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A NEW THERMAL VACUUM FACILITY at the MARTIN MARIETTA WATERTON PLANT

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ABSTRACT

A new Thermal-Vacuum facility has been recently completed at the Martin Marietta Waterton plant near Denver, Colorado. The facility was designed, fabricated, installed and tested as a turn-key project by Pitt-Des Moines Inc. and CVI Inc. The chamber has a 5.49 M by 6.10 M (18' by 20') flat floor and a half-cylindrical roof with a diameter of 5.49 M (18'). Both ends of the chamber have full cross section doors, with one equipped with translating motors for horizontal motion. The chamber is provided with four 0.91 M (36") cryopumps to obtain an ultimate pressure of 9×10^{-8} Torr (Clean-Dry-Empty). The thermal shroud is designed to operate at a maximum of -179 °C (-290 °F) with an internal heat input of 316 MJ/Hr (300,000 BTU/Hr) using liquid nitrogen. The shroud is also designed to operate at any temperature between -156 °C (-250 °F) and 121 °C (+250 °F) using gaseous nitrogen, and heat or cool at a rate of 1.1 °C (2 °F) per minute.

INTRODUCTION

In September of 1991, Pitt-Des Moines Inc. and CVI, Inc. completed work on a new Thermal-Vacuum facility for Martin Marietta. The vacuum chamber and associated equipment were installed in an addition to an existing building at Martin Marietta's plant located near Waterton, Colorado. The chamber was designed as a general purpose facility for thermal-vacuum testing of components or systems for satellites and space vehicles, and complements existing capabilities at the plant. While the new chamber shares rough vacuum pumping equipment and bulk LN_2 storage with the existing chambers, it is otherwise functionally independent of the other chambers. The chamber and support equipment is controlled from a central console mounted on a mezzanine adjacent to the chamber.

The facility consists of three main systems: the chamber system, the vacuum system and the thermal system. The chamber system incorporates the vacuum boundary elements, including penetrations and doors, the personnel and equipment access bridges and the internal hardpoints for mounting test articles and support equipment. The vacuum system comprises the external equipment required to evacuate the chamber, repressurize it, and purge for personnel entry. The thermal system includes the shroud and LN_2 and GN_2 equipment necessary for establishing the desired temperature environment in the chamber. Support systems include utility LN_2 and GN_2 supplies, instrumentation and control, and primary and backup power distribution.

This paper will provide an overview of each of these systems, including each system's operational features and performance requirements.

CHAMBER SYSTEM

Vacuum Chamber

As shown in Figure 1, the vacuum chamber for the facility is in the shape of a mailbox, with a flat operating shroud floor, vertical sidewalls to the midheight, and a cylindrical roof. The chamber floor is 5.49 M (18') wide by 6.10 M (20') long and is flush with the elevation of the surrounding laboratory. In order to match these floor elevations, the chamber is mounted on supports in a pit formed into the foundation for the building addition. The chamber is rigidly attached to a large concrete seismic mass to provide a stable vibration isolated platform for test operations.

This vacuum chamber shape provides several operational and construction advantages. The flat floor minimizes wasted internal volume and allows simple shroud and chamber supports. It also provides a minimum distance between the item under test and the external support equipment. The flat vertical side walls also minimize penetration complexity and difficult interfaces with the surrounding building partitions.

Chamber Doors

Access to the chamber is provided through o-ring sealed doors located on the east and west ends of the chamber. The PDM FLEX-SEAL door flange system was used on both doors, since it accommodated the square lower corners and door size without costly field machining. The east door is motorized and mounted on rails that permit it to translate outward and then south. The door system consists of three motor driven screw jacks that provide east-west door motion and a motor driven rail drive to move the door in a north-south direction. Limit switches on the system provide door position information to an local programmable logic controller (PLC), which automatically sequences the door motion. The local PLC is also linked to the main console PLC to prohibit door removal if a safe oxygen atmosphere is not present in the chamber. When fully open, the east door provides complete access to the full chamber cross-section. The west door is not currently motorized, with removal requiring the use of temporary rigging equipment. It can be outfitted with the same handling equipment as the east door.

Access Bridges

At each end of the chamber are bridges [Figure 2] which span the door handling trench and provide access for personnel and equipment to the chamber from the laboratory floor. Each bridge is raised and lowered by a hydraulic system connected to the local control panel used for the door removal system. Limit switches on the system provide door position information to the local PLC which automatically sequences the bridge motion. The bridges have machined rails to allow the use of air casters to move equipment across the bridges and into the chamber.

Internal Rails

Two full length internal rail hardpoints [Figure 3] are provided along the chamber floor for the support of test articles. These rails are aligned with the bridge rails and are also machined to permit the use of air casters. The rails may be removed for cleaning or maintenance and are not actively thermally controlled.

Internal Hardpoints

Overhead, 12 pin hardpoints [Figure 4] projecting through the shroud plane provide lifting points for internal rigging. The hardpoints are threaded into sockets so that may be removed for cleaning, modification or for shroud removal. The hard points can each be loaded vertically to 3340 N (750 pounds).

Penetrations

The chamber is provided with over 80 penetrations, located predominantly on the vertical north and south walls [Figure 5]. Those on the south wall support the instrumentation, power, and control of the test article, and range in size from 914 mm (36") to 25 mm (1"). These penetrations communicate with a secure control room one floor below the main control room. Those on the north wall are primarily related to systems required for chamber and shroud operation. The largest of these is 406 mm (16") in diameter. Several penetrations are located in the cylindrical top of the chamber, the largest of these being the four 914 mm (36") cryopump penetrations. Five 304 mm (12") viewports are also provided, with four located in a horizontal plane approximately 2 meters above the laboratory floor and the fifth on top of the chamber. The viewports are equipped with lockable metal security covers.

VACUUM SYSTEM

The vacuum system provides the equipment to evacuate the chamber to the design conditions of 9.0×10^{-8} Torr (clean/dry/empty), 9.0×10^{-6} Torr (hot shroud) and 6.0×10^{-6} Torr (ambient shroud, passive gas load of 0.15 Torr-liter/sec of Nitrogen), and then return it to a safe condition for personnel entry at atmospheric pressure.

Rough Vacuum Pumping

The roughing segment of this system utilizes the existing Martin Marietta rough vacuum pumping system. The existing system consists of two parallel blowers and one backing pump. The line connecting the chamber to the pump contains a cold trap to stop oil migration from the roughing pumps. A high vacuum gate valve is installed at the chamber for isolation of the roughing system during high vacuum pumping of the chamber. A spectacle blind flange is installed between the cold trap and pumping system to allow blinding of the roughing line if service is required. The cold trap is supplied with a refrigerant compressor for closed loop operation. A warm gaseous nitrogen line can introduce gas to the roughing line at the cold trap to assist in the warm up of the trap.

