TEST FACILITY FOR 6000 HOUR LIFE TEST OF 30 CM MERCURY ION THRUSTER

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ABSTRACT

The environmental and instrumentation requirements for long term testing of electrical propulsion thrusters impose severe and unusual requirements upon the simulation facility. High speed ions ejected from a mercury thruster erode material from collecting surfaces which is then scattered and redeposited upon other surfaces with resultant damage to the chamber and test article. By collecting the thruster plume on a frozen mercury suface, damage to the thruster and chamber by back-scattered erosion products is minimized. Provisions for unattended operation, remote data acquisition, personnel safety, and instrumentation for assessing thruster performance are discussed in this paper.

1. INTRODUCTION

Electrical propulsion engines for extended space missions require test periods comparable to the intended flight time to demonstrate satisfactory long-term performance. This is because the operation of these devices is typically optimized at some specific design point and hence accelerated testing during a life test is not possible. The facility must provide an adequate environment for the thruster with maximum reliability at minimum initial and operating costs.

Some features of the test facility can be made to adequately simulate the ultimate space environment. Those which cannot must be controlled to the extent that damage to the thruster is prevented and thruster performance is not degraded or obscured. In the following sections the requirements for evaluating the endurance of a 30 cm Kaufman type mercury thruster and a facility designed to meet these requirements are discussed.

2. 30 CM KAUFMAN THRUSTER DESCRIPTION

The thruster module* tested was scaled from the SERT II thruster for operation at a specific impulse of 2750 seconds at a 27 millipound thrust level. The thruster module is described in some detail in References 1 and 2

*Thruster development was carried out under a cooperative program between the NASA Lewis Research Center and the Hughes Research Laboratories.

and shown in Figure 1 mounted on the test chamber dome. The thruster envelope is 43 cm diameter by 21 cm long. The thruster has an anode 30 cm in diameter and has a mercury flow rate of 12.4 grams per hour. This thruster module is expected to form the basis of near future prime propulsion systems not only for interplanetary vehicles but also for orbit raising of synchronous satellites. Endurance testing of the thruster was therefore undertaken by the Space Simulation Laboratory which had the facilities and experience necessary for long term thermal vacuum testing.

The purpose of the endurance test is to demonstrate stable performance of the thruster system over long periods of time in an environment which approximates space conditions.

3. THRUSTER ENVIRONMENT REQUIREMENTS

The chamber design must provide a vacuum of 10^{-6} Torr, an adequate temperature environment, and a disposal/collection system for the thruster expellant. The effluent of the thruster consists of high energy mercury ions which will sputter erode whatever beam collector that they may strike (approximately 10^{19} ions per second leave the thruster traveling at approximately 3.6×10^6 cm/sec). These ions must be collected in a manner which minimizes the destruction of the collector and has minimal effect on the thruster operation.

If for instance, the ion stream strikes a stainless steel collector, stainless steel will be eroded and back-sputtered upon thruster and chamber components. Some of the sputtered material will deposit on the thruster accelerator grids. Other sputtered material will penetrate the grid holes and be deposited in the interior of the thruster. The result will be degradation of the thruster by conditions which will not be encountered in a space mission.

If on the other hand, the ion stream impinges only on mercury surfaces, the sputtered material is mercury which when deposited on the thruster will reevaporate due to the operating temperature of the thruster and will not deposit on the interior of the thruster. To meet the 10^{-6} Torr or better pressure requirement of the thruster, the mercury collecting surfaces must be maintained at a temperature of -50°C or lower.

4. TEST FACILITY DESCRIPTION

A cutaway view of the endurance test chamber is shown in Figure 2 and a cross-sectional drawing is shown in Figure 3. The most significant feature of the chamber design is the use of mercury as the ion beam collector material. Consequently, back-sputtered material from the collector is the same as the propellant and is fully compatible with the thruster and all its components. Furthermore, it is easily evaporated from heated surfaces of the thruster and easily trapped on refrigerated surfaces. The axis of the vacuum tank is vertical to accommodate the liquid state of the mercury when not frozen. The ion engine is located at the top of the chamber so that the ion beam projects vertically downward onto the frozen mercury pool. Mercury which has been frozen out on the liners drips back into the collector upon thawing.

