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**MEETING TODAY'S REQUIREMENTS
FOR LARGE THERMAL VACUUM TEST FACILITIES**

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ABSTRACT

The Lockheed Thermal Vacuum Facility at Sunnyvale, California, completed late 1986, is one of the largest multi-program facilities constructed to date. The horizontal 12.2 m (40 ft.) diameter by 24.4 m (80 ft.) long chamber has removable heads at each end and houses a thermal shroud providing a test volume 10.4 m (34 ft.) diameter by 24.4 m (80 ft.) long. The chamber and thermal shroud are configured to permit the insertion of a 6.1 m (20') wide x 24.4 m (80') long vibration isolated optical bench.

The pumping system incorporates an internal cryopumping array, turbomolecular pumps and cryopumps to handle multi-program needs and ranges of gas loads. The high vacuum system is capable of achieving clean, dry and empty pressures below 1.3×10^{-6} Pa (10^{-8} torr).

The thermal shroud is a closed loop LN₂ circulation system incorporating a subcooled heat exchanger. A GN₂ warm-up system is utilized to return the thermal shroud to ambient temperature.

The facility also includes the following systems:

- Chamber Air/GN₂ Repressurization
- Chamber Purge and Air Handling System
- Internal Heat Flux Simulator
- Communications System
- Closed Circuit TV System
- Ambient Thermal Control System

The facility is controlled from a remote control console. Sufficient local control is provided for local checkout and maintenance.

INTRODUCTION

The most advanced state-of-the-art thermal vacuum chamber facility for full scale satellite and systems integration testing by LMSC is in the final stage of completion.

LMSC initiated the Delta Chamber project by soliciting proposals to a performance specification with an early 1985 start and project completion date in late 1986.

The Delta Chamber designed and built by PDM/CVI is a second generation multi-purpose, quick turnaround, full space environment facility capable of pumping large gas loads.

The test volume is 10.4 m (34') diameter x 24.4 m (80') long with a flat floor section removable from either end of the chamber.

The chamber is unique because a full length thermally stable vibration isolated optical bench may be installed through either end and operated under vacuum at ambient or cryogenic temperatures.

The specifications required the facility to have:

- (1) 30-day test period
- (2) Four hour pumpdown to .7 Pa (5 microns)
- (3) Six hour shroud cooldown
- (4) Sustain a 700 KW heat load with shroud temperatures less than 110°K
- (5) Pumping for .44 PaL/S (.0033 TL/S) helium, 110000 PaL/S (825 TL/S) nitrogen, and 856000 PaL/S (6420 TL/S) water gas loads.
- (6) Plus or minus 1°K shroud temperature control at ambient temperature.

The Delta chamber is a multi-purpose chamber designed and constructed as a turnkey fixed price facility.

CHAMBER

The chamber as shown in Figure 1 is 12.2 m (40') dia. x 24.4 m (80') long with side moving top supported heads at each end giving unobstructed high bay access from sides and top of chamber opening. Chamber stiffening will support a 22700 Kg (50 kip) monorail load inside the chamber while under vacuum.

Both IR heating cage and test article are capable of being supported from top or bottom. The monorail contains a swing in place section outside the chamber at each end to interface with high bay handling structures. Bottom support of test article and IR cage allows movement to and away from chamber on air transporters. The upper three-fourths of the IR cage may remain in the chamber.

Movement in and out of the chamber of the flat shroud platform is on air transporters as is the insertion of an optical bench.

The chamber shell is Type 304 stainless steel polished to give an emissivity of less than .2. All external structures are carbon steel.

A distribution duct runs the length of the chamber along each side for repressurization and ventilation distribution.

All inside surfaces are accessible for cleaning and will be washed and given a black light inspection and NVR test followed by a bakeout and TCQM analysis to demonstrate the residual internal cleanliness.

Instrumentation ports for program use are located along both sides of the chamber at two elevations (See Figure 2) which are accessible from both internal and external platforms.

LN₂ connections to the bottom removable shroud are flanged with aluminum seals. Connections to the chamber head shroud sections employ hairpin pipe sections with bayonet connections on each end of the hairpin for ease of assembly.

VACUUM SYSTEMS

The high vacuum pumping system in this chamber includes an internal cryopumping array, external cryopumps, and turbomolecular pumps. While these can be used simultaneously, the size and capacity of each of them are not simultaneously determined by any single test condition. The LN₂ shroud acts as an infinite water vapor pump when at cryogenic temperature. Figure 2 shows the arrangement of the high vacuum pumping systems and the test volume.

The shroud is required for thermal control and is the primary contributor to water pumping speed at LN₂ temperature. The internal cryopumping array is required to handle a large nitrogen gas load. Testing at high vacuum with the shrouds at room temperature requires the external cryopumps, while extended testing with the large helium gas loads is accommodated by the turbomolecular pumps.

ROUGHING PUMPS

The chamber roughing pumps are in two separate skids manifolded together to provide 22700 m³/h (13368 cfm), designed to start at atmospheric pressure and to reach .7 Pa (5 microns) in four hours with the passive nitrogen gas load of 167 PaL/S (1.25 TL/S).

Both skids have valved connections to the roughing line which contains an LN₂ trap.

Each Leybold-Heraeus skid contains a 11360 m³/h (6684 cfm) lead blower followed by 4360 m³/h (2567 cfm) and 2350 m³/h (1383 cfm) blowers backed by a 808 m³/h (475 cfm) mechanical pump.

The pumpdown time to .7 Pa (5 microns) is extendable to 24 hours by a roughing line valve and a programmable controller.

CRYOPUMPS

The high vacuum pumping system utilizes five (5) CVI TM 1200, 1.22 m (48 inch) cryopumps. The pumping capacity required from this source is determined by the test pressure requirements associated with tests to be conducted with the thermal shroud at ambient temperature. Determination of the net pumping speed of these pumps, interior to the shroud, involves use of a Monte Carlo analysis of the combination of an ambient baffle, LN₂ baffle, and nozzle with 1.32 m (52 inch) GNB gate valve.