High Vacuum Pumping

The high vacuum system consists of four 914 mm (36") CVI Inc. cryopumps, each with a high vacuum gate-type isolation valve, mounted on the upper cylindrical part of the chamber. Connected to the cryopumps are the following support systems:

- LN_2 supply to the internal shrouds
- roughing lines
- high pressure helium supply to the expanders
- Heated GN_2 supply for regeneration
- Heated GN_2 supply for removal of LN_2 from the internal shroud
- auxiliary port for general use, with hand valves

The passive LN_2 supply for the internal shrouds is drawn from a run tank (secondary LN_2 storage) and forced through vacuum jacketed lines to the cryopumps by the vapor-space pressure in the run tank. Liquid level control is performed by vent valves on the exhaust side of the internal shroud system. Boiloff gas is piped to the central vent system and transmitted to the run tank area for venting outside the building. The roughing system for the cryopumps consists of a single rotary pump located in the mechanical room, and valves to connect the pump to one cryopump at a time. Helium gas for cryopump expander operation is supplied by flex hoses run from the compressors mounted on the elevated south platform. The regeneration system GN_2 is piped from the receiver in the mechanical room to the chamber area where it is heated and distributed to each cryopump.

To warmup the cryopump for regeneration or shutdown, warm GN_2 is supplied to the inlet side of the internal shroud system. By addition of GN_2 at this point, all LN_2 in the shroud is forced out into the central vent system.

Repressurization System

The chamber repressurization system provides a connection from the vacuum chamber to the ambient temperature nitrogen receiver or to the room air. The nitrogen and room air piping combine into a common inlet pipe to the chamber. The system elements include: a flow control valve to control the rate of repressurization, an in-line filter to insure cleanliness of the incoming air or nitrogen, a flexible hose to stop piping vibrations from reaching the chamber, a high vacuum gate valve to isolate the chamber from the repressurization system during vacuum pumping, and a relief valve to prevent excessive pressure to build up against the vacuum gate valve. Within the chamber, the common inlet pipe branches into two pipes with a silencer at the end of each pipe to lessen the noise during repressurization and to break up the incoming flow so that it will not impinge on the shrouds or test articles. The nitrogen branch of the repressurization system contains a restricting orifice. The restricting orifice provides pressure drop during repressurization and limits the amount of flow possible to the vessel in the event of a control valve failure. The room air branch of the repressurization system contains an isolation valve and has a filter/silencer at its inlet to reduce the noise during repressurizat ion. A safety interlock will limit GN_2 repressurization to a value less than one atmosphere and switch to room air for final equalization.

Purge System

The chamber purge system consists of a HVAC-type blower which draws room air through the chamber to replenish the oxygen content. The blower is connected to the vacuum chamber with duct work which is vibration isolated with a flexible rubber section. A high vacuum gate valve is at the chamber connection to isolate the blower from the chamber during vacuum pumping. A high vacuum gate valve is mounted on the nozzle for isolation of the air inlet during vacuum pumping. A HEPA filter is mounted on the inlet vacuum gate valve to insure cleanliness of the incoming air to the chamber. The chamber oxygen monitoring system consists of two oxygen analyzers independently drawing samples from the chamber. The samples are drawn by a diaphragm pump which draws air from the chamber through a tube for each analyzer. A high vacuum valve isolates each oxygen monitoring system from the chamber during chamber vacuum pumping. A solenoid operated calibration valve is located in the line to each analyzer. It is a three way valve which allows either room air or chamber air to flow to the oxygen analyzer. A flow switch in the line checks to be sure that there is flow to the analyzer. The controls to open the chamber door remain deactivated until both oxygen sensors indicate a safe environment inside the chamber.

SUPPORT SYSTEMS

Liquid Nitrogen Supply System

LN_2 is supplied to the chamber Run Tank from the existing Martin Marietta storage sphere using a transfer pump [Figure 6]. The Run Tank is designed to provide buffer storage of LN_2 for use on the 18x20 Thermal-Vacuum Chamber, instead of drawing all needed LN_2 directly from the main LN_2 sphere. With this arrangement, a test in the 18x20 chamber can be continued for up to 5 hours while maintenance is performed on the main storage sphere or LN_2 transfer pump. The secondary function of the Run Tank is to serve as the ultimate heat sink for the shrouds and program loads by way of the subcooling coil. Finally, the run tank serves as a recovery system in the event that LN_2 is to be removed and stored from the shrouds, program loads or water vapor pump.

The LN_2 transfer system consists of the pump, associated inlet and outlet isolation valves, a cooldown valve, and piping from the LN_2 sphere to the run tank. A temperature element in the cooldown line determines if the cooldown valve is needed to be open. If all the valves around the pump are closed, a pressure relief valve will protect the system from overpressure. The PLC will automatically maintain the tank at a preset level and interlocks will also prevent closure of all valves and trapping of LN_2.

The run tank is a 22.7 M^3 (6000 gallon) double wall LN_2 storage tank located on the exterior pad on the south side of the building. Inside the inner tank is the subcooler coil connected to the Shroud and Auxiliary LN_2 systems. The run tank is equipped with a level sensor (based upon differential pressure) that controls the operation of the LN_2 transfer pump at the main LN_2 sphere. The vent system from the inner tank is provided with a pressure control valve which is used to vent excess gas to maintain a nominal 103 KPa to 138 KPa (15 to 20 PSIG) pressure in the vapor space. To provide makeup GN_2 during top fill operations, a supply from the receiver with a pressure regulator has been provided. The tank is also equipped with provisions for filling from a tank truck and pressurization using a pressure building coil.

Gaseous Nitrogen Supply System

Gaseous nitrogen is supplied to the facility by use of an electric vaporizer. Nitrogen leaves the vaporizer and is piped to a receiver inside the building at 21 $^{\circ}$C (70 F) plus/minus 2.8 $^{\circ}$C (5 F) by a SCR controlled electrical power supply. The SCR output is based on the temperature measured at the vaporizer outlet. A high temperature limit will shut down the power to the unit if the heater temperature reaches 149 $^{\circ}$C (300 F). The temperature of the GN_2 leaving the vaporizer is continuously indicated at the main control console.

Instrumentation and Control System

The chamber and support systems are controlled from a central console located one floor above the chamber operating floor. The console [Figure 7] houses the main system Programmable Logic Controller (PLC), all instrumentation displays, all valve and equipment controls, and the central data logging system. The front panel provides a graphic depiction of all chamber systems.

Interlocks for operation of valves and equipment are provided by a Programmable Logic Control system. The system consists of an Allen-Bradley PLC-5 unit mounted in the main rack inside the control console and two remote Input/Output racks, one mounted above the vacuum chamber and another on the south exterior pad. The three racks contain removable input, output, power supply, communications and processor cards. A plug has been provided in the front right face of the control console for connection of a supplied Allen-Bradley T-50 programming terminal.

The data logging system is designed to acquire and record the shroud temperatures, chamber pressure and roughing line pressure during a test. The shroud temperatures are sensed by Type E thermocouples distributed throughout the shroud zones. Temperatures in the auxiliary LN_2 circuits are monitored by Type E thermocouples.