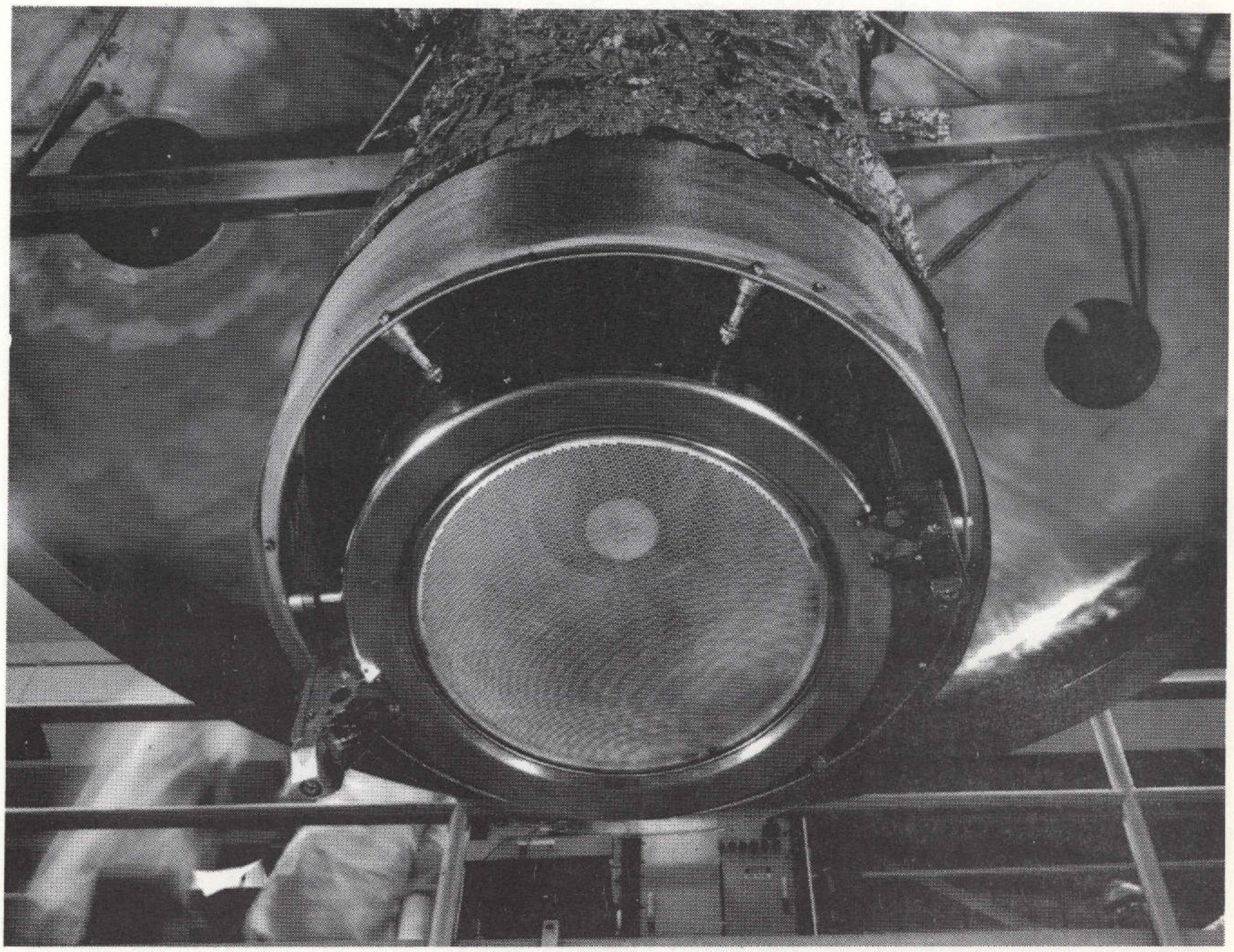

FIGURE 1. 30 CM KAUFMAN THRUSTER MODULE (PHOTO 4R32265)

