N93-15613

A NEW APPROACH FOR PERFORMING CONTAMINATION CONTROL BAKEOUTS IN JPL THERMAL VACUUM TEST CHAMBERS [1]

Kenneth R. Johnson, Dr. Daniel M. Taylor,
Robert W. Lane, Maximo G. Cortez, Mark R. Anderson
California Institute of Technology
Jet Propulsion Laboratory
Pasadena, California 91109-8099

ABSTRACT

Contamination control requirements for the Wide Field/Planetary Camera II (WF/PC II) are necessarily stringent to protect against post-launch contamination of the sensitive optical surfaces, particularly the cold charge coupled device (CCD) imaging surfaces. Typically, thermal vacuum test chambers have employed a liquid nitrogen (LN2) cold trap to collect outgassed contaminants. This approach has the disadvantage of risking recontamination of the test article from shroud offgassing during post-test warmup of the chamber or from any shroud warming of even a few degrees during the bakeout process. By using an enclave, essentially a chamber within a chamber, configured concentrically and internally within an LN2 shroud, a method has been developed, based on a design concept by Taylor (Ref. 1), for preventing recontamination of test articles during bakeouts and subsequent post-test warmup of the vacuum chamber. Enclaves for testing WF/PC II components were designed and fabricated, then installed in three of JPL's Environmental Test Lab chambers. This paper discusses the design concepts, operating procedures and test results of this development.

INTRODUCTION

The WF/PC II has been designed as an on-orbit replacement of WF/PC I to enhance the performance of the Hubble Space Telescope by providing a view of the far-ultraviolet spectral region using improved CCD sensors which operate below a temperature of -60°C. The far-ultraviolet performance of WF/PC II is extremely sensitive to molecular contamination of the optics and the CCDs. Thus, very stringent contamination control requirements have been mandated to minimize the molecular emission rate of all subsystems within the instrument's structural housing. Molecular emission rates are to be minimized by baking all flight hardware at elevated temperatures under vacuum conditions ($<1 \times 10^{-5}$ Torr).

1] The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

In 1989, JPL determined that conventional vacuum chambers could not be used to bake hardware to the stringent WF/PC II requirements. In fact, one conventional vacuum chamber that was baked at 125°C for several weeks did not even yield contaminant background levels low enough to permit direct measurement of the cleanliness level of most WF/PC II hardware. Consequently, a new approach for performing contamination sensitive bakeouts was devised based on three criteria set forth by Taylor[2]: (1) the test article hardware must not be recontaminated by outgassed volatiles at any time during the bakeout, contamination level testing, or post-test warmup of the chamber; (2) the background emission rate of the chamber hardware must be negligible as compared to that of the test article hardware; and (3) the contamination measurement method must positively verify that the required cleanliness results have been met.

By June 1990, one chamber (ETL Chamber 13) had been reconfigured and by June 1991, two additional chambers had been reconfigured (ETL Chambers 15 and 10). Subsequently, an effective bakeout operating procedure was developed after several operational trials which yielded background cleanliness level results acceptable for WF/PC II hardware. Figure 1 presents a side view of the overall enclave and LN2 shroud configuration as installed in the JPL ETL Chamber 10. Figure 2 is a flow schematic illustrating Chamber 10 shroud and enclave temperature control systems. The labels VGN and VLN signify valves on GN2 and LN2 lines, respectively.

CHAMBER RECONFIGURATION DESIGN CONCEPTS

The test article containment system was designed to prevent recontamination of the test article hardware. By enclosing the test article inside an enclave, and by always maintaining the temperature of the enclave walls higher than that of the test article throughout the duration of the bakeout, the outgassed volatile contaminants are prevented from condensing on the inner walls of the enclave. Instead, the contaminants exit through strategically placed orifices in the enclave and are removed from the chamber either by the vacuum pumping system or by condensing on the LN2-cooled shroud. Before conducting the post-bakeout final cleanliness testing of the test article, the enclave temperature is lowered slowly to prevent condensation on the enclave wall of volatiles still emitting from the test article (whose temperature lags that of the enclave). After post-bakeout testing is done, the shrouds are warmed slowly while the enclave is purged with high purity GN2 to minimize the possibility of contaminants backstreaming into the enclave.

