GSFC SPACE SIMULATION LABORATORY CONTAMINATION PHILOSOPHY: EFFICIENT SPACE SIMULATION CHAMBER CLEANING TECHNIQUES

Juan A. Roman and George F. Stitt
Space Simulation Test Engineering Section
NASA Goddard Space Flight Center

Felix R. Roman, Ph. D.
Department of Chemistry
University of Puerto Rico, Mayaguez Campus

ABSTRACT

This paper will provide a general overview of the molecular contamination philosophy of the Space Simulation Test Engineering Section and how the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) space simulation laboratory controls and maintains the cleanliness of all its facilities, thereby, minimizing down time between tests. It will also briefly cover the proper selection and safety precautions needed when using some chemical solvents for wiping, washing, or spraying thermal shrouds when molecular contaminants increase to unacceptable background levels.

INTRODUCTION

The Space Simulation Test Engineering Section at GSFC is responsible for the design and implementation of space simulation tests in order to produce simulations of vacuum, temperature, and solar environments required for the qualification of flight hardware at the component, subsystem, system, and spacecraft levels. Examples of these tests are thermal vacuum, thermal balance, and molecular outgassing tests. The section has 10 thermal vacuum chambers ranging in size from 0.6 m x 0.6 m (2 ft x 2 ft) up to approximately 8.2 m x 12.2 m (26 ft x 40 ft). Figures 1, 2, and 3 show pictures of several GSFC thermal vacuum chambers. Table 1 provides general facility capabilities.

The section is challenged to support the testing requirements of GSFC in-house and out-of-house flight projects. These projects can vary greatly in terms of molecular outgassing test (bakeout) requirements from sounding rockets, Hitchhikers, or Get Away Special (GAS) projects that have minimum outgassing requirements up to the Hubble Space Telescope (HST) which thus far has the most stringent outgassing requirements supported by the laboratory.

In order to effectively and efficiently support this wide range of customers, the section implemented a standard molecular outgassing criteria for all the thermal vacuum chambers. The first outgassing criterion for the vacuum chambers is an accretion rate for a 10 MHz

Thermoelectric Quartz Crystal Microbalance (TQCM) of 300 Hz/hr or less for three consecutive hours with its crystal at -20°C and the chamber shroud at 100 °C or its maximum operating temperature. This represents a mass loss of 4.2×10^{-7} g/hr or 133 Å for a unit density material (ref. 1). The second criterion is a nonvolatile residue (NVR) sample of 3.0×10^{-3} grams of residue with no unusual components for the last 8 hours of every test performed. This NVR or "cold finger" sample is collected using a small electroplated stainless steel cylinder with 142 cm^2 (22 in^2) of nominal surface area. These molecular outgassing criteria were established many years ago and have been very successful at keeping all the vacuum facilities at a uniform level and provides an acceptable compromise to the wide variety of customer needs.

During fiscal year (FY) 1996, a total of 392 tests totaling 42, 848 hours were performed in the Space Simulation Laboratory. They were comprised of 76 thermal vacuum/thermal balance tests, 103 normal bakeout tests, 115 outgassing certification tests in box with cold shrouds, and 98 chamber post test recertifications. Figure 4 shows the total hours per test facility and Table 2 shows test type per facility. This workload represents one of the busiest years for the laboratory.

OUTGASSING TESTS

Normal Bakeouts

The test activities in the laboratory are divided primarily into two major groups which are thermal vacuum testing and bakeouts. The bakeout group is subdivided into two types. The first one is the "normal" bakeout where the chamber shroud heats the test item and the TQCM sensor inside the chamber measures the outgassing levels. The final outgassing rate of the test item and facility will be the same at the completion of the test. Figures 5 and 6 show the inside shroud of Facility 241 and its TQCM sensor head.

Outgassing Certification

The second type of bakeout is the "outgassing certification test" with chamber cold shrouds. The test item is heated within an isothermal outgassing measurement box shown in Figure 7. During these types of bakeouts the chamber shrouds are kept significantly colder, approximately -100 °C, than the level at which the item is being baked out in order to provide negligible contribution to the outgassing measurement being performed. The outgassing measurement box is heated by film heaters attached to the outside surface. Power is evenly distributed throughout the box and is insulated with one layer of insulation to provide a near isothermal condition inside. The box has vent holes for the outgassed molecules to escape. It also has a TQCM holder that positions the exposed crystal slightly inside the box with a view towards the test item. An outgassing measurement box inside Facility 240 can be seen in Figure 8. This is the most accurate measurement of outgassing since the conductance path is known and the TQCM outgassing measurement represents the hardware status. This type of setup has allowed the laboratory to meet the HST stringent 1 Hz/hr outgassing criteria that otherwise could have not been met under normal bakeout conditions.

COMMON PROBLEMS

A common problem faced by the laboratory during bakeouts is the presence of non vacuum compatible materials or improperly cured materials which are high outgassers within the test article. Examples of these items are electrical connector inserts, adhesives, absorber materials, tie-wraps, grommets, connector caps, and many more. These high outgassers significantly extend the duration of the bakeout and in some cases can severely contaminate the flight hardware and the vacuum chamber.

Another problem is the high level of molecular contamination on the thermal shrouds after the execution of an outgassing certification test with chamber cold shrouds. The shrouds have acted as a big scavenger plate collecting most of what was outgassed from the test item. The condition of the empty chamber after the test and after the removal of the box does not equal the outgassing rate of the hardware baked out. In order to attempt to protect the chamber; a scavenger plate is operated at near liquid nitrogen temperatures, -180 °C, to collect some of the outgassed materials throughout the test. Due to the small temperature difference between the shroud and the scavenger plate, approximately 80 °C, it does not collect all of the outgassed materials and some adhere to the shroud and the shell of the facility. This condition impacts the ability to perform any test immediately after this one, other than another box certification due to the high contamination background left on the shrouds.