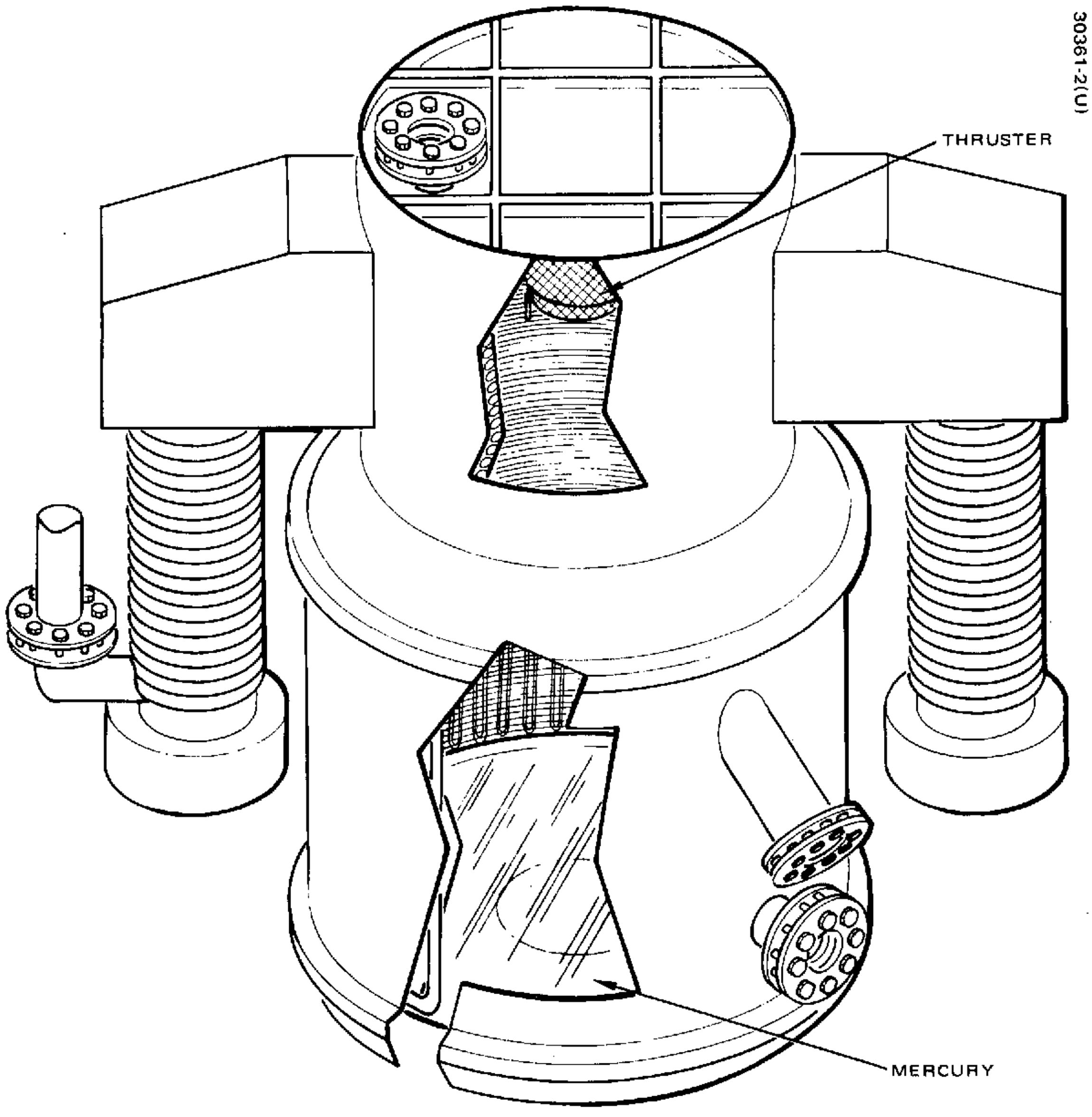

FIGURE 2. MERCURY THRUSTER ENDURANCE TEST CHAMBER

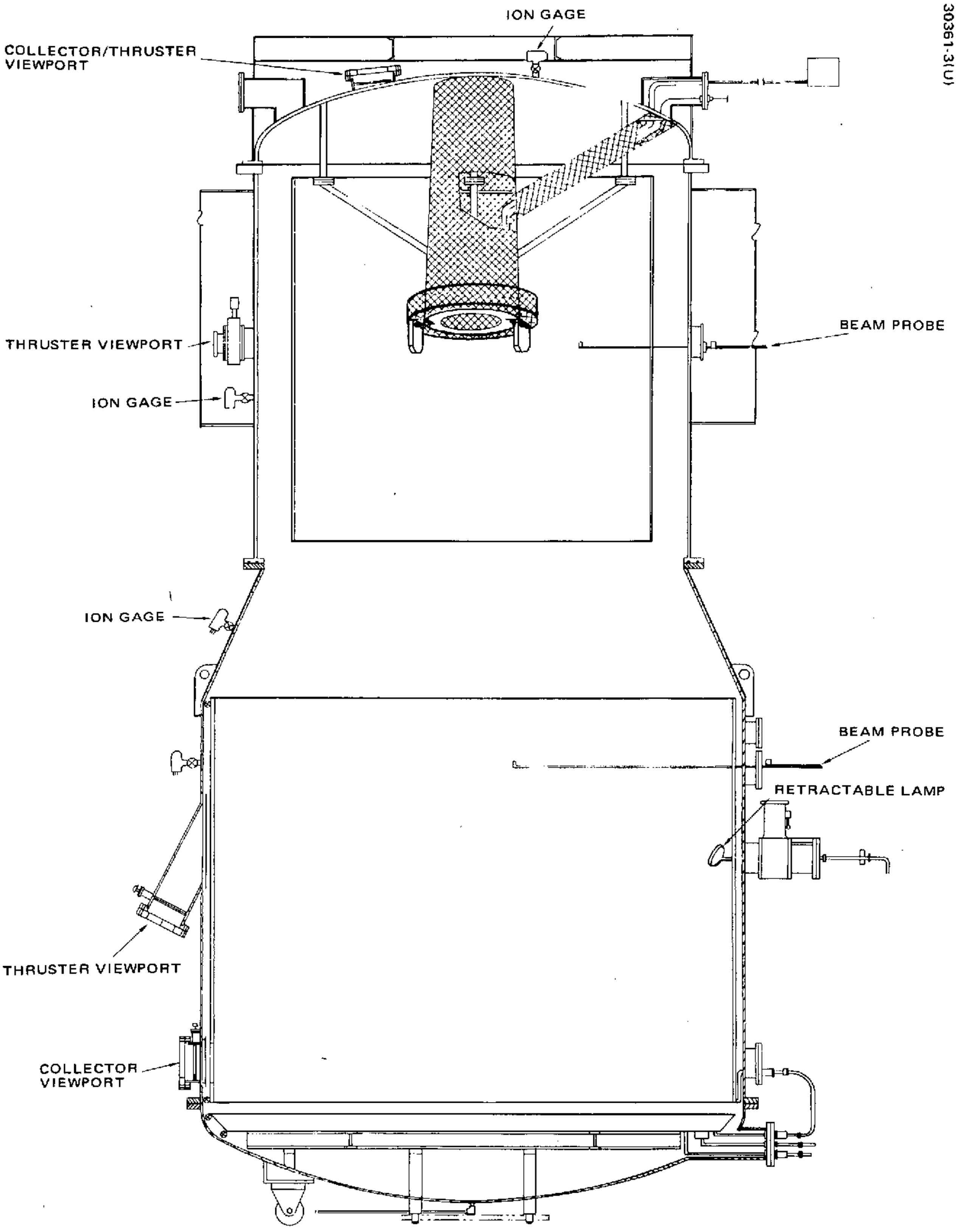

FIGURE 3. ENDURANCE TEST CHAMBER CROSS-SECTION

The test chamber consists of the following four major components:

1) Chamber dome on which thruster is mounted

2) Central cylindrical section 87 inches diameter by 80 inches high on which diffusion pumps are mounted

3) Lower section 110 inches diameter by 108 inches high with transition section mating to central cylindrical section

4) Lower endbell 110 inches diameter with collector pan which contains 4600 pounds of mercury

The test chamber is provided with two independent pumping systems, each consisting of a 32 inch diffusion pump, a 4 inch diffusion pump, and a 140 cfm mechanical pump. (See Figure 4.) The chamber is roughed through the large diffusion pump, which is turned on when an appropriate vacuum is achieved. The mechanical pump backs the diffusion pump until gas loads stabilize; the small diffusion pump then backs the large diffusion pump (via valving) and the mechanical pump then backs the small diffusion pump.

If the pressure rises significantly in the foreline, a pressure sensor turns off diffusion pump power, closes all valves to isolate the chamber, and activates the appropriate annunciator and alarm signals. When diffusion pump power is turned off, quick cool water coils are activated, accelerating the rate at which the diffusion pump oil cools. An interconnecting line and valve permits the use of either mechanical pump with either or both diffusion pumps, giving additional flexibility in the event of malfunctions.

Loss of electrical power causes the valves in the vacuum system to close, isolating the chamber from the roughing or backing line. The diffusion pump heaters also go off, the roughing pumps stop, and the roughing lines vent automatically to prevent pump oil from being drawn into the lines. Upon return of electrical power, the pumps will restart, but the vacuum valves will not open until adequate vacuum is achieved in the roughing or backing line because of the pressure sensor interlock.

The test chamber thermal system as shown in Figure 4 utilizes liquid nitrogen from the building storage tanks. In the event of failure of this supply, an emergency LN_2 backup system is automatically switched into the system. Liquid nitrogen flow to the chamber is controlled by a pneumatically operated cryogenic throttling valve, responding to a proportioning temperature controller. The controller is set to give the collector shroud an operating temperature of $-196^{\circ}C$ or lower as required by operating conditions of the thruster. The LN_2 enters the collector shroud, flows through the lower shroud, then to the upper shroud, and exits as gaseous nitrogen to atmosphere. A throttling hand valve and a bypass valve permits balancing the system to minimize LN_2 usage within constraints imposed by thruster operating conditions.