Enclaves were fabricated from stainless steel in two main parts: a can and a cover. After fabrication, both the cans and covers were electro-polished to remove surface embedded contamination. The enclaves were installed in the chambers and were thermally isolated from the LN2 shrouds by multilayer insulating blankets.

2] New Technology Report: Hardware Containment System for Vacuum Bakeout, August 1992

The background contaminant emission rate of the chamber hardware is minimized first by sufficiently baking the enclave at a temperature higher than the maximum expected operating temperature of the test article, then by lowering the enclave to a nominal operating temperature of the test article. It was assumed that sufficient baking had been completed when the measured contamination rate did not change more than 5 % over a 24 hour period.

The contamination measurement method is a multistep process and involves the use of several instruments. Before any contamination measurements are made, the chamber pressure must be well below 1×10^{-5} Torr. Chamber pressures are measured using convectron gauges to 1×10^{-3} Torr and ion gauges below that pressure . Below pressures of 1×10^{-5} Torr, high level contamination rates are measured using a Residual Gas Analyzer (RGA), a quadrupole mass spectrometer with an electron multiplier that senses molecules in the range of 0 to 200 atomic mass units (AMU). The RGA enables real time monitoring and interpretation of gas composition and chamber pressure. Low level contamination rates are measured using two types of quartz crystal microbalances (QCM) using 15 MHz crystals with a sensitivity of 1.56×10^{-9} g/cm^2Hz: (1) a thermoelectric QCM, or TQCM, which has thermoelectric devices that can control the crystal's temperature between 80°C and -55°C; and, (2) a cryogenic QCM, or CQCM, which has only a heating capability. CQCM crystals must be cooled conductively using a heat sink (attached to a heat exchanger whose temperature is controlled by a LN2/GN2 temperature control system), then warmed to the desired test temperature with the CQCM instrument heater. This system can effectively control the crystal temperature between -170°C and 80°C. The RGA, TQCM, and CQCM were all mounted and aligned such that they have a significant view factor only of their respective enclave orifices in order to minimize the possibility of measuring back scattering contaminants from the chamber door.

Although all three reconfigured chambers used an RGA, a TQCM and a CQCM for contamination measurements, the instruments were mounted differently in Chamber 10 (10' diameter x 10' long) than they were in Chambers 13 and 15 (3' diameter x 5' long). For Chamber 10, a stainless steel shutter was developed that could be operated from outside the chamber which, when in the up position would provide a large opening for contaminant flow at high outgassing rates as well as a flow path to the RGA, and when in the down position would close the opening entirely. The TQCM and the CQCM were mounted on the enclave cover and fitted directly in-line with enclave orifices. The TQCM and CQCM orifices are always open and are unaffected by the shutter position. During bakeout operations, the crystals are kept hot until the chamber vacuum level and the RGA readings indicate that measurements of cold crystal frequency rate change can be made without excess contaminant accumulation. Figure 3 gives a detailed view of the shutter assembly and the TQCM and CQCM mounts on the enclave cover in Chamber 10.

For Chambers 13 and 15, a stainless steel shutter was developed (designed for use in the smaller chambers) that could be operated from outside the chamber which would open the orifice flow paths to the CQCM, the TQCM and RGA for high level contamination measurements (Position 1), and would leave open only the CQCM orifice for low level contamination measurements (Position 2). Figure 4 shows detail of the Chamber 13 and 15 assemblies.

BAKEOUT PROCEDURES

The following procedure for performing bakeouts to yield high level cleanliness test articles has been developed over the past two years through analysis of test data.

1. Rough pump to about 5×10^{-2} Torr and turbopump to 1×10^{-5} Torr. Heat the TQCM and/or CQCM to 75°C and maintain that temperature throughout the pump-down. Also, keep the enclave and the LN2 shroud at ambient temperature during pumpdown. Open the shutter to allow unhindered gas flow from the enclave.

2. When at the 10^{-5} Torr range, begin heating the enclave to the maximum bakeout temperature while allowing the temperature of the shroud to drift slowly upward. This heating is often done in steps to avoid excessive pressure buildup in the chamber due to high outgassing rates.

3. As the temperature of the enclave rises and the bakeout proceeds, the chamber pressure fall to an asymptotic value indicating a steady state condition where the pumping system rate equals the bakeout outgassing rate. When the maximum bakeout temperture has been attained and the chamber pressure has leveled off, maintain this condition (soak) for about 12 to 24 hours.