The following speeds have been determined:

	<u>Warm Shroud</u>	<u>Cold Shroud</u>
Nitrogen	200,800	116,000 liter/sec
Water	456,250	--- liter/sec
Hydrogen	142,500	82,500 liter/sec
Helium	100,000	57,500 liter/sec

TURBOMOLECULAR PUMPS

The high vacuum system also utilizes four (4) Balzer turbomolecular pumps with .762 m (30 inch) GNB gate valves. The turbos provide the pumping speed to handle the large long term helium gas loads. A Monte Carlo analysis has also been used to determine the pumping speeds of the baffle/nozzle/elbow/valve and two baffle combination of the turbomolecular pump mountings. The following speeds have been determined:

	<u>Warm Shroud</u>	<u>Cold Shroud</u>
Nitrogen	20,000	11,600 liter/sec.
Water	20,560	--- liter/sec.
Hydrogen	22,240	12,840 liter/sec.
Helium	21,721	12,560 liter/sec.

INTERNAL CRYOPUMPING ARRAY

An internal, flat panel cryopumping array has been incorporated into the chamber shroud system to maintain the specified chamber pressure during periods of high active GN₂ gas loads (825 TL/S). The nitrogen pumping portions of this array are maintained at 20°K with a 1,000 watt helium refrigerator designed and supplied by CVI. Our experience with cryopumping arrays of this type indicates the capture probability is limited to about 0.22. With a total cryopumping array surface area of 139 m² (1500 sq. ft.), the nitrogen speed will be 2,100,000 liter/sec.

LN₂ SHROUD

The chamber shroud is maintained at LN₂ temperatures with a subcooled refrigeration system that will be described later. This shroud acts as an infinite pump for water. The effective water speed will be:

2.85 x 10⁸ liter/sec. based on 1022 m² (11000 sq. ft.) of shroud surface

VACUUM GAUGING

Vacuum gauging instrumentation in the chamber consists of five Granville Phillips 303 Vacuum Process Controllers, each reading both a convector and an ion gauge, at two chamber locations (a total of ten locations, each with both gauge types). The convector gauges are used for chamber pressures down to .13 Pa (1 micron), and the ion gauges are used below that point.

All the convector gauges are located in the annular space between the thermal shrouds and the chamber walls, while all but one of the ion gauges are located interior to the thermal shrouds. The other ion gauge is located in the annular space. All interior ion gauges are mounted on flanges, off removable shroud panels, facilitating gauge removal either from the annular space or from the interior of the shroud without disturbing the chamber penetration vacuum integrity.

TEST ENVIRONMENT AND CONTROL

TEST REGIMES

Table 1 presents the test regimes as divided between operation with a cold shroud and warm shroud, and with and without an optical bench inside the chamber. The chamber pressures shown at the bottom of Table 1 are nominal and will vary with actual conditions and chamber history.

Each item of the high vacuum pumping system is an element in a particular regime. For example, the most efficient means of pumping the large nitrogen active gas load is with an internal helium array, whereas cryopumps are the ideal choice under warm shroud conditions.

Passive gas loads are present during all phases of vacuum, whereas the active gas loads are intermittent and may have an accumulative total of 45.4 Kg (100 pounds) of water and 9.1 Kg (20 pounds) of nitrogen during a typical test cycle.

With an optical bench in the chamber, several new sources of gas loads are present - vibration isolator leakage, outgassing from a warm shroud, outgassing from multi-layered insulation, and outgassing from the optical bench and its internals.

Both roughing and chamber repressurization are extendable to eliminate air current disturbances particularly with use of an optic bench. Vacuum performance in the different regimes is shown by the nominal pressure listed in Table 1.

LN₂ SHROUD SYSTEM

The shroud is fabricated of flat 1100F aluminum extrusion incorporating the LN₂ tube. These extrusions are shop fabricated into flat panels 1.22 m (4 ft.) wide by 7.62 m (25 ft.) long and painted with 3M's ECP-2200 solar absorber coating. The cylinder and end closeouts of the shroud are fabricated from the same basic 1.22 m (4 ft.) wide panel. See Fig. 3.

Thermal control is maintained with a pressurized recirculating subcooled LN₂ system. This approach was selected to maintain thermal uniformity with the high design heat loads on the shrouds. The total shroud is divided into ten thermal control zones. Flow rates can be modulated through each of the zones.

In addition to the specified heat load from the test article, the shroud will also see the radiation heat load from the chamber walls which adds 25 kw to the total heat load.

With the specified 700 kw heat load, the total shroud heat load will be 725 kw, or 223 BTU/hr/sq. ft.

Under full design heat loads, the maximum allowable temperature at any point on the shroud is 110°K. The LN₂ will be supplied to the shroud at 82.8°K (-311°F), or lower, and its temperature is allowed to increase by 13.9°K (25°F) as it passes through the shroud. Half way between two LN₂ tubes, where the fluid is leaving the shroud, the temperature will be 102.2K (-275.4°F).

A schematic of the LN₂ circuit is presented on Figure 4. State points are shown for the circuit operating at most critical conditions with full design heat load applied to the shroud system.

The minimum pressure point is critical because the fluid must remain in the liquid state throughout the system. At the minimum pressure point, 755 kPa (109.5 psia), this state is maintained, since the maximum temperature will be 96.7°K and nitrogen will be in the liquid state at any pressure above 614 kPa (89 psia).

The subcooling coil submerged in the LN₂ of the LN₂ Storage Tank is designed to produce a 11.1°K (20° Rankin) temperature drop with an LN₂ flow of 111 m³/h (490 gpm).