Also, cryogenics pumps can be damaged by the long term exposure of high levels of molecular outgassing contamination. They operate on the principle of entrainment of molecules on a cooled surface by weak van der Waals or dispersion forces (ref. 2). Molecular contaminants can permanently condense and damage the pump condensing arrays and contaminate the pump charcoal assembly as shown in Figure 9. The cryogenic pump was removed from Facility 241 after 4,984 hours of operation.

MAINTAINING THE CLEANLINESS OF THERMAL VACUUM FACILITIES

The goal of the laboratory is to have all thermal vacuum chambers in compliance with the standard laboratory criteria established. Therefore, several measures to prevent contamination and to remove it once it is present have been instituted.

Inspection

In order to avoid the presence of unacceptable items inside the test facility during a test, the laboratory relies on the project Quality Assurance (QA) process and lead engineers responsible for the hardware to comply with the materials outgassing specification for flight hardware (ref. 3). Furthermore, the laboratory senior personnel perform a final visual inspection of the test article and related hardware after completion of the setup and before closing the chamber door and commencing the test. In some cases this process captures these unacceptable materials which have escaped inspection, therefore, eliminating the potential contamination problem associated with them.

Post Test Recertification

After each test, if the outgassing condition for the empty chamber at maximum operating temperature is higher than the standard laboratory criteria; a post test recertification or normal bakeout with the empty chamber is performed. This post test recertification will return the chamber to its initial outgassing level. Throughout this phase TQCM data are being collected at -20 °C and when the laboratory criteria are met the chamber cold finger is flooded with liquid nitrogen for the last 8 hours of operation. After the chamber has been returned to atmospheric conditions the cold finger sample is collected and analyzed by the GSFC Materials Branch and their support contractor Unisys Corporation.

The chemical analysis of the residue is performed by Gas Chromatography-Mass Spectrometry (GC/MS) and Infrared Spectrometry. It provides quantitative and qualitative information on the contaminants present at the last phase of the test. The report indicates the amount of residue collected for a given time and lists all material in decreasing order. Also, it provides possible sources of the contaminants and background information on the chamber.

Both conditions, TQCM measurements and the chemical analysis of the cold finger, must be met in order for the facility to be considered clean and in compliance with the laboratory criteria established. From data accumulated by the laboratory the average facility post test recertification takes approximately 2.5 days.

Solvent Cleaning

As the pressure of the chamber is decreased and the temperature of the shroud is increased the vapor pressure of the compounds present in the test item increases as they are outgassed. Later they are deposited on the inside surface of the chamber as the pressure and temperature are returned to atmospheric conditions. Therefore, there is a need to establish a quick and efficient way for lowering these contaminants to acceptable background levels when they become too high.

In the case when these molecular contaminants present are not easily baked out at the chamber maximum operating temperature and/or it will require more than double the normal recertification time; another approach must be followed. This approach requires the proper selection of a solvent that can dissolve the contaminants that have been adhered to the chamber shrouds. The selection must be accomplished very carefully in order to remove the contaminants and at the same time maintain personnel safety and comply with the Engineering Services Division Safety Manual (ref. 4) and the Occupational Safety and Health Administration (OSHA) 29 CFR Part 1910.106 requirements (ref. 5).

The laboratory implemented, on examination, a solvent cleaning procedure developed to reduce the levels of molecular contaminants within acceptable levels. The solvent selection is based on a simple rule in organic chemistry "alike dissolve alike". For example, the contaminants detected in the thermal vacuum chambers are mostly hydrophobic organic compounds which are highly soluble in non polar organic solvents. This means that hydrophobic non polar, or reduced polarity, organic compounds have a high affinity (solubility) for non polar organic solvents such as pentane, hexane, decane, toluene, and xylene. However, personnel safety considerations as mentioned before, must be taken into account when evaluating these solvents. Pentane is highly volatile and flammable. Toluene and xylene are less volatile and flammable but highly toxic to humans. Therefore, hexane and decane were selected to be evaluated on the laboratory facilities.

Detailed procedures implementing the cleaning process for vacuum chambers 2.7 m x 4.3 m (9 ft x 14 ft) or smaller were developed (ref. 6 and 7) by MANTECH-NSI Technology Services Corporation -- in-house support service contractor for the space simulation laboratory.

The laboratory was not able to gather significant amount of data regarding the use of these solvents to reduce molecular contamination in vacuum chambers due to the high workload present. Facility 237 was the only one that was cleaned with hexane after not meeting the laboratory criteria after more than 70 hours in bakeout at 100 °C. Figure 10 shows the TQCM frequency change for a 10 MHz sensor at -20 °C and the chamber shroud at 100 °C before and after cleaning the facility with hexane.

The chamber shroud was wiped down three times with hexane to make sure that the maximum removal of contaminants was achieved. It was observed that the outgassing rate decreased almost 200 Hz/hr and met the laboratory criteria after approximately 50 hours of bakeout. Also, the amount of residue collected in the cold finger sample was reduced from 0.9 mg to 0.7 mg.

CONCLUSION

The Space Simulation Test Engineering Section can effectively and efficiently support a wide range of customers by maintaining all their thermal vacuum chambers at a uniform level and in a midpoint of the molecular contamination spectrum. Therefore, this enables the laboratory to be able to support stringent requirements like the ones for the HST using outgassing certification measurement boxes and at the same time support GAS payloads and sounding rockets.

To completely dedicate one or more thermal vacuum facilities for tests that possess less stringent outgassing requirements would not be cost effective. Furthermore, this would reduce the laboratory through-put and hamper its ability to support our customers by limiting the number of facilities available.

The future of molecular contamination is moving toward more stringent requirements with more sensitive optics and detectors, when needed, and less requirements for low cost and fast track projects which are not sensitive to contamination. GSFC vacuum laboratory is taking aggressive steps to support both spectrums.