THERMAL SYSTEM

Shroud System

The shroud system consists of subassemblies fabricated from aluminum extrusions (that include passage ways for the thermal conditioning fluids) welded onto aluminum sheet materials. End shrouds are attached to the chamber's end doors and move with those doors. Floor sections of the shroud system are fabricated from aluminum plate with channel shaped aluminum extrusions that also include passage ways for thermal conditioning fluids. The sidewalls, ceiling panels and floor panels are removable from the chamber, using a tailored handling fixture.

This shroud system is divided into seven thermal control zones. All floor sections of the shroud are designed to support the loads incurred from test technicians walking on the shroud. A complete schematic of the shroud LN_2/GN_2 piping and distribution system is presented in Figure 8.

The test function of these shrouds is to provide an adequate thermal simulation of the specified test conditions. Using LN_2 as the thermal conditioning fluid, they will simulate the thermal sink conditions of the satellite environment and using GN_2 as the thermal conditioning fluid, a wide range of thermal simulations can be produced (both steady-state and thermal ramps). In the steady-state LN_2 mode, subcooled liquid nitrogen (e.g., liquid at temperatures well below the boiling point associated with the elevated pressures within the closed loop system) is circulated through the shroud system and absorbs the heat loads originating from the test article and from the warmer, outside chamber walls. All seven shroud thermal control zones are connected in series with each other, in this mode. With LN_2 circulating through the shrouds at 0.3 M^3/Min (80 gpm) and a heat load of 3.72 W/M^2 (40 watts/ft^2) applied to the shrouds, the fluid temperature rise through the shroud will be approximately 7.2 ^{o}C (13 F).

In GN_2 operating modes (steady-state and transient), the seven shroud zones are connected in parallel with each other. Flow control valves at the exit of each zone are automatically modulated by temperature controlled valves in a feedback control loop to maintain uniform thermal control over the shroud zone temperatures. As in the LN_2 operating mode, the fluid absorbs the combined heat loads from the test article and the chamber walls. The shroud system and its' GN_2 Thermal Control System are designed to support steady-state operations with the shroud temperature ranging from -179 to 121 ^{o}C (-250 F to +250 F). They will also support transient thermal ramp tests over this temperature range, at rates up to $\pm$ 1.1 ^{o}C/Min ($\pm$2.0 F/minute). Depending on the test conditions and the test article, the GN_2 controlled shroud may serve as either heat sink or heat source.

LN_2 Supply System

Liquid nitrogen for the thermal system is drawn from the Run Tank and fed to the Main Pump Skid. The LN_2 Main Pump Skid includes two parallel LN_2 pumps. The Shroud LN_2 Pump supplies LN_2 to the chamber shroud system and the Auxiliary LN_2 Pump supplies LN_2 for the GN_2 Thermal Unit, the Program Loads (auxiliary LN_2 zones) and the LN_2 Vaporizer. At elevated pressures (above one atmosphere) LN_2 will have elevated boiling temperatures (above the 77.4 K at one atmosphere). By maintaining sufficiently elevated pressures throughout the complete LN_2 circuit, the fluid can absorb heat from the thermal loads and still remain in the liquid state. In this system, a low pressure point is created at the throat of the venturi that's located just upstream of the LN_2 pump inlets. In steady state operating modes, these pumps draw LN_2 from the subcooling heat exchanger, in the Run Tank, through a venturi, where any necessary make-up LN_2 is introduced. Either or both of these pumps can be operated in an off-line, closed loop mode or feed the liquid through the respective loads. A schematic of this pump skid subsystem is presented in Figure 9.

GN_2 Thermal Unit

The GN_2 Thermal Control Unit manufactured by CVI Inc.is a stand-alone skid mounted system supplying thermally controlled GN_2 to the shroud system using a 75 HP turbine as the circulating device and a combination of electric heater and LN_2 mixer/injector for thermal modulation. A schematic of this skid subsystem is presented in Figure 10. This closed loop, GN_2 system is designed to provide steady-state shroud operations at any selected temperature between -179 and 121 °C (-250 F and +250 F). It will also support shroud thermal transients within the range of 1.1 °C/Min (2.0 F/minute). Maximum flow rate is required from this system to accomplish the maximum warm-up and cooldown rates; much lower flow rates are required at the design steady-state operating conditions. The rotational speed of the hermetically sealed turbine unit is automatically modulated by a variable frequency drive. This speed is modulated by a controller using turbine load feedback. A 100 KW, in-line electric heater adds heat to the circulating stream, when heat is being added to the GN_2. When heat is being extracted from the GN_2, the supply temperature is maintained by injecting a spray of LN_2 into the circulating fluid. Both power to the heater and LN_2 to the mixer are controlled by a temperature controller. Excess or make-up GN_2 is accommodated by pressure regulating valves on a vent line and on a GN_2 supply line from the GN_2 Receiver Tank.

For steady-state operation at -179 °C (-250 F), with an internal heat load of 65.4 MJ/Hr (62,000 Btu/hr), the turbine operates at about 3,000 rpm, supplying about 7390 Kg/Hr (16,300 lb/hr) of GN_2 and maintaining the maximum shroud temperature differential within ±11.1 °C (±20 F). For steady-state operation at 121 °C (+250 F), with an internal heat extraction of 22.2 MJ/Hr (21,000 Btu/hr), the turbine operates at about 6,000 rpm, supplying about 4310 Kg/Hr (9,500 lb/hr) of GN_2 and maintaining the maximum shroud temperature differential within ±11.1 °C (±20 F). During 1.1 °C/Min (2.0 F/min) transients between -179 and 121 °C (+250 F and -250 F), flow rate and rpm will vary from 23100 Kg/Hr (51,000 lb/hr) and 8,600 rpm at -179 °C (-250 F) to 9980 Kg/Hr (22,000 lb/hr) and 13,000 rpm at 121 °C (+250 F).

CONCLUSIONS

The new Thermal Vacuum facility completed by PDM and CVI for Martin Marietta verified the utility and value of several of it's novel features. The mailbox shape of the vacuum vessel proved to be a convenient, space-saving arrangement for test operations. The shape also met the required vacuum level and leak tightness requirements in an economical manner. In the GN_2 Thermal Unit, the use of the cold turbine circulator appears to be a reliable solution for shroud operations between -179 and +121 °C (-250 and +250 °F). It also permitted much smaller line sizes and skid size over that required using a warm blower with a heat exchanger.

Pitt-Des Moines, Inc.

