
2.12	Continue chamber evacuation with the mechanical pumps	______	______	______
2.13	When the liner and collector are warmed to approximately 0°F stop evacuation of the chamber, close foreline valves V-1 and V-2, Figure 23	______	______	______
2.14	Close SOV-14 until mercury drain operation is complete	______	______	______
2.15	Initiate backfill of the chamber to 500 torr as indicated on the Alphatron gauge	______	______	______

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

2.0 SHUTDOWN (CONTINUED)	Initial	Time	Date
2.16 Open valve V-7, V-8 and GN_2 supply valve V-11, Figure 23			
2.17 When backfill is complete close GN_2 supply valve V-11			
<u>Transfer of Mercury from Collector</u>			
2.18 Initiate the drain procedure of the mercury from the collector to the mercury reservoir			
2.19 Close valves V-1 through V-6, and open valve V-7, Figure 25			
2.20 Start 50 cfm vacuum pump Figure 25, Open V-9			
2.21 Open vacuum valve V-8, Figure 25			
2.22 Fill LN_2 cold trap, Figure 25			
2.23 Open reservoir vacuum valve V-4, Figure 25, and evacuate ullage			
2.24 Open mercury fill valve V-1, Figure 25			
2.25 Close mercury fill valve V-1, Figure 25, when pressure gauge G-1 fluxuates, indicating all mercury drained.			
2.26 Close reservoir vacuum valve V-4, Figure 25			
2.27 Open valve V-3, Figure 25			
2.28 Open GN_2 shutoff valve V-2, Figure 24			
2.29 Increase reservoir pressure to approximately 5 psig with dry GN_2			

(Cont'd)

(Cont'd)

TABLE 3 - FACILITY OPERATING PROCEDURE

2.0 SHUTDOWN (CONTINUED)	Initial	Time	Date
2.30 Close GN_2 shutoff valve V-2, Figure 25			
2.31 Shut down 50 cfm vacuum pump, Figure 25			
Chamber Backfill and Securing of Systems			
2.32 When drain operation of the mercury has been completed reevacuate the chamber to 5×10^{-1} torr or less using the mechanical pump. Open foreline valves V-1, and V-2, Figure 23			
2.33 Open SOV-14 and continue warming liner and collector to approximately 10°C			
2.34 Initiate backfill of the chamber to laboratory ambient pressure using GN_2 (CAUTION-keep door secured)			
2.35 Close foreline valves, V-1 and V-2, Figure 23			
2.36 Open GN_2 supply valve V-11, Figure 23			
2.37 When chamber backfill is complete, remove sampling port and check mercury vapor concentration with mercury vapor detector			
2.38 If mercury concentration level is acceptable open chamber door			
2.39 If mercury concentration level is not acceptable, evacuate the chamber and again backfill with GN_2			
2.40 Repeat steps 2.32 through 2.39 as required			
2.41 Secure all systems and check for proper shutdown			

TABLE 4 - OPERATING INSTRUCTIONS FOR SERT II LIFE TEST CONSOLE*

1. Close back doors of Test Console.

2. Connect interconnect harnesses between Test Console and PCU connectors mounted in vacuum chamber passthroughs. This mates the Test Console bulkhead connectors J4, J5, J6 and J7 to the PCU.

3. Plug AC power cord into 220-volt single phase AC outlet.

4. Open recorder doors and set chart drive switches to the OFF position.

5. Swing out recorder chart carriers and set recorder ON-OFF switches to the ON position.

6. Set the Honeywell u-BLOC AC power switch (located beneath the u-BLOC front panel) to ON position.

7. Set the three power ON-OFF switches of the NEXUS command module power supplies to the ON position. These switches are located on the telemetry panel beneath the TLM panel meters.

8. Set the two DVM AC power ON-OFF switches to the ON position and set DVM range selector switch of DVM No. 1 to the 150-volt position.

9. Place GE main breaker switch DSI in the ON position. Refer to Figure 27 for location of this breaker. The following lamps should be lit:

    a. Three NEXUS command module power supply lamps
    b. Numeral lamps on both DVM's
    c. Power lamp on thermistor panel
    d. Power lamp on command panel
    e. Some command logic indicator lamps on the command panel (number of lamps lit will be dependent on logic setting which existed when shutdown was initiated).

10. Set panel power toggle switch TS-1 to the ON position. The panel power lamp DS2 should now be lit. Refer to Figure 28 for lamp location.

11. Set Sorenson power supply coarse voltage control to its extreme counter-clock-wise position.

12. Set Sorenson power supply current adjust control to 20 amps.

13. Place Sorenson power supply DC circuit breaker in the ON position.

*This table is based on the "Operating Instructions for SERT II Life Test Console," supplied by NASA-LeRC, except for changes incorporated by the NASA Project Manager.

(Cont'd)

(Cont'd)

TABLE 4 - OPERATING INSTRUCTIONS FOR SERT II LIFE TEST CONSOLE

14. Depress lamp test switch located on command panel and see that all logic indicating lamps are lit. Lamps should be replaced to correct any unlit condition noted during the lamp test before proceeding.*

15. Send shutdown command. All commands are sent by using the following switch sequence:

    a. Depress and hold command selector switch. Each command has a separate switch on the command panel. For location of switches, refer to Figure 27.

    b. Depress pulse initiate button located on command panel while command selector switch is still being held down. The particular lamp which is an integral part of each command selector switch should be lit after each command is executed.

16. Send the following commands to provide initial set points for thruster startup. NOTE: Use switch sequence outlined in Step 15 whenever sending a command. For EX-1 send disable OLSD command first.

    a. S1C
    b. S2A
    c. S3B
    d. Zero bias

17. Set industrial timer for print interval time (variable from 0 - 15 minutes) desired on Recorder No. 1. This timer is located on right side of console above main breaker.

18. Open Recorder No. 1 glass door. Locate chart ON-OFF switch midway on left side of recorder. Set this switch to the ON position.

19. Insert safety key in key switch S1 and turn key clockwise to the ON position. Refer to Figure 28 for key switch location.

20. Set DVM No. 1 volt-ohms switch to the 150-volt position.

21. Depress start button S3. The Control Panel lamp DSI (located on Figure 28) and power lamp on Sorenson power supply should now be lit.

22. Verify that PCU is in shutdown mode, by noting that command panel shutdown lamp is on. Re-send shutdown command if this lamp is not lit.

*Many of the lamps or the lamp relays failed to function throughout the test, but, in accordance with instructions from the NASA-Project Manager, they were not replaced.

(Cont'd)

(Cont'd)

TABLE 4 - OPERATING INSTRUCTIONS FOR SERT II LIFE TEST CONSOLE

23. Rotate Sorenson coarse voltage-adjust control clockwise until DVM No. 1 reads the desired DC operating voltage.

24. Record reading on control panel elapsed time indicator labeled "PRE-HEAT TIME". Manually reset this meter to zero.

25. Send pre-heat command. Verify that pre-heat lamp on command panel and small red lamp located below pre-heat time meter on control panel is lit.

26. Verify that the following TLM meters are reading

    I3, V3, V4, I7, V7, V8 HIGH, V8 LOW, V9, V10 HIGH and V10 LOW

    NOTE: I2 will read > 4.0 volts in pre-heat. This reading will drop when propellant command is initiated.

27. Set DVM selector switch to Position No. 3 and set volt-ohm switch on DVM No. 1 to 15-volt position.

28. Record V3 readout from DVM No. 1 and I3 readout from DVM No. 2

    V3 typical = 3.1 volts ± 10%
    I3 typical = 4.5 volts ± 10%

29. Set DVM selector switch to Position No. 4

30. Record V4 readout from DVM No. 1

    V4 typical = 3.1 volts ± 10%

31. Set DVM selector switch to Position No. 7

32. Record V7 readout from DVM No. 1 and I7 readout from DVM No. 2

    V7 typical = 3.6 volts ± 10%
    I7 typical = 4.2 volts ± 10%

33. Set DVM selector switch to Position No. 8

34. Record V8 LOW readout from DVM No. 1 and I8 readout from DVM No. 2

    V8 LOW typical (before neutralizer light) = 5 + volts
    V8 LOW typical (after neutralizer light) = 3 volts ± 10% for S3A
    V8 LOW typical (before neutralizer light) = 3.6 volts ± 10% for S3B
    I8 typical = 3.9 volts ± 10%

(Cont'd)

(Cont'd)

TABLE 4 - OPERATING INSTRUCTIONS FOR SERT II LIFE TEST CONSOLE

35. Set DVM selector switch to Position No. 9

36. Record V9 readout from DVM No. 1

    V9 typical for zero bias = 3.0 volts ± 10%

37. Set DVM selector switch to Position No. 10

38. Record V10 LOW readout from DVM No. 1 and ARC counter readout from DVM No. 2

    V10 LOW typical = 8.5 volts ± 10%

39. Set DVM selector switch to Position No. 11

40. Record V8 HIGH readout from DVM No. 1 and overload indicator readout from DVM No. 2

    V8 HIGH typical (before neutralizer lights) = 4.3 volts ± 10%
    V8 HIGH typical (after neutralizer lights) = 0.4 volt

41. Set DVM selector switch to Position No. 12.

42. Record V10 HIGH readout from DVM No. 1

    V10 HIGH typical = 4.7 volts ± 0.4 volt

43. With DVM selector switch still set to position No. 12, set thermistor selector switch to baseplate position.

44. Record baseplate temperature readout on DVM No. 2. Use thermistor calibration chart to convert voltage readout to temperature.

45. With DVM selector switch still set to Position No. 12, set thermistor selector switch to 8KHz position.

46. Record 8KHz temperature readout on DVM No. 2. Use thermistor calibration chart to convert voltage readout to temperature.

47. Allow thruster to pre-heat a minimum of one and one-half hours.

48. Open Recorder No. 2 glass door. Locate chart ON-OFF switch midway on left side of recorder. Set this switch to the ON position.

49. Set DVM selector switch to Position No. 2

(Cont'd)

(Cont'd)

TABLE 4 - OPERATING INSTRUCTIONS FOR SERT II LIFE TEST CONSOLE

50. Send propellant command. Verify that command panel pre-heat lamp comes on.

51. Verify that V2 TLM panel meter is reading and that I2 TLM panel meter has dropped from its original near full scale reading to some lower value.

52. Record V2 readout from DVM No. 1
    Record I2 readout from DVM No. 2

53. Send operate command. Verify that operate lamp on control panel is lit and that lamp located beneath control panel elapsed time indicator labeled "Engine Time" is lit. Verify that V5 and V6 TLM panel meters are reading.

54. Switch through Position Nos. 1 through 12 on DVM selector switch and record readings of DVM Nos. 1 and 2 for all these positions. Position No. 12 will give PCU temperature readouts on DVM No. 2 providing the thermistor selector switch is in the baseplate or 8KHz position.

TROUBLE-SHOOTING AIDS

1. If none of the lamps called out in Step No. 9 indicate, check to see that AC power cord is plugged in and that the outlet used has power.

2. If command panel power lamp and logic lamps do not light after Step No. 9 is executed, check to see that u-BLOC power supply switch is ON and check for continuity of fuses mounted along side of this switch.

3. If power lamp on thermistor panel does not light after Step No. 9 is executed check fuse mounted on thermistor panel.

4. If panel power lamp on control panel does not light after Step No. 10 is executed, check 5-amp fuse mounted on control panel and panel power lamp.

5. If contactor click is not heard and control panel lamp labeled "PC ON" does not light when Step No. 20 has been executed, check to see that door interlocks are closed.

6. If Sorenson power supply goes into current limit when operate command is initiated, check to see that Sorenson current adjust control is set at 20 amps.

7. The Sorenson power supply may go into current limit unexpectedly during a nominal steady state running mode. This may be caused by transient spikes triggering the SCR in the Sorenson power supply protection circuit. This SCR must be cut off by removing power. To do this - depress the emergency STOP button. Turn coarse voltage control to zero and repeat Step Nos. 15 through 47 to restart thruster.

TABLE 5 - TEST PARAMETER IDENTIFICATION AND NOMINAL VALUES

Symbol	Designation (and Alternate Designations Used During Test)	Nominal Value or Range*
V2	- Main Propellant Vaporizer Heater Voltage (Thruster Vaporizer Voltage)	1.1 to 1.3 VDC
I2	- Main Propellant Vaporizer Heater Current (Thruster Vaporizer Current)	1.7 to 2.0 a
V3	- Main Cathode Heater Voltage (Thruster Cathode and Isolator Heater Voltage)	7.0 to 11.0 VDC
I3	- Main Cathode Heater Current (Thruster Cathode and Isolator Heater Current)	1.40 to 1.60 a
V4	- Discharge Chamber Supply Voltage (Main Anode Voltage)	37.0 VDC
I4	- Discharge Chamber Supply Current (Main Anode Current)	1.70 to 1.90 a
V5	- Ion Beam Supply Voltage (Screen Voltage, Positive High Voltage)	3175 to 3225 VDC
I5	- Ion Beam Supply Current (Screen Current)	250 ma
V6	- Accelerator Supply Voltage (Accelerator Voltage, Negative High Voltage)	-1650 to -1700 VDC
I6	- Accelerator Supply Current (Accelerator Current)	<1.7 ma
V7	- Neutralizer Cathode and Vaporizer Heater Voltage	4.0 to 6.0 VDC
I7	- Neutralizer Cathode and Vaporizer Heater Current	1.8 to 2.1 a
V8	- Neutralizer Keeper Electrode Supply Voltage (Neutralizer Keeper or Anode Voltage)	22 to 24 VDC
I8	- Neutralizer Keeper Electrode Supply Current (Neutralizer Keeper or Anode Current)	0.2a
V9	- Neutralizer Emission Supply Voltage (Neutralizer Bias Voltage)	0 VDC
I9	- Neutralizer Emission Supply Current (Neutralizer Current)	250 ma
V10	- Main Cathode Keeper Supply Voltage	9 to 15 VDC
I10	- Main Cathode Keeper Supply Current	0.3 a (Not measured)
	Arc Counter	
	Overload	
	Sun Thermistor	
	Shadow Thermistor	
	Neutralizer Thermistor	
	Neutralizer Tank Pressure (Thruster Fuel Tank Pressure)	

*At Thruster System Input Voltage of 66 volts DC, and operation in the AAA Mode.

(Cont'd)

(Cont'd)

TABLE 5 - TEST PARAMETER IDENTIFICATION AND NOMINAL VALUES

Symbol	Designation (and Alternate Designations Used During Test)	Nominal Value or Range*
	PCU 8kHz Thermistor	
	PCU Base Plate Thermistor	
	Test Console 5 Volt Test	
	Test Console 9 Volt Test	
	Thruster System Elapsed Time - Preheat	
	Thruster System Elapsed Time - Engine	
	Thruster System Input Voltage	66.0 VDC
	Thruster System Input Current	
	Thruster System Operating Mode	AAA
	Thruster System Voltage to Ground	
	Test Facility, Pressures (4)	
	Veeco, RG75-PCU Area	
	Veeco, RG75-Thruster	
	NRC, 751-Thruster	
	NRC, 751-Chamber "Outside"	
	Collector Temperature	
	Liner Temperature	
	PCU Temperature (Cold Plate)	
	**PCU Cold Plate Temperature	
	**PCU Case Temperature (Top)	
	**Thruster Case Temperature	

*At Thruster System Input Voltage of 66 volts DC, and operation in the AAA Mode.

**Recorded only during startup through Run No. 7

TABLE 6 - SUMMARY OF OPERATING HOURS BY RUN NUMBER

Run No.	Thruster No.	PCU No.	Test Console No.	Operating Hours In The Run	Accumulated Total Operating Hours
1	P-4	*	GE-B	6.2	6.2
2	P-4	*	GE-B	25.0	31.2
3	P-20	EX-1	LTC-1	0	31.2
4	P-20	EX-1	LTC-1	26.0	57.2
5	P-20	PT-1	LTC-1	738.1	795.3
6	P-20	PT-1	LTC-1	402.6	1197.9
7	P-15	PT-1	LTC-1	0.5	1198.4
8	P-15	PT-1	LTC-1	30.0	1228.4
9	P-20	PT-1	LTC-1	6742.9	7971.3**

*PCU No. 3S2020BM121A1 was a part of Test Console GE-B.
**Not including 38.6 hours in the Preheat Mode. Thruster No. P-20 Neutralizer System operating time was as follows:

1209.4 hours in AAA Mode before Run No. 9 (including operation at NASA-LeRC).
2737.6 hours in AAA Mode during Run No. 9 (as of 3/27/70).
4005.3 hours in BAA Mode during Run No. 9 (as of 9/22/70).

2737.6 + 4005.3 = 6742.9 hours in AAA and BAA Modes during Run No. 9.
1209.4 + 2737.6 = 3947.0 hours in AAA Mode, total.
3947.0 + 4005.3 = 7952.3 hours in AAA and BAA Modes, total.

(BAA Mode with Beam Current I5 = 200 ma corresponds to 80% thrust level of AAA Mode with Beam Current I5 = 250 ma. Operation in BAA Mode was initiated after Neutralizer Control Loop became unstable in AAA Mode.)

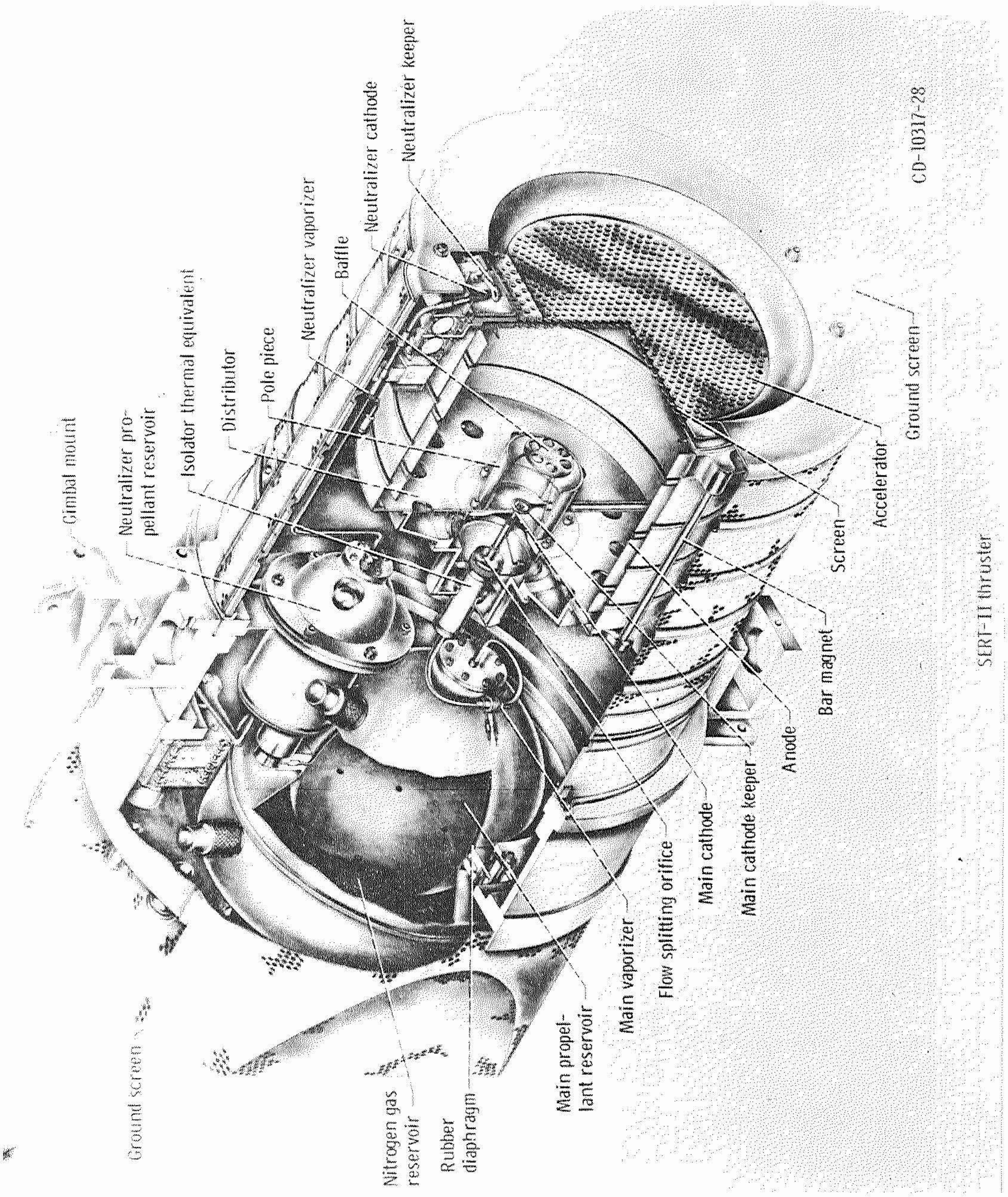
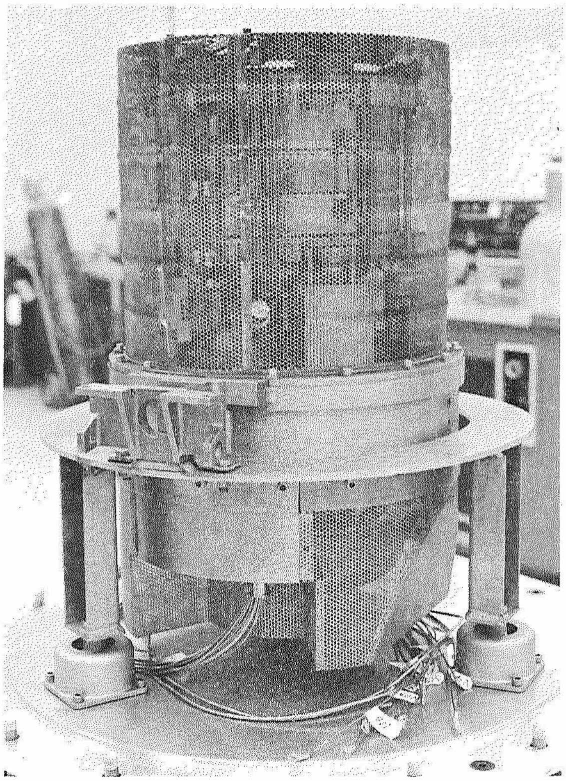
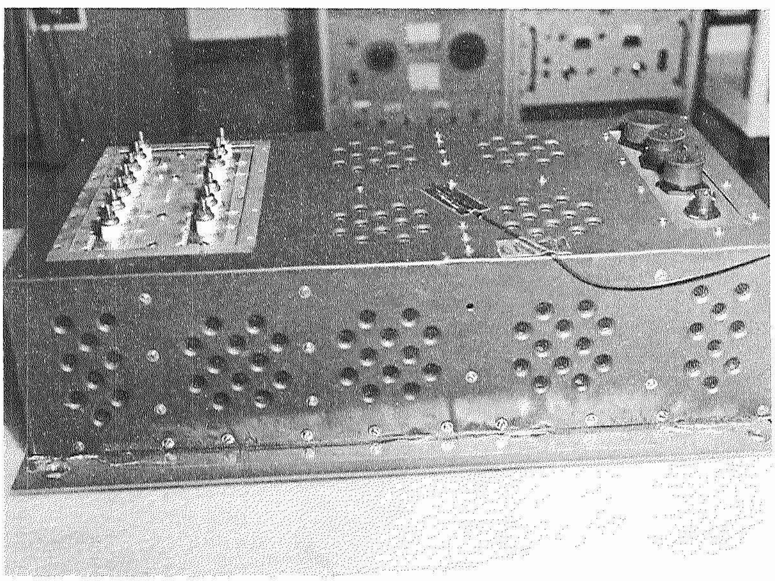


FIGURE 1. SERT II THRUSTER (NASA DRAWING)

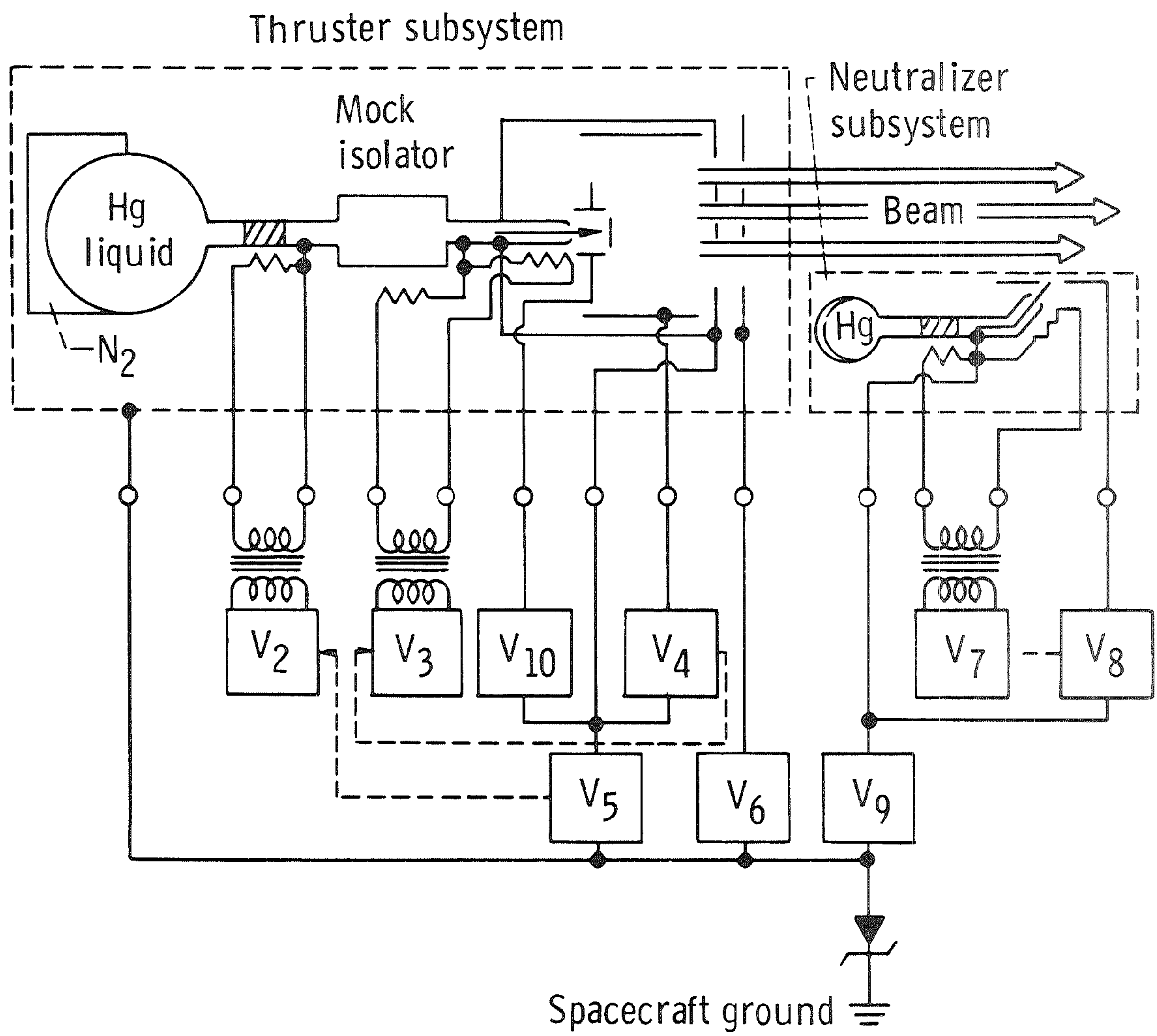


A – ION THRUSTER P-4 PRIOR TO TESTING IN RUN NO. 1



B – POWER CONDITIONING UNIT PT-1 AFTER REPAIR OF TERMINAL AND BEFORE RUN NO. 5

FIGURE 2. THRUSTER P-4 AND POWER CONDITIONING UNIT PT-1



V_2, Main vaporizer voltage
V_3, Main cathode voltage
V_4, Main anode voltage
V_5, Screen voltage
V_6, Accelerator voltage
V_7, Neutralizer cathode and vaporizer voltage
V_8, Neutralizer anode voltage
V_9, Neutralizer bias voltage
V_{10}, Main keeper voltage

FIGURE 3. ELECTRICAL SCHEMATIC OF SERT II THRUSTER
(NASA DRAWING)

