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REPORT EBT-P010

FUSION ELMO BUMPY TORUS ENERGY

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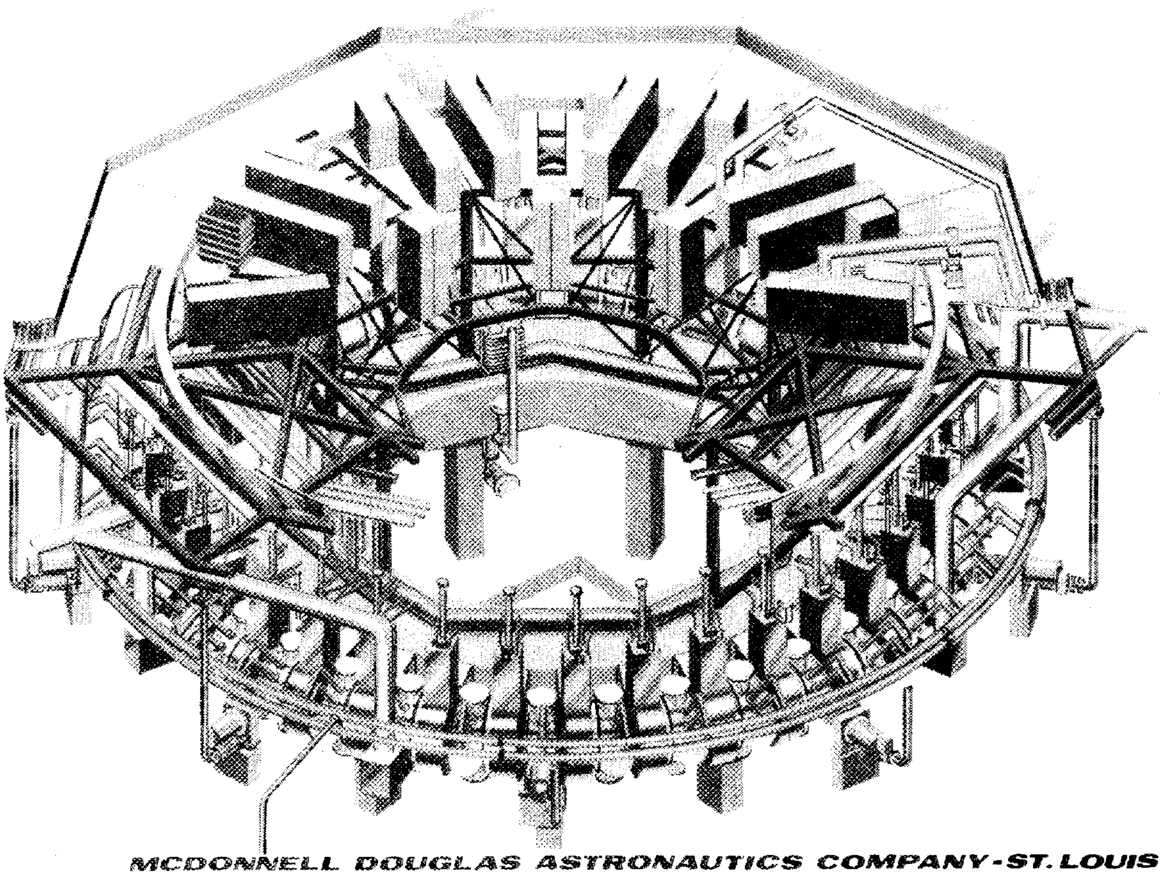
Elmo Bumpy Torus Proof Of Principle

PHASE II — TITLE 1 REPORT

Volume VII CRYOGENIC SYSTEM



MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - ST. LOUIS DIVISION

Saint Louis, Missouri 63166 (314) 232-0232

MCDONNELL DOUGLAS CORPORATION

PRELIMINARY DESIGN REPORT

CRYOGENIC SYSTEM

VOLUME VII

PREPARED BY: ______________________
T. J. Poteat, Manager
EBT-P Cryogenic System

APPROVED BY: ______________________
H. F. Imster, Manager
EBT-P Engineering - MDAC

APPROVED BY: ______________________
R. J. DeBellis, Manager
EBT-P Project - MDAC

APPROVED BY: ______________________
J. D. Stout, Manager
EBT-P Engineering - ORNL

APPROVED BY: ______________________
A. L. Boch, Manager
EBT-P Project - ORNL

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ACRONYMS, ABBREVIATIONS AND INITIALISMS

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BDDB	EBT-P Baseline Design Data Book
C/L	Centerline
CVI	CVI Incorporated
EBT-P	Elmo Bumpy Torus Proof of Principle
°F	Degrees Fahrenheit
GDC	General Dynamics Corp
GHE	Gaseous Helium
GHZ	Gigahertz
GN_2	Gaseous Nitrogen
HE	Helium
HZ	Hertz
I&C	Instrumentation and Control
JT	Joule Thompson
ℓ	Liter
LHE	Liquid Helium
LN_2	Liquid Nitrogen
K	Kelvin
MCC	EBT-P Master Control Console
MDAC	McDonnell Douglas Astronautics Co.
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
ORNL	Oak Ridge National Laboratory
ORVIP	Oak Ridge Valley Industrial Park
PACE	Plant and Capital Equipment
PSI	Pounds Per Square Inch
PSIA	Pounds Per Square Inch Absolute
PSIG	Pounds Per Square Inch Gage
RFP	Request for Proposal
R/L	Refrigerator Liquefier
SCF	Standard Cubic Feet

ACRONYMS, ABBREVIATIONS AND INITIALISMS (Continued)

TBD	To be Determined
TEMA	Tubular Exchange Manufacturers Association
UBC	Uniform Building Code
VAC	Volts Alternating Current
W	Watt

GREEK

ϕ	Phase

1.0 INTRODUCTION AND SUMMARY

This document, Volume VII EBT-P Cryogenic System Title I Design Report, describes the system that resulted from the Title I Preliminary Design effort. It is a self-contained document that can be read apart from the other Volumes comprising the EBT-P Title I Report. This document is a contract deliverable item and provides the detail necessary to support the Cyrogenic System design contained in the EBT-P Baseline Design Data Book (BDDB).

The following EBT-P Project personnel have contributed to this volume:

- D. A. Bowers - EBT-P Thermodynamics
- M. J. Delaney - EBT-P Strength
- C. E. Fechter - EBT-P Materials
- R. D. Politowski - EBT-P Design
- T. J. Poteat - EBT-P Cryogenic System Manager

1.1 CRYOGENIC SYSTEM OVERVIEW

The cryogenic system stores, supplies, distributes and controls helium and nitrogen required for operation of the EBT-P device. Saturated liquid helium at approximately 4.2°K is supplied to the 36 mirror magnet coils and the 6 gyrotron magnet coils to maintain them in the superconducting temperature region. Liquid helium for the mirror coils is supplied on demand and is controlled by a liquid level gage that is integral with the mirror coil dewar assembly. Liquid helium for the gyrotron coils is supplied by batch filling the dewars prior to the beginning of each day of operation.

Helium vented from the magnet dewars and gyrotron dewars is recovered, reliquified and recirculated through the system in a closed loop during normal modes of operation.

Saturated liquid nitrogen at approximately 80K is supplied to the 36 mirror magnet dewar and the 6 gyrotron magnet dewar insulation system shields. The shields for both the mirror and gyrotron dewars are supplied by a quasi flooded system. In addition, liquid nitrogen is supplied to the 6 vacuum system pump traps on demand and to batch fill diagnostic devices prior to beginning each day of operation.

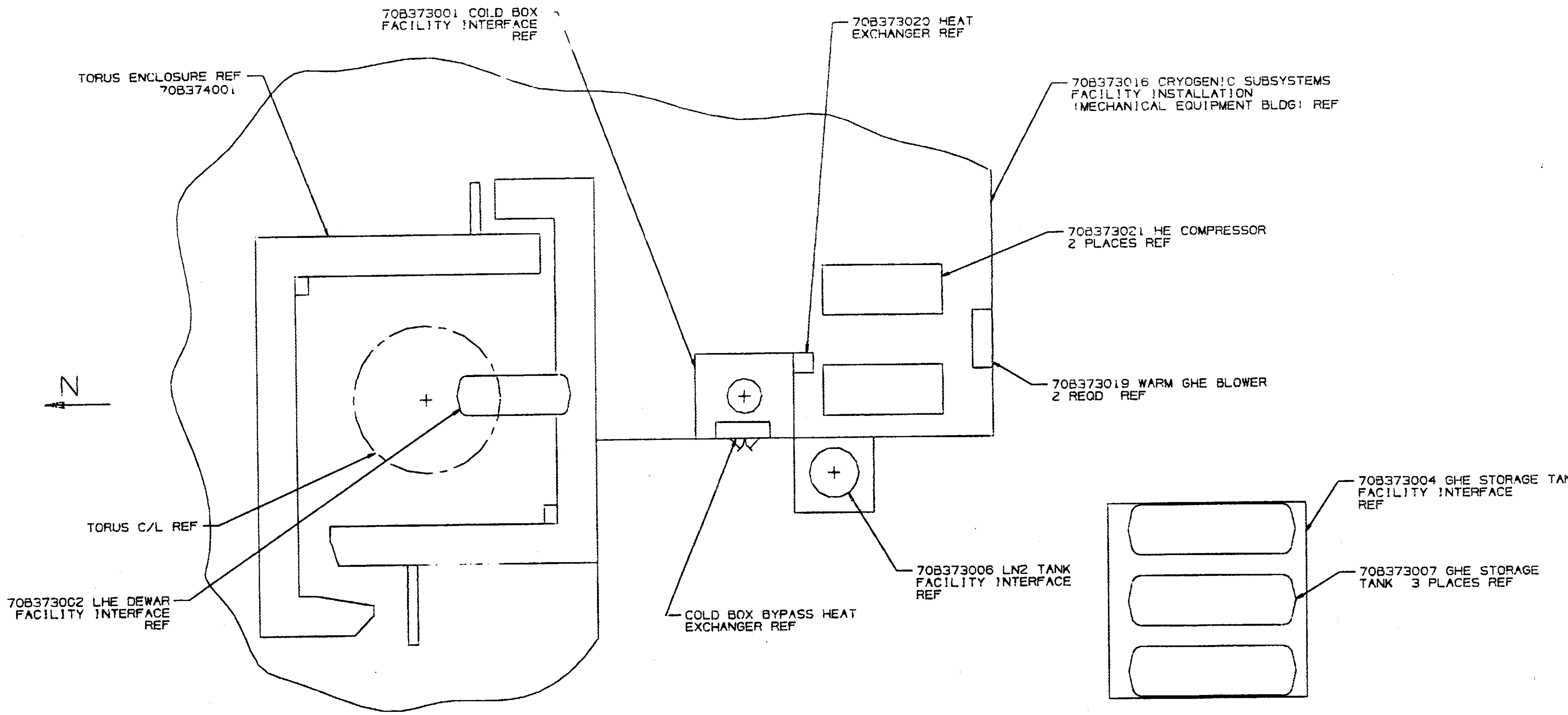
Waste nitrogen gas vented from the magnet dewar and gyrotron dewar shields and pump traps is collected and vented outside the device facility.

Low pressure GN_2 is supplied to various usage points in the device facility by an LN_2 to GN_2 vaporizer on the liquid nitrogen storage dewar.

The cryogenic system consists of the following major elements:

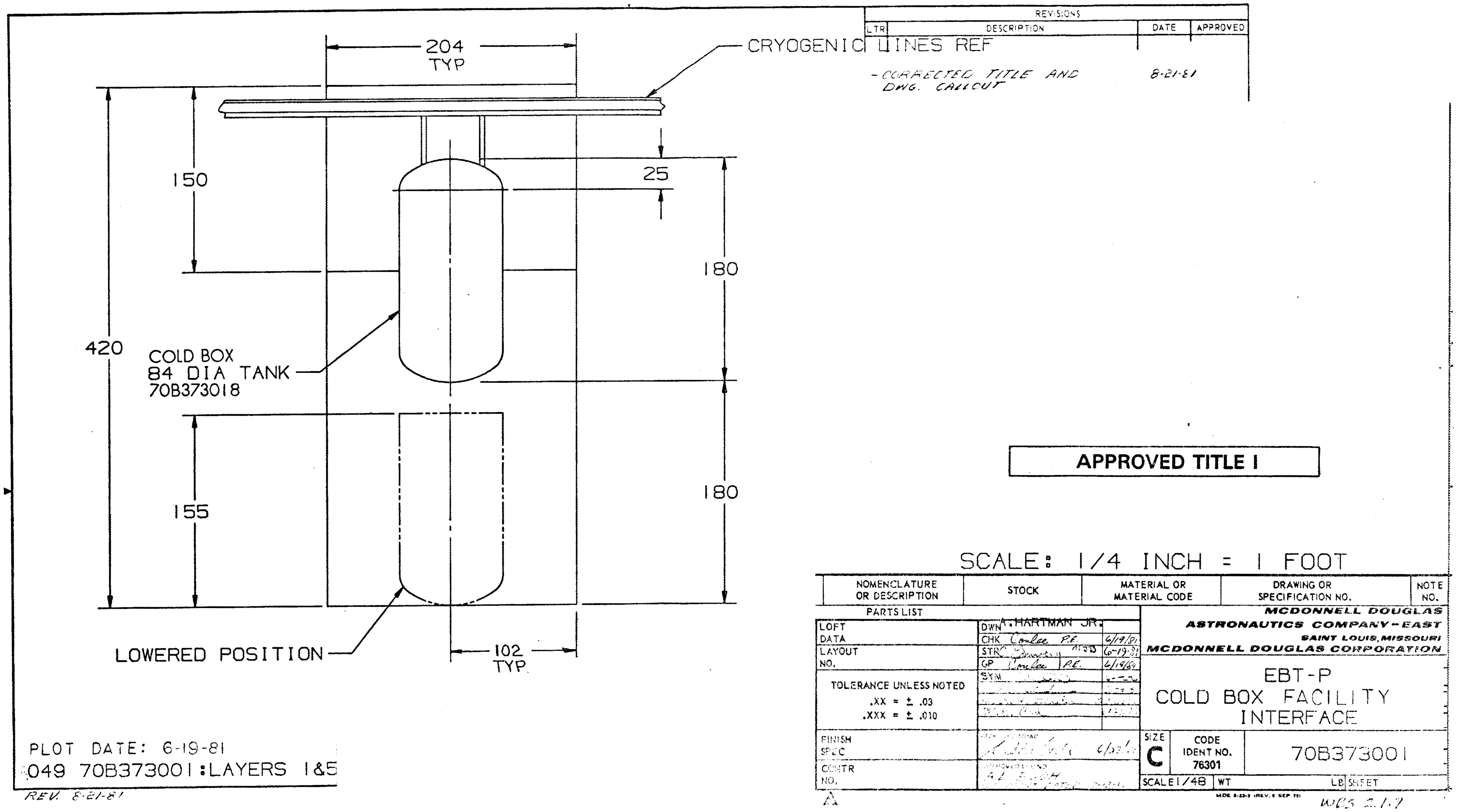
- Closed Cycle Helium Refrigerator/Liquefier (Includes Two Compressor Skids and Cold Box)
- Liquid Helium Storage Dewar
- Three High Pressure Gaseous Helium Storage Tanks
- Cryogenic Helium Distribution System
- Gaseous Helium Distribution System
- Liquid Nitrogen Storage Dewar
- Liquid Nitrogen Distribution System
- Auxiliary Heat Exchanger for Cooldown and Warm-up
- Instrumentation and Control System
- Gaseous Nitrogen Distribution and Vent System
- Vapor Cooled Lead Blowers
- Cold Box By-Pass Heat Exchanger
- Gas Purification Subsystem

The installation of these elements in the Oak Ridge Valley Industrial Park (ORVIP) facility is shown in Figure 1. The functional relationship of the elements is shown in system block diagram Figure 2.



EQUIPMENT LAYOUT
FIGURE 1

(SEE DWG 70B373011)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CRYOGENIC LINES REF
204
TYP
150
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180
420
COLD BOX
84 DIA TANK
70B373018
155
180
LOWERED POSITION
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DWN A. HARTMAN JR.
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TOLERANCE UNLESS NOTED
.XX = ± .03
.XXX = ± .010
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MCDONNELL DOUGLAS
ASTRONAUTICS COMPANY-EAST
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
COLD BOX FACILITY
INTERFACE
SIZE C
CODE IDENT NO. 76301
70B373001
SCALE 1/48
WT
LB
SHEET
PLOT DATE: 6-19-81
049 70B373001:LAYERS 1&5
REV. 8-21-81
WBS 2.1.7

1.2 OPERATIONAL MODE SUMMARY

To support the EBT-P device, the cryogenic system must operate in several modes. The device operates in only two modes (1) Plasma power on and (2) plasma power off. However, the cryogenic system must operate in 6 modes.

These modes are as follows:

- Start-up (Refrigerator/Liquefier)
- Cooldown (Loads)
- Steady-State (Device Operating With Plasma)
- Stand-by (No Plasma)
- Warm-up (Loads)
- Anomaly Response

A complete description of each of the modes is presented in the Design Criteria Section 3.0 of this report.

1.3 DESIGN CRITERIA SUMMARY

The mirror magnet and gyrotron magnet design along with the operational mode requirements defined herein establish most of the system design criteria. Key criteria are as follows:

- Cool LN_2 Shields To $\approx$80K
- Maintain LN_2 Insulating Shields At Operating Temperature
- Cool Magnets From 300 To 4.2K
  - At Controlled Rate
  - With He
  - Minimum Time
- Fill Magnets With LHe
- Maintain Magnet Dewar LHe Liquid Level Within Operating Limits
- Maintain Magnet Dewar LHe Temperature Within Operating Limits

- Maintain Fluid Flow To Vapor Cooled Leads
- Maintain Lead Temperature Within Operating Limits
- Recycle all He
- Liquify He To Compensate For Vaporization Losses
- Provide GN_2 for General Facility Use
- Provide LN_2 To Service Diagnostics
- Warm Shields To Ambient Temperature
- Warm Magnets To Ambient Temperature
  - At Controlled Rate
  - With GHe
  - Minimum Time
- Protect Equipment and Personnel
- Continue Device Operation in event of Specific Malfunctions
- Recover Quickly From Malfunctions
- 16 Hours Steady-State (Magnets Powered)
- 8 Hours Stand-By
- Repeated For 5 Days
- 88 Hours Maximum Stand-By
- Four Weeks Shutdown Each Year For Major Maintenance
- Operate In Radiation Environment
- Monitor and Control By One Operator

1.4 PERFORMANCE SUMMARY

The performance characteristics that evolved from the Title I effort are as follows:

SIZES AND CAPACITIES

- LN_2 Storage $\approx$ 9000 Gallons Net
- LH_e Storage $\approx$ 17,300 Liters Net (or 504,000 SCF Gas)
- GH_e Storage $\approx$ 150,000 SCF @ 300 Psig
- Piping To Handle Full Flow
- Each Compressor Skid Rated for Stand-By Heat Load +50% Margin $\approx$ (195 ℓ/hr + 1430 W)

- Refrigerator/Liquefier Rated For Maximum Heat Load +50% Margin ≈ (280 ℓ/hr + 2000 W)

RELIABILITY AND REPAIR TIMES

- 9000 Hour MTBF Typical
- 16 Hour MTTR Typical

2.0 PURPOSE AND SCOPE

This volume details the EBT-P Cryogenic System Title I design. The cryogenic System Title I effort was directed toward establishing a system design that could be implemented by a cryogenic system contractor operating under a fixed price contract during Title II.Two major categories of material resulted from this effort. The first is a procurement specification that describes the system that will be procurred, and second, drawings describing the system interfaces with the remainder of the device and its facility.

During the course of the Title I effort a number of trade studies and analyses were prepared to select between design alternatives and to support design details. These are described in Section 5.0.

2.1 TITLE I OUTPUT

The following is a listing of the data prepared during Title I to support the design documented herein.

DRAWINGS

- 70B373000 EBT-P Block Diagram, Liquid and Gaseous System, Cryo
- 70B373001 EBT-P Cold Box Facility Interface
- 70B373002 EBT-P Liquid Helium Dewar Facility Interface
- 70B373004 EBT-P Gaseous Helium Storage Tank Facility Interface
- 70B373005 EBT-P Helium Manifolds, Cryo-Pump Systems *
- 70B373006 EBT-P Liquid Nitrogen Storage Tank Facility Interface
- 70B373008 EBT-P Magnet Supply/Return Manifolds, Cryo
- 70B373009 EBT-P Magnet Interface, Cryo
- 70B373010 EBT-P Magnet Supply/Return Envelopes, Cryo
- 70B373011 EBT-P Facility Routing Envelopes, Cryo

* This drawing is now absolete as a result of the current vacuum pump system configuration

- 70B373007 EBT-P Gaseous Helium Storage Tank
- 70B373013 EBT-P Gyrotron Interface
- 70B373014 EBT-P Gyrotron Supply/Return Manifolds, Cryo
- 70B373015 EBT-P Gyrotron Supply/Return Envelopes, Cryo
- 70B373016 EBT-P Cryo Subsystems Facility Installation
- 70B373017 EBT-P Liquid and Gaseous System Schematic
- 70P373000 Procurement Specification

ANALYSIS AND TRADE STUDIES

- Distribution Line Pressure Losses
- Distribution Thermal Losses
- Material Compatibility
- Magnet Interface Analysis
- LN_2 Dewar Lease or Buy Trade Study

UNRESOLVED DESIGN ISSUES

- He Filling and Cooldown
- LN_2 Shield Filling and Control
- He Venting
- Gyrotron Configuration
- Vapor Cooled Lead Flow
- R/L Operation
- Overall System Heat Losses
- Magnetic Materials vs Field Uniformity

3.0 DESIGN CRITERIA

The design criteria utilized for the cryogenic system was obtained from the following sources:

- RFP and ORNL Reference Design
- MDAC Proposal and Title I Activity
- Device Operational Modes

Early in Title I it became clear that a complete system operating scenerio would be required to fully define the design criteria. This analysis evolved in six distinct operational modes.

3.1 OPERATING MODES

Six distinct operating modes have been defined for the cryogenic system. These were established from an analysis of the device operating characteristics as shown in Table I. A description of the cryogenic system operation for each mode is included in this section.

Table I Device/Cryogenic System Operational Comparison

EBT-P DEVICE	CRYO SYSTEM
• Pre Test Operations	• Start-Up
• Magnet Cool Down	• Cool Down
• Magnets Powered	
No Plasma	• Standby
Heating Plasma	• Steady State
• Magnets Unpowered	• Standby
• Suspending Operations	• Warm-Up
• Equipment Anomalies	• Anomaly Response
Magnet Quench	
Cryo System Failures	
Device Equipment Failures	

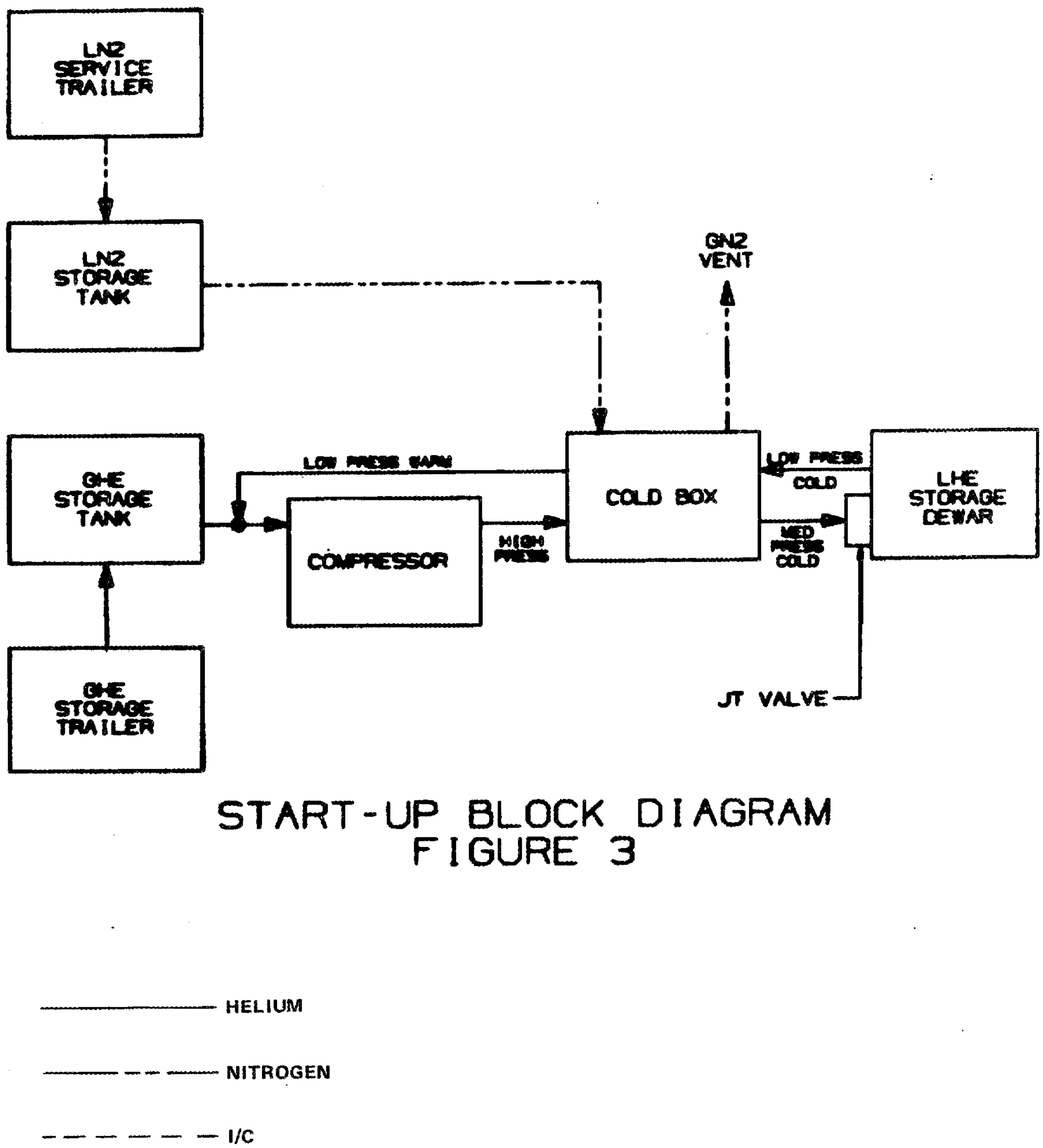
A description of the cryogenic system operation identified by operating mode follows.

3.1.1 Start-Up - A block diagram of the Start-Up Mode is shown in Figure 3. Following decontamination of the compressor, cold box and storage dewar by alternately evacuating and back filling with pure dry helium gas, gas from the GHe storage tanks is compressed by the compressor skids and is delivered to the cold box. The high pressure gas stream is refrigerated in the cold box and expanded (JT expansion) into the liquid helium storage dewar. Cold gas from the storage dewar is returned back through the cold box to reduce the temperature of the incoming high pressure stream from the compressors. The stream exits the cold box and is recompressed. After approximately 12 hours of bootstrap cooldown of the system elements, LHe will begin to collect in the storage dewar. Six Airco number 85 bulk delivery trailer loads of gaseous helium (approximately 500,000 SCF) will be required to fill the 17,300 ℓ LHe dewar. The helium dewar will fill at a rate of approximately 700 liters per hour.

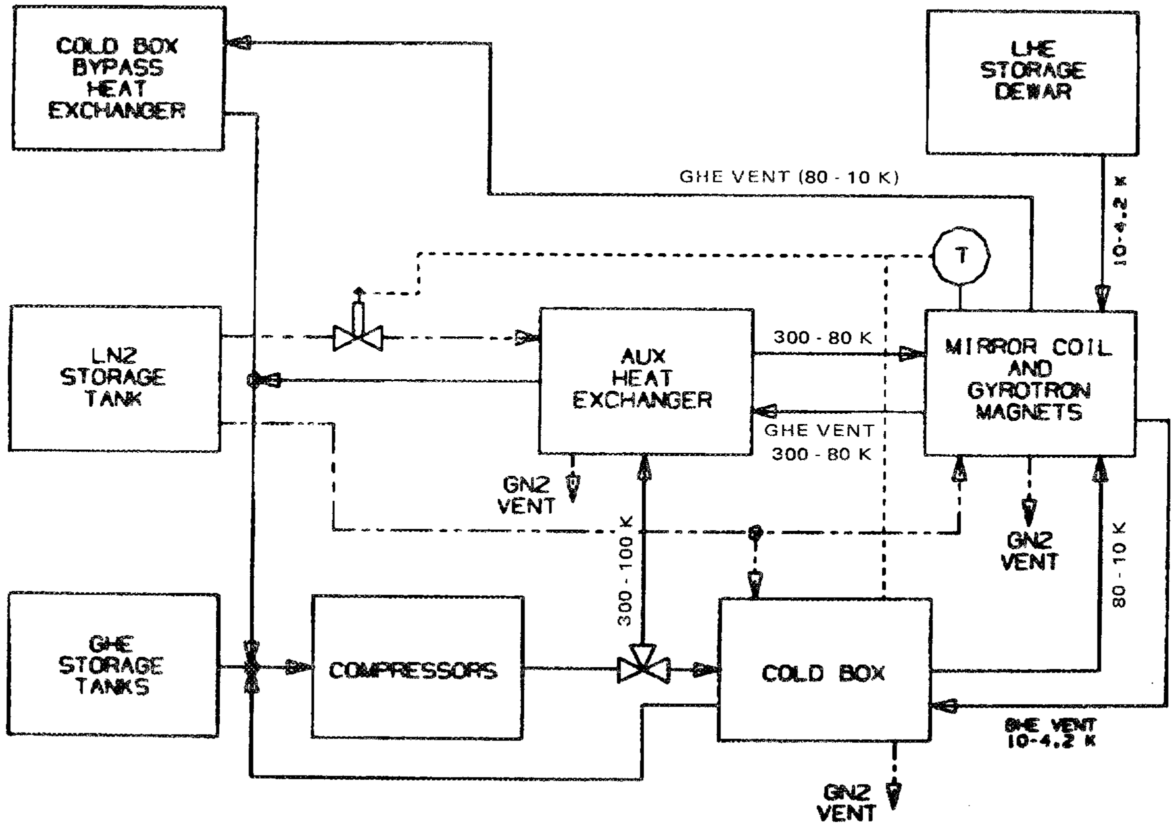
During the start-up mode, other operations related to the cryo system may be performed or initiated. These include operation of the LN_2 cooled vacuum pump traps, cooldown of the LN_2 insulation shields in the mirror magnet dewars and gyrotron dewars, initial cooldown of the mirror magnet coils and gyrotron coils and delivery of GN_2 to the various use points. It should be noted that the system includes no provision to fill the LHe storage dewar from a cryogenic tank trailer.

3.1.2 Cooldown - A block diagram of the Cooldown Mode is shown in Figure 4. Cooldown is applicable to the mirror and gyrotron magnet coil containers and is accomplished in three distinct steps following system decontamination and cooldown of the dewar LN_2 cooled insulation shields. The three steps are (1) cooldown from ambient temperature 300K to approximately 100K utilizing an auxiliary heat exchanger, (2) cooldown from 100K to approximately 10K utilizing cold gas produced by the R/L and (3) cooldown from 10°K to the operating temperature of 4.2°K utilizing liquid helium.

The rate of cooldown of the mirror magnet is limited by thermal stresses induced in the mirror coil magnet pack. These stresses are related to the temperature differential across the magnet pack. The rate of cooling is controlled by sensors in the magnet pack via the



START-UP BLOCK DIAGRAM
FIGURE 3



COOLDOWN BLOCK DIAGRAM
FIGURE 4

HELIUM

NITROGEN

I/C

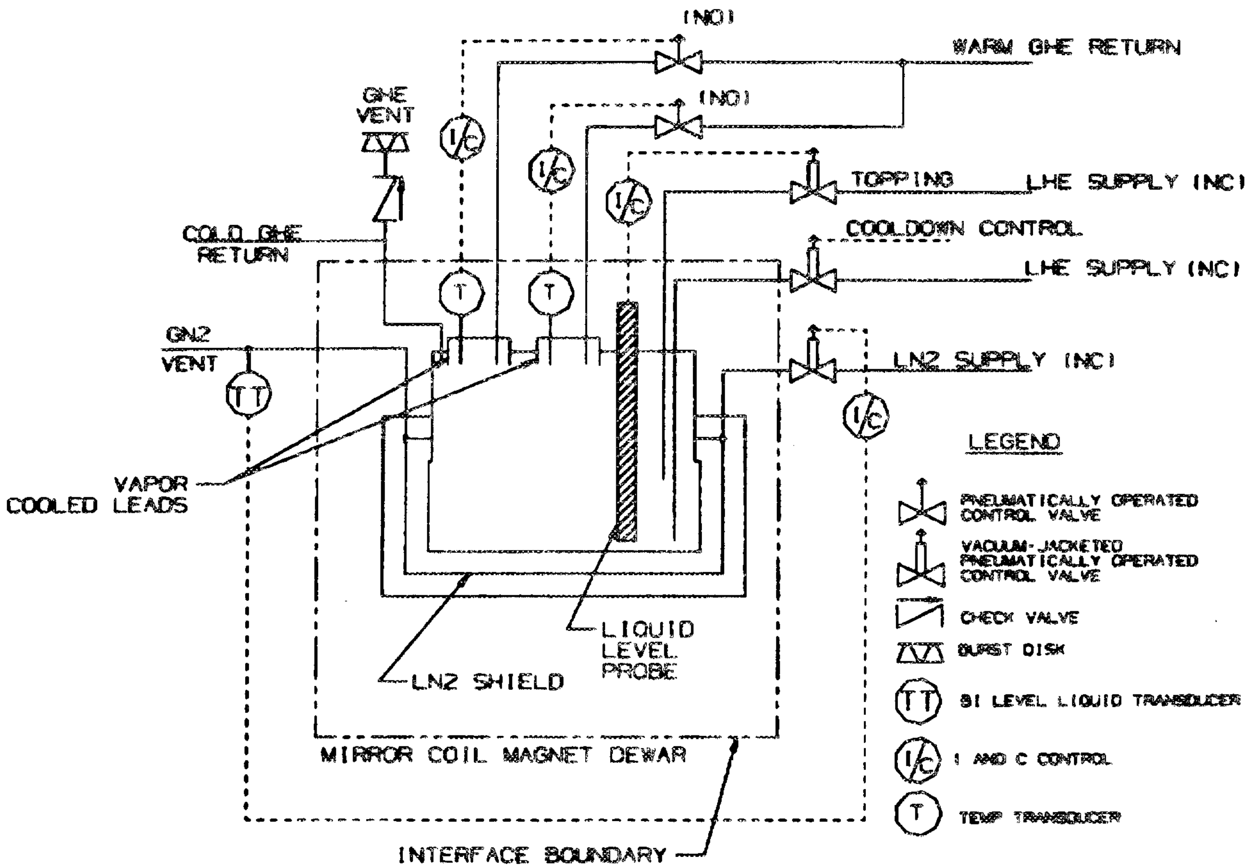
I&C system or by a predetermined cooldown schedule. To date, no cooldown limitations have been identified for the gyrotron magnet. However, cryogenic system limitations will impose certain design requirements on the gyrotron magnet dewar.

System decontamination is accomplished by first opening the mirror magnet cooldown valve as shown in Figure 5 and the gyrotron magnet fill valve as shown in Figure 6. The mirror magnet and gyrotron magnet coil vessels and interconnecting distribution piping is then evacuated to approximately 1 x 10^{-2} torr. The vaccum is broken with pure dry helium gas. The evacuation-helium gas vacuum fill process is repeated until the contamination level reaches acceptable levels.

The system is configured to provide an alternate decontamination approach in the event that the evauation - helium gas vacuum fill process proves to be unsatisfactory. This approach utilizes the gas purification subsystem to remove contaminants from the gas stream as gas is circulated through the whole system. During the initial start-up, warm gas is circulated through the entire system including the compressors, gas purification subsystem, cold box, storage dewar, distribution system and mirror and gyrotron magnets. Contaminants are thus trapped in the gas purification subsystem.

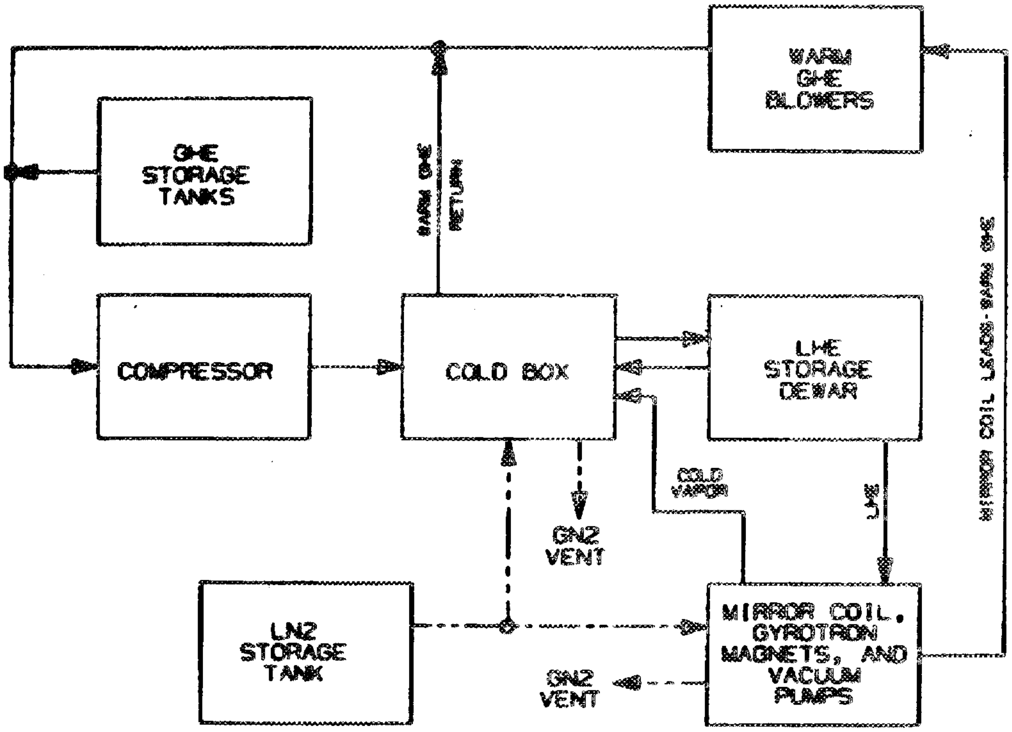
Following decontamination and prior to starting cooldown helium flow, the mirror magnet and gyrotron magnet dewar LN_2 insulation shields are cooled by opening the flow control valves. Liquid nitrogen flows through the shields and out the vent lines thus cooling the shields to approximately 80K. When LN_2 collects in the vent line, the flow control valve is closed by a signal from the bilevel liquid transducer via the I&C system. The control valve is cycled to open and close by the I&C system thus maintaining LN_2 in each of the dewar shields.

The 300-100K cooldown step is accomplished by directing part of the compressor gas stream through the auxiliary heat exchanger and the distribution system into the cooldown valve of the mirror magnet and the fill valve of the gyrotron magnet. After the helium flow rate is set, LN_2 is introduced into the LN_2 pass of the auxiliary heat exchanger. The LN_2 flow rate is controlled to reduce the temperature as rapidly as possible without exceeding the mirror magnet temperature differential limits. When the mirror magnet coil temperature reaches approximately 100K gas flow through the auxiliary heat exchanger is stopped



MIRROR MAGNET DEWAR
INTERFACE SCHEMATIC

FIGURE 5



STEADY STATE AND STANDBY BLOCK DIAGRAM
FIGURE 7

——————— HELIUM

——— — — ——— NITROGEN

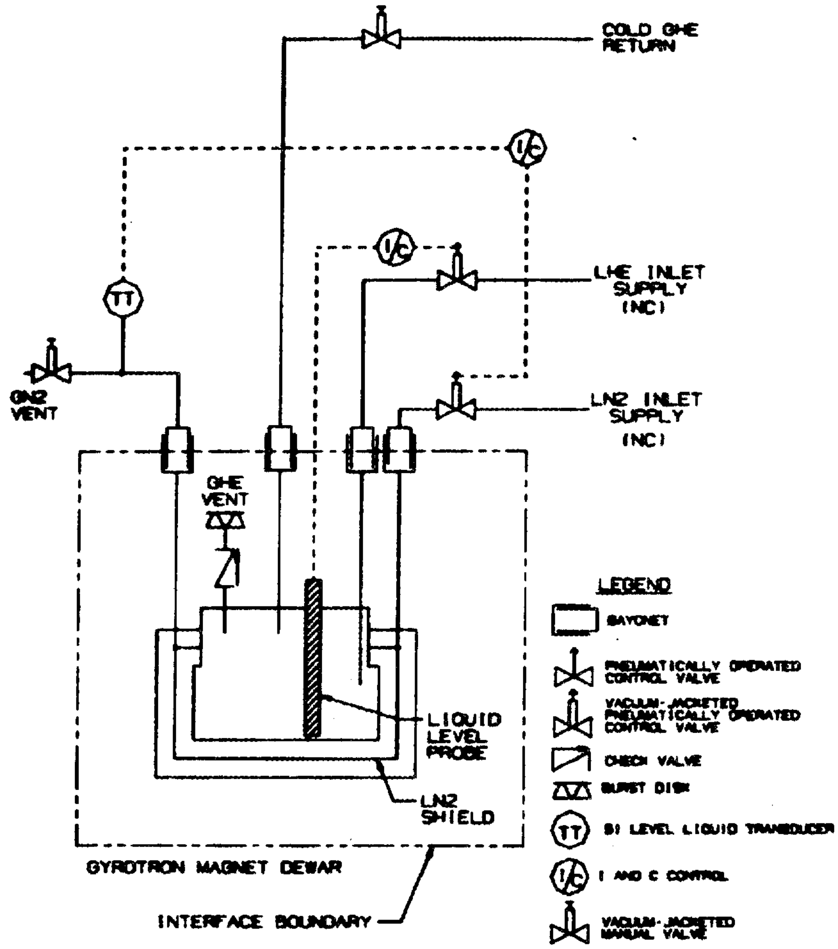
— — — — — — I/C

and a portion of the cold box discharge stream is delivered to the distribution system. The cold box is used to refrigerate the gas flowing in the loop thus reducing the temperature at a controlled rate to approximately 10K. Below 10K, flow from the cold box is suspended and LHe is introduced into the system from the storage dewar. Flow to each mirror magnet and gyrotron magnet dewar continues until it is full. Liquid level instrumentation in each dewar is used by the I&C system to generate a full signal and close the cooldown valves of the mirror magnets and fill valves of the gyrotron magnets.

The use of a single manifold to deliver both liquid and cool down gas precludes controlled cooldown of the mirror magnets and gyrotron independently. In addition, individual mirror or gyrotrons magnets cannot be cooled down at a controlled rate when liquid must be delivered to the other magnets to keep them cold. However, it is possible, as described below, to cooldown and fill individual or groups of magnets and gyrotrons as long as the others are placed on hold and allowed to settle at an equilibrium temperature of approximately 100K with their fill valves closed.

a. Close the LHe valves to all magnet and gyrotron dewars.
b. Start the flow of GHe into the bottom fill line of the mirror magnets or fill line of the gyrotron magnets. Reduce the gas temperature by the methods prescribed for a normal cooldown until the temperature of the dewars being cooled matches that of the dewars on hold.
c. Open all cooldown valves to cooldown and fill all dewars.

3.1.3 Steady-state - A block diagram of the Steady-state mode is shown in Figure 7. Liquid helium is delivered from the storage dewar to each mirror magnet dewar to keep it full during plasma operation. The liquid level in each dewar is controlled by opening the topping valve. Signals generated by the I&C System from the respective liquid level probes will open the valve when liquid is required. The operating liquid level band is set to cause the valves to cycle approximately once every minute. (Actual valve operation will be determined during machine development testing). This will eliminate the potential of super heating the vapor trapped between the valves and the dewars, and will increase the quality of the initial slug of fluid delivered to the mirror magnet.



GYROTRON MAGNET DEWAR
INTERFACE SCHEMATIC
FIGURE 6

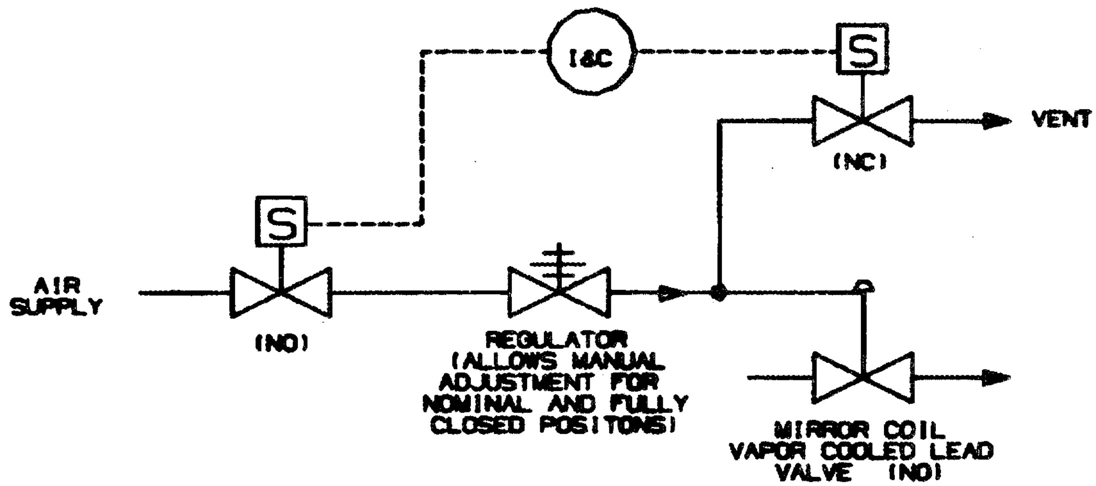
The gyrotron dewars are batch filled each day prior to operation. They are filled through the fill valve shown in Figure 6. Signals generated by the I & C System from the respective liquid level probe will close the valve when the dewar is full.

Vapor resulting from boil-off leaves each mirror and gyrotron magnet dewar via a vent line. Cold vapor at approximately 4.2K is expelled from each dewar vent and is returned to the cold box via a return manifold system. In the cold box, the cold vapor stream is utilized to reduce the temperature of the incoming stream from the compressors and then is returned to compressor suction.

A second path is utilized to cool the mirror magnet vapor cooled leads. Vapor drawn through the leads exits as a warm gas. Temperature of the gas is approximately ambient at the outlet of the leads. The flow rate of gas from each lead is controlled by a three position pneumatically operated flow control valve. The valve positions are (1) manually closed, (2) nominal flow, and (3) full open. Vacuum pumps maintain the pressure drop across the valve to cause sonic flow through the valve seat. Sonic flow across the valve minimizes flow rate changes in the leads resulting from pressure fluctuations in the dewar or temperature changes in the leads.

The nominal flow rate is utilized to dissipate the I^2R heating generated in each lead when the mirror magnets are powered. The flow rate is set by adjusting the pressure on the valve operator as shown in Figure 8. The method for determining the nominal flow rate required for each lead and how the rate is to be set after installation of the magnet on the device has not been established. Additional work will be required during Title II to resolve these issues. In the event of an over temperature condition in a lead, the I&C system decreases the valve operator pressure to fully open the valve. The I&C system monitors the temperature transducer installed in each lead. If a lead continually runs warm, the flow of cooling gas can be increased by manually decreasing the pressure on its valve operator. Warm gas from the mirror magnet leads is collected in a manifold and returned to compressor suction.

Liquid nitrogen for the mirror magnet and gyrotron magnet dewar insulating shields is controlled by a valve on the inlet of each shield. The system operates as a quasi-flooded system. The valve opens and remains open until liquid is detected in the vent line. When



STEADY STATE VAPOR COOLED LEAD CONTROL BLOCK DIAGRAM
FIGURE 8

liquid is detected the valve closes. It remains closed until the liquid in the line vaporizes and then it opens to complete the fill cycle. During Title II additional analysis will be required to verify that the quasi flooded approach is superior to a flooded system. The final selection will be based on this analysis and recommendations from companies that bid on the system. Expended nitrogen is collected in a manifold and dumped into the environment outside the device facility.

3.1.4 Stand-by - This mode is similar to the steady-state mode. The limits on the fill level band will be increased to reduce cycling of the liquid flow control valves. After the LHe storage dewar is filled, the output of the R/L will be reduced to match the stand-by system losses. The output of one compressor skid provides sufficient capacity to hold the system in the stand-by mode.

During Standy-by, flow through the vapor cooled leads must be reduced to prevent the formation of frost balls and mechanical cycling of the lead connections to the magnet pack. The approach to flow control of the vapor cooled leads during Stand-by was not selected during Title I and thus remains an open issue that will be resolved during Title II. One approach that was considered and will be investigated further in Title II is to stop the lead blowers and open a bypass loop around the blowers. Thus the pressure in the magnet dewar vent line and the outlet of the vapor cooled leads will be approximately equal. To establish the proper flow rate through the leads, throttling of flow through either the blowers bypass loop or the vent line will be required.

3.1.5 Warm-up - This mode is similar to the cool-down mode, except that an electrical heater in the auxiliary heat exchanger is utilized to warm the helium gas stream. Gas temperature is controlled by cycling the heater "on" and"off" under control of the I&C System. All magnets and gyrotrons must be warmed together if forced warming is desired. However, it may be possible to "force warm" one or more magnets or gyrotrons and keep the remainder below approximately 100K as follows:

a. Close the LN_2 Valves to the shields of the dewars to be warmed.
b. Close the liquid helium valves to all dewars that are to remain cold.
c. Open the bottom fill valves on the magnet dewars and fill valves on the gyrotrons to be warmed.

d. Start the flow of GHe into the dewars and steadily increase the flow rate to establish a maximum based on the dewar operating pressure. The rate may be modulated to avoid inducing excessive thermal stresses.
e. Increase the inlet gas temperature by cycling the heater to obtain the desired warm-up rate.

3.1.6 Malfunction Response - System characteristics related to malfunctions are described in this section. The discussion assumes that a plasma exists prior to onset of the malfunction unless otherwise stated.