The LN₂ makeup venturi is designed to provide a minimum LN₂ pump suction pressure of 418 kPa (60.6 psig) when the LN₂ level in the storage tank is at its minimum (just covering the subcooling coil). The tank static head plus tank vapor pressure, coupled with the geometry of the venturi and pressure losses between the venturi and the pump inlet, establish the minimum suction pressure.

The total LN₂ flow will be supplied through any two of the three cryogenic pumps provided on the circulation skid and connected in parallel. Each of these is a 5.08 cm x 10.16 cm x 19.05 cm (2" x 4" x 7.5") CVI centrifugal pump with 19.05 cm (7.5 inch) impeller and 14.9kW (20 HP) motor.

Two of these pumps will be supplying 55.7 m³/h (245 gpm) of LN₂ each, while operating at 13.3 kW (17.8 BHP). The third cryogenic pump is a reliability backup.

AMBIENT BAFFLE TEMPERATURE CONTROL

During testing with the shroud at ambient temperature, all surfaces forming the test volume must remain at a constant temperature. The shroud baffle in front of the cryopumps must be shielded from the cold surfaces of the cryopumps. This is accomplished by electrically heating a secondary baffle located between the shroud baffle and the cryopumps. The shroud baffle is to be maintained within 1°K of the temperature of the rest of the shroud.

Following a radiation heat transfer analysis of the cryopumps and baffle systems, the distributed electric heater power has been sized for satisfaction of the temperature control requirements.

Control will be achieved by proportionally controlling the electric heater power to minimize the temperature difference between the secondary baffle and the nominal chamber wall.

SPECIMEN HEATING

Thermal balance testing is accomplished through use of the LN₂ shroud as a "heat sink" and infrared (IR) lamp as a heat source.

The IR lamps are mounted on a cylindrical framework with end closeouts providing a heat source from all view angles of the test specimen. The IR cage with lamps and wiring is designed for minimum shadowing of the cryogenic heat sink.

The IR lamps are divided into 100 zones, each zone controlled by a motor operated transformer. The system is capable of being varied from zero to 80 volts, 110 volts, or 220 volts by stepper motors. Under emergency conditions, one of the two emergency generators is dedicated to supply IR power, and an uninterruptable power supply will maintain program control during power switchover. Manual control of each of the 100 autotransformers is also provided should the need arise.

WARMUP WITHOUT CONDENSATION

An electrically heated recirculating GN_2 warmup system is used to return the shrouds to room temperature, following tests. The shrouds can be warmed from LN_2 temperature to room temperature in eight (8) hours. See Fig. 5. Warmup of the helium cooled internal cryoarray is expedited with a thaw heater, included as part of the helium refrigeration system.

An LN_2 cooled scavenger panel is maintained in its cold state as all the rest of the chamber equipment is warmed up. All condensible materials will therefore be accumulated at this scavenger panel rather than dispersed throughout the chamber area.

TEST FIXTURES

The monorail along the top centerline of the chamber has a double set of trolley flanges. The top set supports an IR cage which can be rolled in or out of the chamber independent of the test article supported from the bottom flange. Test article support at the monorail is by two trucks 8 feet apart. The close out disc and test article may be removed and inserted from either end of the chamber. The monorail contains a "swing in place" section outside the chamber, at each end, to interface with high bay handling structures.

Both test article and IR heating cage may be supported from underneath. Rails running the full length of the chamber will support the bottom 1/4 of the cage. The upper 3/4 of the cylindrical IR cage is supported on separate tracks from the lower quarter section and may remain in the chamber during insertion and removal of the bottom 1/4 section.

Support of the test article cradle support is integral with the bottom 1/4 shroud section which, when outside the chamber, may be moved to and from the chamber on air transporters. Use of an optical bench as a work platform requires removal of the flat shroud platform.

Horizontal surfaces flush with the outside high bay floor (see Fig. 2) allow the bottom shroud platform and optic bench to be moved in and out of the chamber on air transporters.

With an optic bench 4.57 m wide x 18.3 m (15 ft. wide x 60 ft.) long in place, two 3.05 m (10 foot) long shroud platform sections may be installed at each end. The pneumatic vibration isolators along each side are captive to the optic bench when moved and provide isolation of the optic bench outside the chamber in the high bay at either end. The table with a clear height of 9.45 m (31 feet) above the table may be moved in and out of the chamber fully loaded. Loads of 1816 kg (4000 pounds) may be supported on each platform section at ambient and vacuum conditions.

WORK PLATFORM STABILITY

Initial requirements were to provide an optic bench capable of functioning in both a controlled ambient temperature environment and a cryogenic temperature environment.

An optic bench is not currently supplied due to changed program requirements. However, design has been completed on an optic bench system and all supporting equipment has been installed.

The optic bench system is designed to provide a work platform inside the chamber capable of alignment stability of less than 20 nanoradians on the work surface. Performance is based on finite element modeling of the structure considering ground and machinery inputs, building attachments, chamber attachments, uncorrelated inputs, plus thermal stability effects on the optic bench.

The chamber support girders and supporting grade beam with piles act as a composite structure providing an end to end slope error of .2 to .3 nanoradians at the isolator support surface.

Where the thermal environment at the optic bench top surface is at LN₂ temperatures, a multilayered insulation blanket system designed to reduce the temperature related end to end deformation to about 1/2 nanoradian for short duration. For longer durations of 30 days, alignment deformations are held to less than 25 microradians.

Work platform stability is provided by an optic bench in both a controlled ambient temperature environment and cryogenic environment.

SPECIMEN OBSERVATION

Two TV cameras are mounted in the test volume with monitors and pan and tilt controls located in the control console. The cameras are the type successfully used on space flights. They are sealed and require a continuous flow of GN₂ cooling gas. Lighting is provided by 12 - 150 watt lamps containing debris shields.