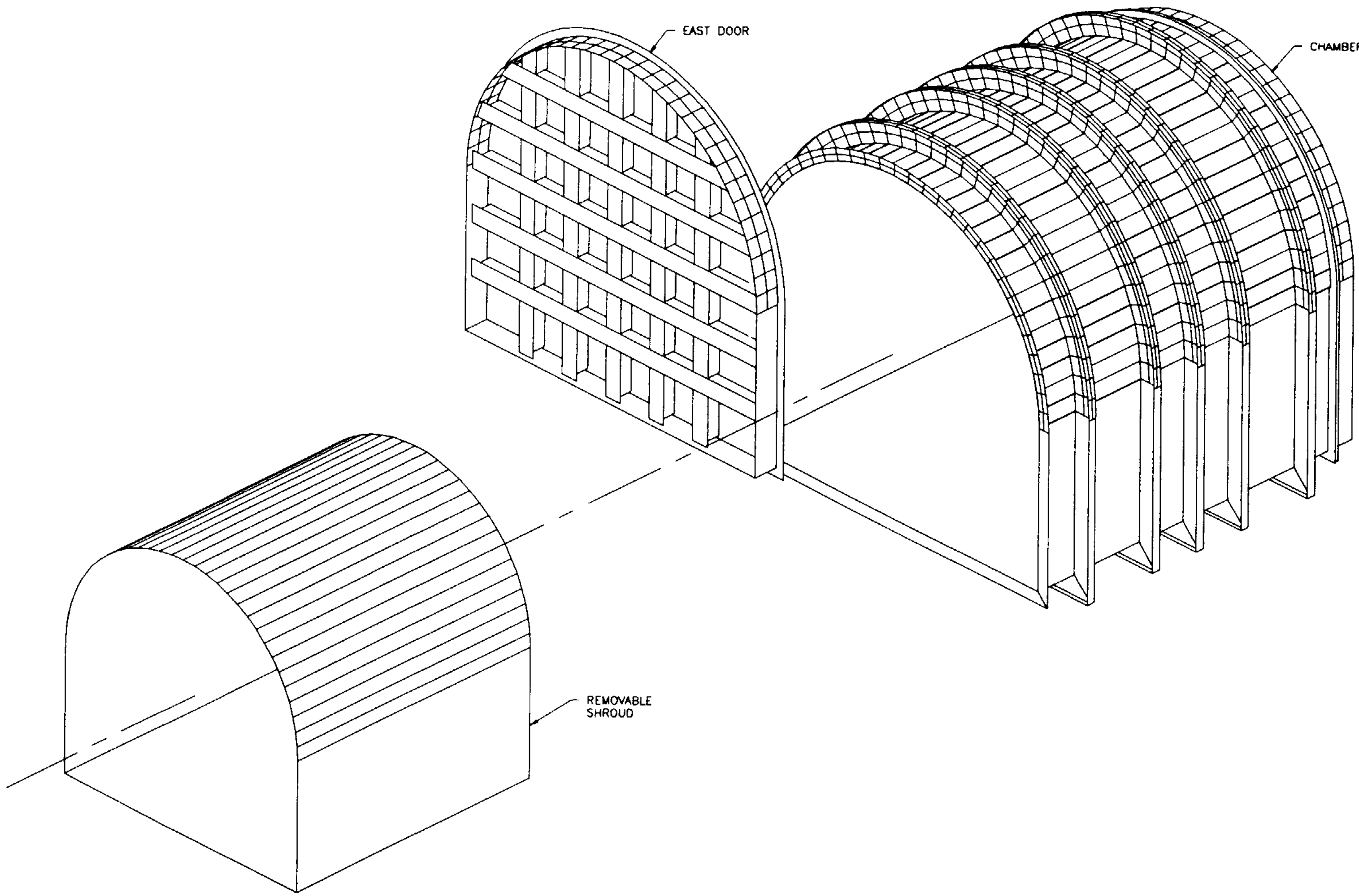

FIGURE 1
GENERAL ARRANGEMENT

PDM®
Pitt-Des Moines, Inc.

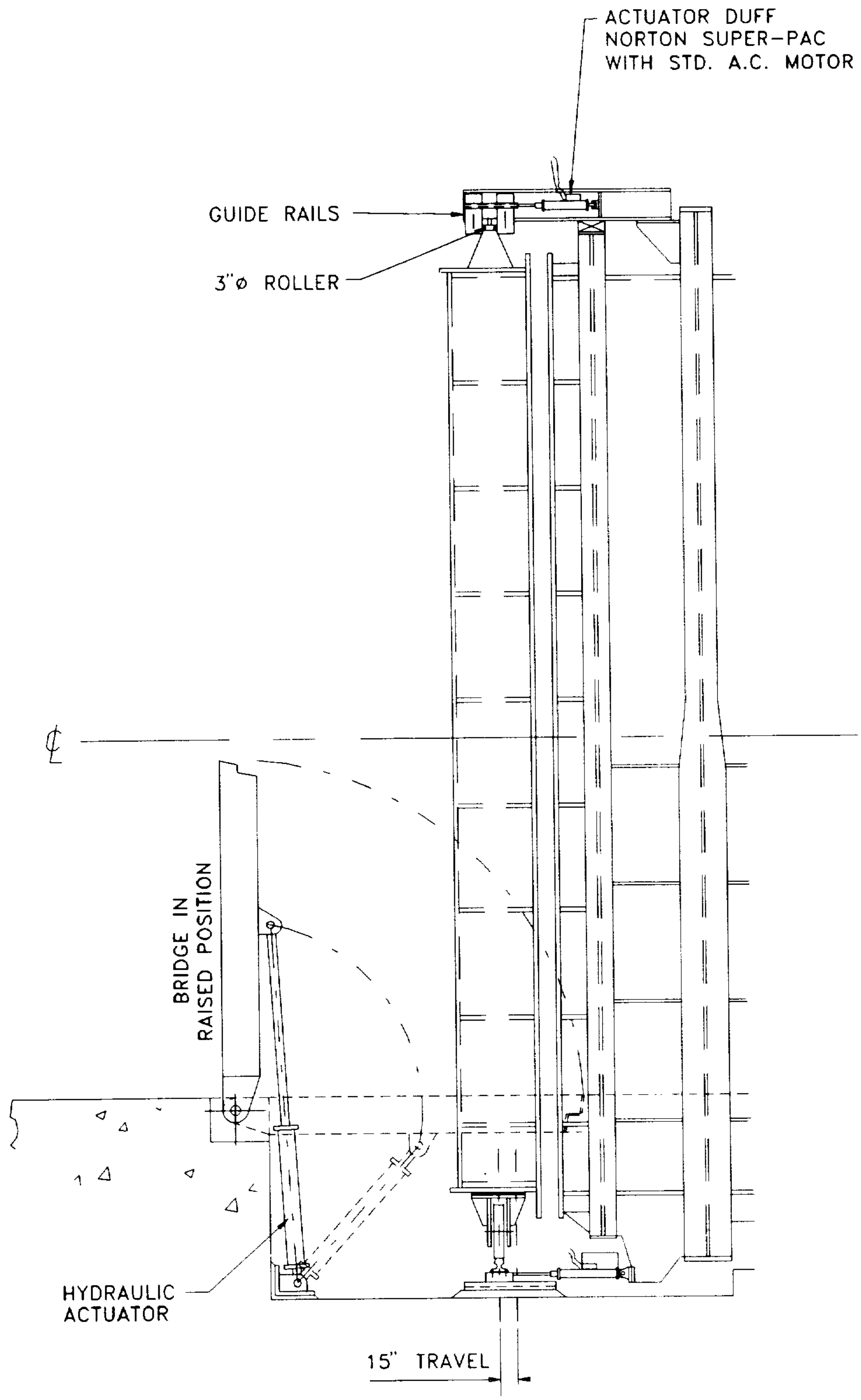

FIGURE 2

EAST DOOR ELEVATION

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Pitt-Des Moines, Inc.