3.1.6.1. Magnet Quench - A single or multiple magnet quench will result in an immediate pressure rise in the affected dewars and loss of plasma. Each magnet is provided with a safety relief line consisting of a check valve and burst disc. The burst disc is set at approximately 28 psia. The quench pressure rise will cause the burst disc to rupture thus protecting the magnet dewar and the remainder of the system. The check valves will minimize the flow of contaminants into the quenched dewars. Additional testing and analysis will be required during Title II to establish the exact pressure setting for the burst discs and to evaluate the operation and safety of the vent system.

Upon detecting the quench, the I&C system will close all fill valves thus making the system safe. The response time of the valve closing is too slow to stop the propagation of pressure spikes into the remainder of the system. The primary concern resulting from pressure spikes is damage to the cold box turbo expanders. They are isolated from the source of the pressure spike by the LHe dewar on the liquid side and the compressors on the gas side. Our initial analysis indicates that they will require no further protection to prevent damage in the event of a quench.

This conclusion is based on two factors. First, the large impedance of the lines and LHe dewar that are connected between the magnet dewars and the turbo expander discharge will dampen the spikes to acceptable levels. Secondly, the compressors and the interconnecting piping will effectively dampen the spikes to the turbo expander inlet. (This conclusion will be verified during title II Detail Design).

Recovery after a magnet quench can be achieved in several ways. Rather than warm-up all the magnets and begin a complete cool-down cycle, the following approach can be utilized to save time and costs and reduce thermal cycling of the mirror magnets provided that the temperature of the quenched magnet packs are below 100K. Analysis has indicated that the magnet pack temperature will not exceed 100K during a quench and that detrimental thermal stresses may not exist below 100K.

a. Verify that the LHE valves to all magnet and gyrotron dewars are closed.
b. Simultaneously start flowing cold GHe into the bottom fill line of the quenched magnets and replacing the ruptured burst discs. Initially the gas flow rate must be kept low to allow matching of the incoming gas temperature to that of the dewar to avoid inducing thermal stresses. After temperature matching, the dewar temperature can be reduced as rapidly as possible within the thermal stress limitations of the magnet or capacity of the system.
c. When the temperature of the quenched magnets equilibrates with that of the unaffected magnets, all bottom fill valves are opened and whole system is cooled down and filled with liquid.

A second approach can be utilized to recover from a mirror magnet quench provided thermal stresses do not impose a restriction and that sufficient quantities of liquid can be forced into the magnet to affect cooldown. This approach is applicable to recovery from a gyrotron magnet quench.

a. Verify that the LHe topping valve is closed on all quenched dewars.
b. Replace all failed burst discs.
c. Continue to maintain LHe flow via the topping valve to all magnets that did not quench.
d. Open the bottom fill valves on all other magnets to begin LHe flow into the dewars. Continue LHe flow until the magnets cool down.

3.1.6.2 Single Compressor Failure - If the device is operating at a power level producing minimal quantities of magnet x-ray heating, no immediate response is required. The limiting factor in this case is the single compressor's capability to handle the flow of gas returning from the vapor cooled leads and cold vapor through the cold box. When the losses (helium vaporization) exceed the compressor's capacity, the magnet and gyrotron dewar pressure will begin to increase. Thus, plasma heating must be suspended to reduce the x-ray heating load on the system or gas must be vented to atmosphere. A valve is provided to dump excess helium to atmosphere via the vent line. Operating time is a maximum of approximately 100 hours at full power under this condition. The limit is controlled by liquid inventory in the LHe storage dewar at onset.

With one compressor operational, the system can hold the device in the stand-by mode indefinitely or the device can be operated at low power levels.

3.1.6.3 Failure of Both Compressors - The plasma can be maintained by venting helium to atmosphere. At full power the device can operate approximately 16 hours maximum. Liquid helium inventory in the storage dewar at onset will establish the time. Stand-by time is approximately 21 hours maximum before the magnets will begin to warm-up.

3.1.6.4 Cold Box Failure - The immediate result of all cold box failures is the suspension of liquid production. A cold box bypass heat exchanger is provided to warm the cold helium gas return stream prior to entering compressor suction. Thus, return gas can be pumped back into the GHe storage tanks. The filling of the GHe tanks can continue until they are full. If the storage tanks were empty at onset, they would fill in approximately 4.3 hours at full upgrade power. Provided liquid helium inventory is available, operation can continue after the tanks are full by venting helium to atmosphere.

3.1.6.5 Vapor Cooled Lead Blower Failures - The failure of one lead blower will not affect operation of the device. Each of the two lead blowers has the capacity to handle the lead flow rate for steady-state operation. In the event that both blowers fail, magnet power must be dumped to avoid damage to the vapor cooled leads.

3.2 DUTY CYCLE

To establish maintenance response times and system reliability allocations, it was necessary to establish a duty cycle. The duty cycle adopted follows.

The system shall be designed to operate continuously 24 hours per day for 48 weeks per year with a useful life of 10 years. The weekly duty cycle shall be 16 hours of steady-state operation followed by 8 hours of stand-by operation for 5 days followed by 64 hours of stand-by. In addition, the system shall accommodate 88 hours of stand-by. Four weeks each year will be allocated for the performance of major maintenance. The device will be warmed to ambient temperature during this period.

3.3 DESIGN CRITERIA LISTING

Design criteria derived from analysis of the operational requirements and those imposed by applicable codes were utilized in the design described herein. They are as follows:

- Remove Detrimental Contaminants from Entire System
- Cool Down Cold Box < 12 Hours
- Cool Down LHe Dewar
- Collect LHe in Dewar
- Cool LN_2 Shields to $\approx$80K
- Cool Magnet From 300 to 4.2K < 7 Days
    - At Controlled Rate
    - With He
    - Minimum Time
- Fill Magnets With LHe
- Recycle All He
- Maintain Dewar Liquid Level Within Operating Limits
- Maintain Magnet Dewar Temperature Within Operating Limits
- Maintain LN_2 Shields at Operating Temperature
- Maintain Fluid Flow Through Vapor Cooled Leads
- Maintain Lead Temperature Within Operating Limits
- Liquefy He to Compensate For Vaporization Losses
- Provide LN_2 to Vacuum Pump Traps
- Provide LN_2 to Service Diagnostics
- Warm Shields to Ambient Temperature
- Warm Magnets to Ambient Temperature

  - At Controlled Rate
  - With GHe
  - Minimum Time
- Protect Equipment and Personnel
- Continue Device Operation in the event of Specific Malfunctions
- Recover Quickly from Malfunctions
- 16 Hours Steady-State (Magnets Powered)
- 8 Hours Stand-By
- Repeated for 5 Days
- 88 Hours Stand-By
- Operate in X-ray Environment
- ASME Boiler and Pressure Vessel Code
  - Section VIII Division 1
- ANSI Standard Code
  - B31.1 Power Piping

    B31.3 Chemical Plant and Petroleum Refinery Piping (Applicable to Compressor Skids Only)

    B16.5 Steel Pipe Flanges, Flanged Valves, and Fittings

    B36.19 Stainless Steel Pipe
- Tubular Exchange Manufacturers Associations (TEMA)
  - Standards
- International Conference of Building Officials
  - Uniform Building Code (UBC)-Seismic Criteria - Zone 2
- Temperatures and Pressures as Predicted For EBT-P System Including Normally Expected Excursions
- LN Storage ≈ 9000 Gallons Net
- LHe Storage ≈ 17,300 Liters Net
- GHe Storage ≈ 150,000 SCF @ 300 PSI
- Piping to Handle Full Flow
- Each Compressor Skid Rate for Stand-By Heat Load + 50% Margin ≈ 195 ℓ/hr + 1430 Watts
- Refrigerator/Liquefier Rated For Total Heat Load + 50% Margin ≈ 280 Liters Per Hour + 2000 Watts
- Instrumented for Monitoring and Control By One Operator

Reliability and Repair Times

- 9000 Hour MTBF Typical
- 16 Hour MTTR Typical

3.3.1 Additional Critieria - Additional criteria are imposed by the performance characteristics of the devices the cryogenic system supports. Those requirements are shown in Tables II, III, and IV. Facility requirements are shown in Table V.

Table II Helium Delivery Requirements

Device Element	Consumption Each Element	Number of Elements	Total Consumption	Fluid Properties (1) Inlet	Outlet
Mirror Magnet		36			
Steady State Dewar Losses	26.8ℓ/hr (≈19.0 W)		964.8 ℓ/hr	Liquid @ 4.2K	Vapor @ 4.2K
Steady State Lead Losses	5.0 ℓ/hr		180.0 ℓ/hr	Liquid @ 4.2K	Gas @ 300K
Total Steady State Losses	31.8 ℓ/hr		1144.8 ℓ/hr		
Standby Dewar Losses	12.7 ℓ/hr (≈9.0 W)		456.8 ℓ/hr	Liquid @ 4.2K	Vapor @ 4.2K
Standby Lead Losses	3.4 ℓ/hr		122.4 ℓ/hr	Liquid @ 4.2K	Gas @ 300K
Total Standby Consumption	16.1 ℓ/hr		579.2 ℓ/hr		
Gyrotron (2)					
Operational Losses	1.2 ℓ/hr	6 (3)	7.2 ℓ/hr	Liquid @ 4.2K	Vapor @ 4.2K
Standby Losses	1.2 ℓ/hr		7.2 ℓ/hr	Liquid @ 4.2K	Vapor @ 4.2K

Notes:
(1) Liquid at 4.2K is saturated liquid in the pressure range of 14.7 ± 0.3 PSIA.
(2) Gyrotrons will be bulk filled daily. Approximate volume of each gyrotron is 60 liters.
(3) Upgrade Requires 15 Total Gyrotrons.

Table III Nitrogen Delivery Requirements (2)

Device Element	Consumption Each Element	Number of Elements	Total Consumption	Fluid Properties (1) Inlet	Outlet
Mirror Magnet (3)	1.5 ℓ/hr (≈66 W)	36	54.0 ℓ/hr	Liquid @ 80K	Vapor @ 80K
Gyrotron Magnet (3)	0.4 ℓ/hr	6	2.4 ℓ/hr	Liquid @ 80K	Vapor @ 80K
Vacuum Pump Trap		6	TBD	Liquid @ 80K	Vapor @ 80K
Soft X-Ray Spectrometer	3 ℓ/hr (4)	1	3 ℓ/hr	Liquid @ 80K	Vapor @ 80K

NOTES:
(1) Delivery pressure at control valve is approximately 25 psig
(2) Cold Box and distribution system consumption is not included.
(3) Flow to these elements is continuous in an automatic quasi flooded system.
(4) This element will be batch filled daily.

Table IV Mirror Magnet Characteristics

LHe Dewar	
Total Volume	30.0 ℓ
Min. Operating Volume	20.0 ℓ
Max. Operating Volume	25.2 ℓ
Pressure Rating (LHe Dewar)	
Design	50 psia
Operating Range	14.7 ± 0.3 psia
Quench Mode Max.	50 psia
Quench Mode Rise Rate in Magnet	230 psi/sec est. max.
Burst Disc Setting	28 psia
Heat Flux (LHe Dewar)	
Operating (plasma powered)	19.0 W (see Table I)
Standby (no plasma power)	9.0 W (see Table I)
Insulation Vacuum Loss	16,800 W
Maximum Cooldown ΔT (300-100°K Range)	10K
Maximum Design Pressure LN_2 Line	30 psig
ΔP Across LN_2 Pass	5 psi

Table V Utility Interfaces

Electrical Power

- 2400 VAC, 3ϕ, 60 HZ
- 450 VAC, 3ϕ, 60 HZ
- 110 VAC, 1ϕ, 60 HZ

Instrument Air

- Filtered and Oil Free Air at 100 PSIG and 104°F

Cooling Water

- Demineralized
- Inlet Temperature to Equipment 100°F
- Maximum Temperature Rise Across Equipment 18°F
- Pressure 120 psig Nominal
- Flow Rate TBD

4.0 DESIGN DESCRIPTION

4.1 INTRODUCTION

The cryogenic system as designed and installed is a complete utility requiring only facility power, cooling water and instrument air for operation. The distribution portion of the system depends on the I & C system for operation while the remainder is supported by its own instrumentation and control subsystem.

The primary function of the cryogenic system is to deliver liquid helium and liquid nitrogen to the EBT-P device and associated equipment and to liquefy helium to compensate for total device losses. Liquid use points include:

(1st level)
- Superconducting gyrotron magnets
- Diagnostics
- Vacuum Pump traps

(2nd level)
- Superconducting mirror magnets
- Diagnostics

In addition, warm gaseous nitrogen is supplied to the vacuum system and for general use on both levels of the device enclosure.

Cryogenic manifolds on the first level are designed to allow additional drops to accommodate the future upgrade to 15 gyrotrons.

Installation of the system in the ORVIP facility is shown in Figure 1. Additional detail of the installation is shown in the drawings listed in Table VI and included in Appendix B.

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Drawings:

- 70B373000A EBT-P Block Diagram, Liquid and Gaseous System, Cryo
- 70B373001 EBT-P Cold Box Facility Interface
- 70B373002 EBT-P Liquid Helium Dewar Facility Interface
- 70B373004 EBT-P Gaseous Helium Storage Tank Facility Interface
- ***• 70B373005 EBT-P Helium Manifolds, Cryo-Pump Systems
- 70B373006 EBT-P Liquid Nitrogen Storage Tank Facility Interface
- 70B373008 EBT-P Magnet Supply/Return Manifolds, Cryo
- 70B373009 EBT-P Magnet Interface, Cryo
- 70B373010 EBT-P Magnet Supply/Return Envelopes, Cryo
- 70B373011A EBT-P Facility Routing Envelopes, Cryo
- *• 70B373007 EBT-P Gaseous Helium Storage Tank
- *• 70B373012 EBT-P Liquid Helium Dewar
- *• 70B373013 EBT-P Gyrotron Interface
- 70B373014A EBT-P Gyrotron Supply/Return Manifold
- *• 70B373015A EBT-P Gyrotron Supply/Return Envelopes, Cryo
- 70B373016A EBT-P Cryo Subsystems Facility Installation
- **• 70B373017A EBT-P Liquid and Gaseous System Schematic
- *• 70B373018 EBT-P Cold Box
- *• 70B373019 EBT-P Lead Blower Interface
- *• 70B373020 EBT-P Auxiliary Heat Exchanger
- *• 70B373021 EBT-P Helium Compressor
- *• 70B373022 EBT-P Liquid Nitrogen Dewar
- *• 70B373023 EBT-P Cryo Supply - Vacuum System

*Indicates a drawing that will be forwarded upon completion.

**This drawing is conceptual and as such does not include all components necessary for system operation.

***This drawing is now obsolete as a result of the current vacuum pump system configuration.

DRAWING LIST

TABLE VI

- 70B374001 EBT-P Device Enclosure Bldg
- 70B378011 EBT-P Control/Computer Room Floor Paln
- 375-413-001 Device Enclosure
- 502-101-001 Plan-Test Center Ground Floor
- 502-101-010 Plan-Test Center Second Floor
- 502-105-001 Sections and Elevations - Test Center

The system is composed of the following major elements.

- Closed Cycle Helium Refrigerator/Liquefier (Includes Two Compressor Skids and a Cold Box)
- Liquid Helium Storage Dewar
- Three High Pressure Gaseous Helium Storage Tanks
- Cryogenic Helium Distribution System
- Gaseous Helium Distribution System
- Liquid Nitrogen Storage Dewar
- Liquid Nitrogen Distribution System
- Auxiliary Heat Exchanger for Cooldown and Warm-up
- Instrumentation and Control Subsystem
- Gaseous Nitrogen Distribution and Vent System
- Vapor Cooled Lead Blowers
- Cold Box By-Pass Heat Exchanger
- Gas Purification System

The system is configured for maximum utilization, flexibility and safety. Redundancy is provided where reliability, maintenance, and cost considerations warrant. Provisions are included to allow continued device operation in the event of a major refrigerator/liquifier failure (requires gaseous helium overboard venting). Continued system refinement during Title II will be directed toward minimizing heat losses and optimizing overall reliability.

Major components of the cryogenic distribution system, as shown in Figure 9, are located in or adjacent to the mechanical equipment building, with the exception of the liquid helium dewar which is on the roof of the device enclosure. Interface drawings for each component will be generated or updated during Title II and controlled by MDAC-St. Louis to insure proper subcontractor direction and minimize system installation problems.

The entire cryogenic system, with the exception of the high pressure gaseous helium tanks and the liquid nitrogen dewar will be procured from one subcontractor during Title II as described in the Procurement Specification shown in appendix A. The subcontractor will be responsible for:

- system optimization/analysis/integration
- detail design
- hardware fabrication
- instrumentation and control interfaces
- system installation

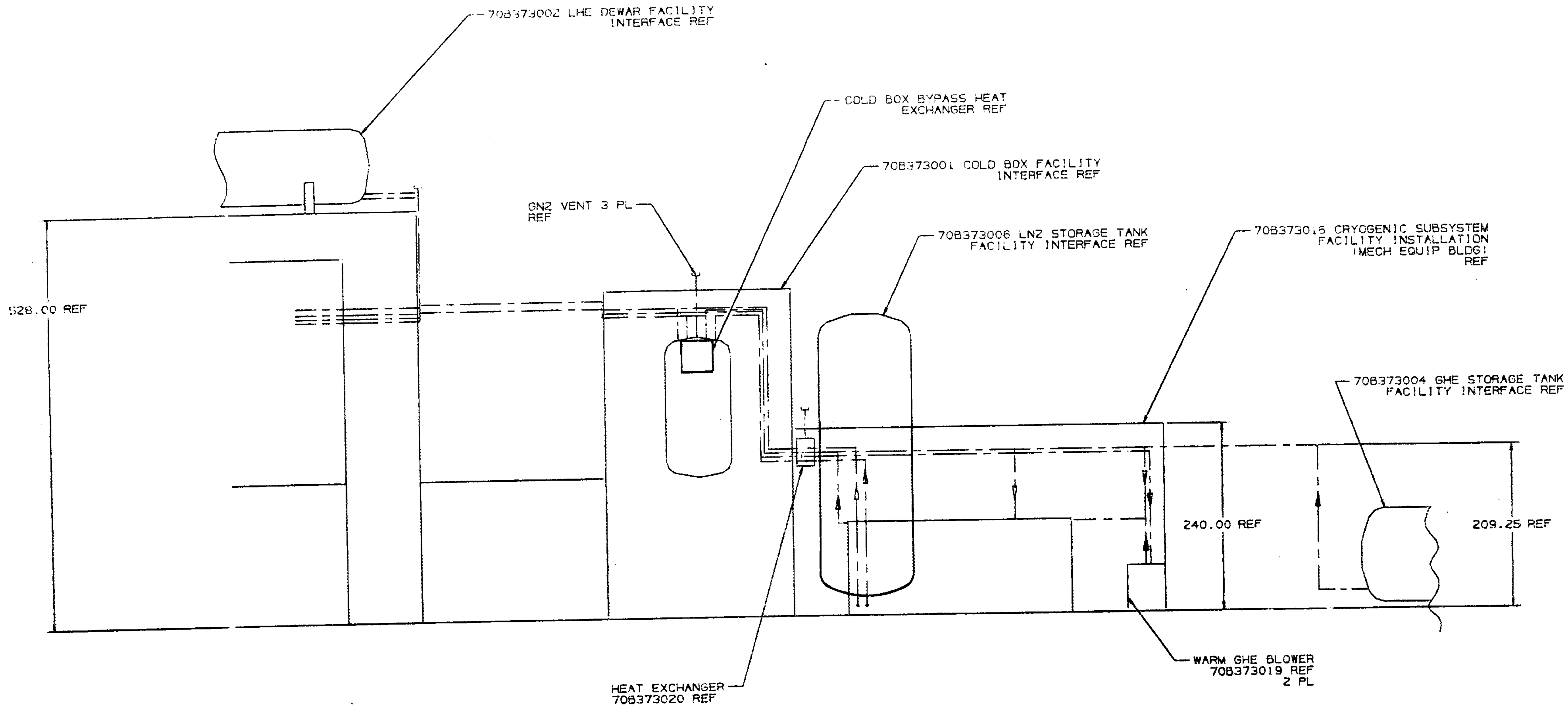
Overall direction will be provided by MDAC through the component interface drawings and system envelope drawings as listed in Table VI. These drawings provide sufficient information to maximize cryogenic subcontractor flexibility while maintaining envelope control required to allow design of the various other EBT-P device subsystems. (Note that these first generation drawings will require changes/updates as the Title II effort continues. Also, since their function is to control general system layout, exact fabrication details and system performance parameters, contained in the procurement specification, are not shown.

The following paragraphs provide a detailed description of the various parts of the cryogenic system and their design philosophy.

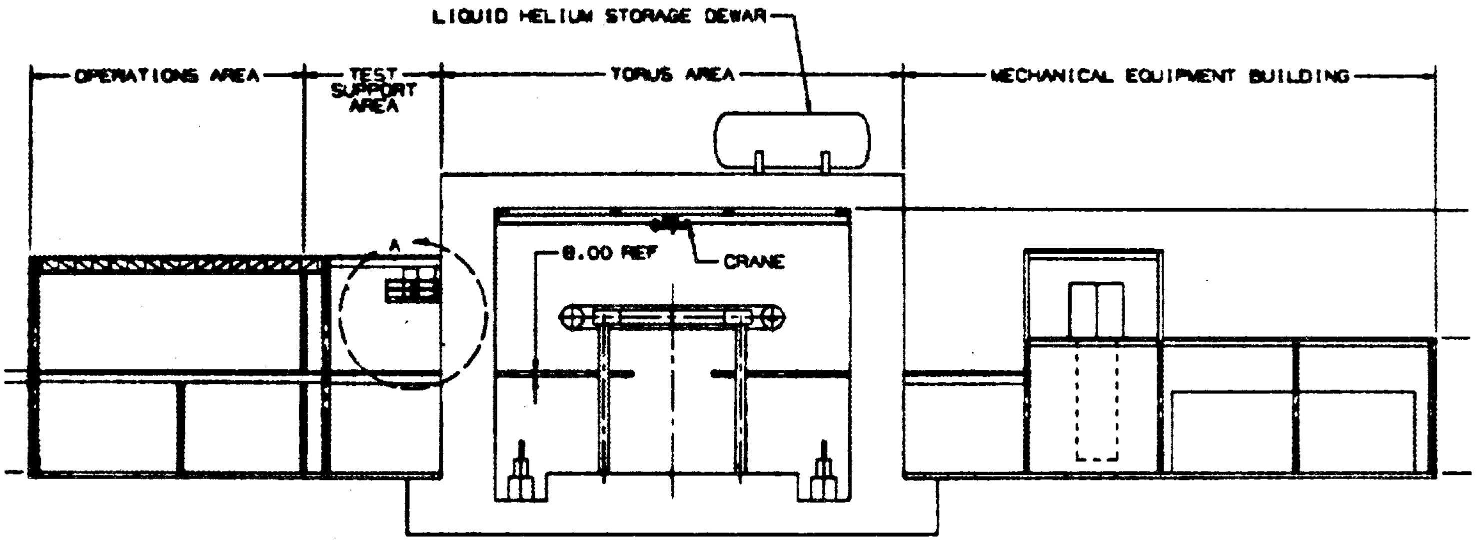
4.2 LIQUID HELIUM STORAGE DEWAR

A liquid helium storage dewar with a capacity of 17,300 liters minimum and a 10 percent ullage is located on the roof of the EBT-P device enclosure, as shown in Figures 10 and 11. The dewar capacity is based on existing proven hardware that is currently being produced. Tank design details include:

- designed/fabricated in accordance with ASME Code Section VIII
- horizontal tank configuration
- 35 psig design pressure
- .75% boiloff maximum over 24 hours



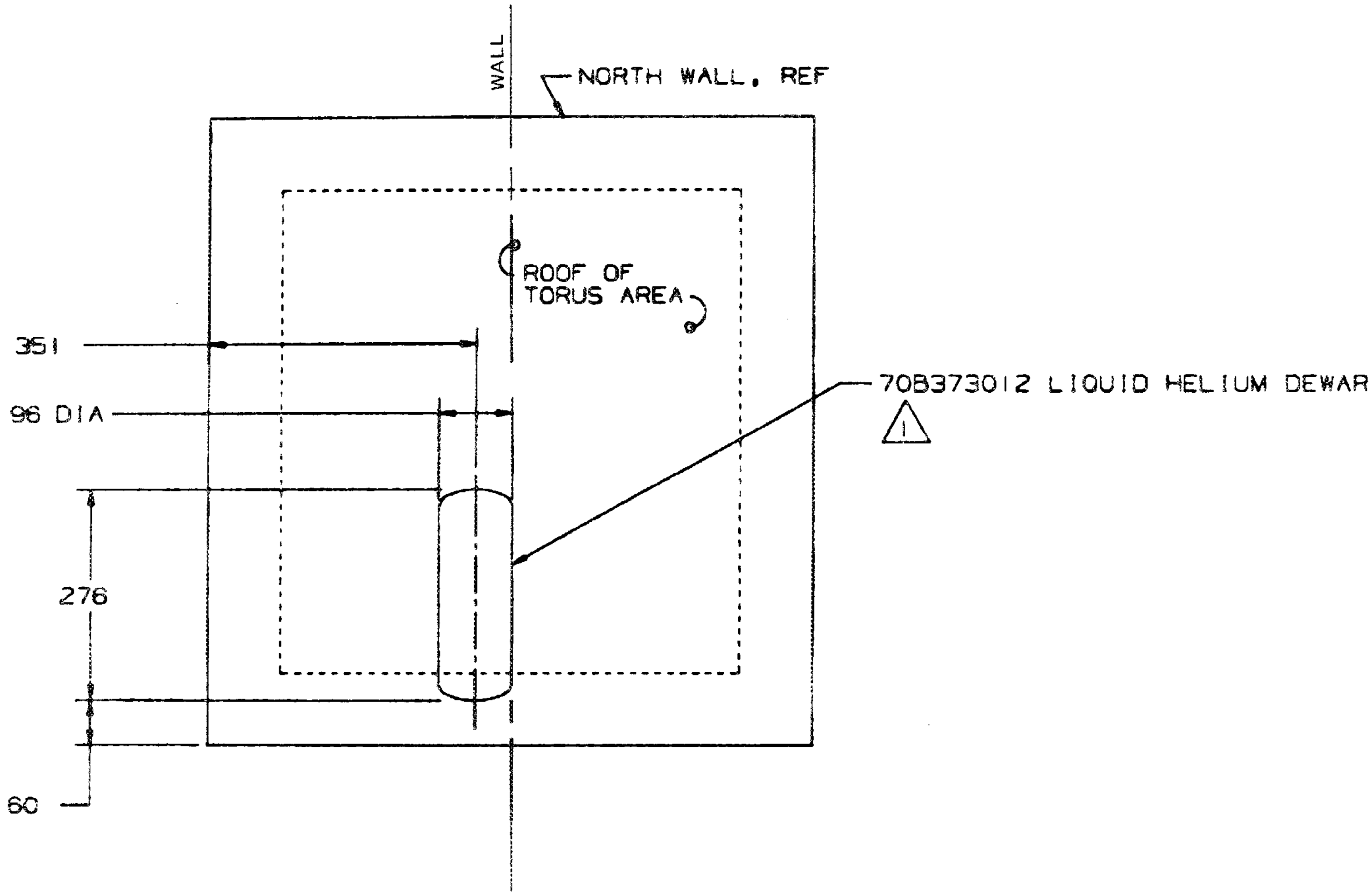
EQUIPMENT LAYOUT
FIGURE 9
(SEE DWG 70B373011)



SECTION LOOKING EAST

HELIUM DEWAR LOCATION

FIGURE 10



HELIUM DEWAR LOCATION

FIGURE 11

- integral joule thompson expansion valve
- getter vacuum enhancement
- one year minimum vacuum integrity
- appropriate safety and maintenance devices
- appropriate instrumentation for I & C interface
- proven and demonstrated design

See Figure 12 for the liquid helium dewar schematic.

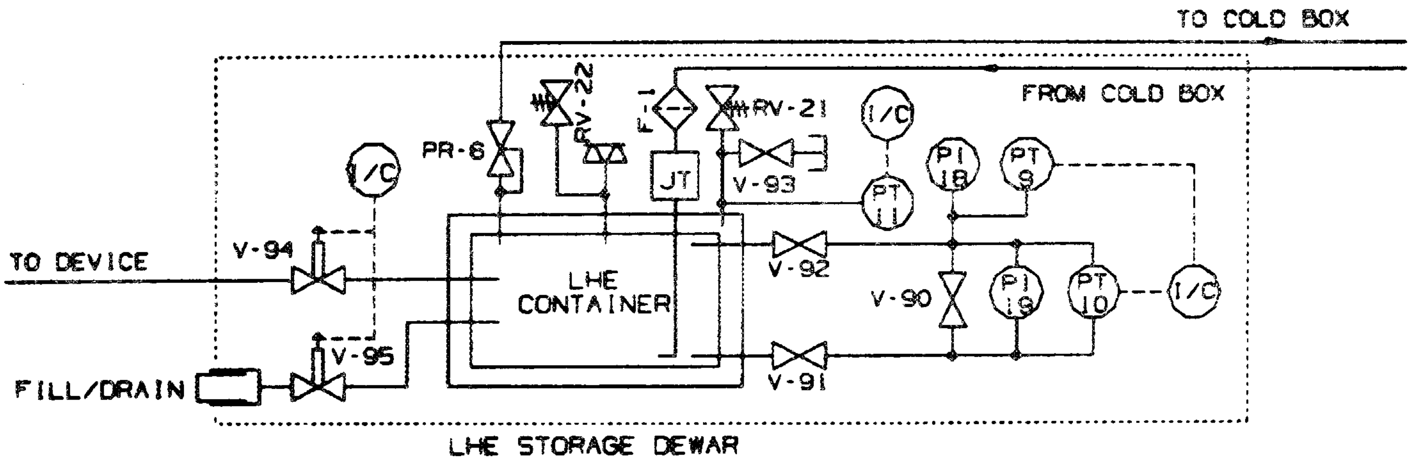
High pressure cold gas is filtered and delivered to the liquid helium storage dewar from the cold box. An integral Joule Thompson (JT) valve liquefies the gas at the dewar inlet. Maximum liquid production is estimated at 700 liters per hour. Cold gaseous helium that is not liquefied in the expansion is returned to the cold box to refrigerate the incoming high pressure helium stream from the compressors.

In the event of a cold box failure, cold helium boiloff gas from the dewar can be either warmed by the cold box by-pass heat exchanger and fed into the compressor inlet or vented to the atmosphere. (Venting would only be required if both compressors had failed or the three gaseous helium storage tanks were full).

Since the output capacity of the two gaseous helium compressors exceeds the flow requirements for mirror magnet cooldown, separate piping is used between the cold box and liquid helium dewar thus allowing some liquid production during the cooldown mode.

Liquid helium is delivered to the use points by head pressure resulting from the elevated location of the dewar. This results in a pressure of approximately 1 psi at the mirror coils and 2.5 psi at the gyrotron magnets.

Piping and facility interface requirements for the dewar installation will be coordinated with the selected cryogenic subcontractor during Title II. Interface drawings will be updated and generated by MDAC-St. Louis.



HELIUM DEWAR SCHEMATIC
FIGURE 12

4.3 CRYOGENIC HELIUM DISTRIBUTION

The cryogenic helium distribution system forms a part of the overall closed loop helium system. It provides saturated liquid at approximately 4.2K to the mirror magnets and gyrotron magnets and returns cold gaseous helium to the cold box. The distribution system in conjunction with the magnet and gyrotron dewar loads forms a very complex network. Therefore, dynamic problems may exist. Both MDAC and the subcontractor choosen to design the complete cryogenic system will evaluate the system during Title II to identify potential dynamic problem areas.

The general piping arrangement shown in Figures 13 through 20, provide the following flow arrangement:

- A single line transports the liquid from the storage dewar to the device enclosure
- The pipe penetrates the enclosure through south wall on the second level
- Within the enclosure liquid helium flow is split to service both the first (gyrotron) and second (mirror magnet) levels
- Liquid helium flow to the first level is manifolded around the lower level with individual drops interfacing with each of the gyrotrons through bayonet connections
- Liquid helium flow to the second level is divided with each leg servicing a half manifold located on the device structure
- Individual drops interface with the mirror magnets from each leg
- Cold gas from both levels is manifolded and returned to the cold box
- Warm gas from the mirror coil vapor cooled leads is manifolded and returned to the compressors

Design details of the liquid and cold gaseous helium transfer lines are as follows:

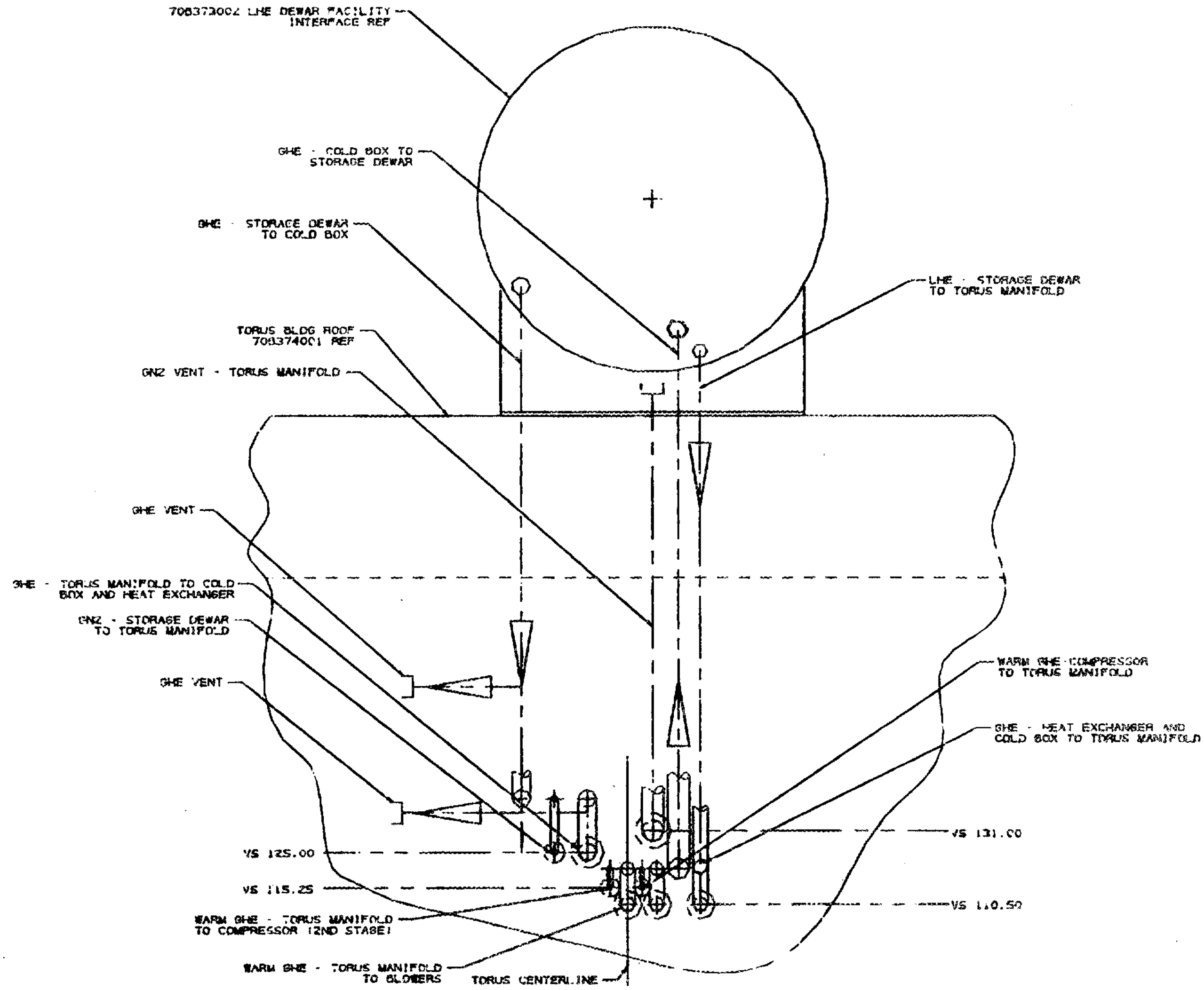
- All welded construction except at the gyrotron interface
- ASTM A240 304L is the principle material
- Remaining materials, are capable of withstanding 10^8 rads/year x-ray dose with no performance degradation during 10 year life
- Modular pipe spools are utilized to minimize field joints and field erection labor

- Pipes are vacuum jacketed utilizing superinsulation and getters to minimize heat leak and to insure vacuum integrity
- All lines are evacuated and sealed prior to delivery
- Bellows are installed in the drop-jackets to provide interface alignment capability
- Pressure relief devices are installed in all blocked lines
- Long stem vacuum jacketed globe valves with pneumatic operators are used to minimize heat losses and facilitate remote operation

Helium vapor formed in the distribution piping which backstreams to the liquid helium dewar is piped back to the cold box. A vapor bleed provision is located in the liquid supply line at the first/second level flow junction and at four locations in the mirror magnet manifolds. These bleed provisions, comprised of a liquid level sensor and a manual valve, and are intended to minimize the amount of vapor ingested by the use points. The manual valves will be fully opened during cooldown to facilitate gas flow to the return line and partially closed afterwards to a position that maintains a liquid level in the fluid line during standby operation. Vapor remaining in the fluid lines is swept into the using device. Note that the bleed provision is not designed to insure a 100% liquid quality in the manifold but rather liquid availability to all magnets for all operational modes. (Provision will be made to allow the addition of pneumatic operators for automatic operation of the bleed valves in the event that it becomes necessary). The need for this provision will be studied during Title II.

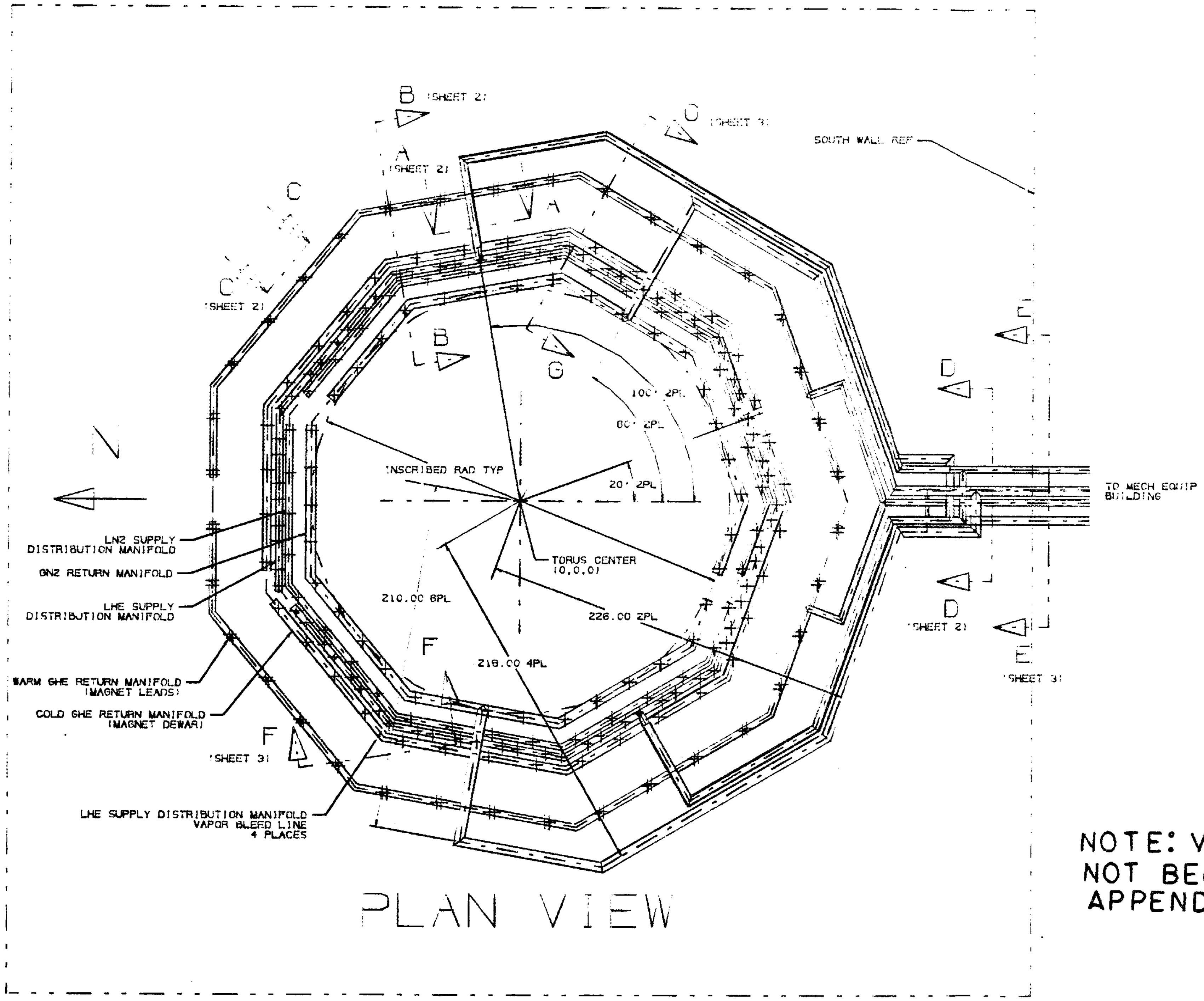
The liquid helium distribution is configured to supply continous demand liquid flow to the mirror magnets and intermittent flow to the gyrotron magnets (batch fill). A pneumatic operated valve in the liquid line to the gyrotrons is closed after the batch fill operation thus stopping all flow to the first level of the device enclosure. Refill of the gyrotron magnet dewars is accomplished by opening the pneumatic valve and reflooding the first level manifold. Since the first level cold gas-bleed provision remains open, only cool down vapor (if any) will be forced thru the gyrotron magnet dewars.

The liquid and cold gas helium manifold on the torus level are fabricated in two half sections. This minimizes the line length to the furthest magnet and allows more generous fabrication tolerances. Drops are located to minimize line length but priority has been given to valve/valve operator accessibility. Each mirror coil drop has internal and external pipe



LIQUID HELIUM FLOW
DEWAR TO SOUTH WALL
FIGURE 13

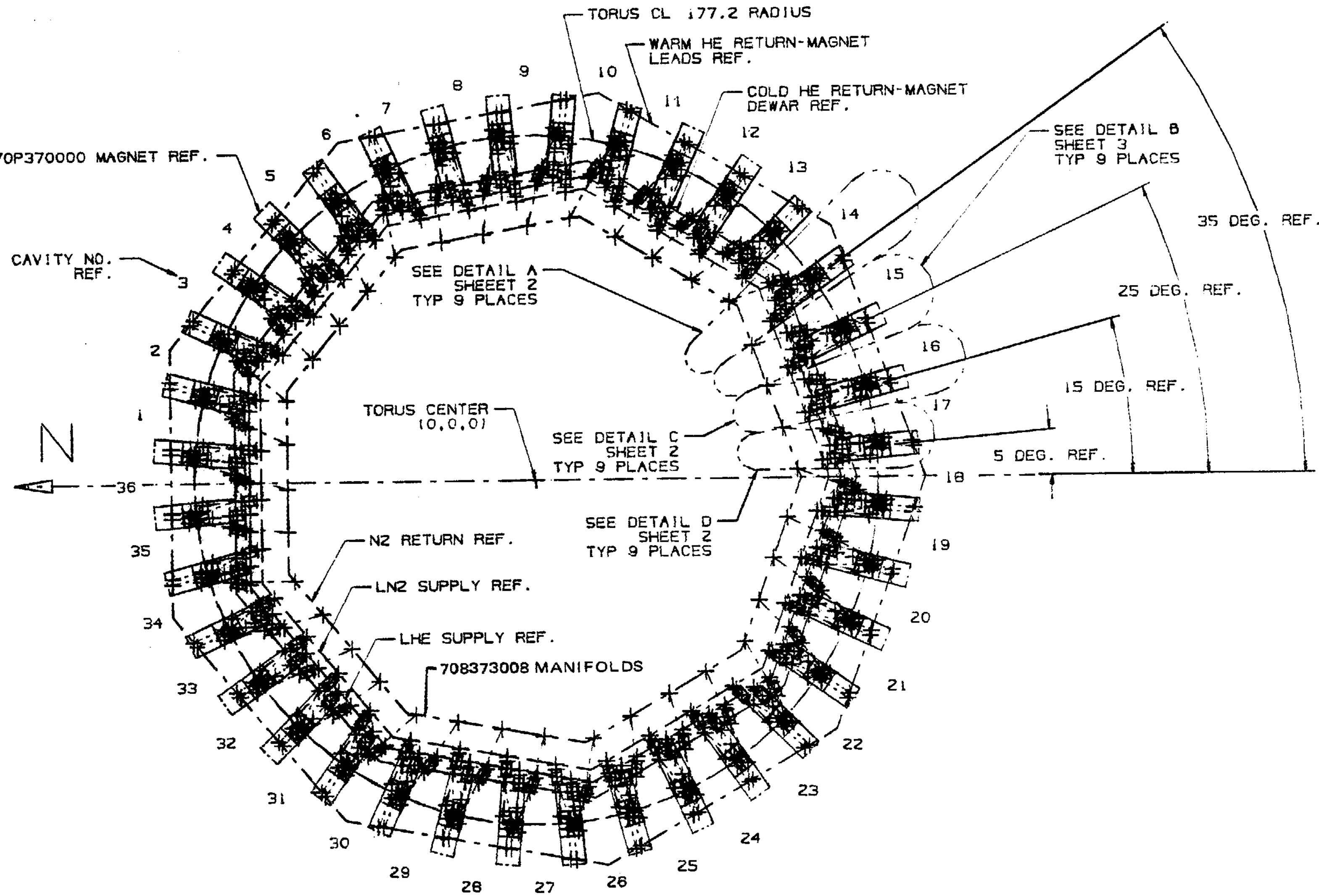
(SEE DWG 70B373011)



NOTE: VACUUM SYS HAS NOT BEEN UPDATED. SEE APPENDIX I.