First, by performing a post test recertification after each test performed that does not meet the laboratory standard criteria, all the thermal vacuum chambers are kept clean and ready for operation with minimum effort. Secondly, by examining different solvent cleaning techniques in an attempt to minimize down time between tests and reducing molecular contaminants background present on the thermal shroud if they were severely contaminated. Therefore, reducing post test recertification time to acceptable duration with minimum impact to the workload. Unfortunately no conclusion can be achieved on this technique until further evaluations are performed and the data are assessed on a more analytical basis. Lastly, is the ability to comply with stringent molecular outgassing requirements such as by performing 1 Hz/hr outgassing certification tests with chamber cold shrouds in support of the HST project and the like.

Furthermore, the Space Simulation Test Engineering Section is moving into the future of contamination monitoring by acquiring jointly with the Contamination Engineering Section a state-of-the-art 200 MHz surface acoustic wave (SAW) sensor to research its operation on vacuum chambers. By using this high performance instrument that is approximately two orders of magnitude more sensitive than current instruments we expect to be able to precisely quantify outgassing rate in super sensitive components.

REFERENCE

1. Molecular Flux Measurement System, TQCM Model MK 10 Operating Manual. QCM Research, Laguna Beach, California.
2. A User Guide to Vacuum Technology, 2nd Edition, 1989, John F. O'Hanlon, John Wiley & Sons
3. Outgassing Data for Selecting Spacecraft Materials, NASA Reference Publication 1124 Rev. 2, November 1990.
4. Safety Manual, Engineering Services Division, September 1990, Goddard Space Flight Center
5. General Industry Standards and Interpretations, Volume 1, Occupational Safety and Health Administration, United States Department of Labor.
6. Procedure for Cleaning Facilities 225, 237, and 239 using Decane, NSI Document No. 26-01-640, MANTECH-NSI Technology Services Corporation.
7. Procedure for Cleaning 7 x 8 and Smaller Thermal Vacuum Chambers Using Hexane, NSI Document No. 26-01-611, MANTECH-NSI Technology Services Corporation.

Table 1: Thermal Vacuum Facilities at GSFC
General Capabilities

FACILITY	TEST VOLUME (meters)	OPERATING PRESSURE (Pascal)	TEMPERATURE RANGE (°C)	UNIQUE CAPABILITIES
225	2.74 D x 4.27 L	< 13.3 μPa	-190 to 150	2 Cryo-pumps, C/F, TQCM, RGA
237	2.13 D x 2.44 L	< 67 μPa	-190 to 100	Diffusion-Pump, C/F, TQCM, RGA
238	3.40 D x 4.32 H	< 67 μPa	-190 to 90	4 Cryo-pumps, C/F, TQCM, RGA
239	2.13 D x 2.44 L	< 67 μPa	-190 to 100	Cryo-pump, C/F, TQCM, RGA
240	0.91 D x 0.91 L	< 13.3 μPa	-160 to 110	Diffusion-Pump, C/F, TQCM, RGA
241	0.91 D x 0.91 L	< 13.3 μPa	-160 to 110	Cryo-pump, C/F, TQCM, RGA
243/244	0.61 D x 0.61 H	< 67 μPa	-190 to 100	Diffusion-Pump, C/F, TQCM, RGA
281	0.91 D x 1.22 L	< 213 μPa	-185 to 100	Cryo-pump, C/F, TQCM, RGA
290	8.23 D x 12.19 H	< 13.3 μPa	-180 to 75	8 Cryo-pumps, C/F, TQCM, RGA

Cold Finger (C/F)
Thermoelectric Quartz Crystal Microbalance (TQCM)
Residual Gas Analyzer (RGA)

Table 2: FY 1996 Test Type per Thermal Vacuum Facility

FACILITY	THERMAL VACUUM TEST	NORMAL BAKEOUT	OUTGASSING CERTIFICATION IN BOX	POST TEST CERTIFICATION
225	8	24	0	17
237	13	13	0	12
238	18	6	0	10
239	6	8	15	7
240	7	2	20	17
241	9	5	9	14
243	7	23	0	16
244	0	7	34	0
281	0	12	37	2
290	8	3	0	3
TOTAL	**76**	**103**	**115**	**98**