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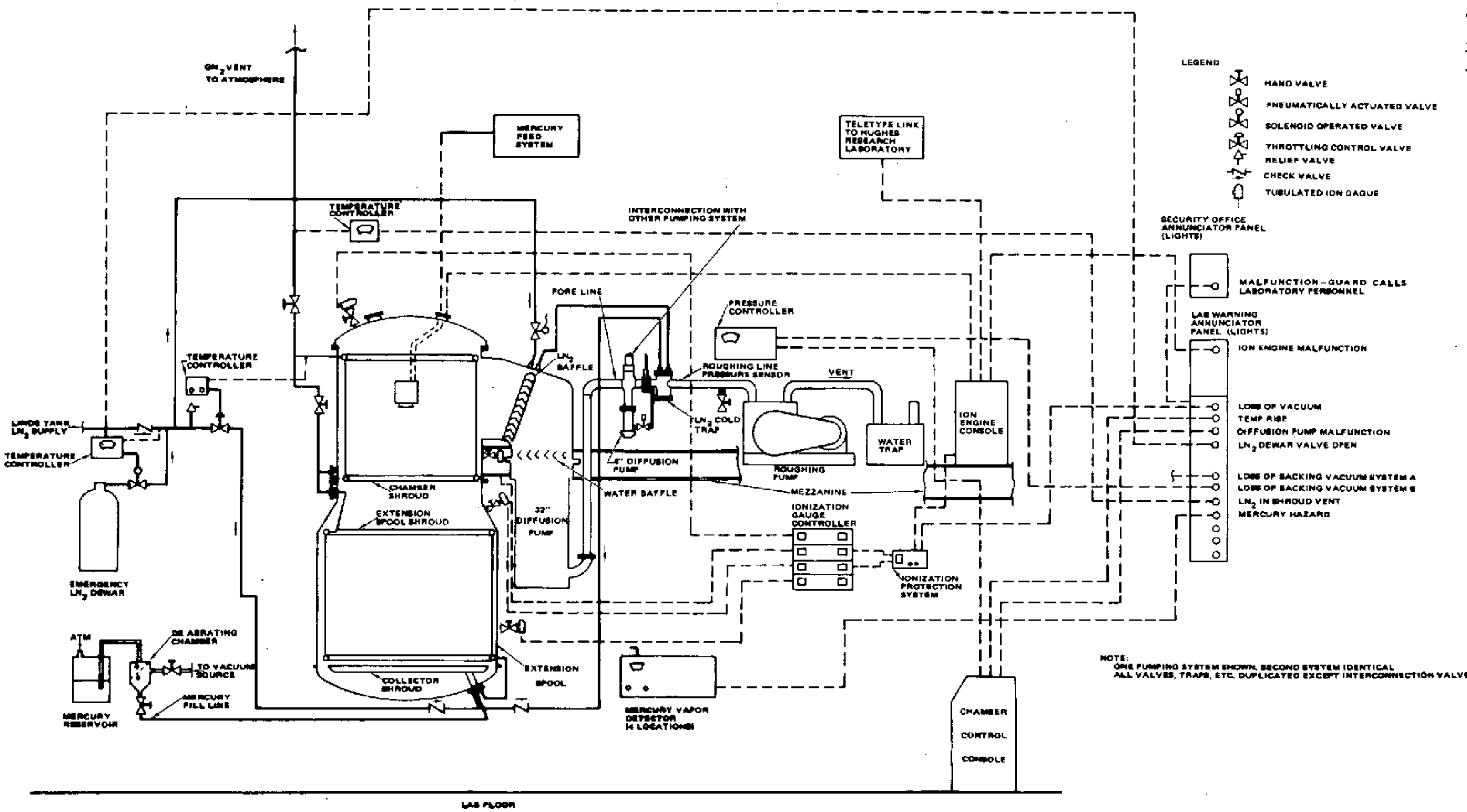

FIGURE 4. BLOCK DIAGRAM OF MERCURY THRUSTER ENDURANCE TEST FACILITY

Liquid nitrogen leaving the diffusion pump baffles is routed through the roughing line mercury cold traps and joins the line supplying the collector shroud to augment the chamber thermal system and reduce cryogenic consumption. The mercury is deaerated as it is being introduced into the evacuated chamber by the system shown at the lower left of Figure 4. The thruster is supplied with mercury propellant from the feed system shown in Figure 5.

5. INSTRUMENTATION

Chamber instrumentation of the following four types is provided:

1) Thruster monitoring

2) Thruster Analysis, i.e., other than continuous operation monitoring of thruster

3) Chamber operation and monitoring

4) Safety monitoring

Thruster monitoring is provided by the thruster power conditioning console which is located on a balcony near the chamber dome in close proximity to the thruster electrical and mercury feed throughs. Local data readout and parameter adjustment is provided on the console. An automatic data acquisition system converts the data to a form compatible with teletype operation. Each of 29 system parameters is scanned hourly and recorded on paper tape which can be read out locally or remotely on a teletypewriter. These same operating conditions (29) can also be remotely interrogated in real time via teletype from the Malibu location of the Hughes Research Laboratories or NASA's Lewis Research Center in Cleveland, Ohio.

Thruster analysis provisions include determination of ion beam profile via Faraday cup probes translated across the beam at two locations (Figure 3) telescopic viewing and photographs through the viewports using the high intensity retractable lighting system. Propellant consumption is determined using the weighing system shown on the feed system board in Figure 6.

Chamber operation monitoring is accomplished by the equipment shown in Figure 3 which is connected into the overall facility as shown in Figure 4. Unattended operation of the facility is an economic necessity because of the long test duration. An annunciator system connected to appropriate detectors monitors the major failure modes of chamber and thruster and provides a display identifying a failure mode locally and at a continuously manned guard station.