4. Flood the shrouds with LN2. Flooding the shrouds usually has the effect of lowering the chamber pressure by a factor of ten. Open the cryopump hi-vac valve.

5. When the the chamber pressure has stabilized, lower the temperature of the TQCM to 0°C and make a measurement of the TQCM frequency change rate. Close the shutter while making this measurement so that the outgassing contaminants flow from the enclave only through the TQCM orifice. To avoid TQCM damage, if the frequency change rate is greater than 8000 Hz/hr, do not operate the TQCM for more than ten minutes before beginning TQCM desorption. Other guidelines are:

   a. for a rate change>1000 Hz/hr - collect data for 30 minutes;
   b. for a rate change between 500 and 1000 Hz/hr - collect data for 1 hour;
   c. for a rate change between 15 and 500 Hz/hr - collect data for 2 hours;
   d. for a rate change<15 Hz/hr - collect data for 4 hours.

6. After collecting frequency rate data, reopen the shutter and reheat the TQCM to the maximum desorption temperature, T_{Max}, to desorb accumulated contaminants. Normally, the TQCM is heated in 20°C increments (holding for 5 to 10 minutes between increments) to avoid thermally stressing the crystals. However, in cases where the contamination control engineer needs data to characterize the identity of the desorbed contaminants, the TQCM is reheated in steps. At each step TQCM

frequency data is gathered to indicate the degree of offgassing that occurs at each increment. These steps are: (1) heat from 0°C to 5°C over a half hour period; (2) heat from 5°C to 15°C over a half hour period; (3) heat from 15°C to 35°C over a half hour period; (4), heat from 35°C to T_{Max} over a half hour period and hold at T_{Max}.

7. Gather TQCM frequency change rate data on a daily basis at 24 hour intervals. Monitor the change rate deltas from day to day. Reheat the TQCM to T_{Max} after each data collection period. When the 24 hour change rate delta is less than 5 to 10%, proceed to the final cleanliness verification test.

8. The final cleanliness verification test is performed with the test article at 20°C. During cooling, the test article radiates heat to a cooler enclave. To prevent recontamination on the enclave from the cooling test article, the enclave temperature is lowered in steps as follows. Lower the TQCM temperature by 10°C (say to 65°C) and begin lowering the test article temperature slowly. When the TQCM frequency change rate due to desorption has leveled off at this lower temperature (65°C), lower the TQCM temperature by 15°C (say to 50°C). Continue lowering the TQCM temperature in steps (to 30°C then to 0°C), until the TQCM frequency stabilizes at 0°C and the test article stabilizes at 20°C. Maintain a test article temperature of at least 15°C higher than the TQCM and 5°C higher than the enclave.

9. When the test article has reached 20°C, the CQCM temperature is lowered directly from 0°C to -70°C. A typical goal for test article cleanliness certification is a TQCM frequency change rate which does not exceed 1-10 Hz/hr at -70°C..

10. When the cleanliness certification goal has been met, the CQCM is reheated to 75°C. Because the thermal lag between the CQCM and its heat exchanger thermal lag protects the crystal from thermal stress, heating in 20°C increments is not required. However, in cases where the contamination control engineer needs data to characterize the identity of the desorbed contaminants, the TQCM is reheated in steps as described in Step 6 above.

11. Close the cryopump hi-vac valve, begin purging the the enclave with high purity GN2, and begin warming the LN2 shrouds slowly. Continue the GN2 purge while the LN2 shrouds are warmed to ambient temperature. Ensure that the LN2 shroud temperature stays at least 20°C below the temperature of both the enclave and test article during the warmup process. When the LN2 shrouds have been warmed to ambient temperature, turn off the vacuum system and continue the backfill of the chamber with high purity GN2 to ambient pressure.

WF/PC II OPTICAL BENCH BAKEOUT RESULTS

Table 1 represents typical results of CQCM measurements taken during a bakeout run of the WF/PC II Optical Bench in Chamber 10.

CONCLUSION

Sensitive optical instruments intended for service in space require a high level of cleanliness to minimize the potential for contamination of optical surfaces. A new approach for performing bakeouts of this sensitive hardware has been developed and demonstrated at JPL. The use of a heated enclave which is mounted concentrically inside of and thermally isolated from the LN2 shrouds inside a thermal vacuum test chamber has been shown to provide acceptably clean bakeout results. This enclave configuration minimizes the possibility of recontamination of test hardware during the post-test chamber warmup.