Figure 1: Facilities 237 and 239 Thermal Vacuum Chambers at GSFC

Figure 2: Facilities 240 and 241 Thermal Vacuum Chambers at GSFC

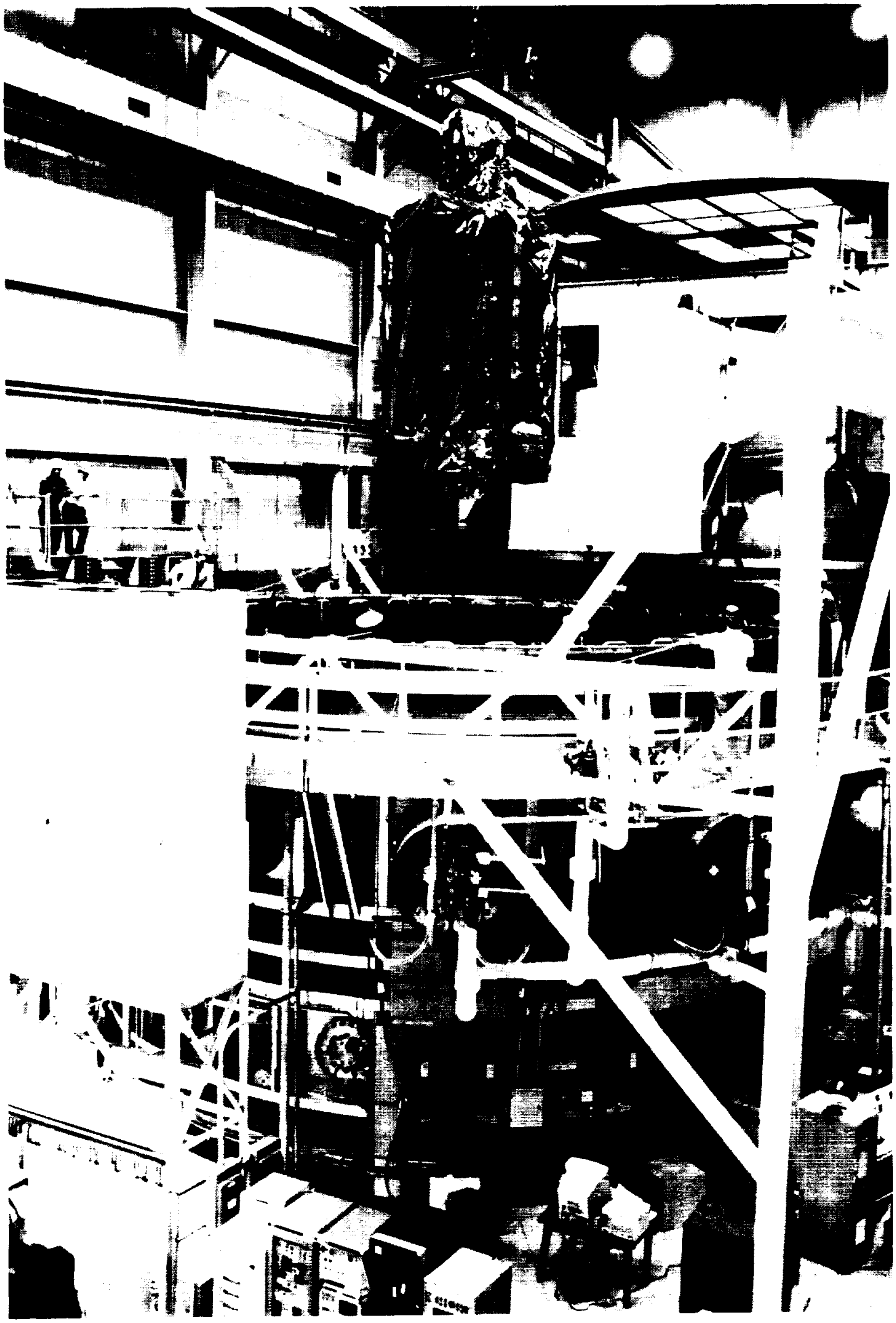