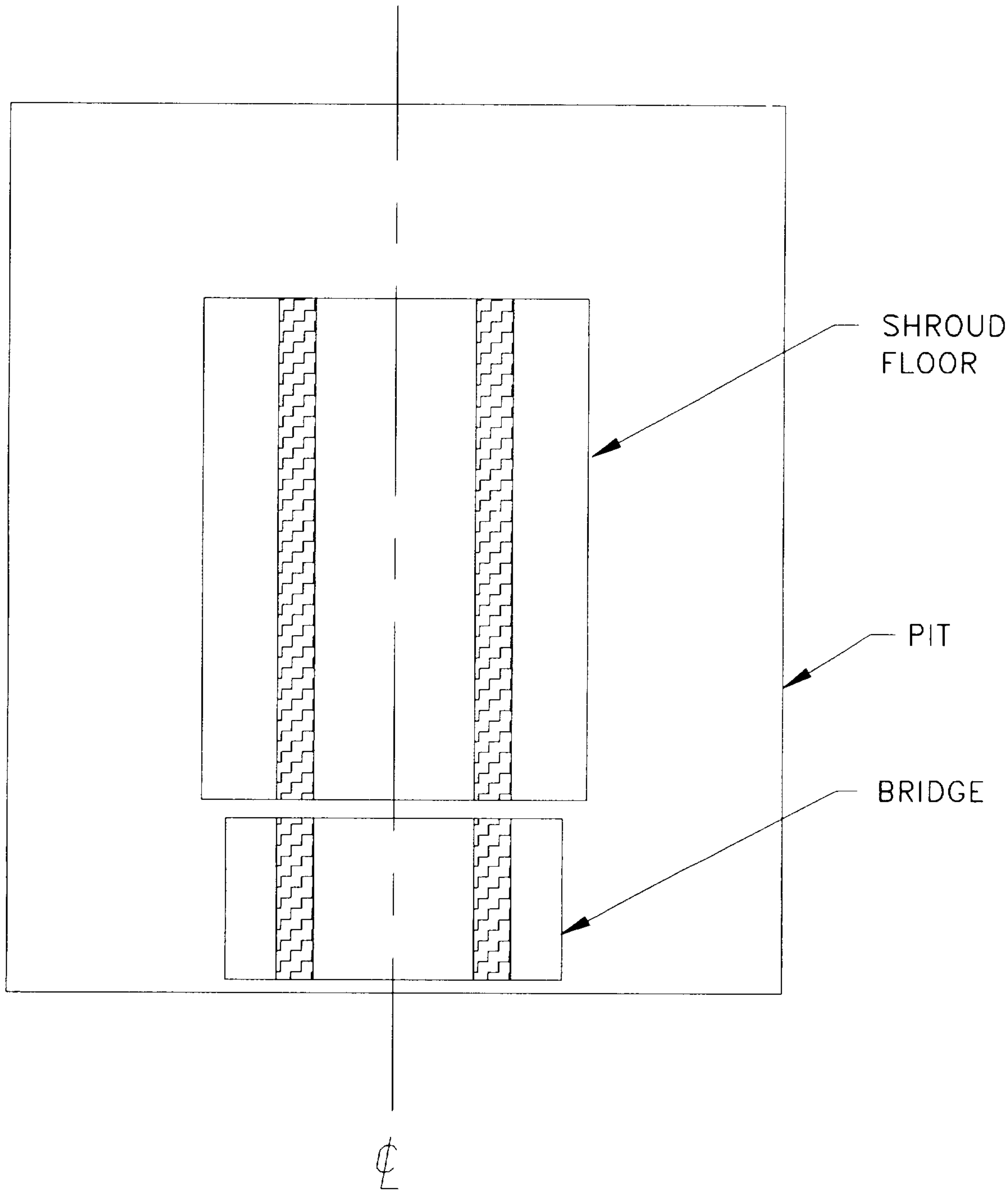

FIGURE 3

RAIL HARDPOINTS – PLAN VIEW

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Pitt-Des Moines, Inc.