REPRESSURIZATION

Normal repressurization is accomplished with dry nitrogen gas supplied through a gas fired, LN₂ vaporizer. Provisions are also included for repressurization with air from the high bay room in front of the chamber.

PROCESS CONTROL & DATA ACQUISITION

CONSOLE

A high degree of flexibility of operations is maintained in this facility by utilizing manual remote controls for all systems in the central control console. All subsystems can be started, controlled, and shut down from the remote control console. Programmed logic controllers are used to automatically maintain many of the process systems on test set points.

A photo of the console is shown in Figure 6.

DATA ACQUISITION

The complete data acquisition system is provided by the customer. The supplied equipment provides the necessary interfaces for that data system.

SAFETY

Personnel safety was of prime importance in developing an interlock system for chamber pumpdown and the repressurization with nitrogen.

With the chamber heads in place, four access doors contain Kirk key lock systems that require master keys to be inserted in the console before chamber pumpdown may commence. The console has two alarms: (1) "Man in chamber" alarm should an emergency stop button inside the chamber be pressed after start of pumpdown, (2) "Chamber not safe to enter" alarm which is a fault condition resulting from any one of 13 safety related items not being satisfied. The reverse of the "Fault condition" is a "Chamber safe to enter" light which includes a positive lock out on the nitrogen supply to the chamber repressurization system.

EMERGENCY POWER AND REDUNDANCY

Emergency electrical power is provided by (2) 500 kW diesel generator sets. They are connected to (2) main load busses, one for equipment and the other primarily for IR power. Automatic transfer switches are on each line. One generator can be committed to both busses should one generator fail to start. The operator must monitor loads brought back on line to stay within the one generator's capacity. The purpose is to maintain a safe thermal balance for the test article.

A secondary power feeder, to a locally mounted power transformer, can be brought into use by manual transfer switches should a fault occur in the principal feed line.

Key elements of the cooling water system are two units each containing circulating pumps and water coolers. Both units are required for initial pumpdown, whereas one unit will handle the steadystate heat load.

Multiple cryopumps and turbopumps provide redundancy. The 1.0 kW helium refrigerator contains two expander turbines. The second turbine is maintained cold and can be brought into service from the control console.

A third LN₂ pump provides backup where two are required for normal flow of 111 m³/h (490 gpm).

Identical backing pumps for the turbo and cryo pumps provide redundant flexibility once the cryopumps are at operating temperature.

Ten nude ion gauges penetrate the shroud into the test volume to provide flexibility and redundancy.

SUMMARY

The Delta chamber is a turnkey thermal vacuum facility designed for multiple program use with large operational gas loads.

The chamber is full sized, double ended, and capable of receiving a full length vibration isolated and thermally stable optical bench.

Completion of the facility will be on schedule in late 1986.