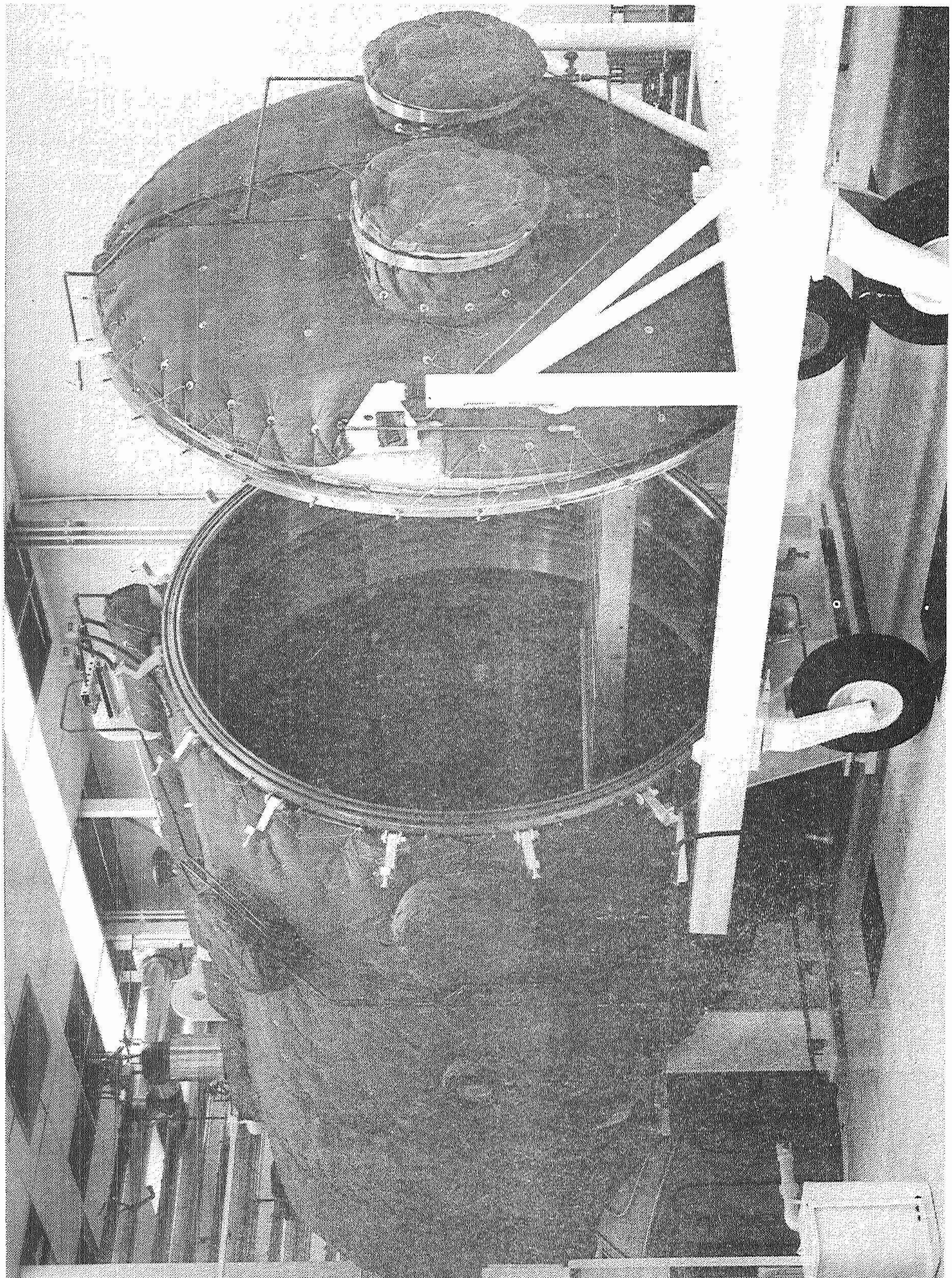


FIGURE 4 8–FOOT DIAMETER SPACE CHAMBER

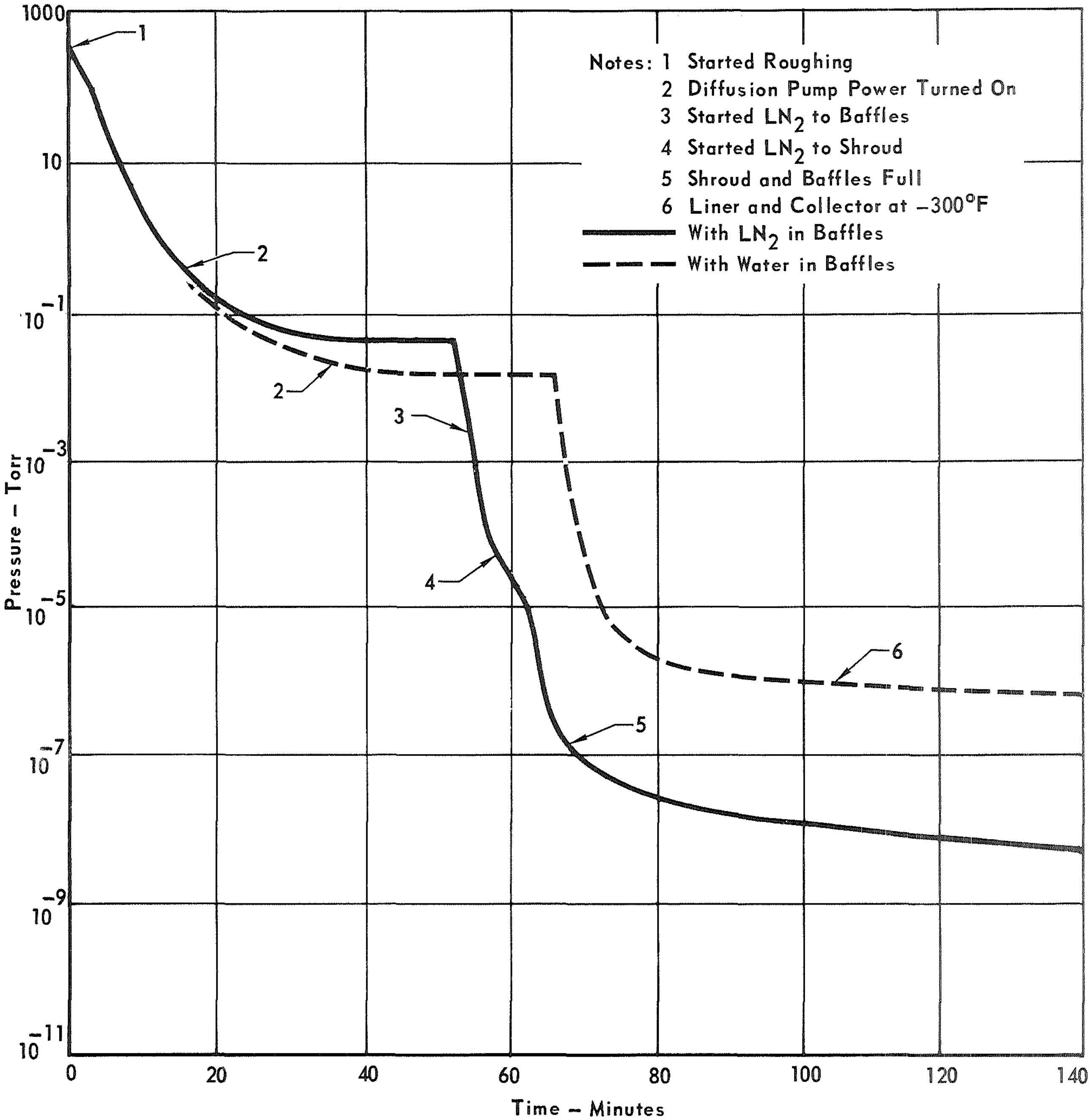
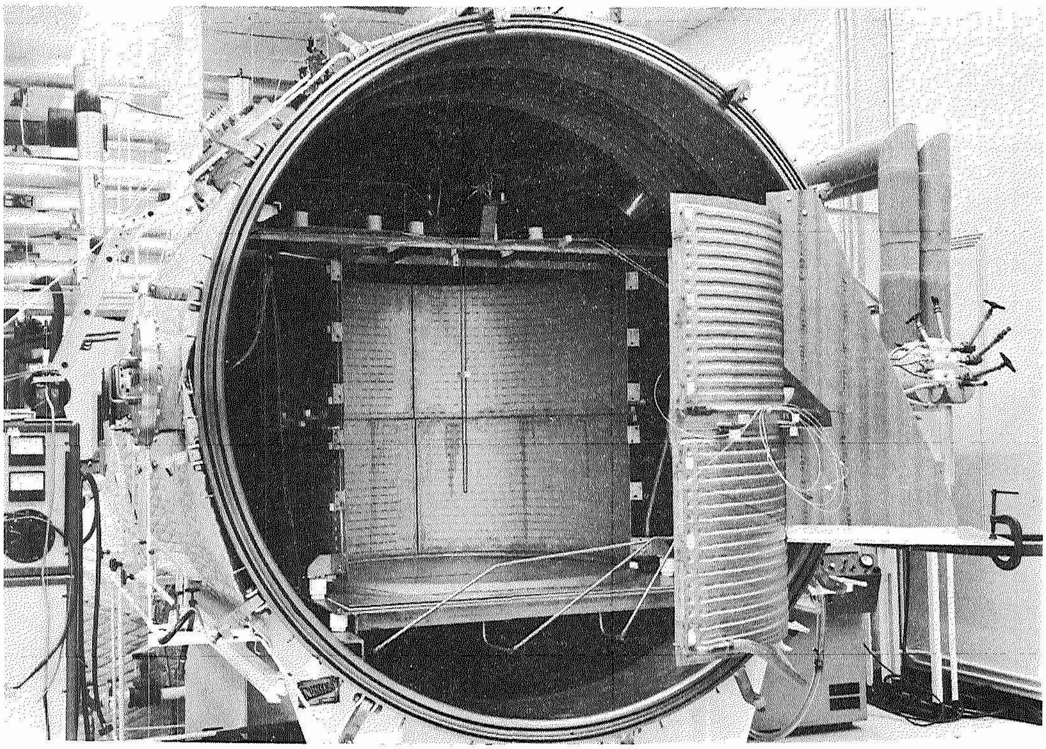
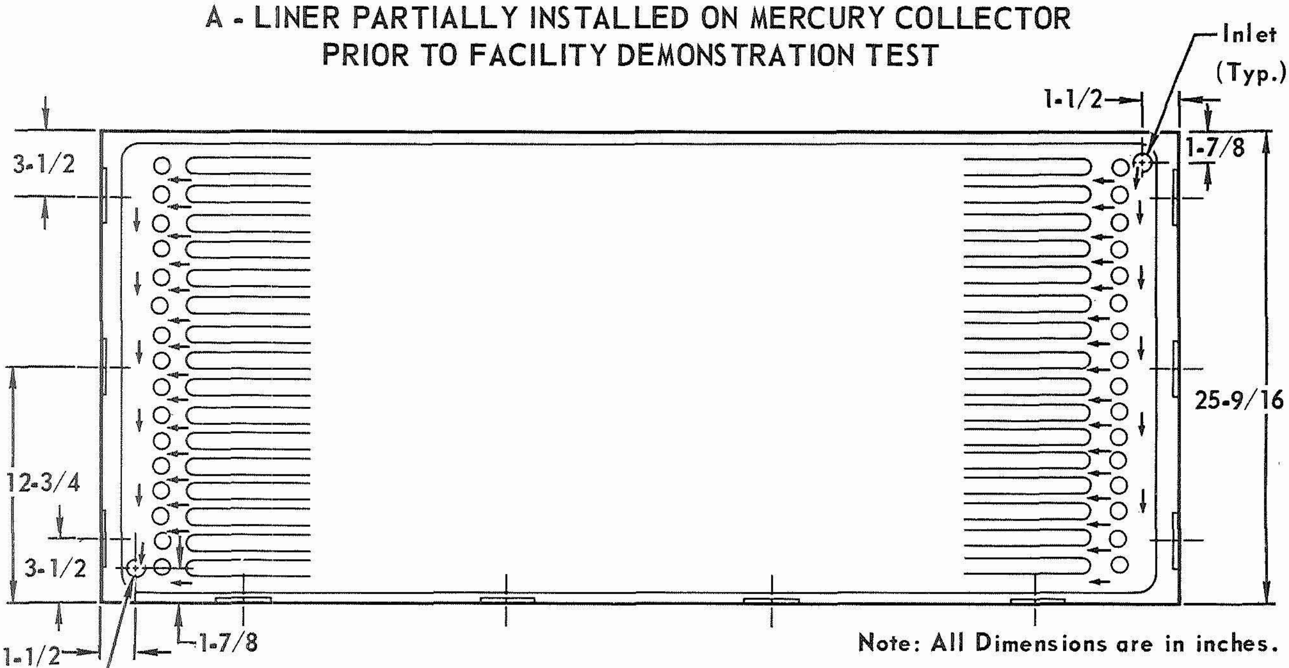


FIGURE 5 RELATIVE PERFORMANCE OF 8–FOOT CHAMBER WITH LN_2 OR COOLING WATER IN BAFFLES



A - LINER PARTIALLY INSTALLED ON MERCURY COLLECTOR PRIOR TO FACILITY DEMONSTRATION TEST



Note 1: Liner Panel, 6 Required, 26 Inch x 59 Inch Nom., Parallel Flow Paths, Type P-22, Single Embossed, 16 Gage Backsheet x 16 Gage Panel Coil, S.S.

Note 2: Collector Panel, 3 Required, 19 Inch x 59 Inch Nom., Parallel Flow Paths, Type P-22, Single Embossed, 12 Gage Backsheet x 16 Gage Panel Coil, S.S.

B - LINER AND COLLECTOR PANEL DETAILS

FIGURE 6 LINER AND COLLECTOR

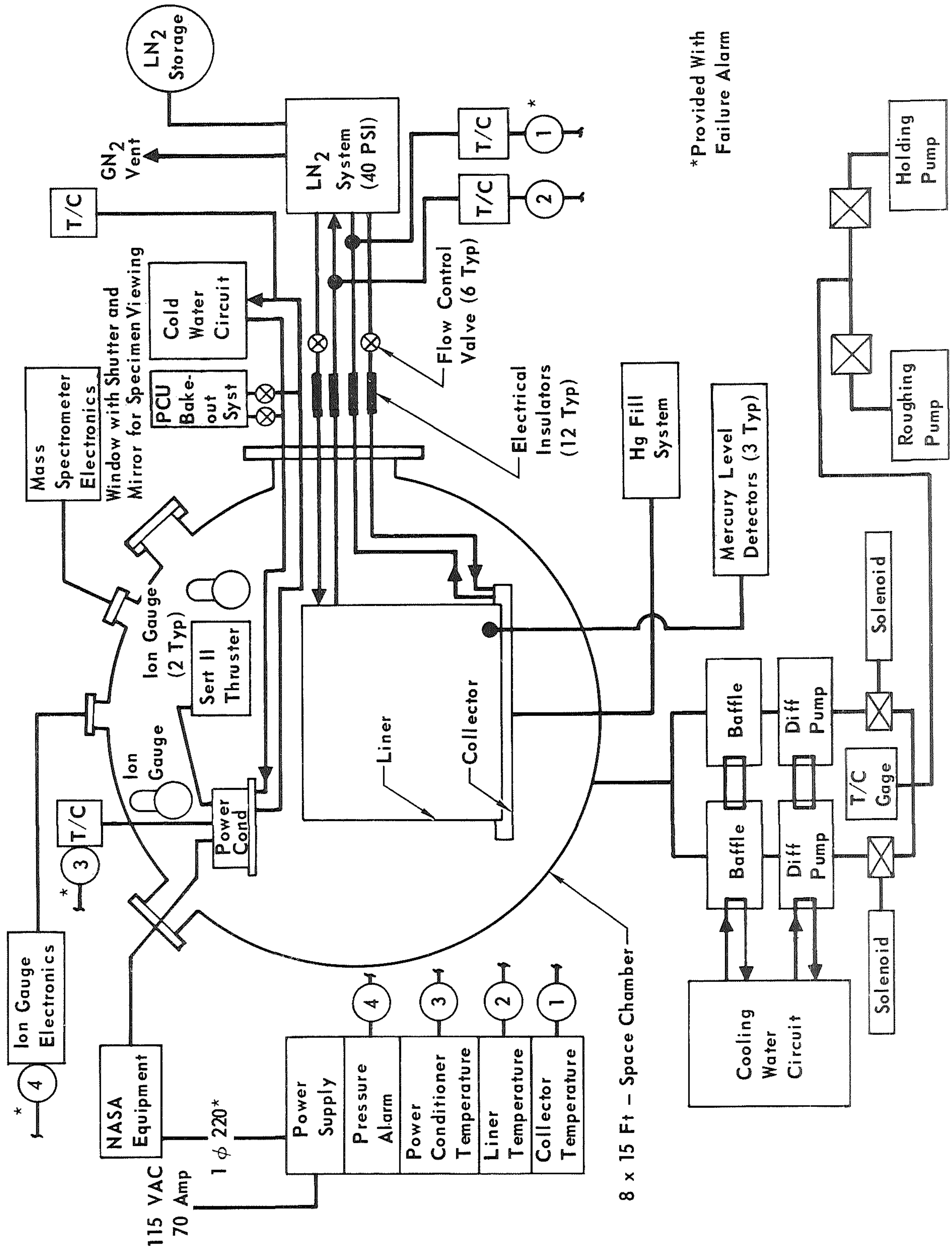


FIGURE 7 ION THRUSTER TEST SETUP DIAGRAM

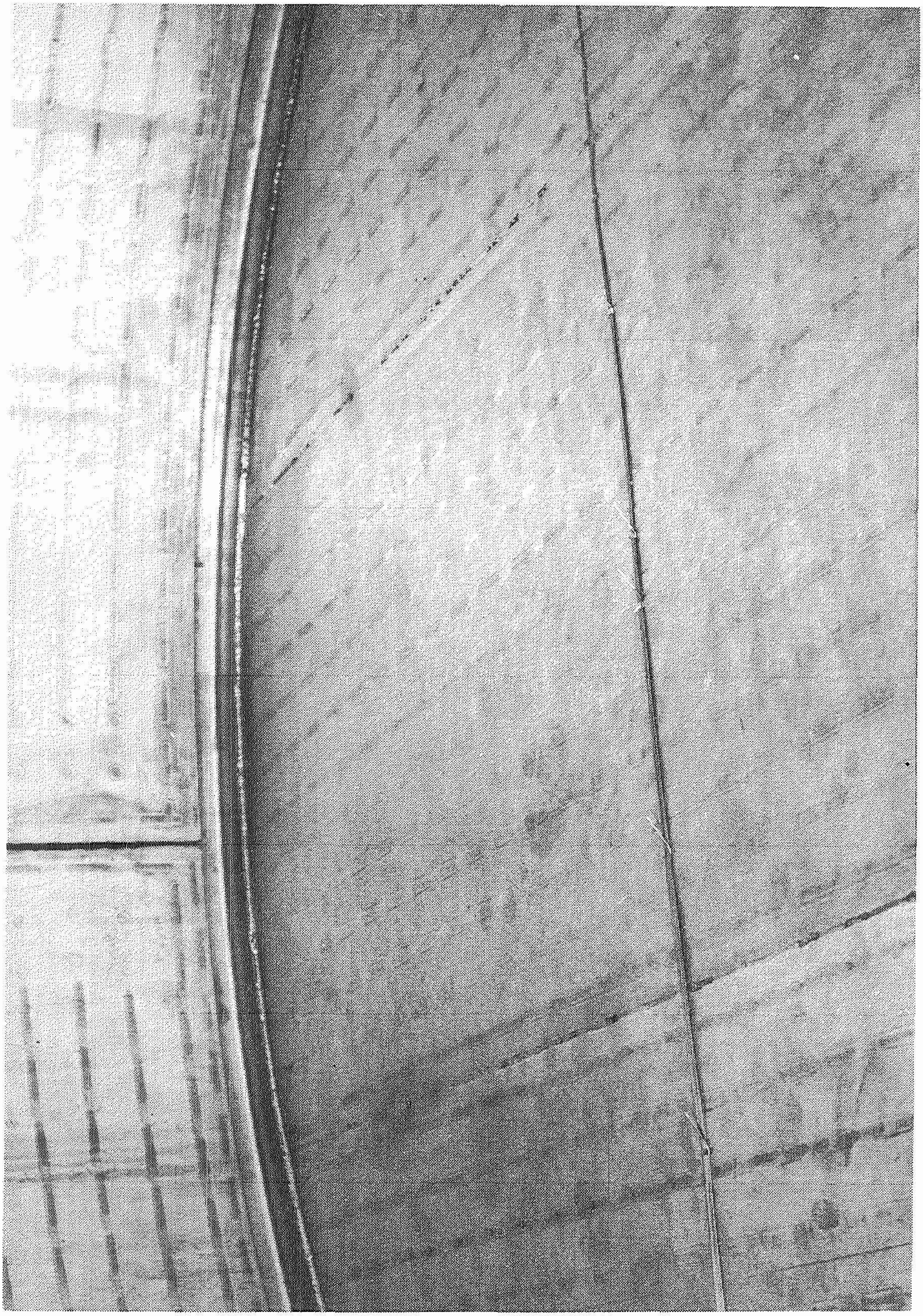
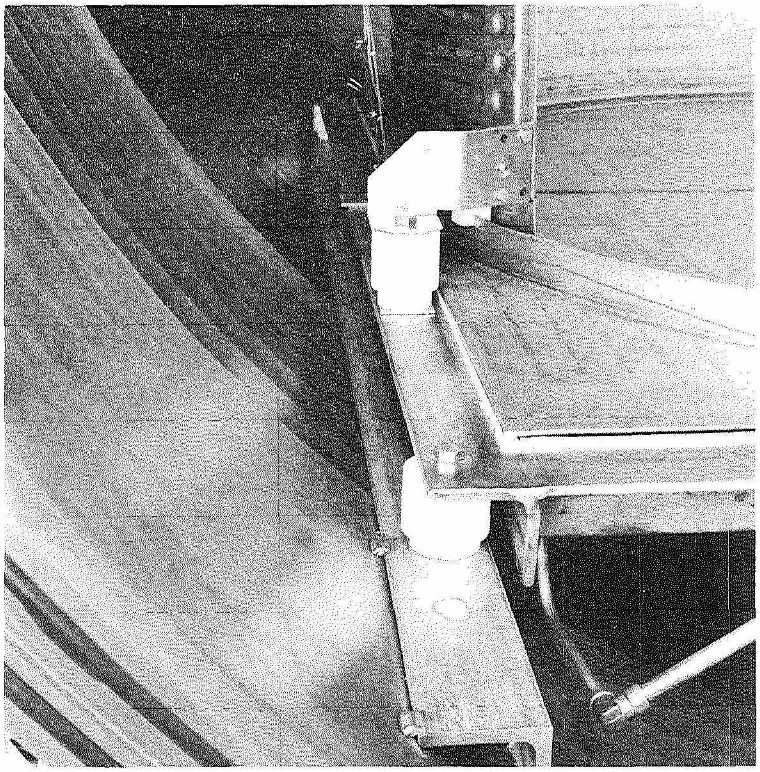
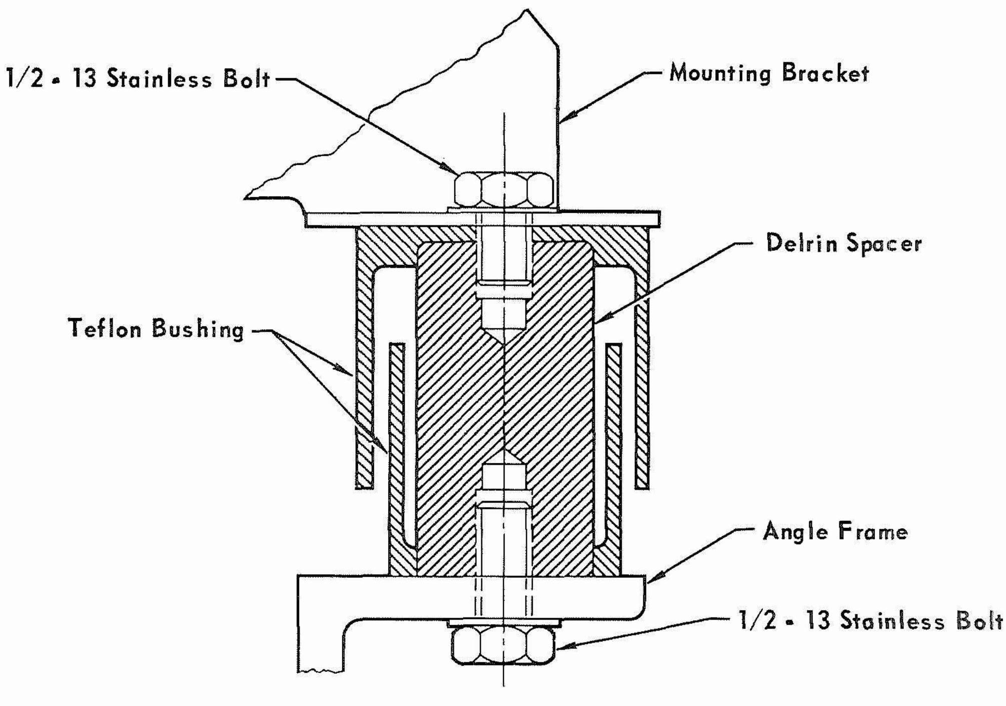


FIGURE 8 INSIDE VIEW OF MERCURY COLLECTOR AND BOTTOM EDGE OF LINER SHOWING THERMOCOUPLES TO MEASURE MERCURY TEMPERATURE



A- ELECTRICAL INSULATORS ON LINER AND COLLECTOR



B- TYPICAL ELECTRICAL INSULATOR MOUNT

FIGURE 9 ELECTRICAL INSULATORS

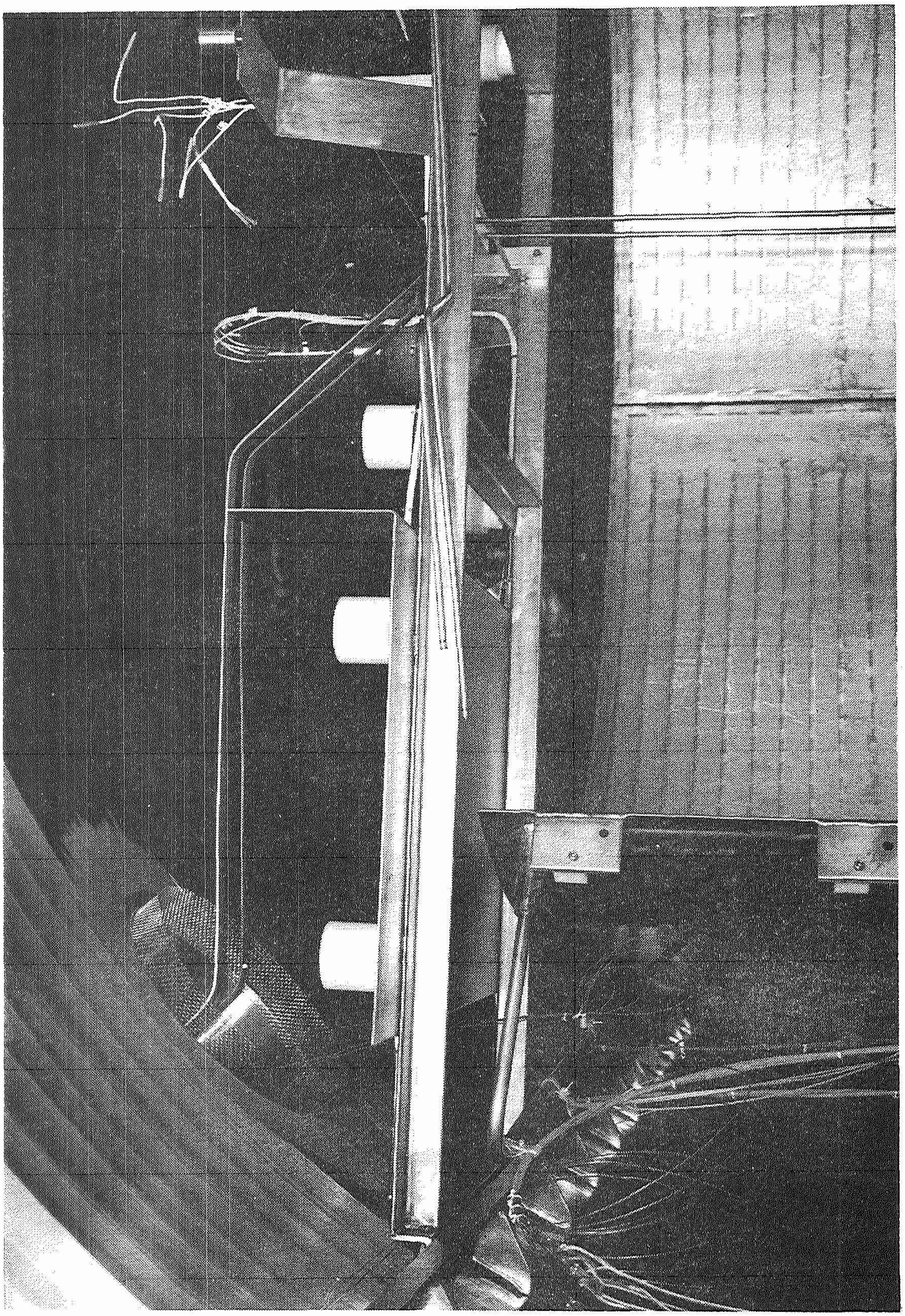
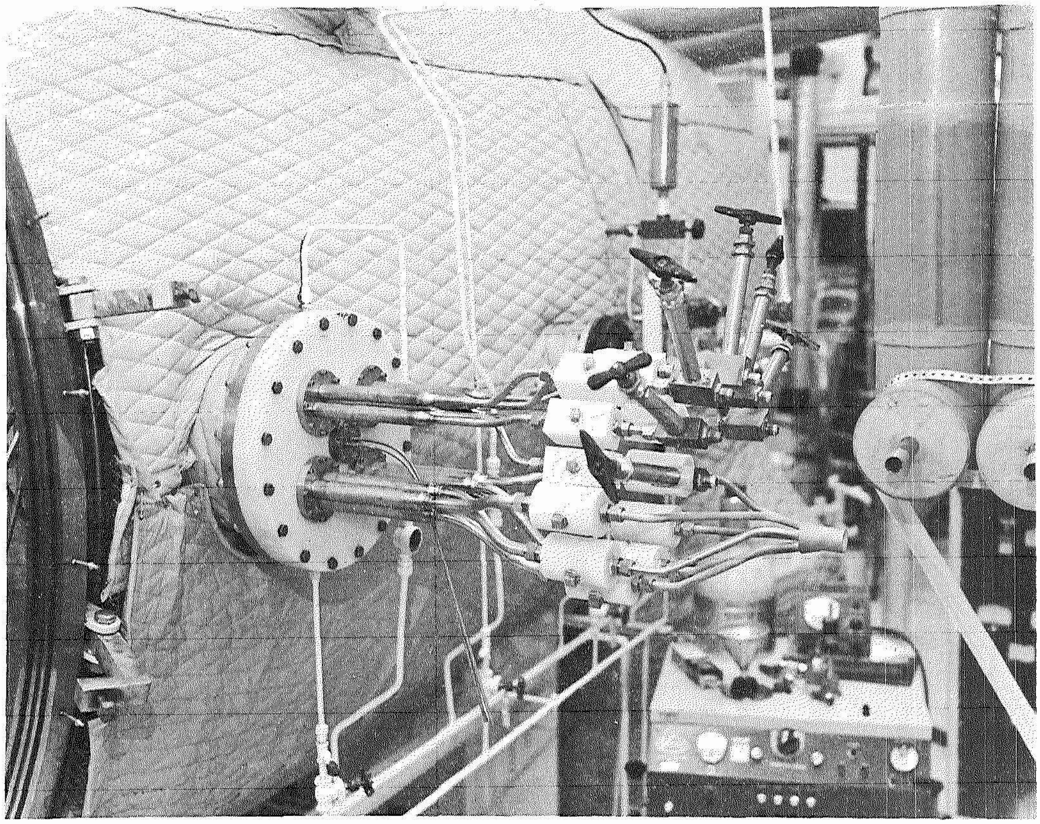
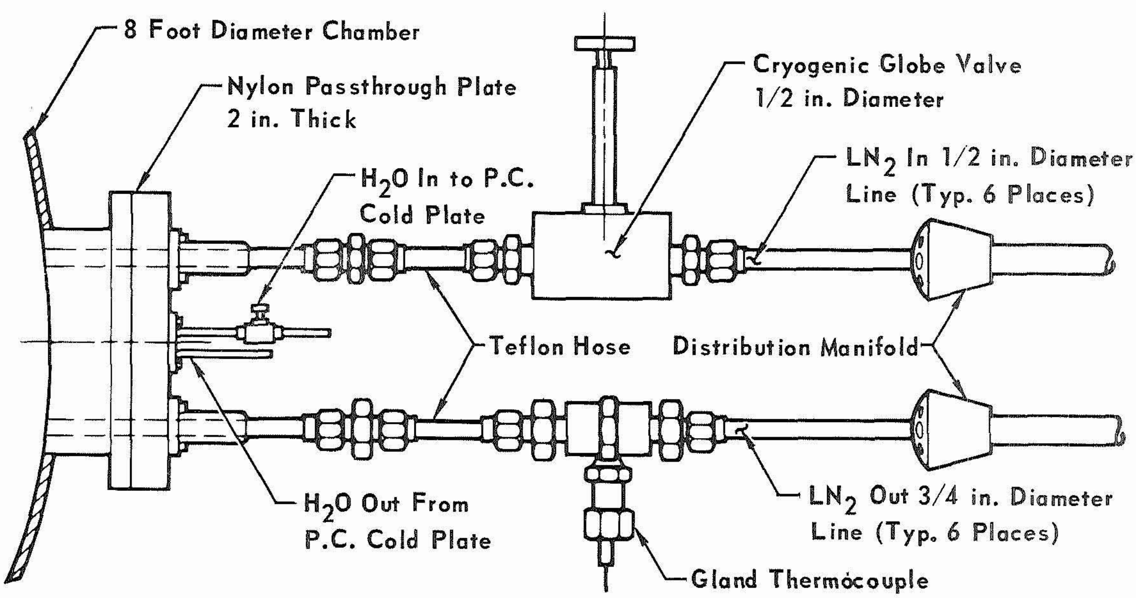