CRYOGENIC MANIFOLDING-TORUS ROOM
FIGURE 14

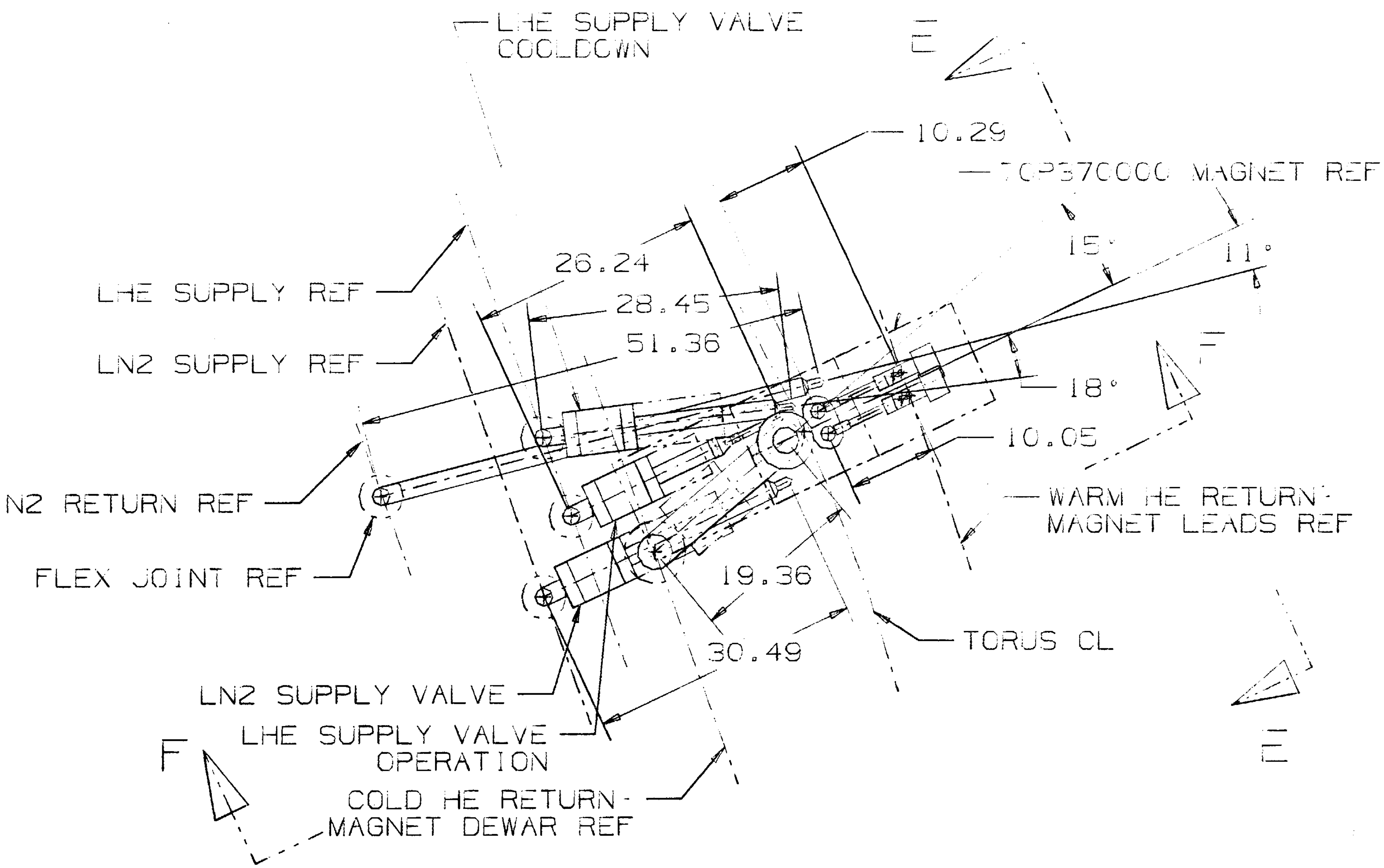
(SEE DWG 70B373008)



PLAN VIEW

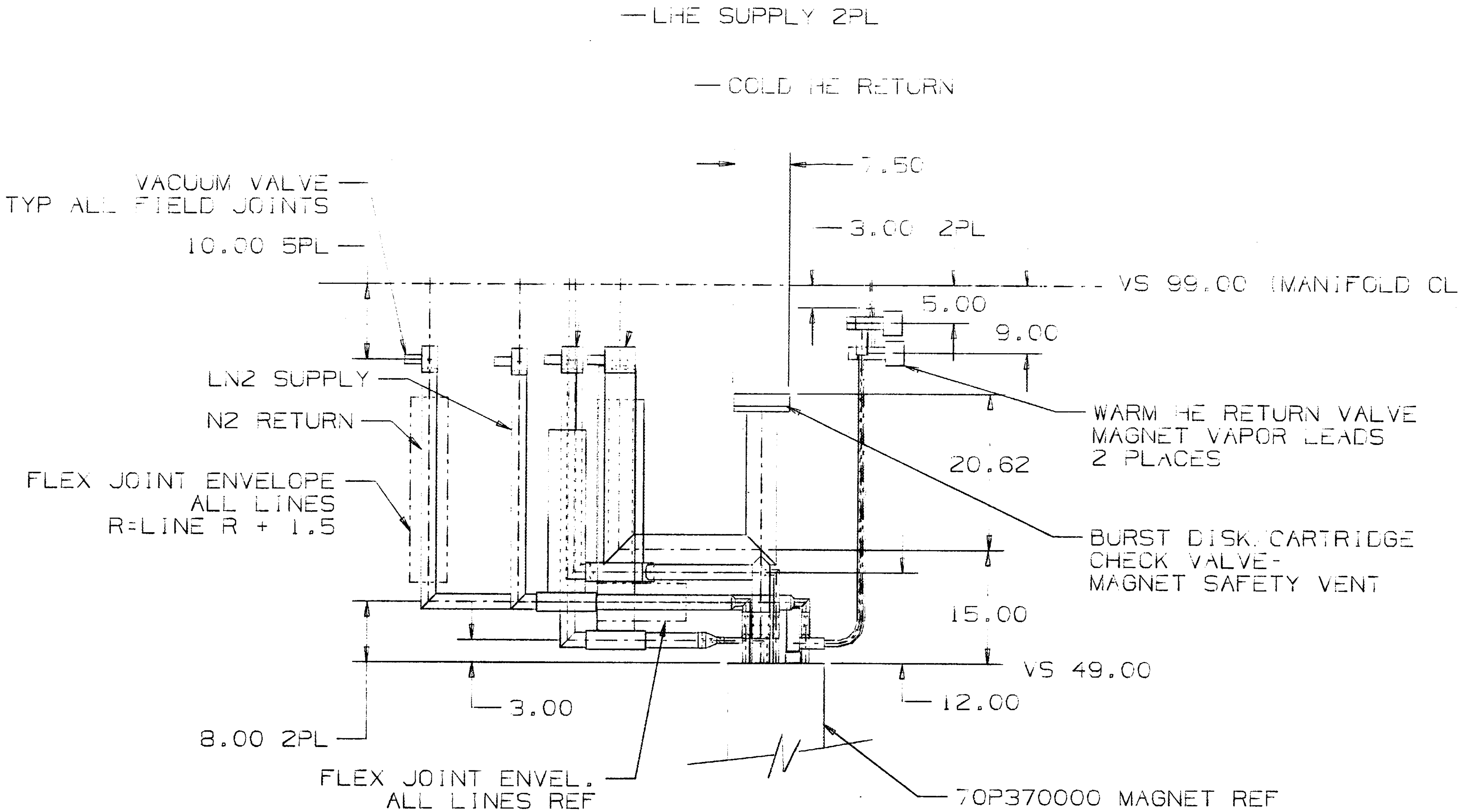
CRYOGENIC DROPS-TORUS ROOM
FIGURE 15

(SEE DWG 70B373010)



MIRROR COIL DROP GENERAL ARRANGEMENT PLAN VIEW
FIGURE 16

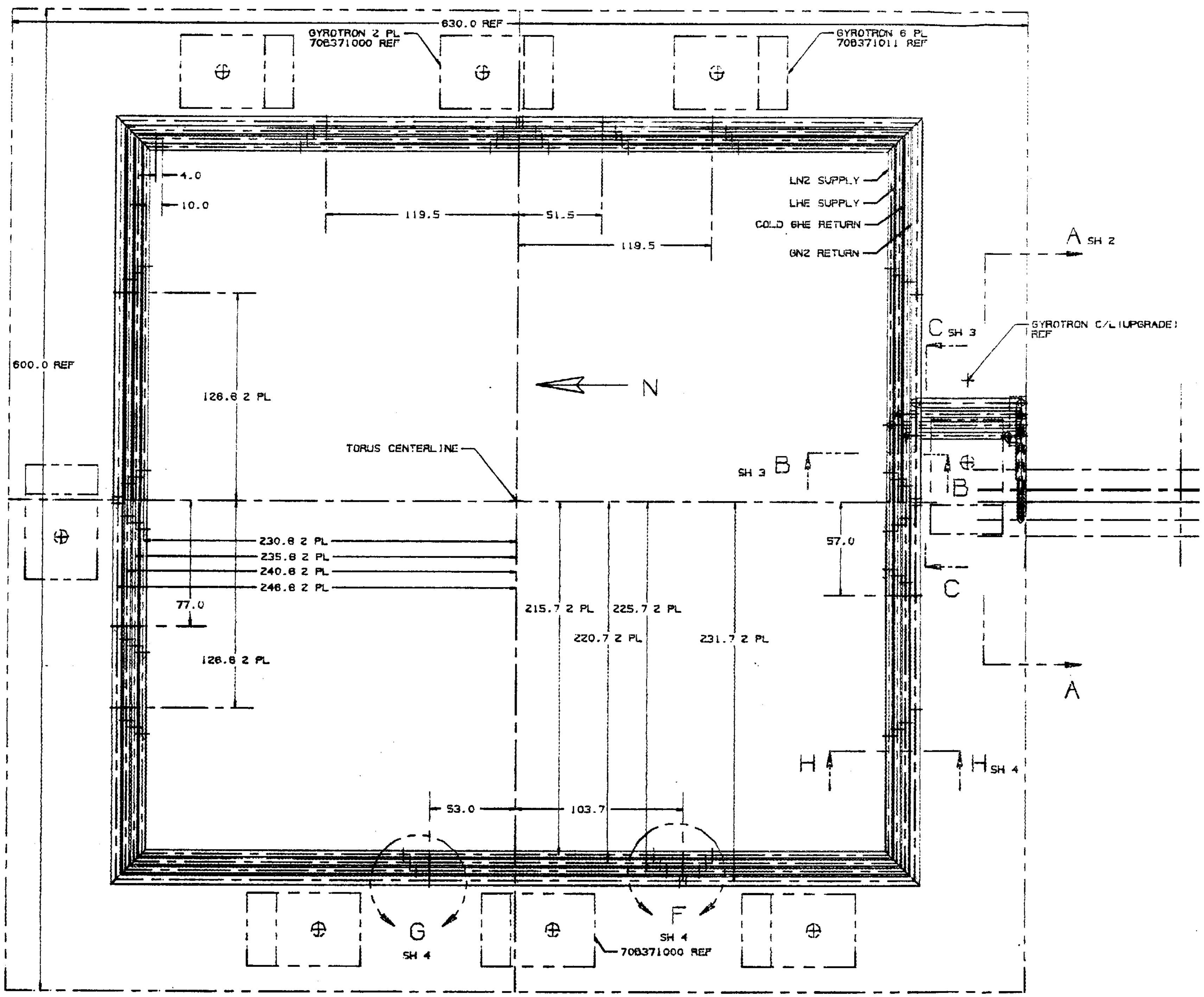
(SEE DWG 70B373010)



MIRROR COIL DROP GENERAL ARRANGEMENT SIGN VIEW

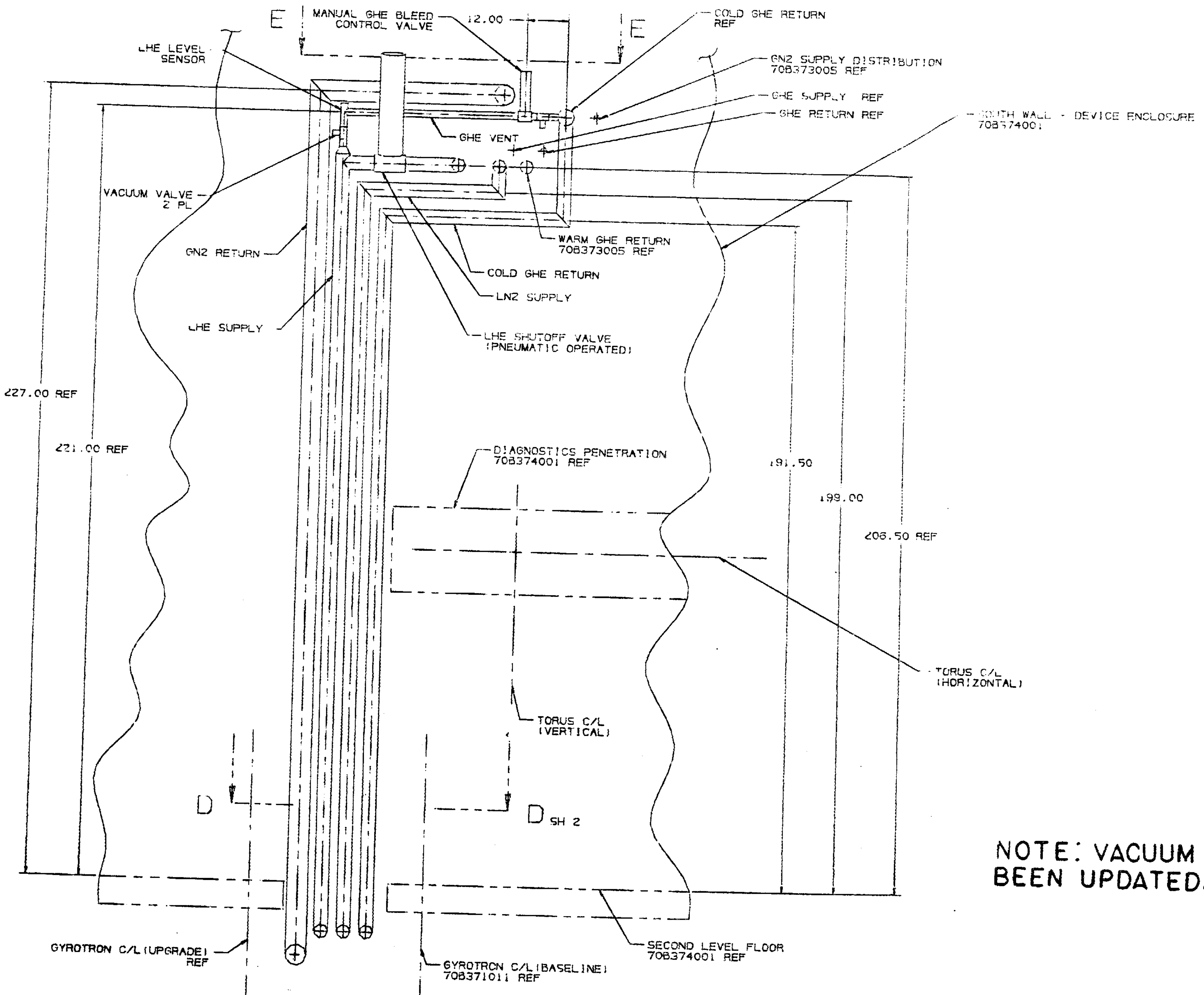
FIGURE 17

(SEE DWG 70B373010)



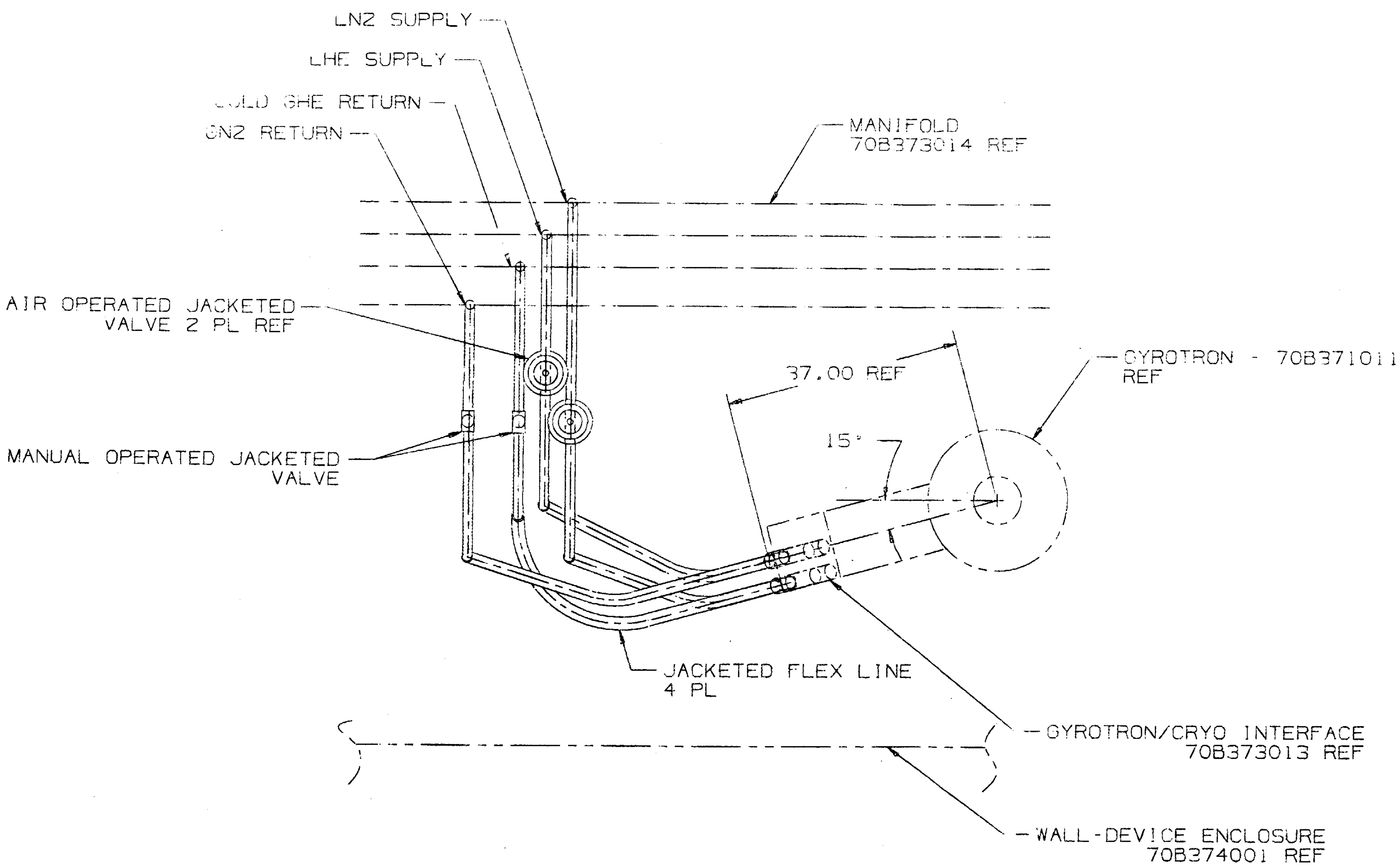
PLAN VIEW: LEVEL 1

CRYOGENIC DISTRIBUTION ROUTING-1ST LEVEL
FIGURE 18
(SEE DWG 708373014)



NOTE: VACUUM SYS HAS NOT BEEN UPDATED. SEE APPEDIX I.

CRYOGENIC DISTRIBUTION ROUTING SOUTH WALL
FIGURE 19
(SEE DWG 70B373014)



GYROTRON DROP GENERAL ARRANGEMENT
FIGURE 20

(SEE DWG 70B373015)

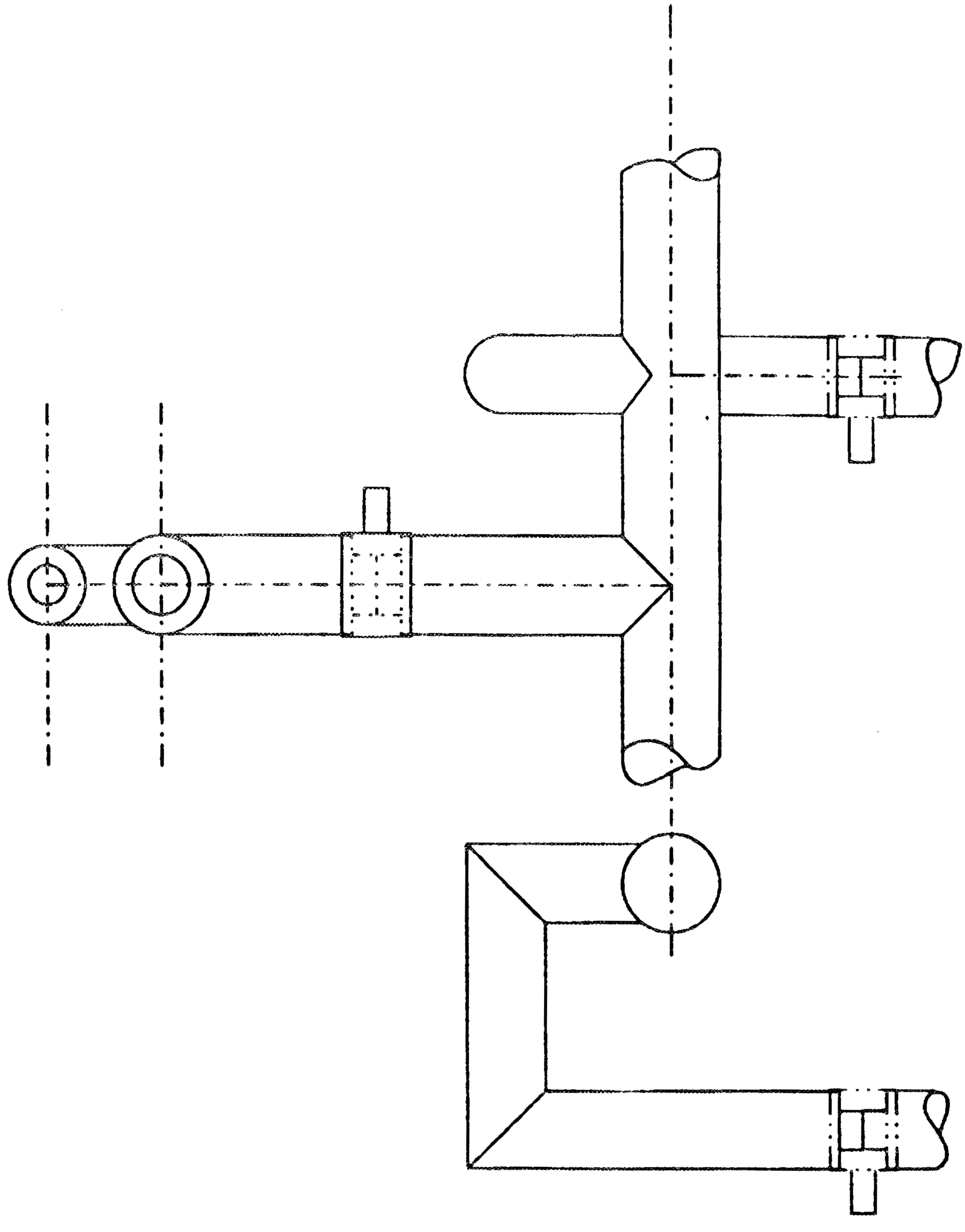
bellows to provide a minimum of 1.5 inch flexibility in each of six degrees of freedom for mirror magnet alignment. There are two separate liquid helium supply drops to each magnet. One is used during cooldown for bottom fill and the other during operation for top fill. Both lines contain pneumatic operated valves and are welded at the mirror coil interface.

Pipe spool lengths are as large as possible based on device enclosure access and handling/shipping requirements. All field joints (except at the gyrotron interface) are welded to minimize heat losses and conserve space. Evaluation of troubleshooting and repair techniques for this all welded pipe system will be done in Title II.

Currently no special provision has been made to minimize the heat leak from the cooldown helium drops after they have been closed off. Space limitations may preclude the possibility of taking the cooldown liquid off the top of the supply manifold and forming a vapor lock as shown in Figure 21. An alternate configuration is shown in Figure 22. Both these options will be analyzed more closely during Title II.

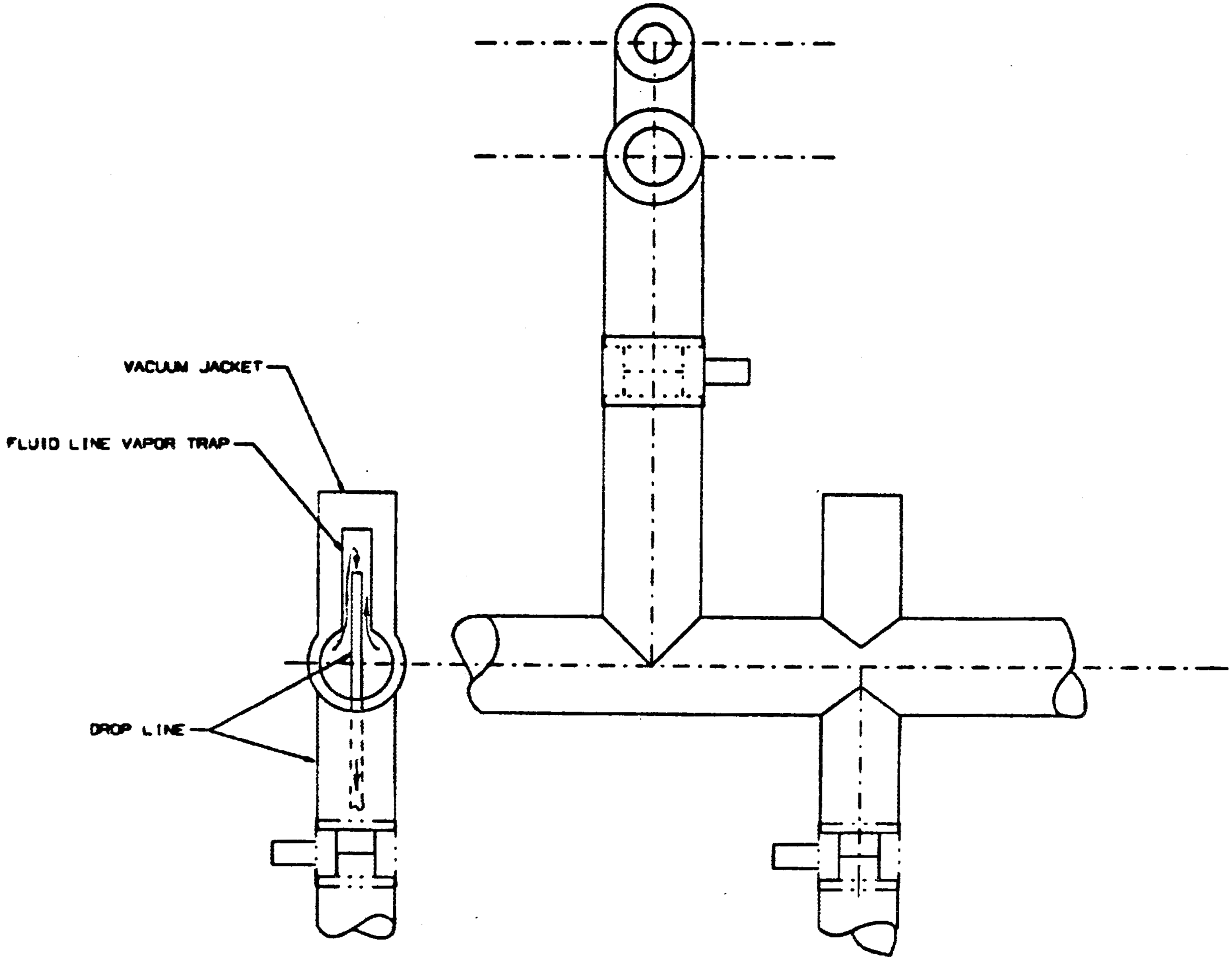
The cold gaseous helium return from the mirror coils is fabricated with a mirror coil quench relief provision. An in-line check valve and burst disk connected in series are connected to each mirror coil return drop. This relief maintains the internal pressure of the mirror coil dewar below its 50 psia design pressure. Presently all quench helium is vented into the torus enclosure. A potential safety problem has been identified for this approach if personnel are allowed in the torus enclosure when the magnets are powered. The potential exists for personnel to come in contact with cold liquid or vapor in the event of a magnet quench. The current operating procedure will preclude personnel from being in the enclosure when the magnets are powered. If this procedure is changed and personnel are allowed in the enclosure with the magnets powered, other options will be examined during Title II for handling vent gases resulting from a magnet quench.

During Title I, various techniques were evaluated for collecting and recycling the gas resulting from magnet quenches. None of the techniques were incorporated because the added system complexity, heat leaks and cost could not be justified based on estimates of the cost of the helium lost.



LHE COOLDOWN LINE VAPOR LOCK - ELBOW

FIGURE 21



LHe COOLDOWN LINE VAPOR LOCK - TRAP

FIGURE 22

Warm gaseous helium bled through the mirror coil vapor cooled electrical leads is manifolded and piped back to the compressor inlet via redundant lead blowers. The temperature of this gas is assumed to be approximately 300K, therefore single walled pipe is used throughout. During Title II, the exit gas temperature will be reexamined. If it is found to be below the dewar point, insulation will be required on the lines inside the torus enclosure.

A pneumatic operated valve is located in each lead drop (2 per magnet) in order to control the gaseous helium flow rate. The pneumatic circuit to these valves provide three valve positions; manually closed, fully opened, partially opened. The partially opened position is sized for normal mirror coil operating helium flow at sonic conditions through the valve. The fully opened position is provided to prevent lead overheating. (Lead temperature increase results in decreasing helium flow for a fixed orifice). Two gaseous helium blowers (vacuum pumps), located in the mechanical equipment building, maintain line suction and sonic flow through each valve in both valve positions. Accumulators will be analyzed during Title II and included if required.

Quench relief provisions for the gyrotron magnet dewars are integral with the dewar. No additional relief is contained in the distribution piping. Quench helium from the gyrotrons is also vented within the device enclosure. There is no current plan to collect and/or recycle gyrotron quench gas.

Helium supply/return drops interface with the gyrotrons through bayonet fittings. A large percentage of the drop length is vacuum jacketed flex hose. Drops tee off the supply manifold between adjacent gyrotrons. This configuration, coupled with the built in line flexibility, provides frontal access for the support equipment used to install/replace gyrotron tubes.

Electrical leads on the superconducting gyrotron magnets are not vapor cooled by a separate flow stream. Therefore, all helium from the gyrotrons is cold gas and is manifolded and returned to the cold box.

An extra liquid helium supply drop and bayonet is provided on both the first and second level to service diagnostic devices or other supplemental equipment. The service drop on the first level is operable only during gyrotron batch fill (block valve open).

Piping layout and facility interface requirments will be controlled by the envelope drawings listed in Table VI.

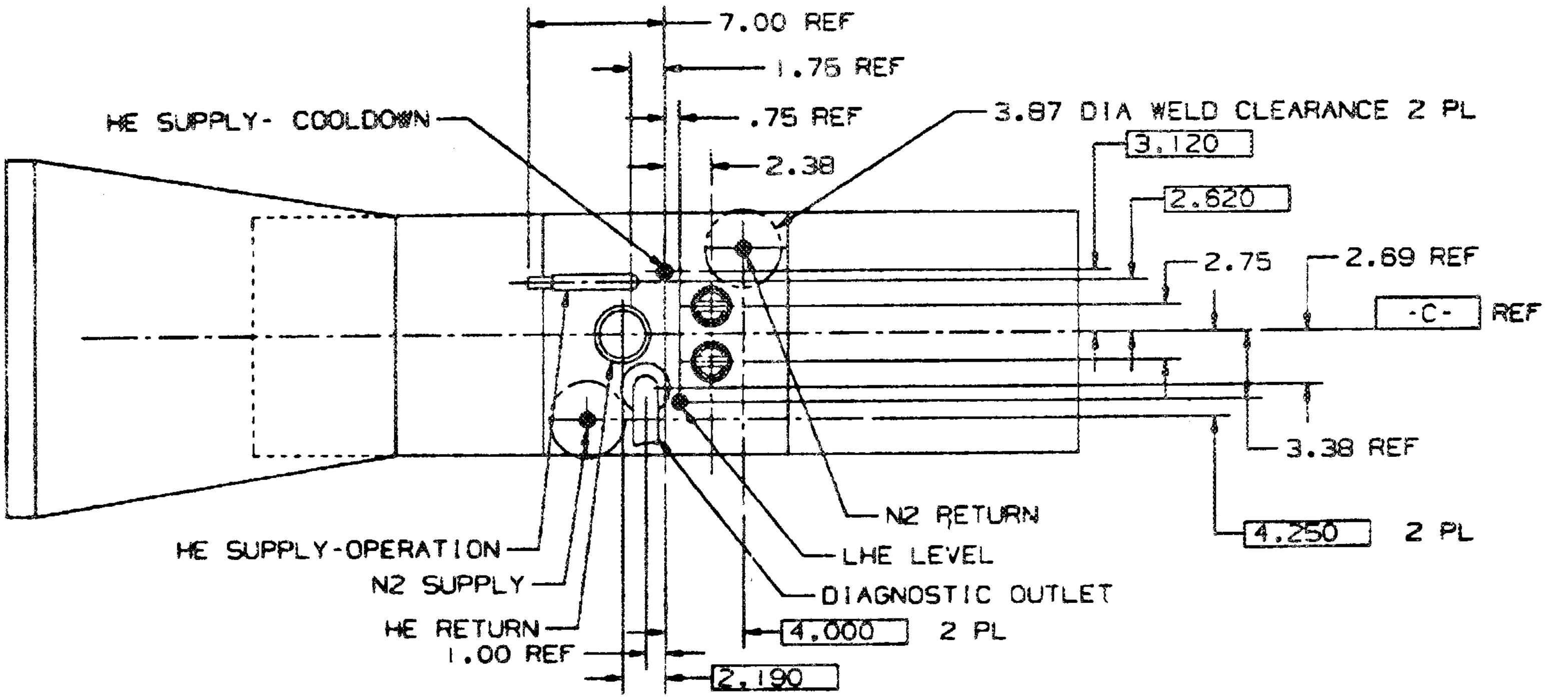
4.4 MIRROR COIL INTERFACE

Cryogenic helium and nitrogen supply and return drops are welded at the magnet interface. Figure 23 and 24 show the general configuration of the magnet interface. Details are shown in drawing 70B373009. The liquid helium supply and return pipes can be removed from the magnet stack to facilitate welding. Clearances for the nitrogen supply and return lines are adequate for either manual or automatic welding. The vapor cooled leads contain internal pipe thread ports to attach the warm helium drops. During Title II, the use of threaded connections in this application will be studied further before making a final decision on their use.

There are two separate liquid helium supply lines utilized on each mirror magnet. Each is provided with a pneumatic operated valve. One is used during cooldown and pipes the liquid to the bottom of the mirror coil dewar. The other is a top fill line that delivers the liquid into the upper end of the mirror coil stack as shown in Figure 25.

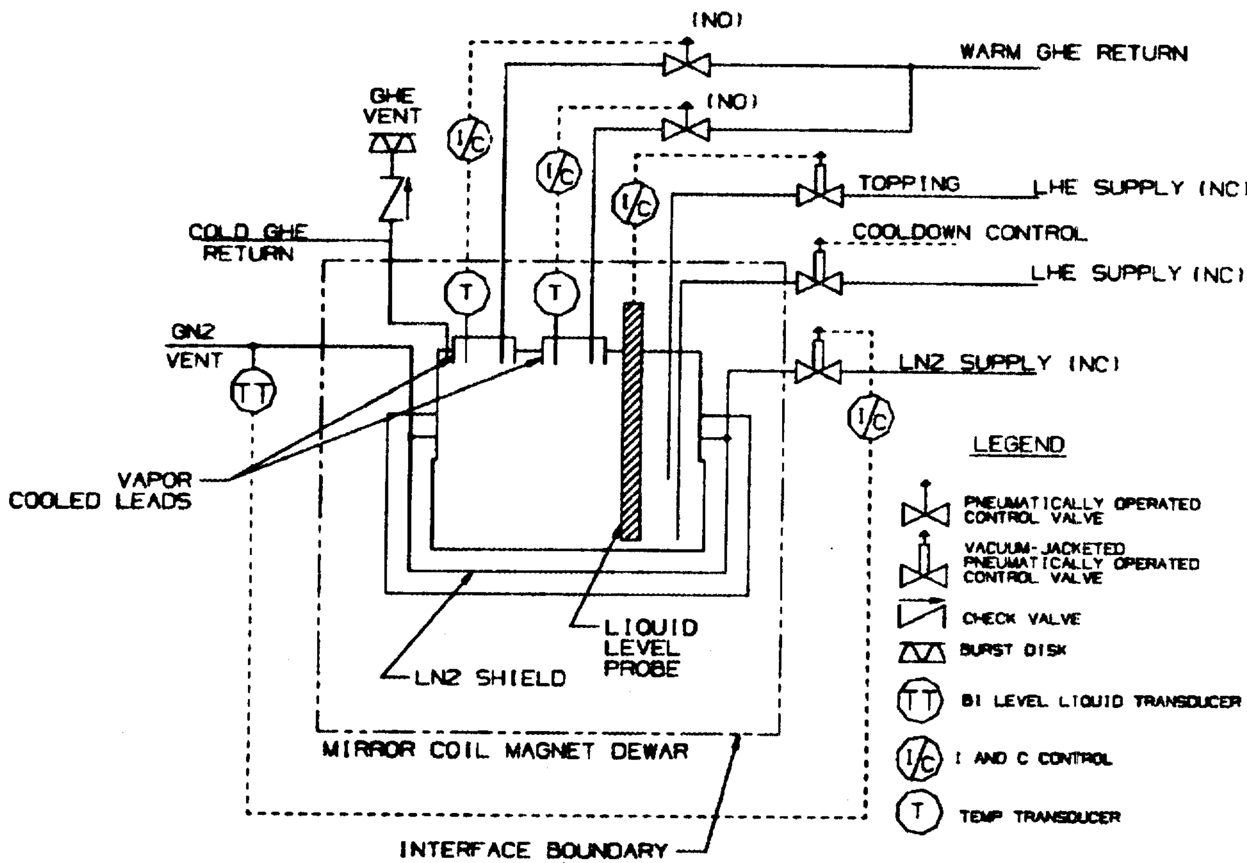
The bottom/top fill approach is a result of cooldown and vapor separation considerations. The bottom fill technique is required for effective and rapid cooldown of the magnet pack. During operation, bottom filling could result in warm helium vapor impinging on the superconducting coils. Helium trapped between the supply valve and the dewar could completely vaporize and begin to warm when the magnet was not demanding liquid. Various alternate methods of filling were considered. The dual line concept was selected because of the low risk involved. See Section 5.0 for details of the analysis.

The interface between the cryogenic system and the mirror magnet involves a number of related concerns that will be resolved during Title II. The major concern is related to the stability of the boiling helium pool in the magnet dewar stack. The stability of the pool



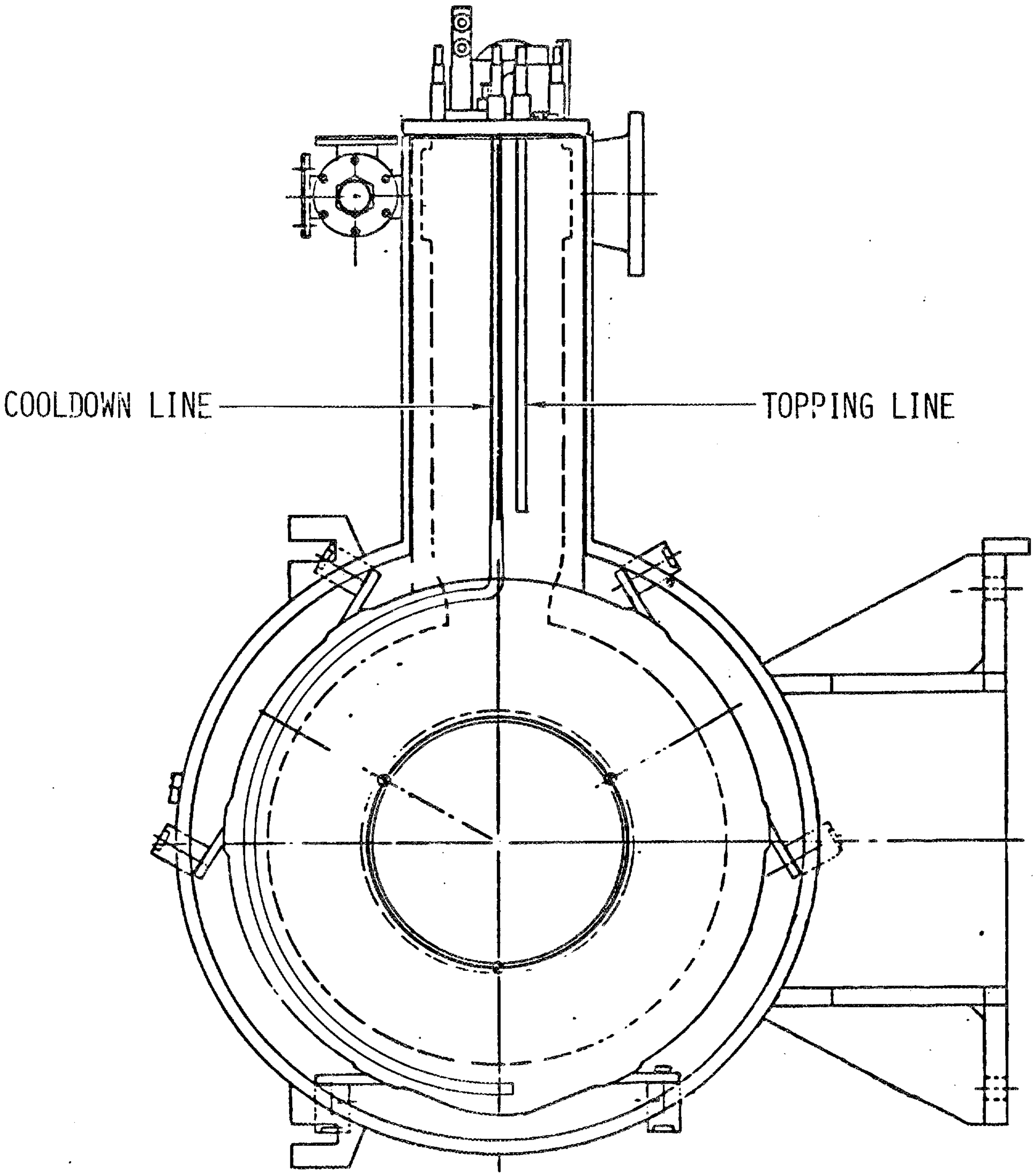
MIRROR COIL INTERFACE

FIGURE 23



MIRROR MAGNET DEWAR
INTERFACE SCHEMATIC

FIGURE 24



MIRROR COIL LHe SUPPLY CONFIGURATION

FIGURE 25

will influence the phase separation process of the fluid that is introduced to maintain the liquid level in the dewar. A highly unstable pool could result in little separation of the liquid from the entrained vapor as fluid is introduced into the dewar.

The helium distribution system maintains a continous supply of liquid that is available to the mirror coils. Instrumentation in the magnet is used to sense the level of the liquid column in the stack and open the supply line valve when the level falls below a specified value. Liquid level height and tolerance is specified by the mirror coil subcontractor.

Gaseous helium is vented either through the magnet stack vent pipe (4.2K gas) or through the vapor cooled leads (300K gas). The stack vent is sized to handle normal operational flow and quench flow to the pressure relief device located in the distribution piping. Suction is provided on the vapor cooled lead return lines to cause sonic flow across valves in the distribution piping. These valves have three positions manually closed, partial open-normal flow, full open-maximum cooling), to protect the leads from overheating during normal operation as well as any anomologous condition.

The liquid nitrogen line is valved on the supply side. Instrumentation on the return side maintains a flooded shield.

All drop lines attaching to the mirror coil contain sufficient flexibility, 1.5 inch minimum in six directions, to allow for alignment after installation. The pipe jacket size is increased at the interface to reduce heat losses in the drop lines.

In the event of a magnet quench, the distribution system will allow either of two modes to re-establish operation:

1. Mirror coil liquid reflood
    - Replace burst disk(s)
    - Open liquid helium cooldown supply valve and reflood affected dewars

   Mirror coil dewar temperature must be 4K to 100K.

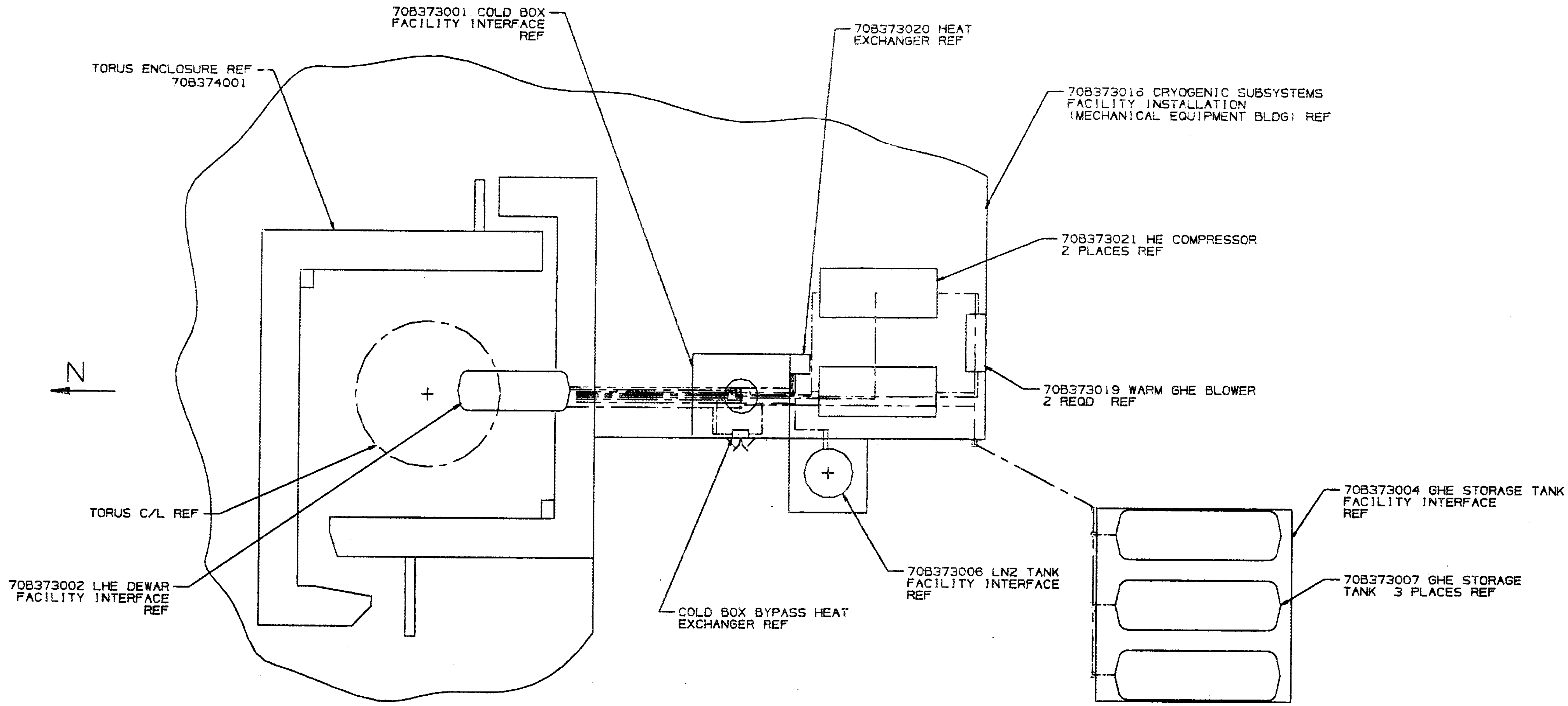
2. Controlled cooldown after quench
   - Replace burst disk(s)
   - Close off liquid helium service to all mirror coils
   - Open bottom fill valve to quenched coils
   - Perform required controlled cooldown procedures for quenched magnets until they reach the temperature of the unquenched magnets
   - Continue cooldown in normal manner

4.5 GASEOUS HELIUM DISTRIBUTION

The gaseous helium distribution system is a closed loop system providing helium to the auxiliary heat exchanger, GHe storage tanks, vapor cooled lead returns and cold box at various temperatures and pressures. The system is designed to recover all gaseous helium during normal modes of operation.

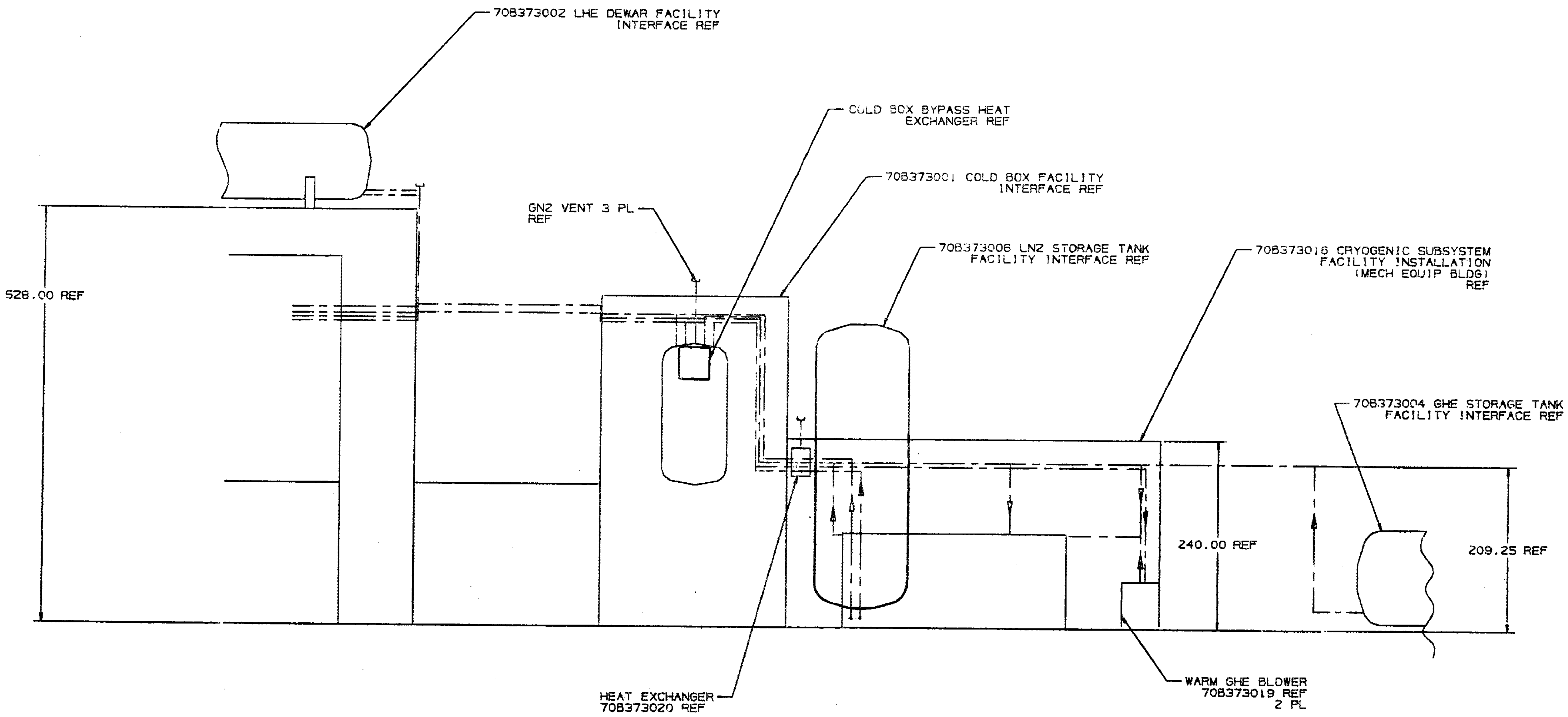
The general piping as shown in Figures 14 through 20, 26, and 27, provides the following flow arrangement:

- Three storage tanks supply warm, low pressure helium to compressor input
- Two parallel compressors supply warm, high pressure helium to the auxiliary heat exchanger and cold box
- The compressors are piped to allow refill of the three storage tanks, using helium return gas, in the event of cold box maintenance or failure
- The auxiliary heat exchanger provides low pressure helium, at temperatures from 300K to 100K, to the mirror magnets during cooldown
- The cold box supplies medium pressure, cold helium to the liquid helium storage dewar for liquefaction and low pressure, cold helium to the mirror magnets during cooldown.
- Warm helium is returned from the mirror magnet vapor cooled leads and cold box to the compressor first stage (two parallel redundant gaseous helium blowers (vacuum pumps) maintain the mirror magnet vapor cooled lead valve pressure for sonic flow).
- Cold helium is returned from the mirror magnets, gyrotrons, and liquid helium dewar to the cold box.



GENERAL PIPING LAYOUT
PLAN VIEW
FIGURE 26

(SEE DWG 70B373011)



GENERAL PIPING LAYOUT
SIDE VIEW
FIGURE 27

(SEE DWG 70B373011)

- A cold box bypass heat exchanger is provided to warm the helium and return it to compressor first stage during cold box maintenance.
- A parallel line allows cold helium from the torus mirror coils and gyrotrons to be passed through the auxiliary heat exchanger during cooldown.

Three gaseous helium storage tanks with a combined volume of 7500 cubic feet (water volume) minimum are located adjacent to the mechanical equipment building. These tanks have a design pressure of 300 psig at 70F and can be filled from cylinder trailers or by the refrigerator/liquefier compressors. The latter option is provided to recover helium return gas during cold box maintenance. This option can also be used to continue device operation for a short period in the event of a cold box failure. The tanks and piping are designed to allow the addition of extra tanks in the future.

Two parallel compressor skids are located within the mechanical equipment building. Each skid is capable of maintaining the standby flow rates thus allowing compressor maintenance during the stand by mode. See section 4.7 for details on the liquifier/refrigerator.