Effective bakeout procedures have been optimized through operational testing and have been shown to provide an effective method for maintaining test article cleanliness during and after sensitive hardware bakeouts.

REFERENCES

1. Taylor, D.M., Soules, D., and Osborn, D.: The JPL Molecular Contamination Investigation Facility, SPIE vol. 1329, Optical Systems Contamination Effects Measurement Control - 1990, pg. 233-244.

Table 1. CQCM Results of a WF/PC II Optical Bench Bakeout Run

Date	Time	Test Article Temp	CQCM Crystal Temp	CQCM Freq. Rate Change
09/29/91	0800	62°C	0°C	115
09/30/91	0900	62°C	0°C	69
10/01/91	0800	62°C	0°C	55
10/02/91	0800	62°C	0°C	52
10/03/91	1100	62°C	0°C	62
10/04/91	1100	62°C	0°C	24
10/05/91	1100	62°C	0°C	25
10/06/91	1100	62°C	0°C	24
10/07/91	1100	62°C	0°C	23
10/08/91	2000	20°C	-70°C	6
10/09/91	0100	20°C	-100°C	19
10/09/91	0600	20°C	-100°C	17.5

JPL

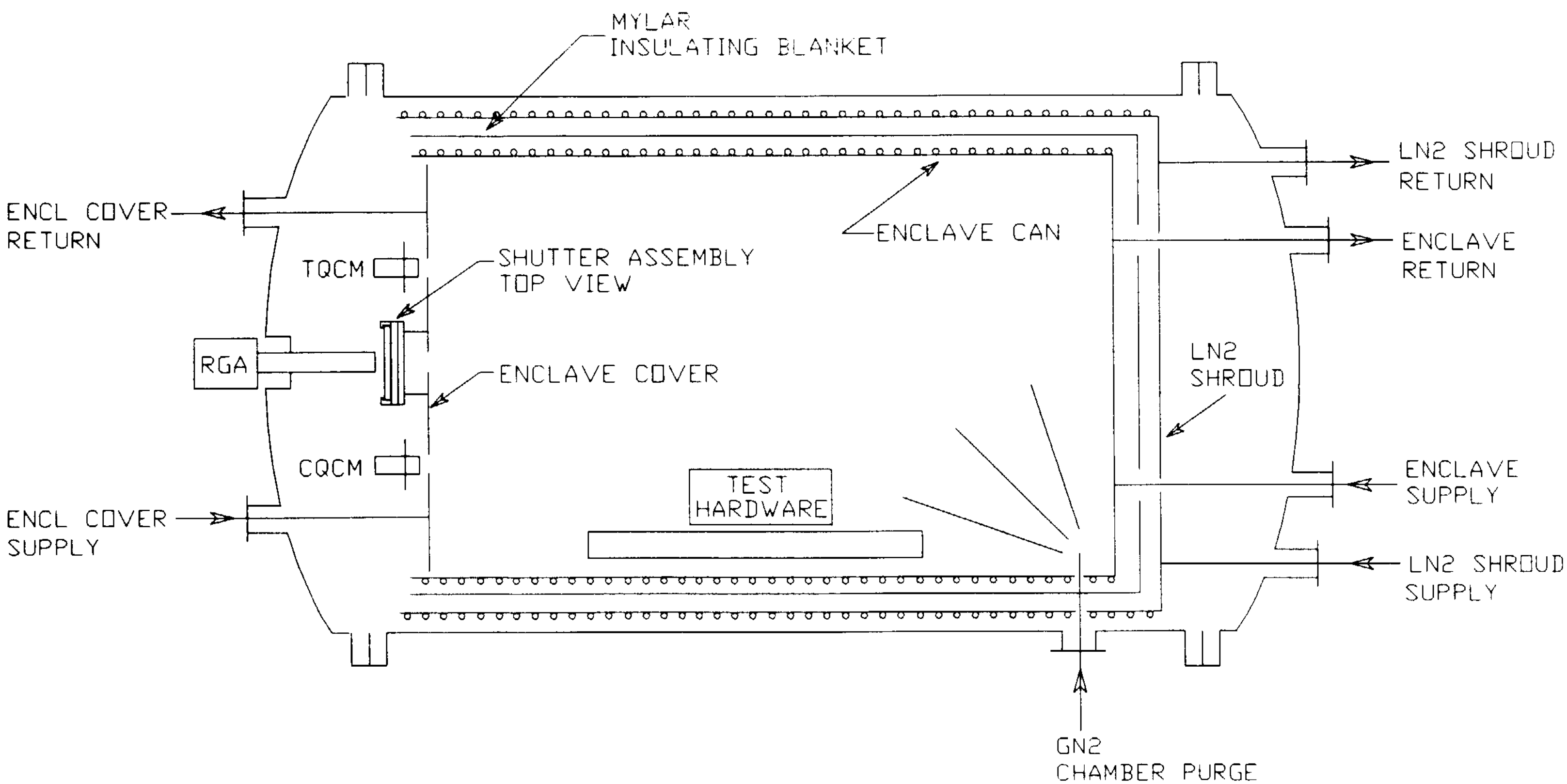

Figure 1. Chamber 10 Enclave Configuration