Figure 3: XTE Satellite Being Loaded Into Facility 290 at GSFC

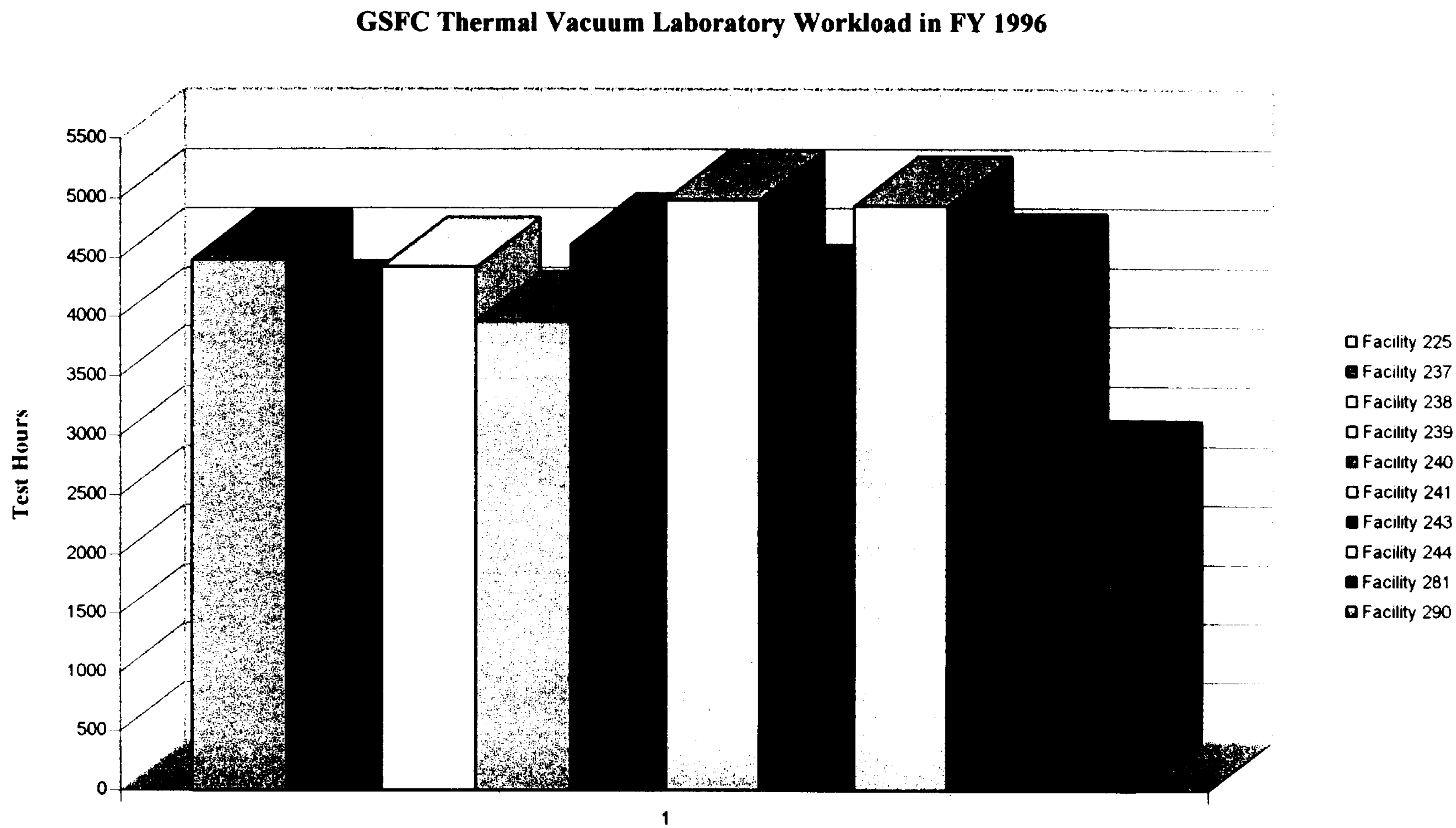

Figure 4: Total Test Hours per Facility

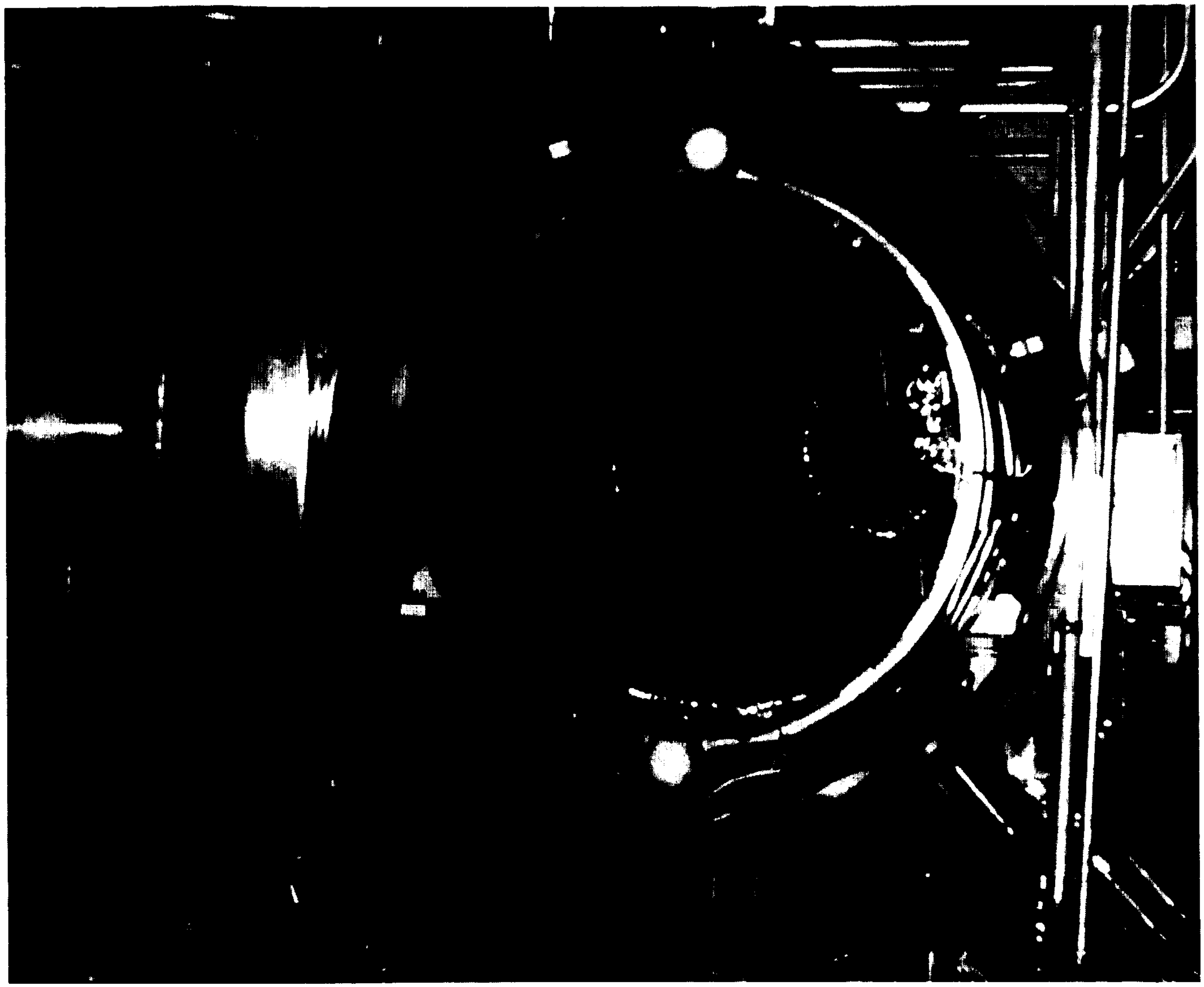