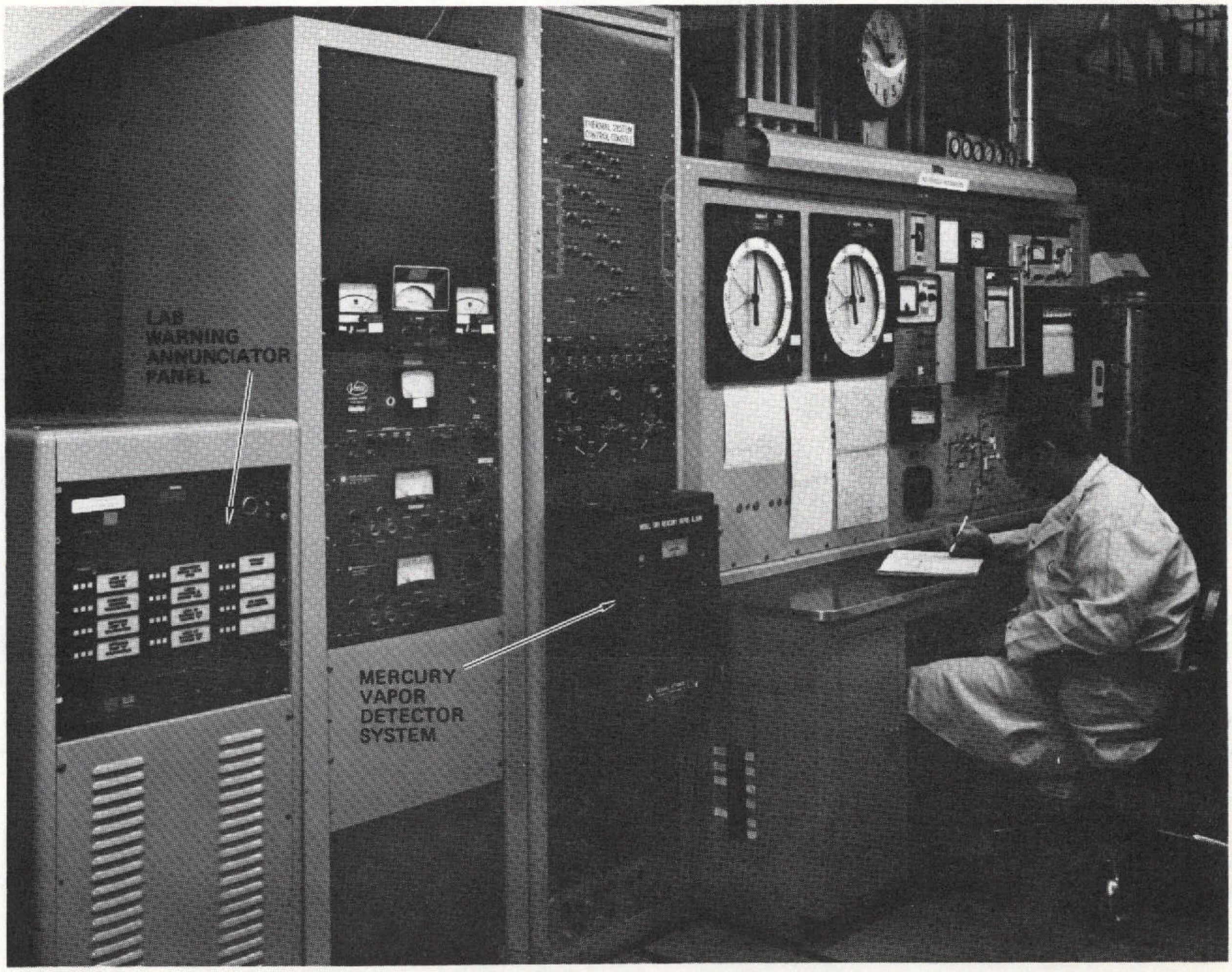

FIGURE 5. TEST CHAMBER CONTROL CONSOLE AND ANNUNCIATOR SYSTEM (PHOTO 30361-5)