An auxiliary heat exchanger is used for device cooldown/warm up operations. High pressure warm helium is regulated down and passed through a liquid nitrogen cooled heat exchanger. The liquid nitrogen flow rate is modulated to provide a controlled cooldown rate of the mirror magnets from 300K to 100K. Return cooldown gas is piped back to the auxiliary heat exchanger and used to refrigerate the incoming warm helium stream. An electric heater is used during warm up. Cooldown performance requirements are shown in Table VII.

Table VII Cooldown Performance Requirements at Each Mirror and Gyrotron Dewar Interface

Load Temperature Range K	Cooldown Element	GHe Flow Rate g/s	Inlet Pressure PSIA	Minimum Inlet Temperature °K	Inlet-Outlet ΔT °K Max	Min
			Mirror Magnet			
300-100	Aux. Heat Exchanger	3.4	25	80	220	10
100-10	Cold Box	2.1	25	50	35	5
		2.1	25	25	30	5
		2.1	25	10	20	5
10-4.2	Dewar	1.0	15.7	4.2	N/A	N/A
			Gyrotron Magnet			
300-100	Aux. Heat Exchanger	0.5	25	80	220	10
100-10	Cold Box	0.3	25	50	35	5
		0.3	25	25	30	5
		0.3	25	10	20	5
0-4.2	Dewar	1.0	15.7	4.2	N/A	N/A

Cold gaseous helium from the cold box is piped to the liquid helium storage dewar for liquifaction (see Section 4.3) and to the torus mirror coils and gyrotron magnets during cooldown. Cold box cold gaseous helium and liquid helium utilize common delivery piping within the device enclosure building. (Cooldown procedures are to be performed simultaneously on both levels. See Section 4.2 for torus mirror coil quench recovery and gyrotron batch fill procedure outlines). See Section 4.7 for details on the liquifier/refrigerator.

4.6 LIQUID NITROGEN DISTRIBUTION

The liquid nitrogen distribution system is a vacuum jacketed open loop system. It provides saturated liquid, from a storage dewar located adjacent to the mechanical equipment building, to the auxiliary heat exchanger, mirror magnets, gyrotron magnets, vacuum pump traps, and cold box. Warm nitrogen from the liquid nitrogen storage dewar vaporizer circuit is provided for general facility uses in the enclosure. A spare manual valve/bayonet drop is located on both levels on the torus enclosure to service diagnostic needs.

The general piping scheme as shown in Figures 14 through 20, 26, and 27 provides the following flow arrangement:

- Liquid nitrogen is piped through the mechanical equipment building to the device enclosure south wall.
- Liquid to the auxiliary heat exchanger and cold box is teed off this line.
- Within the enclosure wall the liquid flow is split to service both the first (gyrotron) and second (mirror magnet) levels.
- Liquid nitrogen flow to the first level is manifolded around the room with individual drops interfacing with the use points.
- Liquid nitrogen flow to the second level is split once again with each leg servicing a half manifold on the device structure.
- Individual drops interface with the use points.
- Cold gas return from both levels is manifolded and piped outside the enclosure where it is vented.

Design details of the liquid and cold gaseous nitrogen are similar to those for helium listed in Section 4.3.

Liquid nitrogen distribution is configured to supply continuous liquid flow to both levels of the device enclosure building. Bilevel liquid sensors located in the mirror magnet and gyrotron magnet nitrogen shield vent lines operate pneumatic control valves to maintain liquid in the shields. As noted, additional work will be performed on this arrangement during Title II to verify the applicability of this approach.

Cold nitrogen return piping is vacuum jacketed within the enclosure building to preclude frost and moisture formation.

Each mirror coil drop has internal and external pipe bellows to provide a minimum of 1.5 inch flexibility in each of six degrees of freedom for mirror coil alignment. As with the helium drops, the nitrogen drop lines have been located for maximum valve/valve operator accessibility. The nitrogen lines are welded at the magnet interface.

Nitrogen supply/return drops interface at the gyrotron with bayonet fittings. A large percentage of the drop length is vacuum jacketed flex hose, as detailed for the helium lines.

4.7 GASEOUS NITROGEN DISTRIBUTION

A portion of the liquid nitrogen inventory is vaporized by a vaporizer circuit in the storage dewar. Gaseous nitrogen is piped into the device enclosure, 2nd level, to mirror cavities 2 and 32 where it is used for vacuum system repressurization.

The gaseous nitrogen line is teed outside the device enclosure south wall and routed around the enclosure 1st level for use by the vacuum system pump stations. See drawing 70B375023 for detail information.

Gaseous nitrogen use rates for the vacuum system will be determined during Title II.

A utility outlet is also provided within the device enclosure on both levels.

4.8 REFRIGERATOR/LIQUIFIER

The refrigerator/liquefier (R/L) consists of two complete and autonomous compressor skids and a cold box assembly. The capacity of the R/L is 2000 watts of refrigeration and (simultaneously) 280 liters per hour of liquification. When operated as a liquefier from an ambient temperature helium gas supply, it will liquefy approximately 700 liters per hour. Each compressor skid is sized to supply gas to provide an R/L capacity of 1430 watts and 195 liters per hour.

4.8.1 Compressors - The compressors are oil-injected screw machines that supply helium gas for system operation. The compressor drivers are electric induction motors with reduced voltage starting. Two identical compressor skids are utilized. Each skid has the capacity to supply helium to maintain the system in the standby mode while the other is being serviced. The compressors have a minimum performance history of 9000 hours of continuous operation without requiring major maintenance.

Both compressor skids are furnished with all the equipment required for operation. The compressors and associated equipment are supplied as complete skid mounted modules to minimize field installation. Components are shock mounted on the skid or the complete skid is shock mounted to prevent transmission of vibration loads into the skid mounting surface.

The oil separators are designed to require off-line regeneration (cleaning) or blowdown no more frequently than once every 8 hours. Instrumentation is provided to indicate when regeneration is required. A safety shutdown feature is incorporated to stop the compressor prior to separator breakthrough. Blowdown is through a common vent. The oil removal system is a proven design with a performance history of 9000 hours of continuous operation or more without major maintenance.

In addition to safety devices required by the design codes, the following compressor interlocks and audio and visual alarms are provided on the refrigerator/liquefier control panel:

- High pressure alarm
- Vibration shutdown
- Low suction temperature and pressure alarm and shutdown
- Low oil pressure alarm and shutdown
- Low cooling water alarm and shutdown
- Motor overheat alarm and shutdown
- Pressure drop alarm across oil removal devices

Each compressor skid is supplied with the following instrumentation located on the compressor control panel:

- Suction temperature and pressure indicator on the first stage.
- Discharge temperatures on each stage.
- Discharge pressures on each stage.
- Automatic recycle control valve with controller capable of handling full compressor flow.
- A completely automatic anti-surge control system which shall not result in venting of helium gas.
- An orifice meter with a calibrated differential pressure gauge shall be installed in the high pressure discharge line to monitor compressor performance.
- All other instrumentation required for operation.
- Running time meter.

The compressors are designed so that damage to the compressor will not occur in the event of the loss of instrument air, coolant, or electrical power.

The compressors are equipped with a control valve in both the first and second stage suction to provide turndown capability to accommodate the modes and associated flow rates described herein. The compressors are designed for completely independent parallel operation. (Actual refrigerator/liquefier operation during modes requiring less than full flow, i.e., or throttled flow, will be determined during Title II).

Because the pressure in the magnet dewars must be maintained at 14.7 $\pm$ 0.3 psia, the compressor first stage must run sub atmospheric. As a result, the compressor first stage and the piping and associated components connecting to the magnet vent lines must be designed utilizing high vacuum technology.

All pressure vessels and shells of shell and tube heat exchangers are designed, fabricated, inspected, tested and stamped in accordance with ASME Section VIII. The piping is designed, fabricated, inspected and tested in accordance with ANSI B31.3. Heat exchangers conform to TEMA standards. All tubes of shell and tube heat exchanges are welded to the tube sheets to prevent leakage.

4.8.2 Cold Box - The cold box consists of the heat exchangers and turbo-expanders required to refrigerate the helium gas. The cold box vessel containing the heat exchangers and turbo-expanders is constructed of carbon steel and insulated to prevent the temperature of the external surface from dropping 5°C below ambient temperature.

The cold box vessel is suspended from a top hat section and the lower section is configured to allow lowering to provide access to internal cold box components. The cold box structure and the mechanism to lower the bottom section is provided in a modular package. The cold box and structure is supported from the mechanical equipment building floor.

The cold box is designed to withstand the warm-up and cool-down cycles that will be encountered during 10 years of operation. Transition joints utilized within the cold box are capable of withstanding 10,000 temperature cycles from 400K to 4K without loss of structural integrity or measurable leakage. Under steady state operating conditions the cold box is capable of maintaining a vacuum level of less than 1 x 10^{-5} torr via the vacuum system that is supplied as part of the cold box. The piping within the cold box and the penetrations from the box are designed to accommodate thermal motion over the entire operating temperature range. All instruments and valves located within the cold box are accessible with the bottom lowered. The piping is laid out to provide for oil removal by solvent flushing.

The cold box includes a 30 micron filter on the warm inlet process streams to prevent migration of particulate matter into the cold box circuits. Downstream filters are provided to prevent migration of solid particles from desiccant beds. The desiccant beds are sized to prevent fluidization of the bed during all operating conditions. The cold box is equipped with a relief device capable of withstanding full compressor flow in case of failure of high or low pressure components.

The design precludes the entrapment of residual air in stagnant dead ended pipe runs during purge evacuation. The layout is designed to prevent the occurrence of thermal oscillations that could interfere with the cryogenic system operation. All cold box heat exchangers are in accordance with TEMA Standards. Shells of tube and shell heat exchangers meet the requirements of and are stamped in accordance with ASME Section VIII. Tubes of shell and tube heat exchanges are welded to the tube sheet to preclude leakage. All lines connecting the cold box with the compressors are isolated with flexible metal joints on the compressor end.

The turbo-exapnders used in the cold box are the gas or oil bearing type with a proven performance history of 9000 hours of continuous operation. The expander design and installation insures that the expanders will not be damaged or their performance degraded when subjected to the variations in flow, temperature, and pressure that will be encountered during operation. The cold box design allows the expanders to be replaced or repaired with minimal warming of the lines and equipment. The design provides for replacement or repair of the expanders within a period of 8 hours between shut-down and resumption of liquid production at rated capacity.

The turbo-expanders are furnished with inlet filters to prevent particles 10 microns or larger from entering the expanders. The filters are equipped with indicators or alarms to indicate when they require maintenance.

Instrumentation provided on the control panel displays turbine inlet and outlet temperatures and pressures, expander speed, and pressure in the brake loop. Protective devices in addition to those required by codes, include overspeed trip, and bearing gas or oil pressure alarm and shutdown. Running time meters are furnished to show total operating time. Instrumentation and equipment is provided to prevent the expanders from being damaged in the case of the loss of instrument power and or air, coolant, or lubricant.

4.8.3 Gas Purification Subsystem - The gas purification subsystem consists of those elements necessary to remove and trap contaminants entrained in the helium gas stream. The purification subsystem removes all contaminants that could degrade the performance or cause malfunction of the cold box or other components of the system when operated with the EBT-P device. The subsystem is designed to prevent the migration of contaminants into progressively colder stages of the cold box under any combination of operational modes. Regeneration of the elements of the purification subsystem can be accomplished without interrupting operation of the cryogenic system. Instrumentation is provided to indicate when regeneration is required and to monitor stream purity. The subsystem removes and traps contaminants from the following sources during all operational modes.

- Make-up gas from the GHe storage tanks, including impurities in the grade A helium feed gas.
- Mirror magnetic and gyrotron magnet coil and insulation materials (G-10, Nomex, Kapton, Mylar tape and EC910 adhesive)
- Compressor lubricants
- Residual contaminants in lines, etc.
- Normal leakage into the system
- Leakage into the system after a magnet quench through the safety relief check valve when cold or the virtual leak after burst disc replacement.

4.9 GYROTRON INTERFACE

Figures 28 and 29 provides the preliminary configuration at the gyrotron interface. Note that current details of the 60, and 90 GHz gyrotrons are rather nebulous. For the purpose of defining the cryogenic distribution system, an interface plane has been established at which bayonet fittings will be located. Location of this plane and the bayonet requirements are controlled by drawing 70B373013.

Unlike the torus mirror coils, there is only a single helium supply to the gyrotron magnet. This single line is used to both cool and batch fill the gyrotron magnet dewar to its required liquid helium level.

There is no current requirement for controlled cooldown of the gyrotron magnets. Initial cooldown, done in concert with the mirror magnets, will be as specified for the mirror coils. Subsequent refills of the gyrotron magnet reservoirs (batch fill) will be done by forced liquid flow. Depending on the time elapsed since the previous fill, the temperature of the supply pipe system, the level of helium remaining in the resorvoirs, etc., some gaseous helium may be forced through the gyrotron magnetic dewars during refill.

Cold gaseous helium is returned to the cold box. A manual valve in the return line is provided to facilitate gyrotron replacement.

The liquid nitrogen piping has a pneumatic valve on the supply and manual valve on the vent. The manual valve is used to isolate the gyrotron as is the valve in the helium return.

All drop lines to the gyrotron contain a large percentage of vacuum jacketed flex line length. This provides not only for the uncertainty of the gyrotron interface but also for frontal access required by gyrotron maintenance equipment. Connections at the gyrotron interface are made with bayonets.

4.10 LIQUID NITROGEN STORAGE

The liquid nitrogen storage dewar is a standard commercial liquid customer station with vacuum jacketed withdrawal line. It will be a MVE Model VLS9000 or equivalent as shown in Figure 30. The dewar will be leased from a commercial gas supplier to reduce PACE costs as described in Section 5.4.

The net storage capacity is 9000 gallons with a 75 psig minimum design pressure and a 26 psig nominal operating pressure. A schematic of the dewar is shown in Figure 31.

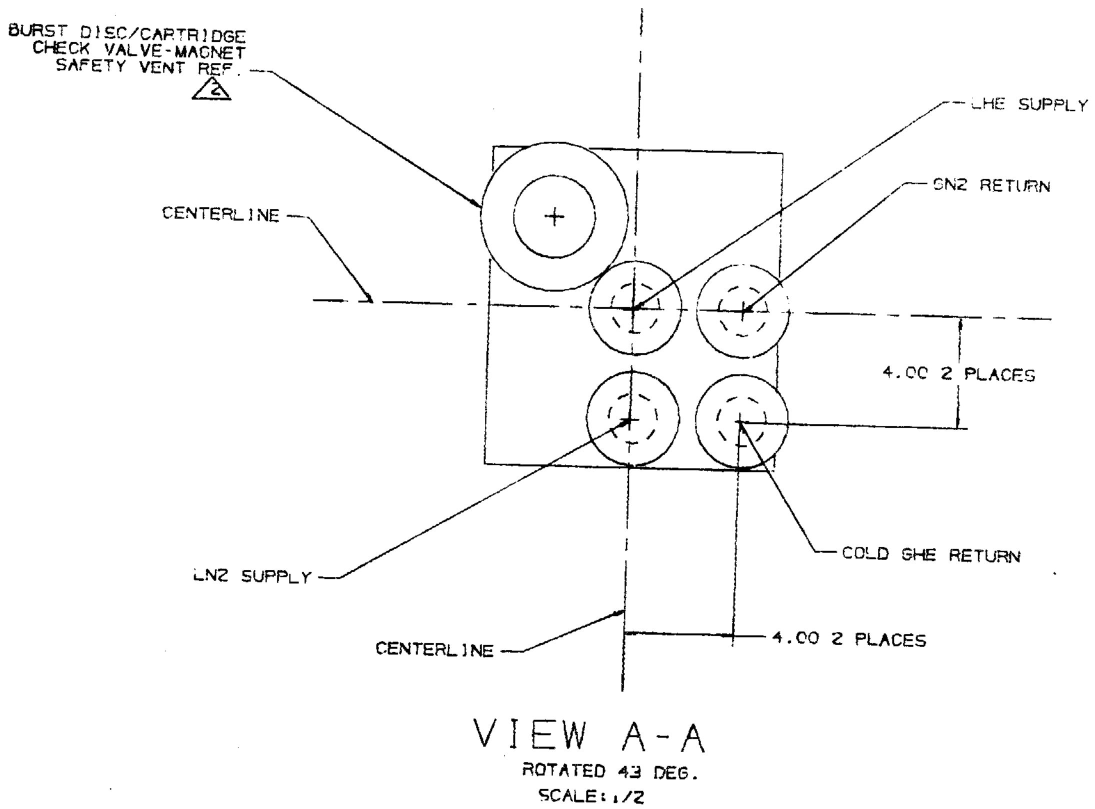
4.11 INSTRUMENTATION AND CONTROL SYSTEM

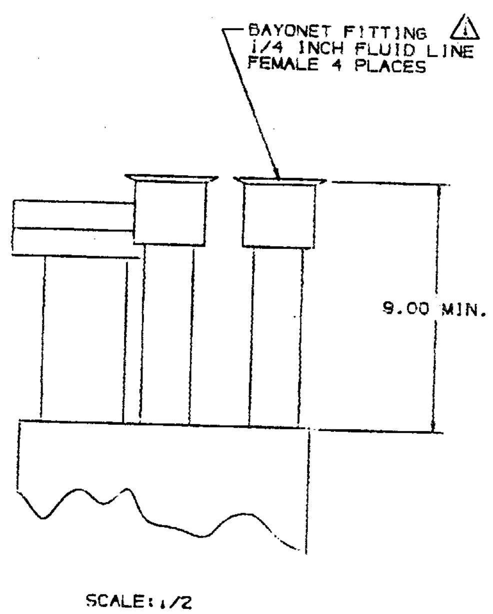
An instrumentation and control (I&C) subsystem is provided to allow a single operator to monitor and control the system during all modes of operation. The instrumentation and control system consists of two major elements. The first includes those instruments and controls that are associated with the distribution system and are provided by MDAC. The second includes those instruments and controls that are associated with the refrigerator/liquefier and are provided by the cryogenic system subcontractor.

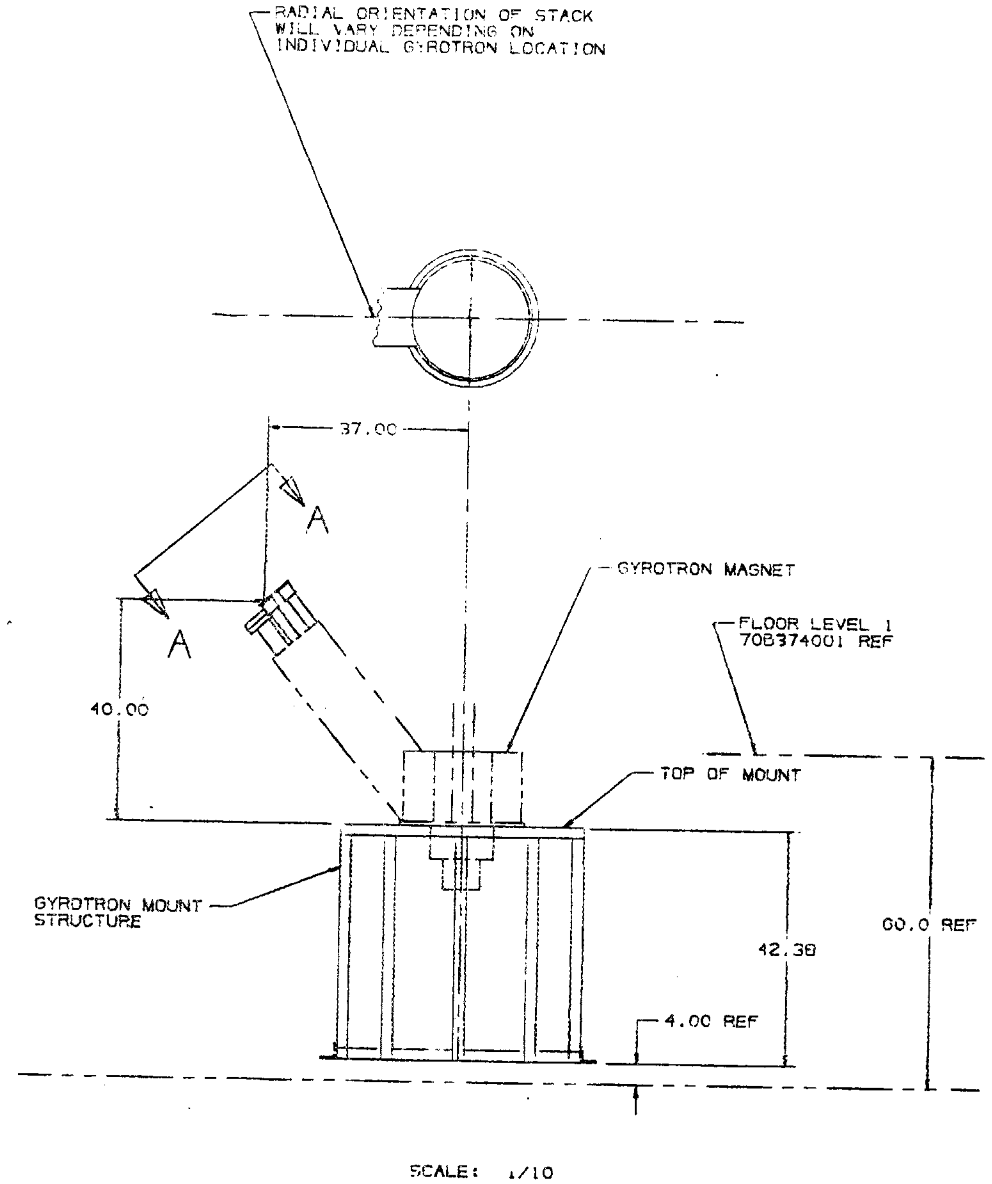
The I&C elements associated with the distribution system are detailed in the I&C Title I report. For clarity those interfaces are shown in Figures 32 through 37. The block diagrams depict the interface between MDAC and the cryogenic system subcontractor.

The subcontractor provides the complete subsystem except as follows:

- Providing and processing the output signal of the liquid level transducers and supplying the 3-15 psig pneumatic control signals to the mirror magnet and gryotron magnet dewar helium fill valves.
- Processing the output signal of the bilevel liquid transducers and supplying the 3-15 psig pneumatic control signals to the mirror magnet and gyrotron magnet dewar nitrogen shield fill valves.
- Providing and processing the output signal of the vapor cooled lead temperature transducers and supplying the 3-15 psig pneumatic control signals to the mirror magnet vapor cooled lead valves.
- Providing and processing the output signal of the mirror coil bobbin transducers and supplying the control signals to the auxiliary heat exchanger. MDAC will provide a 3-15 psig pneumatic signal to control LN_2 flow during cooldown and a 0-5 vdc signal to control the heater during warm-up.

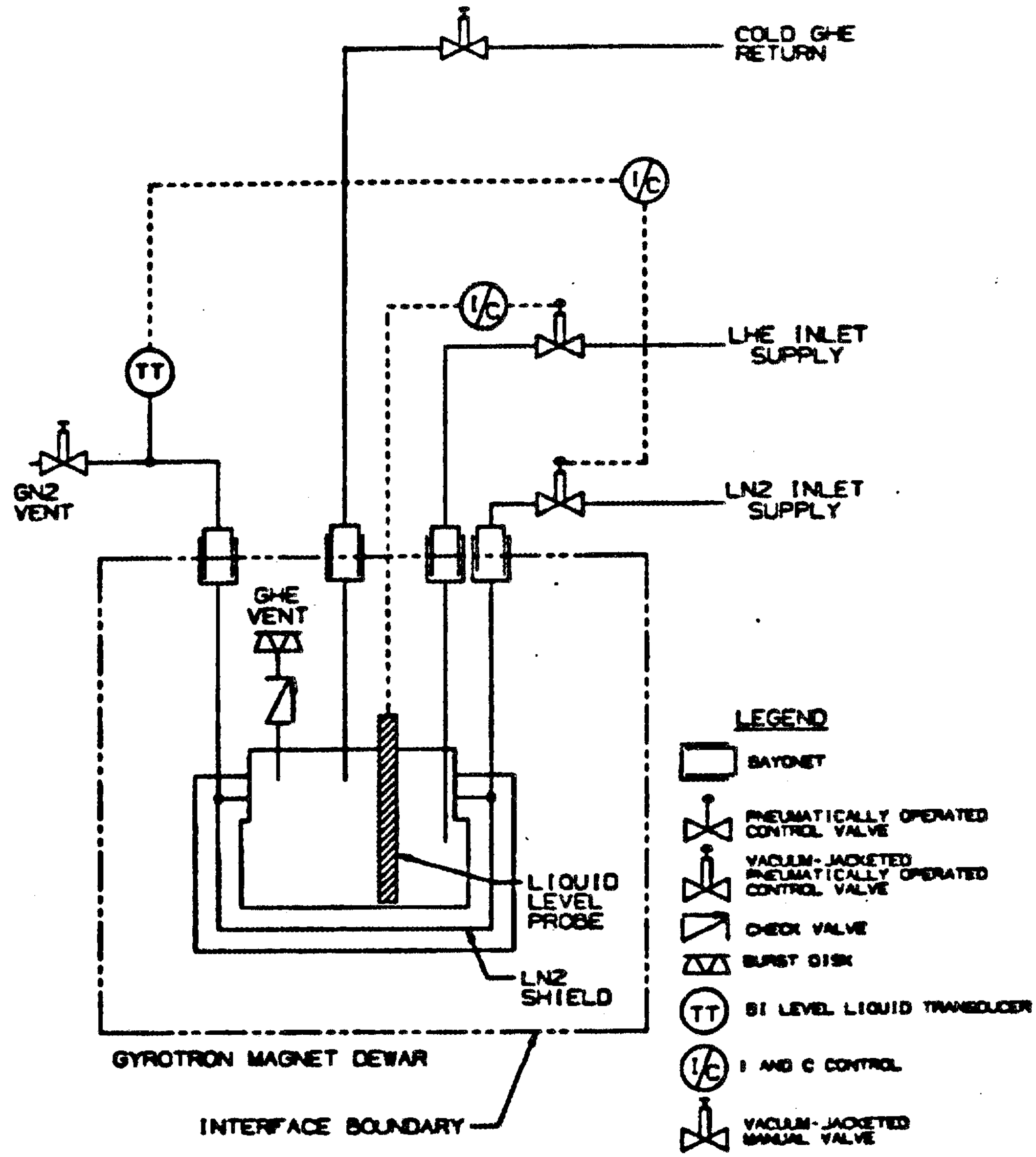






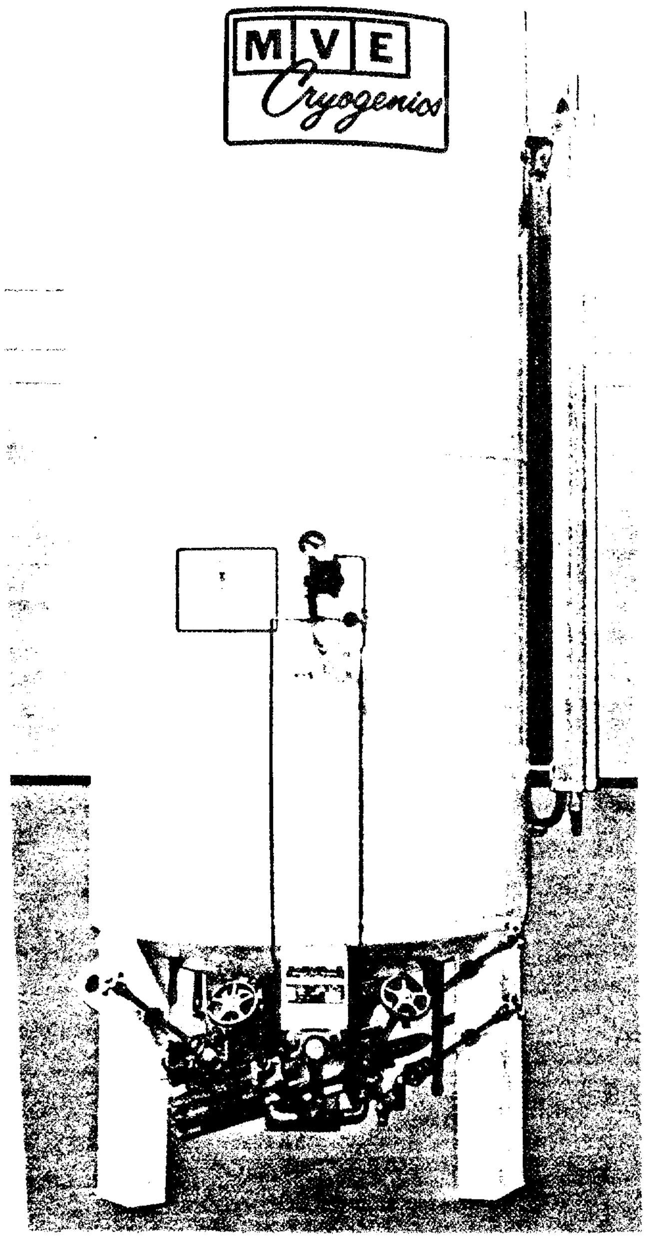
GYROTRON SUPERCONDUCTING MAGNET INTERFACE
FIGURE 28

(SEE DWG 708373013)

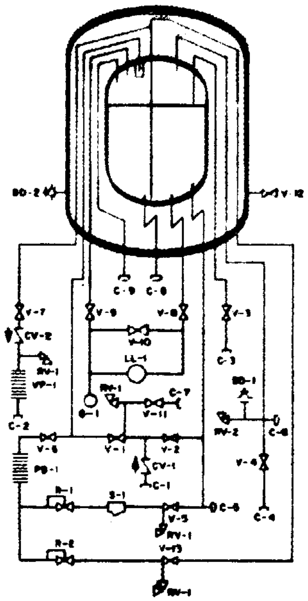


GYROTRON MAGNET INTERFACE

FIGURE 29



LN$_2$ DEWAR
FIGURE 30



NOMENCLATURE

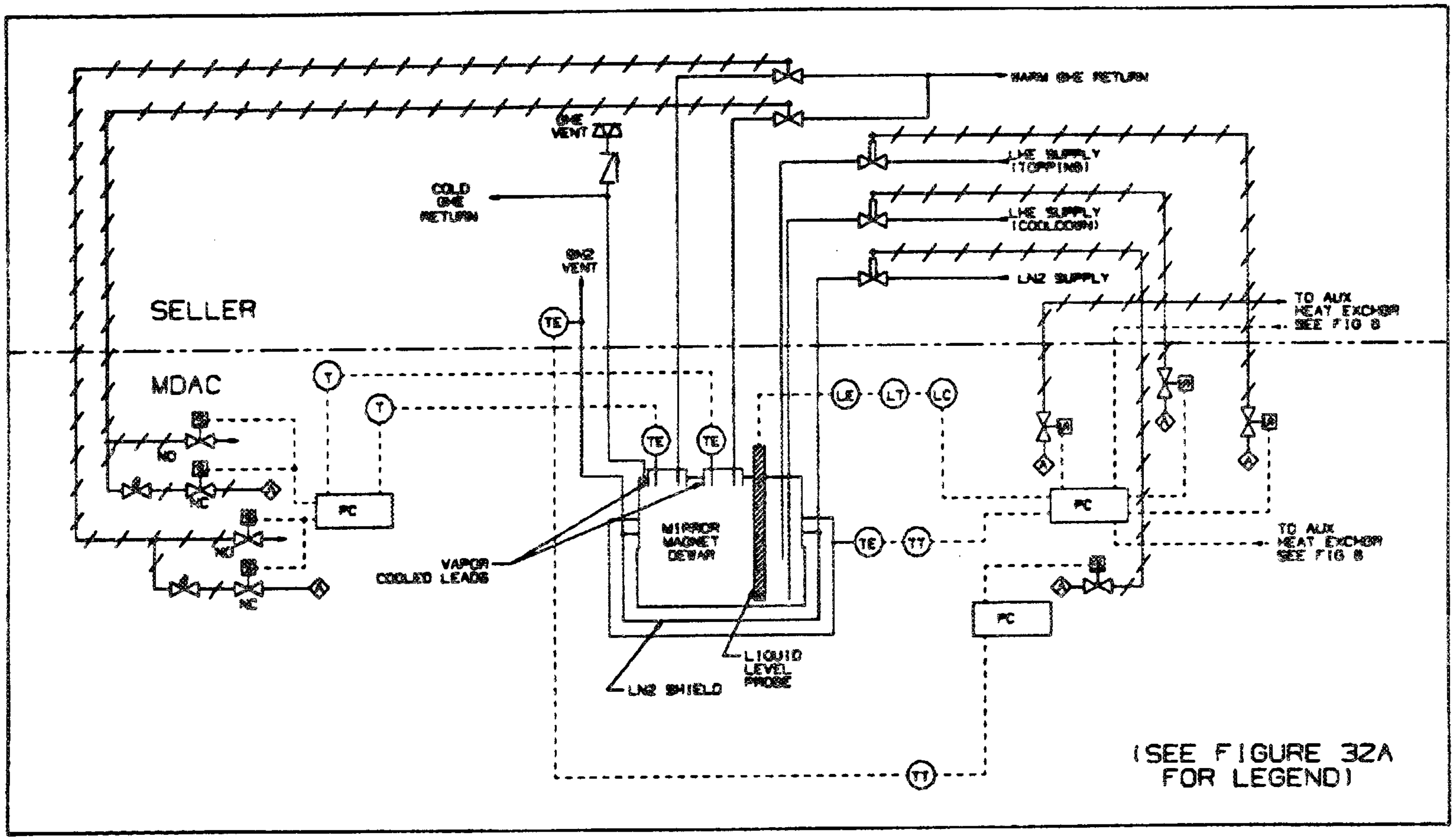
SYMBOL	DESCRIPTION
V-1	VALVE, TOP FILL
V-2	VALVE, BOTTOM FILL
V-3	VALVE, FULL TRYCOCK
V-4	VALVE, VENT
V-5	VALVE, PRESSURE BUILDING
V-6	VALVE, PRESSURE BUILDING AND ECONOMIZER ISOLATION
V-7	VALVE, GAS USE
V-8	VALVE, LIQUID PHASE (HIGH)
V-9	VALVE, GAS PHASE (LOW)
V-10	VALVE, EQUALIZATION
V-11	VALVE, DRAIN
V-12	VALVE, EVACUATION

SYMBOL	DESCRIPTION
V-13	ISOLATION VALVE, ECONOMIZER
CV-1	CHECK VALVE, FILL
CV-2	CHECK VALVE, GAS USE
R-1	REGULATOR, PRESSURE BUILDING
R-2	REGULATOR, ECONOMIZER
RV-1	RELIEF VALVE, LINE, 350 P.S.I.
RV-2	RELIEF VALVE, TANK
BD-1	BURST DISC, TANK
BD-2	BURST DISC, ANNULAS
PB-1	PRESSURE BUILDING COIL
LL-1	GAUGE, LIQUID LEVEL
G-1	GAUGE, PRESSURE
S-1	STRAINER

SYMBOL	DESCRIPTION
C-1	CONNECTION, FILL
C-2	CONNECTION, GAS USE
C-3	CONNECTION, FULL TRYCOCK
C-4	CONNECTION, VENT
C-5	CONNECTION, LIQUID WITHDRAWAL (CAPPED)
C-6	CONNECTION, VENT (CAPPED)
C-7	CONNECTION, DRAIN
C-8	CONNECTION, PUMP WITHDRAWAL (CAPPED)
C-9	CONNECTION, PUMP RETURN (CAPPED)
VP-1	VAPORIZER

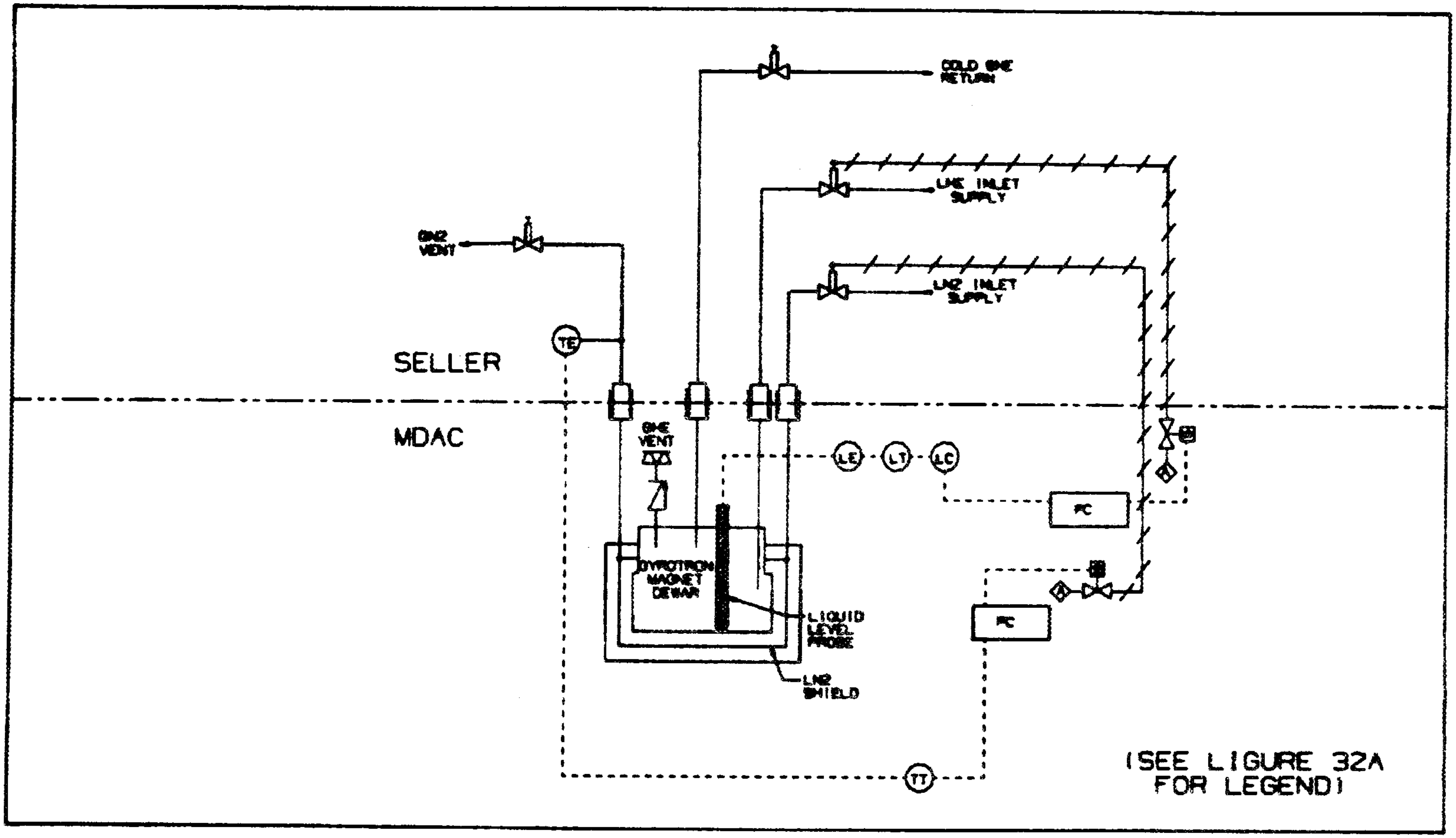
LN_2 DEWAR SCHEMATIC

FIGURE 31



MIRROR MAGNET I&C INTERFACE

FIGURE 32



GYROTRON MAGNET I&C INTERFACE

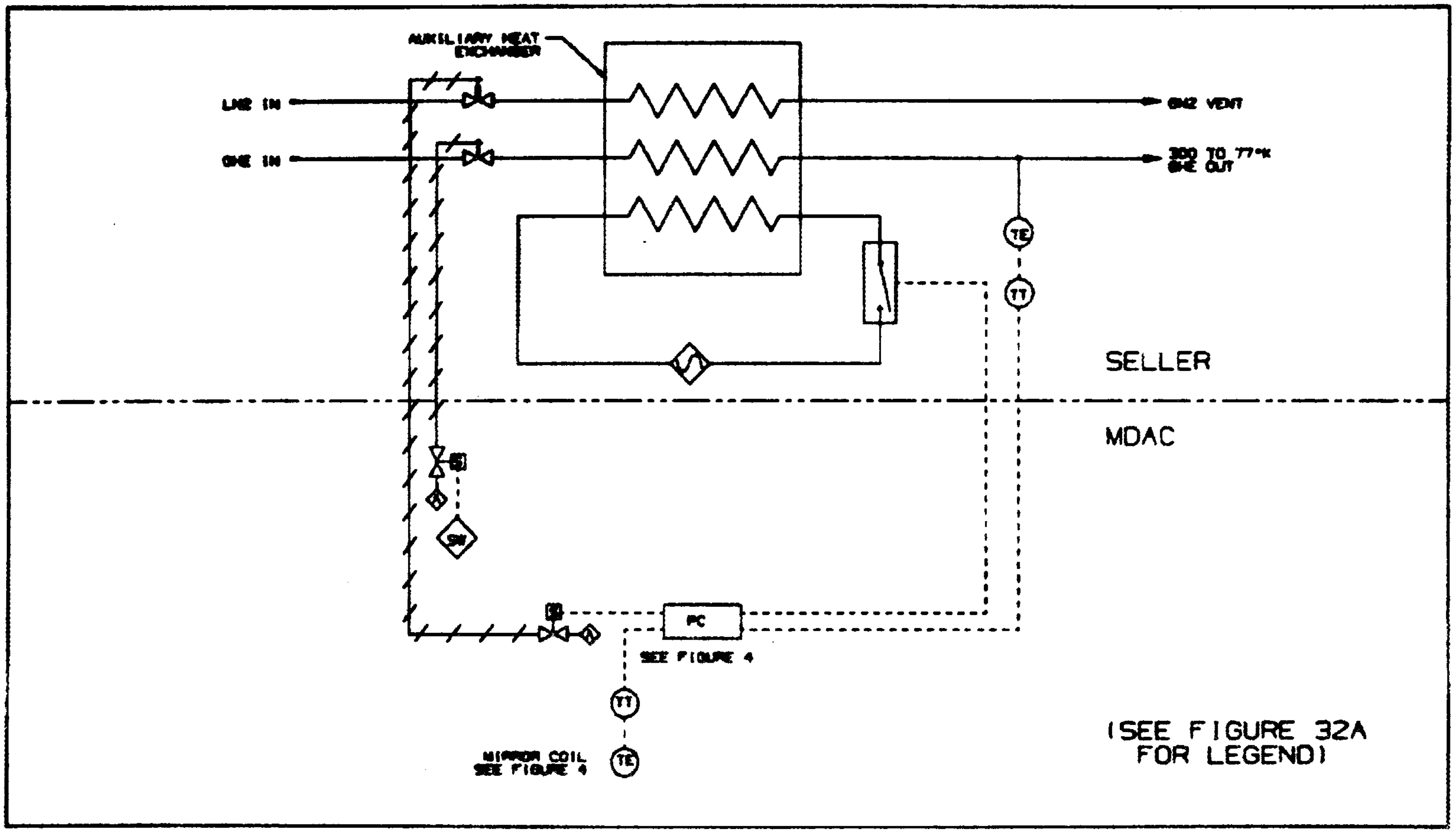
FIGURE 33

LEGEND

	AIR
	COMMAND
	INTERLOCK
	OUTPUT
	SOFTWARE
	AC POWER
	AC RELAY
	BAYONET
	SOLENOID VALVE
	MANUAL VALVE
	PNEUMATIC VALVE
	VAC JACKETED PNEU VALVE
	RELIEF VALVE
	CHECK VALVE
	BURST DISK
	SWITCH
	PRESS REGULATOR
	AIR LINE

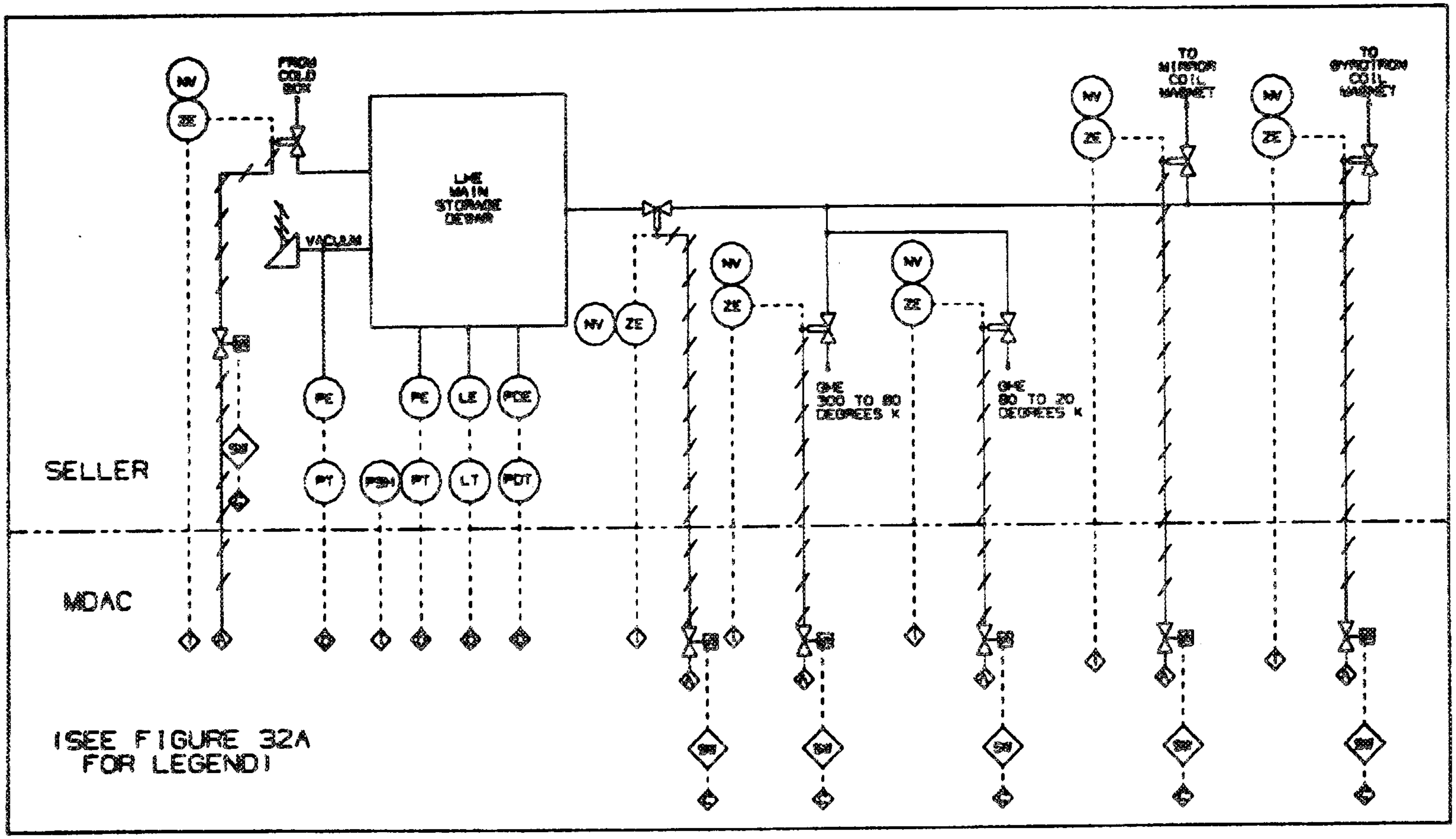
JC	CURRENT CONTROLLER
LE	LEVEL SENSOR
LT	LEVEL TRANSDUCER
NV	PNEU VALVE
PC	PROCESS CONTROLLER
PDE	DELTA PRESSURE SENSOR
PDT	DELTA PRESSURE TRANSDUCER
PE	PRESSURE SENSOR
PSH	OVERPRESSURE SWITCH
PT	PRESSURE TRANSDUCER
SE	SPEED SENSOR
ST	SPEED TRANSDUCER
T	BILEVEL LIQUID TRANSDUCER
TE	TEMPERATURE SENSOR
TT	TEMP TRANSDUCER
ZE	POSITION SENSOR