Figure 5: Facility 241 Thermal Shroud

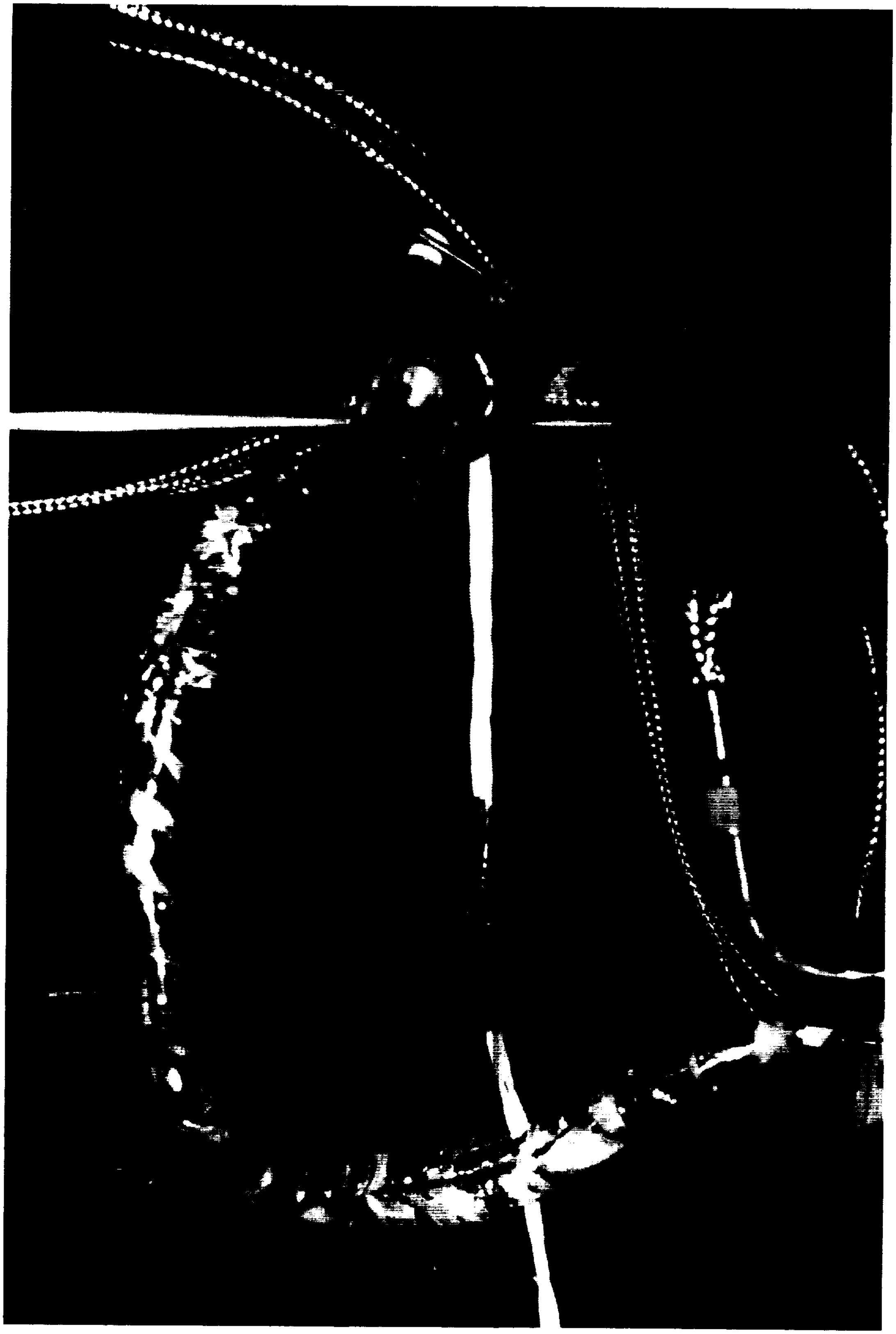

Figure 6: Facility 241 TQCM Sensor Head

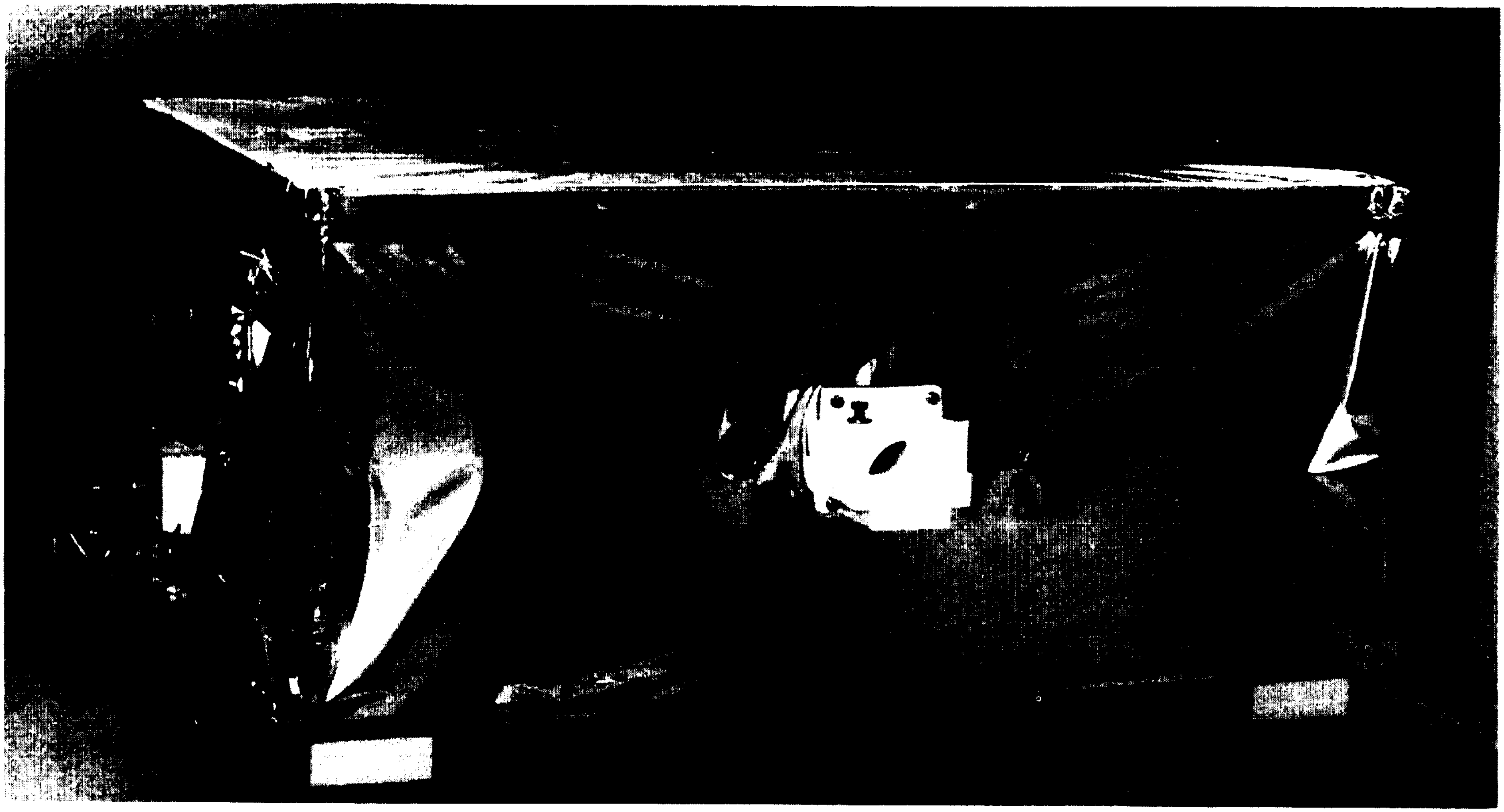