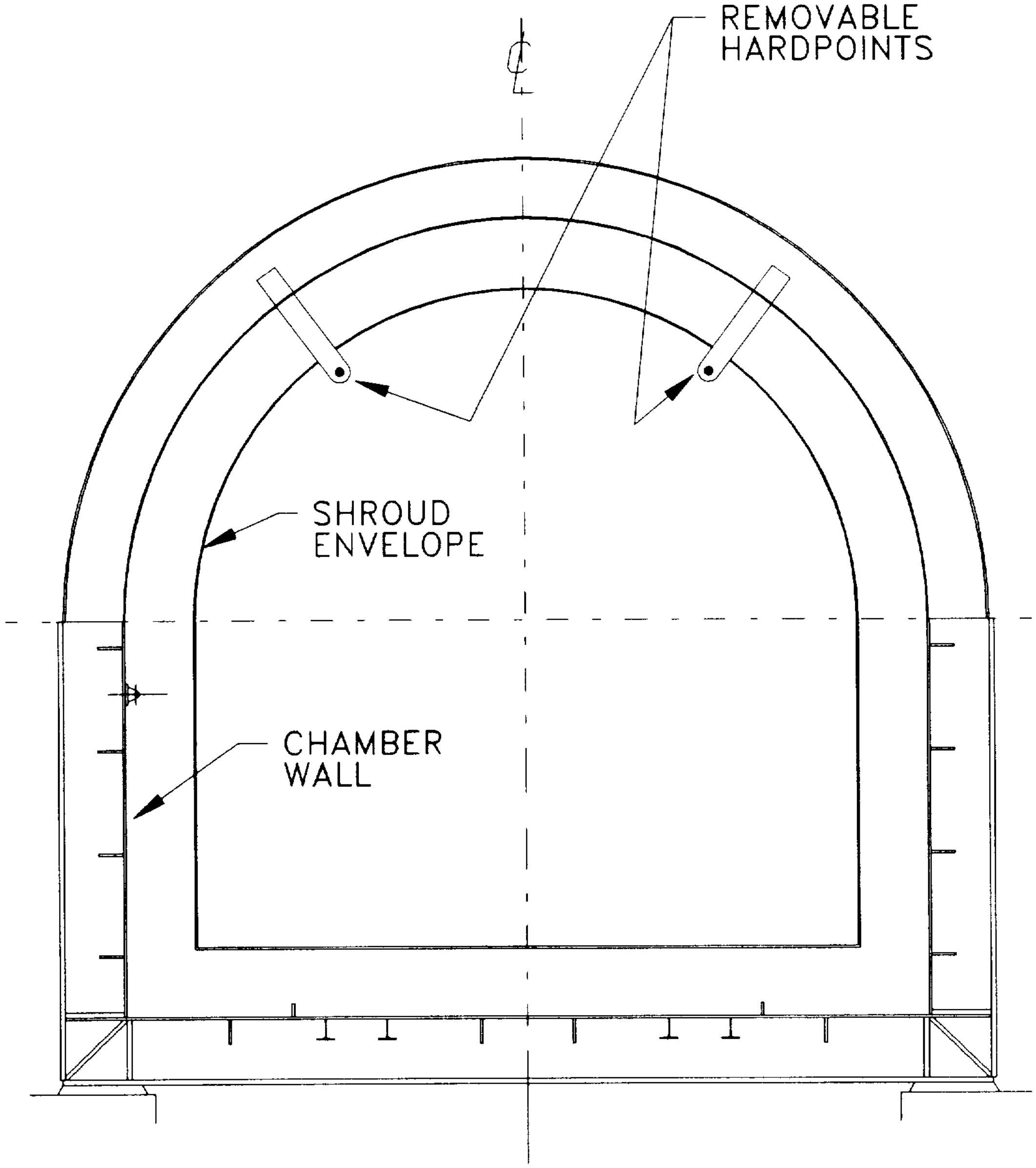

FIGURE 4

PIN HARDPOINTS

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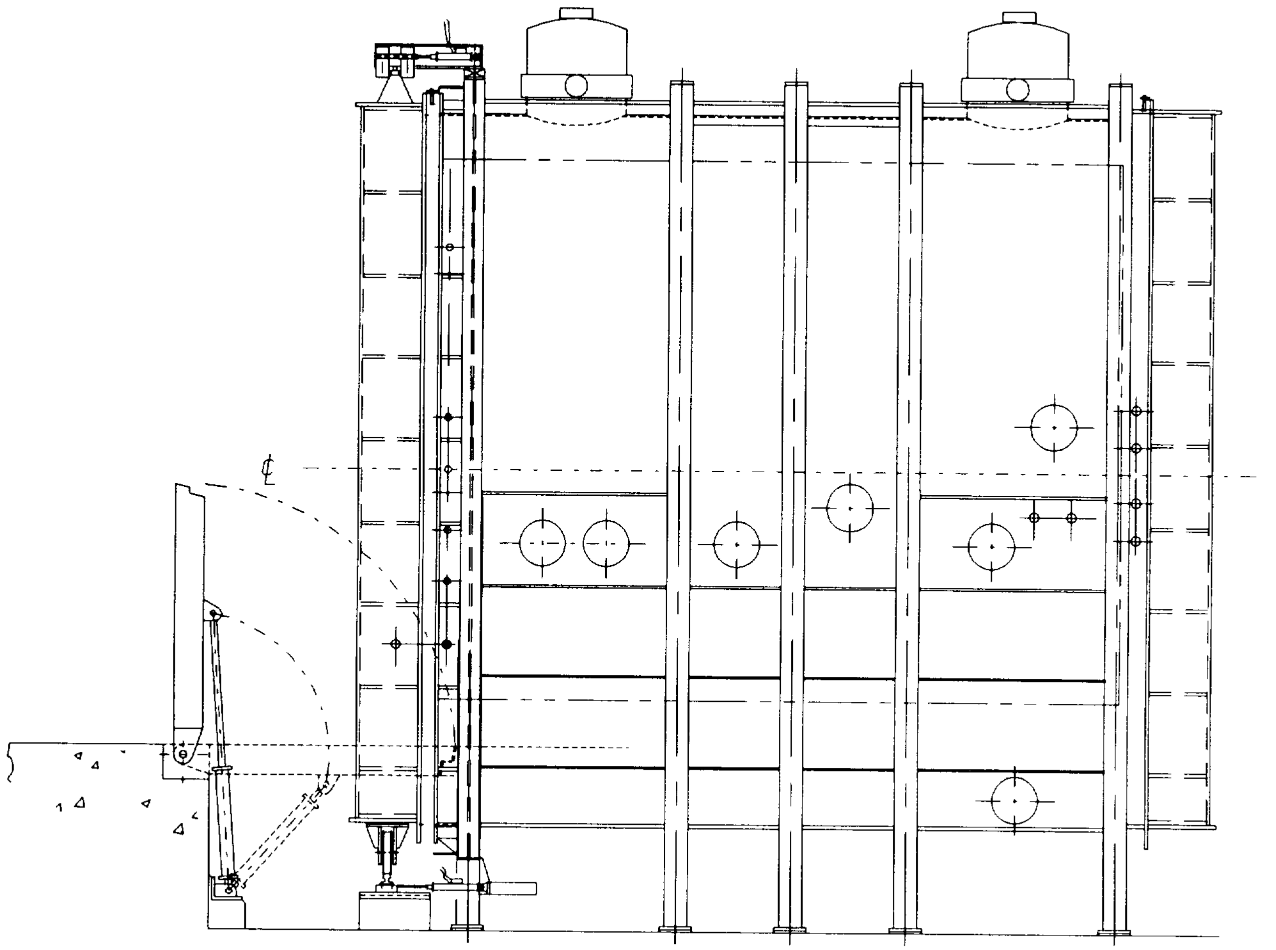

FIGURE 5

NORTH PENETRATIONS

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Pitt-Des Moines, Inc.