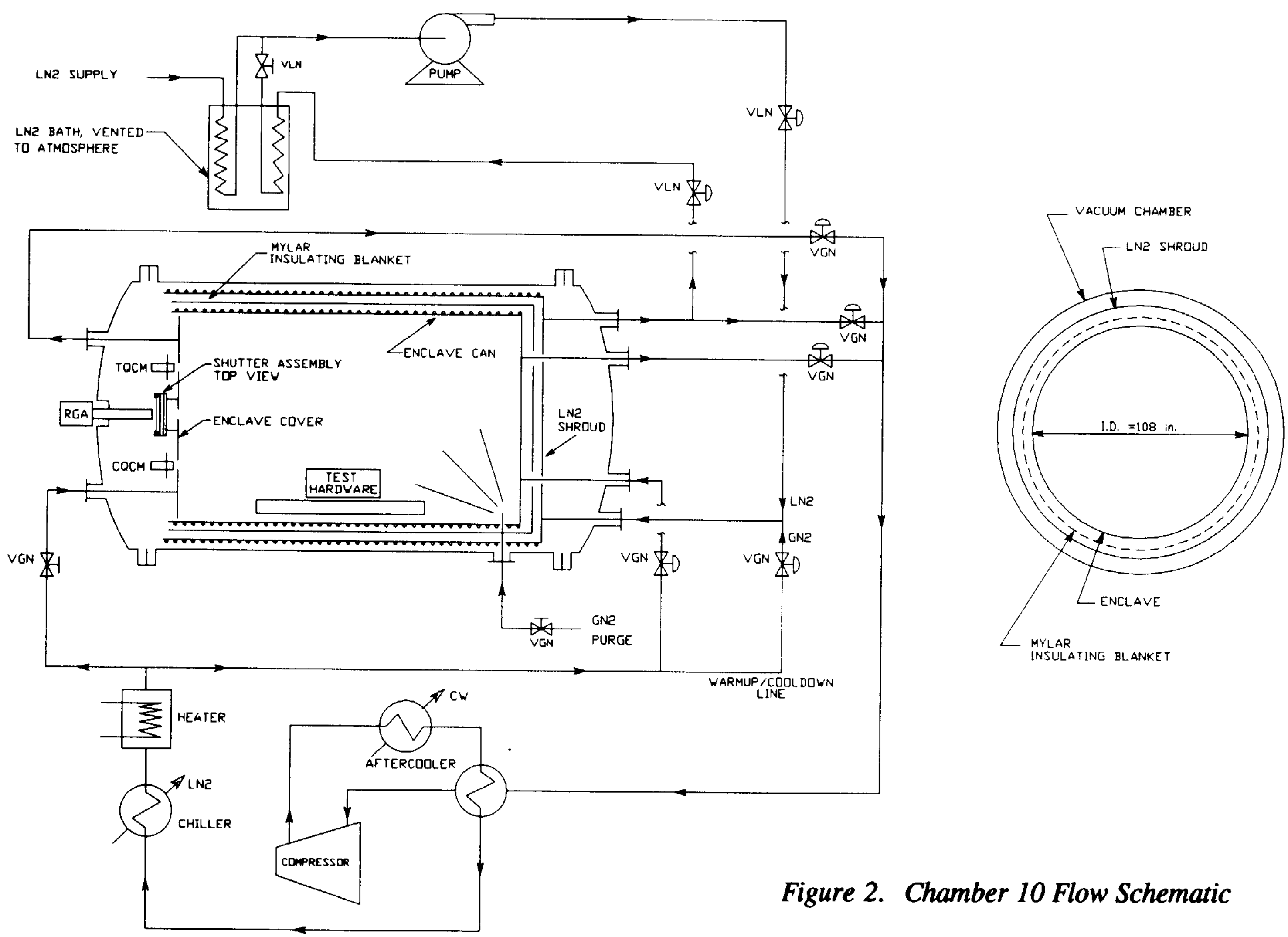

Figure 2. Chamber 10 Flow Schematic

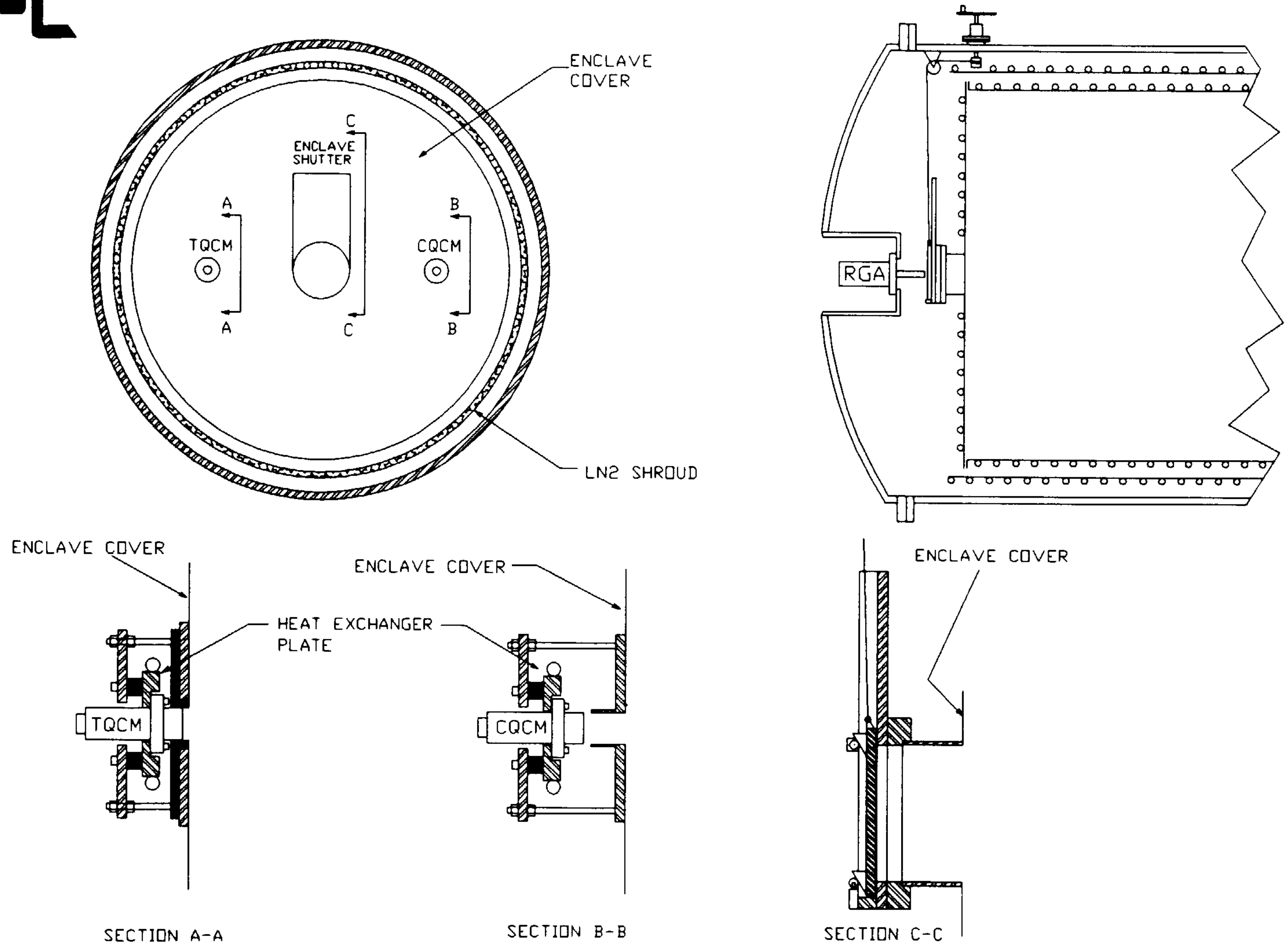

Figure 3. Chamber 10 Detail of Shutter and Mounts for RGA, TQCM and CQCM

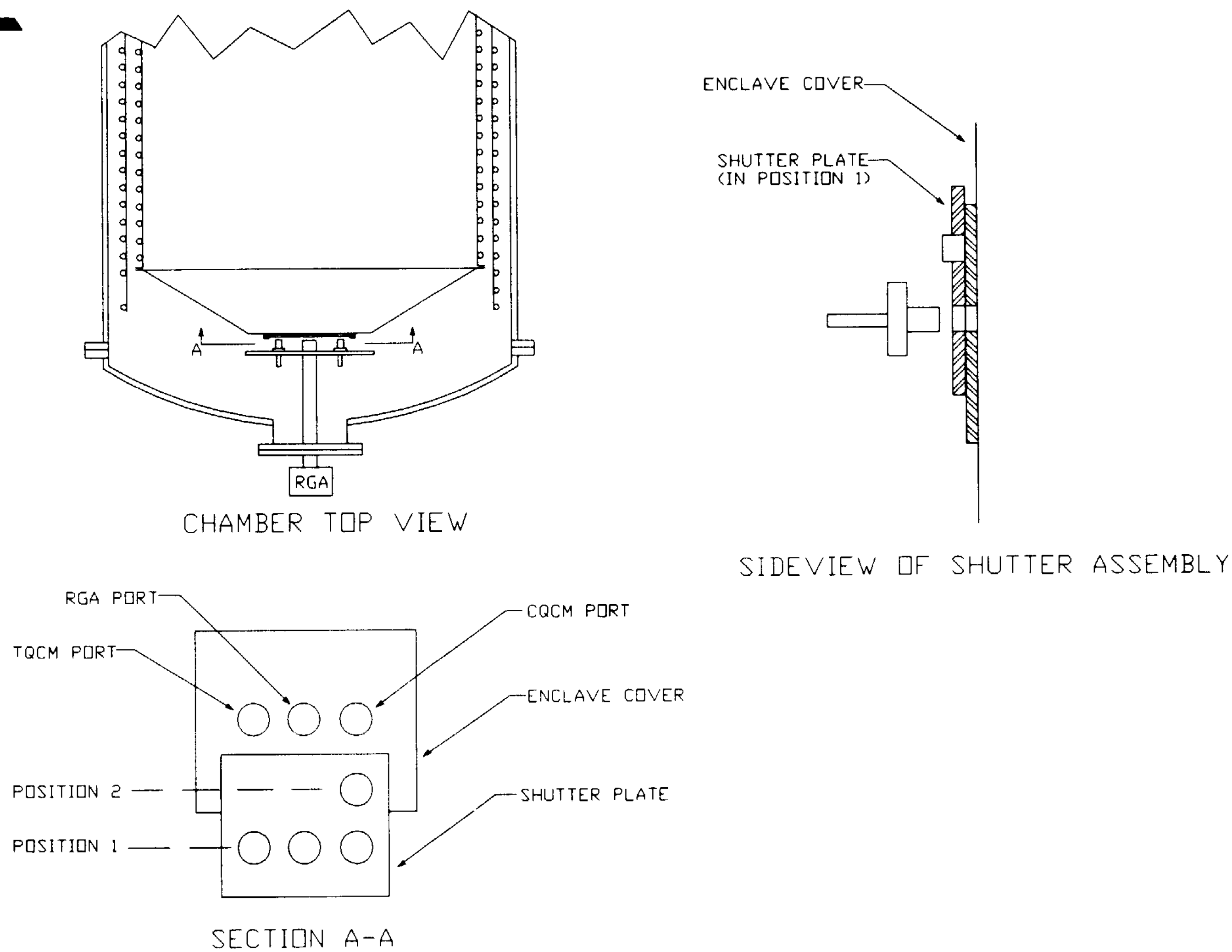

Figure 4. Chamber 13 Detail of Shutter and Mounts for RGA, TQCM and CQCM