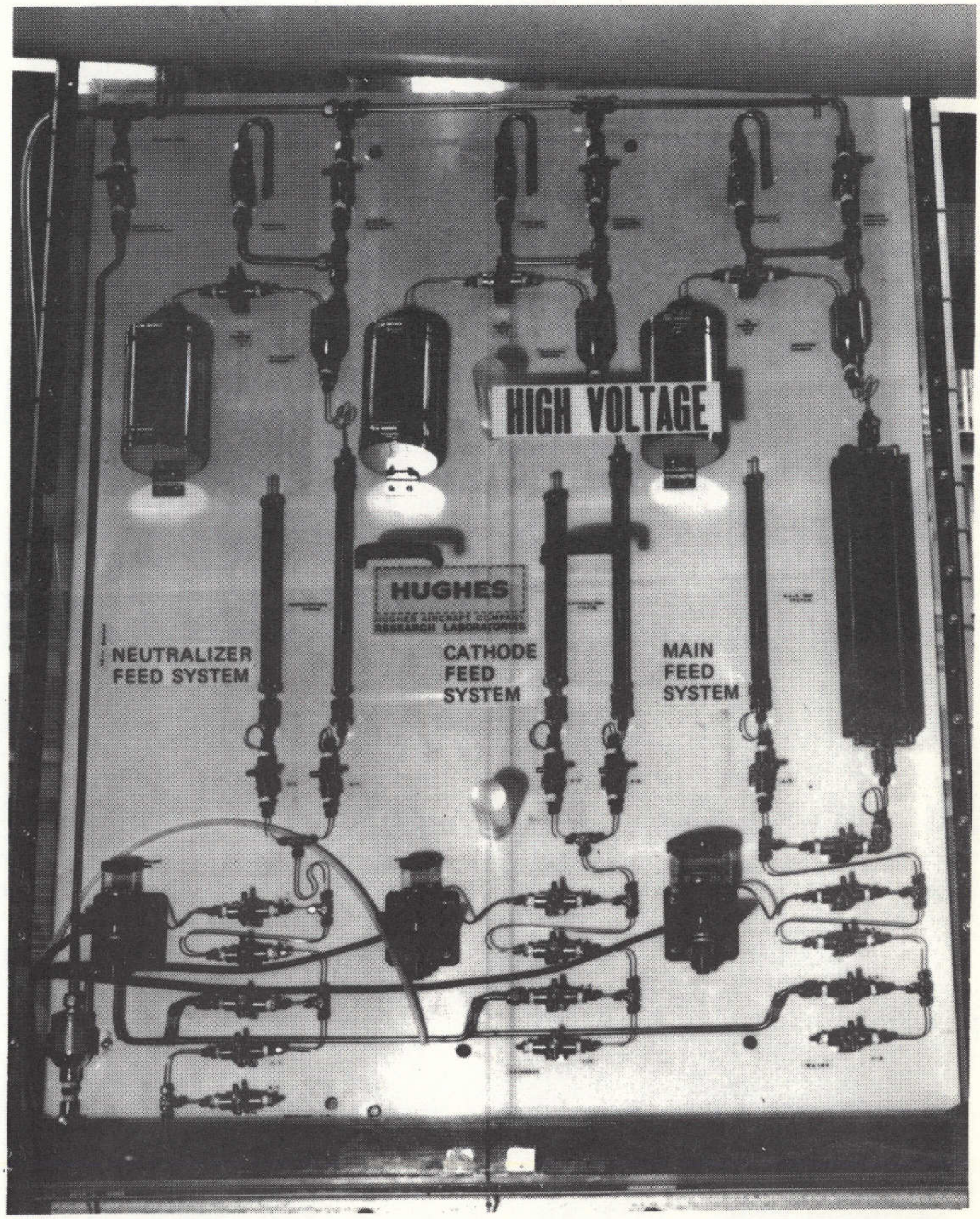

FIGURE 6. THRUSTER PROPELLANT FEED SYSTEM (PHOTO 30361-6)

Safety monitoring for the presence of mercury vapor is continuously done at four locations: three locations beneath the chamber endbell and one inside the propellant feed system housing. Sampling is done for 4 minutes at each of the four locations with a 1 minute purge intervening for a total cycle time of 20 minutes. The continuously cycling mercury vapor detector and the annunciator system is shown in Figure 5 alongside the chamber operating console.

6. HEALTH AND SAFETY PRECAUTIONS

The endurance test facility is installed in a laboratory which also contains numerous thermal vacuum systems and two vibration test facilities which are used for thermal vacuum vibration testing of spacecraft. The possibility of mercury vapor exposure to personnel or test articles is remote after the thruster has been installed in the test chamber. However, during installation or removal of the thruster, there is finite possibility of mercury or mercury vapor exposure.

Extreme care has been taken to ensure that neither personnel nor test articles are exposed to mercury hazards. A mercury handling procedure has been prepared and implemented. Special mercury vapor monitoring apparatus, mercury cleanup equipment, and personnel protection suiting is used when the chamber must be opened for operations on the thruster.

An isolation tent, shown in Figure 7, is provided for operations which must from time to time be performed on the thruster. The tent is large enough to enclose the chamber dome with the thruster mount and two or more technicians. Laboratory air is pulled in through holes in the top at a rate adequate to ensure that the mercury vapor density inside is below the 0.01 mg/m^3 TLV value and expelled into the laboratory through an activated charcoal filter which has been treated with iodine to absorb mercury vapor. Expelled air is periodically monitored for mercury vapor and the charcoal filter is replenished if a detectable level is observed.

Temperature of the chamber walls and the mercury collector is lowered to the laboratory dew point and the laboratory temperature is lowered as much as possible in preparation for opening the chamber. Exposure time of the opened chamber and components which have been inside the chamber is minimized by preparation in advance of the moves to be made and by bagging of exposed components in polyethylene and/or by transfer of exposed items to the isolation tent.