FIGURE 10 POWER CONDITIONING UNIT COLD PLATE AND THRUSTER SUPPORT ASSEMBLY



A-ELECTRICALLY INSULATED LN_2 AND WATER PASSTHROUGHS AND VALVES



B-FLUID LINE INSULATION SYSTEM

FIGURE 11 FLUID PASSTHROUGHS

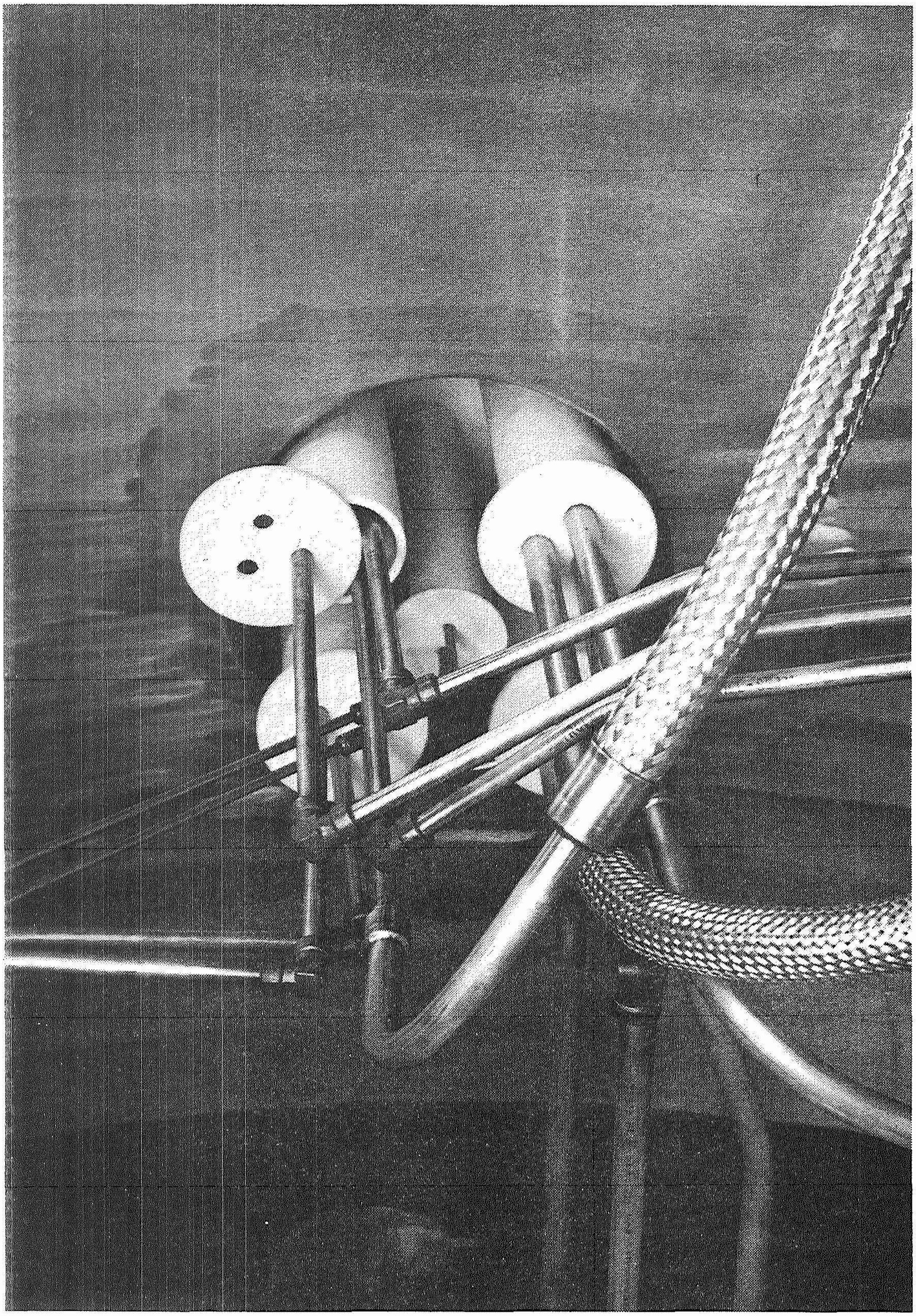


FIGURE 12 ELECTRICALLY INSULATED AND MERCURY-SHIELDED LN_2 AND WATER PASSTHROUGHS AS SEEN FROM INSIDE CHAMBER

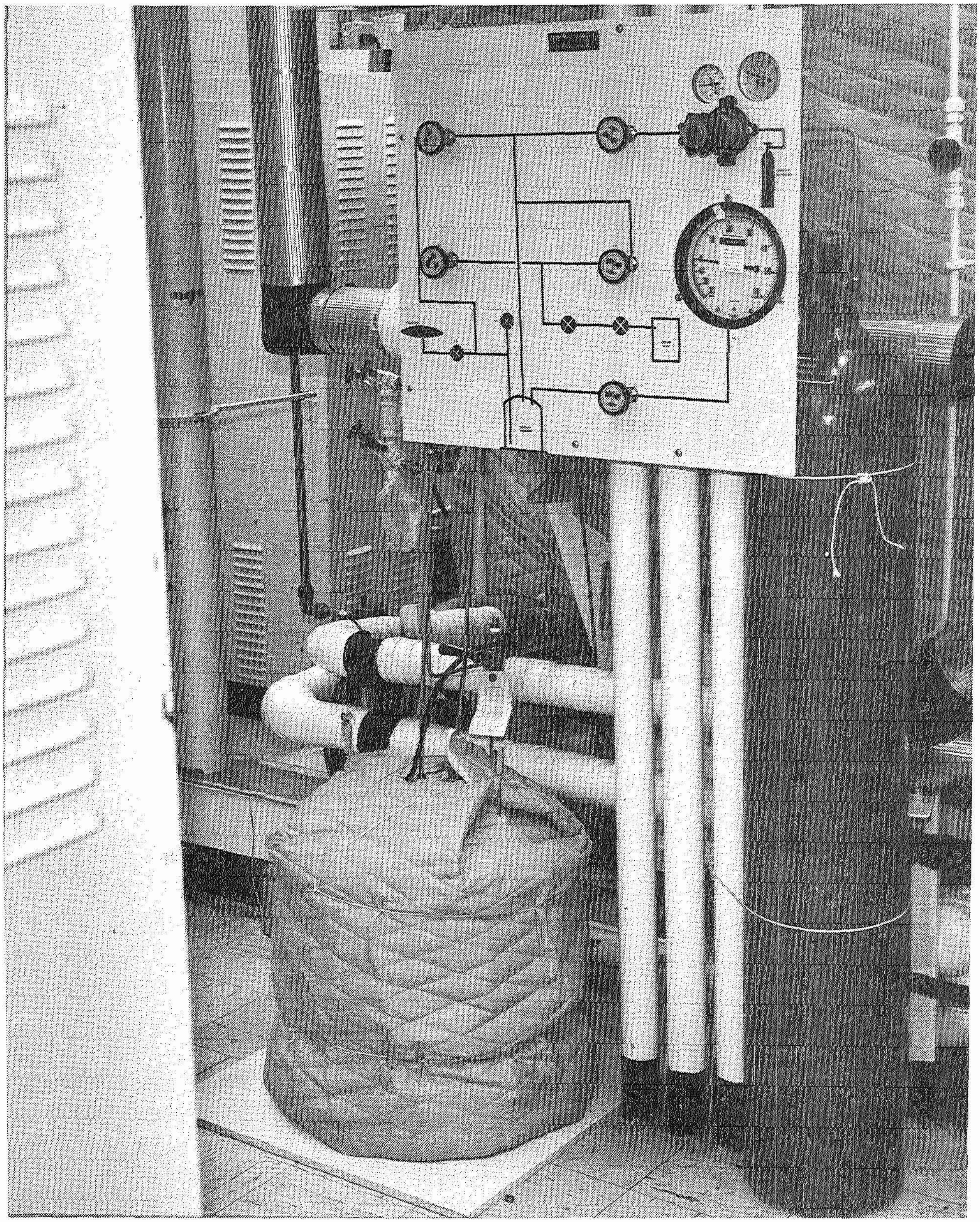


FIGURE 13 MERCURY FILL-DRAIN SYSTEM

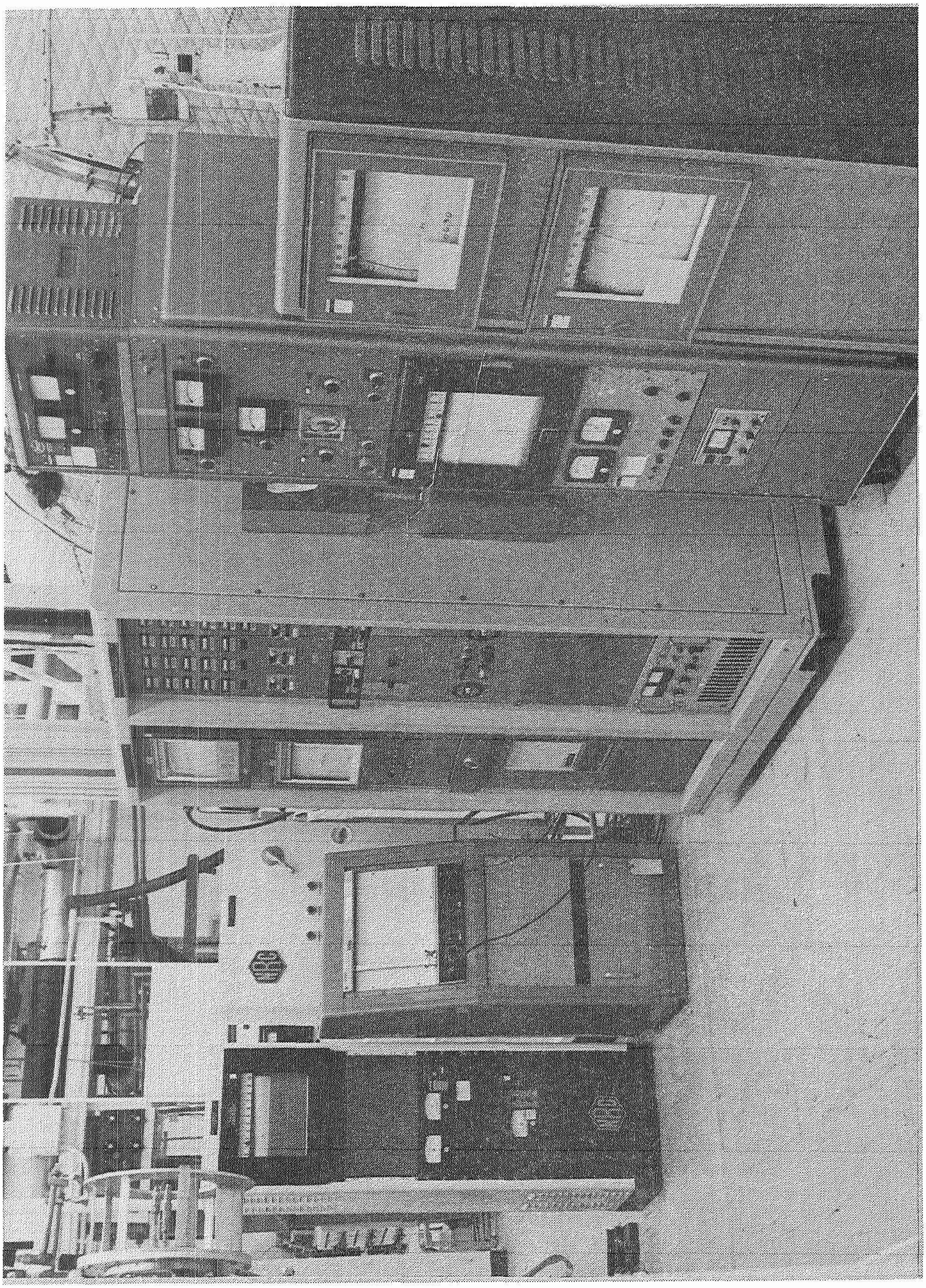


FIGURE 14 GFE AND MDC TEST CONSOLES

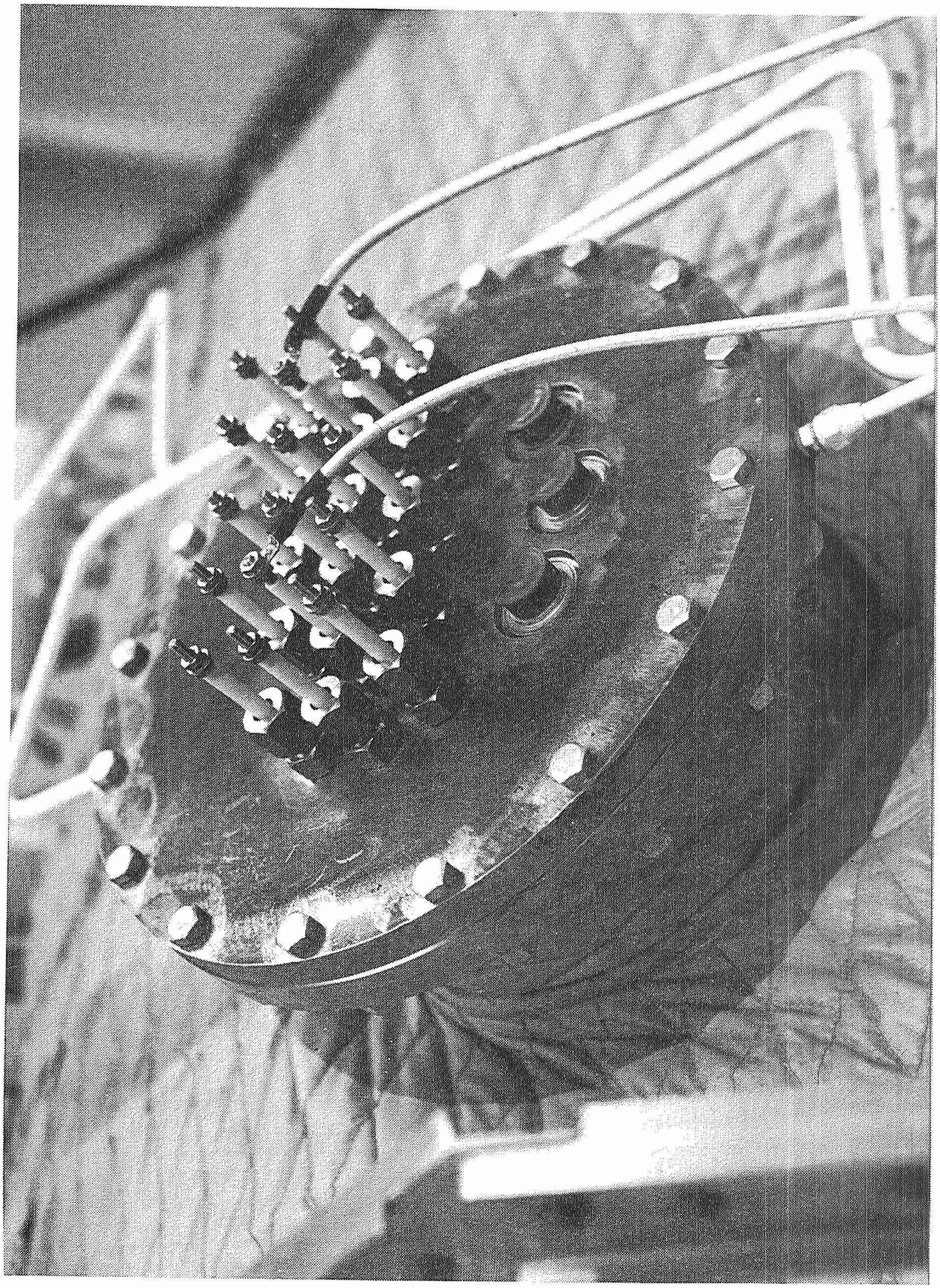


FIGURE 15 THRUSTER AND PCU ELECTRICAL PASSTHROUGHS

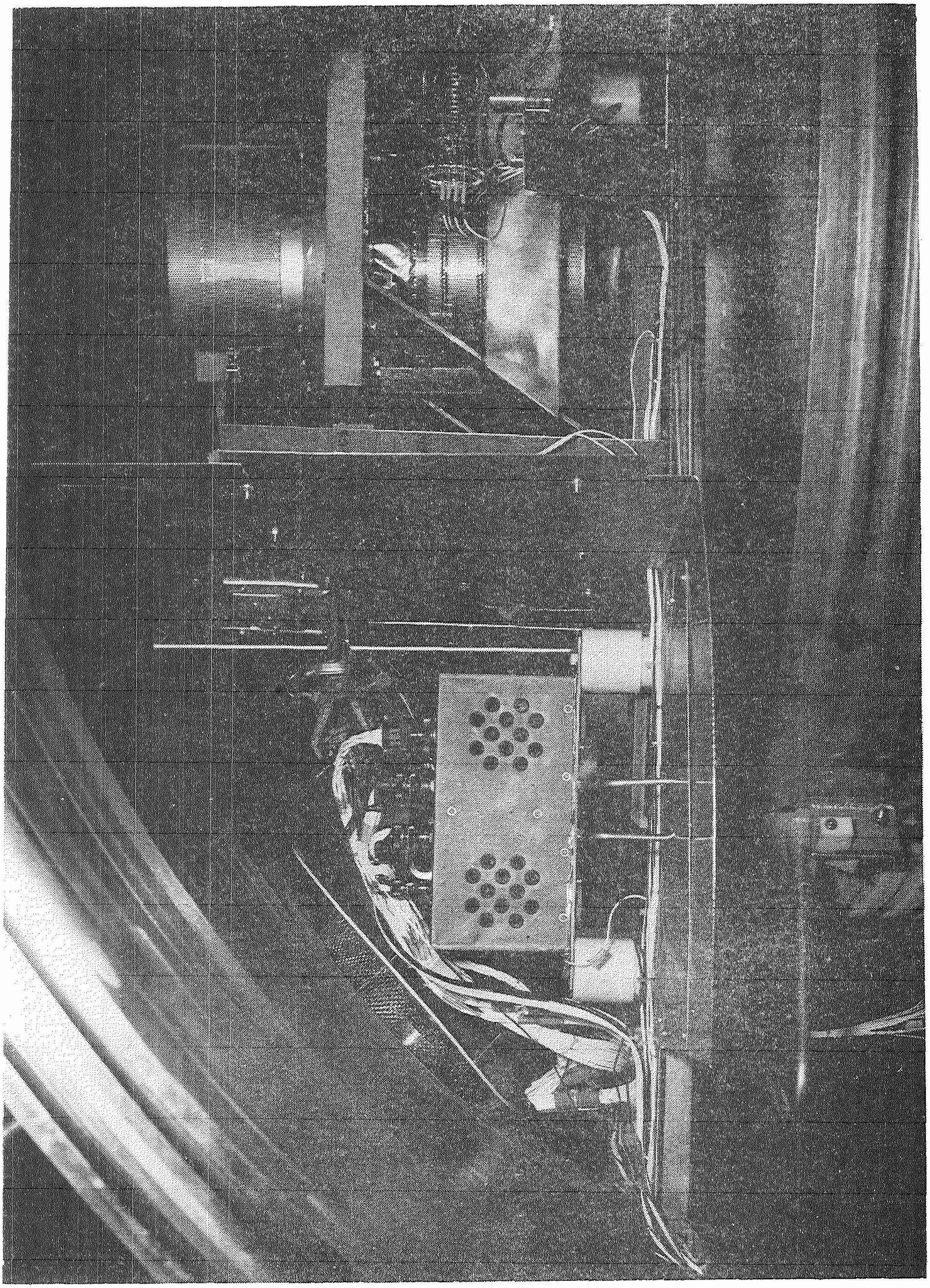


FIGURE 16 THRUSTER P–20 AND PCU EX–1 IN CHAMBER PRIOR TO RUN NO. 3

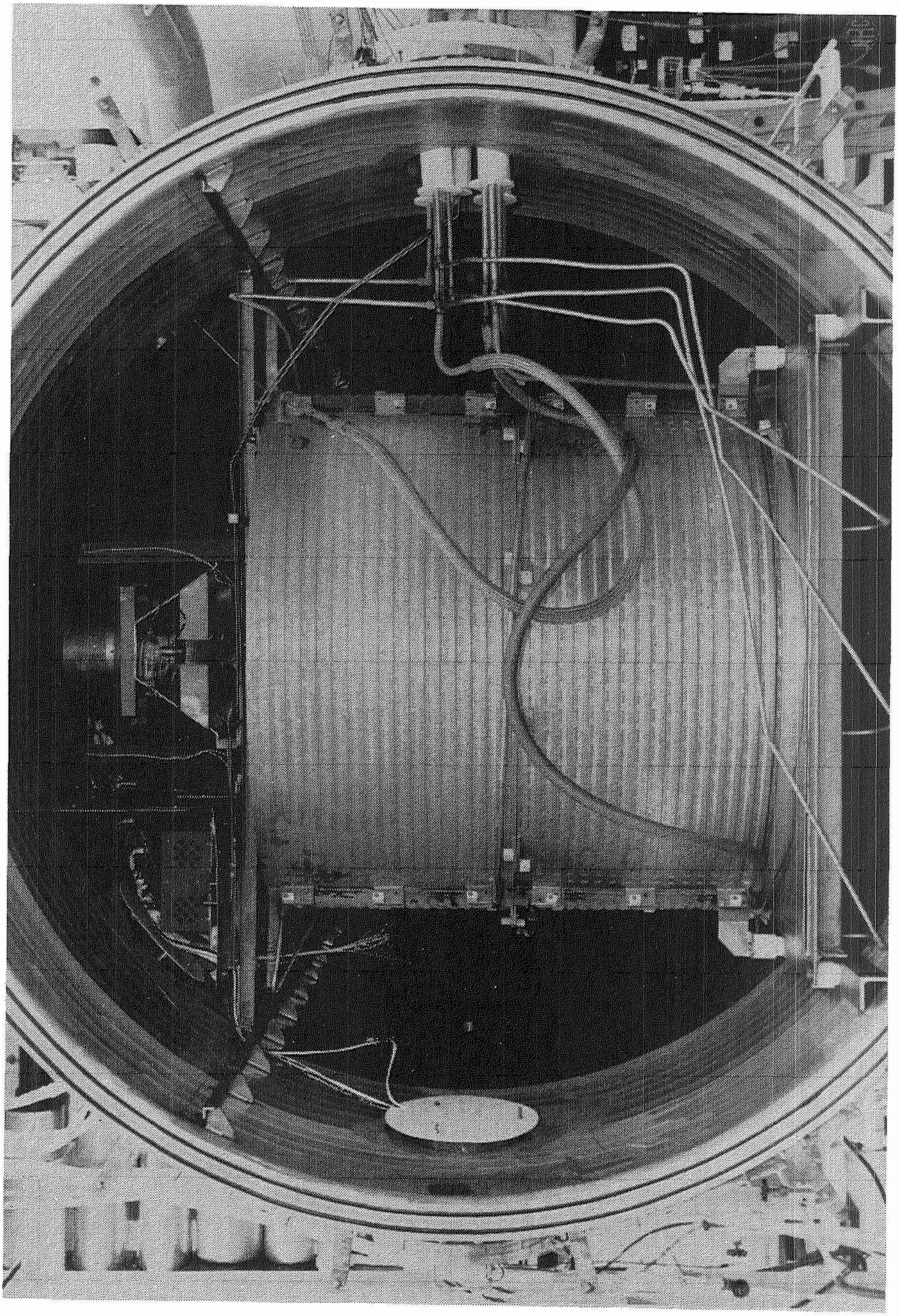


FIGURE 17 THRUSTER P–20 AND PCU EX–1 INSTALLED IN CHAMBER PRIOR TO TESTING IN RUN NO. 3

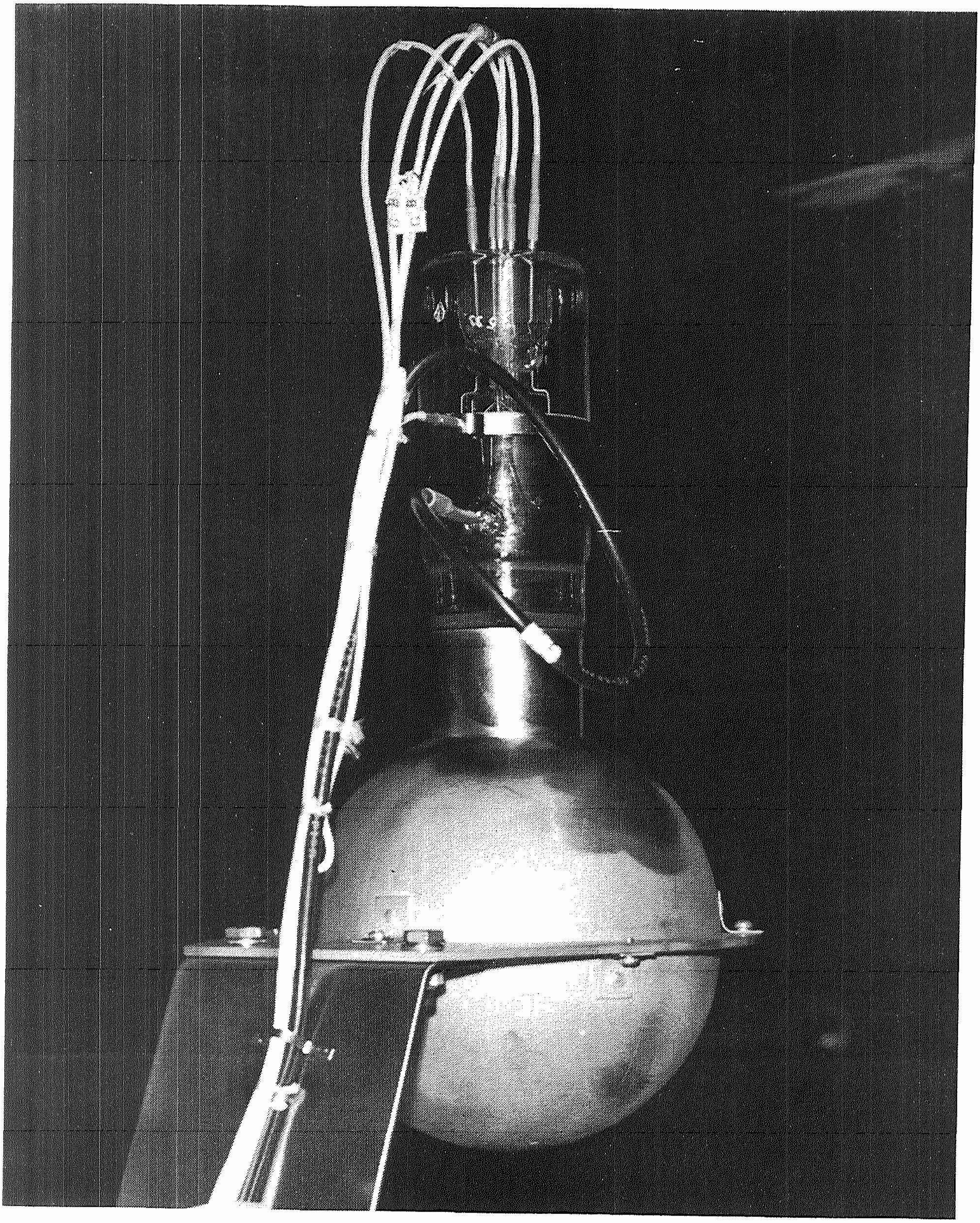


FIGURE 18 VACUUM GAUGE WITH SPHERICAL BAFFLE

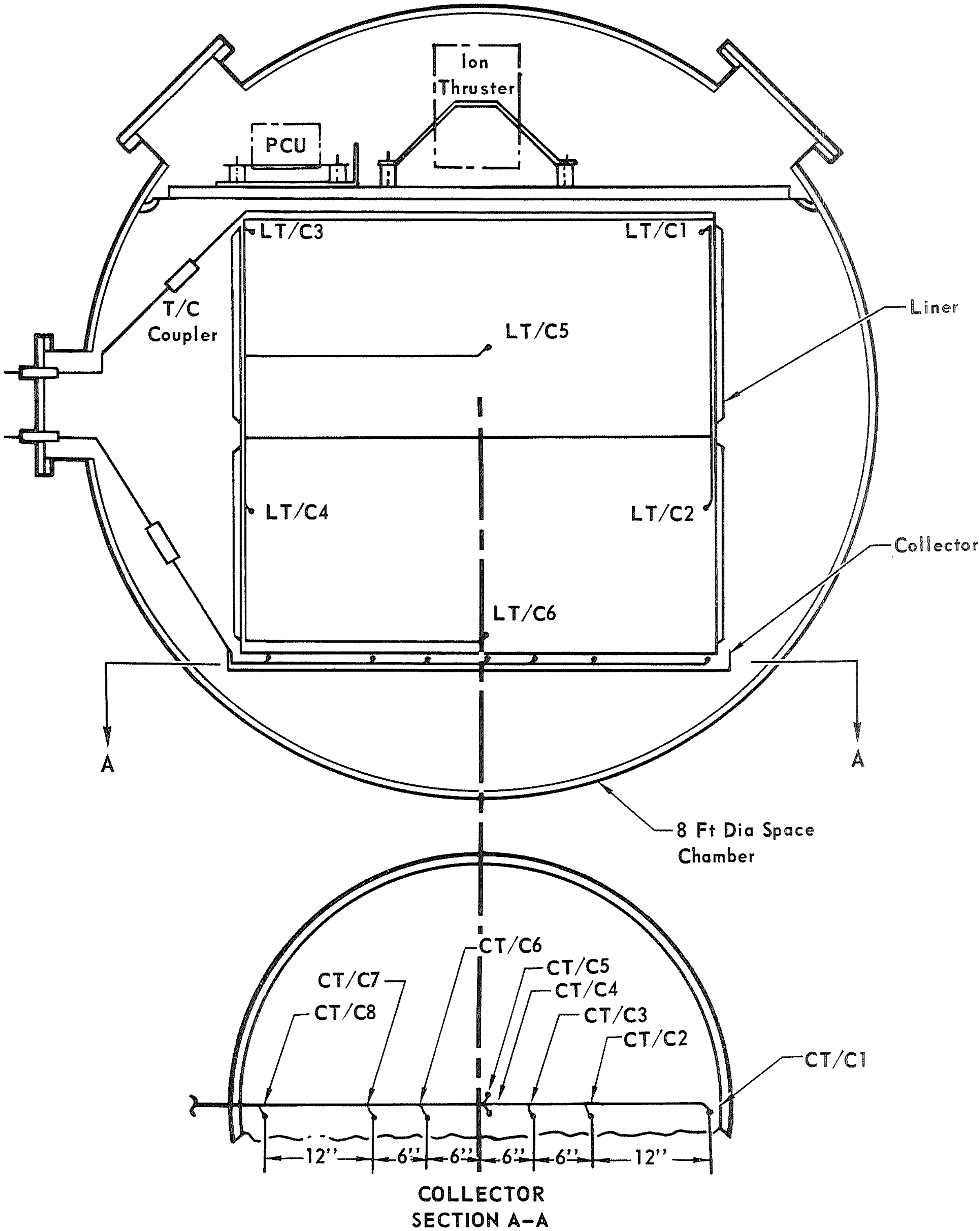