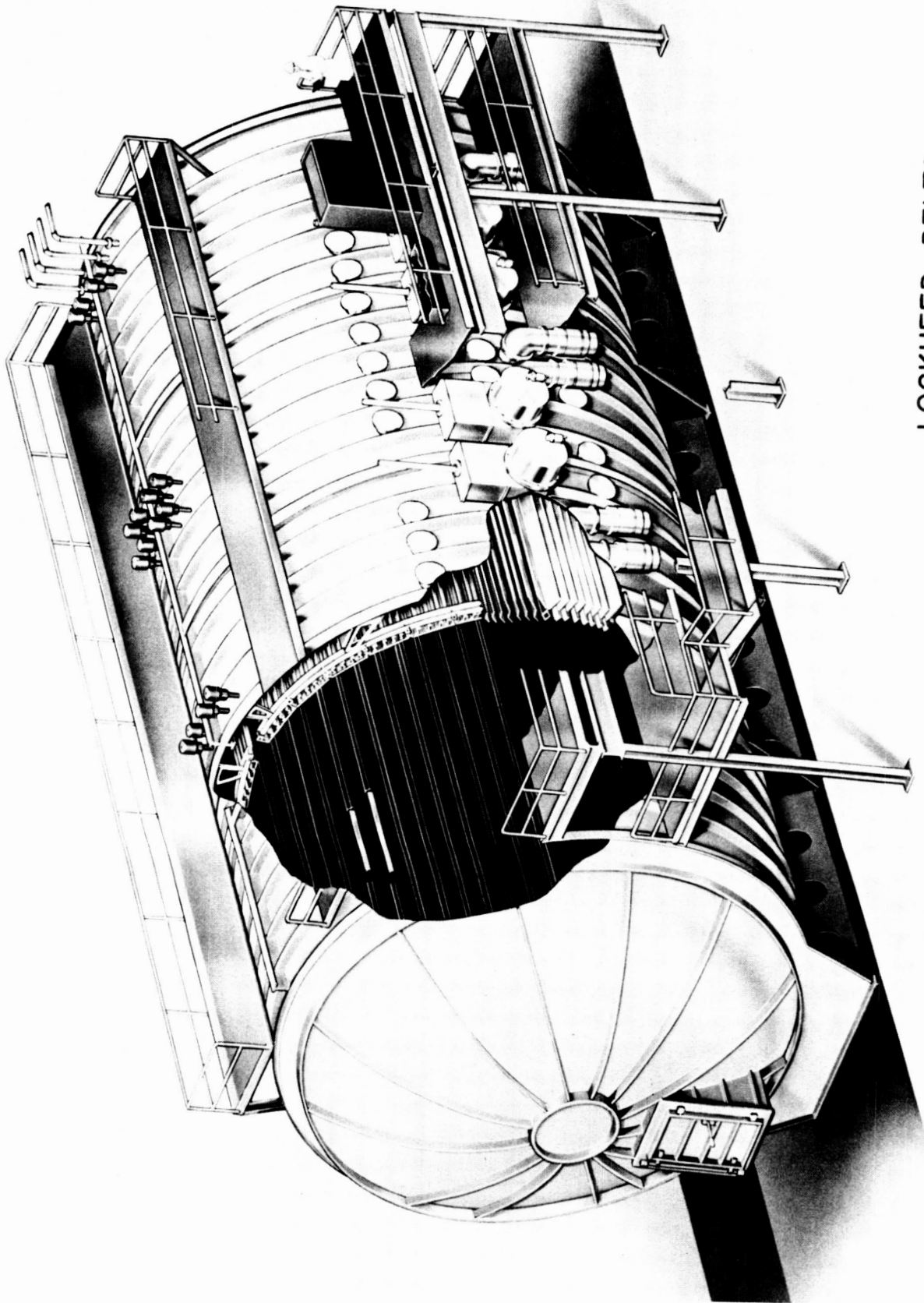
Table 1
Test Regimes
(SI Units)*

	WITHOUT OPTIC BENCH			WITH OPTIC BENCH	
	CD & E	PASSIVE GAS LOADS	ACTIVE GAS LOADS	SHROUD COLD	SHROUD WARM
Roughing		.67 Pa in 4 Hrs			Extendable to 24 Hrs
Gas Loads, Pa L/S	Outgas	GN ₂ 208 He .44	GN ₂ 110,000 H ₂ 856,000	GN ₂ 216 H ₂ 56 He .44 H ₂ .06	GN ₂ 216 H ₂ 63 He .44 H ₂ .06
Shroud Temperature	90°K	90°K	90°K	90°K	Ambient Temp. Controlled to ± 1° K
High Vacuum Pumps		Internal H ₂ Array Cryopumps Turbo-molecular Pumps Shroud			
Nominal Vacuum Pressure, Pascal	1.3x10 ⁻⁶	1.1 x 10 ⁻⁴	5.3 x 10 ⁻²	1.3 x 10 ⁻⁴	1.1 x 10 ⁻³
Chamber Warmup and Repress.	Air in 1 Hr, or GN ₂ Extendable to 12 Hrs.				

*See Table 1A for US Customary Units

Table 1A
 Test Regimes
 (US Customary Units)

	WITHOUT OPTIC BENCH			WITH OPTIC BENCH	
	CD & E	PASSIVE GAS LOADS	ACTIVE GAS LOADS	SHROUD COLD	SHROUD WARM
Roughing		5 Microns in 4 Hrs			Extendable to 24 Hrs
Gas Loads, TL/S	Outgas	GN ₂ 1.25 He .0033	GN ₂ 825 H ₂ 6400	GN ₂ 1.62 H ₂ .42 He .0033 H ₂ .00047	GN ₂ 1.62 H ₂ .47 He .0033 H ₂ .00047
Shroud Temperature	90°K	90°K	90°K	90°K	Ambient Temp. Controlled to ± 1° K
High Vacuum Pumps		Internal H ₂ Array Cryopumps Turbomolecular Pumps Shroud			
Nominal Vacuum Pressure, Torr	1x10 ⁻⁸	8.3x10 ⁻⁷	4x10 ⁻⁴	1x10 ⁻⁶	8x10 ⁻⁶
Chamber Warmup and Repress.	Air in 1 Hr, or GN ₂ Extendable to 12 Hrs.				