7. OPERATING EXPERIENCE

To date four thruster tests have been completed in this facility and a fifth is in progress. After an initial shakedown operation, which included simulation of the thruster heat load, minor corrections were made in the annuciator system and the operating procedure. A thruster was then installed and operated for approximately 100 hours. To maintain the chamber pressure

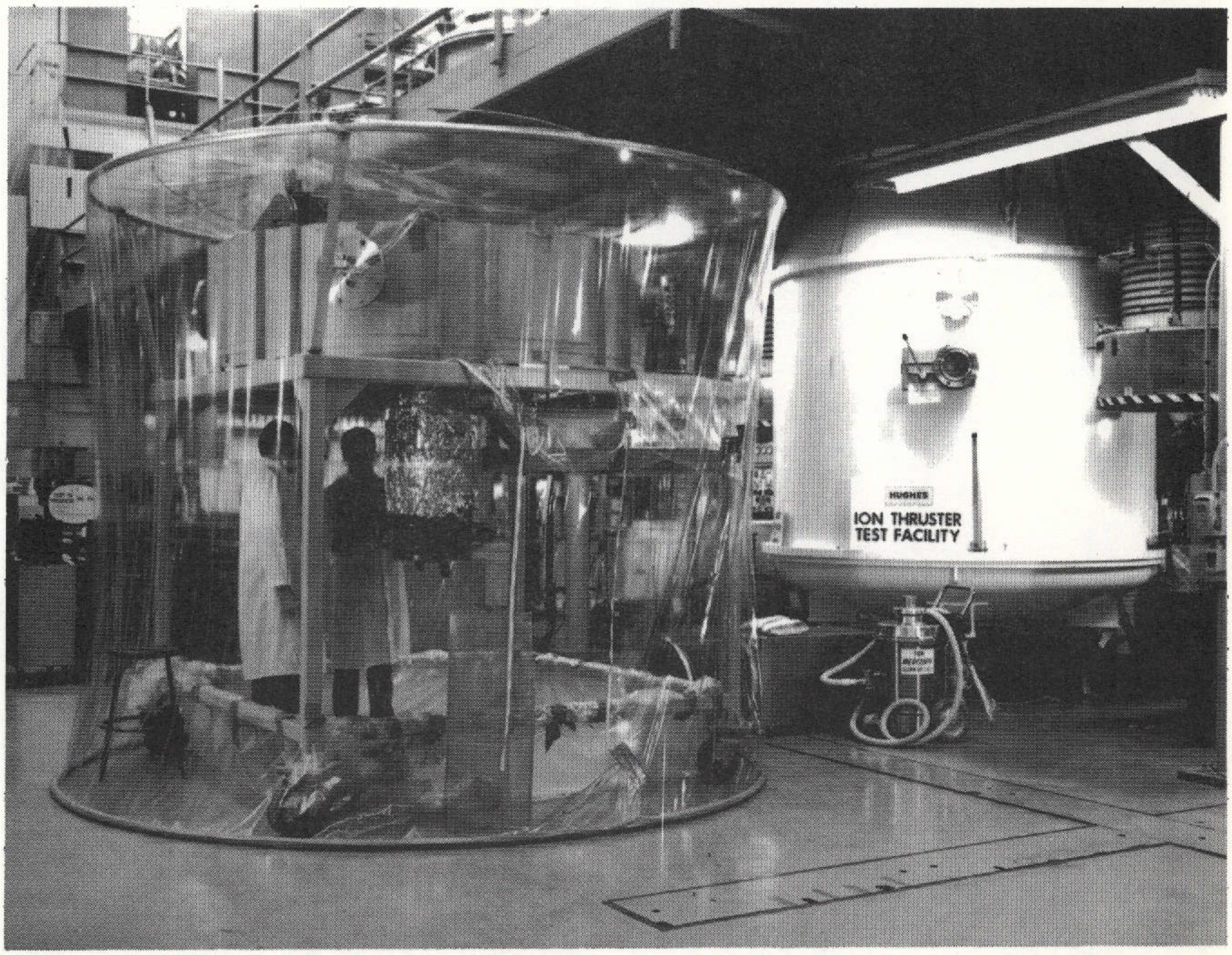

FIGURE 7. ISOLATION TENT ENCLOSING CHAMBER DOME WITH THRUSTER MOUNT (PHOTO 4R32268)

as measured by No. 4 ion gage* low on the 10^{-6} scale, it was necessary to run the upper part of the upper shroud at LN_2 temperature. This resulted in freezing the mercury in the propellant feed lines when the thruster was turned off. A thermal fix consisting of a thermal blanket and four heaters on the thruster mounting structure was installed.

The thermal fix was verified during the following 500 hour test of the thruster. All of the facility features were exercised during this period, beam profile measurements were made, and photographs were made through the angled viewport using a Questar telescope with illumination provided by the retractable lamp. Tests of 500 and 1100 hours duration followed. Present plans call for future tests of up to 6000 hours in this facility.

SUMMARY

An endurance test facility for verifying long duration performance of mercury thrusters has been designed, assembled, and operated satisfactorily. Significant features of the facility are 8 foot diameter frozen mercury collector and the ability to perform long term unattended operational testing of a 30 cm ion thruster. The facility has been used for thruster tests up to 1100 hours duration. The long duration tests possible in this facility have resulted in identifying thruster characteristics which shorter tests did not reveal.

ACKNOWLEDGEMENTS

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*Gage 4 looks directly at the collector through the thruster ion beam. Gages 1 and 2 are behind shrouds and read consistently an order of magnitude lower.

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