FIGURE 19 THERMOCOUPLE LOCATIONS FOR FACILITY DEMONSTRATION TEST

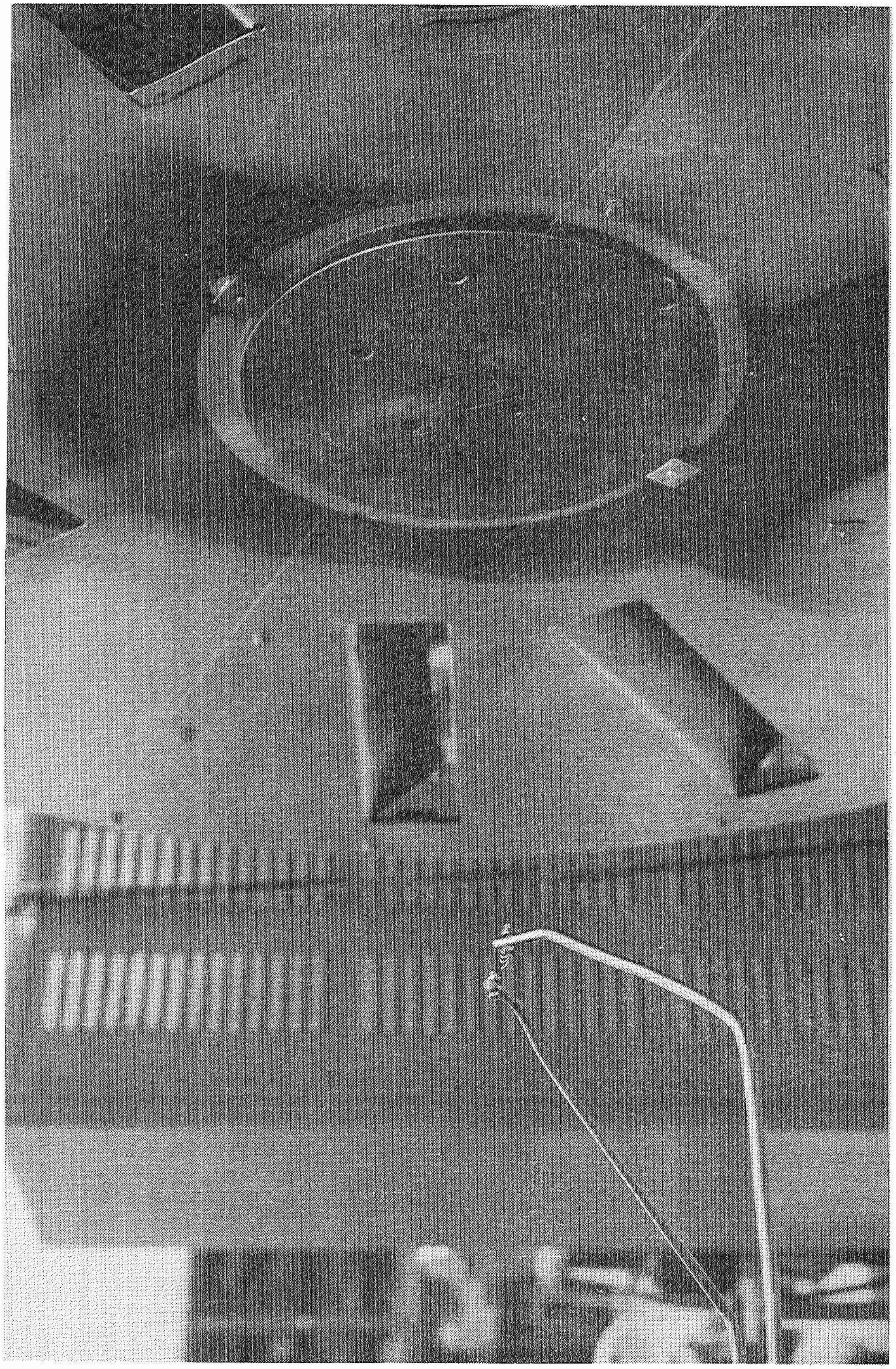


FIGURE 20 PROTOTYPE ELECTRON BOMBARDMENT DEVICE AND DUMMY COLLECTOR

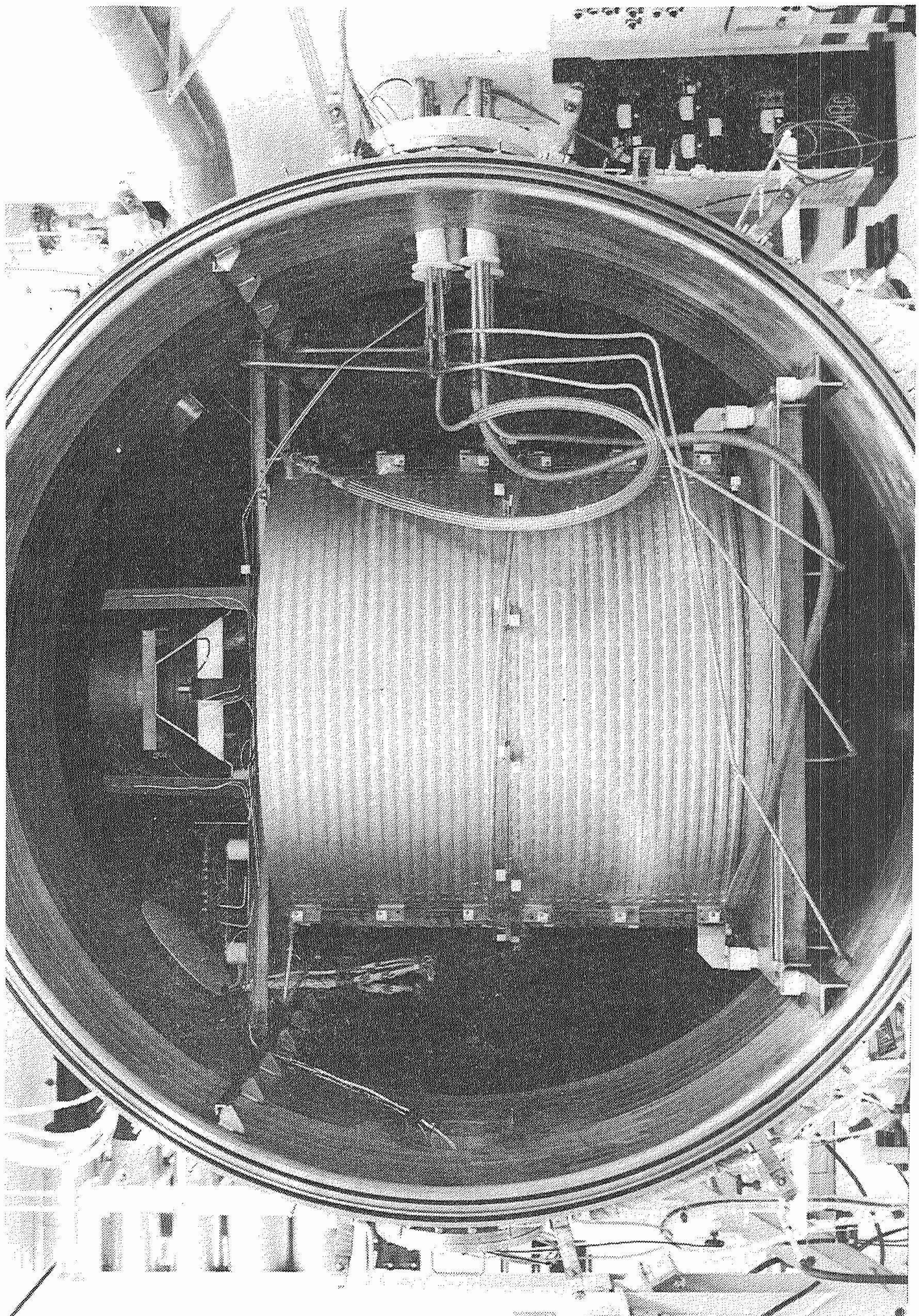


FIGURE 21 THRUSTER P-4 INSTALLED IN CHAMBER PRIOR TO TESTING IN RUN NO. 1
(PCU WAS INSTALLED IN CONSOLE OUTSIDE CHAMBER)

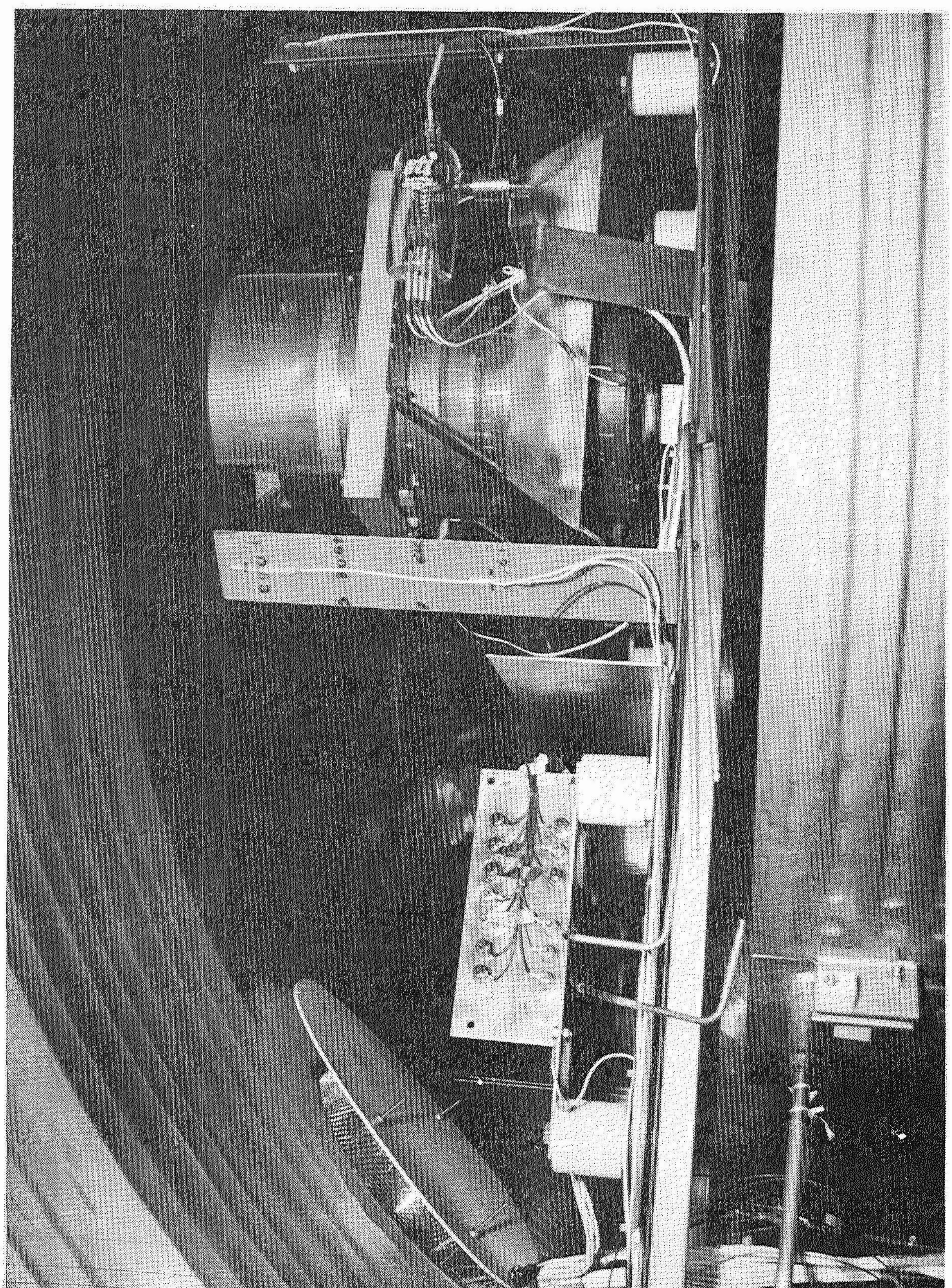


FIGURE 22 TERMINAL BOARD AND LEADS AFTER ELECTRICAL ARCING IN RUN NO. 1

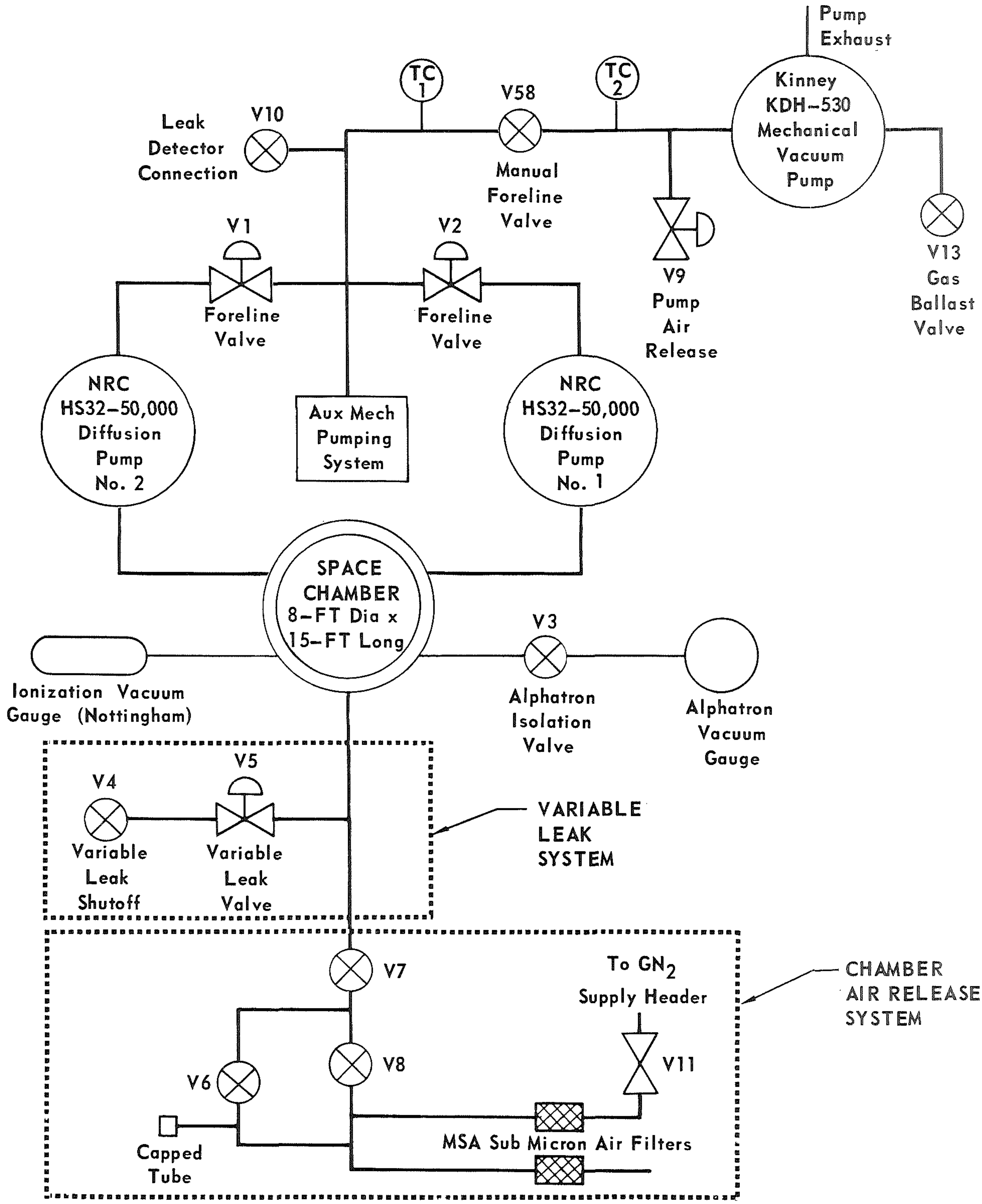


FIGURE 23 8–FT SPACE CHAMBER EVACUATION AND BACKFILL SYSTEMS

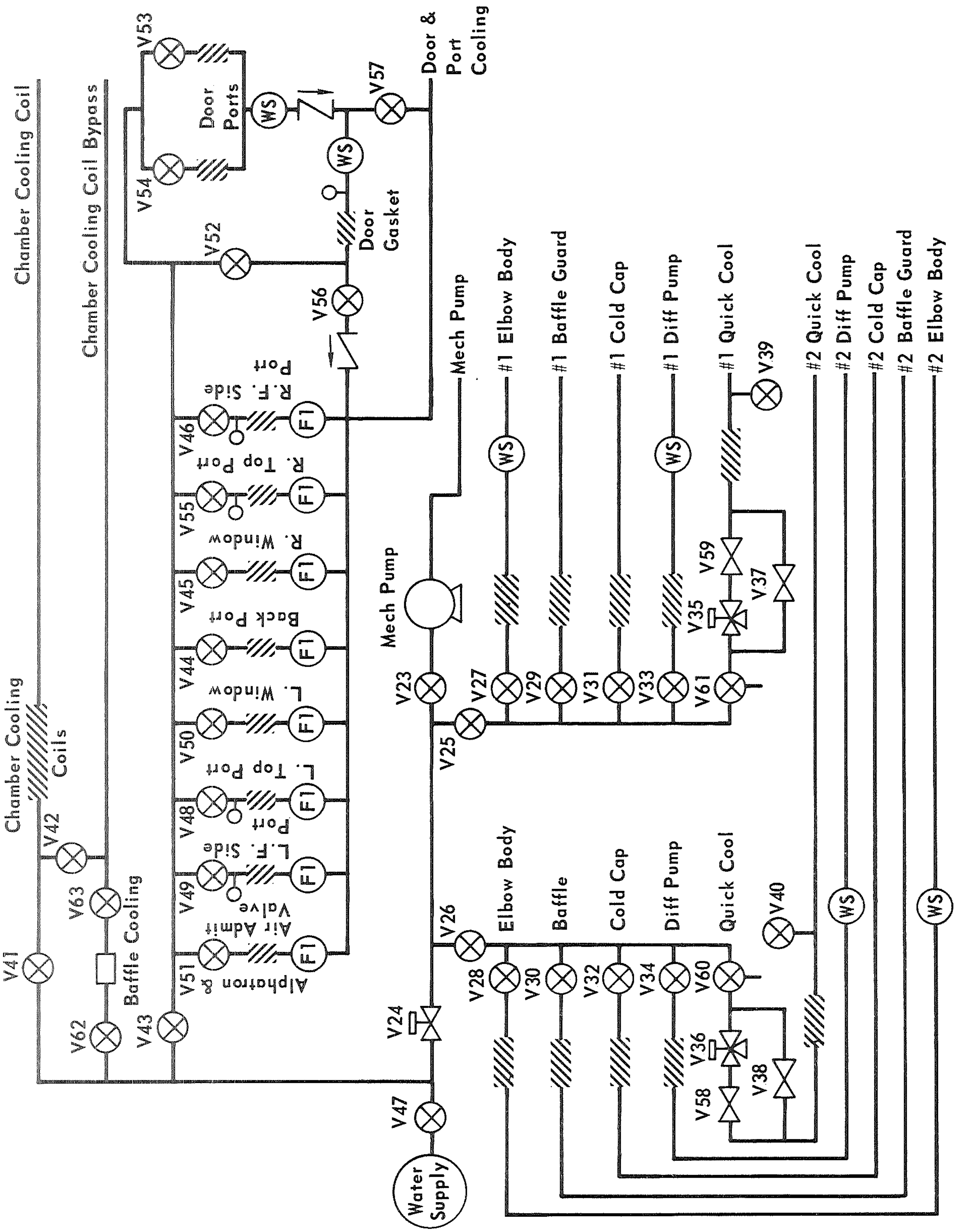


FIGURE 24 8–FT SPACE CHAMBER COOLING WATER SYSTEM

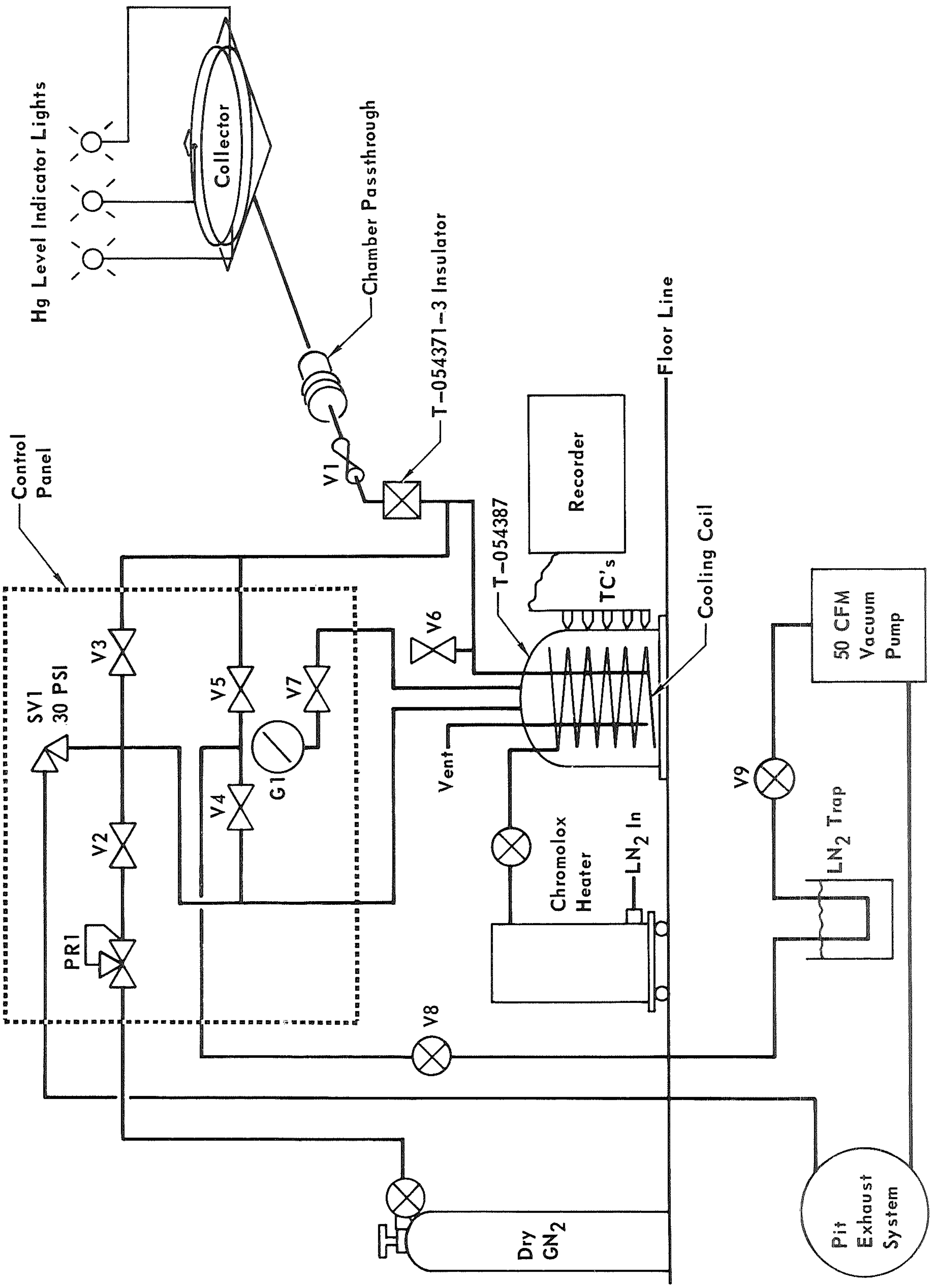


FIGURE 25 MERCURY TRANSFER SYSTEM

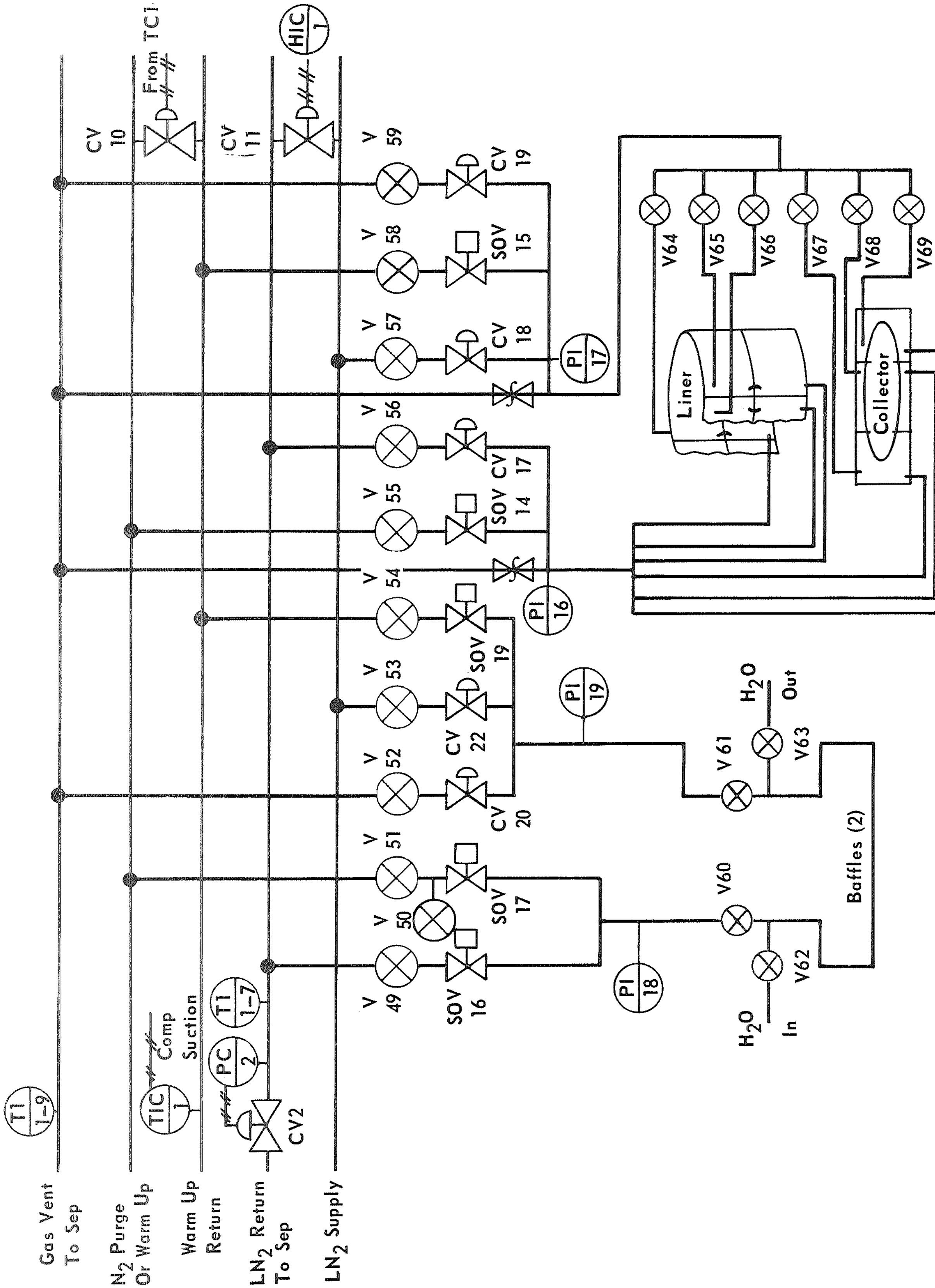


FIGURE 26 LINER, COLLECTOR AND CHAMBER BAFFLES TEMPERATURE CONTROL SYSTEM

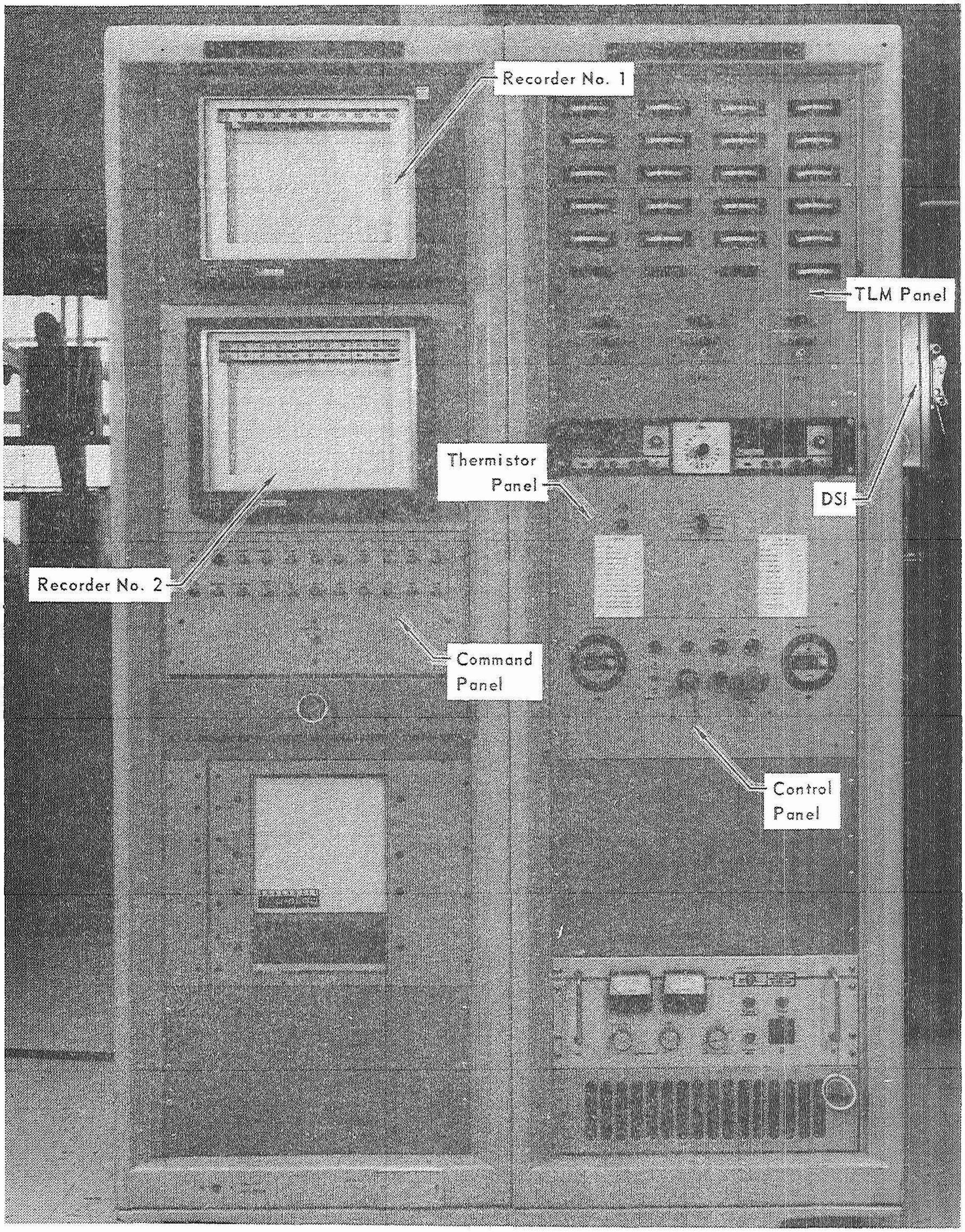


FIGURE 27 NASA–LeRC–SUPPLIED COMMAND, INSTRUMENTATION, AND POWER CONSOLES (NASA PHOTO C–69–2090)