(LEGEND FOR FIGURES 32 - 37A)
FIGURE 32A



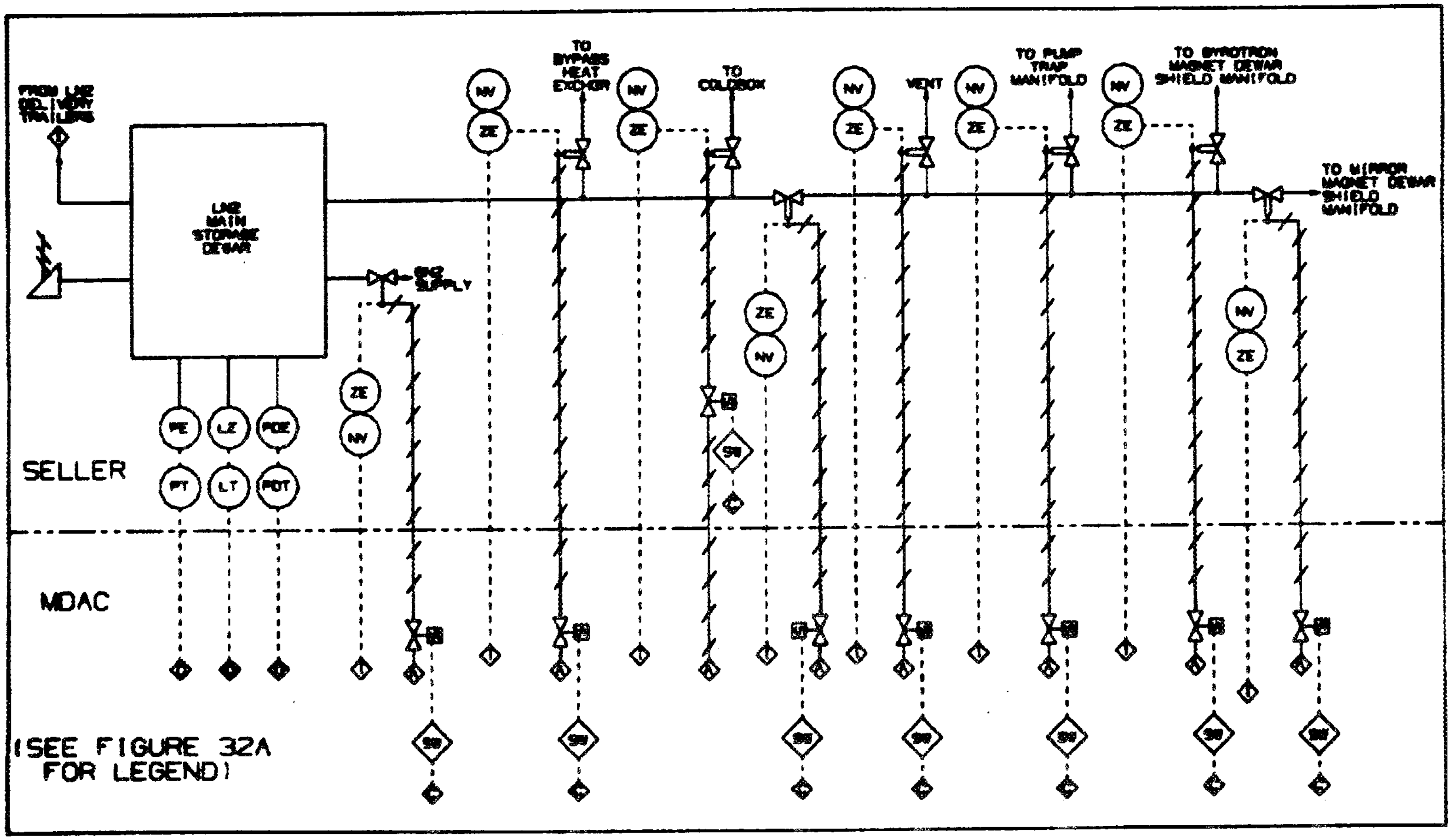
AUX HEAT EXCHANGER I&C INTERFACE

FIGURE 34



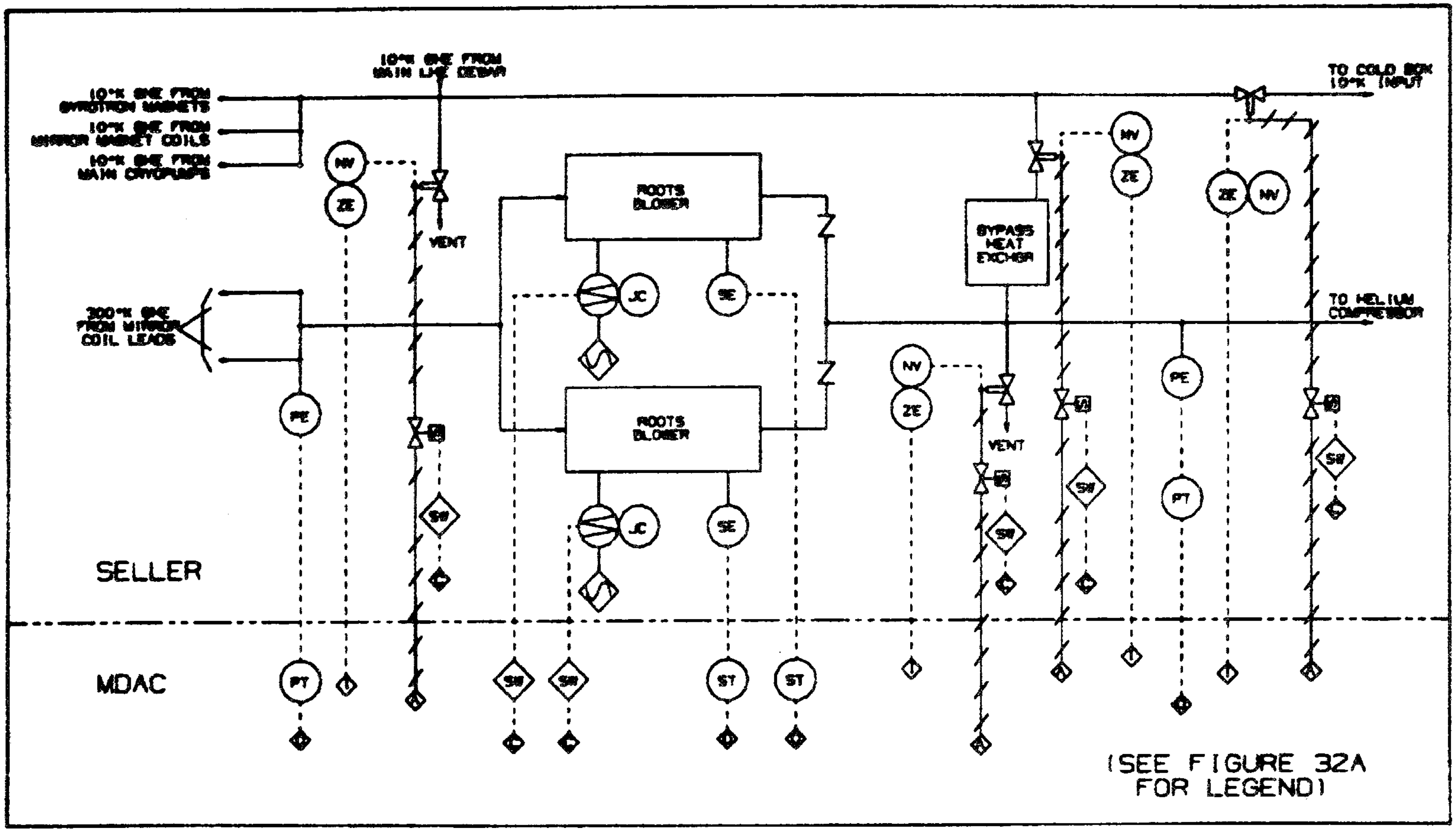
HELIUM DISTRIBUTION SYSTEM I&C BLOCK DIAGRAM

FIGURE 35



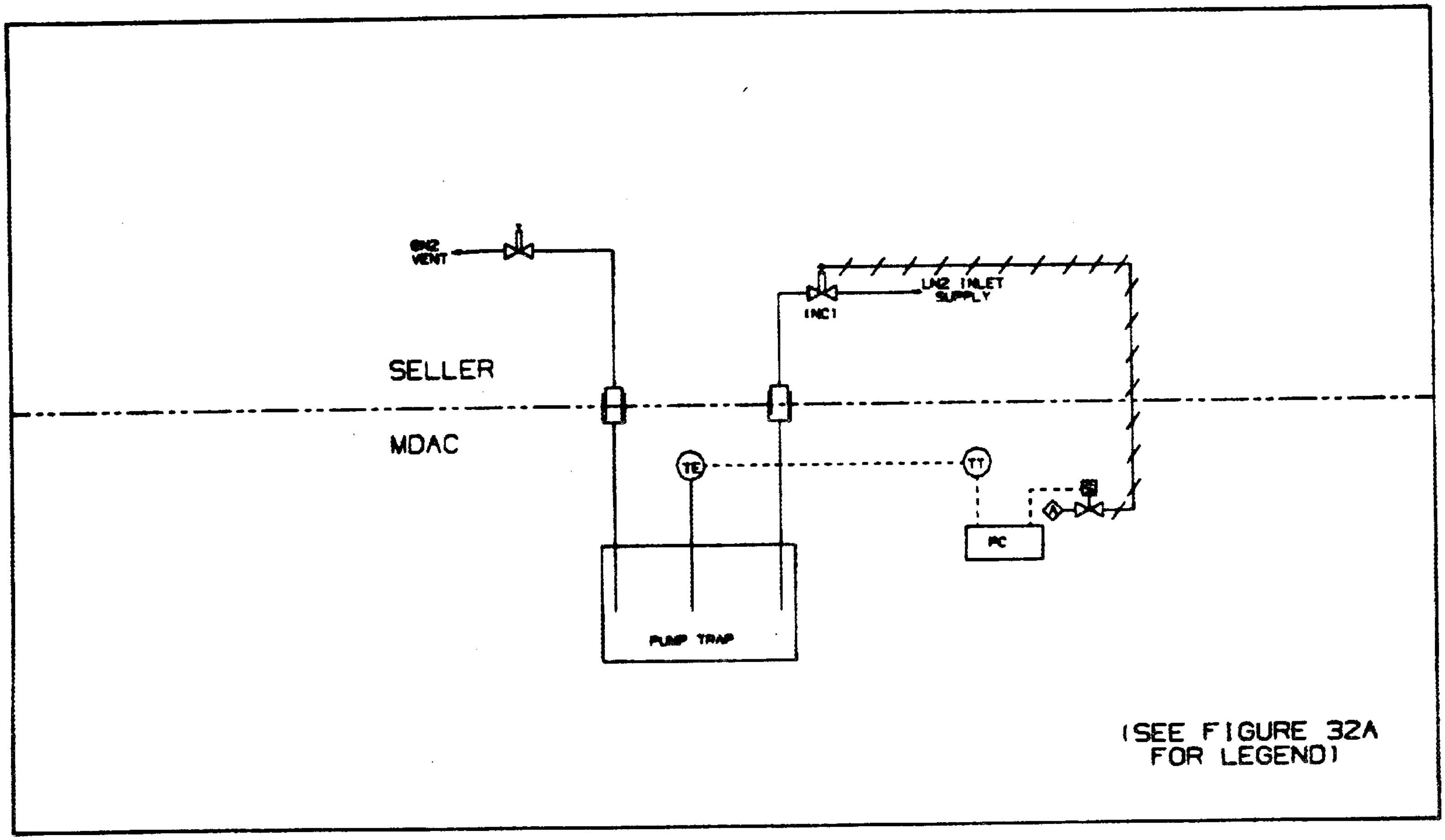
NITROGEN DISTRIBUTION SYSTEM I&C BLOCK DIAGRAM

FIGURE 36



HELIUM RETURN I&C BLOCK DIAGRAM

FIGURE 37



PUMP TRAP DEVICE I&C INTERFACE

FIGURE 37A

A secondary control center is located in the EBT-P control room as shown in Drawing 70B378011 and provides the necessary control functions for both manual or computer assisted operation. The secondary control center mimics a control console located in the mechanical equipment building. The complete system (MDAC I & C and subcontractor equipment) provides all control and monitoring functions required to operate the complete system. The control functions are designed as interlocked permissives using an Allen Bradley PLC-3 Process Controller. The refrigerator/liquefier and cryogenic distribution system control center includes a process flow schematic. Cryogenic system status, caution and warning, and master control are accomplished from the EBT-P Master Control Console (MCC) as shown in Drawing 70B378011.

Control of the complete cryogenic system except as noted is performed from either the control console or the secondary control center, but not from both simultaneously. The transfer of control from either location is bumpless for the discrete and analog systems. All automatic safety shutdown controls required to protect the facility or equipment, are independent of either manual or computer operating control. Annunciation of each shutdown is displayed on both the control console, secondary control center and monitored by the computer.

The control console provides visible indications for the valve positions and compressor on/off conditions. Contact closures for these are also provided for the secondary control center. Fault conditions that preclude normal operation of the helium refrigerator/liquefier are displayed on the control console and secondary control center with interface capability to the MCC and computer system. The secondary control center provides meters or digital displays for all flow meters, temperature and pressure measurements, or other readouts essential to operation of the helium refrigerator/liquefier, and distribution systems. Analog or binary-coded signals representing these quantities are provided for MCC status and control.

4.12 OPEN DESIGN ISSUES

A number of design issues remain unresolved at the conclusion of Title I preliminary design. These issues will be addressed and resolved during Title II detailed design. The issues and resolution approaches are summarized in Table VIII.

Table VIII Design Issues and Resolution Approach

Issue	Resolution Approach
• Mirror Magnet Cooldown	• Determine schedules and instrumentation requirements during machine development testing.
• Mirror Magnet Burst Disc Setting	• GDC to rerun analysis. Set pressure to be verified during machine development testing.
• Mirror Magnet Relief Check Valve	• MDAC to analyze and further define hardware implementation.
• Mirror Magnet Pool Stability and Vent Line Vapor Entrainment	• To be evaluated during machine development testing along with implementation of fill valve.
• Vent Line Connective Heat Transfer	• MDAC to analyze and verify results during machine development testing.
• LN_2 Shield Flow Control	• MDAC to analyze and compare to true flooded system. Selected approach to be verified during machine development testing.
• Gyrotron Configuration	• MDAC to impose design requirements on supplier(s).
• Distribution System Bleed By Pass	• MDAC to verify requirement and select hardware approach.
• Valve Seals	• MDAC to monitor CVI tests and obtain life cycle data during machine development testing.
• Vapor Cooled Lead Flow	• MDAC to analyze and verify results during machine development testing.
• R/L Operation- Full Flow vs Turn Down	• MDAC and cryogenic subcontractor will determine during Title II.

Table VIII Design Issues and Resolution Approach (Continued)

Issue	Resolution Approach
• Distribution System Heat Loads	• MDAC and cryogenic subcontractor will optimize distribution system during Title II.
• Valve Motor Magnetic Materials	• MDAC will determine effect on field uniformity during Title II.

5.0 SUPPORTING ANALYSIS

5.1 LIQUID HELIUM DISTRIBUTION SYSTEM

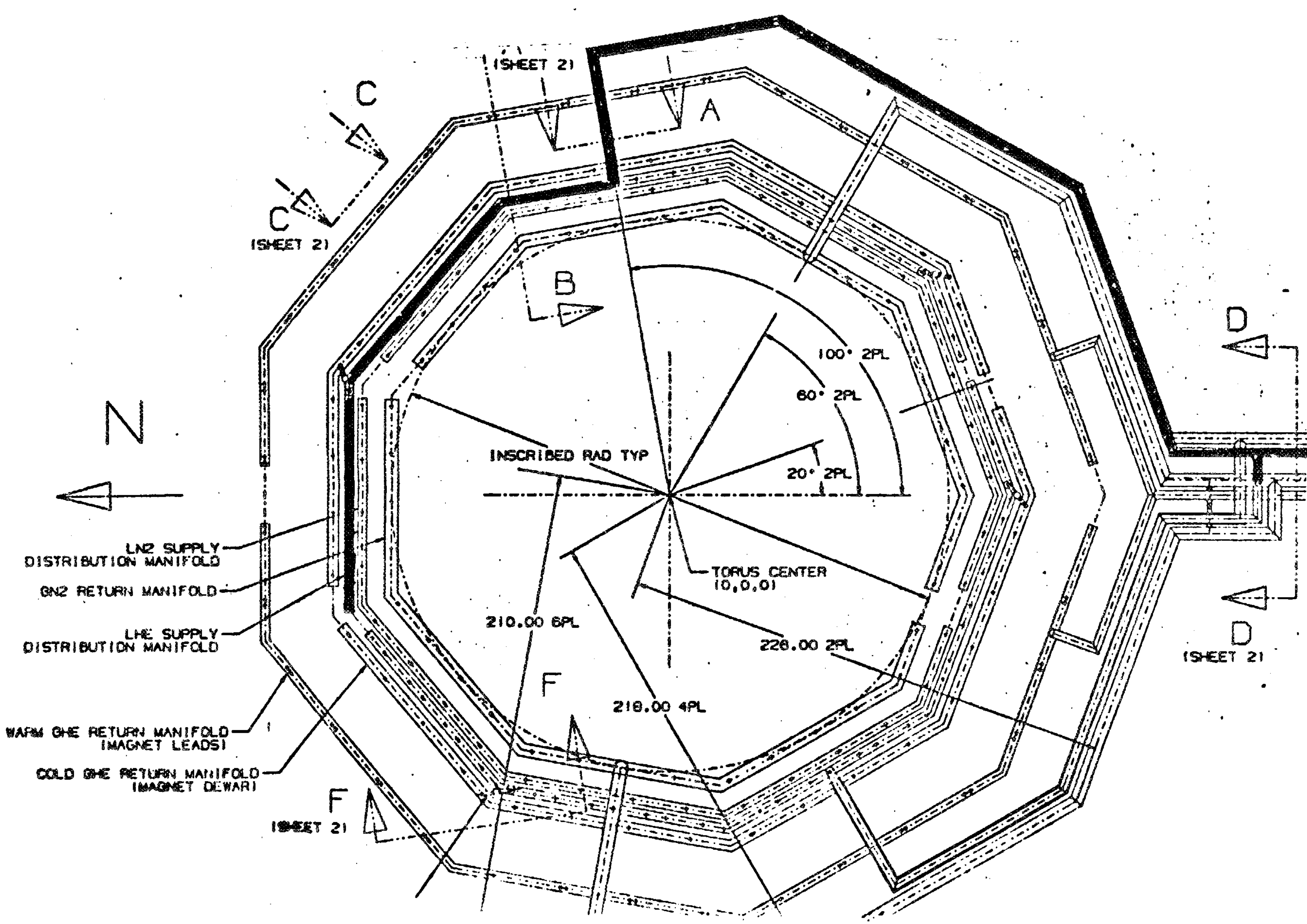
A preliminary study was performed to demonstrate the liquid helium distribution system's capability to supply cryogenic helium to the thirty-six device magnets. Combinations of low LHe mass flowrates and high heat leaks could potentially result in a situation in which only helium vapor would reach the magnet dewars. A secondary objective was to compile a list of the heat leaks into the system for the latest configuration of manifolds, valves, etc.

The approach taken here was, first, to follow the supply LHe transport piping from the main storage dewar down to the individual magnet dewars and identify the heat leaks to the system. Then two potential operating conditions were identified which appeared to be most severe with respect to supplying LHe. Finally, each of these conditions was studied to define the system's performance.

A vacuum-jacketed, 2.0 inch O.D. insulated fluid line supplies the LHe distribution manifold, which in turn feeds the 36 magnet dewars. At each magnet location two LHe supply lines connect the dewar to the manifold. One line, the "bottom-fill line", extends to the bottom of dewar and is used for the initial filling process. The second line, the "top-fill" line, extends only slightly into the stack and is used to maintain the LHe level. One primary motivation for this study was to determine the effects of heat leaks from the bottom-fill line, since during normal operation these heat inputs will ultimately "percolate" up into the supply manifold and thereby get propogated downstream to other magnets. In order to assess these effects the following two conditions were examined:

Condition 1 - No magnets demanding LHe except the last magnet at the end of the manifold run. See Figure 38. Heat leaks from all "upstream" bottom-fill lines were included. This condition will tend to produce large vapor quantities in the manifold at the last magnet location.

Condition 2 - All magnets demanding LHe except the last magnet. From the first magnet on the supply manifold, it's assumed that the dewars fill sequentially. The question here is



LIQUID HELIUM LINE ANALYZED

FIGURE 38

to determine if the magnets upstream of the last will be filled before the last magnet consumes its approximately 20 minute LHe reserve in the stack.

An analytical approach using an expression of the first law was formulated into an automated code to yield the LHe quality at intervals along the flow path, where

$$\text{quality, } x = \frac{\text{mass of vapor}}{\text{mass liq./vapor mixture}}$$

The expression employed related the heat leak, Q, and quality, x, at two locations along the flow-path in the following manner:

$$\dot{Q} = \dot{M}\left[(h_2 - h_1) + \frac{V_2^2 - V_1^2}{2gc} + \frac{g}{gc}(Z_2 - Z_1)\right] \quad (1)$$

where

$$h_2 - h_1 = (h_{f2} - h_{f1}) + (x_2 h_{fg_2} - x_1 h_{fg_1}) \quad (2)$$

Changes in pressure along the flow were approximated from

$$h_{f2} - h_{f1} \doteq \left(\frac{dh}{dp}\right)_{SAT} (P_2 - P_1) \quad (3)$$

Nomenclature:

1	inlet (upstream) flow position
2	outlet (downstream) flow position
$\dot{Q}$	heat leak into LHe
$\dot{M}$	LHe mass flow rate
h_f	enthalpy of saturated liquid
h	enthalpy of LHe flow mixture
h_{fg}	heat of vaporization

V	velocity of LHe flow mixture
Z	elevation relative to datum position
g	gravitational acceleration
g_c	gravitational constant
$\left(\frac{dh}{dp}\right)_{SAT}$	Slope of the saturated liquid curve on enthalpy-pressure coordinates
p	Static pressure of flow

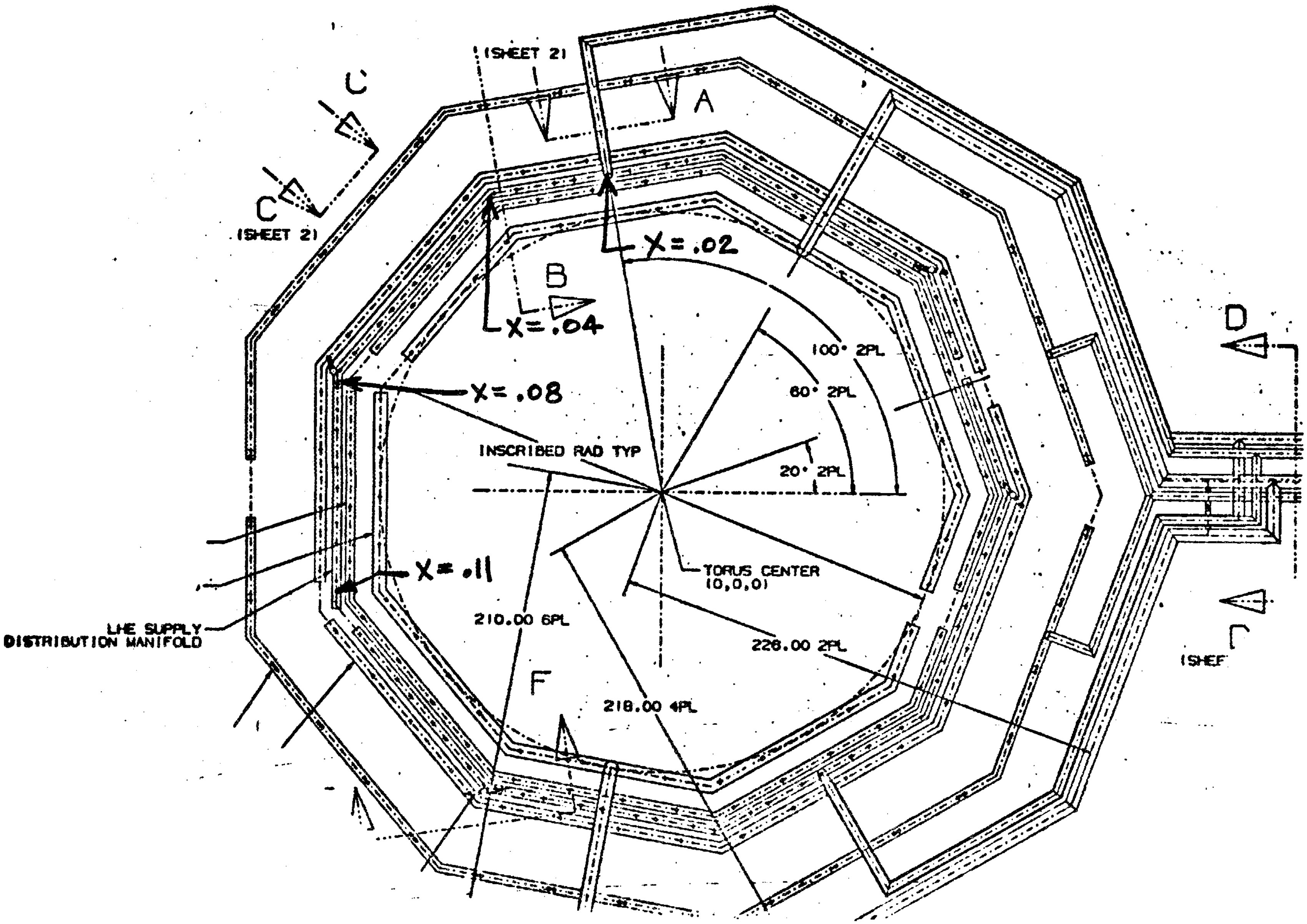
Results were obtained first for condition (1) operation. LHe pressures in the system appear below in Table IX.

Table IX LHe Pressures

14.7 Psia	In Storage Dewar (Assumed)
~15.7 Psia	In Horizontal Distribution Manifold (Calculated)
~14.5 Psia	In Magnet Stack (Calculated)

Pressure losses in the 2 inch O. D. distribution manifold are nil in this condition due to the low (~ 1 Ft/Sec) flow velocities which result. Essentially all of the pressure drop occurs through the 1/2" O. D. fill line and valve. These preliminary results will undoubtedly be refined by subsequent analyses of the proposed system. Variation of the LHe quality along the flow path is shown in Figure 39. Heat leaks, primarily, produce a quality of 11% at the drop and heat leak in the fill line cause an additional increase in quality, so that the last magnet stack is actually supplied with LHe at a quality of 15% (note $V_v/V_v + V_c) =$ 0.57 and a mixture flowrate of ~ 1 ℓ/s. The pressure drop in the cold gaseous helium (GHe) 3 inch O. D. return line from the magnets to the cold box was also assessed. The gas flow rate was based upon a LHe vaporization of 32 ℓ/Hr per magnet less 5 ℓ/Hr for the vapor cooled leads, or 27 ℓ/Hr per magnet. The pressure drop was negligible (< 0.01 psi) in this GHe return line.

For operating Condition (2) it was assumed that the magnets dewars would fill sequentially starting with the dewar nearest the LHe inlet from the manifold. In reality some liquid



LIQUID HELIUM QUALITY IN MANIFOLD - CONDITION 1

FIGURE 39

will likely be filling the "last" magnet also, but for a conservative assessment sequential filling was assumed to compute the time that a full, last magnet must survive. Approximately 11ℓ of stack volume exists to be filled at each of the nine magnet locations by a flowrate of about 0.48 ℓ/s, which is established by the 1.2 psid across the fill line. The result means that all eight magnets "upstream" of the last magnet would be filled within four minutes. Therefore, this last magnet should survive this operating scenario assuming the LHe level in the stack is maintained to provide at least a four minute reserve.

The heat leaks to the LHe distribution system were computed and are based upon measured values for insulated transfer lines, line spacers, and valves as provided by CVI. A summary of these results appears in Table X.

The results of this study indicate that the current design for the LHe distribution system is adequate to supply the magnet dewars with liquid helium under the expected heat load conditions.

Table X Summary of Calculated LHe System Heat Loads

1.	Mirror magnets		
	Conduction/Radiation	19.0W	
	Vapor cooled leads		5.0 ℓ/Hr
	Total 36 magnets	684W	180 ℓ/Hr
2.	Gyrotrons		1.2 ℓ/Hr
	Total for 6	—	7.2 ℓ/Hr
3.	LHe Storage Dewar	3.8W	
4.	Drop lines		
	Supply 7.92 W ea. Total =	285W	
	Return 2.32 W ea. Total =	83W	
5.	Hex Sections		
	Supply Total	15.9W	
	Return Total	21.1W	
6.	Hex Supply and Return		
	Supply Total	16.7W	
	Return Total	21.6W	
7.	Gyrotron		
	Supply Total	19.3W	
	Return Total	21.9W	
8.	Gyrotron Drop Lines		
	Supply Total	29.4W	
	Return Total	34.6W	
9.	Miscellaneous		
	3" Valves (4)	40.6W	
	2" Valves (4)	18.4W	
	3" Line (40 Ft)	6.4W	
	2" Line (40 Ft)	4.6W	
	TOTAL REFRIGERATION LOAD	1306.2W	
	TOTAL LIQUEFATION LOAD		187.2 ℓ/HR

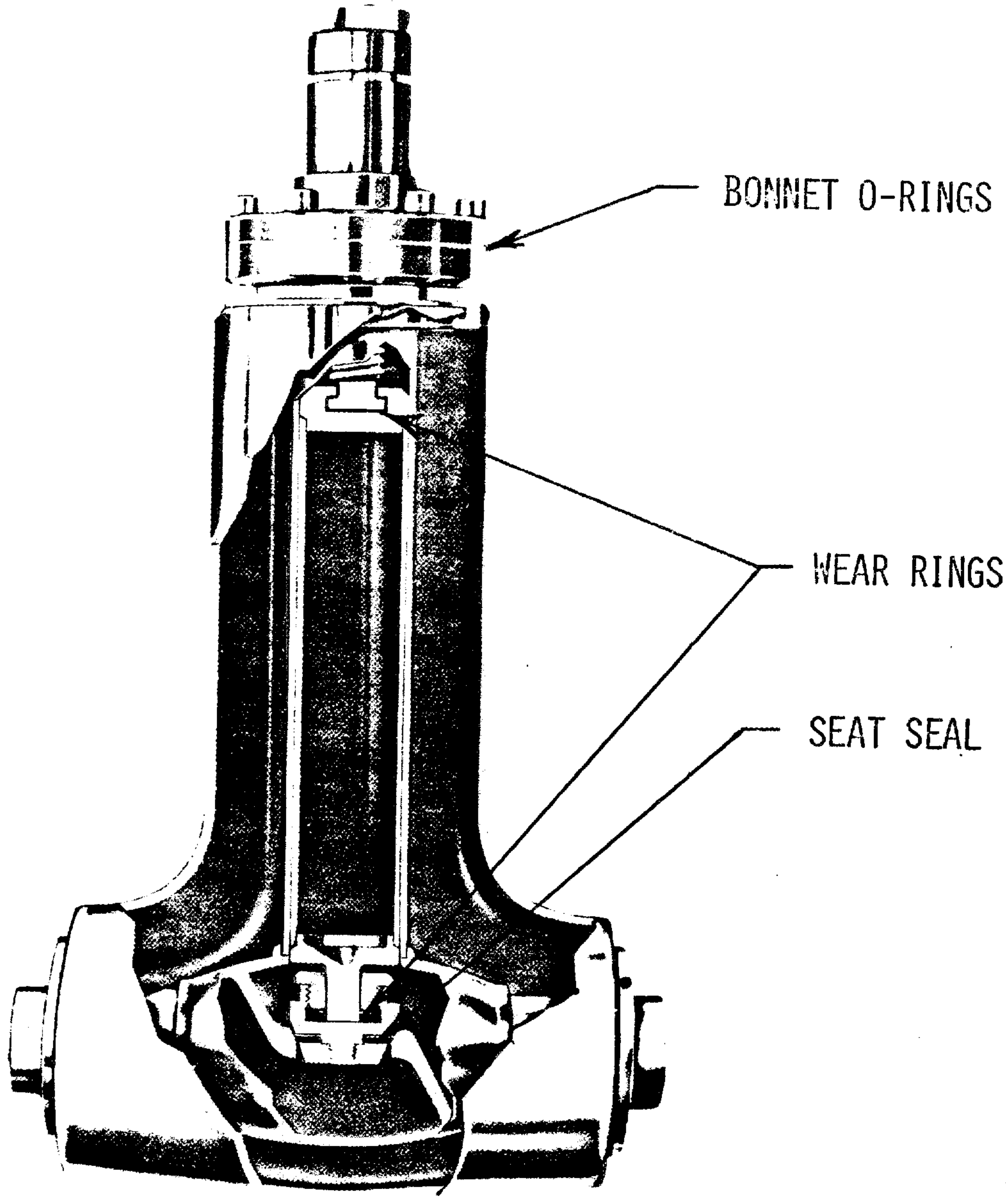
5.2 MATERIALS IN CRYOGENIC SYSTEM RADIATION RESISTANCE

A survey was made of the nonmetallic materials used in cryogenic system components that will be exposed to radiation. Those components are the vacuum-jacketed pipe, cryogenic on-off valves, and the penumatic valve operators. A total dosage of 10^8 rads (x-rays) was assumed over the 10-year operating life. The results of the survey are summarized in Table XI, XII, XIII, and XIV. Figures 40, 41, 42, and 43 illustrate the approximate location of the materials. As shown in the tables, materials that are unacceptable will be changed to acceptable materials or will be scheduled for periodic replacement (approximately 1 year).

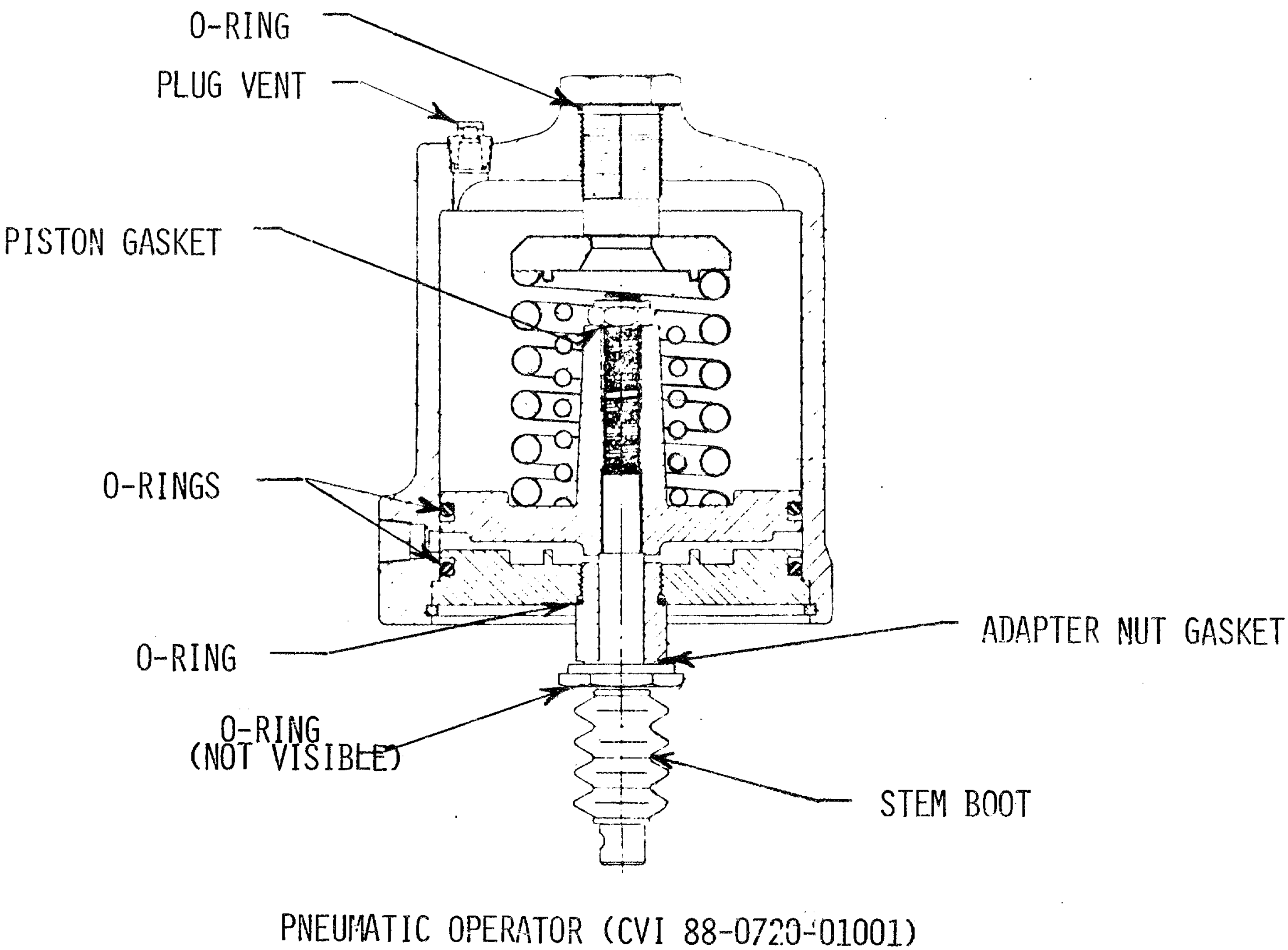
The seat in the cryogenic on-off valve is considered to be the most critical of the items which require a material change. Therefore, a functional test will be conducted using the proposed substitute material, polyimide, during Title II.

USE OF MAGNETIC MATERIALS

The largest use of a magnetic material in the cryogenic system near the torus is the pneumatic valve operators which contain approximately 20 pounds each of carbon steel. Based on a preliminary analysis, this low weight plus the distance of the operator from the torus centerline (greater than 1.5 meters) will cause no deleterious effects. During Title II, additional analysis will be conducted as part of the field uniformity study to unify the preliminary conclusions.

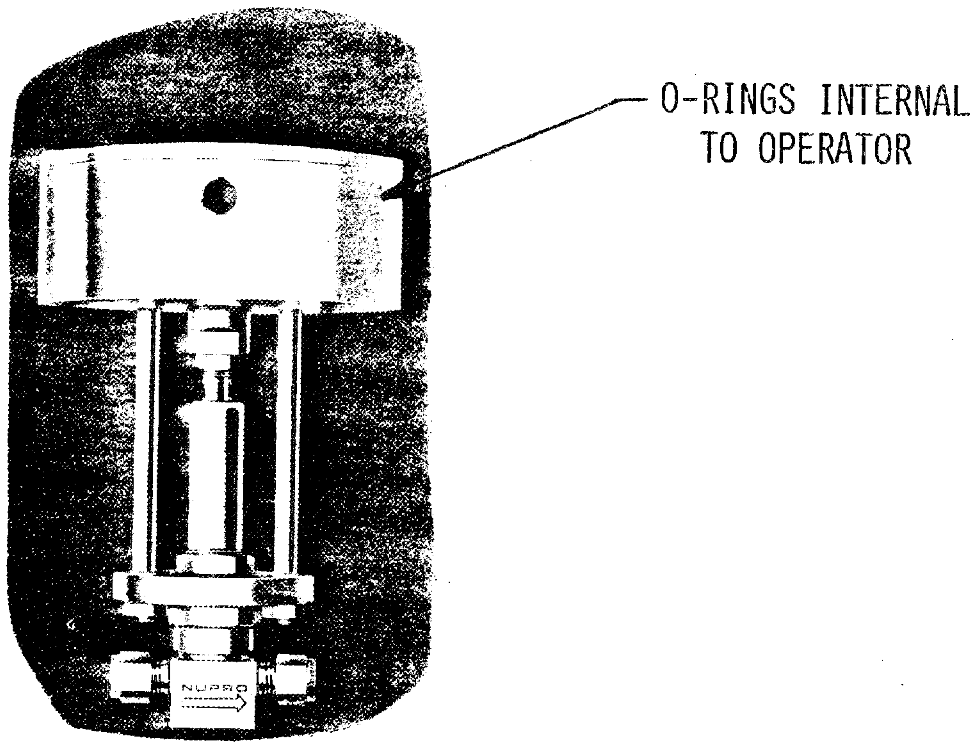


CRYOGENIC VALVE (CVI V-2070-050-J-S, V-1070-050-J-S, V-1060-050-J-S)
FIGURE 40



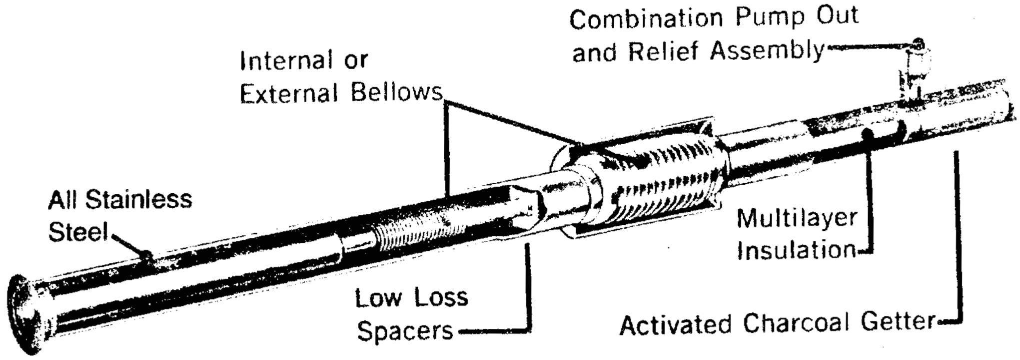
PNEUMATIC OPERATOR (CVI 88-0720-01001)

FIGURE 41



CRYOGENIC VALVE/OPERATOR (NUPRO 55-8BG-STE-93 NO)

FIGURE 42



VACUUM JACKETED PIPE

FIGURE 43

Table XI Material Compatibility Survey Vacuum-Jacketed Pipe - (CVI)

Part	Material	Useful Life Under Radiation	Change Recommended Yes	No	Rationale	Replacement Candidates
O-Ring On Evacuation/Relief Valve Cap	Buna-N	10^7 RADS		X	Part can be replaced if and when needed (for evacuation)	Not required
O-Ring In Evacuation/Relief Valve	Polyurethane	10^9 RADS		X	Material should last life of EBT-P	Not required
Insulation Layer	Aluminized Mylar	10^7	X		Function of insulation critical to system performance	Aluminized Kapton
G-10 GRP	Insulation Spacers	10^9 RADS		X	Material should last life of EBT-P	Not required
Getter Material	5A Modecular sieve material	$>10^9$ RADS		X	Material should last life of EBT-P	Not required
Insulation Layer	Dexstar Paper	$>10^9$ RADS		X	Material should last life of EBT-P	Not required

Table XII Material Compatibility Survey Cryogenic Valves CVI V-2070-050-J-S, V-1070-050-J-S, V-1060-050-J-S)

Part	Material	Useful Life Under Radiation	Change Recommended Yes	No	Rationale	Replacement Candidates
Seat Seal	KEL-F (Fluorocarbon)	10^7 RADS	X [1]		This part is the most important part of the valve. Failure will cause leakage	Polyimide
Bonnet O-Rings	Viton A (Fluorocarbon)	10^7 RADS	X [1]		Failure will cause leakage	Polyuethane
Wear Ring	Teflon	Very short	X		Failure will cause leakage	Polyimide

[1] Periodic replacement may make a change unnecesary.

Table XIII Material Compatibility Survey Cryogenic Valve/Operator (NUPRO SS-8BG-STE-93N0)

Part	Material	Useful Life Under Radiation	Change Recommended Yes	No	Rationale	Replacement Candidates
O-Rings in Operator	Viton	10^7	X △1		Failure of O-ring would cause erratic opeator function	Polyurethane

△1 Periodic replacement may make a change unnecessary.

Table XIV Material Compatibility Survey Pneumatic Operator (CVI 88-072-01001)

Part	Material	Useful Life Under Radiation	Change Recommended Yes	No	Rationale	Replacement Candidates
Stem Boot	Neoprene	10^7		X	Boost is simply a dust cover. Failue would probably not adversely affect operator functions. Should be replaced at refurbishment of operator.	Not required
Adapter Nut Gasket	Red fiber	Unknown		X	Failure would not adversely affect operator functions. Should be replaced at refurbishment of operator.	Not required
O-Rings	Buna-N	10^7 RADS	X △1		Operator leakage is unacceptable.	Polyurethane polyimide ethylene propylene
Piston Gasket	Nylon	10^7 RADS	X △1		Operator leakage is unacceptable.	Polyurethane, polyimide, ethylene propylene
Plug Vent	Pastic	Unknown	X		Minor change	Metal

△1 Periodic replacement may make a change unnecessary.

5.3 MAGNET INTERFACE ANALYSIS

During Title I considerable effort was expended in defining the functional interface between the mirror magnet and the cryogenic system. This interface has a significant impact on the cryogenic system configuration and operational characteristics of the magnet. Three major interface problem areas were identified and analyzed. They are:

- Magnet quench and pressure relief
- Magnet cooldown and filling
- Vapor cooled lead temperature control

The analysis of each of these areas is discussed in subsequent paragraphs.

5.3.1 Magnet Quench and Pressure Relief - The mirror magnet helium dewar is not equipped with a safety relief device. Therefore, the cryogenic system must relieve the dewar pressure in the event of a quench or other anamoly. The central issue at the beginning of Title I was the quantity of heating energy deposited in the helium inside the dewar and the rate at which it would be deposited. If both the quantity and rate were low, a manifolded relief system could be utilized. However if both were high, individual reliefs for each magnet would be required to minimize propagation delays that would overpressurize the dewar.

From the beginning, the MDAC position was that the heating rate and the quantity of energy deposited were high. On the other hand, early GDC analysis indicated values that were much lower than anticipated by MDAC. The situation was aggrevated by an initial magnet dewar design pressure of 30 psia.

Due to these uncertainties, it was decided to place a quick acting relief device immediately above each magnet dewar. The size of the device was selected to match the size of the magnet dewar vent line. A burst disk was selected as the relief device.

Relief valves were investigated as a candidate for the relief device. They were subsequently eliminated as a result of uncertainties of the propagation delay in opening when subjected to a rapidly increasing pressure spike. The concern was that the magnet dewar would overshoot its pressure limitation before the relief valve could sense the pressure rise and react to relieve it. This concern was based on early analysis that indicated that the rise rate ocurred rapidly.

Analysis of the ORNL open dewar test data confirmed the MDAC position on the quench pressure rise rate and the quantity of heat energy deposited in the helium inside the dewar. Analysis of this data resulted in an internal magnet redesign and an increase to 50 psia for the magnet dewar operating pressure and an increase in the size of the dewar vent line.

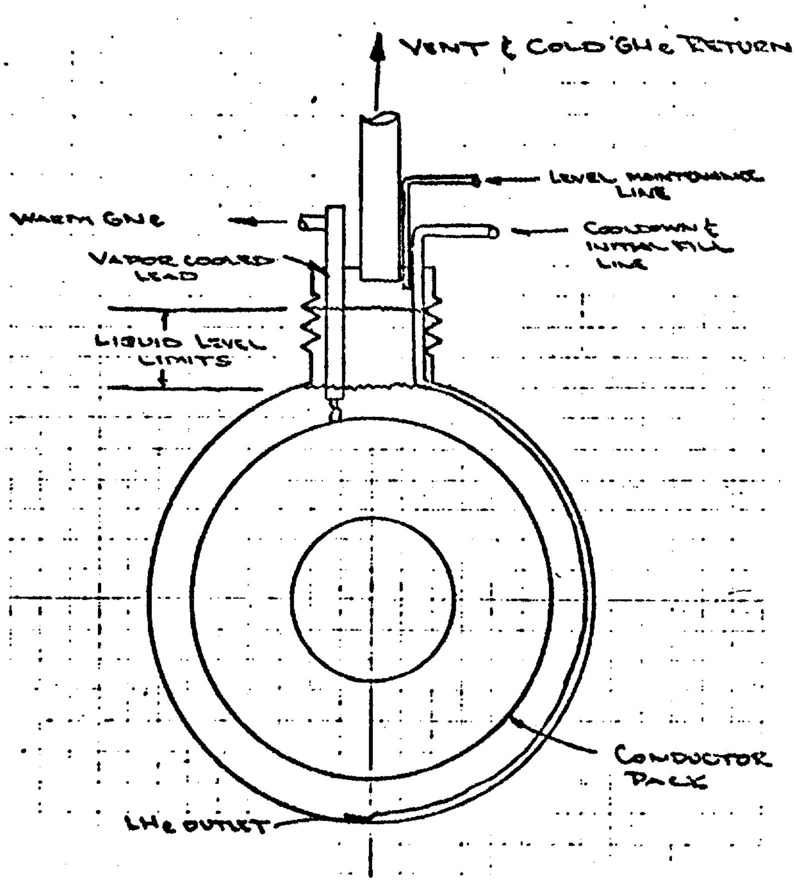
5.3.2 Magnet Cooldown and Filling - The magnet cooldown and filling techniques are controlled by two divergent requirements. During cooldown, it is ideal to have the fluid introduced at the bottom of the magnet pack so that it will flow up through the pack on its way out of the dewar. On the other hand, vapor entrained in the fluid during filling could cause magnet stability problems when it impinges on the powered magnet pack. As a result four fill and cooldown approaches were analyzed. The candidates evaluated were:

- Separate Top and Bottom Fill
- Top Fill
- Bottom Fill
- Combination Top and Bottom Fill

The analysis of each follows in the subsequent paragraphs.