LOCKHEED DELTA
THERMAL - VACUUM CHAMBER

Figure 1. Lockheed delta thermal-vacuum chamber

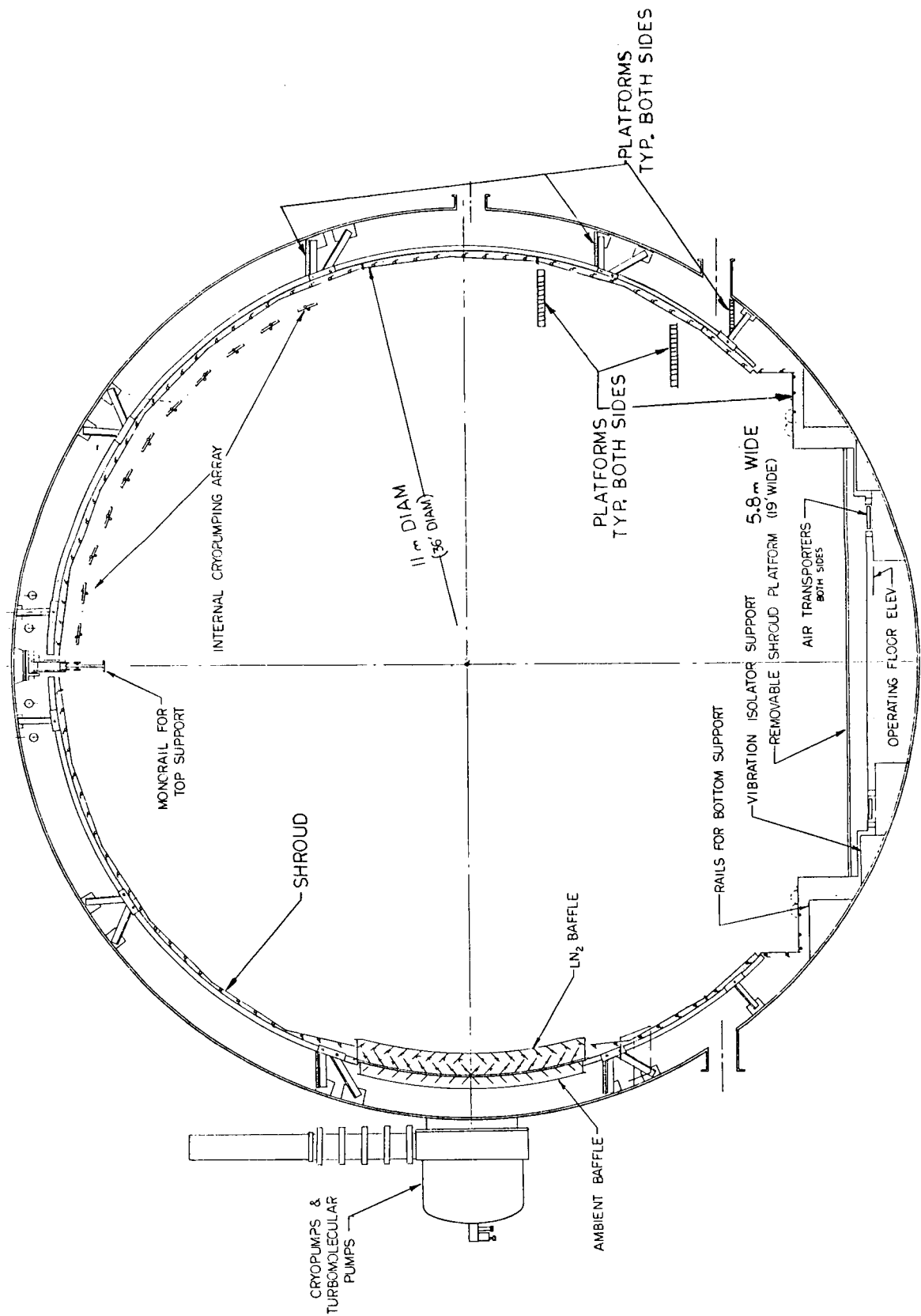


Figure 2. Chamber features