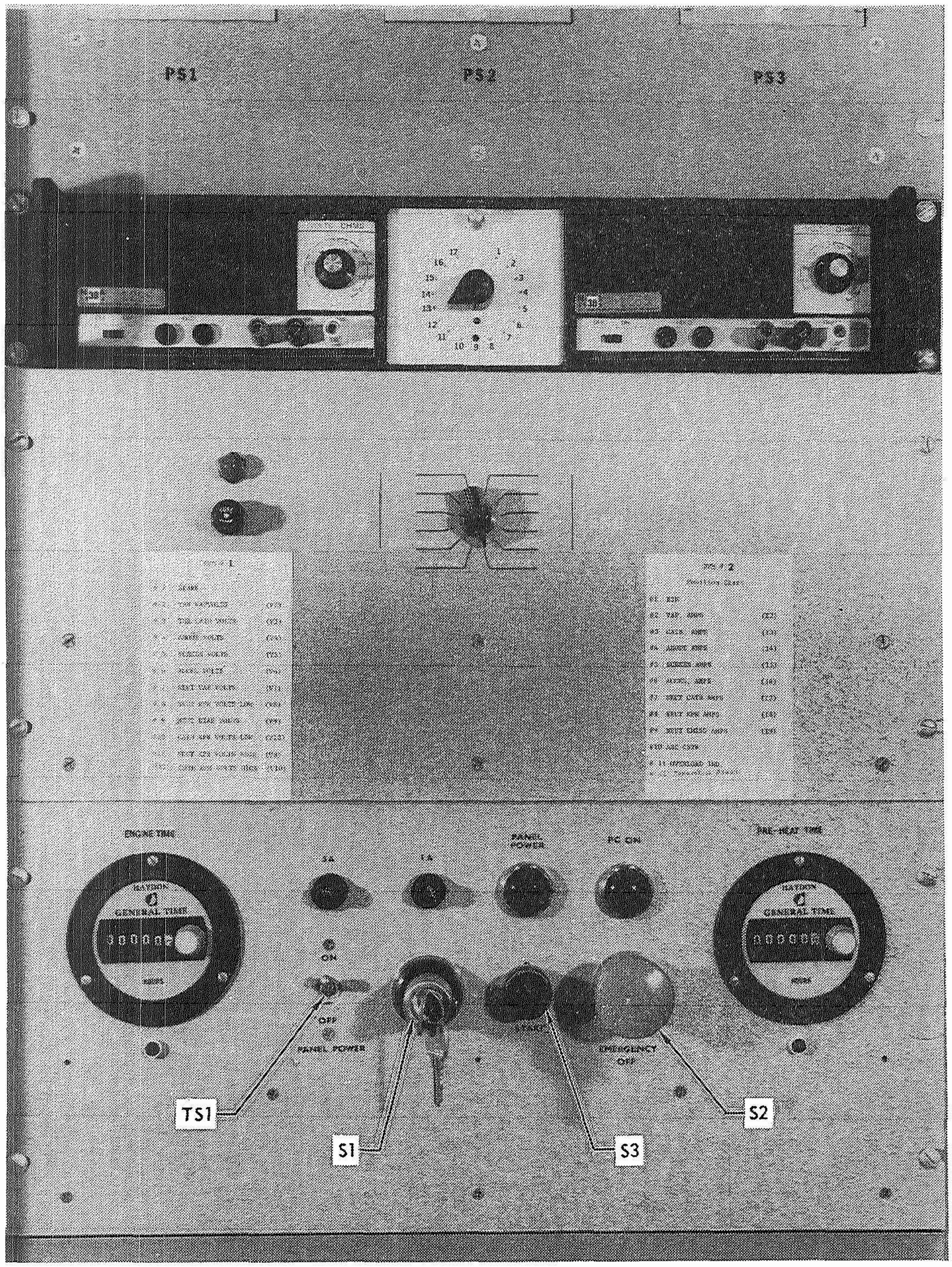


FIGURE 28 NASA–LeRC–SUPPLIED INSTRUMENTATION AND POWER CONSOLE, CLOSEUP VIEW (NASA PHOTO C-69-2089)