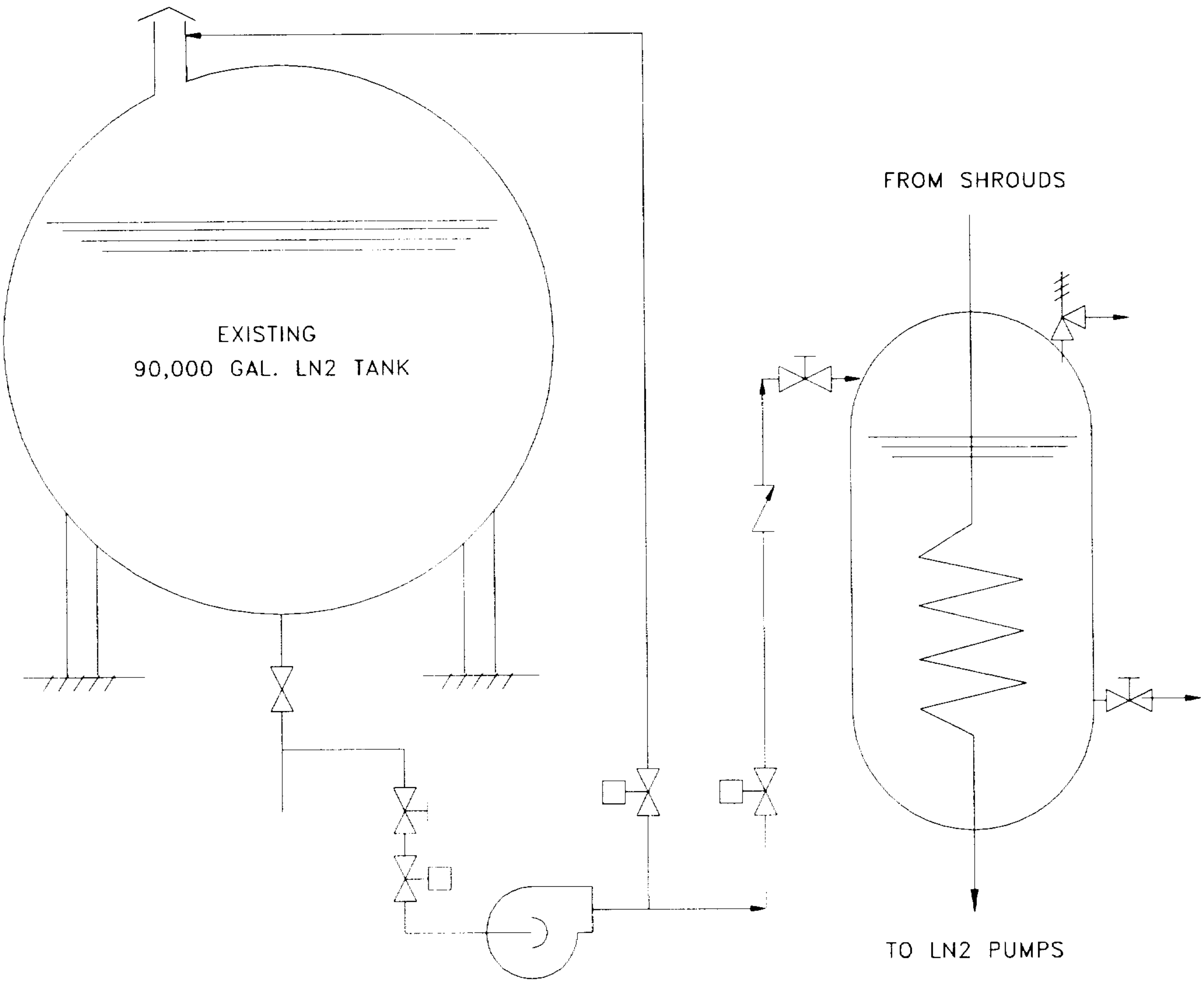

FIGURE 6

LN2 SUPPLY SYSTEM

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Pitt-Des Moines, Inc.

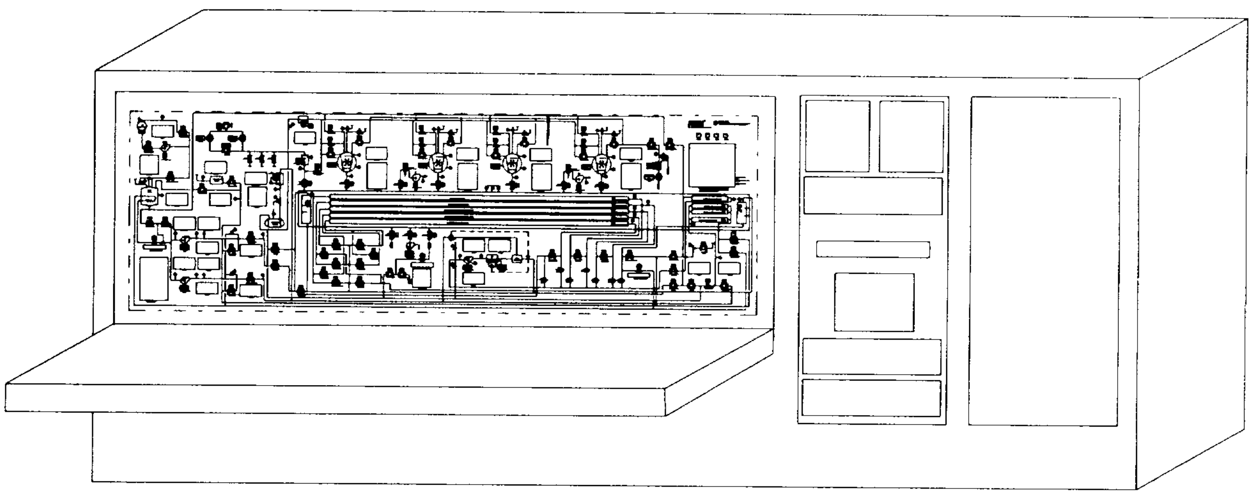

FIGURE 7

CONTROL CONSOLE

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C-3

Pitt-Des Moines, Inc.

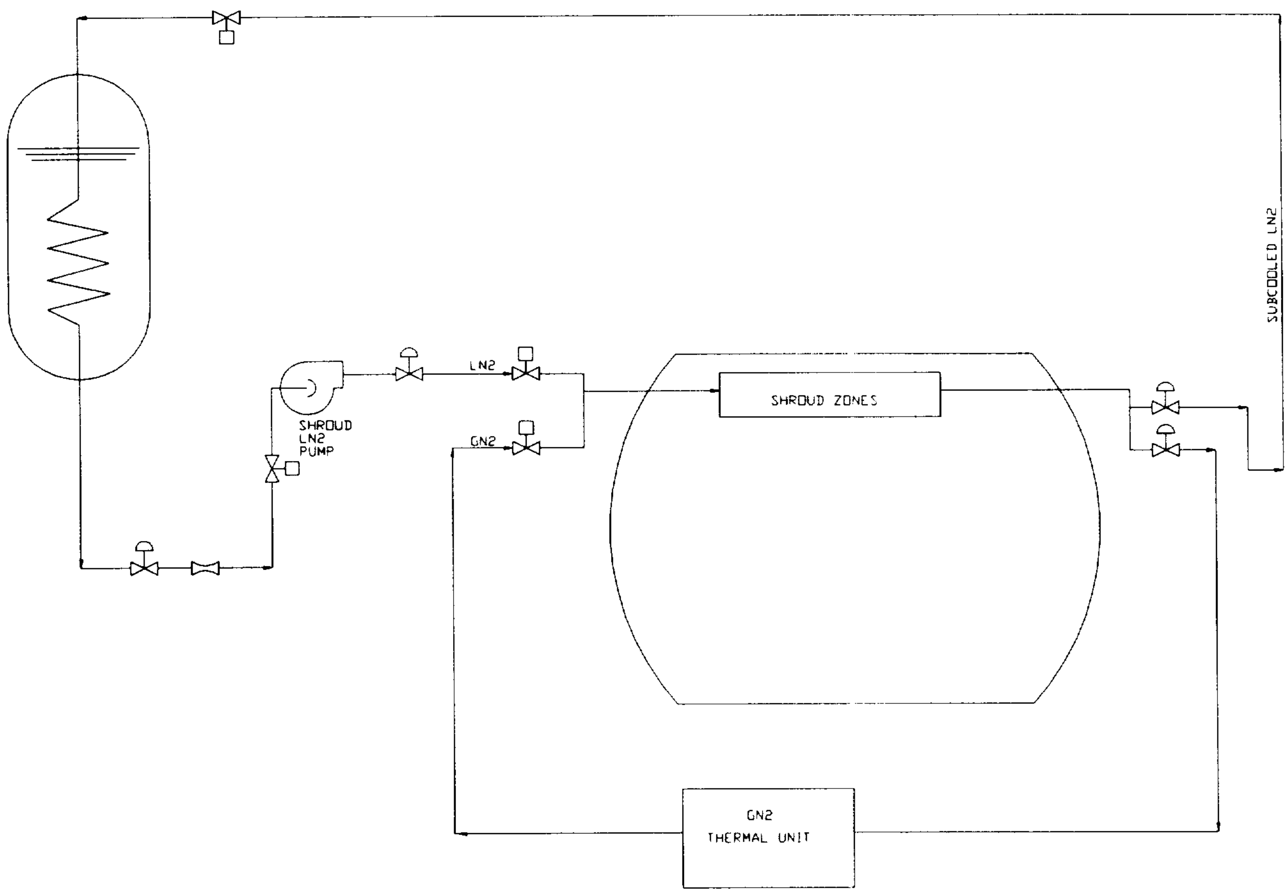

FIGURE 8

SHROUD LN2/GN2 SYSTEM

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Pitt–Des Moines, Inc.