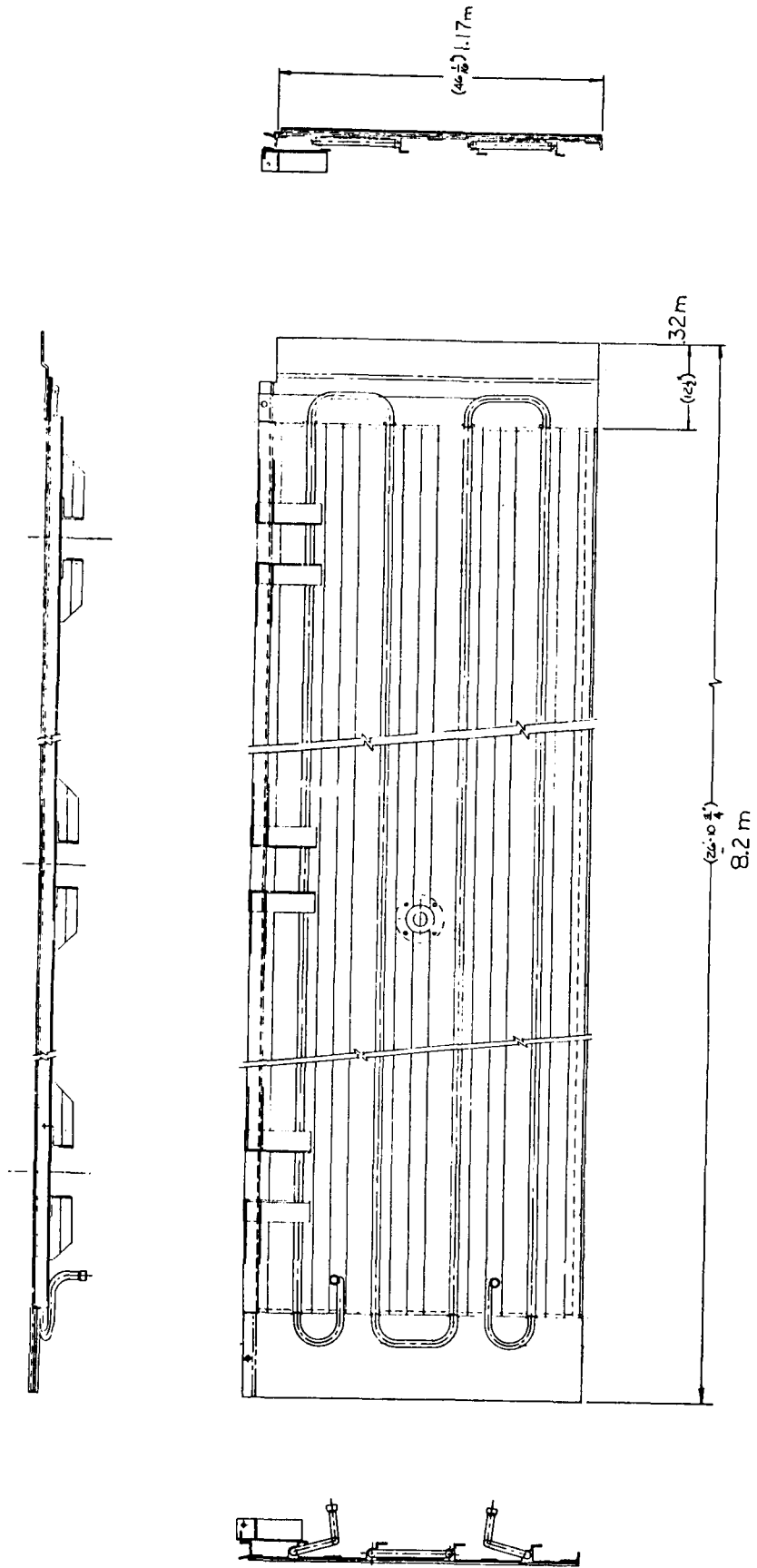


Figure 3. Typical shroud panel

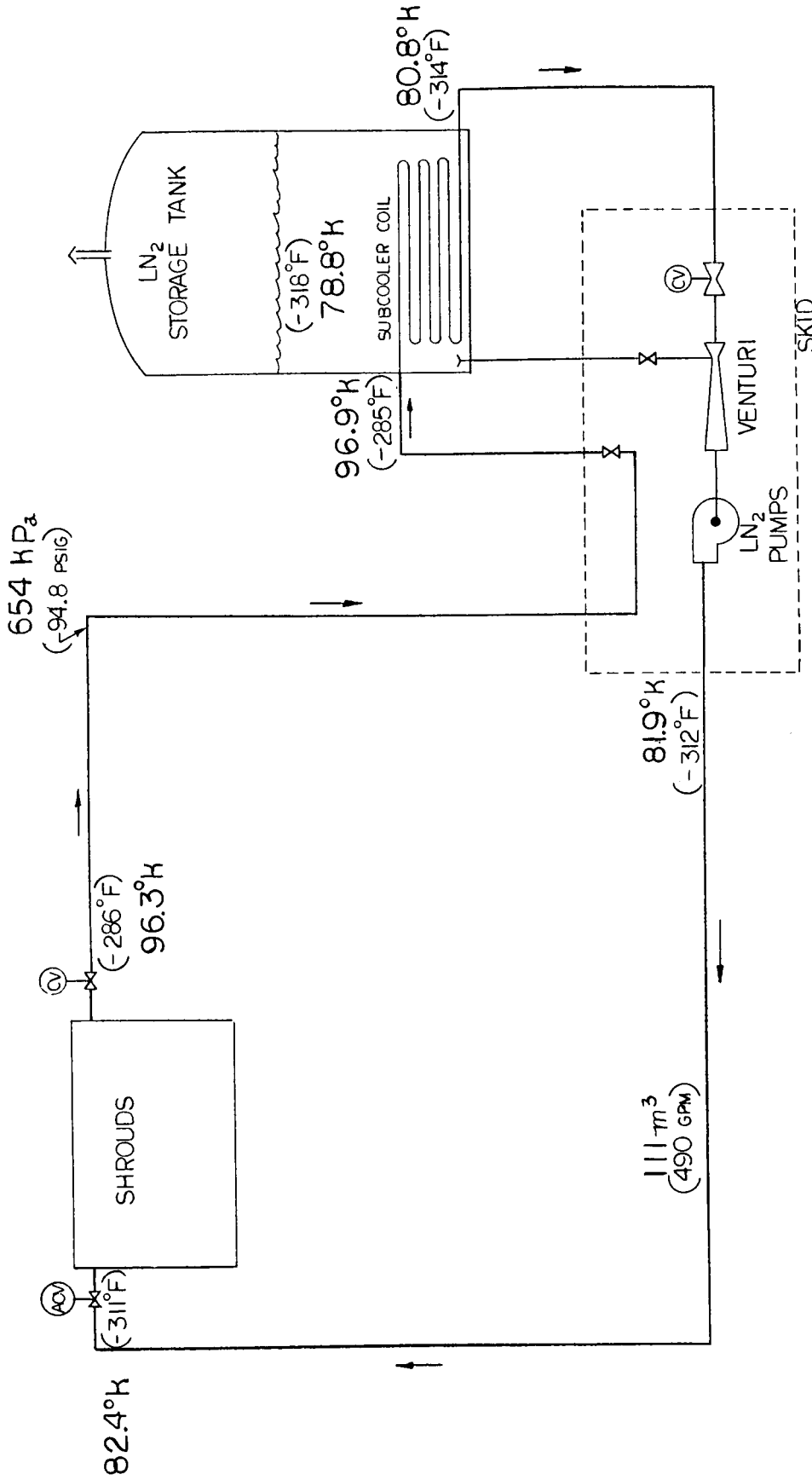


Figure 4. LN₂ system at design conditions