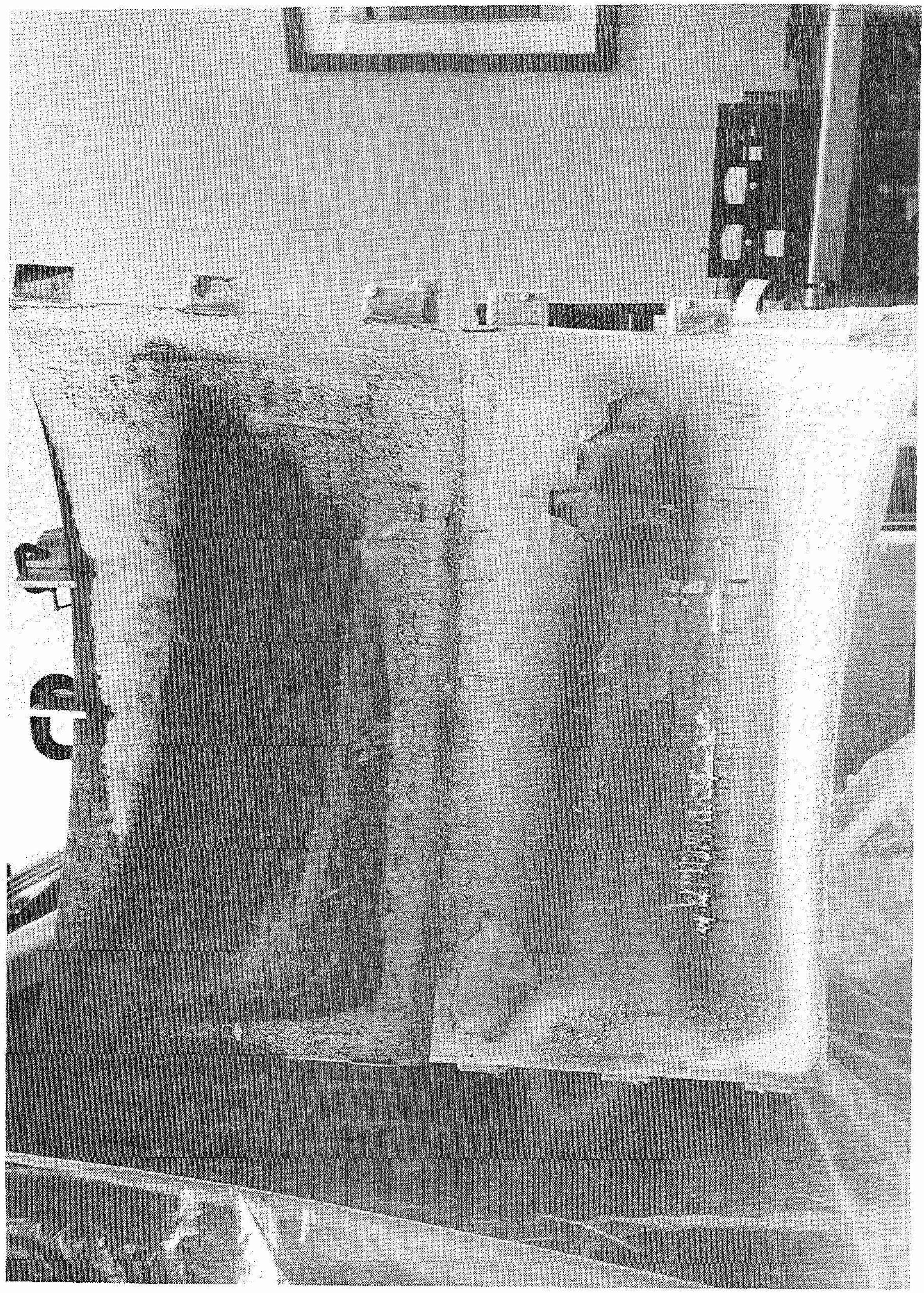


FIGURE 29 LINER WITH DEPOSITS OF MERCURY AND FROST (FROM AMBIENT AIR) AFTER RUN NO. 9

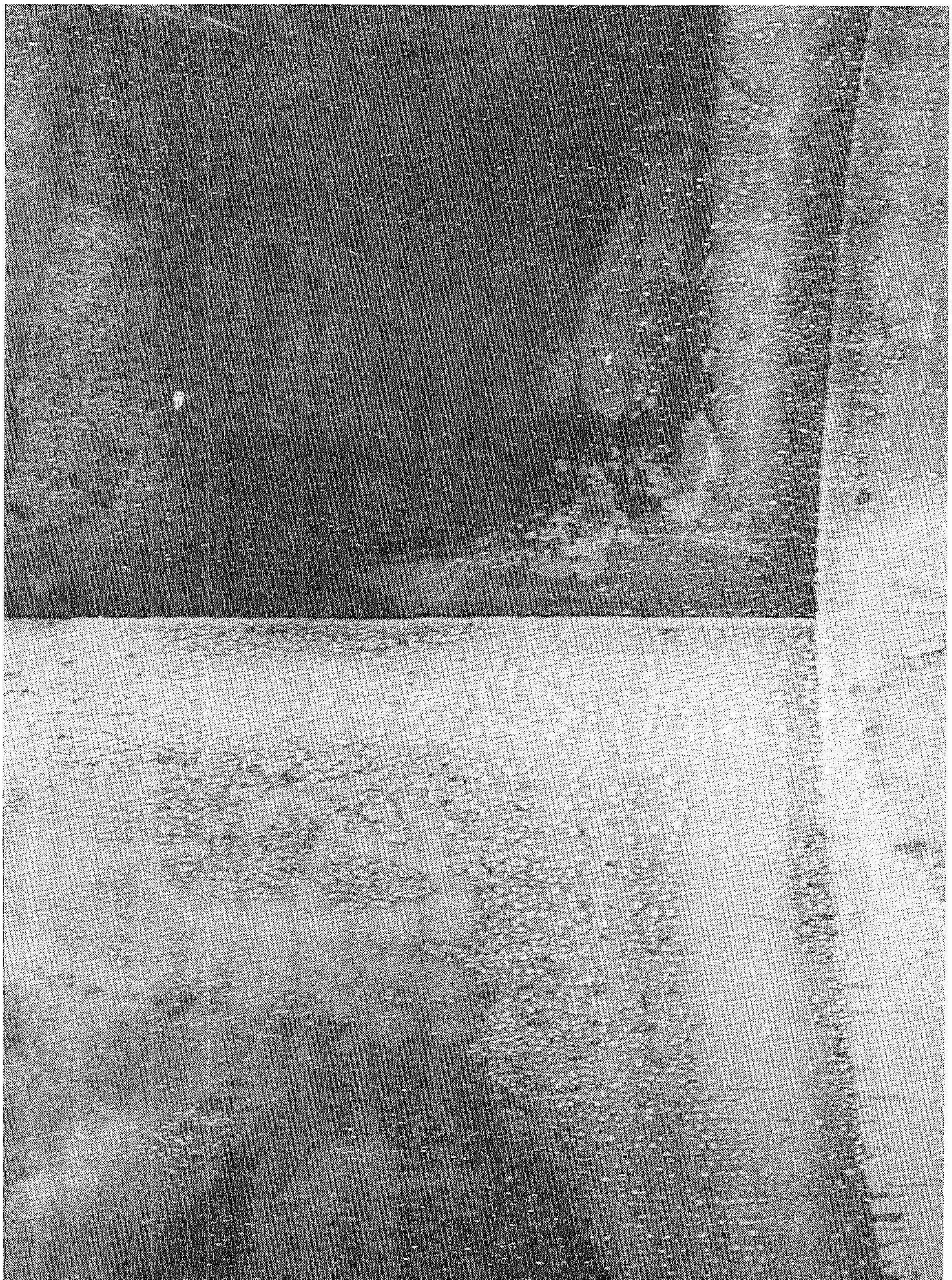


FIGURE 30 COLD LINER AND MERCURY SURFACE WITH DEPOSITS AFTER RUN NO. 9

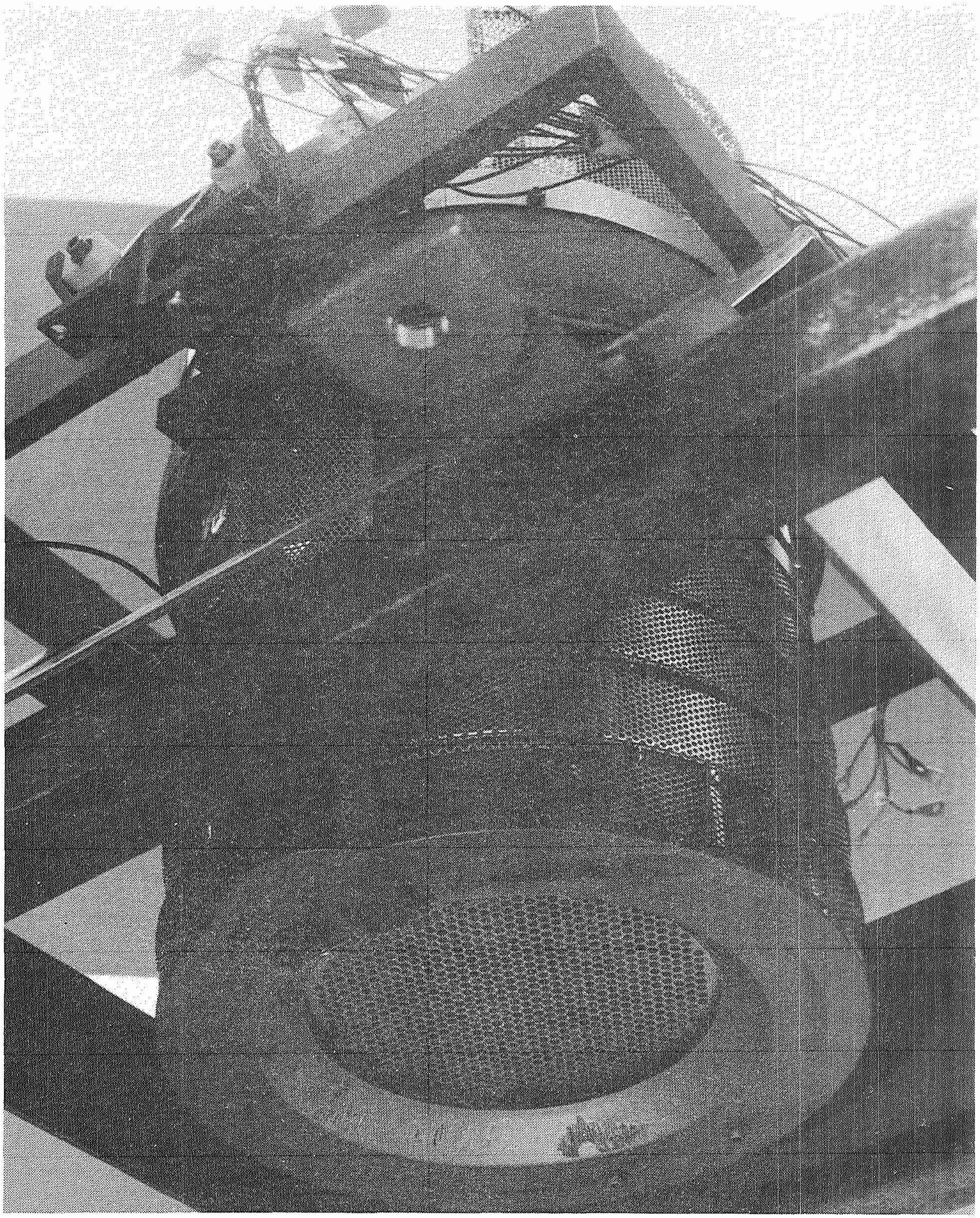


FIGURE 31 THRUSTER MODEL P20 (IN TEST FIXTURE) AFTER RUN NO. 5

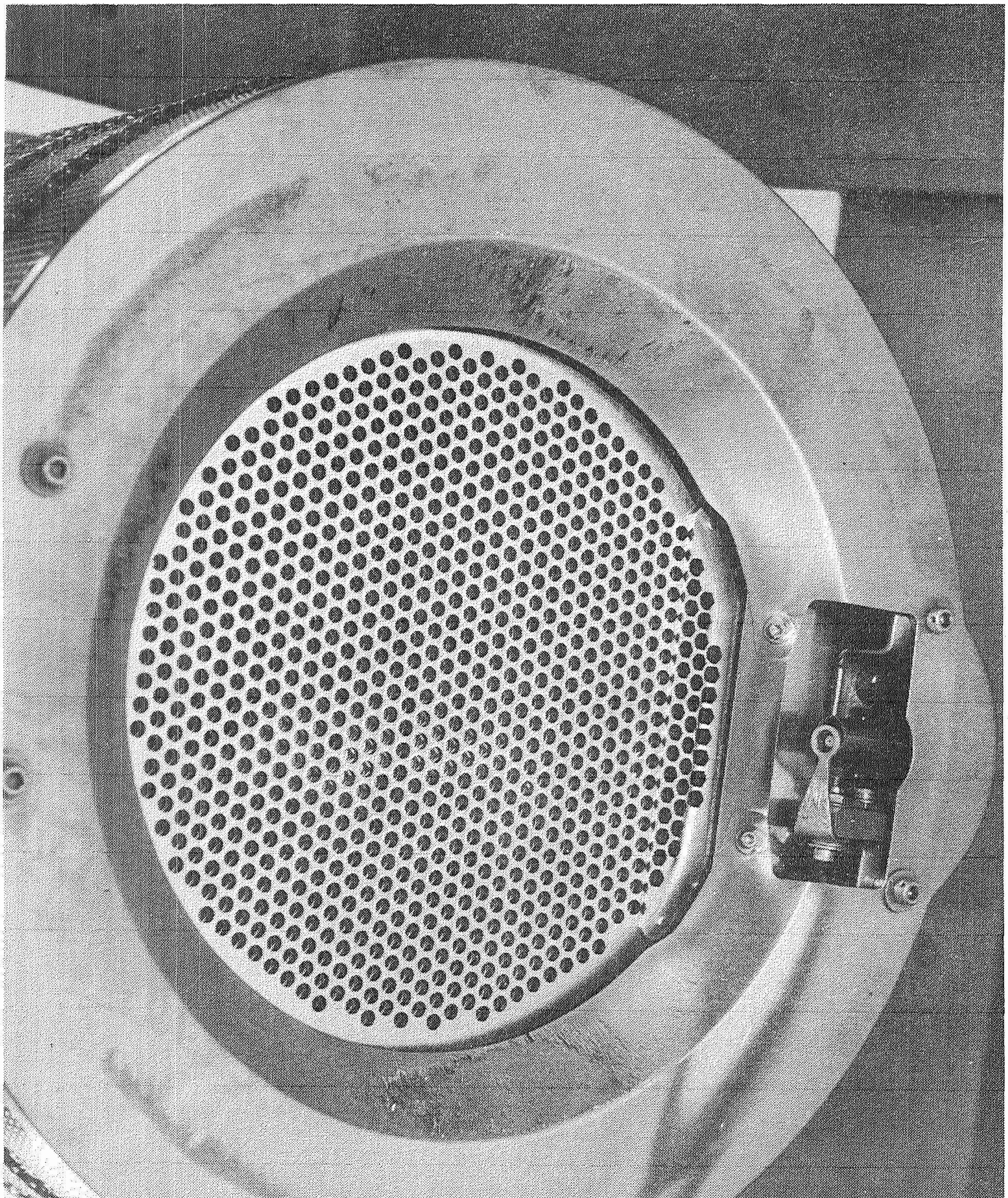


FIGURE 32 GRID AND NEUTRALIZER OF THRUSTER P20 AFTER RUN NO. 5

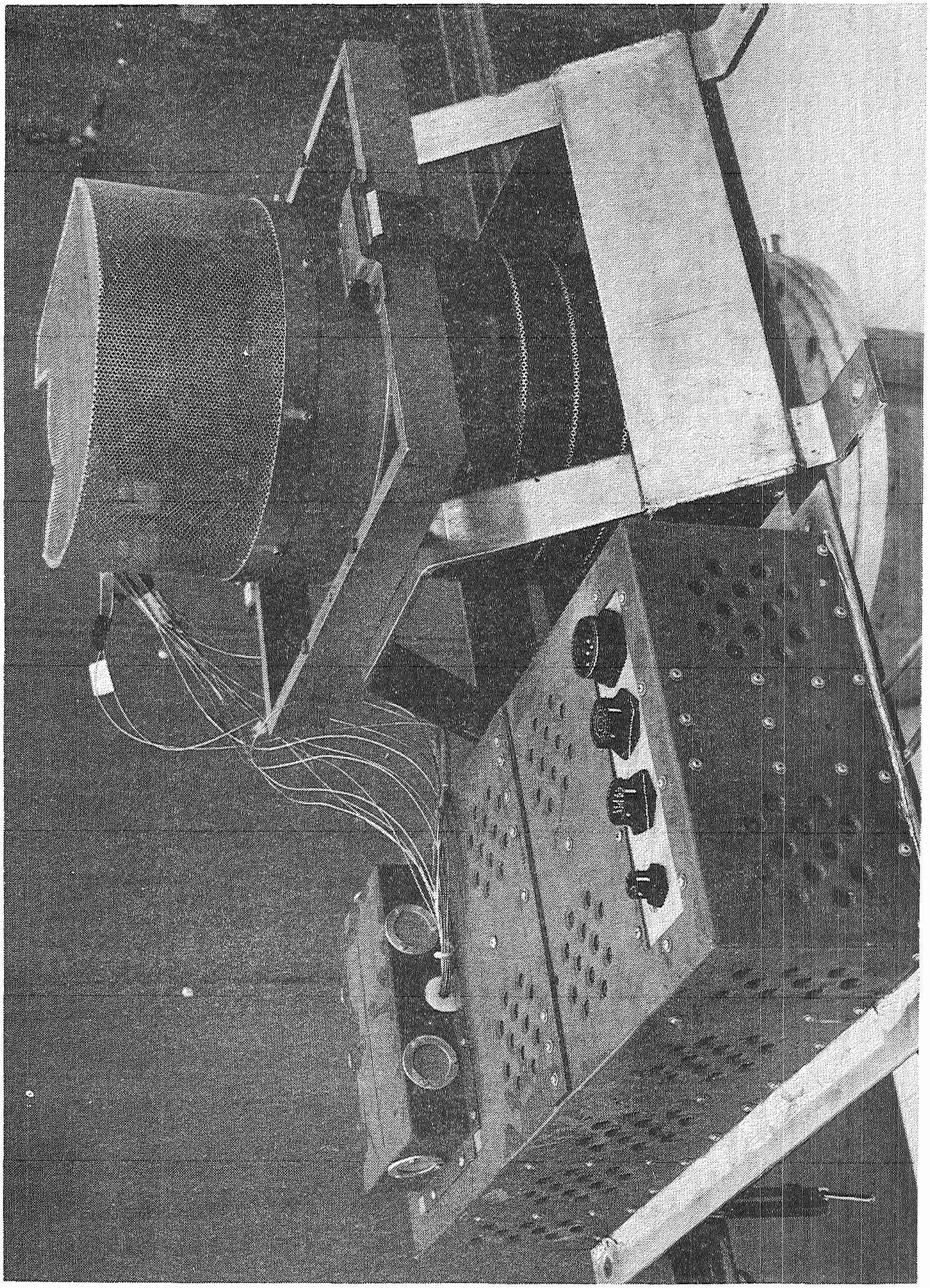


FIGURE 33 THRUSTER P–20 AND POWER CONDITIONER PT–1 AFTER RUN NO. 9

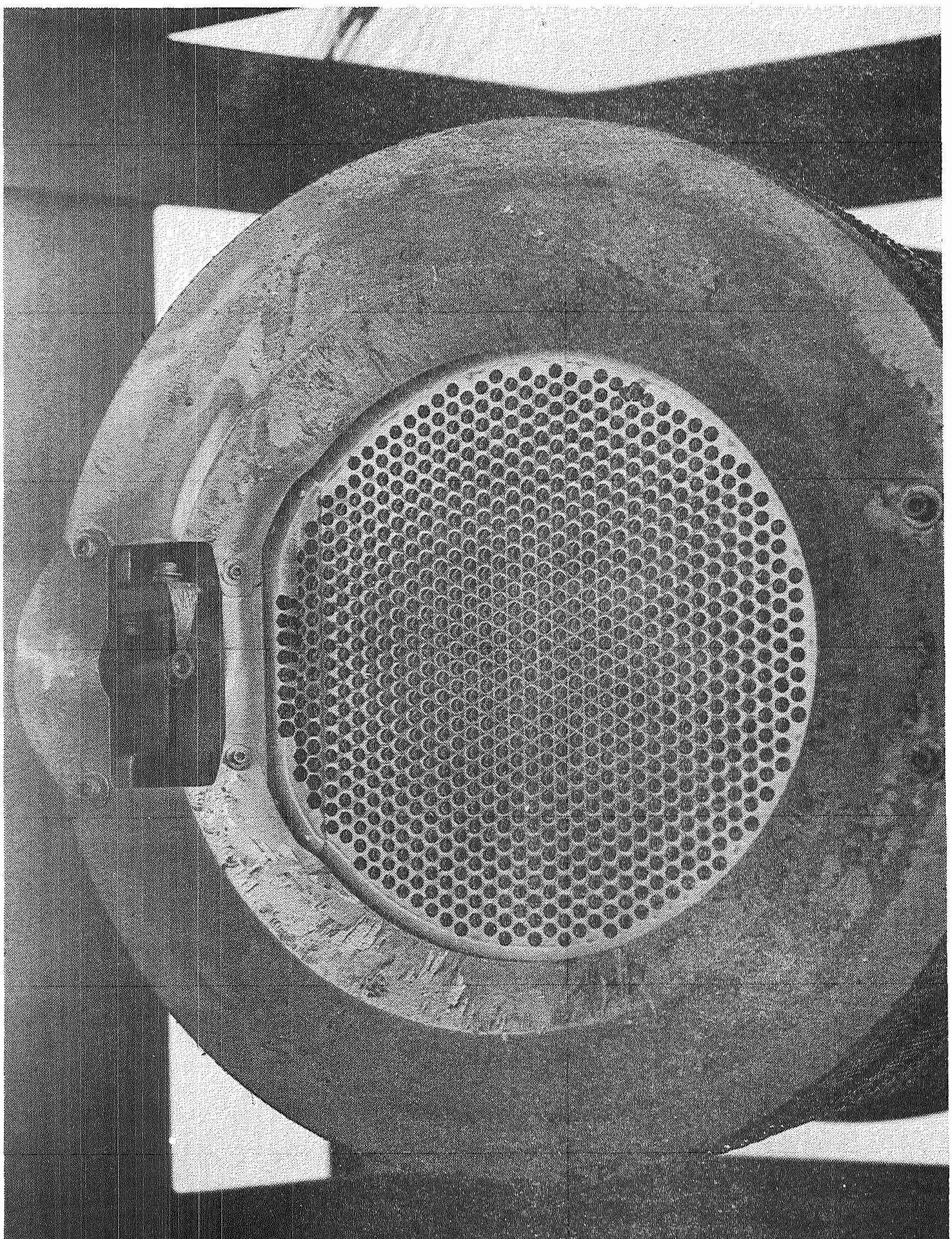


FIGURE 34 GRID AND NEUTRALIZER OF THRUSTER P–20 AFTER RUN NO. 9

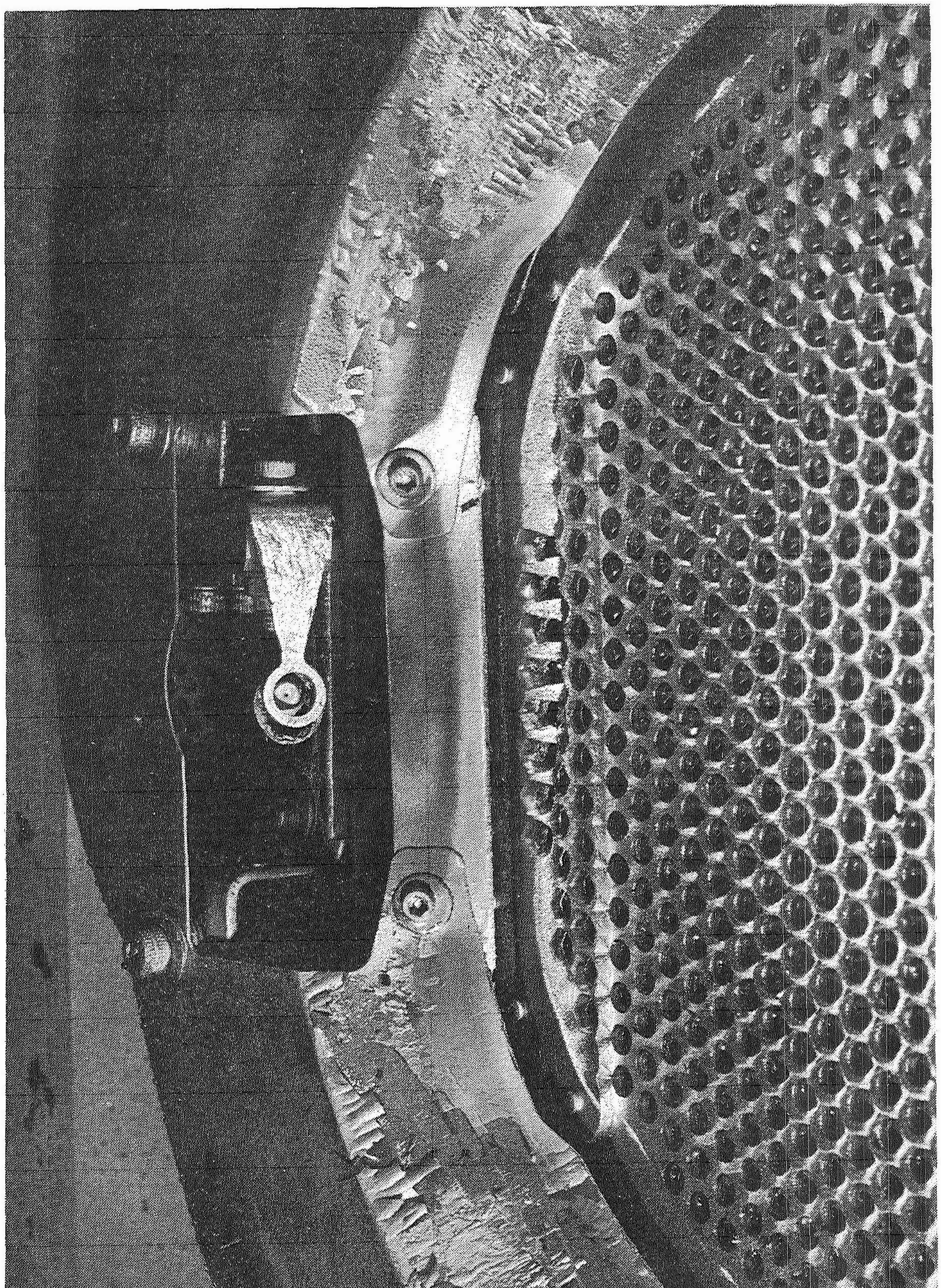


FIGURE 35 GRID AND NEUTRALIZER OF THRUSTER P-20 AFTER RUN NO. 9

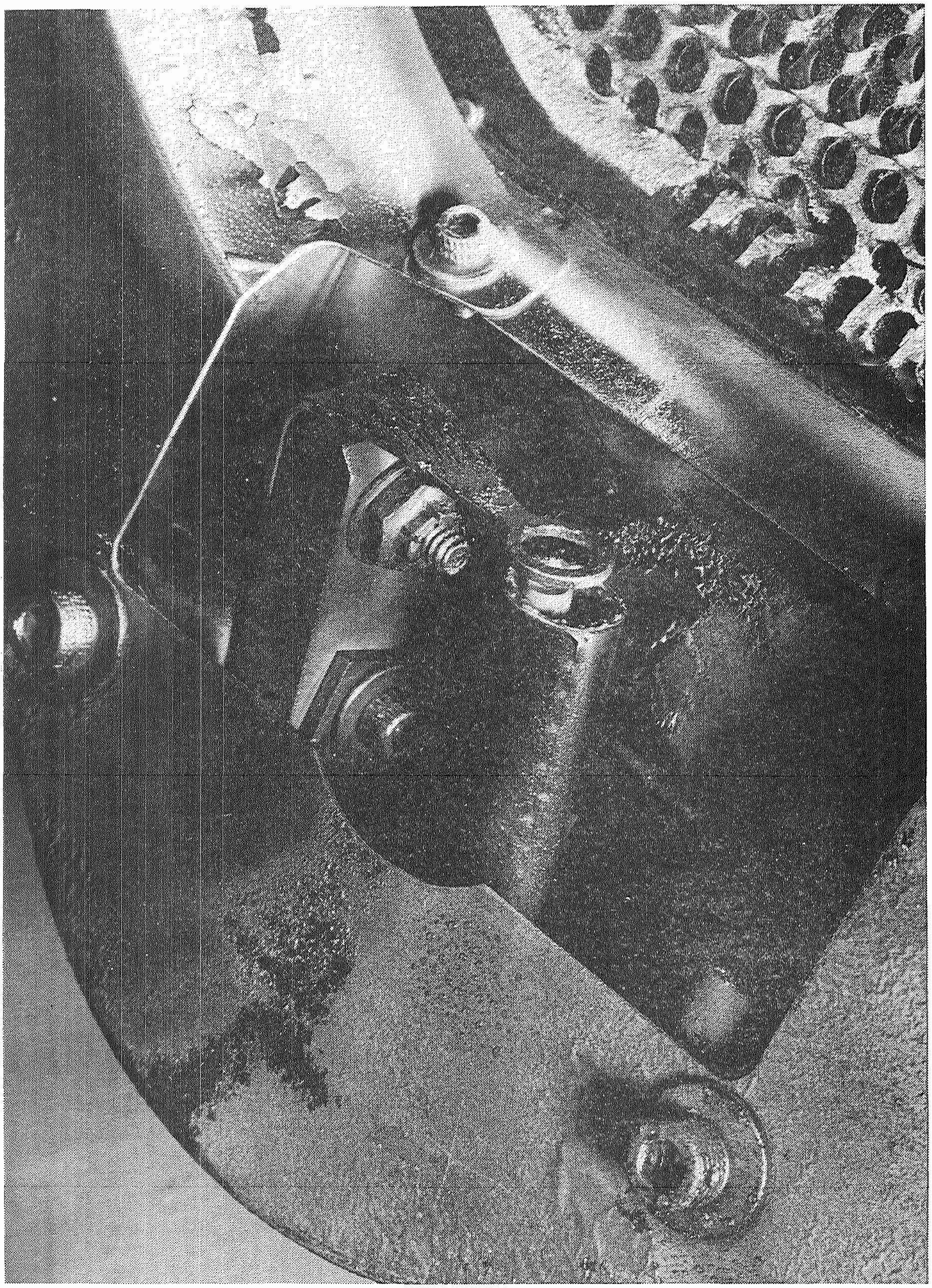


FIGURE 36 GRID AND NEUTRALIZER OF THRUSTER P–20 AFTER RUN NO. 9

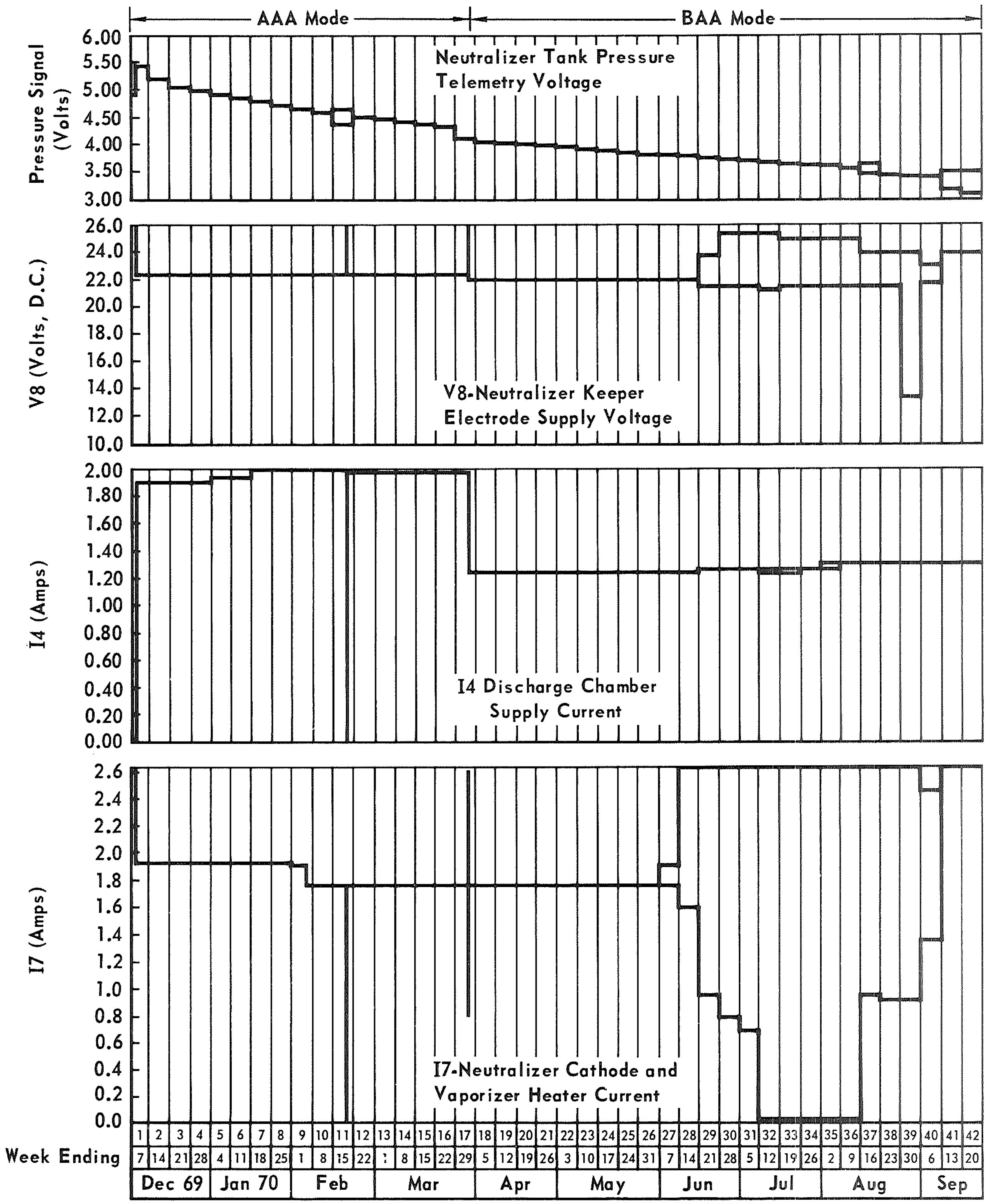


FIGURE 37 THRUSTER SYSTEM OPERATING PARAMETERS
FOR THRUSTER P-20 AND PCU PT-1 IN RUN NO.9

APPENDIX A

CHRONOLOGICAL RECORD OF EVENTS*

09-26-68 Date of contract.

10-11-68 Design drawings and procedures completed.

10-14-68 Design drawings and procedures delivered to and discussed with NASA-LeRC.

10-23-68 Design drawing approval received from LeRC.

11-01-68 Fabrication in accordance with design drawings completed.

11-12-68 Mercury received from LeRC.

11-19-68 Facility demonstration test initiated. Performed chamber residual gas analysis with collector and liner cold. Witnessed by R. Nicholls (NASA Project Manager) and C. Nichols of LeRC.

11-21-68 Performed chamber residual gas analysis with collector and liner warm. Facility demonstration test completed satisfactorily.

03-15-69 Stop Work Order received from LeRC.

06-18-69 Extension of Stop Work Order received from LeRC.

07-10-69 Direction received from LeRC to resume work on test program. Vacuum chamber preparation and checkout started.

07-17-69 Ion Thruster P-4 received from LeRC.

07-23-69 Chamber checkout performed, as necessitated by prior interruption of test program.

07-25-69 Test Console GE-B and Thruster Dummy Load Console No. 1 received from LeRC.

07-29-69 Life Test Run No. 1 started, using Thruster P-4 and Test Console GE-B (which included PCU 3S2020BM121A1). Run No. 1 interrupted, at direction of NASA Project Manager, after 6.2 hours of elapsed time, because of excessive electrical arcing inside the test chamber. Visual examination revealed that arcing occurred at terminal board which joined thruster electrical leads to chamber

*Thruster system accumulated total operating hours vs calendar time is shown in bar chart form in Figure A-1.

passthrough leads, with LeRC-furnished insulators mounted to simulate PCU output terminals. Terminal board removed and thruster electrical leads spliced directly to chamber passthrough leads, at direction of NASA Project Manager. Vacuum gauge (Veeco Model RG75) temporarily installed in PCU area at direction of NASA Project Manager.

07-31-69 Run No. 2 started using Thruster P-4 and Test Console GE-B. PCU EX-1 received from LeRC.

08-01-69 Run No. 2 interrupted, at direction of NASA Project Manager, after 31.2 accumulated total operating hours, to install PCU EX-1. Thruster P-20 received from LeRC.

08-02-69 PCU shield extension fabricated and installed, at request of NASA Project Manager.

08-04-69 Chamber evacuation started in preparation for Run No. 3.

08-05-69 Test Console LTC-1, required to operate PCU EX-1, received. Run No. 3 started, using Thruster P-20, PCU EX-1, and Console LTC-1. Run No. 3 interrupted, without accumulating any additional operating hours, at direction of NASA Project Manager, to redistribute PCU power input leads at the chamber passthroughs.

08-06-69 Run No. 4 started, using Thruster P-20, PCU EX-1, and Test Console LTC-1.

08-07-69 Thruster P-4 returned to LeRC.

08-08-69 Run No. 4 interrupted, after 57.2 accumulated total operating hours, at direction of NASA Project Manager, to replace PCU EX-1 with PCU PT-1. PCU PT-1 received from LeRC.

08-09-69 Pressure gauge (Veeco RG-79) permanently installed in PCU area. Instrumentation wire bundle, furnished by LeRC, added to test setup between test console and thruster.

08-10-69 Run No. 5 started, using Thruster P-20, PCU PT-1, and Test Console LTC-1. Two chamber gas analyses performed at request of NASA Project Manager, following the start of thruster operation. PCU EX-1 returned to LeRC.

08-12-69 Test Console service door opened causing automatic shutdown. Thruster system promptly restarted and Run No. 5 resumed.

08-13-69 Chamber gas analysis performed, at request of NASA Project Manager, to investigate slight pressure rise in chamber.

09-10-69 Run No. 5 interrupted, after 795.3 accumulated total operating hours, by failure of screen high voltage power supply (V5) in PCU.

09-10-69	Failure Report No. 1 prepared.
09-12-69	PCU removed from chamber and returned, by NASA Project Manager, to LeRC for repair.
09-18-69	Thruster removed from chamber and returned to LeRC, at request of NASA Project Manager.
09-30-69	Thruster P-20 and PCU PT-1 received from LeRC.
10-01-69	Run No. 6 started, using thruster P-20, PCU PT-1, and Test Console LTC-1.
10-18-69	Run No. 6 interrupted, after 1197.9 accumulated total operating hours, at request of NASA Project Manager, to replace Thruster P-20 with Thruster P-15 and so that NASA could make minor modifications in PCU PT-1.
10-20-69	Thruster P-15 received from LeRC.
10-21-69	PCU PT-1 modifications completed by LeRC personnel at MDC.
10-22-69	Run No. 7 started, using Thruster P-15, PCU PT-1, and Test Console LTC-1.
10-23-69	Run No. 7 interrupted, after 1198.4 accumulated total operating hours, by a failure in the thruster cathode and isolator heater circuit of PCU PT-1. At the request of the NASA Project Manager, the PCU was removed from the chamber and was returned, by LeRC personnel, to LeRC for repair.
10-24-69	Failure Report No. 2 prepared.
10-26-69	PCU PT-1 received from LeRC and Run No. 8 started, using Thruster P-15, PCU PT-1, and Test Console LTC-1.
10-28-69	GFE recorders malfunctioned.
10-29-69	Run No. 8 interrupted, after 1228.4 accumulated total operating hours, by failure in anode circuit of the thruster system. PCU PT-1 and Thruster P-15 removed from chamber and returned, by the NASA Project Manager, to LeRC for repair.
10-30-69	Failure Report Nos. 3 and 4 prepared.
10-31-69	Stop Work Order received from LeRC.
11-10-69	Direction received from LeRC to resume work on test program.
11-18-69	Stop Work Order received from LeRC.

*1 12-01-69	Direction received from LeRC to resume work on the test program. Thruster P-20 and PCU PT-1 received from LeRC.
2 12-02-69	Run No. 9 started, using Thruster P-20, PCU PT-1, and Test Console LTC-1. System operated in AAA mode (Beam Current I5 = 250 ma).
3 12-19-69	Run No. 9 interrupted because of momentary main electrical power interruption.
12-20-69	Run No. 9 resumed. Failure Report No. 5 prepared.
4 02-11-70	Run No. 9 interrupted by rise in chamber pressure due to vacuum pump zero-speed switch failure.
02-12-70	Run No. 9 resumed. GFE recorder malfunctioned. Failure Report Nos. 6 and 7 prepared.
5 03-27-70	Thruster system operation (in the AAA mode) noted to become unstable. Various operating modes tested and system put into BAA mode, at direction of NASA Project Manager, in attempt to stabilize operation (Beam Current I5 = 200 ma).
6 04-28-70	Various operating modes tested, at direction of NASA Project Manager, in attempt to stabilize operation. Operation in BAA mode resumed.
7 05-03-70	Run No. 9 interrupted by depletion of LN_2 supply and warming of collector and liner temperatures above -150°F (-101°C). Run No. 9 resumed after LN_2 supply was replenished.
05-04-70	Failure Report No. 8 prepared.
05-16-70	GFE recorder malfunctioned.
05-18-70	Failure Report No. 9 prepared.
8 05-30-70	Run No. 9 interrupted by momentary main electrical power interruption.
06-01-70	Failure Report No. 10 prepared.
06-25-70	GFE recorder malfunctioned.
9 06-26-70	Various operating modes tested and 30-volt zener diode safety clamp between V1 and ground replaced with 100-volt unit, at direction of NASA Project Manager, in attempt to stabilize operation. Operation in BAA mode resumed.
06-29-70	Failure Report No. 11 prepared.

*Circled numbers identify major events for Run No. 9 indicated in Figure A-1.

08-06-70 GFE recorder malfunctioned.

08-10-70 Failure Report No. 12 prepared.

10 08-12-70 Run No. 9 interrupted by rise in chamber pressure due to opening of fuse in electrical power supply to one diffusion pump. Run No. 9 resumed after pump was restarted and pressure was reduced in chamber.

08-14-70 Failure Report No. 13 prepared.

11 09-08-70 Run No. 9 interrupted by momentary main electrical power interruption. Failure Report No. 14 prepared.

12 09-11-70 Run No. 9 interrupted, at direction of NASA Project Manager, because beam current (I5) decreased from a normal value (200 ma) to approximately zero.

09-14-70 Failure Report No. 15 prepared.

13 09-21-70 Evaluation of thruster system started at MDC by R. Nicholls, R. Vetrone, and W. Kerslake of LeRC.

09-22-70 Evaluation of thruster system continued at MDC by R. Nicholls, R. Vetrone, and W. Kerslake.

14 09-23-70 Evaluation of thruster system completed, and thruster and PCU removed from chamber. Thruster and mercury samples taken, by R. Nicholls and W. Kerslake, to LeRC.

10-20-70 All remaining GFE shipped to LeRC.

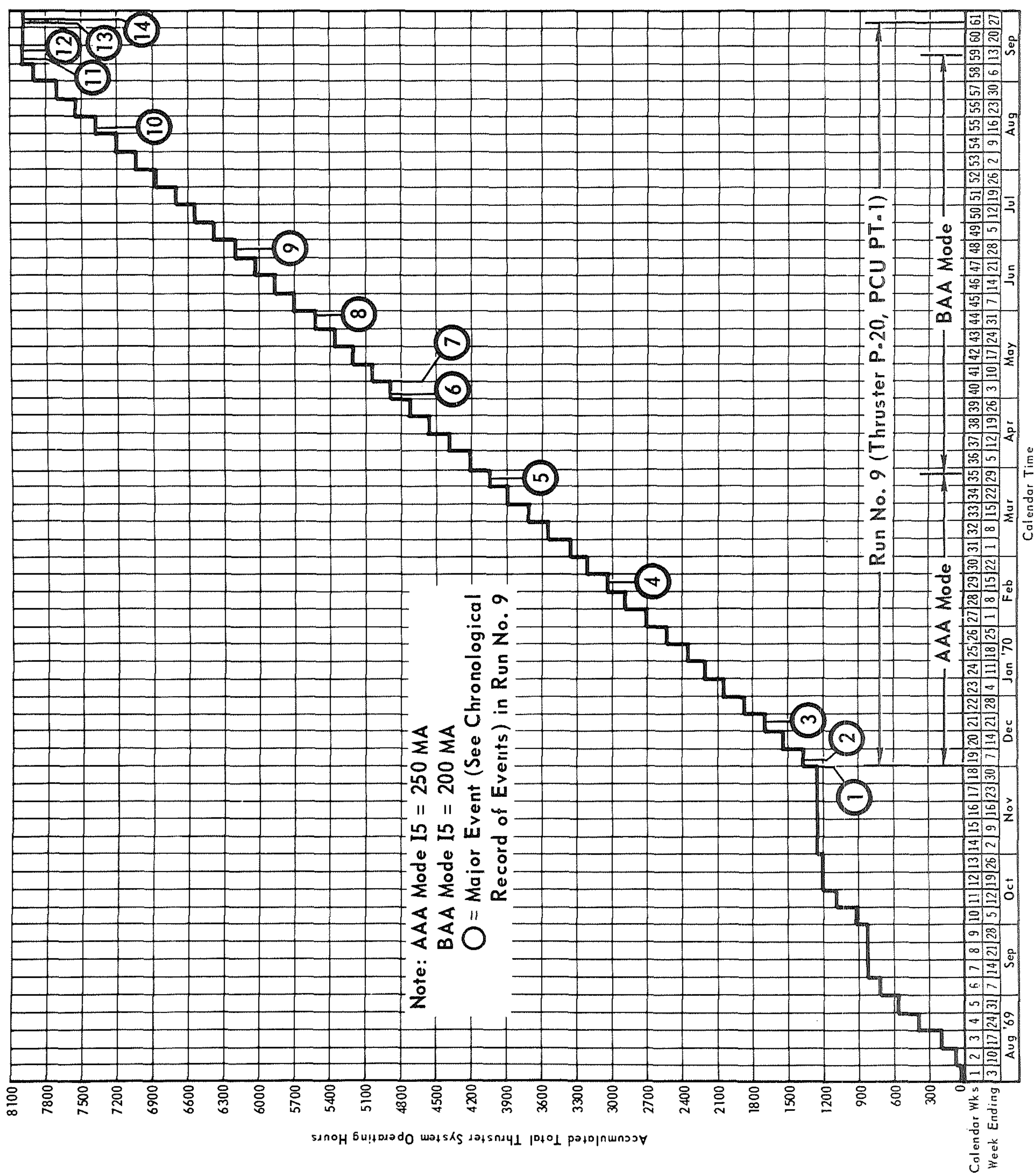


FIGURE A-1 THRUSTER SYSTEM OPERATING HOURS

APPENDIX B
FACILITY DEMONSTRATION TEST DATA

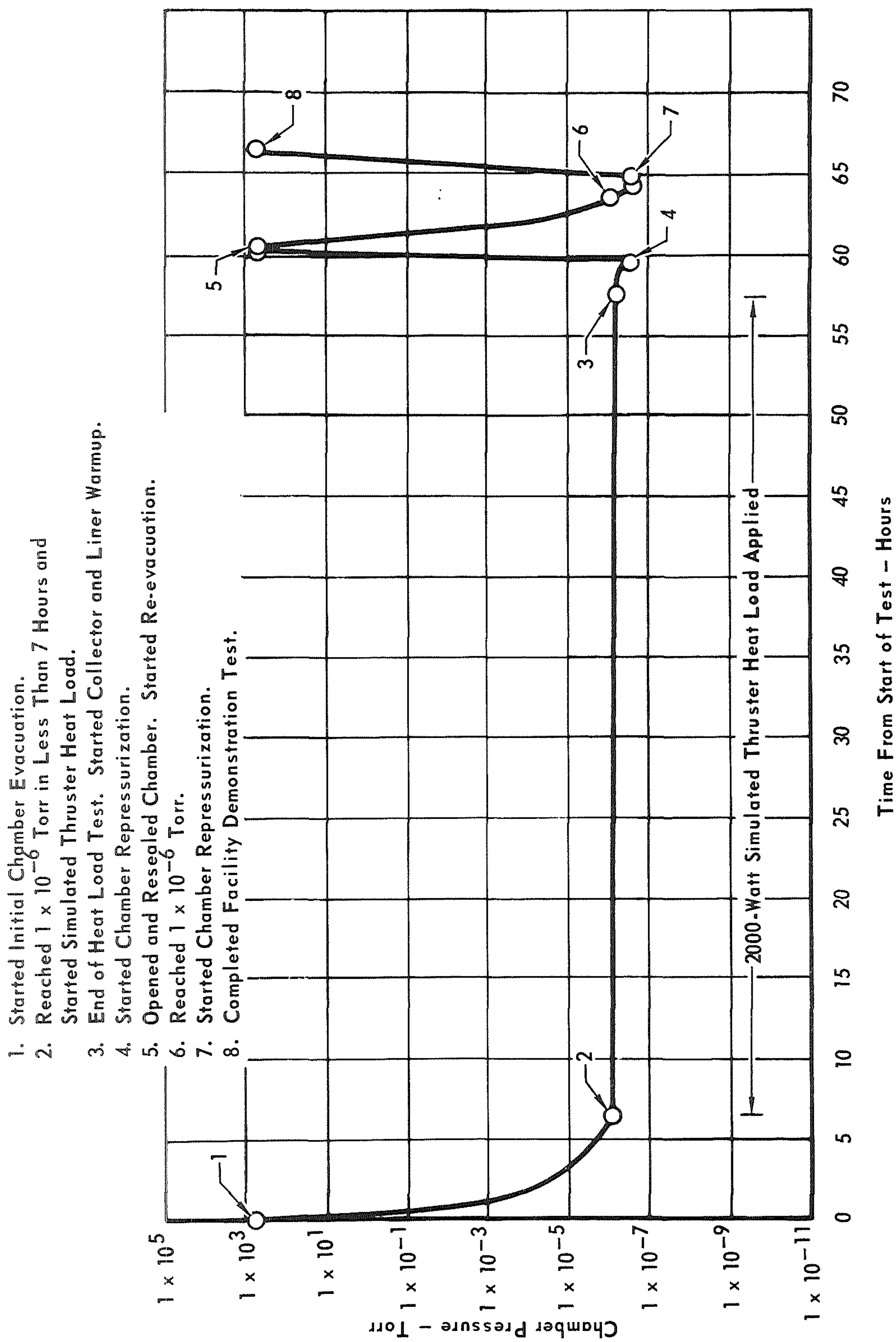


FIGURE B-1 PRESSURE-TIME HISTORY FOR FACILITY DEMONSTRATION TEST

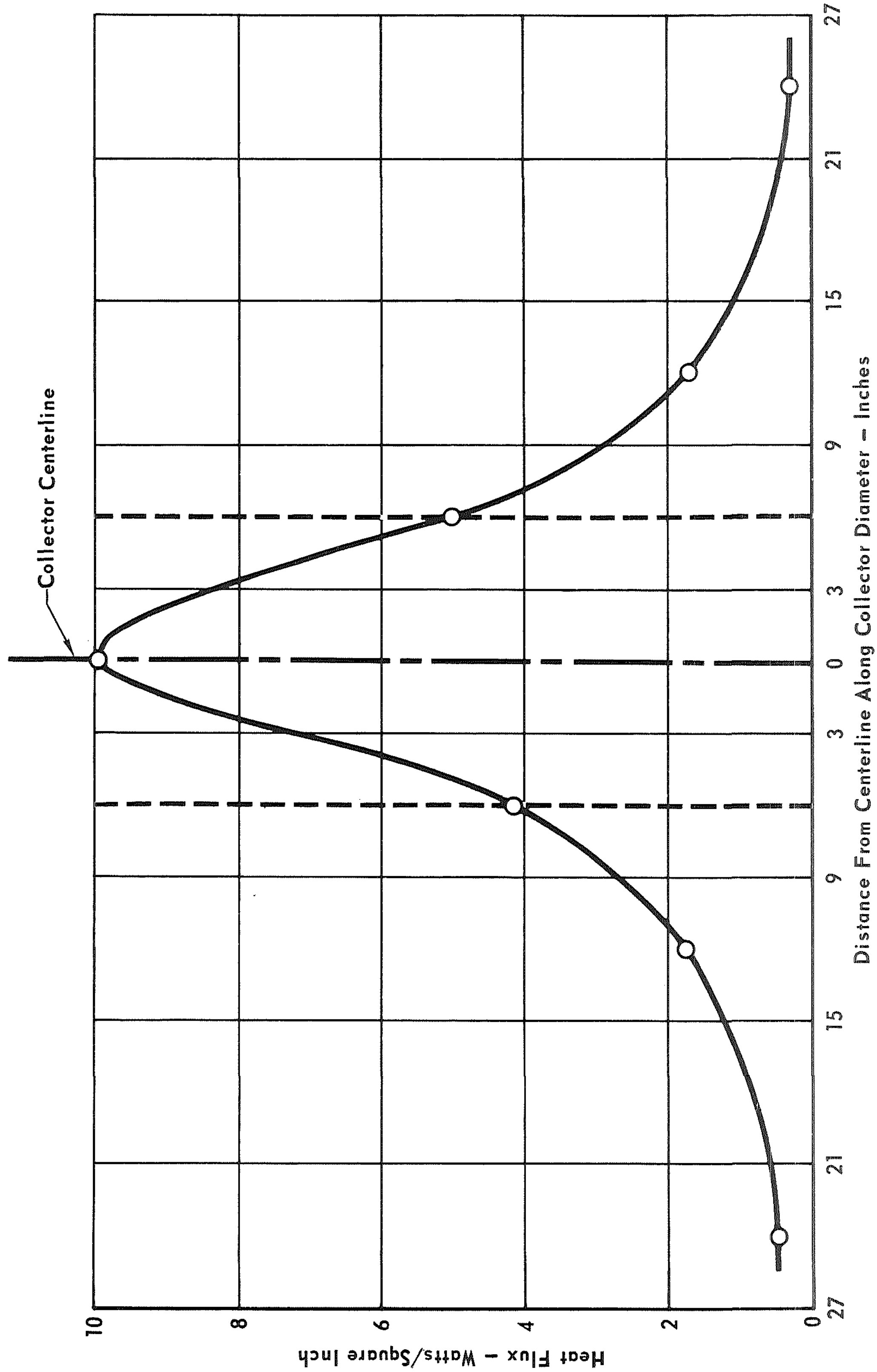
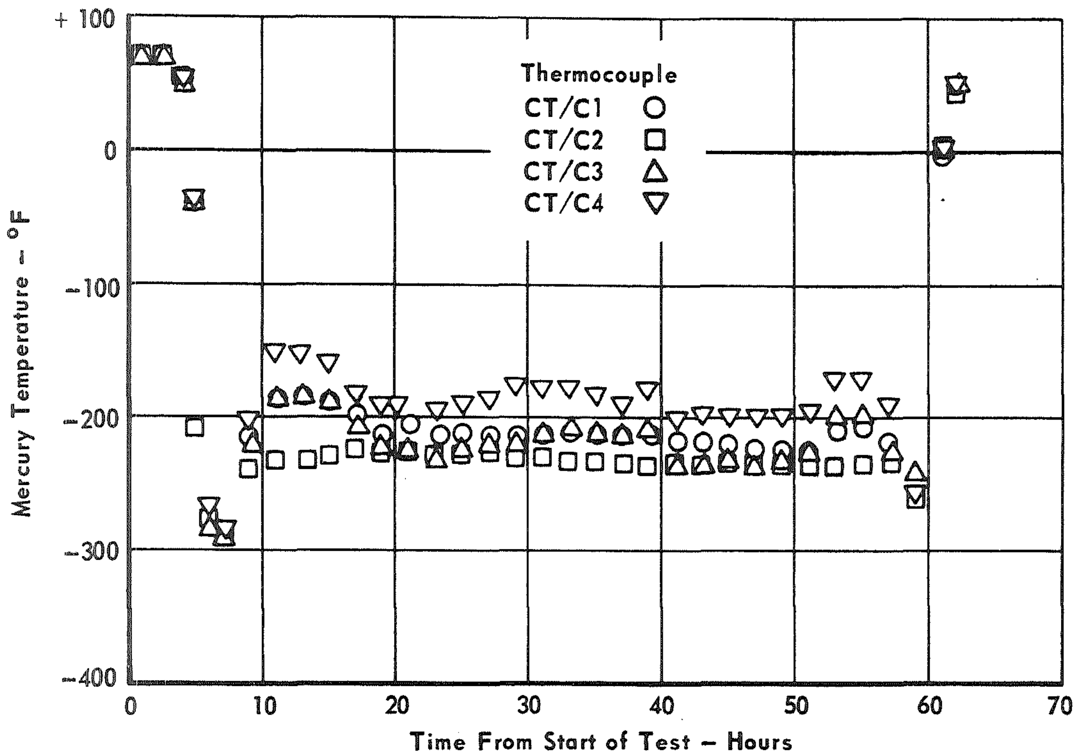
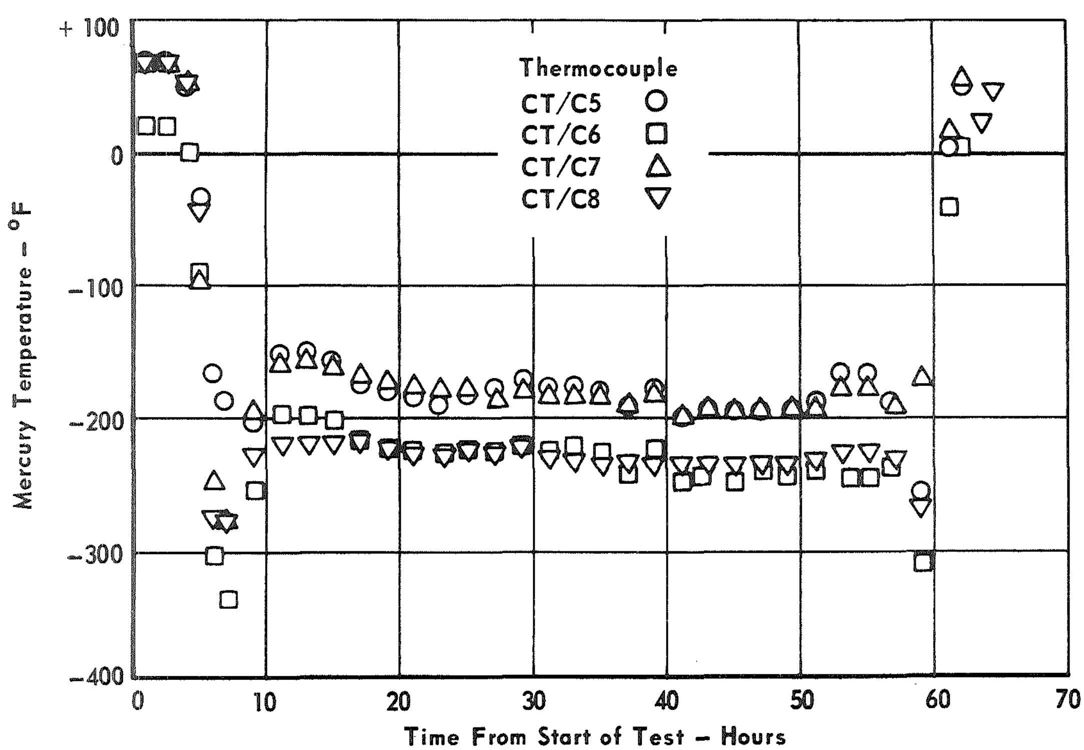