5.3.2.1 Separate Top and Bottom Fill - This technique provides a separate valve and line for cooldown from the bottom and filling from the top as shown in Figure 44. Compared to a single fill line the advantages and disadvantages are:

- Advantages
  - Good Cooldown Path
  - No Vapor Impingement On Coil Pack



SEPARATE TOP AND BOTTOM FILL

FIGURE 44

- Disadvantages
  - More Complex Hardware
  - Higher Magnet Heat Leak
  - Higher Distribution Losses

5.3.2.2 Top Fill - This technique provides a single valve and line entering from the top for cooldown and filling as shown in Figure 45. The advantages and disadvantages are:

- Advantages
  - Single Magnet penetration
  - No vapor impingement on Coil Packs

- Disadvantages
  - Inefficient Cooldown Path

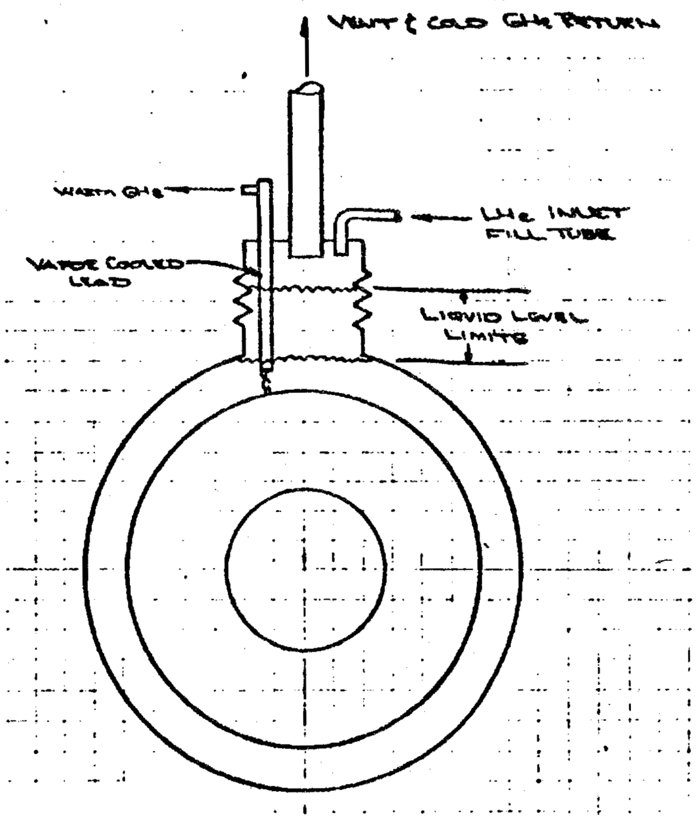
5.3.2.3 Bottom Fill - This technique provides a single valve and line entering from the bottom for cooldown and filling as shown in Figure 46. The advantages and disadvantages are:

- Advantages
  - Single Magnet Penetration
  - Good Cooldown Path

- Disadvantages
  - Vapor impinges on Coil Pack

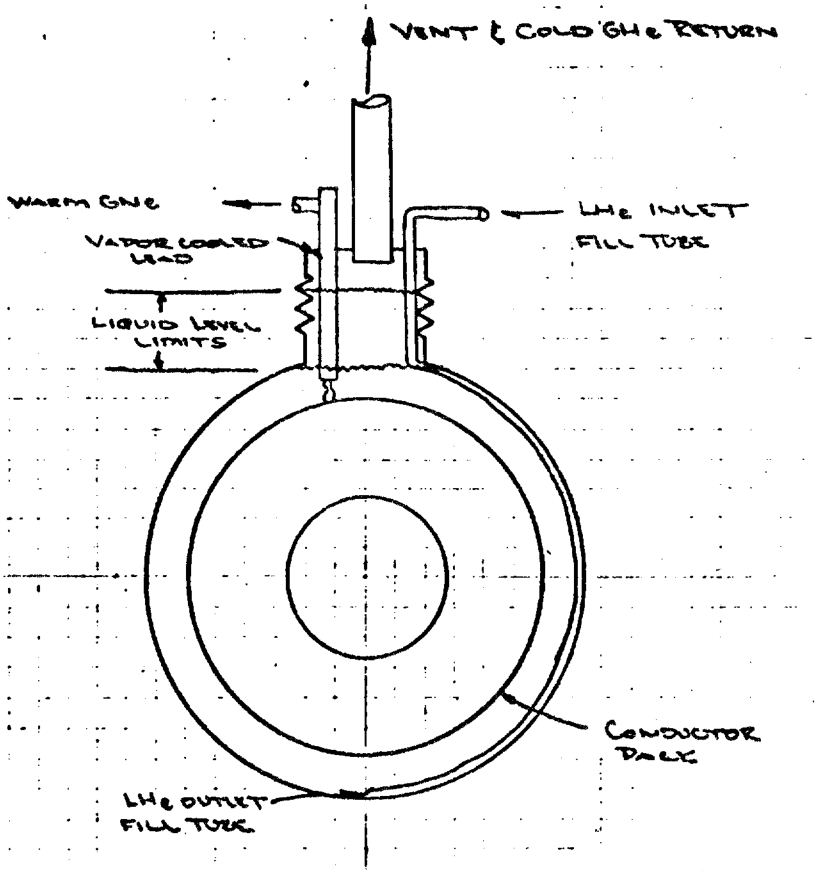
5.3.2.4 Combination Top and Bottom Fill - This technique provides a single valve and line penetration. However, the single line is connected to the bottom for cooldown and to the top for filling as shown in Figure 47. The advantages and disadvantages are:

- Advantages
  - Single Magnet Penetration
  - Good Cooldown Path
  - No vapor impingement on Coil Pack



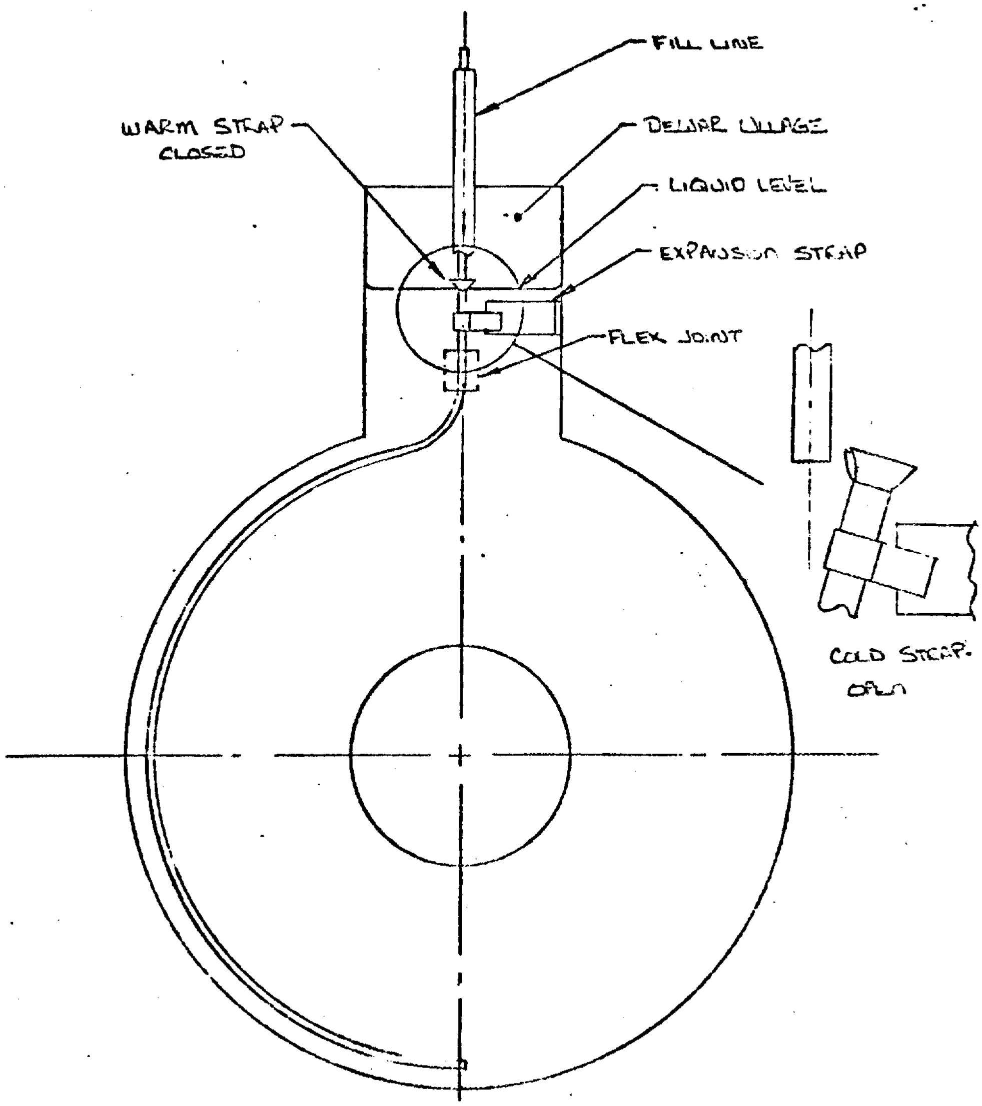
TOP FILL

FIGURE 45



BOTTOM FILL

FIGURE 46



COMBINATION TOP AND BOTTOM FILL
FIGURE 47

- Disadvantages
  Requires Hardware Development

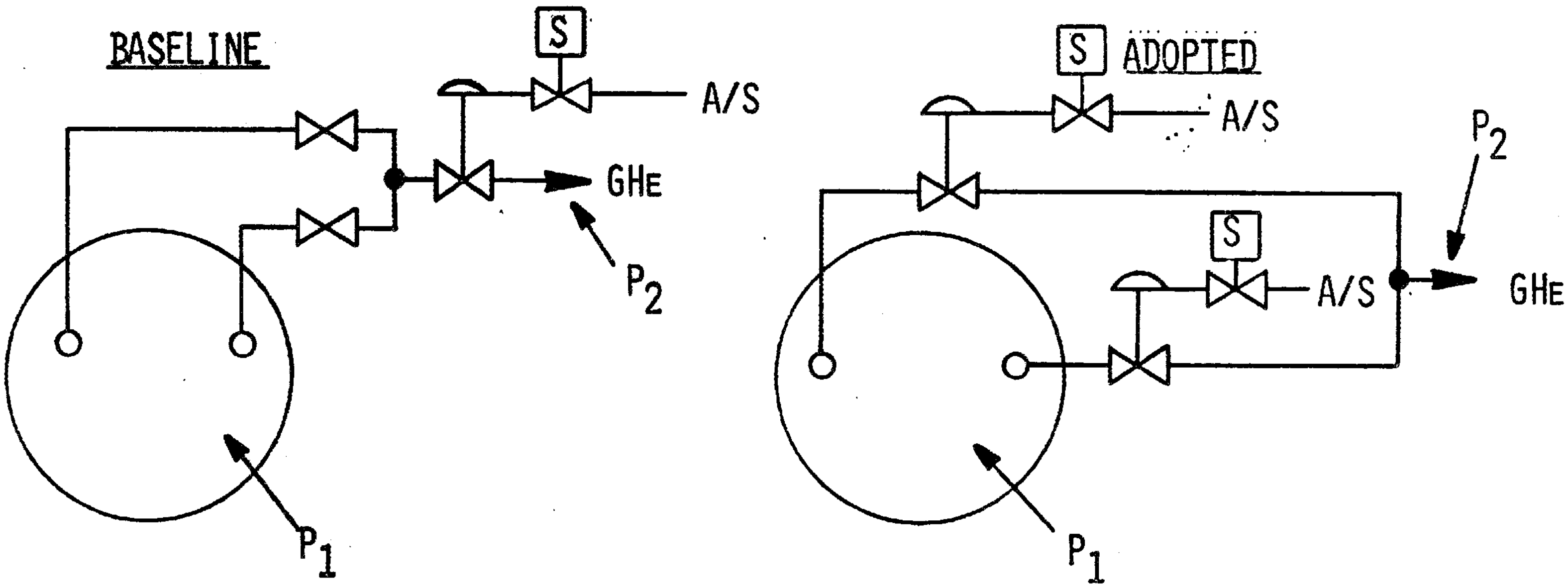
5.3.2.5 Conclusions - The separate top and bottom fill technique was selected because it offered minimum risk in both the fill and cooldown operations. The additional distribution line heat loads resulting from this approach were not sufficient to warrant the risks associated with the other techniques.

5.3.3 Vapor Cooled Lead Temperature Control - The magnet vapor cooled power leads are sensitive to both pressure and temperature changes. Figure 48 summarizes the problem with the baseline approach and depicts the approach adopted.

5.4 LN_2 DEWAR ACQUISITION TRADE STUDY

The proposed LN_2 storage and supply system consisted of a storage dewar and a pump skid to affect liquid transfer. Early in Title I, the proposed approach was replaced with a pressure transfer system. The transfer is accomplished by vaporizing a small portion of the liquid in the dewar to pressurize the ullage space. This transfer approach is utilized in many commercial installations and the hardware is available from local commercial liquid suppliers.

Having adopted the pressure transfer approach and identifying the approximate capacity requirements, it was concluded that it would be more cost effective to lease the hardware than to procure it with PACE funds.



OPERATION

- HAND VALVES SET AT INSTALLATION TO PROVIDE REQUIRED FLOW
- INCREASE IN TEMPERATURE OF ONE LEAD WILL DECREASE FLOW
- FLOW THROUGH EACH LEAD SENSITIVE TO RATIO OF P_1/P_2

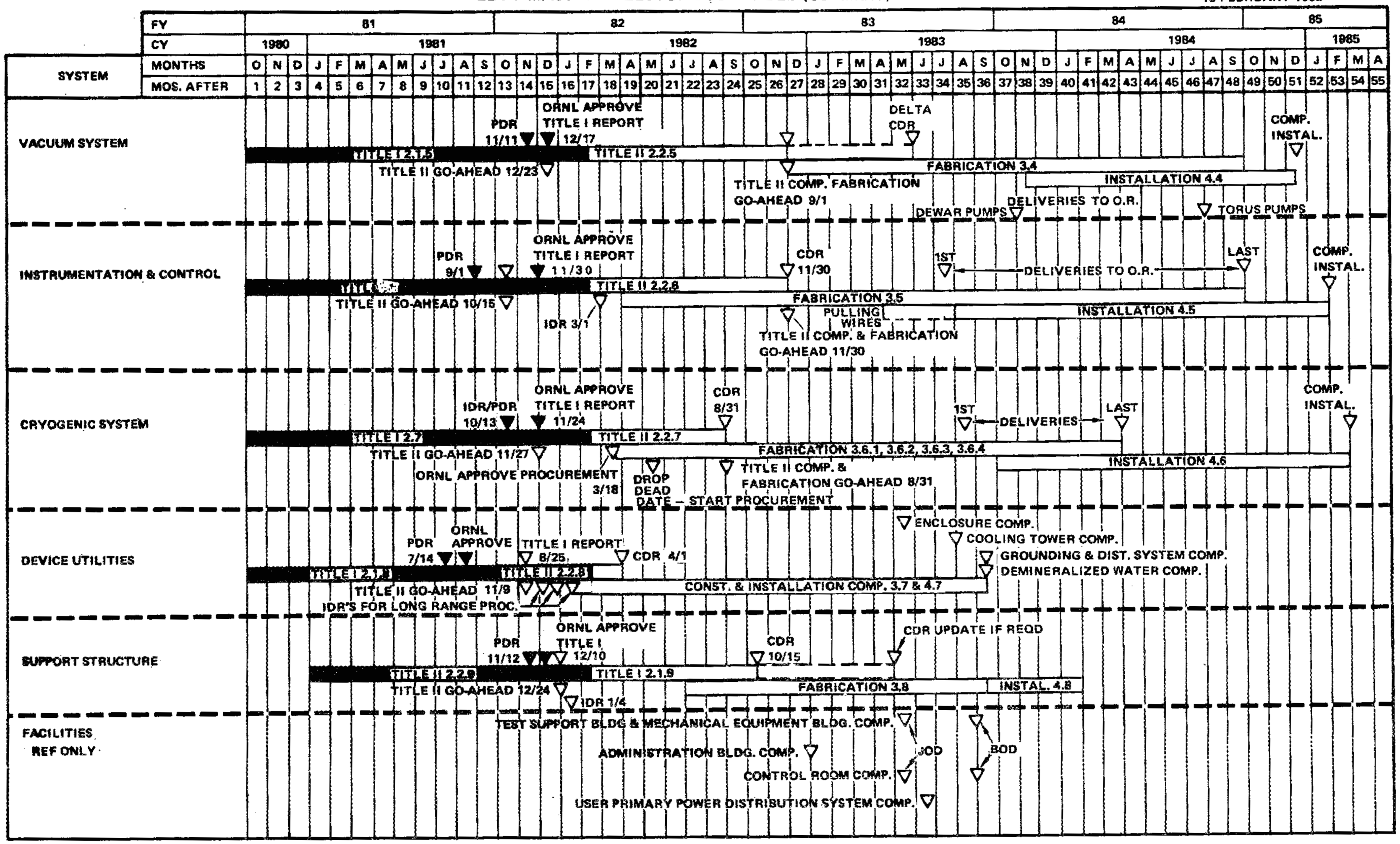
- RATIO OF P_1/P_2 SET FOR SONIC FLOW ACROSS VALVES
- TEMPERATURE OF EACH LEAD CONTROLLED BY CHANGING ORIFICE SIZE OF VALVE - MANUAL
- OVERRIDE PROVIDED TO INCREASE FLOW FROM NOMINAL UPON OVER TEMPERATURE CONDITION - AUTOMATIC

(NOTE: VAPOR COOLED LEAD FLOW WILL BE ANALYZED/VERIFIED DURING TITLE II.)

STEADY STATE VAPOR COOLED LEAD ANALYSIS
FIGURE 48

PACE
EBT-P MASTER MILESTONE SCHEDULE (Continued)

15 FEBRUARY 1982



NOTE: ORNL APPROVE ALL LONG LEAD REQUESTS AT THE IDR

13–5122D

APPENDIX A PROCUREMENT SPECIFICATION

APPLICATION:

NEXT ASSEMBLY 70B370000

MODEL 1056

SPECIFICATION NO. 70P373000

FSCM NO. 76301

DATE 24 November 1981

PROCUREMENT SPECIFICATION FOR

REFRIGERATOR/LIQUEFIER STORAGE AND DISTRIBUTION SYSTEM

PREPARED BY: T. J. Poteat
Cryogenic System Manager

APPROVED BY: J. B. Browne
EBT-P Engineering Contract Services

APPROVED BY: H. F. Imster
EBT-P Engineering Manager

APPROVED BY: R. J. DeBellis
EBT-P Project Manager, MDAC

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
ST. LOUIS, MISSOURI 63166

APPROVED BY: A. L. Boch per letter dated 24 November 1981
A. L. Boch
EBT-P Project Manager, ORNL

Union Carbide Division, Oak Ridge National Laboratory
Oak Ridge, Tennessee

APPROVED TITLE II

CONCURRING SIGNATURES

f. CB Michael Delaney
M. Delaney
EBT-P Strength

for G. W. Wille
EBT-P Materials

D. W. Haas
D. W. Haas
EBT-P Systems Integration Manager

R. J. Dannenmueller
EBT-P Magnet System Manager

INDEX OF EFFECTIVE PAGES

The pages of this document currently in effect are listed below in numerical order. The letter listed after the page number identifies the latest revision affecting that page.

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3	-	48	-				
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31	-						
32	-						
33	-						
34	-						
35	-						
36	-						
37	-						
38	-						
39	-						
40	-						
41	-						
42	-						
43	-						
44	-						
45	-						

QTY REQD		PART OR IDENT NO.	NOMENCLATURE OR DESCRIPTION	SUPPLIER PART NUMBER	SUPPLIER NAME AND ADDRESS	SUPPLIER FSCM NO.	UNIT WT
1	-1	-5	STORAGE AND DISTRIBUTION SYSTEM	TBD	TBD	TBD	N/A
1	-1	-3	REFRIGERATOR/ LIQUIFIER	TBD	TBD	TBD	N/A
1	EA	-1	ASSEMBLY	TBD	TBD	TBD	N/A

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TABLES AND FIGURES

1.0 SCOPE - This Procurement Specification (PS) establishes the minimum performance, design, fabrication, delivery, installation and acceptance test requirements for a cryogenic system that is part of the Elmo Bumpy Torus Proof of Principle device (EBT-P).

1.1 COMPLIANCE - The delivered and installed equipment shall comply with this specification and subtier documents in every detail or Seller shall rework it to achieve compliance at no cost to MDAC-STL or MDAC-STL's customers.

1.2 ENGINEERING RESPONSIBILITIES - The Seller shall prepare system assembly and installation drawings and specifications as required by the Subcontractor Data Requirements Package. These drawings and specifications shall provide sufficient detail to allow MDAC to evaluate compliance with this specification. The design shall be supported by a complete analysis of the system prepared by the Seller. The analysis shall contain sufficient detail to allow MDAC to evaluate the performance and reliability of the system. All Seller drawings shall be coordinated with MDAC interface drawings that are a part of this specification. Any repair procedures that become necessary shall be reported to MDAC and shall comply with ASME, ANSI or other applicable repair procedures.

Additional Seller engineering responsibilities are set forth in the Subcontractor Statement of Work (SSOW).

2.0 APPLICABLE DOCUMENTS - The documents including revisions, amendments, change notices, changes, and supplements of issue in effect on 1 July 1981, or when otherwise indicated in 2.6, form a part of this specification to the extent specified. When so referenced, full titles, revision letters, and dates of issue are omitted for brevity of reference and the short form reference shall be understood to be the specific issue identified in 2.6. Where paragraph numbers are given without reference to another document, it shall be understood that the referenced paragraphs are of this specification.

2.1 SUPERSEDENCE - If any of the documents specified herein are changed during the life of the Purchase Order (PO), the Seller shall not use the later issue without prior written approval from MDAC-STL.

2.2 NORMAL PRECEDENCE - If any requirements of the PO, this PS or the documents invoked herein are conflicting, the following precedence shall apply:

a. The PO shall take precedence over this PS.
b. This PS shall have precedence over all documents invoked herein.

2.3 UNCERTAIN PRECEDENCE - Where a conflict of precedence cannot be resolved by the above, the particulars of any technical problem shall be forwarded to the cognizant MDAC-STL engineer for resolution.

2.4 SUBPARAGRAPH APPLICABILITY - Where paragraphs of this specification or any other document are referenced herein, it shall be understood that all subparagraphs of the referenced paragraphs are applicable unless otherwise noted.

2.5 WAIVERS - Seller is encouraged to submit recommendations at any time for waivers on all or portions of individual industrial and Government specifications and standards in the interest of economy without sacrifice of performance. All waivers must be approved by MDAC-STL, prior to incorporation.

2.6 APPLICABLE DOCUMENTS

American Society of Mechanical Engineers (ASME)

- o Boiler and Pressure Vessel Code, Section VIII, Division 1 "Pressure Vessels".

American National Standards Institute (ANSI)

- o B31.1 Power Piping
- o B31.3 Chemical Plant and Petroleum Refinery Piping
- o B16.5 Steel Pipe Flanges and Flanged Fittings
- o B36.19 Stainless Steel Pipe

American Society for Testing and Materials (ASTM)

- A53, Specification for Welded and Seamless Pipe
- A312, Specification for Seamless and Welded Austenitic Stainless Steel Pipe
- A36, Specifications for Structure Steel
- A240, Heat Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Fusion Welded Unfired Pressure Vessel

National Bureau of Standards

- NBS Technical Note 631, Thermodynamic Properties of Helium
- NBS Technical Note 629A, Thermodynamic Properties of Nitrogen

Compressed Gas Association (CGA)

- Handbook of Compressed Gases
- Safety Relief Device Standards, Pamphlet S-1 Parts 2 and 3

Manufacturers Standardization Society of the Valve and Fittings Industry (MSS)

- SP-61, Hydrostatic Testing of Steel Valves
- SP-25, Standard Marking System for Valves, Fittings, Flanges, and Unions.

Pipe Fabrication Institute (PFI)

- ES4, Standard Practice, Shop Hydrostatic Testing of Fabricated Piping
- ES5, Standard Practice, Cleaning Fabricated Piping
- ES11, Recommended Practice for Permanently Affixing Identification Symbols to Fabricated Piping.

Tubular Exchanger Manufacturer Association (TEMA)

- Standards

Instrumentation Society of America (ISA)

- ISA - S5.1 1973, Standard Instrumentation Symbols and Identification

United States Air Force (USAF)

- AFR-161-35, Hazardous Noise Exposure

U.S. Department of Energy (DOE)

- ERDA Manual, Chapter 0550, Occupational Safety Standards
- ERDA Manual, Chapter 0552, Fire Protection

National Electrical Manufacturers Association (NEMA)

o NEMA Standards for Electrical Control

American Institute of Electrical and Electronics Engineers (IEEE)

o Standards

Tennessee State and Local Building and Safety Codes Uniform Building Code

o Seismic Zone Number 2

Federal Standards

Federal Standard No. 595A Colors

McDonnell Douglas Astronautics Company - St. Louis

Drawings:

***o 70B373000 Rev A EBT-P Block Diagram, Liquid and Gaseous System, Cryo

o 70B373001 EBT-P Cold Box Facility Interface

o 70B373002 EBT-P Liquid Helium Dewar Facility Interface

o 70B373004 EBT-P Gaseous Helium Storage Tank Facility Interface

o 70B373005 EBT-P Helium Manifolds, Cryo-Pump Systems

o 70B373006 EBT-P Liquid Nitrogen Storage Tank Facility Interface

***o 70B373008 EBT-P Magnet Supply/Return Manifolds, Cryo

o 70B373009 EBT-P Magnet Interface, Cryo

***o 70B373010 EBT-P Magnet Supply/Return Envelopes, Cryo

***o 70B373011 Rev A EBT-P Facility Routing Envelopes, Cryo

o 70B373007 EBT-P Gaseous Helium Storage Tank

*o 70B373012 EBT-P Liquid Helium Dewar

o 70B373013 EBT-P Gyrotron Interface

***o 70B373014 Rev A EBT-P Gyrotron Supply/Return Manifold

***o 70B373015 Rev A EBT-P Gyrotron Supply/Return Envelopes, Cryo

o 70B373016 Rev A EBT-P Cryo Subsytems Facility Installation

***,**o 70B373017 Rev A EBT-P Liquid and Gaseous System Schematic

*o 70B373018 EBT-P Cold Box

*o 70B373019 EBT-P Lead Blower Interface

*o 70B373020 EBT-P Auxiliary Heat Exchanger

*Indicates a drawing that will be forwarded upon completion.
**This drawing is conceptual and as such does not include all components necessary for system operation.
***This drawing does not reflect the current vacuum pump system requirements as described herein.

*o 70B373021 EBT-P Helium Compressor
*o 70B373022 EBT-P Liquid Nitrogen Dewar
o 70B374001 EBT-P Device Enclosure Building
o 4975-502-102 Device Enclosure - Structural
o 4975-502-101 Plan-Test Center Mechanical Equipment Building
o 4976-375-413 Sections and Elevations - Test Center
o MDE-6-20-1 Supplier Packaging Instructions for MDAC-STL Material

3.0 REQUIREMENTS

3.1 GENERAL - The cryogenic system described herein shall comply with the requirements of this specification.

3.1.1 Item Definition - EBT-P is an experimental toroidal fusion energy device with a 4.5 meter major radius and 36 sectors. Each sector consists of a superconducting magnet (mirror coil) and mirror cavity. The steady-state EBT-P plasma is contained by the magnetic field generated by the 36 mirror coils.

Each mirror coil consists of a liquid helium cooled (pool boiling) NbTi winding enclosed in a stainless steel case. Power is supplied to the coils from a high current dc power supply through helium vapor-cooled leads. Plasma heating is provided in part by the injection of microwave power at 28, 60, and 90 GHz into the toroidal vessel from the gyrotron power supplies. The 60 and 90 GHz gyrotrons contain liquid helium cooled (pool boiling) superconducting coils. Drawing 70B373011 shows the location of the cryogenic system elements installed in the MDAC Fusion Energy Facility that will be located in the Valley Industrial Park, Oak Ridge, Tennessee. The Seller shall be responsible for installing the system as shown in drawing 70B373011. MDAC will provide mounting pads for the cold box, compressor skids, LHe storage dewar, nitrogen dewar, GHe storage tanks, auxiliary heat exchanger, lead blowers and bypass heat exchanger. In addition, mounting pads will be provided for the gas purification subsystem if it is not part of the cold box.

3.1.2 Cryogenic System Description - The cryogenic system stores, supplies, distributes and controls helium and nitrogen required for device operation. Liquid and gaseous helium is supplied to the device in a closed loop. Nitrogen liquid and gas is supplied to the device in an open loop.

The cryogenic system is an integral part of the EBT-P device. It shall include but not be limited to the following major elements:

a. Closed Cycle Helium Refrigerator/Liquefier (Includes Two Compressor Skids and Cold Box)
b. Liquid Helium Storage Dewar
c. Three High Pressure Gaseous Helium Storage Tanks (MDAC supplied)
d. Cryogenic Helium Distribution System
e. Gaseous Helium Distribution System
f. Liquid Nitrogen Storage Dewar (MDAC Supplied)
g. Liquid Nitrogen Distribution System
h. Auxiliary Heat Exchanger for Cooldown and Warm-up
i. Instrumentation and Control System
j. Gaseous Nitrogen Distribution and Vent System
k. Vapor Cooled Lead Blowers
l. Cold Gas By-Pass Heat Exchanger
m. Gas Purification Subsystem

The helium element is a closed loop system that provides saturated liquid (approximately 4.2°K) to the mirror and gyrotron superconducting coil dewars. Gaseous helium at approximately 300°K and 4.2°K is returned to the refrigerator/liquefier for reliquefaction. The system is designed to recover all helium gas during normal modes of operation.

The liquid nitrogen element is an open loop system that vents waste GN_2 outside the torus building. Saturated liquid nitrogen is supplied to the auxiliary heat exchanger, cold box, gas purification subsystem (if separate from the cold box), diagnostics and the insulating shields of the mirror and gyrotron magnet dewars.

A cryogenic system block diagram and schematic are shown in drawings 70B373000 and 70B373017, respectively. The Sellers equipment shall be compatible with these drawings. A block diagram of the vacuum pump LN_2 traps and a drawing showning their location are shown in Figures 10 and 11 respectively.

3.1.3 Interface Definition - The cryogenic system shall mate with the EBT-P Device and its facility. Drawings describing the system interface requirements will be prepared and controlled by MDAC and incorporated by reference into this specification. A listing of applicable interface drawings is shown in Section 2.6. Figures 1, 2 and 10 show the system functional interfaces with the mirror magnets, gyrotron magnets and vacuum pump traps, respectively. Utility interfaces are specified in Table V. The Seller shall prepare detailed drawings showing cryogenic system interface requirements.

3.1.4 Physical Requirements - The cryogenic system shall be designed, fabricated and installed in accordance with the requirements of this section.

3.1.4.1 General Requirements

a. The system shall mate with all device and facility interfaces as defined by the drawings denoted in Section 2.6 and shall operate from the utilities shown in Table V. The Seller shall specify in his proposal electrical power, instrument air and demineralized water requirements for each element of the System. In addition, he shall specify all TBS (to be specified) variables that appear in this procurement specification. During the detailed design phase, the Seller shall prepare and submit for MDAC approval drawings showing the location of pipe hangers and other detailed facility interface requirements. These drawings shall be compatible with the facility data supplied by MDAC.

b. The system shall be designed such that it may be monitored and controlled by one person during all modes of operation except as noted. Cryogenic system availability, reliability and maintainability shall be primary design criteria.

c. Any subsystem that contains moving parts shall be designed to provide failure free operation for a minimum of 9000 hours of operating time or the Seller shall replace the defective components at no cost to MDAC. Any component of the system involving no moving parts shall be designed to be maintenance and failure free for at least one year of operation or the Seller will replace the component at no cost to MDAC. These subsystem design life requirements apply to the entire cryogenic system unless superceded by minimum design life requirements stated in the performance paragraph for a specific subsystem.

d. The system shall be fabricated in modular packages that will minimize field erection effort. Pipe spools shall be fabricated to conform to MDAC drawings and shall minimize field joints. The size of individual spools that install in the torus enclosure shall not be larger than an envelope measuring 20 feet long by 17 feet high by 1.75 feet deep. This size is a result of enclosure entrance restrictions.

e. All working media connections within the vacuum-jacketed cold box shall be welded. No mechanical joints or brazing shall be used. Bi Braze joints (or equivalent) shall be used for the joining of dissimilar metals and shall be welded to adjacent piping.

f. All cryogenic lines within the system shall be welded unless otherwise specifically stated.

g. The system shall comply with the Tennessee State and Local Building and Safety Codes Uniform Building Code-Seismic Zone Number 2.

h. The system shall have a useful life of 10 years minimum when maintained in accordance with procedures established by the Seller.

i. The Seller shall provide a list of scheduled maintenance tasks that are necessary to maintain the system in satisfactory operating condition. These maintenance tasks shall be accomplished within the time allotted in the duty cycle. See paragraph 3.2.2.

j. The Seller shall provide a list of recommended spare parts necessary to maintain the system.

k. System components located out-of-doors shall maintain specified performance while subjected to environmental temperature limits of -20°F to 130°F and a relative humidity ranging from 20% to 100% of saturation including rain and snow. Those components located under roof shall maintain specified performance while subjected to environmental temperature limits of +40°F to 130°F and a relative humidity ranging from 20% to 100%.

l. All system components located within the torus enclosure shall be capable of withstanding an x-ray dose of 2×10^7 rads/year average for 10 years while continuing to operate at rated performance.

m. The system shall meet the audible noise requirements stated in Air Force Regulation AFR-161-35 Hazardous Noise Exposure.

n. The system shall conform to the standards of the U.S. Department of Energy ERDA manual Chapter 0550, Occupational Safety Standards and Chapter 0552, Fire Protection.

o. No single failure or occurance shall result in an unacceptable hazard to personnel.

p. Cryogenic circuits that can be isolated and blocked shall be provided with a pressure relief valve. These valves shall be sized in accordance with the standards of the Compressed Gas Association (CGA) Handbook of Compressed Gases and Safety Relief Device Standards. Relief devices shall be sized to protect the system from failure in the event of a fire around the equipment and loss of equipment vacuum. Furthermore, the system and its components shall be designed to preclude equipment damage or failure or hazzard to personnel in the event of a power or instrument air failure.

q. A manually operated valve and bayonet nipple arrangement shall be installed in both the liquid helium and liquid nitrogen distribution systems on both floors of the torus room. These will be used to draw off liquid for use in the experimental diagnostic devices.

r. All distribution piping shall be cleaned in accordance with Pipe Fabrication Institute (PFI) document ES5 or other MDAC approved specification prior to installation.

s. External leakage of piping joints shall not exceed 1×10^{-10} scc/second of helium when tested per ANSI, ASME or Seller specification as approved by MDAC.

t. All pressure vessels shall be designed, fabricated, inspected, tested and stamped in accordance with Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code unless otherwise specified.

u. All piping shall be designed, fabricated, inspected and tested in accordance with ANSI B31.1 unless otherwise specified. Ten percent (10%) of the welds of the process piping selected at random shall be 100% radiographically inspected.

v. All valves, fittings, flanges, connections etc. subjected to sub-atmospheric pressure shall be designed and fabricated utilizing high vacuum technology.

w. All heat exchanges shall be designed, fabricated and tested in accordance with TEMA and ASME Standards and Specifications. Tubes of tube and shell heat exchangers shall be welded to the tube sheet to form a leak tight seal between the tube end and the tube sheet.

x. Isolation values, switches, etc. and test points shall be provided to permit equipment checkout and to aid in isolation of malfunctions.

3.1.4.2 Material Requirements

a. All equipment located out of doors shall be weather proofed.

b. External carbon steel equipment surfaces shall be sandblasted and receive one coat of waterproof primer and one 2 mil coat of epoxy paint of a light tan number 13711 per FED-STD-595 color. Stainless steel surfaces shall not be painted.

c. All materials installed within the torus enclosure as defined in 70B373011 shall be non-magnetic except for various parts in the valve operators.

d. ASTM A240 304L stainless steel shall be the principle material utilized for the fabrication of lines and components in contact with helium and nitrogen.

e. ASTM A36 carbon steel shall be utilized for all structural fabrication outside of the torus area.

f. Pressure vessel material shall conform to ASTM specifications as identified in the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 "Pressure Vessels."

g. Piping materials shall conform to ASTM specifications as identified in ANSI B31.1 Power Piping except for those lines on the compressor skid which shall conform to ANSI B31.3 Chemical Plant and Petroleum Refinery Piping. Piping materials shall also conform to ANSI B36.19, ASTM A53 and ASTM A312 material specifications in accordance with ANSI B31.1 and B31.3 previously mentioned.

h. All thermal calculations concerning helium or nitrogen shall be made using data from the National Bureau of Standards NBS Technical Note 631 Thermodynamic Properties of Helium and NBS Technical Note 629A Thermodynamic Properties of Nitrogen.

i. All flange and flange-fitting materials shall conform to the standards of ANSI B16.5 Steel Pipe Flanges and Flanged Fittings.

j. All materials shall be compatible with the fluids and materials that they contact during operation. Galvanic effects shall be considered i nthe selection of materials.

3.2 CHARACTERISTICS

3.2.1 Functional Characteristics - The cryogenic system shall perform the following functions within the performance limits specified herein. Specific helium and nitrogen delivery requirements of each of the loads are given in Tables I and II.

3.2.1.1 Operational Modes - The cryogenic system shall function to provide the following modes of operation.

Mode

- o Start-up (liquefaction)
- o Cooldown (loads)
- o Steady-State
- o Stand-by
- o Warm-up (loads)
- o Magnet Quench or Insulation Loss
- o Post Equipment Failure

3.2.1.1.1 Start-Up Mode - The System shall provide for 12 hour maximum start-up of the Refrigerator/Liquefier. Instrumentation displays shall indicate start-up readiness upon power application. After completion of the start-up procedures and within 12 hours of beginning, the liquefier/refrigerator shall begin to fill the helium dewar with liquid at its rated capacity. See paragraph 3.2.2.1(2). Gas for liquefaction shall be supplied from the three MDAC supplied helium gas storage tanks. LN_2 for system operation including the vacuum pump LN_2 traps shall be supplied from the MDAC supplied storage dewar.

3.2.1.1.2 Cool-Down Mode - Prior to starting helium flow the magnet and gyrotron dewar LN_2 shield cooldown shall be accomplished by opening the flow control valves to cause LN_2 to flow into the distribution system from the LN_2 storage dewar. Flow shall continue until LN_2 starts to flow in the dewar shield N_2 vent lines. The Seller shall provide the LN_2 shield control valves (See Table VI) and bi-level (liquid nitrogen sensor) LN_2 transducers as shown in Figures 1 and 2. MDAC will process the transducer output and provide a pneumatic control signal to the valves.

Following evacuation and breaking the vacuum with helium the system shall cool the mirror magnet and gyrotron magnet dewars and all interconnecting piping from room temperature to the operating temperature of approximately 4.2°K. See Table IV for details. The mirror magnets shall be cooled through the magnet cool-down line (see Figure 1). The gyrotrons shall be cooled and batch filled through the dewar fill line (see Figure 2) as described in the Stand-by Mode Section. Pneumatic control signals for mirror magnet cool down valve operation will be provided by MDAC. The Seller shall provide the valves as shown in Table VI.

Helium gas shall be utilized to transfer heat from the mirror magnet dewars during cool-down. It shall be used in a forced convection circulation loop with LN_2 as the initial source of refrigeration. The refrigerator compressors shall circulate the helium gas. A flow control valve shall be provided to meter the GHe flow rate during cool-down. At the start of the cool-down operation, GHe shall circulate from the refrigerator compressors through the auxiliary heat exchanger and to the magnets via the Cryogenic Helium Distribution System. During the initial cooldown phase, warm return gas from the magnet vent lines shall bypass the cold box and return to compressor suction via the return pass of the auxiliary heat exchanger and the by-pass heat exchanger. As the cool-down process continues, return gas from the magnet will drop in temperature and shall be passed through the top, or warm end heat exchanger in the cold box to be heated by the high pressure output of the compressors. A LN_2 control valve installed in the auxiliary heat exchanger shall be utilized to control the temperature of the discharge stream relative to the return gas temperature. MDAC will provide the pneumatic signals for control of the valve. When the temperature of the magnets approaches 100°K the auxiliary heat exchanger shall be bypassed and all cooling will be provided by the refrigerator/liquefier. When 10°K is reached the LHe storage dewar valve shall open to cool the magnets to LHe saturation temperature.

Once the mirror magnet dewars have been cooled down and initially filled, the system shall supply liquid to the mirror magnet dewars through the topping valves to maintain them in the Steady-State Mode or Stand-by Mode.

3.2.1.1.3 Steady-State Mode - The system shall supply LHe from the LHe storage dewar to the mirror magnets via the distribution system. The system shall provide helium to maintain the liquid level in the mirror magnet dewars via the topping fill lines as specified in Table I (see Figure 1). Pneumatic control signals for operation of the Seller supplied valves will be provided by MDAC. The gyrotron magnet dewars shall be bulk filled during the Stand-by Mode as described below. Boiloff helium from both the mirror magnet and gyrotron dewars shall be vented back as cold gas through the cold box for reliquefaction. Some of the boiloff helium shall be vented as warm gas through the mirror magnet vapor-cooled electrical leads and shall be returned to compressor suction via the lead blowers. The refrigerator/liquefier shall produce liquid from the return gas streams to compensate for heat load losses in the system.

LN_2 shall be supplied from the LN_2 storage dewar to the helium refrigerator/liquefier, vacuum pump LN_2 traps and the thermal insulation shields in the mirror magnet and gyrotron magnet assemblies. Flow through the mirror magnet and gyrotron magnet dewar shields and vacuum pump LN_2 traps shall be controlled by MDAC supplied pneumatic signals to the Seller supplied flow control valves. Expended GN_2 shall be vented to the atmosphere outside the torus building.

3.2.1.1.4 Stand-by Mode - The stand-by mode of operation shall be identical to the steady-state mode except as follows. A reduction in the heat load of the mirror magnets as specified in Table I, and the bulk filling of the gyrotron magnet dewars and diagonistic dewars shall be the only differences.

The system shall provide helium to maintain the liquid level in the mirror magnet dewars via the top fill lines. Helium shall be vented back for reliquefaction as in the steady-state mode.

The system shall supply LHe from the LHe storage dewar to bulk fill the gyrotron magnets via the distribution system and fill lines. Flow shall continue until the dewar is full. MDAC will provide a pneumatic signal to open and close each fill valve. Vapor resulting from the bulk filling operation and from normal boil-off shall be returned to the refrigerator/liquefier for liquefaction. The Seller shall supply the valves as shown in table VI.

The system shall supply LN_2 from the LN_2 storage dewar to bulk fill the diagnoistic dewars via the distribution system and transfer hoses. Flow shall continue until the dewars are full. Manual valves shall be used to control LN_2 flow. Vapor resulting from the bulk filling operation shall be vented into the enclosure area.

3.2.1.1.5 Warm-Up Mode - The warm-up mode of operation is essentially the reverse of the cool-down process. An electrical heater shall warm the GHe in the auxiliary heat exchanger. An intermediate fluid may be utilized to affect heat transfer to the GH_e. The heating rate of the magnets will be controlled by an electrical signal provided by MDAC. The system shall be designed to allow natural warming of the system and its loads.

3.2.1.1.6 Magnet Quench or Insulation Loss - The system shall accommodate a single or a multiple magnet quench without sustaining damage or causing a system manfunction. In addition, it shall accommodate the loss of insulation of a single mirror or gyrotron magnet. See Tables III and VII for details.

3.2.1.1.7 Post Equipment Failure - The system shall be capable of maintaining the mirror magnets and gyrotron magnets at operating (steady-state) conditions in the event of the following failures:

a. Failure of a single compressor
b. Failure of both compressors
c. Failure of the cold box
d. Failure of a single vapor cooled lead blower

Venting of helium is permissible to accomplish this requirement.

3.2.2 Performance Characteristics - The system shall be designed to operate continuously 24 hours a day for 48 weeks per year with a useful life of at least 10 years. The weekly duty cycle shall be 16 hours of steady-state operation followed by 8 hours of stand-by operation for 5 days followed by 64 hours of stand-by. In addition, the system shall accommodate 88 hours of stand-by. The system shall be designed to allow one person to monitor and control it during all modes. The system shall be designed to allow all routine and periodic maintenance tasks to be performed during the stand-by portion of the duty cycle. While these maintenance tasks are being performed, helium flow to the mirror magnets shall not be interrupted. Four weeks each year will be allocated for the performance of major maintenance. The device will be warmed to ambient temperature during this period.

Cryogenic system reliability and availability shall be a primary design consideration. The system shall be designed to accept all possible combinations of temperature, pressure and flow rates associated with the operational conditions and perturbations described herein without interrupting operation or causing system failure. The system shall be designed to effect smooth transition from one operating mode to another as described herein without interrupting operation or causing system failure. Proven engineering techniques, equipment and instrumentation and control systems shall be utilized to assure the availability of the cryogenic system for EBT-P experiment operation.

The installed system shall provide the following performance as a minimum:

(1) Storage, distribution, delivery and control of LHe to the 36 mirror magnet dewars during steady-state operation as specified in Table I.

(2) Storage, distribution, delivery and control of LHe to the 36 mirror magnet dewars and concurrent batch filling of the 6 gyrotron magnet dewars as specified in Table I during stand-by operation. The refrigerator/liquefier shall be capable of increasing the inventory in the LHe storage dewar at the rate of 300 liters/hour minimum during stand-by. The distribution manifold shall be sized to accommodate a future upgrade to 15 gyrotrons total.

(3) Recovery and recycling of both cold and warm GHe from the mirror magnets and gyrotron magnets.

(4) Storage, distribution, delivery and control of LN_2 to the 36 mirror magnet shields, 6 gyrotron magnet shields, 6 vacuum pump LN_2 traps and diagnostic equipment as specified in Table II. All GN_2 returning from the mirror magnets, gyrotron magnets and vacuum pump LN_2 traps shall be collected and vented outside the torus building.

(5) Delivery of helium to cool-down 36 mirror magnets and 6 gyrotron magnets from 300°K to 4.2°K within the constraints specified in Table III. The system shall be capable of delivering cool-down helium as specified in Table IV.

(6) Sustain and survive without cryogenic system equipment failure or interruption of system operation a simultaneous quench of up to 36 mirror magnets as specified in Table III and/or loss of vacuum of one mirror magnet. The maximum (initial) pressure rise will be in the magnet dewars and their local liquid helium and cold gas return piping. The maximum dewar pressure (overshoot after disc rupture) occurs approximately 0.5 seconds after the quench event.

(7) Sustain and survive without cryogenic system equipment failure or interruption of system operation a quench and/or loss of vacuum of a single gyrotron magnet as specified in Table VII. The maximum dewar pressure (overshoot after disc rupture) occurs approximately 1.0 seconds after the quench event.

(8) Provide the capability to recover quickly from a quench of 1-36 mirror magnets or one gyrotron magnet without warming any magnet above the post quench equilibrium temperature. The post quench equilibrium temperature is not expected to exceed 100°K. The system shall be capable of recovering (returning to steady state or stand-by operation) in two modes. First, LHe shall be admitted directly to the affected magnet dewars at a rate constrained by both the magnet burst disc pressure limitations (Table III) and the ability of the refrigerator liquefier to accept large quantities of warm gas without malfunction or failure. Secondly, with the unaffected magnets full of LHe and isolated from the liquid helium supply, the system shall be configured to use cold GHe (100°K to 10°K) to cool the affected magnets down to the temperature level of the unaffected magnets, after which cold GHe and/or LHe shall be used to complete the normal cool-down of all magnets.

(9) Warm up the mirror and gyrotron magnets from 4.2°K to 300°K using GHe. During warm-up the cryogenic system shall be capable of providing a gas flow rate of up to 3.4 gm/sec to each of the 36 mirror magnet and a 0.5 gm/sec to each of the 6 gyrotron magnets. The

heater in the auxiliary heat exchanger shall be capable of transferring 120,000 watts to the GHe flow stream. The magnet pressure and T constraints as specified in Table III shall not be exceeded.

(10) Provide the capability to complete a test run (steady state operation) before returning to the standby mode and/or warming up after any of the equipment failures identified in Section 3.2.1.1(7). Specifically, failure of one compressor, failure of both compressors, failure of the cold box, and failure of one lead blower. The length of time the system can continue to supply liquid is constrained by the inventory on hand at the time of the failure. Helium venting is permissible to accomplish this requirement.

3.2.2.1 Helium Refrigerator/Liquefier Performance

(1) The refrigerator/liquefier, which consists of a cold box and two compressors, shall provide TBS watts of refrigeration at 4.2°K and TBS liters/hr simultaneously when supplied with utilities as specified by the Seller. The utilities will be furnished by MDAC-STL (see Table V). The refrigerator/liquefier shall be sized to provide a 50% margin on the maximum system load. The maximum system load shall consist of those loads shown in Table I for steady state plus distribution loads as calculated by the Seller and approved by MDAC. Distribution loads shall include all thermal losses in both the liquid delivery piping and manifolds and the cold gas manifolds and return piping. Losses from piping on both levels of the torus enclosure shall be included in calculating the distribution losses.

(2) The refrigerator/liquefier shall be sized to provide a 50% margin on the standby system heat loads when operating with one compressor skid. The standby system heat loads shall consist of those loads shown in Table I for standby plus the distribution loads described in paragraph 3.2.2.1(1).

(3) MDAC-STL shall utilize the refrigerator/liquefier at times solely as a liquefier. It shall be capable of providing TBS liters/hr at 4.2°K and 1 atm when supplied with helium gas at 300°K. This value is the start-up liquefaction rate, identified in paragraph 3.2.1.1 1 .

(4) In order to evaluate the reliability of the system, the Seller shall provide an estimate of meantime between failures (MTBF) for the following major components of the refrigerator/liquefier:

- o Compressor (bearing, gear boxes, lube system and seal gas systems)
- o Expansion turbines
- o Valves
- o Heat exchanger fouling
- o Instruments
- o Gas purification subsystem
- o Any other item with an MTBF of less than one year accumulated operating time within the duty cycle specified

The Seller shall indicate the length of time required to repair each malfunction noted above and the cost of parts to replace or repair the component.

During cold box downtime liquid stored in the storage dewar shall be used to maintain the flow of LHe to the mirror magnets at the stand-by mode flow rate as specified in Table I. The gas shall be returned to the GHe storage tanks until they are full and subsequently reliquefied after the cold box is returned to operation. After the tanks are filled, gas venting is permissible.

(5) The refrigerator/liquefier shall be designed and instrumented to permit shutdown under the following conditions:

- o Normal shutdown: the refrigerator/liquefier shall be shutdown and secured within one hour by a single operator.
- o Emergency shutdown: it shall be possible to stop the refrigerator/liquefier from the master control console without damage to the system.
- o Automatic shutdown: The refrigerator/liquefier shall automatically shut itself down without damage to the system in the event of a malfunction.

(6) If the refrigerator/liquefier requires periodic defrost for the removal of contaminants that may be present in the helium makeup gas or otherwise enter the system, the Seller shall provide the capability to accomplish an orderly shutdown, defrost and startup. Shutdown

followed by defrost and start-up shall be accomplished in 16 hours maximum.

The refrigerator/liquefier shall be permanently equipped with all components necessary to introduce warm gas from the compressors into all internal components and to remove contaminants to a maximum concentration of 10 parts per million. The design shall allow a single operator to accomplish defrost.

(7) The Seller shall supply a flow sheet (P&ID) with the refrigerator/liquefier, complete with line sizes, valves, instruments, and components. In addition to the flow sheet, a complete set of operating instructions shall be provided. Special emphasis shall be placed on detailing simple effective procedures that one operator can follow during system operation, including upsets and recovery and during all changes of operating mode, to insure uninterrupted service and long term system reliability. These instructions shall provide step-by-step procedures for the following operations:

- o Evacuation and purge
- o Startup from a warm condition
- o Steady-state
- o Stand-by
- o Warmup
- o Quench recovery
- o Post equipment failure recovery
- o Behavior of the refrigerator in case of power failure or emergency shutdown
- o Transition between modes

(8) The refrigerator/liquefier shall be designed to allow the removal (evacuation) of contaminants from internal piping and the backfilling with helium. This shall be accomplished by evacuation in two hours maximum. Removal of air from dead ended pipes shall be sufficient to prevent the occurrence of plugs during cool-down, start-up and operation of the refrigerator/liquefier.

(9) The equipment shall be designed to prevent a helium loss of more than 2500 SCF/year.