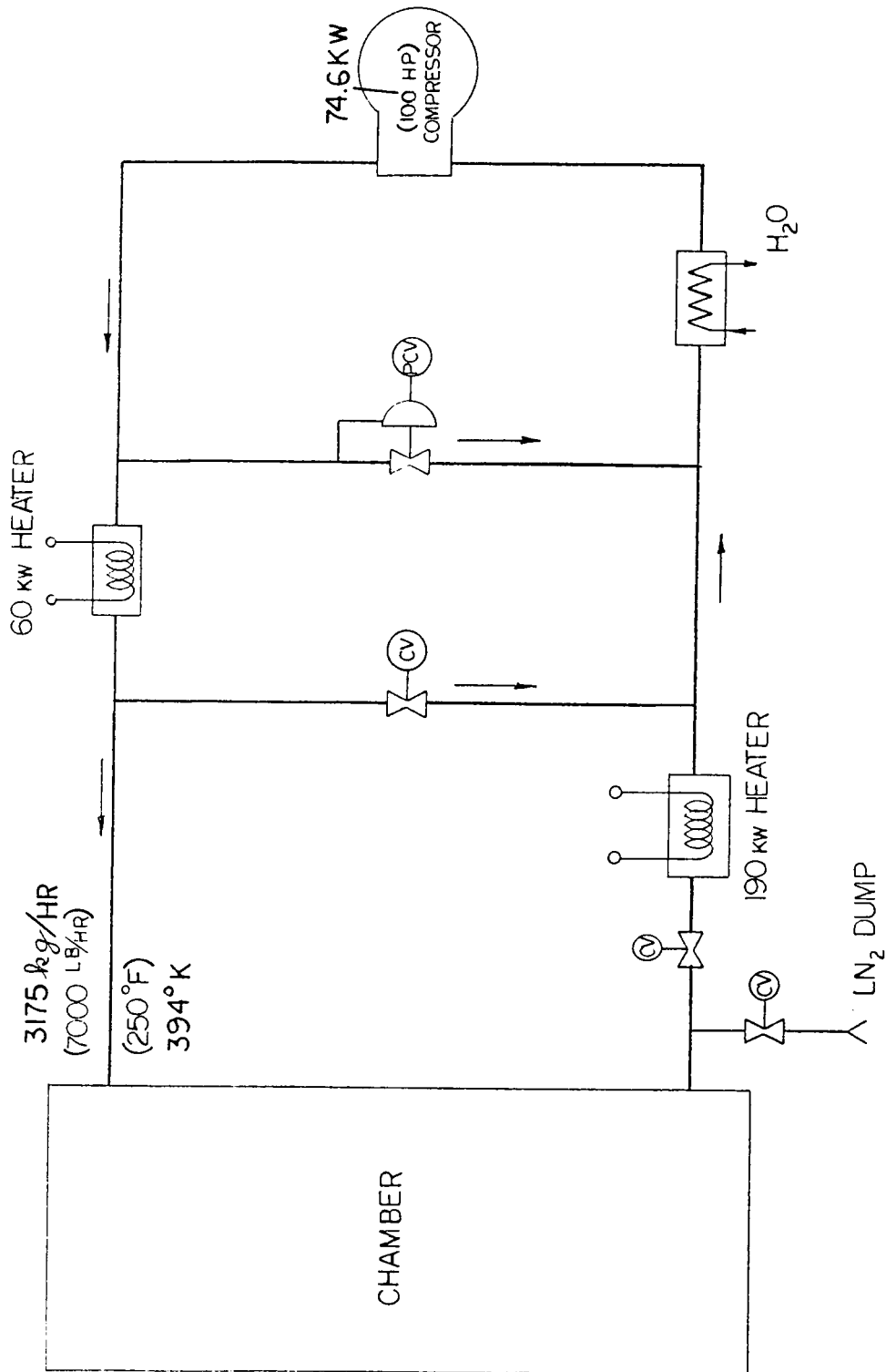


Figure 5. GN₂ warmup unit

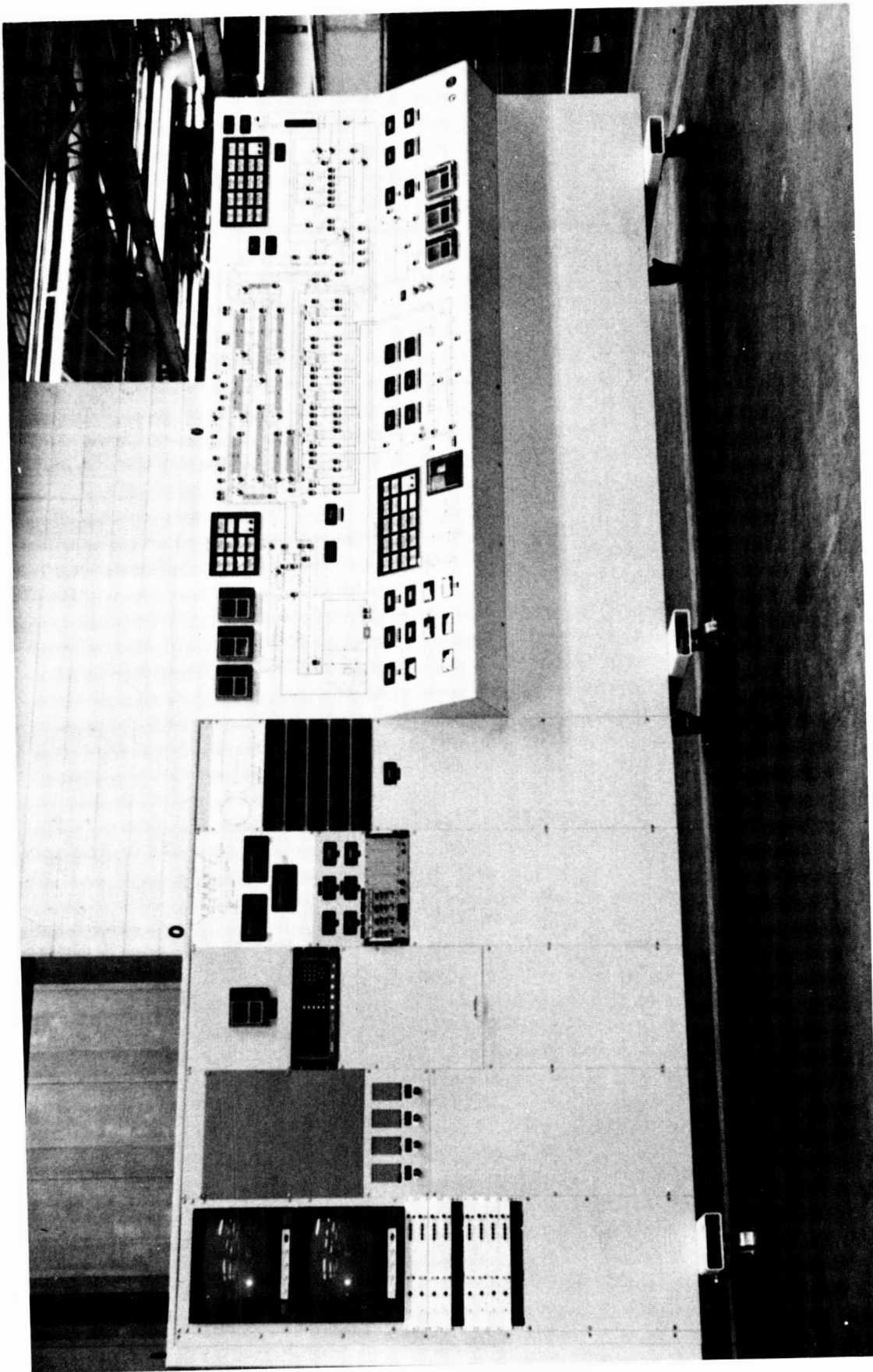


Figure 6. Chamber control console