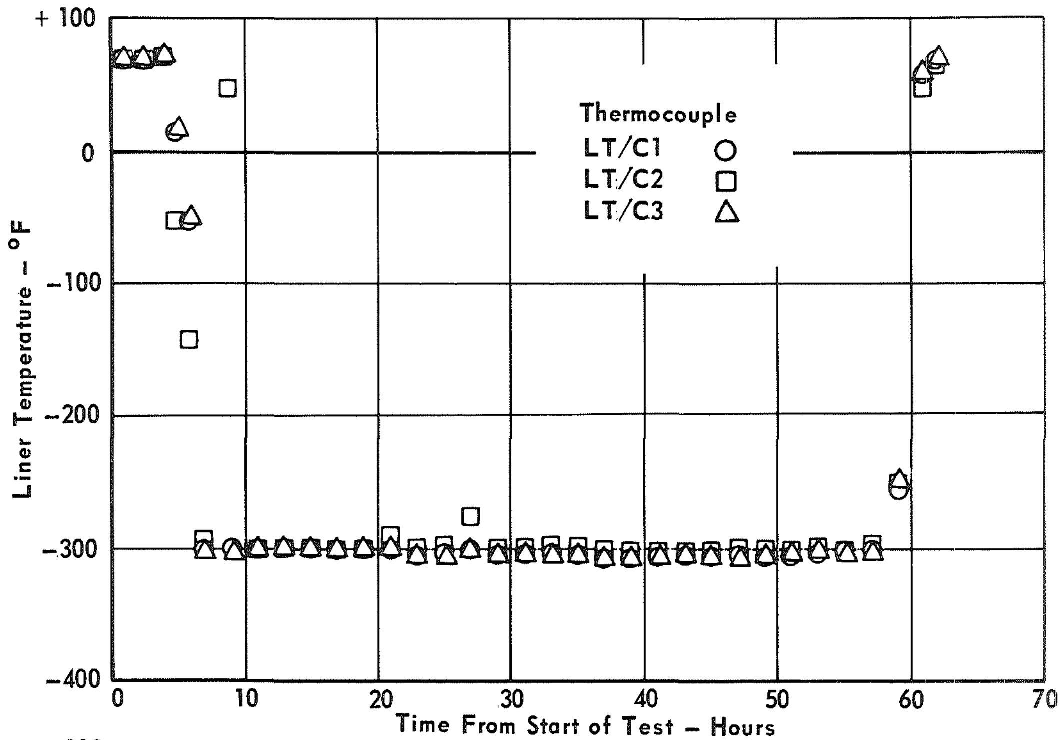
FIGURE B-2 POWER DISTRIBUTION CURVE FOR A SIMULATED THRUSTER HEAT LOAD OF 2000 WATTS

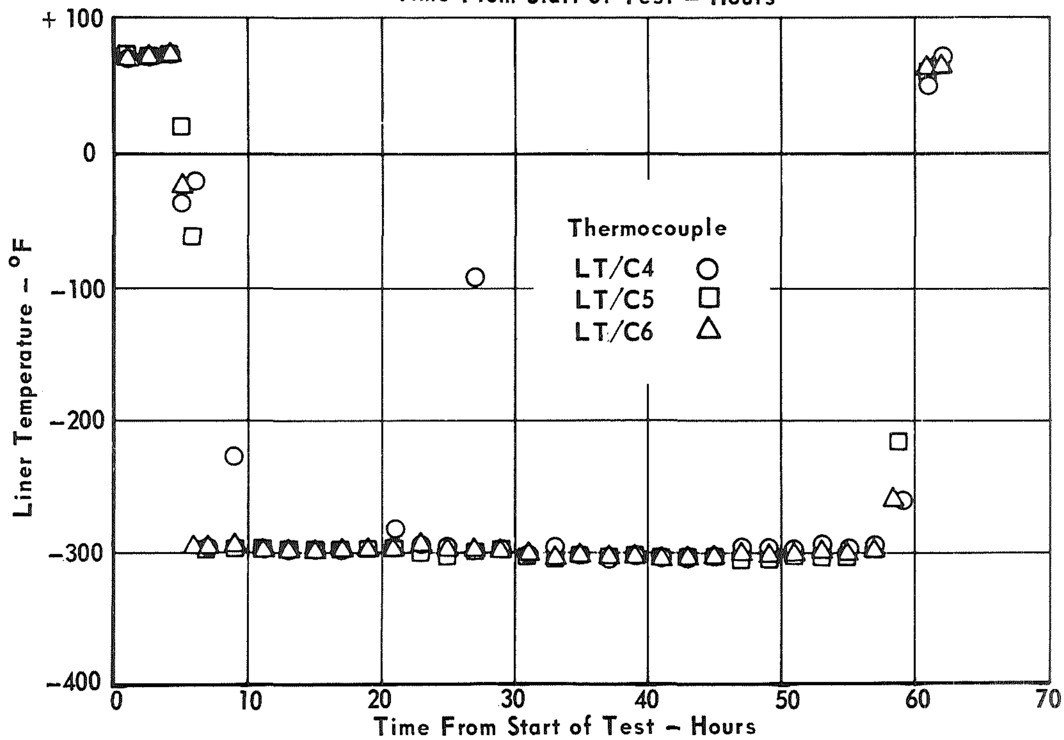




(Note: See Figure 19 for Thermocouple Locations)

FIGURE B-3 MERCURY TEMPERATURE - TIME HISTORY DURING FACILITY DEMONSTRATION TEST





(Note: See Figure 19 for Thermocouple Locations)

FIGURE B-4 LINER TEMPERATURE – TIME HISTORY DURING FACILITY DEMONSTRATION TEST

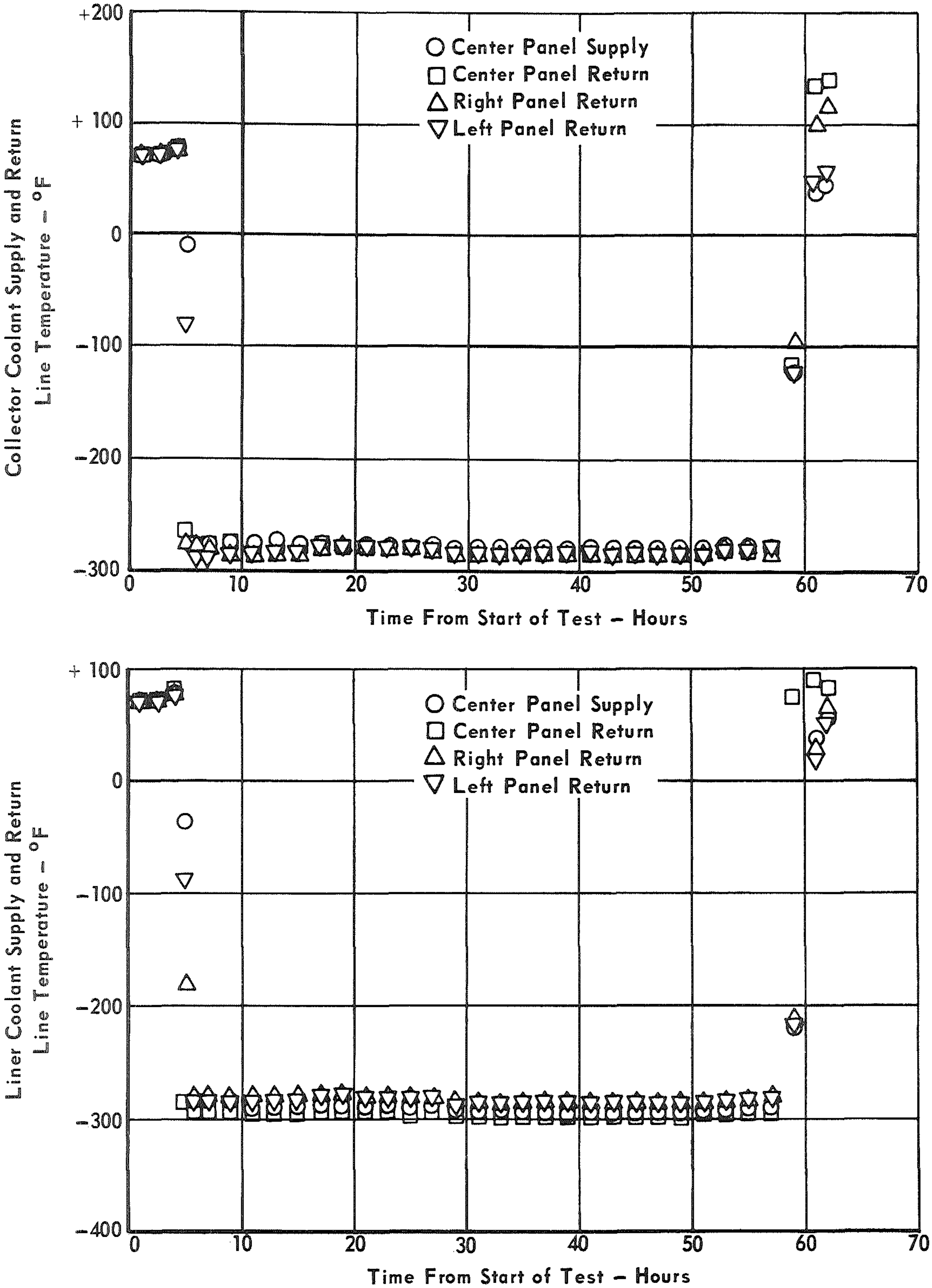


FIGURE B–5 COLLECTOR AND LINER COOLANT SUPPLY AND RETURN LINE TEMPERATURE – TIME HISTORY DURING FACILITY DEMONSTRATION TEST

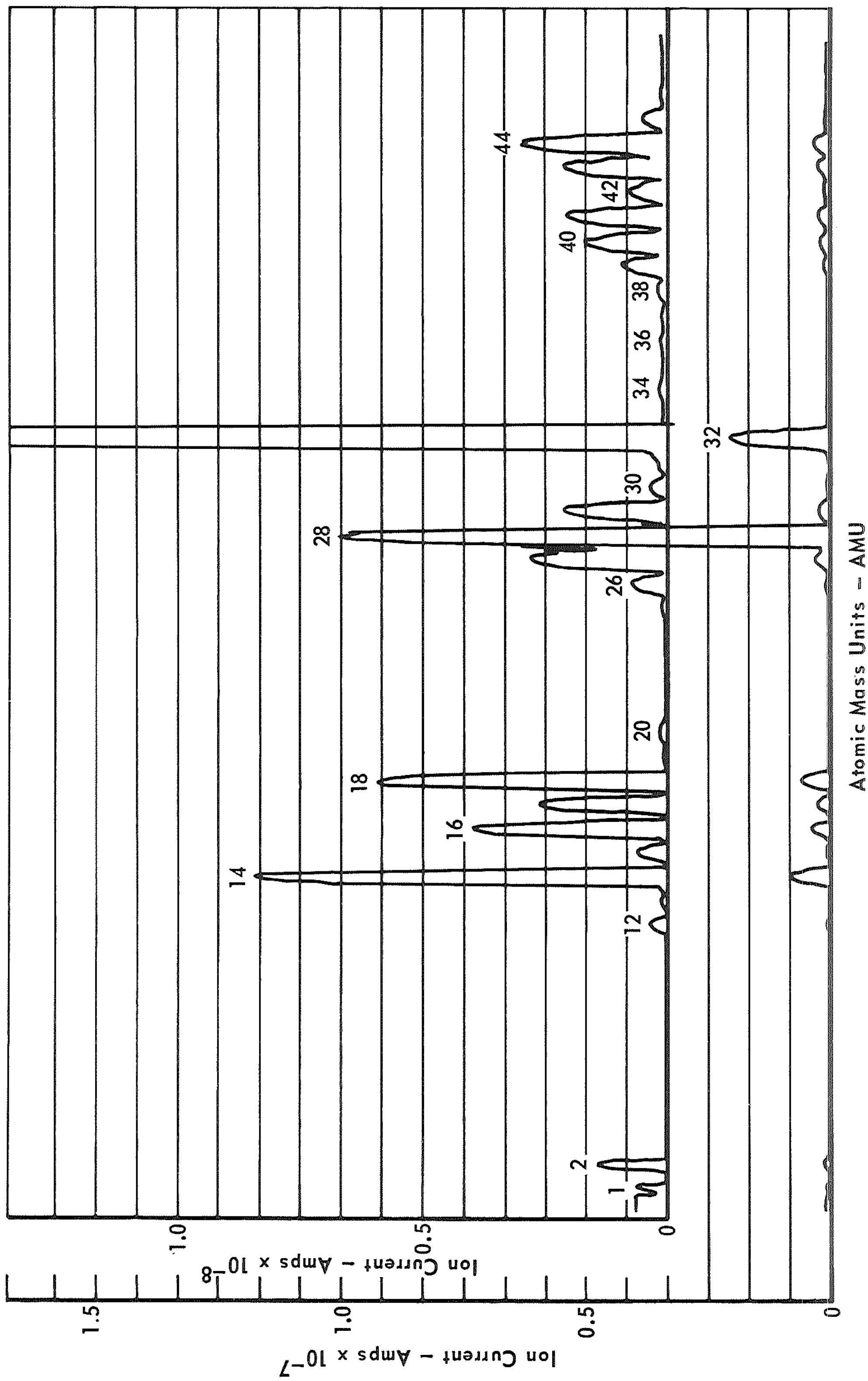


FIGURE B–6 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST WITH COLLECTOR AND LINER COLD
TRACE 1 AMU 1 – 47

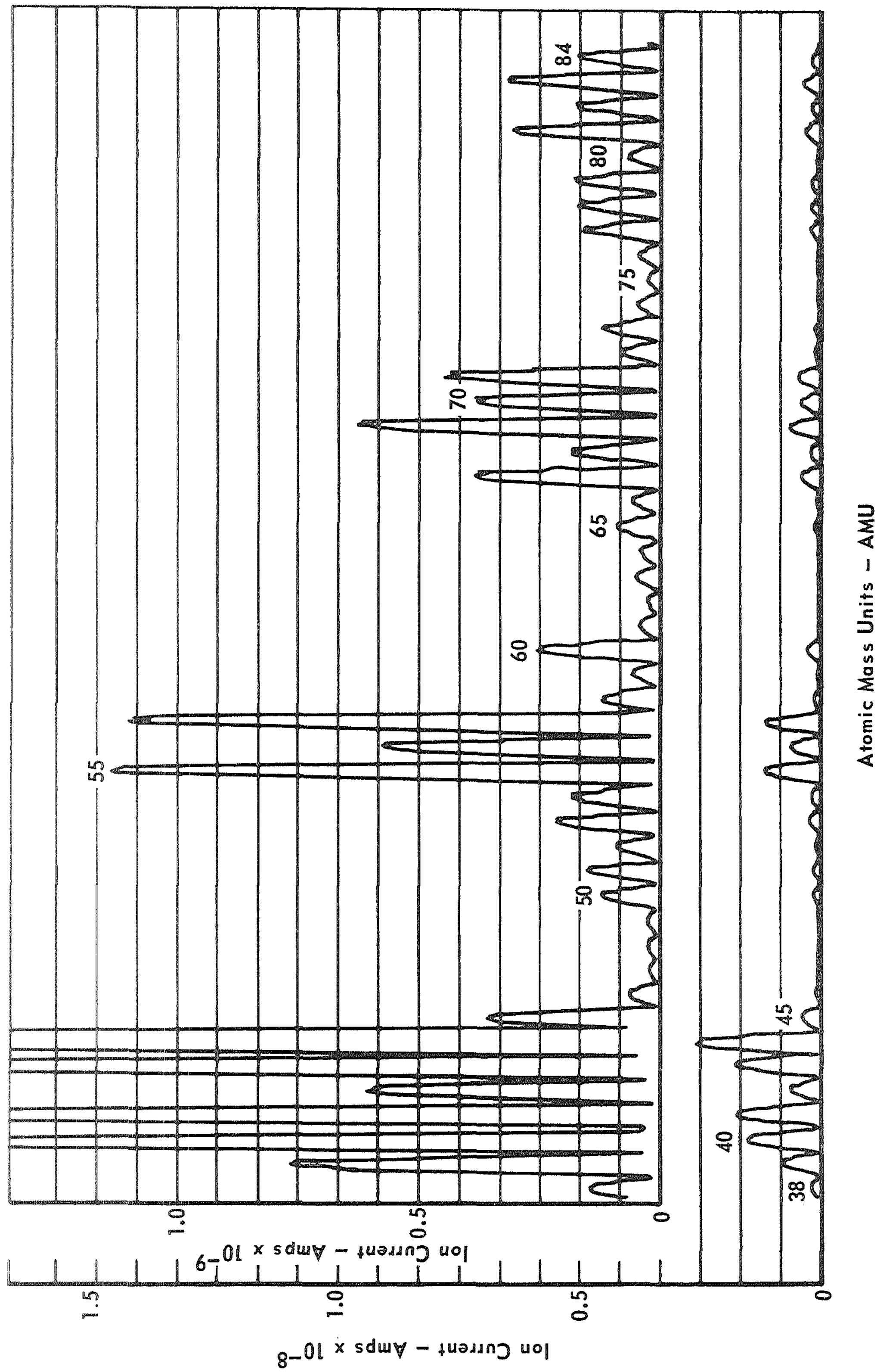


FIGURE B–7 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST
WITH COLLECTOR AND LINER COLD
TRACE 2 – AMU 38 – 84

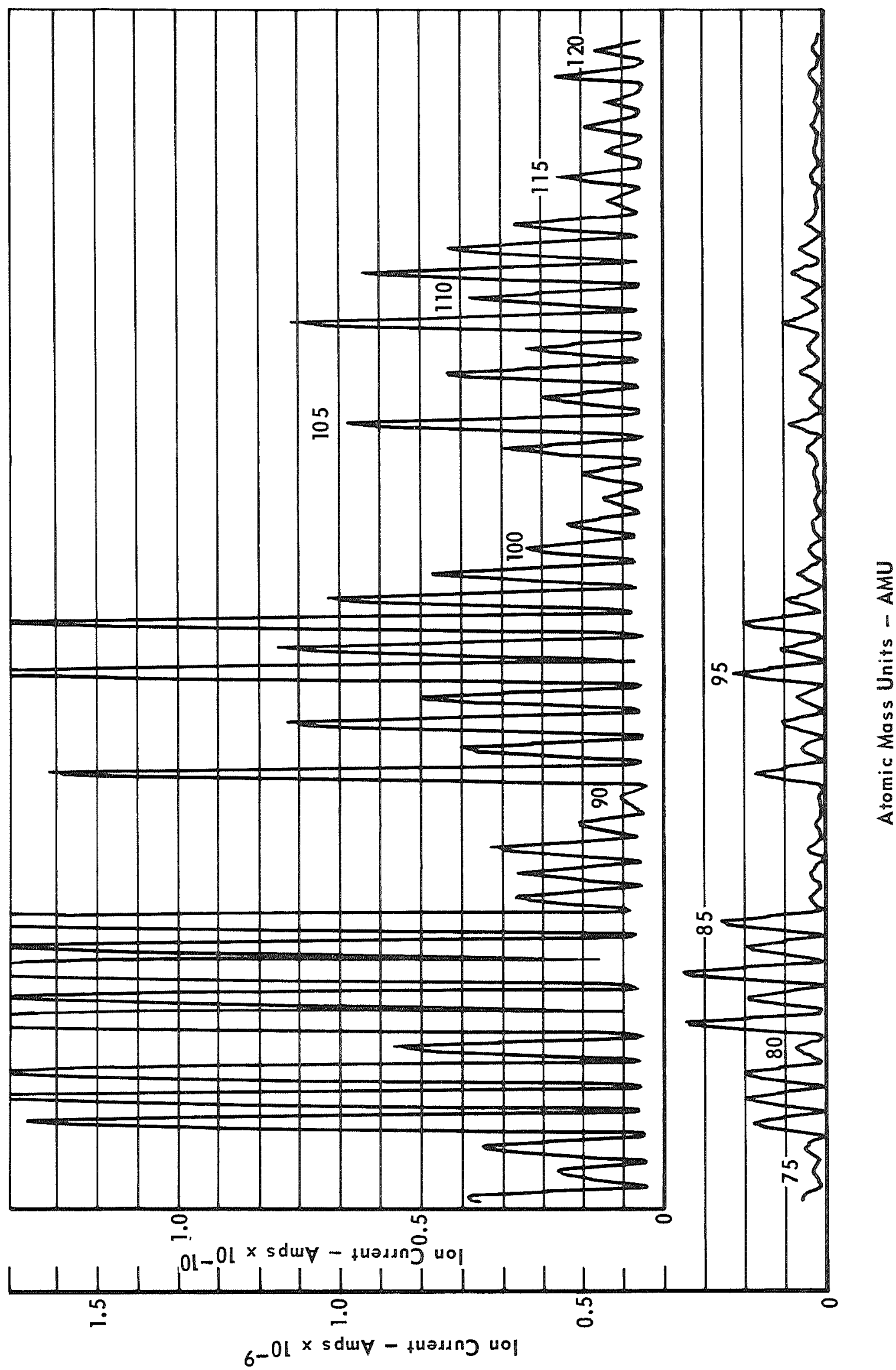


FIGURE B-8 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST
WITH COLLECTOR AND LINER COLD
TRACE 3 – AMU 74 – 119

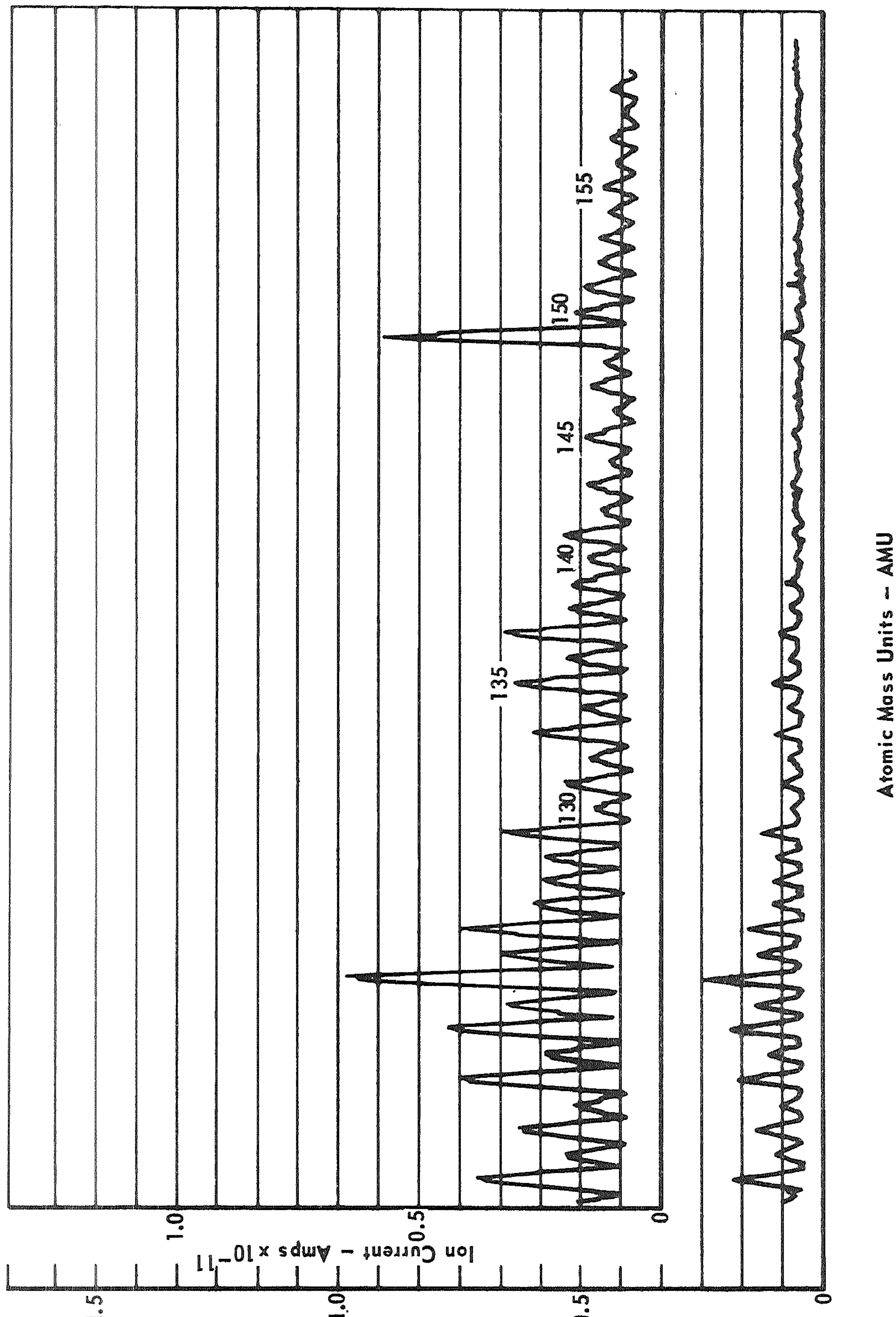


FIGURE B-9 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST WITH COLLECTOR AND LINER COLD

TRACE 4 – AMU 114 – 159

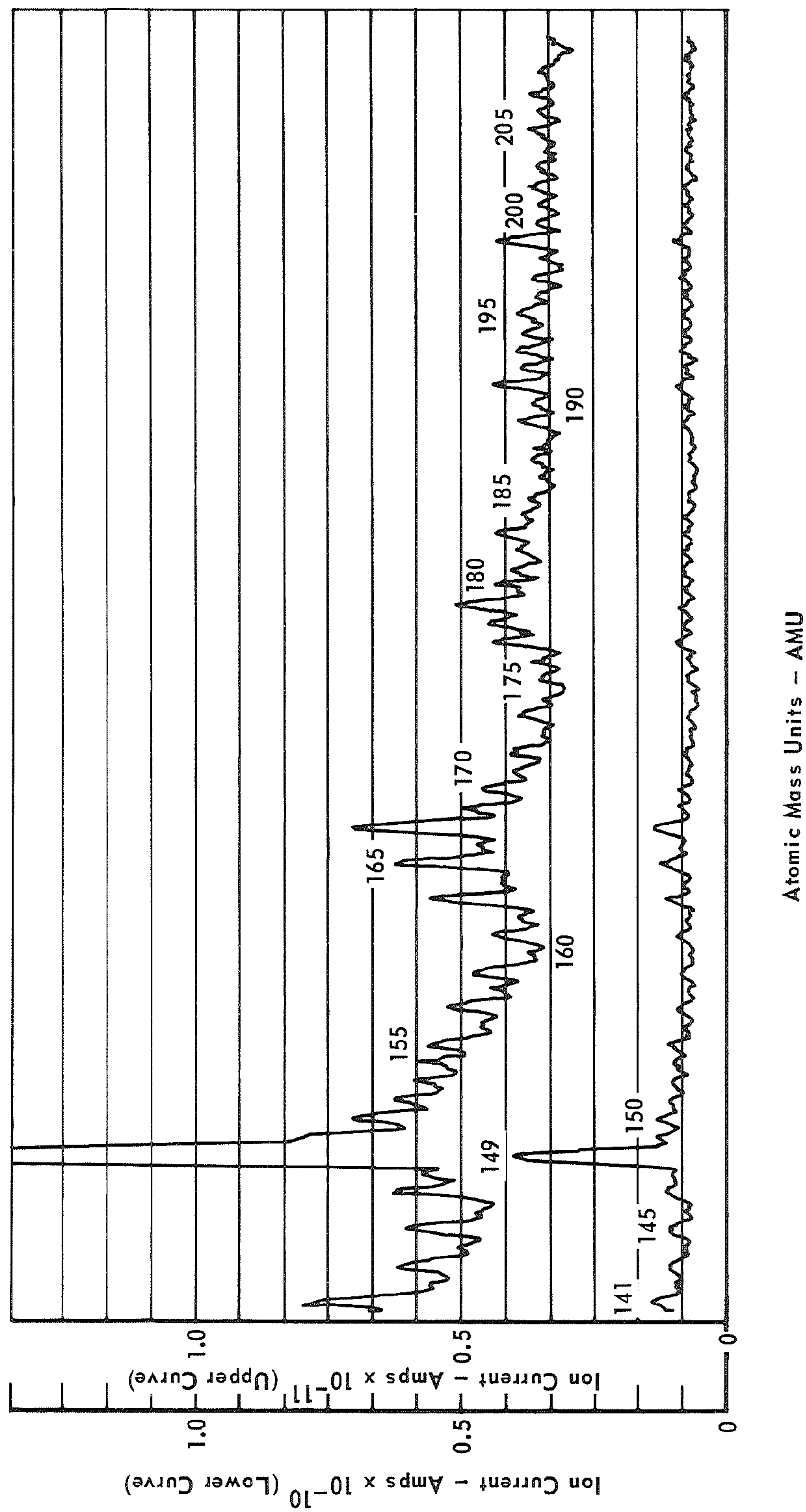


FIGURE B–10 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST
WITH COLLECTOR AND LINER COLD
TRACE 5 – AMU 141 – 207