(10) The equipment shall be designed to operate in the environment specified in paragraph 3.1.4.1(k).

3.2.2.1.1 Compressor Performance - The compressors shall be oil-injected screw machines capable of supplying helium gas for system operation. Two identical compressor skids shall be provided. Each skid shall have the capacity to supply helium to maintain the system in the standby mode (as defined in Section 3.2.2.1(2)) while the other is being maintained. The compressors shall have a proven performance history of 9000 hours of continuous operation or more without major maintenance as documented by at least one installation that utilizes compressors made by the same manufacturer and are of the same type and approximate size or larger.

a. Both compressor skids shall be furnished with all the equipment required for operation within the requirements of this specification.

b. The compressors and associated equipment shall be supplied as a complete skid mounted module to minimize field installation. Components shall be shock mounted on the skid or the complete skid shall be shock mounted to prevent transmission of vibration loads into the skid mounting surface.

c. The compressors shall be supplied with a sealing system that guarantees that the compressor helium gas loss shall be the same or less when the compressor is not running compared to that when the machine is running.

d. The compressor shall be designed to be free of oil drippings, seepage, or leakage. The oil separators shall be of a design that does not require off-line regeneration (cleaning) or blowdown more frequently than once every 8 hours. The oil separation system shall be considered an integral part of the gas purification subsystem specified in section 3.2.2.1.2.3. Instrumentation shall be provided to indicate when regeneration is required. A safety shutdown feature shall be incorporated to stop the compressor prior to separator breakthrough. Blowdown shall be through a common vent. The oil removal system shall be of a proven design with a performance history of 9000 hours of continuous operation or more without major maintenance.

e. The compressor drivers shall be electric induction motors with reduced voltage starting. An interlock shall be provided to prevent simultaneous starting of both compressor skids.

f. In addition to safety devices required by the design codes noted herein, the following compressor interlocks and audio and visual alarms shall be provided on the refrigerator/liquefier control panel:

- o High pressure alarm
- o Vibration shutdown
- o Low suction temperature and pressure alarm and shutdown
- o Low oil pressure alarm and shutdown
- o Low cooling water alarm and shutdown
- o Motor overheat alarm and shutdown
- o Pressure drop alarm across oil removal devices

g. Each compressor skid shall be furnished with the following instrumentation located on the compressor control panel as a minimum:

- o Suction temperature and pressure indicator on the first stage.
- o Discharge temperatures on each stage.
- o Discharge pressures on each stage.
- o Automatic recycle control valve with controller capable of handling full compressor flow.
- o A completely automatic anti-surge control system which shall not result in venting of helium gas.
- o An orifice meter with a calibrated differential pressure gauge shall be installed in the high pressure discharge line to monitor compressor performance.
- o All other instrumentation required for operation.
- o Running time meters

h. The compressors shall be designed so that damage to the compressor shall not occur in the event of the loss of instrument air, coolant, or electrical power.

i. The compressors shall be equipped with a control valve in both the first and second stage suction to provide turndown capability to accommodate the modes and associated flow rates defined herein.

j. Each compressor skid shall be designed for completely independent parallel operation.

k. All pressure vessels and shells of shell and tube heat exchangers shall be designed, fabricated, inspected, testing and stamped in accordance with ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

l. All piping shall be designed, fabricated, inspected and tested in accordance with ANSI B31.3.

m. Noise levels shall not exceed the values specified in USAF AFR-161-35.

n. Heat exchangers shall conform to TEMA standards. Tubes of tube and shell heat exchangers shall be welded to the tube sheet to form a leak tight seal between the tube end and the tube sheet.

3.2.2.1.2 Cold Box Performance - The cold box containing the heat exchangers and turbo-expanders shall be constructed of carbon steel and insulated in such a manner that the temperature of any point on the external surface shall be within 5°C of ambient temperature. The cold box will be installed as shown in Drawing 70B3730011. The cold box facility interface is shown in Drawing 70B3730001.

a. The cold box vessel shall be suspended from a top hat section and the lower section configured to allow lowering to provide access to internal cold box components. The cold box structure and the mechanism to lower the bottom section shall be provided by the Seller. The structure shall support the cold box from the mechanical equipment building floor as defined in 708373001.

b. The cold box shall be designed to withstand the warm-up and cool-down requirements of this specification.

c. Transition joints utilized within the cold box shall be capable of withstanding 10,000 temperature cycles from 400°K to 4°K without loss of structural integrity or measurable leakage.

d. Under steady state operating conditions the cold box shall be capable of maintaining a vacuum level less than 1 x 10^{-5} torr via the vacuum system supplied as part of the cold box.

e. The piping within the cold box and the penetrations from the box shall be designed to accommodate thermal motion over the entire operating temperature range.

f. All instruments and valves located within the cold box shall be accessible with the bottom lowered to allow for inspection and maintenance.

g. The piping shall be laid out to provide for oil removal by solvent flushing.

h. The cold box shall include a 30 micron filter on the warm inlet process streams to prevent migration of particulate matter into the cold box circuits.

i. Downstream filters shall be provided to prevent migration of solid particles from desiccant beds. The desiccant beds shall be sized to prevent fluidization of the bed during the operating conditions specified herein.

j. The cold box shall be equipped with a relief device capable of withstanding full compressor flow in case of failure of high or low pressure components. Under these conditions, the performance of shells and vessels shall not be degraded.

k. The design shall prevent entrapment of residual air in stagnant dead ended pipe runs during purge evacuation.

l. The piping layout design shall prevent the occurrence of thermal oscillations that could interfere with the cryogenic system operating performance as specified herein.

m. All cold box heat exchangers shall be in accordance with TEMA Standards. Tubes of tube and shell heat exchangers shall be welded to the tube sheet to form a leak tight seal between the tube end and the tube sheet. Shells of tube and shell heat exchangers shall meet the requirements of and be stamped in accordance with ASME Boiler and Pressure Vessel Code Section VIII, Division 1.

n. All lines connecting the cold box with the compressors shall be isolated with flexible metal joints on the compressor end.

3.2.2.1.2.1 Turbo-Expanders Performance - The turbo-expanders shall be of the gas or oil bearing type with a proven performance history of 9000 hours of continuous operation or more and documented by at least one cold box installation that utilizes turbines made by the same manufacturer and are of the same type and approximate size or larger.

a. The expander design and installation shall insure that the expanders are not damaged nor their performance degraded when subjected to the variations in flow, temperature, and pressure as specified by the operating modes defined herein.

b. The Seller shall design the refrigerator/liquefier such that the expanders can be replaced or repaired with minimal warming of lines and equipment.

c. Provisions shall be made to allow replacement or repair of the expanders within a period of 8 hours between shut-down and resumption of liquid production at rated capacity. The seller shall provide the necessary amount of redundancy to accomplish this task and shall provide the necessary components with the refrigerator/liquefier.

d. The turbo-expanders shall be furnished with inlet filters to prevent particles 10 microns or larger from entering the expanders. The filters shall be equipped with indicators or alarms to indicate when they require maintenance. The filters shall be sized to accommodate 9000 hours of operation without maintenance.

e. Gas bearing turbo-expanders if utilized shall be provided with a bearing gas surge volume or magnetic thrust bearings to allow rapid shut-down without damage to the turbine. The bearing gas shall be vented to the compressor suction.

f. The expander brake shall be capable of continuous (stepless) control of loading from steady state to standby capacity.

g. Minimum instrumentation displayed on the control panel shall measure turbine inlet and outlet temperatures and pressures, expander speed, and pressure in the brake loop. Protective devices in addition to those required by codes specified herein shall include overspeed trip, and bearing gas or oil pressure alarm and shutdown. Running time meters shall be furnished to show total operating time.

h. The Seller shall provide instrumentation or equipment required to prevent expanders from being damaged in the case of the loss of instrument power and or air, coolant, or lubricant.

i. The system shall be designed to prevent equipment damage in the event of a single or multiple magnet quench. Pressure rise rate is 230 psi/sec in the mirror magnet helium dewar. The rate is based on a 28 psia burst disc that fails in 0.12 seconds. Pressure in the liquid supply, vapor and warm gas return lines and the magnet dewar will reach 50 psia maximum in 0.5 seconds.

3.2.2.1.2.2 Cold Box Valves Performance

a. All cold box valve seats and plugs shall be of a hard material to resist erosion that would affect performance of system. Design life shall be at least 9000 hours of operating time.

b. Packed valves shall be installed with the lowest pressure exposed to the packing (excluding vacuum).

c. The gland packing of extended stem valves shall remain at ambient temperature during normal operation.

d. Cryogenic valves mounted in the cold box shall not include any threaded or flanged connections, including bonnets or stuffing boxes within the vacuum space.

e. All valves shall be stamped with flow direction arrows on the bonnet, vacuum jacket or body.

f. A valve shall be installed on each of the connecting lines at the cold box to provide isolation when the line is removed. Those lines that can trap a cryogenic fluid when the isolation valve is closed shall be equipped with a relief valve.

g. All valves operating at sub-atmospheric pressure shall be packless.

3.2.2.1.2.3 Gas Purification Subsystem Performance - The gas purification subsystem shall consist of those elements necessary to remove and trap contaminants entrained in the helium gas stream. The purification subsystem shall remove all contaminants that would degrade the performance or cause malfunction of the cold box or other components of the system when operated as specified herein. The subsystem shall be designed to prevent the migration of contaminants into progressively colder stages of the cold box during any combination of operational modes described herein. Regeneration of the elements of the purification subsystem shall be accomplished without interrupting operation of the cryogenic system. Instrumentation shall be provided to indicate when regeneration is required and to monitor purity of the gas stream. In addition, provisions shall be incorporated to automatically shut the system down in the event of purifier breakthrough. The subsystem shall remove and trap contaminants from the following sources during all operational modes.

(1) Make-up gas from the GHe storage tanks, including impurities in the grade A helium feed gas. MDAC will sample each trailer for purity before the gas is admitted into the system.
(2) Mirror magnet and gyrotron magnet coil and insulation materials (G-10, Homex, Kapton, Mylar tape and EC910 adhesive)
(3) Compressor lubricants
(4) Residual contaminants in lines, etc.
(5) Normal leakage into the system
(6) Leakage into the system after a magnet quench through the safety relief check valve when cold or the virtual leak after burst disc replacement.

3.2.2.2 Liquid Helium Storage Dewar Performance

(1) The dewar shall be a proven design that has been fabricated and tested by the manufacturer.
(2) The liquid helium dewar shall have a net storage capacity of not less than 17,300 liters minimum with a 10% ullage volume.
(3) The design pressure of the LHe container shall be 35 psig minimum. It shall be designed, fabricated, tested and stamped in accordance with ASME Boiler and Pressure Vessel Code Section VIII, Division 1.
(4) The LHe dewar shall be constructed with the axis of the vessel in the horizontal position and shall be mounted on a skid base. Lifting lugs shall be provided to handle the vessel and skid assembly.

(5) Heat leak into the vessel shall not exceed .75% boiloff per 24 hours when filled to design capacity.

(6) The JT valve shall be specified by the Seller.

(7) Connections for installation of transfer lines shall be in accordance with drawing 70B373012.

(8) A getter/molecular sieve shall be attached to the LHe surface to help maintain the insulating vacuum. The vacuum space shall maintain insulation integrity for a minimum of one year without re-evacuation.

(9) Safety relief valves shall be installed on the dewar liquid volume and vacuum space and shall be sized in accordance with the Compressed Gas Association Handbook of Compressed Gases and Safety Relief Device Standards for external fire and vacuum loss.

(10) A flanged port with a 4-inch manual vacuum valve shall be installed on the vacuum jacket to facilitate vacuum maintenance. The valve shall be capped off with an "O" ring seal.

(11) A seal-off connection with an adaptor shall be provided to permit installation of a vacuum gauge.

(12) Instrumentation shall include a LHe level indicator and dewar pressure gage. Transducers shall be provided to allow remote display of both parameters.

(13) If required an electrical heater may be installed in the dewar to facilitate performance testing of the R/L and/or turndown control (see Section 4.2).

3.2.2.3 Gaseous Helium Storage Tanks Performance - Three gaseous helium storage tanks will be supplied by MDAC-STL. The Seller shall be responsible for integrating these tanks into the design of the overall system. The combined storage capacity of the gaseous helium tanks will be 7500 ft^3 (water volume). The design pressure will be 300 psig internal and 15 psig external.

3.2.2.4 Cryogenic Helium Distribution System Performance - The cryogenic helium distribution system shall interconnect the LHe dewar, auxiliary heat exchanger, cold box, mirror magnet, and gyrotron magnet assemblies, as shown in the drawings listed in paragraph 2.6. The following individual sections of cryogenic transfer lines and associated values are required as a minimum:

- o Cold box feedline to dewar
- o A cold gas return line from the storage dewar to the cold box
- o A LHe supply line between the storage dewar and the mirror and the gyrotron magnet supply manifolds
- o Mirror coil supply and return and gyrotron magnet supply and return manifolds
- o Cold gas return to the cold box from the mirror magnet and gyrotron magnet return manifolds
- o Helium gas cooldown lines from the auxiliary heat exchanger and cold box to the LHe supply line
- o Diagnostic tap on each level

(1) The LHe cryogenic lines shall be vacuum jacketed, utilizing superinsulation, getters, etc. as required to minimize heat leak. All lines shall utilize internal bellows to relieve thermal stresses.

(2) The LHe cryogenic lines from the supply and vent manifolds to the mirror coils (70B373010) shall contain sufficient flexibility through internal and external bellows sections to accept a maximum displacement of 1.50 inches in each of 6 degrees of freedom at the magnet interface in addition to manufacturing and installation tolerances.

(3) A combination pressure relief/seal-off valve shall be provided on each transfer line section and each field weld joint to permit evacuation of the vacuum space. Seal materials utilized in the valve shall be polyurethane.

(4) All transfer line connections shall be accomplished by welding except at the gyrotron interface. Field welded connections shall be of standard design and shall minimize heat loads into the cryogenic fluid. The gyrotron helium supply and return lines shall be terminated with male bayonets supplied by the Seller. The Seller shall specify the part number of the mating female half.

(5) Shut off valves shall be installed in the distribution system as shown in drawings 70B373010, 70B373014, 70B373008, and 70B373017.

(6) All valves shall be long stem vacuum jacketed globe type with pneumatic actuators that operate from 3 to 15 psig instrument air. Valve requirements within the torus enclosure shall be as specified in Table VI.

(7) The pressure drop characteristics and heat losses of the cryogenic distribution system shall be compatible with the delivery requirements specified in Table I. For example, the cold helium return piping in conjunction with the compressors must be sized to maintain the mirror magnet bath pressure and corresponding temperature within the specified range.

(8) The vacuum space in the vacuum jacket of the transfer lines and field joint vacuum spaces shall be isolated from equipment vacuum.

(9) Adequate pressure relief devices shall be installed in the cold gas return lines to maintain system pressure below 35 psig in the event of magnet system quench, loss of insulating vacuum, or other anomalous conditions requiring emergency venting. Burst discs shown on drawing 70B373010 shall be set at 28 psia. The check valve setting shall be a compromise between minimizing back flow of contaminants and overpressurizing the magnet dewar.

(10) Design pressure of fluid lines shall be 100 psi minimum.

(11) The lines including field joints shall maintain vacuum integrity for 10 years minimum.

(12) The cryogenic helium lines shall be fabricated by welding 304L stainless steel.

(13) All vacuum insulated piping in the torus enclosure shall utilize Kapton H muli-layer insulation, Dexiglas paper insulators if required and polyimide or G-10 spacers.

(14) The distribution system design shall prevent oscillations that would limit system life or proclude operation as specified herein.

3.2.2.5 Gaseous Helium Distribution System Performance - The gaseous helium distribution system shall interconnect the helium compressor to the cold box, high pressure helium storage tanks, auxiliary heat exchanger, bypass heat exchanger and the vapor cooled lead cooling returns on the mirror coil magnet assemblies. The gaseous helium distribution system is shown in drawings 70B373008, 70B373010, 70B373014, 70B373009, 70B373001, 70B373004, 70B373017, 70B373011, 70B373019 and 70B373020.

(1) The gaseous helium distribution lines shall be fabricated by welding 304L series stainless steel.

(2) All lines and manifolds inside the facility that may potentially carry cold gas shall be insulated to ensure that no exposed surface will have a temperature lower than the dew point of ambient air. Insulation materials shall be capable of withstanding the radiation dose specified herein without degradation of performance. Valve requirements within the torus enclosure shall be as specified in Table VI.

(3) All automatic or remotely operated valves shall be pneumatically operated from 3 to 15 psig instrument air.

(4) Two blowers and an accumulator shall be installed in the warm GHe return to maintain sonic flow across the flow control valves. One blower shall provide redundant back-up for the other. The flow control valves shall be provided with pneumatic operators.

(5) Design pressure of fluid lines shall be 300 psi minimum.

3.2.2.6 Liquid Nitrogen Storage Dewar Performance - The liquid nitrogen storage dewar shall supply LN_2 to the cold box, mirror magnet and gyrotron magnet thermal shield assemblies, vacuum pump LN_2 traps and auxiliary heat exchanger. In addition, it shall provide LN_2 for diagnostic equipment. The dewar will be a standard commercial unit with a pressure building circuit, a minimum capacity of 9000 gallons, and a vacuum jacketed withdrawal line. It will be operated at a pressure of 25 psig. MDAC will supply the dewar. The Seller shall be responsible for integrating this dewar into the design of the overall system.

3.2.2.7 Liquid Nitrogen Distribution System Performance - The liquid nitrogen distribution system is a vacuum jacketed superinsulated distribution loop that connects all the LN_2 load points to the storage dewar.

The heat loads (delivery requirements) specified in Table II do not include line losses. The LN_2 distribution system is shown schematically in drawing 70B373017. It shall supply the following:

- o LN_2 heat shield surrounding the mirror coil magnets
- o LN_2 heat shield surrounding the gyrotron magnets
- o LN_2 cooling for steady state operation of the refrigerator/liquefier
- o LN_2 supply to the auxiliary heat exchanger
- o LN_2 supply to diagnostics
- o LN_2 supply to the gas purification system
- o LN_2 supply to the vacuum pump traps as shown in Figures 10 and 11.

(1) All LN_2 supply lines shall be superinsulated and vacuum jacketed. All vacuum insulated piping in the torus enclosure shall utilize Kapton H multi-layer insulation, Dexiglas paper insulators if required and polyimide or G-10 spacers.

(2) A combination seal-off/pressure relief valve shall be provided on each transfer line section and each field joint to permit evacuation of the vacuum space. Seal materials utilized in the valve shall be polyurethane.

(3) Each section of LN_2 line shall be capable of sustaining vacuum at 10^{-5} torr for a minimum of 10 years without re-evacuation.

(4) Shut-off valves shall be installed in the LN_2 distribution system as shown on schematic drawing 70B373017.

(5) All valves used for flow control shall be long stem vacuum jacketed globe type with pneumatic actuators.

(6) Valve requirements within the torus enclosure are shown in Table VI.

(7) Design pressure for fluid lines shall be 100 psi minimum.

(8) The LN_2 transfer lines from the supply and vent manifolds to the mirror coils (70B373010) shall contain sufficient flexibility through internal and external bellows sections to accept a maximum displacement of 1.50 inches in each of 6 degrees of freedom at the magnet interface in addition to manufacturing and installation tolerances.

(9) The liquid nitrogen distribution lines shall be fabricated by welding 304L stainless steel. Field welded connections shall be of standard design and shall minimize heat leak into the cryogenic fluid.

(10) The gyrotron nitrogen supply and return lines shall terminate with male bayonets supplied by the Seller. The Seller shall specify the part number of the mating female half.

3.2.2.8 Gaseous Nitrogen Distribution System Performance - The gaseous nitrogen distribution lines consists of atmospheric vents from the various LN_2 use points.

(1) All GN_2 vent lines within the torus area shall be vacuum jacketed. All vacuum insulated piping in the torus enclosure shall utilize Kapton H multi-layer insulation, Dexiglas paper insulators if required and polyimide or G-10 spacers.
(2) All GN_2 vent lines outside the torus area but within the building shall be insulated to ensure that exposed surfaces will not have a temperature lower than the dew point at ambient air.
(3) The GN_2 vent lines shall vent outside the building.
(4) The GN_2 vent lines shall not terminate on a roof or near any equipment that could be damaged by cold gas or an accidental vent of liquid nitrogen.
(5) Valve requirements within the torus enclosure are shown in Table VI.
(6) Design pressure for fluid lines shall be 100 psig minimum.

3.2.2.9 Auxiliary Heat Exchanger Performance - The auxiliary heat exchanger is required to condition the helium gas circulated through the mirror and gyrotron coils during the cooldown (300°K to approximately 100°K) or warm-up (4.2°K to 300°K) process.

(1) The LN_2/GHe heat exchanger shall condition the helium gas temperature to cool-down 36 mirror magnets and 6 gyrotron magnets from 300°K to 100°K as specified in Table IV. The heat exchanger shall cover the entire range specified in Table IV.
(2) Pressure drop through the helium side shall not exceed 5.0 psi when flowing 125 gm/sec of gaseous helium at 300°K.
(3) The LN_2 heat exchanger shall be connected to the transfer lines as shown on drawing 70B373017.
(4) A LN_2 control valve shall be installed on the heat exchanger to allow temperature control of the cool-down discharge stream.

(5) A GHe heater shall be provided in the heat exchanger to facilitate the warm-up process of the mirorr coil and gyrotron systems.

(6) The GHe heater shall be electric and shall provide a minimum of 120,000W of heating to the helium gas stream.

(7) Power input to the GHe heater shall be controlled to limit the temperature differential across the mirror coils per Table III.

(8) The auxiliary heat exchanger shall conform to TEMA standards listed in Section 2.6.

(9) The auxiliary heat exchanger shall be designed, fabricated and stamped in accordance with ASME Boiler & Pressure Vessel Code, Section VIII, Division 1.

3.2.2.10 Bypass Heat Exchanger Performance - The bypass heat exchanger is required to prevent cold helium gas from entering the compressor suction when the cold box is down for repair or maintenance. Cold gas returning from the mirror magnet and gyrotron magnet dewars will bypass the cold box and be warmed in the bypass heat exchanger before entering the compressor suction.

(1) The bypass heat exchanger shall accept and warm the total helium gas load for steady state operation as defined in Table I.

(2) When operating with the total steady state gas load, the pressure drop through the bypass heat exchanger shall be such to allow the mirror magnet and gyrotron magnet dewars to operate at a pressure of 14.7±0.3 psia.

(3) The temperature of the gas on the compressor side of the heat exchanger shall be such to prevent damage or malfunction of the compressors.

(4) The bypass heat exchanger shall conform to TEMA standards listed in Section 2.6.

(5) The bypass heat exchanger shall be designed, fabricated and stamped in accordance with ASME Boiler and Pressure Vessel Code Section VIII, Division 1.

3.2.2.11 Instrumentation and Control System Performance - An instrumentation and control (I&C) subsystem shall be provided to allow a single operator to monitor and control the system during all modes of operation identified herein.

The capability for a single operator to monitor and control the system shall be defined as follows. The I&C system supplied by the seller shall provide those displays and controls necessary to allow one person to operate the system from the master control room. The single operator will be assisted by personnel who can make manual adjustmenets on the system elements under his control.

The Seller shall be responsible for the complete subsystem except as follows:

(1) Providing and processing the output signal of the liquid level transducers and supplying the 3-15 psig pneumatic control signals to the mirror magnet and gyrotron magnet dewar helium fill valves.

(2) Processing the output signal of the bilevel liquid transducers and supplying the 3-15 psig pneumatic control signals to the mirror magnet and gyrotron magnet dewar nitrogen shield fill valves.

(3) Providing and processing the output signal of the vapor cooled lead temperature transducers and supplying the 3-15 psig pneumatic control signals to the mirror magnet vapor cooled lead valves.

(4) Providing and processing the output signal of the mirror and gyrotron coil instrumentation and supplying the control signals to the auxiliary heat exchanger. MDAC will provide a 3-15 psig pneumatic signal to control LN_2 flow during cooldown and a 0-5 vdc signal to control the heater during warm-up.

A control center shall be located in the EBT-P control room as shown in Drawing 70B378011 and shall provide the necessary control functions for both manual or computer assisted operation. The control center shall mimic a control console located in the mechanical equipment building. The seller shall provide all control and monitoring required to operate the complete system except as noted here-in. These control functions shall be designed as interlocked permissives using an Allen Bradley PLC-3 Process Controller. The refrigerator/liquefier and cryogenic distribution system control center shall include a process flow schematic, and shall be subject to MDAC-STL approval.

Cryogenic system status, caution and warning, and master control shall be accomplished from the EBT-P Master Control Console (MCC) as shown in Drawing 70B378011. The Seller shall provide the necessary status signals and process feedback terminals to monitor, sequence, and adjust the operating parameters of the system from the MCC.

Control of the complete cryogenic system except as noted may be performed from either the control console or the control center, but not from both simultaneously. The transfer of control from either location shall be bumpless for the discrete and analog systems. All automatic safety shutdown controls that are required to protect the facility or equipment, shall be independent of either manual or computer operating control. Annunciation of each shutdown shall be displayed on both the control console, control center and monitored by the computer. Figure 3 defines the general cryogenics/instrumentation system interface. Detail interfaces are shown in Figures 4, 5, 6, 7 and 8.

(1) The control console and microprocessor shall be supplied by the Seller. The console shall provide visible indications for the valve positions and compressor on/off conditions. Contact closures for these shall also be provided for the control center.

(2) Fault conditions that preclude normal operation of the helium refrigerator/liquefier shall be displayed on the control console and control center with interface capability to the MCC and computer system.

(3) The control center shall provide meters or digital readouts for all flow meters, temperature and pressure measurements, or other readouts essential to operation of the helium refrigerator/liquefier, and distribution systems. Analog or binary-coded signals representing these quantities shall be provided for MCC status and control.

(4) The Master Control Console will be provided by MDAC-STL. The Seller shall recommend those parameters required for the safe monitoring and control of the cryogenics system. MDAC-STL will also provide the software for interdependent systems interlocks to permit the safe and orderly start-up and fail-safe shutdown.

4.0 QUALITY ASSURANCE PROVISIONS - The ability of the cryogenic system defined by this specification to meet the requirements specified in Section 3.0 shall be verified by the performance of inspections, analyses, and tests as described herein. The Seller shall develop and MDAC will approve plans for pre-acceptance testing and inspection prior to shipment. The plan shall include tests which may be conducted at sub-tier supplier levels, manufacturing in process inspections, and sub-assembly performance testing as applicable.

The cryogenic system acceptance tests shall be performed at Oak Ridge Valley Industrial Park following installation in the EBT-P facility. The acceptance tests shall be performed in accordance with an acceptance test procedure prepared by the Seller and approved by MDAC-STL. Verification of performance of the refrigerator/liquefier shall be conducted independently from the cryogenic distribution system. The Seller shall provide all equipment and materials for all tests. MDAC will provide technicians and technical supervision to perform the acceptance test under the direct supervision of the Seller. Training of MDAC-STL and/or ORNL technicians in the operation of the cryogenic system shall be accomplished at the EBT-P facility as part of the acceptance test.

4.1 PRE-ACCEPTANCE TESTS - Pre-acceptance testing consists of those tests and inspections conducted on components and subassemblies during the fabrication of the equipment to assure that the requirements of this specification are being met. These tests shall include, but not be limited to the following:

(1) Cold Box and Piping - All piping, valves, and vessels in the cold box shall be subjected to pneumatic testing in accordance with the ASME Pressure Vessel Code and Power Piping Code. All fluid lines shall be

helium leak tested. Maximum leakage shall not exceed 1×10^{-10} scc/second. If applicable, all valves shall be tested in accordance with MSS document SP-61, Hydrostatic Testing of Steel Valves. Also, all piping shall be tested to standards of Pipe Fabrication Institute (PFI) document ES4, Standard Practice, Shop Hydrostatic Testing of Fabricated Piping.

(2) Cold Box Vacuum - The cold box piping, vessels, heat exchangers, and other components shall be subjected to normal operating pressures by flowing Helium gas either from the compressor or an external pressure source. When tested at operating pressure and ambient temperature, the vacuum level shall not exceed 1×10^{-5} torr for one hour when pumped with the vacuum system supplied with the cold box.

(3) Compressor Performance - Following completion of the installation of the compressor, the compressor shall be operated under design conditions for a period of 24 hours to verify compliance with this specification. The Seller shall specify the tests required to demonstrate performance of the compressor skids.

(4) Vacuum Jacketed Piping - The Seller shall perform and the piping shall pass a thermal short test on each individual vacuum jacketed spool.

(5) Auxiliary Heat Exchanger - All piping, valves, and vessels in the auxiliary heat exchanger shall be subjected to pneumatic testing in accordance with the ASME Pressure Vessel Code and Power Piping Code. All fluid lines shall be helium leak tested. Maximum leakage shall not exceed 1×10^{-10} scc/second. If applicable, all valves shall be tested in accordance with MSS document SP-61, Hydrostatic Testing of Steel Valves.

(6) By-pass Heat Exchanger - All piping, valves, and vessels in the by-pass heat exchanger shall be subjected to pneumatic testing in accordance with the ASME Pressure Vessel Code and Power Piping Code. All fluid lines shall be helium leak tested. Maximum leakage shall not exceed 1×10^{-10} scc/second. If applicable, all valves will be tested in accordance with MSS document SP-61, Hydrostatic Testing of Steel Valves.

4.2 ACCEPTANCE TESTS - The final acceptance test of the refrigerator/liquefier shall be conducted following installation and checkout by the Seller. The final acceptance test of the cryogenic distribution system shall be conducted in conjunction with the final acceptance tests of the complete EBT-P device or, at the option of the Seller, prior to connecting the magnets utilizing dummy magnet loads.

The helium refrigerator/liquefier shall be tested to meet the requirements specified herein. The output of the refrigerator/liquefier shall be measured with either a calorimeter, (supplied by the Seller as part of the refrigerator package) or with the use of a calibrated heater permanently installed in the liquid helium dewar. If the liquid helium dewar is used for the acceptance of the refrigerator/liquefier, the heat leak shall be be determined by measuring the steady-state boil-off rate with all lines in place, and vacuum annulus evacuated to specification requirements. The heat leak shall not exceed the requirements specified in 3.2.2.2(5). The refrigerator/liquefier shall meet or exceed the requirements specified in 3.2.2.1 for a minimum of 24 hours.

Acceptance testing of the distribution system after installation but before connecting the magnet dewars shall include pneumatic testing at twice the operating pressure, external leak testing of the system, internal leak testing of valves, heat leak verification testing and mechanical integrity testing of all dynamic components including instrumentation. After connecting the magnet dewars, the system (with magnet fill valves open) shall be pneumatically tested at 52.5 psig. Magnet burst discs shall be removed and the open stack capped off to perform this test. After the pneumatic test, the burst discs shall be replaced and the whole system shall be leak tested.

The acceptance tests shall include demonstrations of operation in all operating modes described herein, and shall demonstrate that the system is suitable for its intended purpose and meets the requirements of this specification.

The Sellers detailed acceptance test procedures shall contain specific requirements, accept/reject criteria, and exact descriptions of each test with provisions to record the types of equipment used during the test. Sellers acceptance test procedures shall be prepared and submitted in accordance with the SDRL.

5.0 PREPARATION FOR DELIVERY

5.1 IDENTIFICATION AND MARKING

a. All separate deliverable items or replaceable components shall be marked with a nameplate. The following data shall be included on the nameplate:
   - Part name
   - Manufacturing name and FSCM no.
   - Specification number (MDAC-STL part no.)
   - Manufacturing serial number
   - Date of manufacture

b. Further all piping shall be marked in accordance with the Pipe Fabrication Institute (PFI) Standards ES11, Recommended Practice for Permanently Affixing Identification Symbols to Fabricated Piping.

c. Further all valves, flanges, fittings, and unions shall be marked in accordance with MSS document SP-25 Standard Marking System for Valves, Fittings, Flanges, and Unions. Valves shall be marked with an arrow indicating the flow direction.

5.2 PACKAGING FOR SHIPMENT AND DELIVERY

a. Conformance - The equipment to be delivered shall be completely assembled (spool level) and shall conform to all requirements of this specification and conformance shall have been established per 4.2. Any area of nonconformance requires MDAC authorization prior to shipment.

b. Documentation - One copy of the acceptance test records per 4.2 shall accompany the equipment.

c. Protection - As a minimum, the equipment shall be protected by installation of Cap-Plugs or other suitable devices on all electrical and pneumatic connections and shall be sealed in a plastic bag to preserve cleanliness. All lines and vessels shall be pressurized to 5 psig minimum with a dry gas prior to shipment.

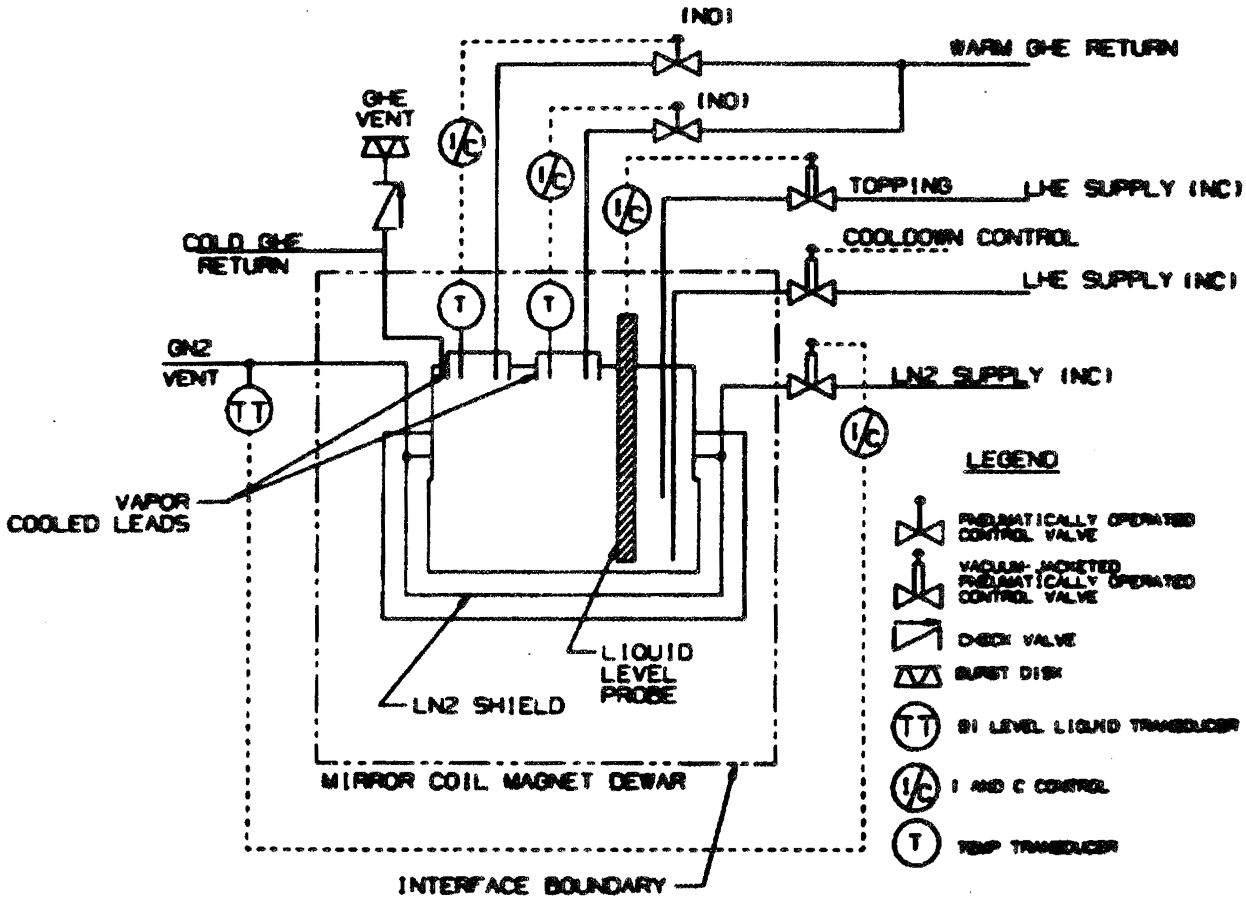
d. Preparation for Shipment - The equipment shall be prepared for shipment in accordance with MDE-6-20-1.

6.0 ACRONYMS AND ABBREVIATIONS - The following definitions are applicable to the acronyms and abbreviations utilized in this specification.

Item	Definition
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CGA	Compressed Gas Association
Cryo	Cryogenics
EBT-P	Elmo Bumpy Torus Proof of Principle Device
ft^3	Cubic feet
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
gm/sec	Grams per second
IEEE	American Institute of Electrical and Electronics Engineers

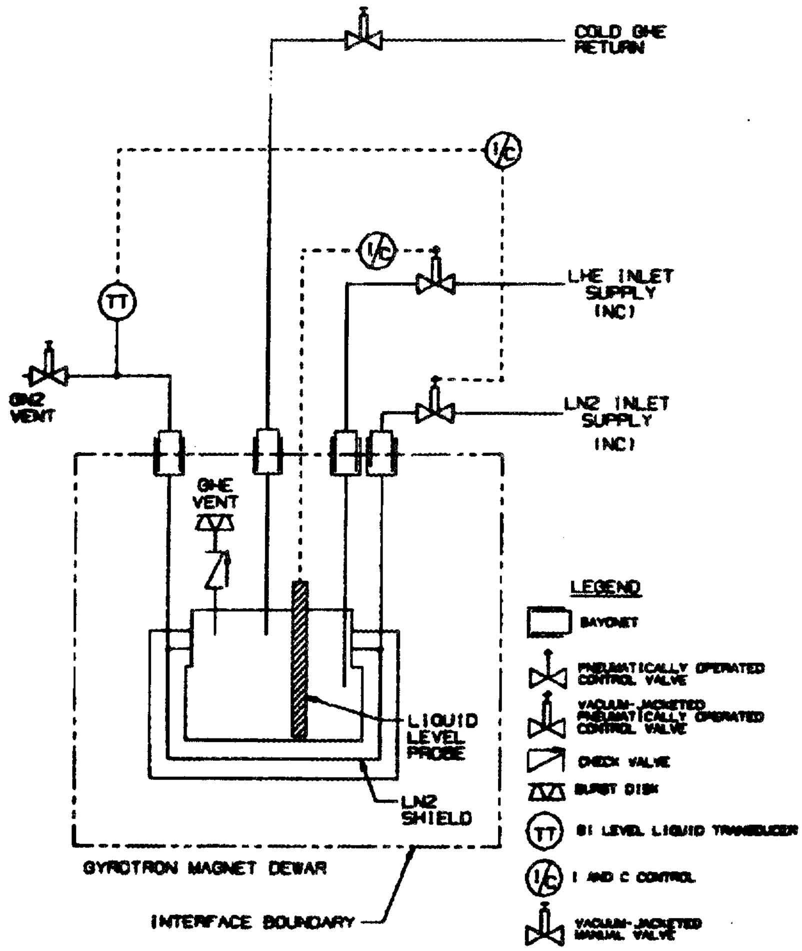
ISA	Instrumentation Society of America
°K	Degrees Kelvin
LHe	Liquid Helium
LN_2	Liquid Nitrogen
MCC	Master Control Console
MDAC	McDonnell Douglas Astronautics Company
MSS	Manufacturers Standardization Society
NBS	National Bureau of Standards
NbTi	Niobium Titanium
NEMA	National Electrical Manufacturers Association
P&ID	Process and Instrument Diagram
PFI	Pipe Fabrication Institute
PO	Purchase Order
PS	Procurement Specification
psi	Pounds per square inch
psig	Pounds per square inch gauge
scc/second	Standard cubic centimeter per second

SCF	Standard cubic feet at standard atmospheric pressure and temperature
SRDP	Subcontractor Data Requirements Package
SSOW	Subcontractor Statement of Work
TBD	To Be Determined (By MDAC)
TBS	To Be Specified (By Seller in Proposal)
TEMA	Tubular Exchanger Manufacture Association



MIRROR MAGNET DEWAR
INTERFACE SCHEMATIC

FIGURE 1



GYROTRON MAGNET DEWAR
INTERFACE SCHEMATIC

FIGURE 2

Table I
Device Helium Delivery
Requirements

Device Element	Consumption [3] Each Element	Number of Elements	Total [3] Consumption	Fluid Properties [1] Inlet	Fluid Properties [1] Outlet
Mirror Magnet		36			
Steady State Dewar Losses	26.8 l/hr (≈19.0 W)		964.8 l/hr	Liquid @ 4.2°K	Vapor @ 4.2°K
Steady State Lead Losses	5.0 l/hr		180.0 l/hr	Liquid @ 4.2°K	Gas @ 300°K
Total Steady State Losses	31.8 l/hr		1144.8 l/hr		
Standby Dewar Losses	12.7 l/hr (≈9.0 W)		456.8 l/hr	Liquid @ 4.2°K	Vapor @ 4.2°K
Standby Lead Losses	5.0 l/hr		180.0 l/hr	Liquid @ 4.2°K	Gas @ 300°K
Total Standby Consumption	16.1 l/hr		579.2 l/hr		
Gyrotron [2]					
Operational Losses	1.2 l/hr	6	7.2 l/hr	Liquid @ 4.2°K	Vapor @ 4.2°K
Standby Losses	1.2 l/hr		7.2 l/hr	Liquid @ 4.2°K	Vapor @ 4.2°K

Notes: [1] Liquid at 4.2°K is saturated liquid in the pressure range of 14.7 ± 0.3 PSIA.

[2] Gyrotrons will be bulk filled daily. Approximate volume of each gyrotron is 60 liters.

[3] Liquid consumption based on the latent heat at 14.7 psia.

Table II

Nitrogen Delivery Requirements [2]

Device Element	Consumption Each Element	Number of Elements	Total Consumption	Fluid Properties [1] Inlet	Outlet
Mirror Magnet [3]	1.5 l/hr (≈66 W)	36	54.0 l/hr	Liquid @ 77°K	Vapor @ 77°K
Gyrotron Magnet [5]	0.4 l/hr	6	2.4 l/hr	Liquid @ 77°K	Vapor @ 77°K
Soft X-Ray Spectrometer [4]	3 l/hr	1	3 l/hr	Liquid @ 77°K	Vapor @ 77°K

NOTES:

[1] Delivery pressure at control valve is approximately 25 psig.

[2] Cold box consumption is not included.

[3] Flow to these elements is continuous in a automatic quasi flooded system.

[4] This element will be bulk filled daily.

Table III
Mirror Magnetic Characteristics

LHe Dewar	
Total Volume	30.0 l
Min. Operating Volume	20.0 l
Max. Operating Volume	25.2 l
Pressure Rating (LHe Dewar)	
Design	50 psia
Operating Range	14.7 ± 0.3 psia
Quench Mode Max.	50 psia
Quench Mode Rise Rate in Magnet	230 psi/sec
Burst Disc Setting	28 psia
Heat Flux (LHe Dewar)	
Operating (plasma powered)	19.0 W
Standby (no plasma power)	9.0 W
Insulation Vacuum Loss	16,800 W
Maximum Cooldown ΔT (300-100°K Range)	10°K (bobbin to winding)
Maximum Design Pressure LN_2 Shield	30 psig
ΔP Across LN_2 Shield	5 psi

Table IV

Cooldown Performance Requirements at Each Mirror and Gyrotron Magnet Interface

Load Temperature Range °K	Cooldown Element	GHe Flow Rate g/s	Inlet Pressure PSIA	Minimum Inlet Temperature °K	Inlet-Outlet ΔT°K Max	Inlet-Outlet ΔT°K MIN
Mirror Magnet						
300-100	Aux. Heat Exchanger	3.4	25	80	220	10
100-10	Cold Box	2.1	25	50	35	5
		2.1	25	25	30	5
		2.1	25	10	20	5
10-4.2	Dewar	1.0	15.7	4.2	N/A	N/A
Gyrotron Magnet						
300-100	Aux. Heat Exchanger	0.5	25	80	220	10
100-10	Cold Box	0.3	25	50	35	5
		0.3	25	25	30	5
		0.3	25	10	20	5
0-4.2	Dewar	0.1	15.7	4.2	N/A	N/A

Table V

Utility Interfaces

Electrical Power

- 2400 VAC, 3ø, 60 HZ
- 220 VAC, 3ø, 60 HZ
- 110 VAC, 1ø, 60 HZ

Instrument Air

- Filtered and Oil Free Air at 15 PSIG and 72°F

Cooling Water

- Demineralized
- Inlet Temperature to Equipment 100°F
- Maximum Temperature Rise Across Equipment 18°F
- Pressure 230 psig
- Flow Rate TBS

Table VI

Valve Requirements
Inside Torus Enclosure

Item	Part Number	Operator
o Magnet Dewar		
LHe Topping	V-2070-050-J-S △1	88-0720-01001 △3
LHe Cooldown	V-1070-050-J-S △1	88-0720-01001 △3
LN_2 Shield	V-1070-050-J-S △1	88-0720-01001 △3
Vapor Cooled Lead	SS-8BG-STE-93NO △2	included with valve
o Gyrotron Dewar		
LHe Fill	V-2070-050-J-S △1	88-0720-01001 △3
He Vent	V-1060-050-J-S △1	None (manual)
LN_2 Shield	V-1070-050-J-S △1	88-0720-01001 △3
Shield Vent	V-1060-050-J-S △1	None (manual)

△1 Part number of CVI Corporation. The basic valve shall be modified by removing the standard parts and replacing them with parts made from the materials shown.

1) Seat Seal - Polyimide
2) Bonnet O-Rings - Polyurethane
3) Wear Rings - Polyimide

△2 Part Number of Nupro Company. The basic valve shall be modified by removing the standard parts and replacing them with parts made from the materials shown.

1) Operator O-Rings - Polyurethane

△3 Part number of CVI Corporation. The valve operator shall be modified by removing the standard parts and replacing them with parts made from the materials shown.

1) O-Rings - Polyurethane
2) Piston Gasket - Polyurethane

△4 Other values located inside the enclosure are optional, however, they shall meet the radiation life requirements specified herein.