Figure 7: Isothermal Outgassing Measurement Box

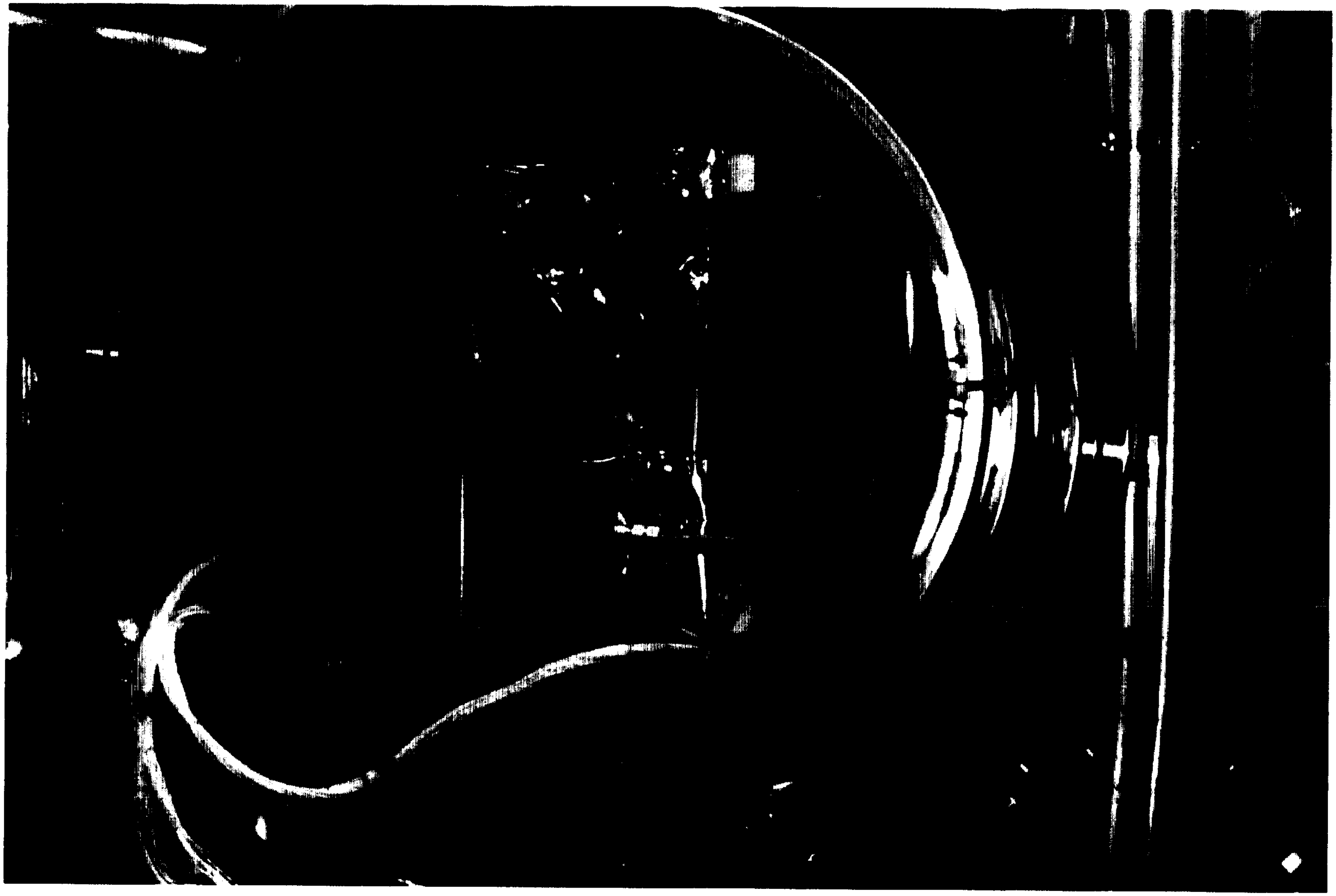

Figure 8: Outgassing Measurement Box inside Facility 240