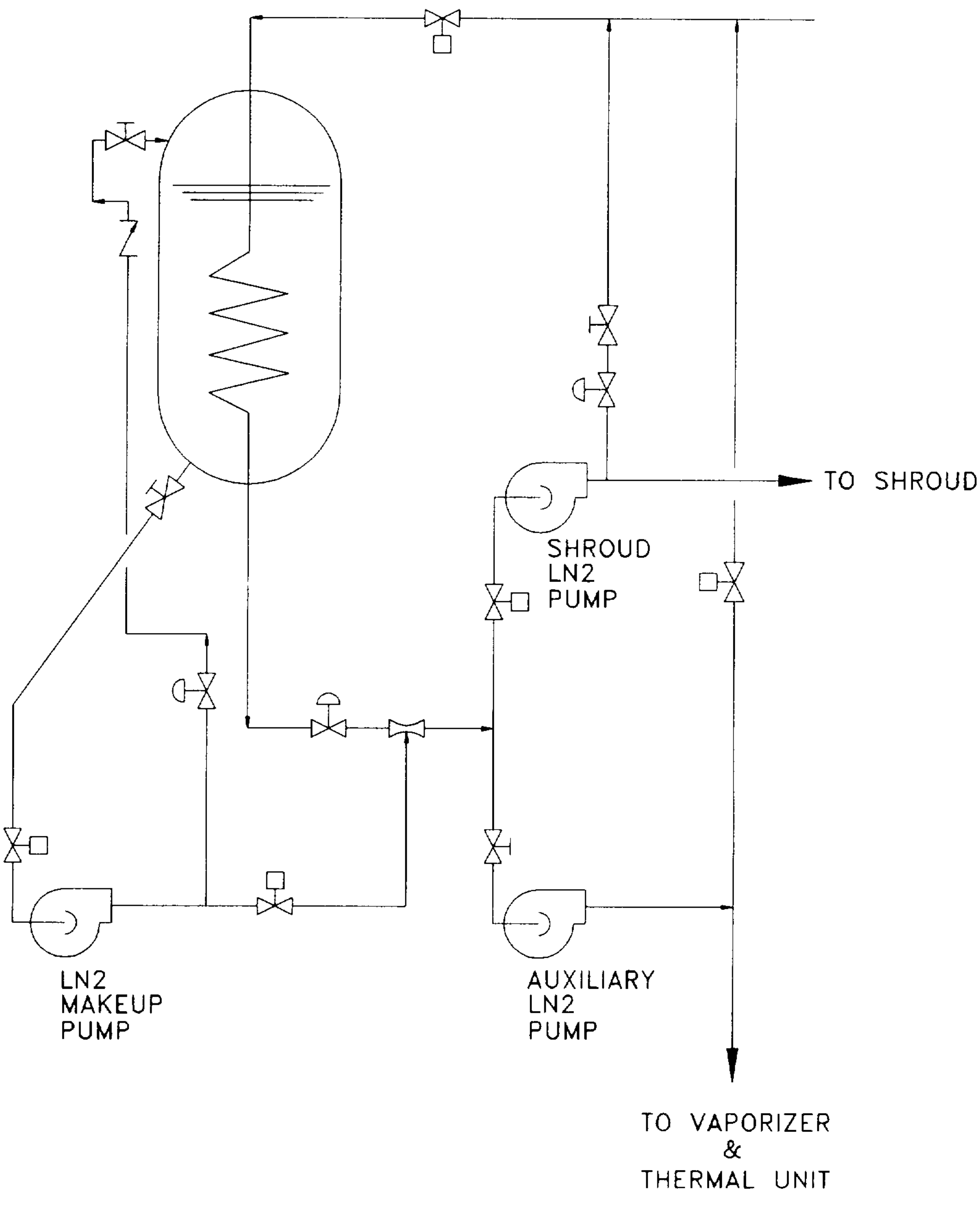

FIGURE 9

LN2 PUMP SKID

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Pitt-Des Moines, Inc.

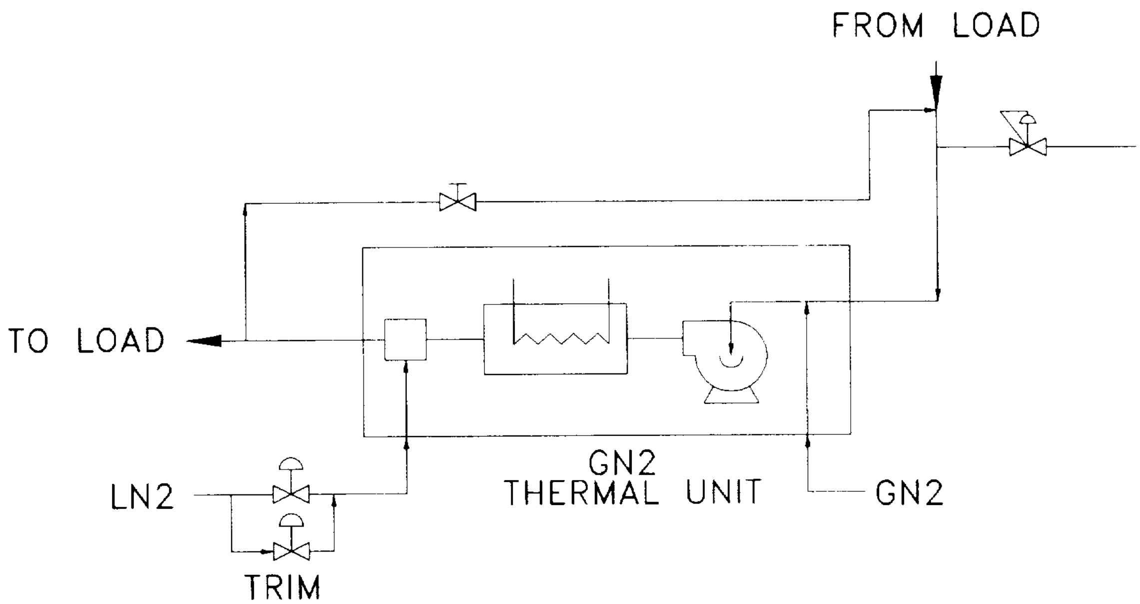

FIGURE 10

THERMAL UNIT

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