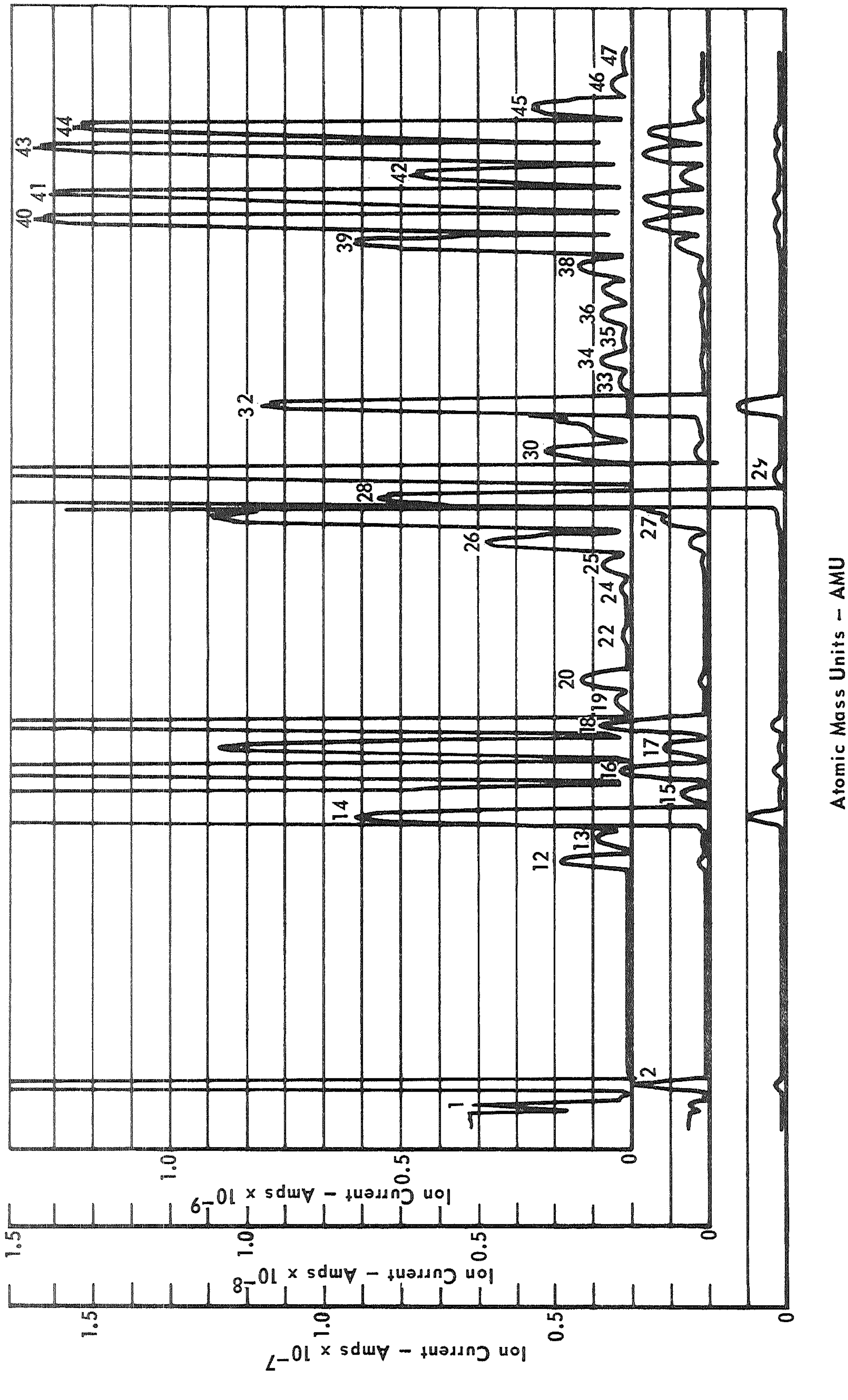


FIGURE B–11 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST WITH COLLECTOR AND LINER WARM
TRACE 1 – AMU 1 – 47

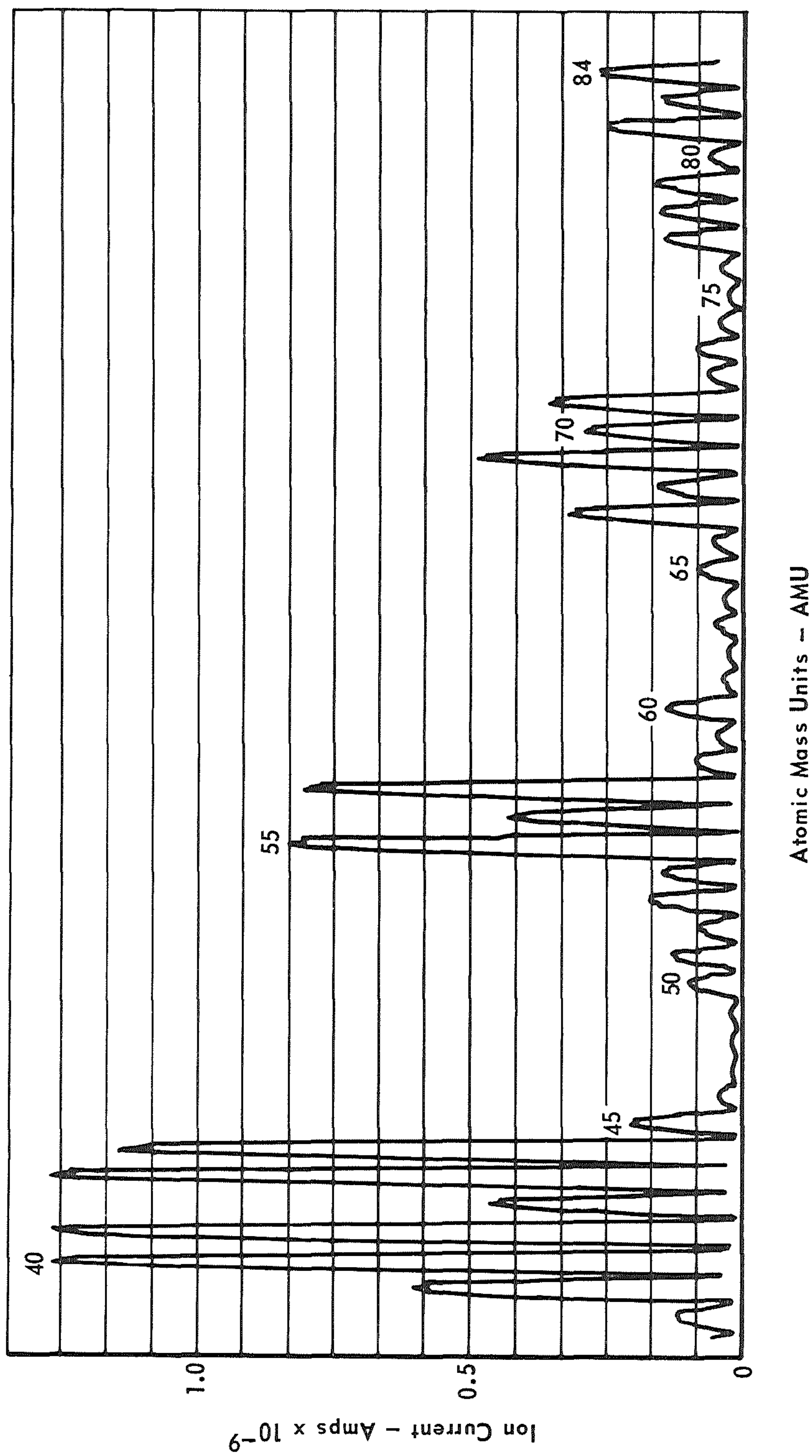


FIGURE B-12 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST WITH COLLECTOR AND LINER WARM
TRACE 2 – AMU 38 – 84

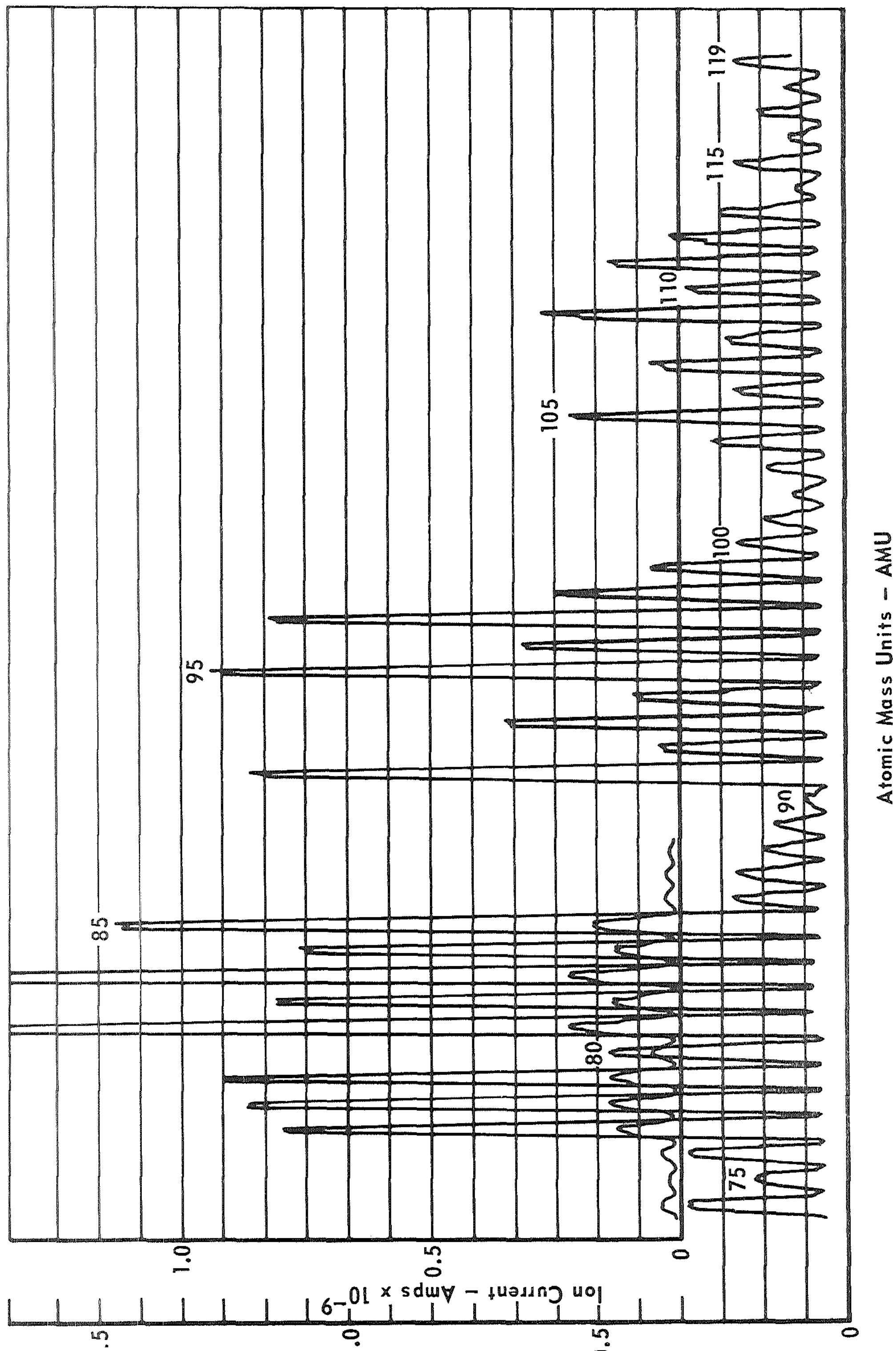


FIGURE B-13 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST
WITH COLLECTOR AND LINER WARM
TRACE 3 – AMU 74 – 119

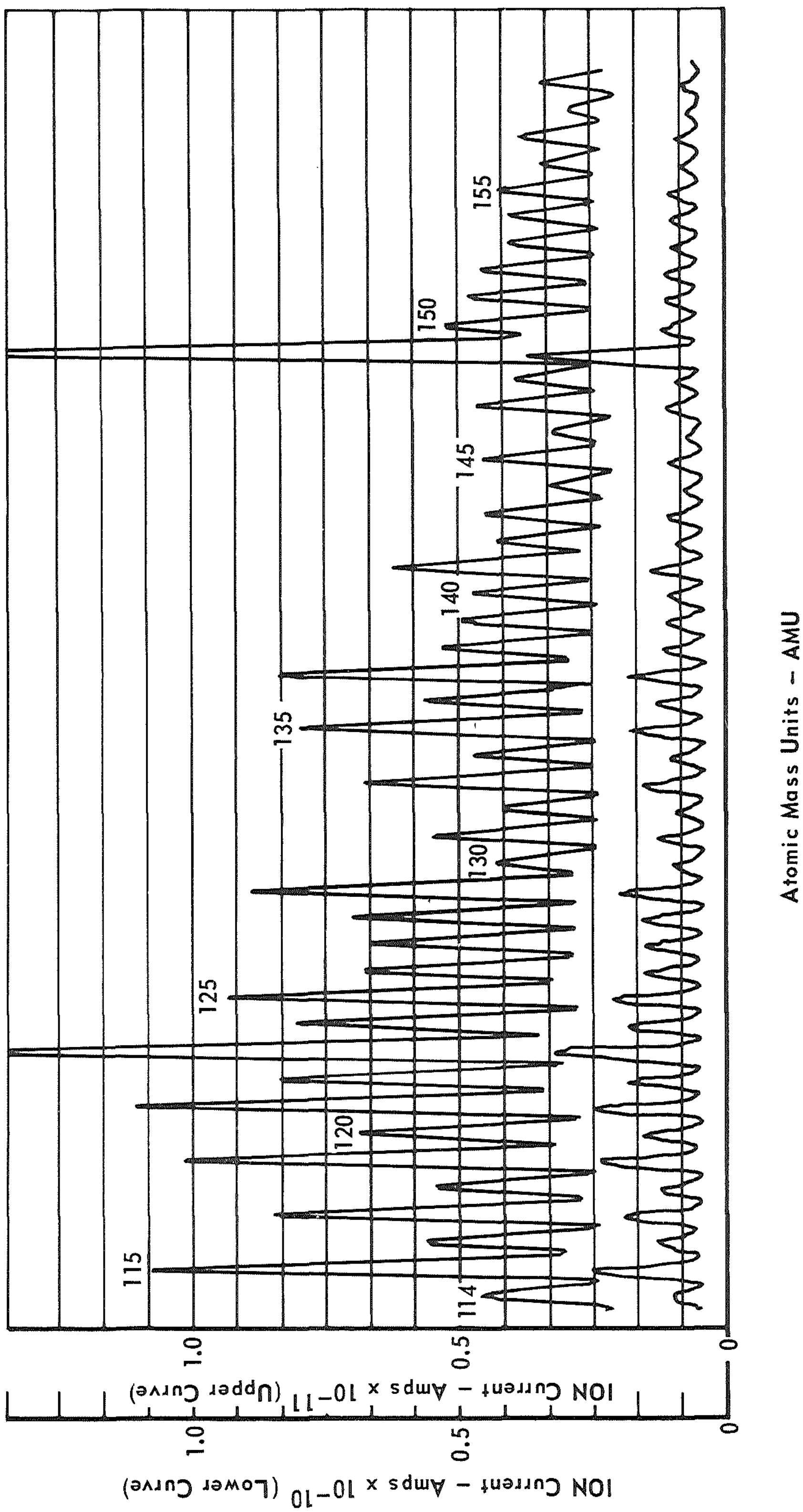


FIGURE B-14 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST WITH COLLECTOR AND LINER WARM

TRACE 4 – AMU 114 – 159

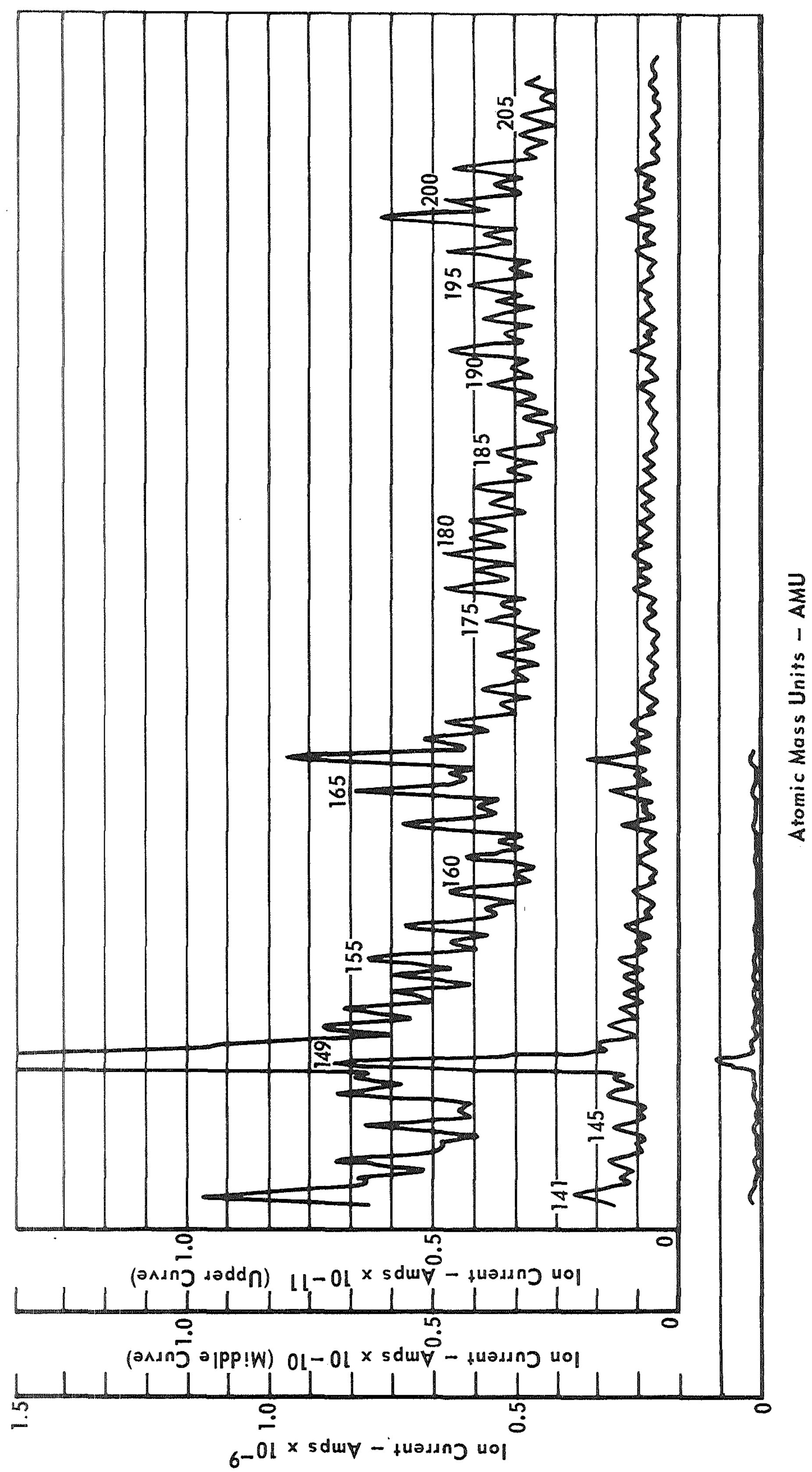


FIGURE B-15 RESIDUAL GAS ANALYSIS AT THE END OF 50 HOUR TEST
WITH COLLECTOR AND LINER WARM
TRACE 5 – AMU 141 – 207

APPENDIX C
FAILURE REPORTS

PAGE 1
REPORT FR NO. 1

Failure Report No. 1 Date 11 September 1969

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 10 September 1969 Time of Failure 1715 Hours

Operating Hours (reading on elapsed time meters) 736.3 (Run #5)

Failure Discovered by J. Olson (2nd Shift)

First Evidence of Failure The indicator lamp on the engine operating time meter was "OFF". Also, telemetry data indicated on DVM #1 and #2 was zero.

Primary Failure High voltage power supply (screen) in the power conditioner unit failed.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

Testing interrupted and the power conditioner unit removed from the test setup and given to the NASA-Program Manager for repair.

PAGE 1
REPORT FR NO 2

Failure Report No. 2 Date 24 October 1969

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 23 October 1969 Time of Failure 0121 Hours

Operating Hours (reading on elapsed time meters) 2.3 (Run #7)

Failure Discovered by R. Nicholls, K. Reader, H. McKinney

First Evidence of Failure Telemetry output of V3 and I3 approximately zero

Primary Failure Thruster Cathode and Isolator Heater Circuit

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

(1) Testing interrupted and the power conditioner unit (PT-1) removed from the test facility and given to the NASA Program Manager for repair per his request.

PAGE 1
REPORT FR NO 3

Failure Report No. 3 **Date** 30 October 1969

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 28 October 1969 **Time of Failure** ______

Operating Hours (reading on elapsed time meters) 28.0 (Run #8)

Failure Discovered by H. F. McKinney

First Evidence of Failure Improper and unsatisfactory operation of Recorder #1 and Recorder #2 mounted in the Life Test Console (LTC #1). Recorder #1 - Print-out is zero on channels 13-19 and 21 thru 23. Recorder #2 (a) The ink supply system to the writting pens fails to supply ink very frequently, (b) When this recorder trys to respond to transient conditions the pens may fall off or become dismounted.

Primary Failure ______

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

PAGE 1
REPORT FR NO 4

Failure Report No. 4 Date 30 October 1969

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 27 October 1969 Time of Failure 1450 Hours

Operating Hours (reading on elapsed time meters) 8.9 (Run #8)

Failure Discovered by R. Vasicek (NASA), H. McKinney

First Evidence of Failure Telemetery Readout of Anode Current (I4) was 3.77 volts (Limit 2.7 to 3.7) when operating thruster system in AAA mode.

Primary Failure

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

PAGE 1
REPORT FR NO. 5

Failure Report No. 5 Date 20 December 1969

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 19 December 1969 Time of Failure 2030

Operating Hours (reading on elapsed time meters) 411.6

Failure Discovered by Plant Security Guard

First Evidence of Failure Automatic alarm sounded at security guard station.

Primary Failure Test Console (LTC #1) automatic shutdown because of momentary (approximately 1 to 2 seconds) main supply power (440 V, 60 Hz) interruption.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

None apparent

Corrective Action:

Restarted ion thruster system per applicable procedures.

PAGE 1
REPORT FR NO 6

Failure Report No. 6 Date 12 February 1970

Report Prepared by H. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 11 February Time of Failure 2215 Hours

Operating Hours (reading on elapsed time meters) 1702.1 Engine Time

Failure Discovered by D. Chapman - 0650, 12 February 1970 (ET 1710.6)

First Evidence of Failure Rise in chamber pressure to 9.3×10^{-6} torr (Normal: 1.2×10^{-6} torr).

Primary Failure Defective switch assembly (zero-speed) on mechanical foreline pump.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

Repair defective switch assembly.

PAGE 1
REPORT FR NO 7

Failure Report No. 7 Date 12 February 1970

Report Prepared by H. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure Noted: 12 February 70 Time of Failure Noted: 0730 Hours

Operating Hours (reading on elapsed time meters) 1710.9

Failure Discovered by H. McKinney

First Evidence of Failure Recorder #1 (24 Channel) in Lewis Test Console #1 printed only the first 12 channels correctly. Channels 13-24 are repeats of Channels 1-12.

Primary Failure

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

Recorder will need repair at the direction of the NASA Program Manager. Last repairs to this unit were made by Leeds and Northrup personnel.

PAGE 1
REPORT FR NO. 8

Failure Report No. 8 Date 4 May 1970

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 3 May 1970 Time of Failure 0730

Operating Hours (reading on elapsed time meters) 3624.3

Failure Discovered by H. McKinney

First Evidence of Failure Collector & Liner Temperatures Warm (>-150°F)(>-101°C) Also Chamber Pressure Increasing

Primary Failure LN_2 Supply Used for Cooling Liner & Collector Depleted

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

No Secondary Failures Noted -

Corrective Action:

(1) Operation of Ion Thruster System was stopped to prevent possible damage caused by operating at test pressures above 2 X 10^{-5} torr.

(2) Replenished LN_2 supply and revised tank fill schedule

PAGE 1
REPORT FR NO. 9

Failure Report No. 9 Date 18 May 1970

Report Prepared by R. A. Dutton for H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 16 May 1970 Time of Failure Between 0730 and 2330

Operating Hours (reading on elapsed time meters) 3910.8 - 3918.8

Failure Discovered by K. Hoffman and D. Chapman

First Evidence of Failure Recorder No. 1 chart drive not working.

Primary Failure Recorder chart drive motor and gears not turning.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

No Secondary Failures Noted.

Corrective Action:

Notified H. Hunczak, NASA-Lewis on 18 May 1970. He stated that he would initiate corrective action.

PAGE 1
REPORT FR NO. 10

Failure Report No. 10 Date 1 June 1970

Report Prepared by R. A. Dutton for H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 30 May 1970 Time of Failure 1915

Operating Hours (reading on elapsed time meters) 4258.6

Failure Discovered by Security Guard

First Evidence of Failure Alarm bell at Guard Station.

Primary Failure Momentary power interruption in laboratory building during wind storm caused LN_2 pump, vacuum pumps, and ion thruster system to shut down automatically.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

No Secondary Failures Noted.

Corrective Action:

(1) Restarted LN_2 pump and vacuum pumps

(2) Put thruster system into preheat mode.

(3) Notified Sanford Jones, NASA-Lewis on 31 May 1970.

(4) Restarted thruster system and put it back into BAA mode, in accordance with instructions from Sanford Jones.

PAGE 1
REPORT FR NO. 11

Failure Report No. 11 Date 29 June 1970

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 25 June 1970 Time of Failure Approx. 07:30

Operating Hours (reading on elapsed time meters) 4865.6

Failure Discovered by R. A. Dutton

First Evidence of Failure Recorder No. 1 chart drive not working.

Primary Failure Recorder chart drive motor and gears not turning.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

No secondary failures noted.

Corrective Action:

Notified Ray Nicholls, NASA-Lewis Program Manager on 26 June 1970. He stated that H. McKinney should initiate corrective action by contacting Leeds & Northrup to provide recorder repair service.

PAGE 1
REPORT FR NO. 12

Failure Report No. 12 Date 10 August 1970

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 6 August 1970 Time of Failure Approximately 1530

Operating Hours (reading on elapsed time meters) 5881.5

Failure Discovered by E. J. Wiessing

First Evidence of Failure Recorder No. 1 chart drive not working.

Primary Failure Recorder chart drive motor and gears not turning.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

No secondary failures noted.

Corrective Action:

Notified Ray Nicholls, NASA-Lewis Program Manager on 6 August 1970 of the repeated Rec. #1 chart drive failure; also notified Leed & Northrup repair service representative.

PAGE 1
REPORT FR NO. 13

Failure Report No. 13 Date 14 August 1970

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 12 August 1970 Time of Failure 1230

Operating Hours (reading on elapsed time meters) 6022.4

Failure Discovered by H. F. McKinney

First Evidence of Failure The first evidence of failure was noted by a rise in chamber pressure.

Primary Failure Main heater fuse for one of the two diffusion pumps opened. Specific cause of fuse opening not known at this time.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Because of the higher test chamber system pressure, the thruster system stability was affected causing an operational shift.

Corrective Action:

Thruster system operating mode was changed to pre-heat for 1.5 hours. Following this pre-heat, operation in the BAA mode appeared normal.

PAGE 1
REPORT FR NO. 14

Failure Report No. 14 Date 8 September 1970

Report Prepared by H. F. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 8 September 1970 Time of Failure 0310

Operating Hours (reading on elapsed time meters) 6659.4

Failure Discovered by Security Guard

First Evidence of Failure The automatic monitoring alarm system was initiated.

Primary Failure The main building power was momentarily interupted by an electrical storm which caused the power contactor in LTC#1 to open.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

No secondary failures noted

Corrective Action:

Following a 1.5 hour pre-heat, operation in the BAA mode appeared normal.

PAGE 1
REPORT FR NO. 15

Failure Report No. 15 Date 14 September 1970

Report Prepared by H. McKinney

Mercury Bombardment Thruster Test

Contract NAS3-11151

Date of Failure 11 September 1970 Time of Failure 13:30

Operating Hours (reading on elapsed time meters) 6742.1

Failure Discovered by E. Wiessing

First Evidence of Failure When recording the 1530 hours system operational data it was noted that the normal operating parameter had changed.

Primary Failure It is indicated that the main fuel supply is depleted.

Secondary Failures (Items failing as a result of the initial failure). To be determined by further inspection.

Corrective Action:

Thruster system operation stopped per NASA Program Manager request.

REFERENCES

1. Kerslake, W. R., Byers, D. C., and Staggs, J. F., "SERT II Experimental Thruster System," AIAA Paper No. 67-700, American Institute of Aeronautics and Astronautics, 11-13 September, 1967.

2. Byers, D. C. and Staggs, J. F., "SERT II: Thruster System Ground Testing," Journal of Spacecraft and Rockets, Vol. 7, No. 1, pages 7-14, January 1970.

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4. Bagwell, J. W., Hoffman, A. C., Leser, R. J., Reader, K. F., Stover, J. B., and Vasicek, R. W., "Review of SERT II Power Conditioning," AIAA Paper No. 70-1129, American Institute of Aeronautics and Astronautics, 31 August - 2 September, 1970.

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