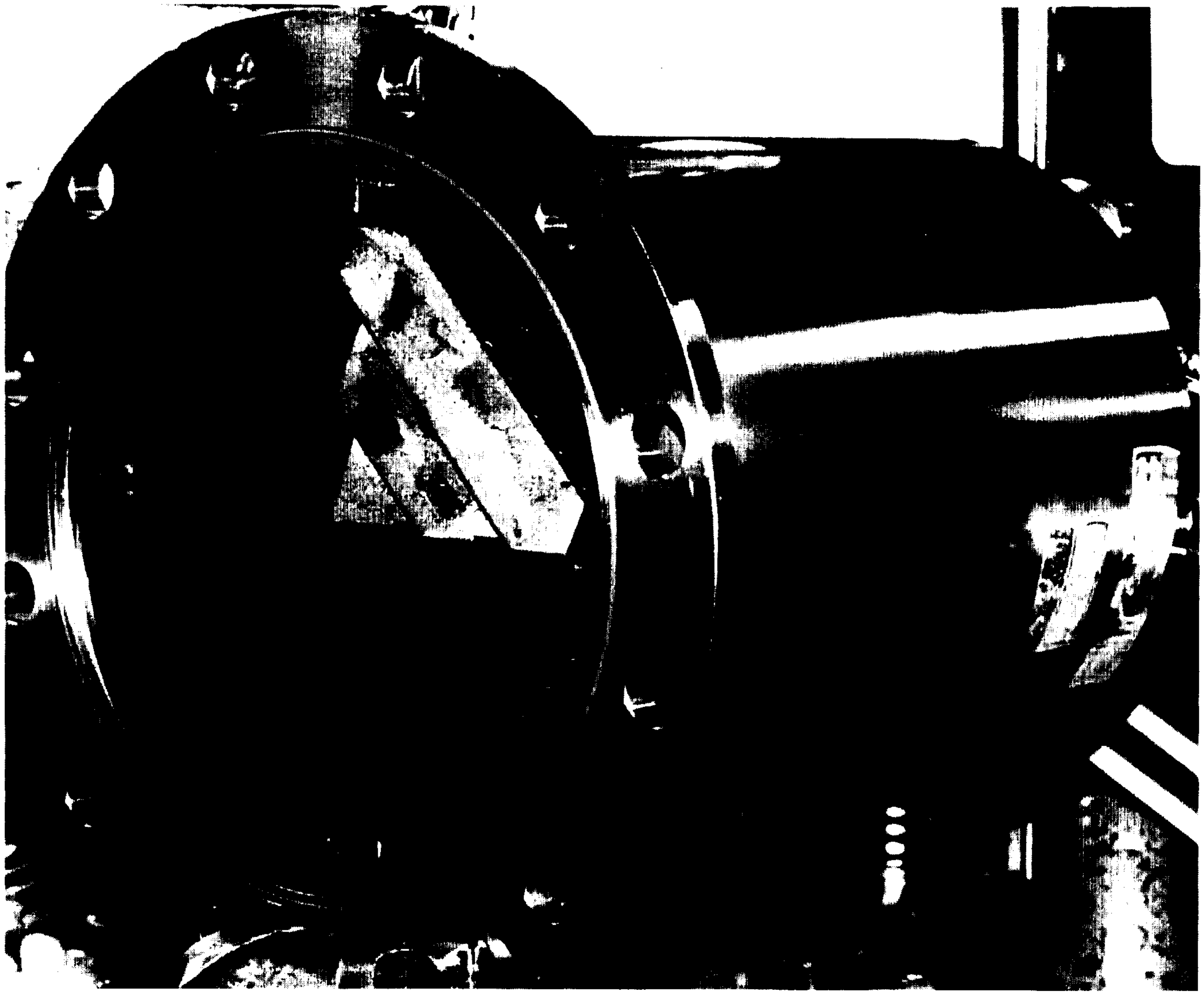

Figure 9: Facility 241 Cryogenic Pump after 4,984 Test Hours

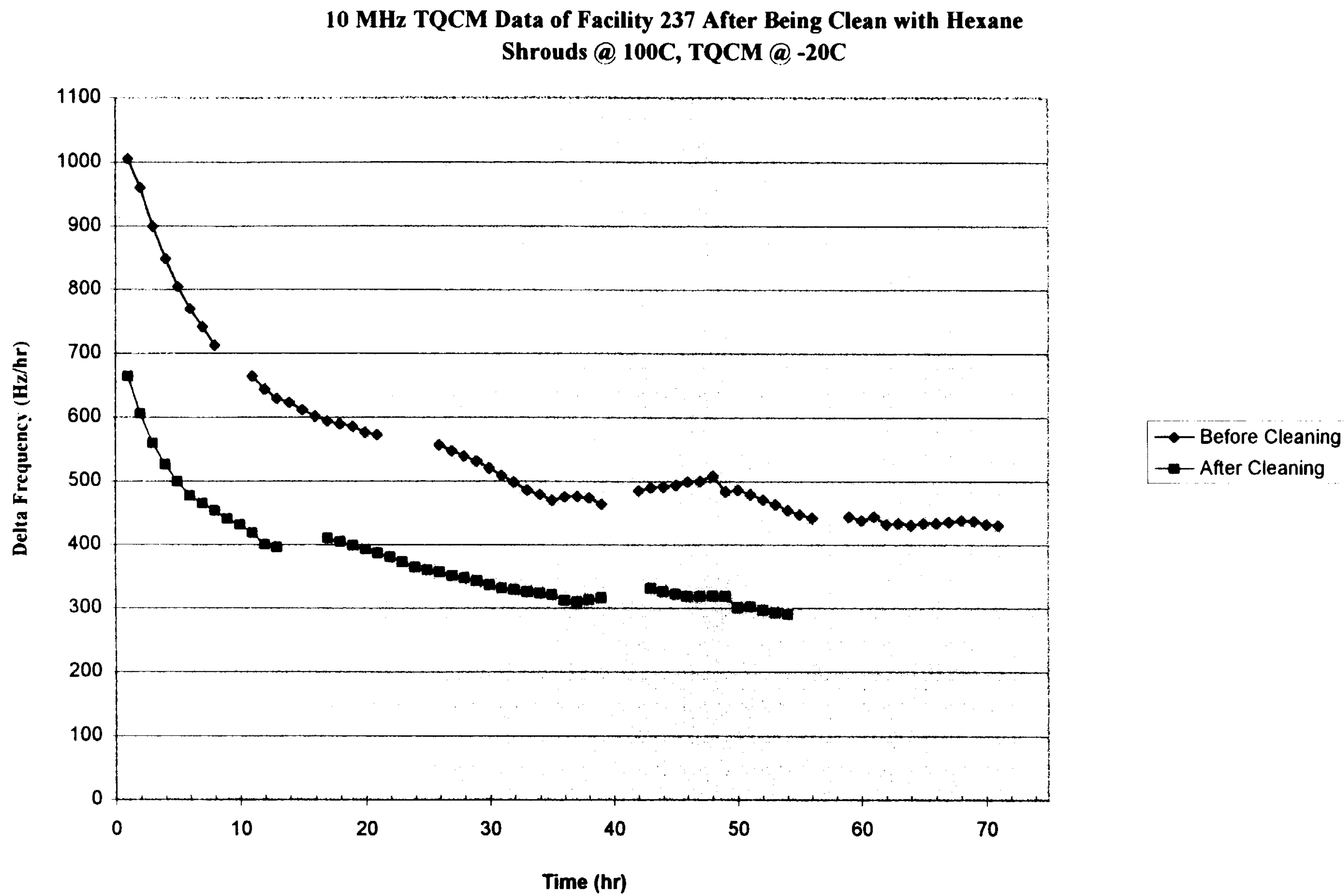

Figure 10: TQCM Data for Facility 237