FIGURE 3

I&C INTERFACE BLOCK DIAGRAM

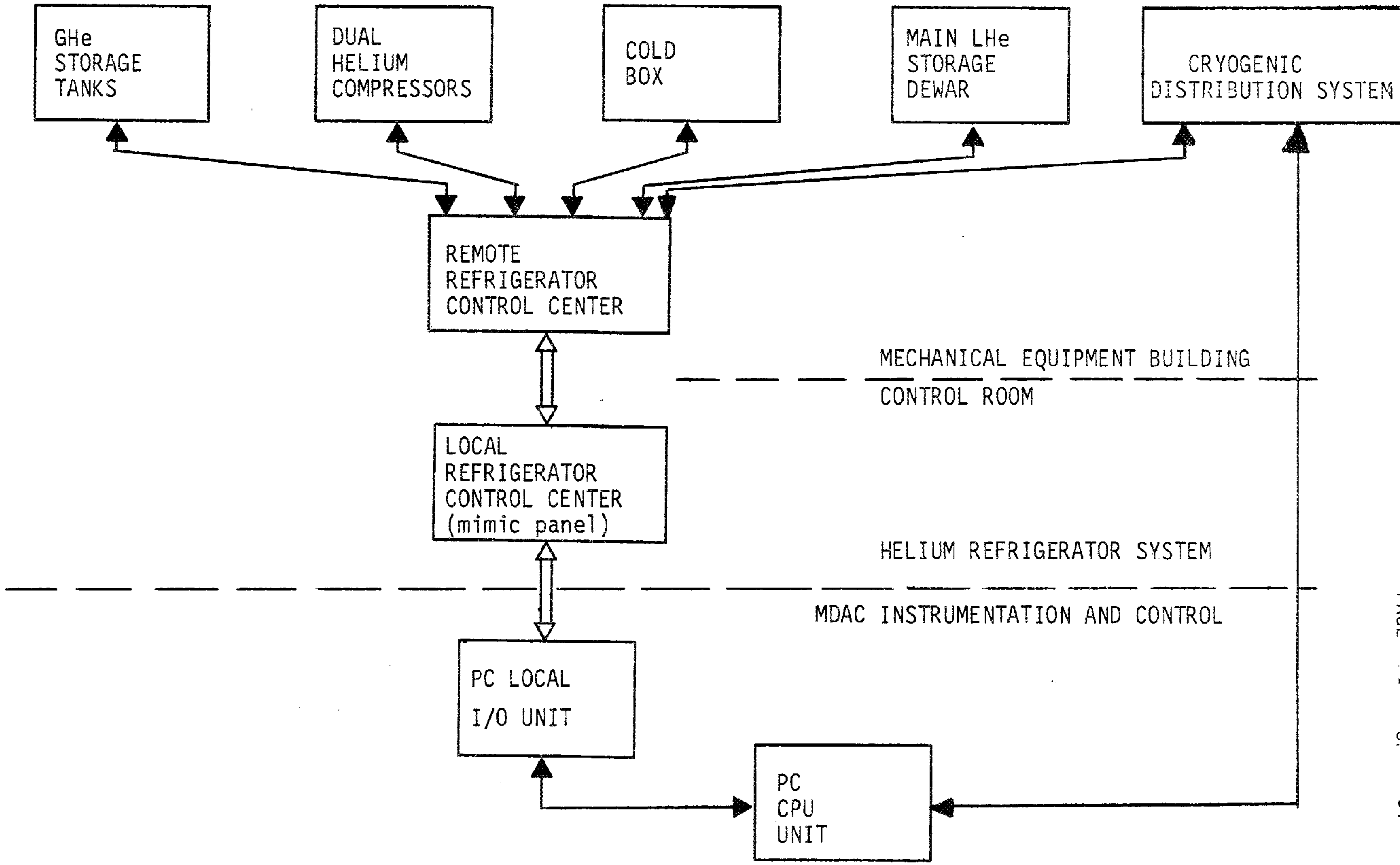
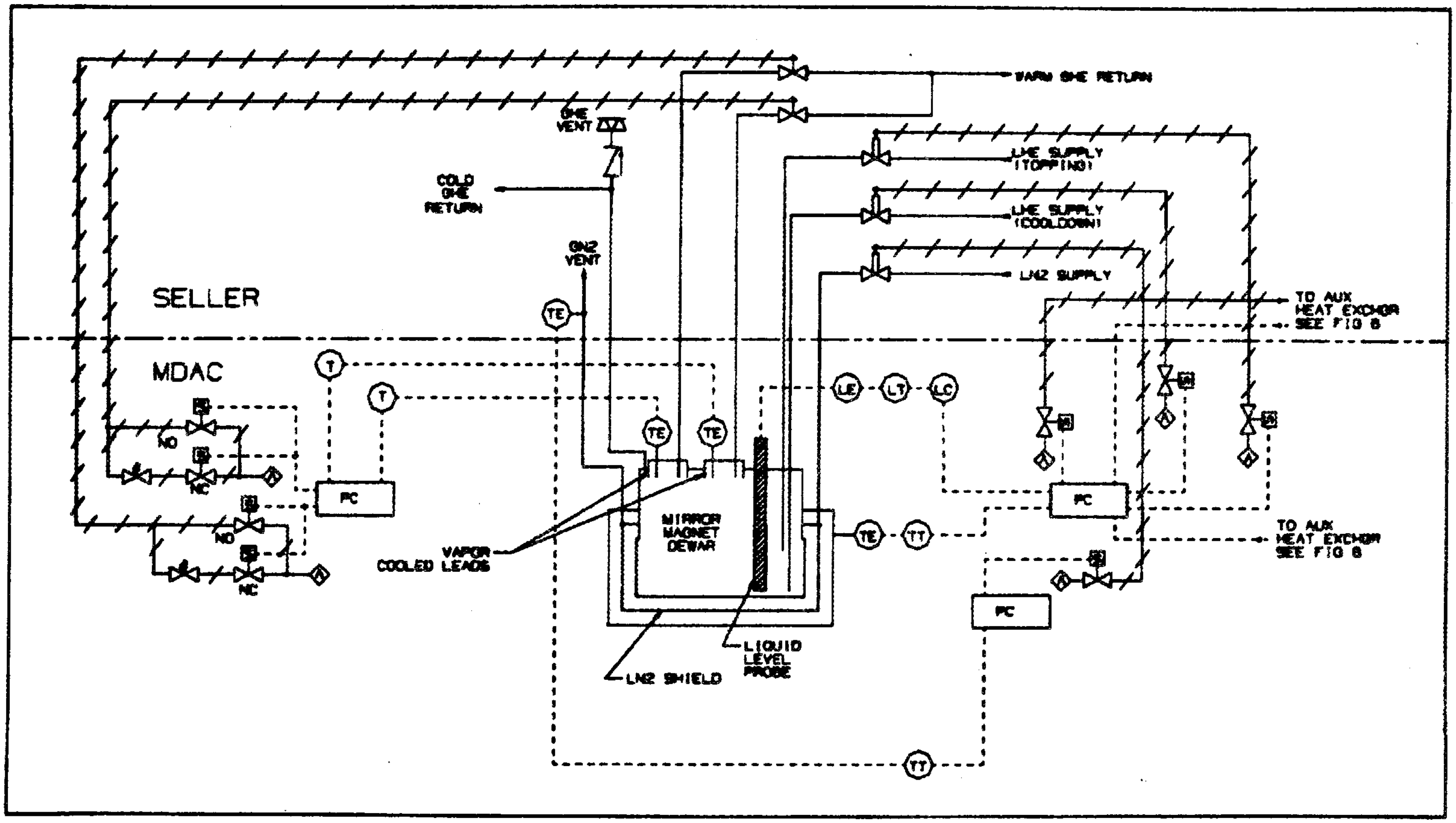
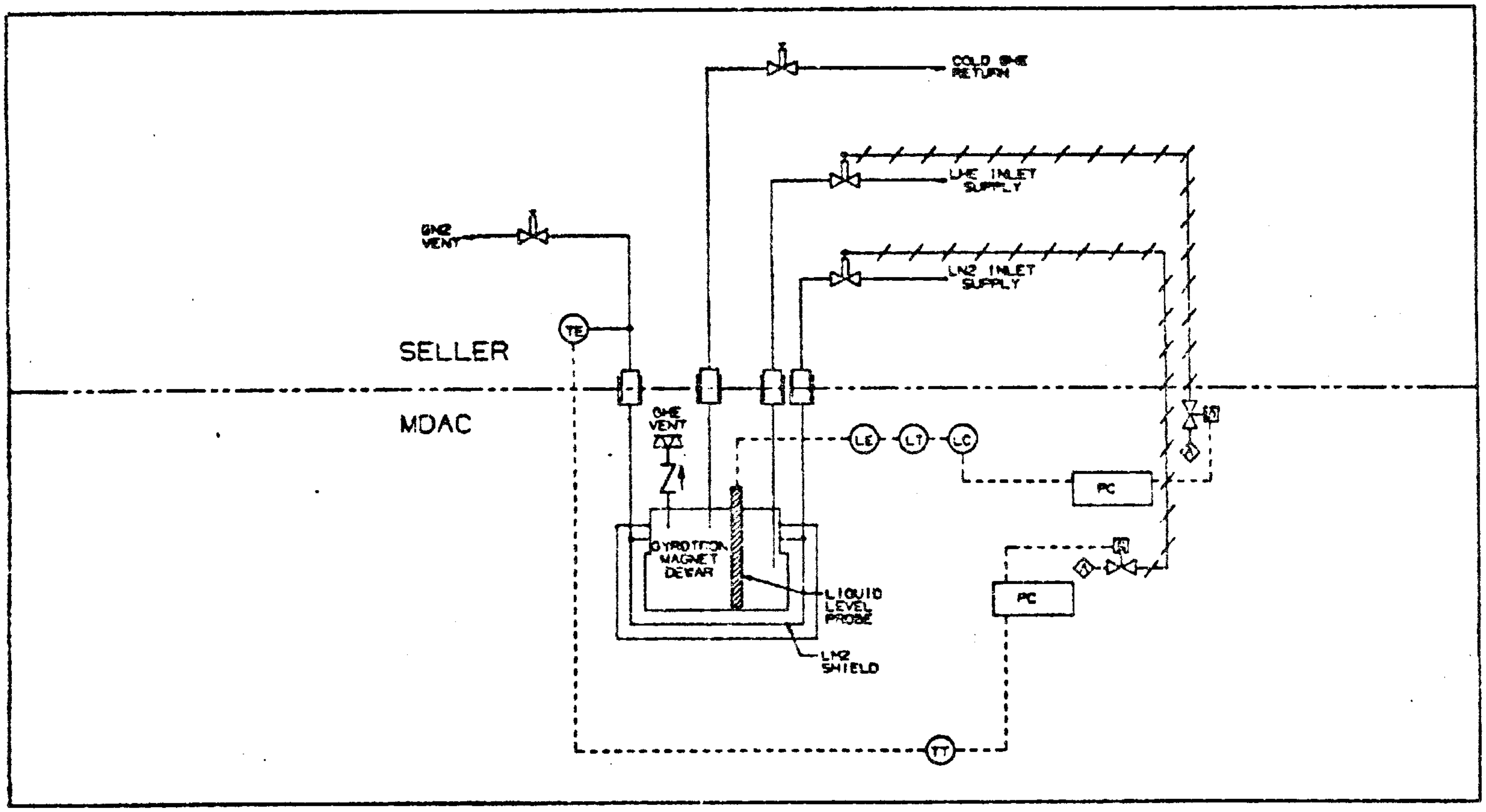


FIGURE 4



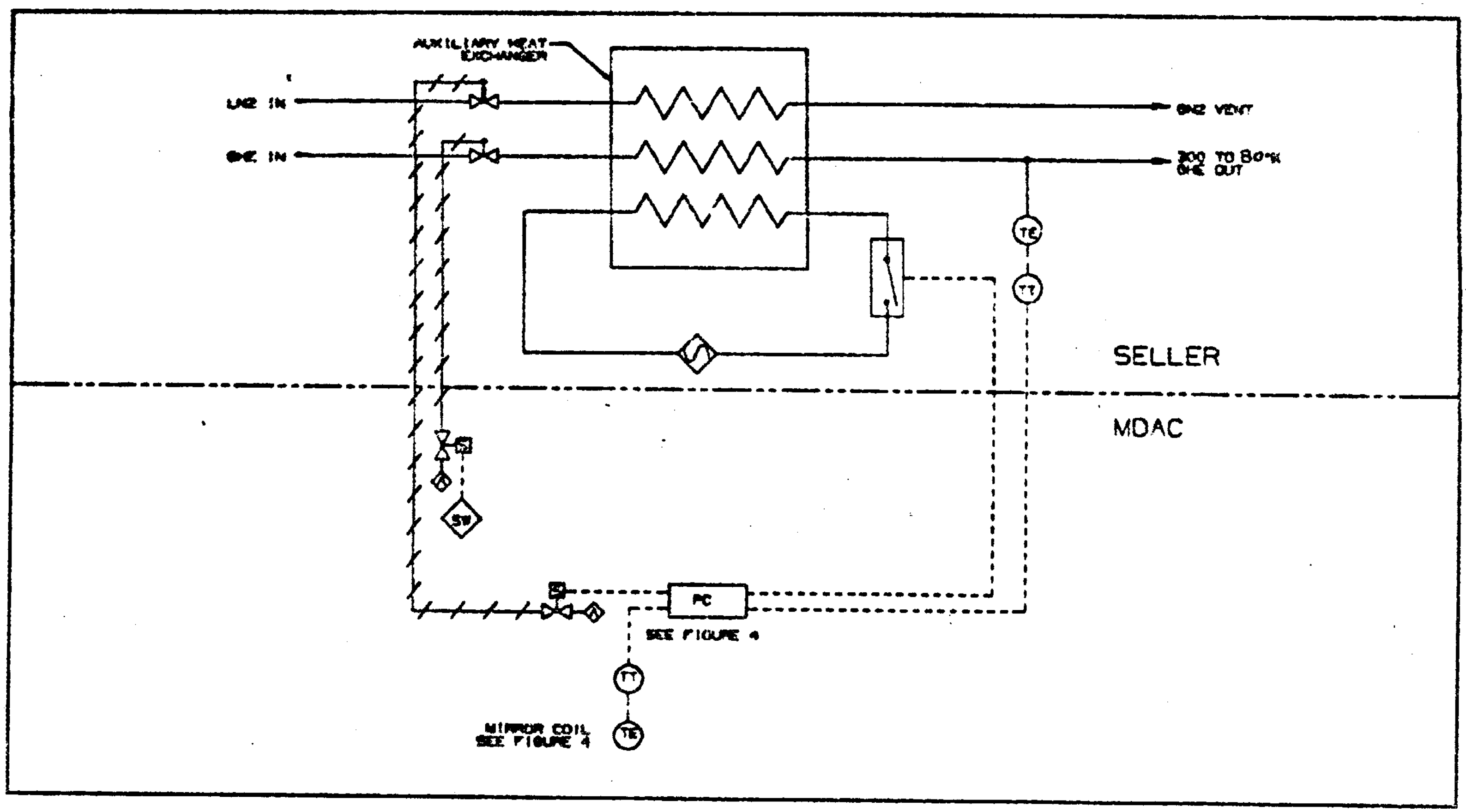
MIRROR MAGNET I&C INTERFACE

FIGURE 5



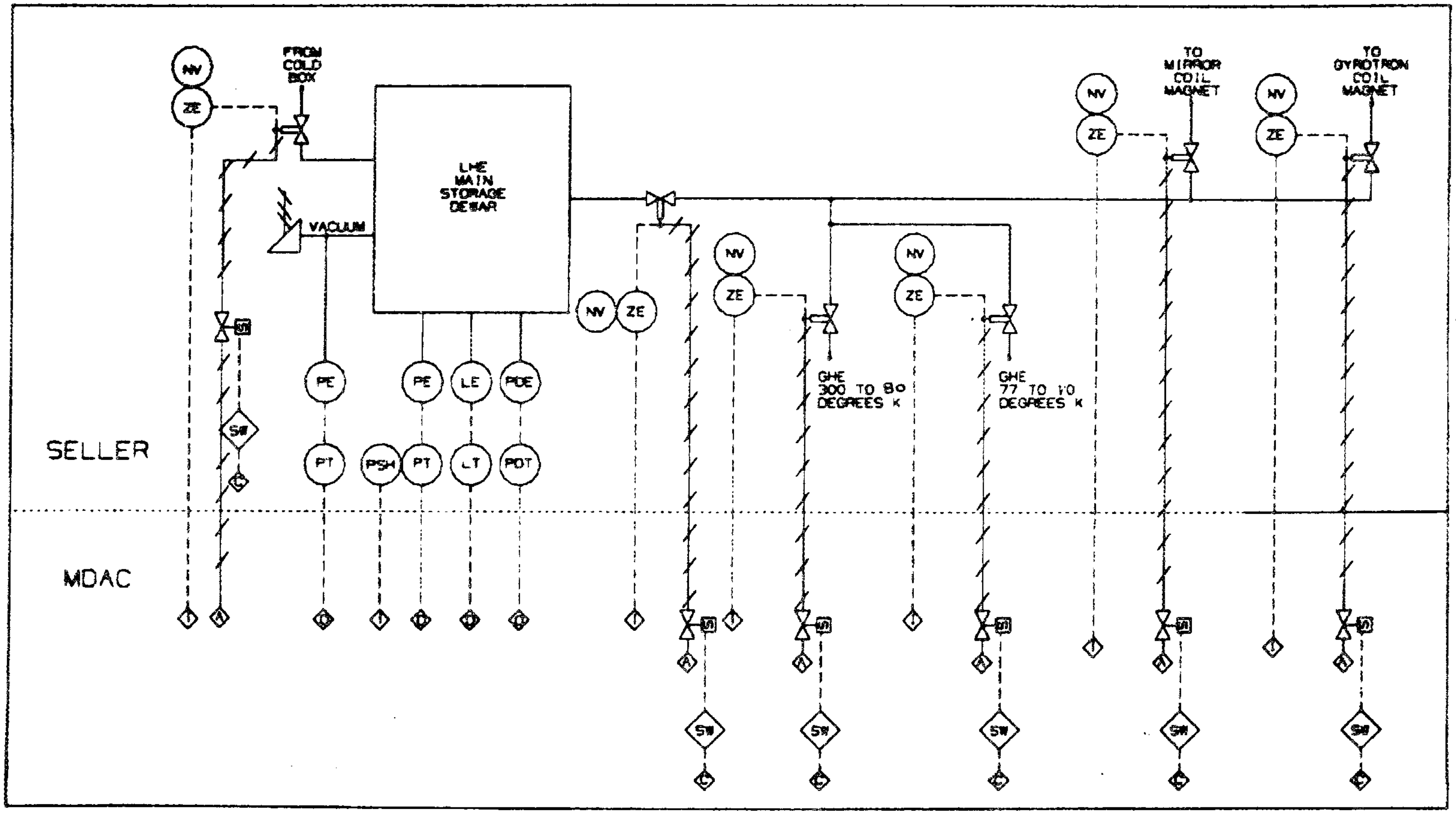
GYROTRON MAGNET I&C INTERFACE

FIGURE 6



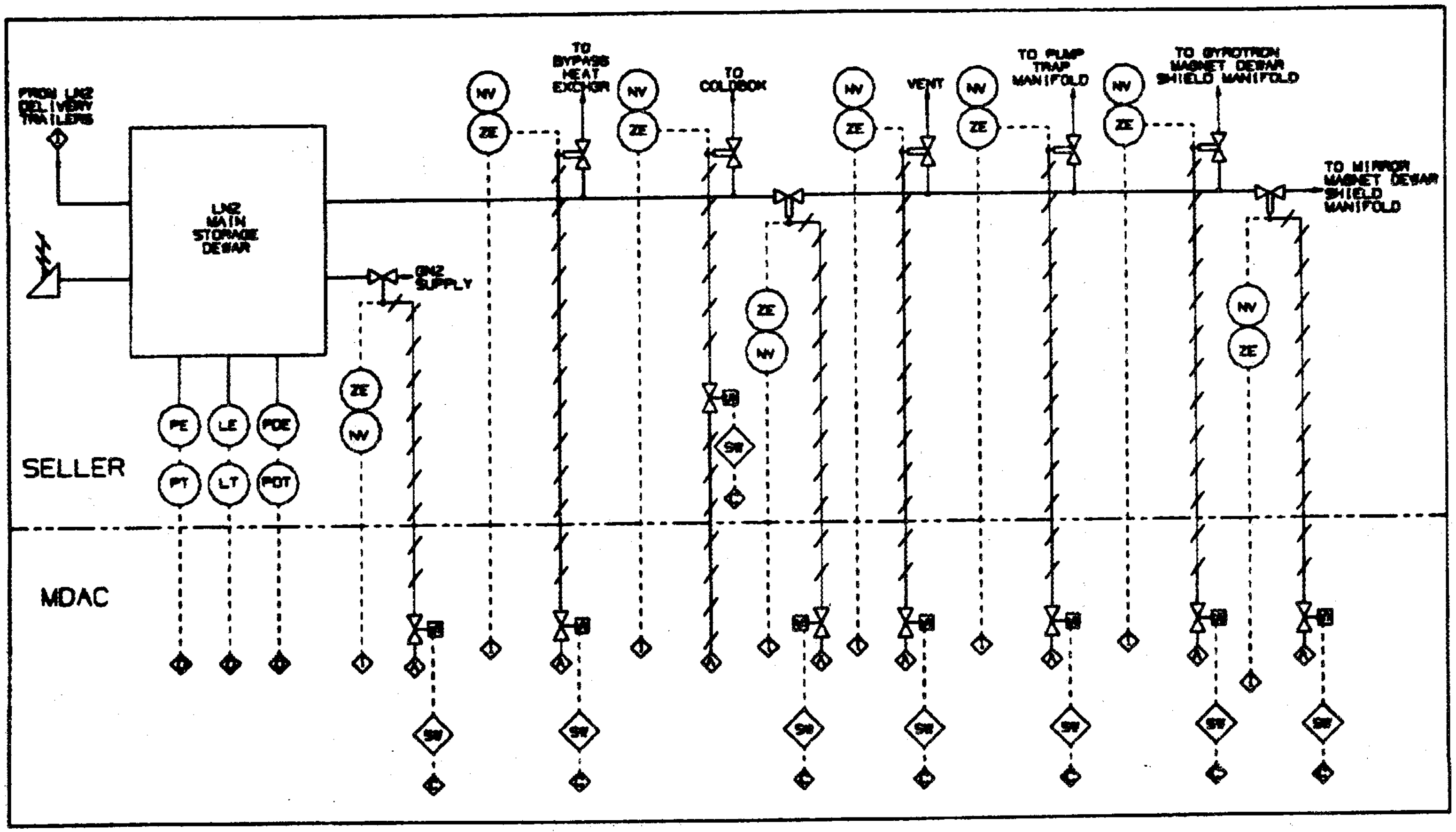
AUX HEAT EXCHANGER I&C INTERFACE

FIGURE 7



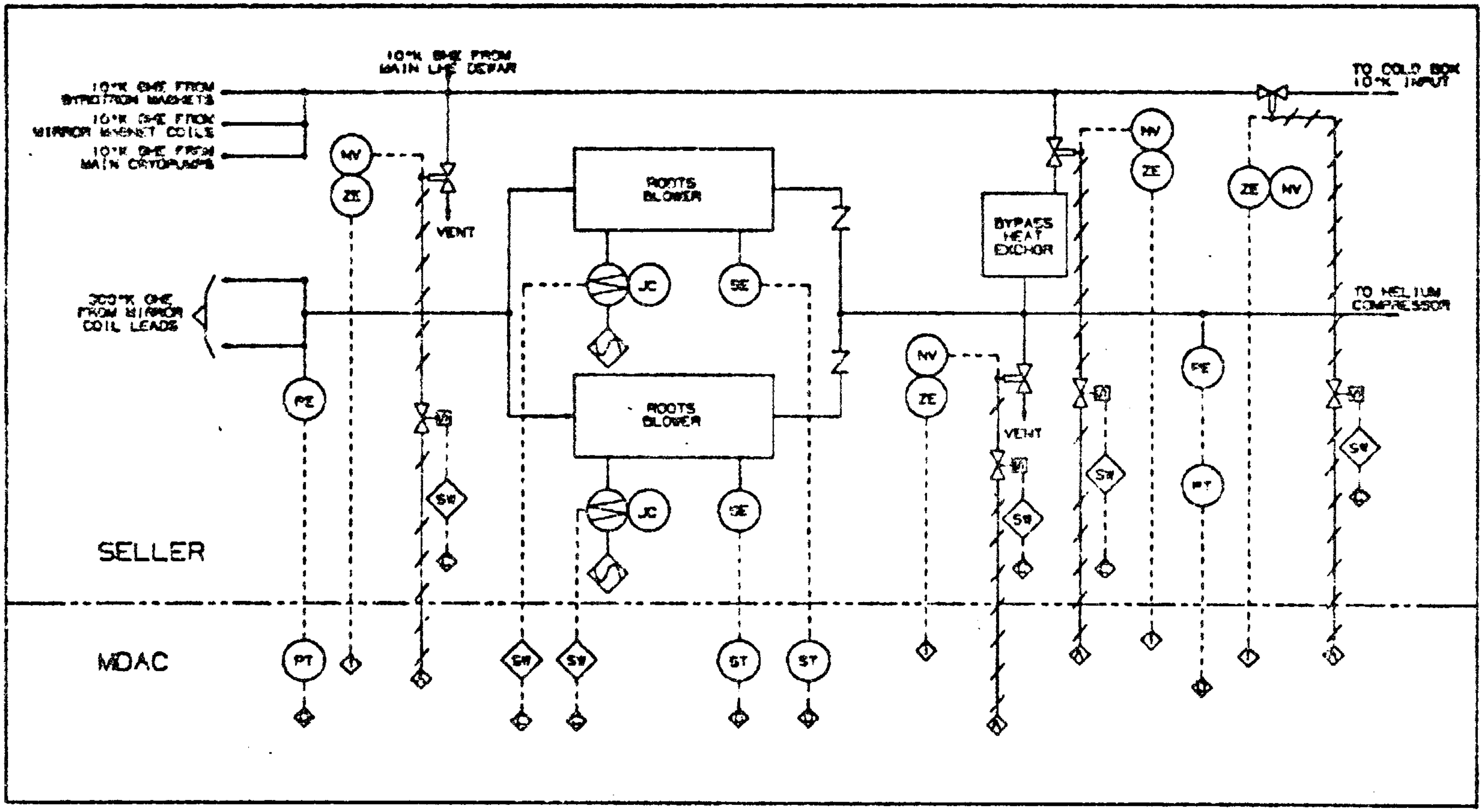
HELIUM DISTRIBUTION SYSTEM I&C BLOCK DIAGRAM

FIGURE 8



NITROGEN DISTRIBUTION SYSTEM I&C BLOCK DIAGRAM

FIGURE 9

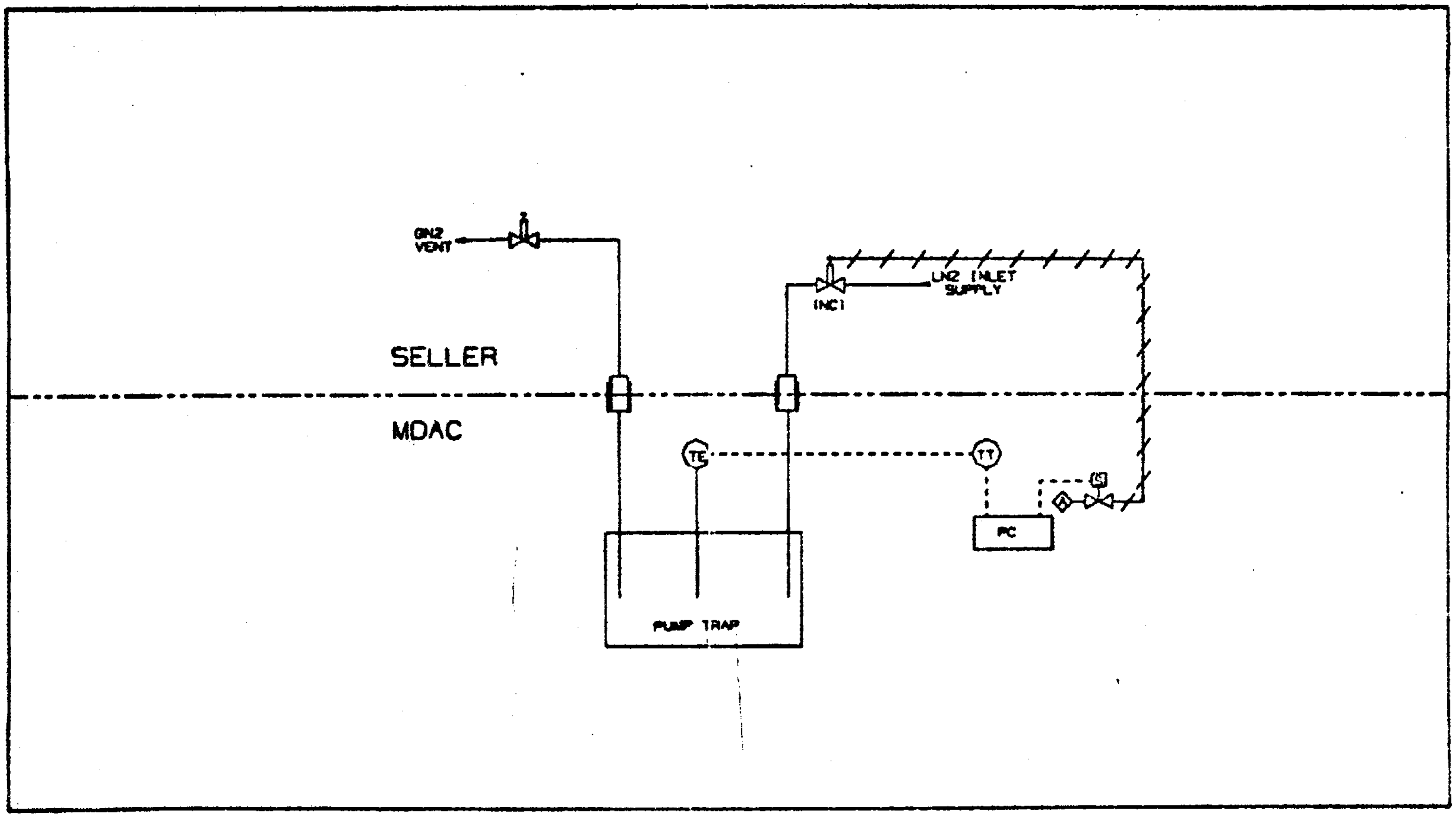


HELIUM RETURN I&C BLOCK DIAGRAM

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS

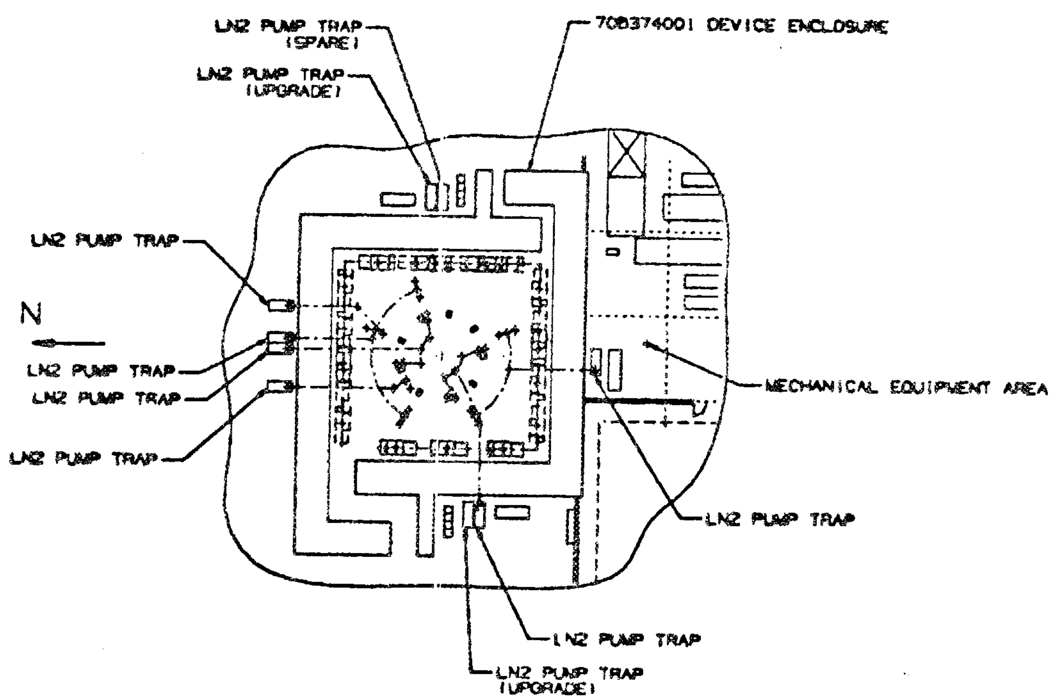
SPECIFICATION NO. 70P373000
FSCM NO. 76301
DATE 24 November 1981

FIGURE 10



PUMP TRAP DEVICE I&C INTERFACE

FIGURE 11



GENERAL ARRANGEMENT-LN2 PUMP TRAPS

FIGURE 12

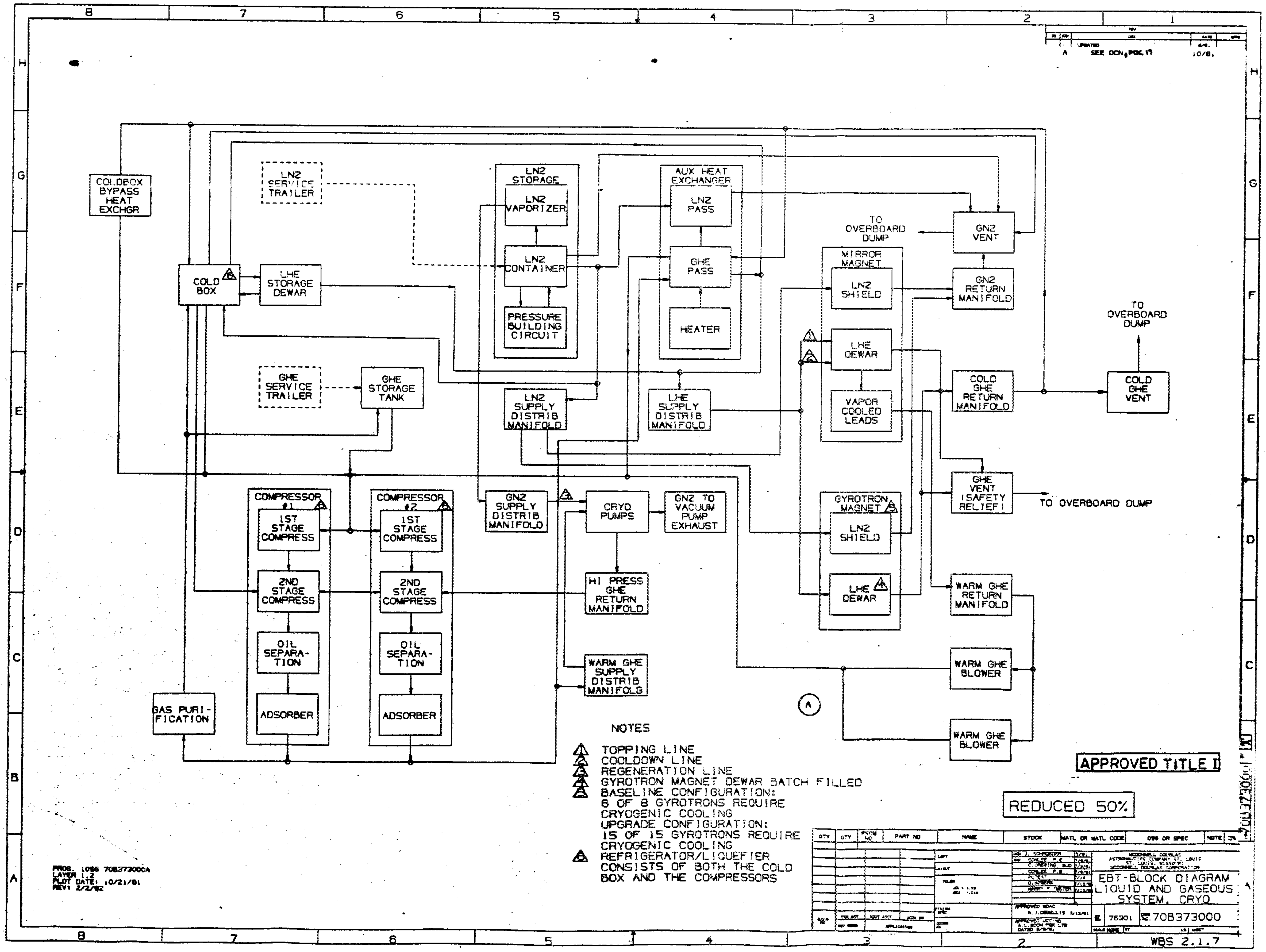
LEGEND

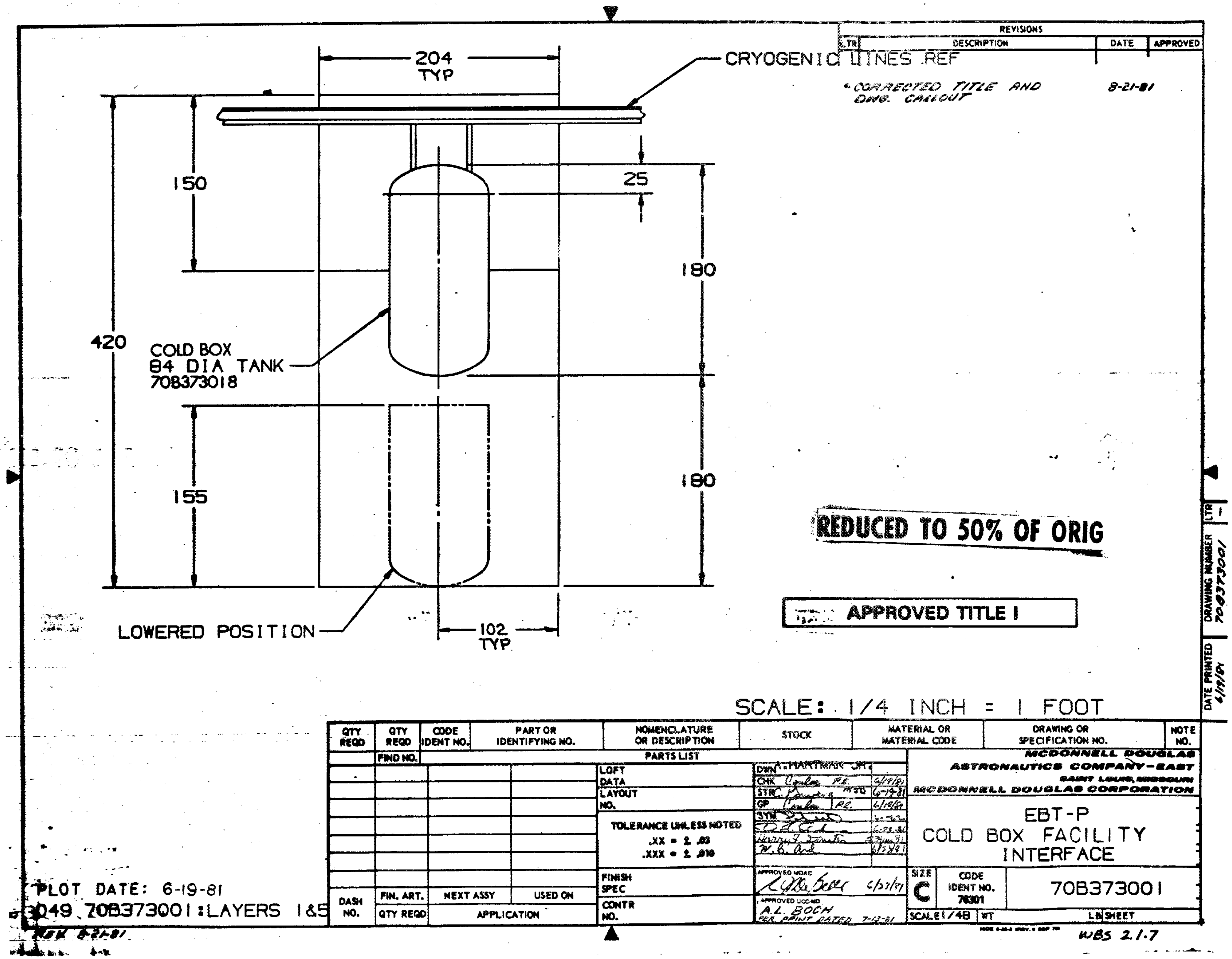
- AIR
- COMMAND
- INTERLOCK
- OUTPUT
- SOFTWARE
- AC POWER
- AC RELAY
- BAYONET
- SOLENOID VALVE
- MANUAL VALVE
- PNEUMATIC VALVE
- VAC JACKETED PNEU VALVE
- RELIEF VALVE
- CHECK VALVE

- BURST DISK
- SWITCH
- PRESS REGULATOR
- AIR LINE

JC	CURRENT CONTROLLER
LE	LEVEL SENSOR
LT	LEVEL TRANSDUCER
NV	PNEU VALVE
PC	PROCESS CONTROLLER
PDE	DELTA PRESSURE SENSOR
PDT	DELTA PRESSURE TRANSDUCER
PE	PRESSURE SENSOR
PSH	OVERPRESSURE SWITCH
PT	PRESSURE TRANSDUCER
SE	SPEED SENSOR
ST	SPEED TRANSDUCER
T	BILEVEL LIQUID TRANSDUCER
TE	TEMPERATURE SENSOR
TT	TEMP TRANSDUCER
ZE	POSITION SENSOR

LEGEND FOR ALL FIGURES


COLDBOX BYPASS HEAT EXCHGR
LN2 SERVICE TRAILER
LN2 STORAGE
LN2 VAPORIZER
LN2 CONTAINER
PRESSURE BUILDING CIRCUIT
AUX HEAT EXCHANGER
LN2 PASS
GHE PASS
HEATER
TO OVERBOARD DUMP
GN2 VENT
MIRROR MAGNET
LN2 SHIELD
GN2 RETURN MANIFOLD
LHE DEWAR
VAPOR COOLED LEADS
COLD BOX
LHE STORAGE DEWAR
GHE SERVICE TRAILER
GHE STORAGE TANK
LN2 SUPPLY DISTRIB MANIFOLD
LHE SUPPLY DISTRIB MANIFOLD
COLD GHE RETURN MANIFOLD
COLD GHE VENT
TO OVERBOARD DUMP
COMPRESSOR #1
COMPRESSOR #2
1ST STAGE COMPRESS
2ND STAGE COMPRESS
OIL SEPARA-TION
ADSORBER
GN2 SUPPLY DISTRIB MANIFOLD
CRYO PUMPS
GN2 TO VACUUM PUMP EXHAUST
GYROTRON MAGNET
LN2 SHIELD
LHE DEWAR
GHE VENT (SAFETY RELIEF)
TO OVERBOARD DUMP
HI PRESS GHE RETURN MANIFOLD
WARM GHE RETURN MANIFOLD
WARM GHE BLOWER
WARM GHE SUPPLY DISTRIB MANIFOLD
GAS PURI-FICATION
WARM GHE BLOWER
NOTES
1 TOPPING LINE
2 COOLDOWN LINE
3 REGENERATION LINE
4 GYROTRON MAGNET DEWAR BATCH FILLED
5 BASELINE CONFIGURATION: 6 OF 8 GYROTRONS REQUIRE CRYOGENIC COOLING
UPGRADE CONFIGURATION: 15 OF 15 GYROTRONS REQUIRE CRYOGENIC COOLING
6 REFRIGERATOR/LIQUEFIER CONSISTS OF BOTH THE COLD BOX AND THE COMPRESSORS
APPROVED TITLE I
REDUCED 50%
EBT-BLOCK DIAGRAM LIQUID AND GASEOUS SYSTEM, CRYO
76301
70B373000
WBS 2.1.7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LTR
DESCRIPTION
DATE
APPROVED
CORRECTED TITLE AND DWG. CALLOUT
8-21-81
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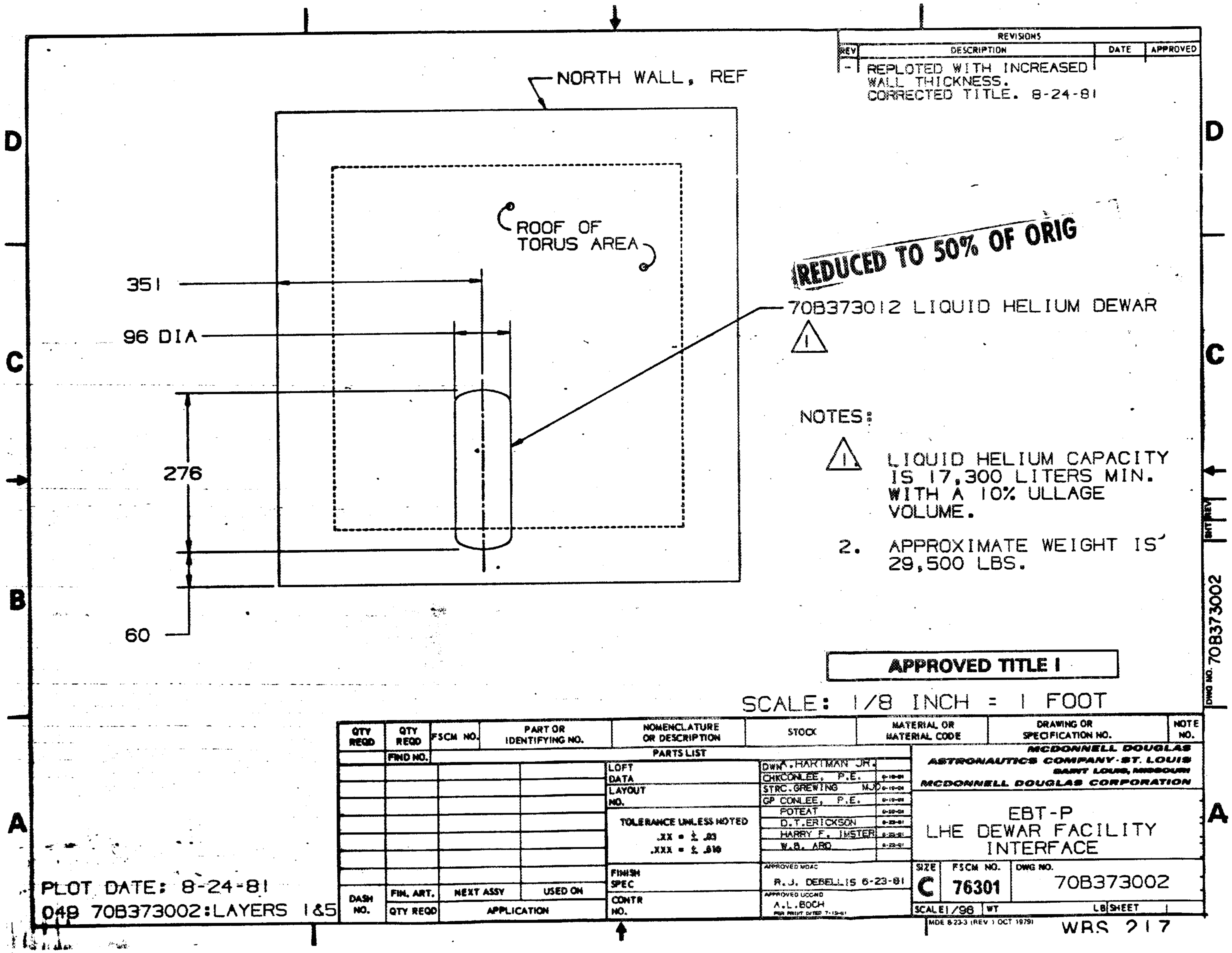
CRYOGENIC LINES REF
150
25
180
420
COLD BOX
84 DIA TANK
70B373018
155
180
LOWERED POSITION
102 TYP
REDUCED TO 50% OF ORIG
APPROVED TITLE I
SCALE: 1/4 INCH = 1 FOOT
DRAWING NUMBER
70B373001
DATE PRINTED
6/19/81
PARTS LIST
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-EAST
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
COLD BOX FACILITY
INTERFACE
SIZE C
CODE IDENT NO. 76301
70B373001
TOLERANCE UNLESS NOTED
DWN A. HARTMAN JR.
SCALE 1/48
SHEET
PLOT DATE: 6-19-81
3049 70B373001:LAYERS 1&5
REV 8-21-81
WBS 2.1.7


REVISIONS
REV
DESCRIPTION
DATE
APPROVED
-
REPLOTED WITH INCREASED WALL THICKNESS. CORRECTED TITLE. 8-24-81
NORTH WALL, REF
ROOF OF TORUS AREA
351
96 DIA
276
60
REDUCED TO 50% OF ORIG
70B373012 LIQUID HELIUM DEWAR
NOTES:
1. LIQUID HELIUM CAPACITY IS 17,300 LITERS MIN. WITH A 10% ULLAGE VOLUME.
2. APPROXIMATE WEIGHT IS 29,500 LBS.
APPROVED TITLE I
SCALE: 1/8 INCH = 1 FOOT
DWG NO. 70B373002
QTY REQD
QTY REQD
FSCM NO.
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
STOCK
MATERIAL OR MATERIAL CODE
DRAWING OR SPECIFICATION NO.
NOTE NO.
FIND NO.
PARTS LIST
LOFT DATA
LAYOUT NO.
TOLERANCE UNLESS NOTED .XX = ± .03 .XXX = ± .010
FINISH SPEC
CONTR NO.
DASH NO.
FIN. ART.
NEXT ASSY
USED ON
QTY REQD
APPLICATION
DWN A. HARTMAN JR.
CHK CONLEE, P.E.
STRC. GREWING
GP CONLEE, P.E.
POTEAT
D.T. ERICKSON
HARRY F. IMSTER
W.B. ARD
APPROVED MDAC
R.J. DEBELLIS 6-23-81
APPROVED UCCND
A.L. BOCH
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
LHE DEWAR FACILITY INTERFACE
SIZE C
FSCM NO. 76301
DWG NO. 70B373002
SCALE 1/96
WT
LB
SHEET 1
MDE 623-3 (REV 1 OCT 1979)
WBS 217
PLOT DATE: 8-24-81
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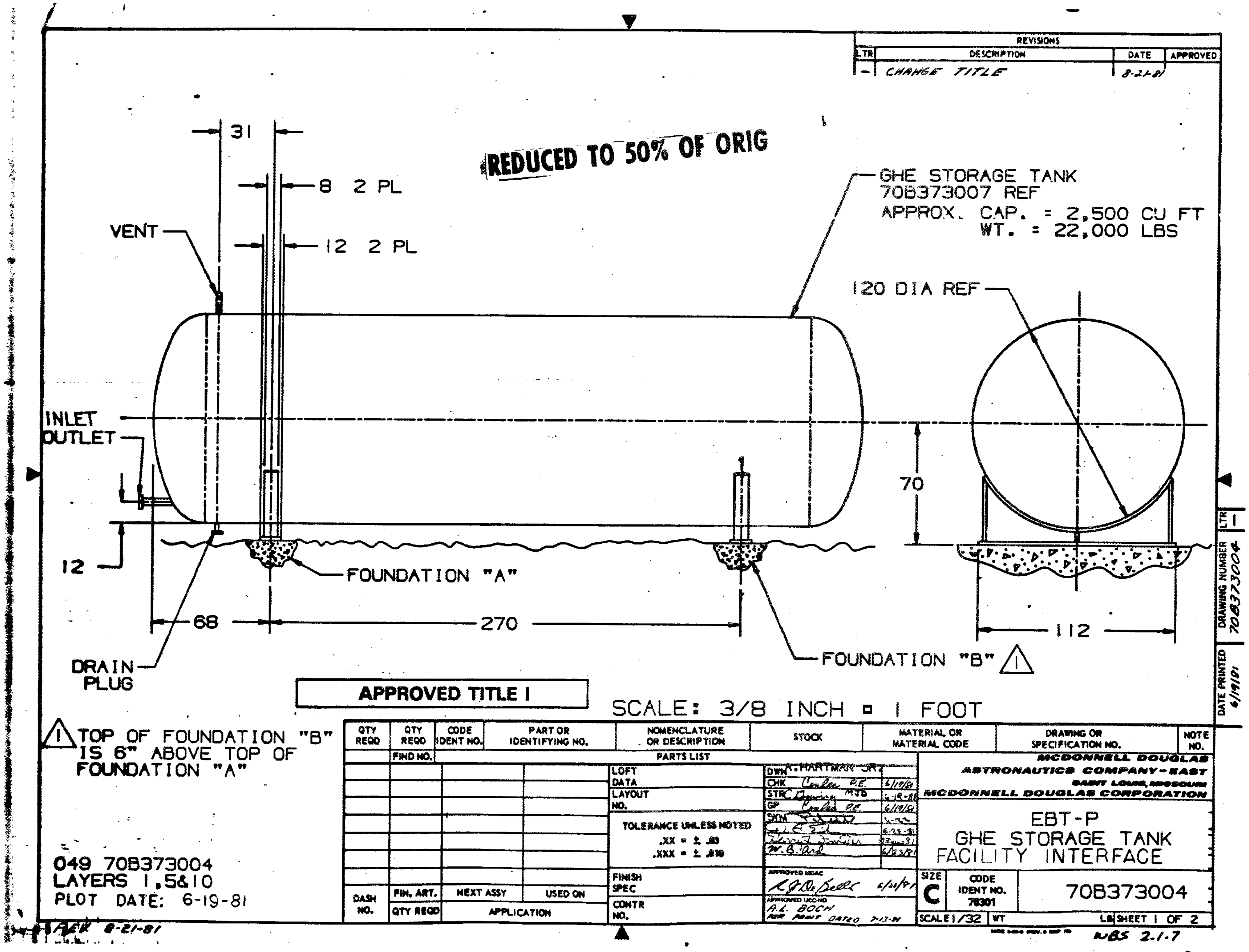
REVISIONS
LTR | DESCRIPTION | DATE | APPROVED
– CHANGE TITLE 8-21-81
REDUCED TO 50% OF ORIG
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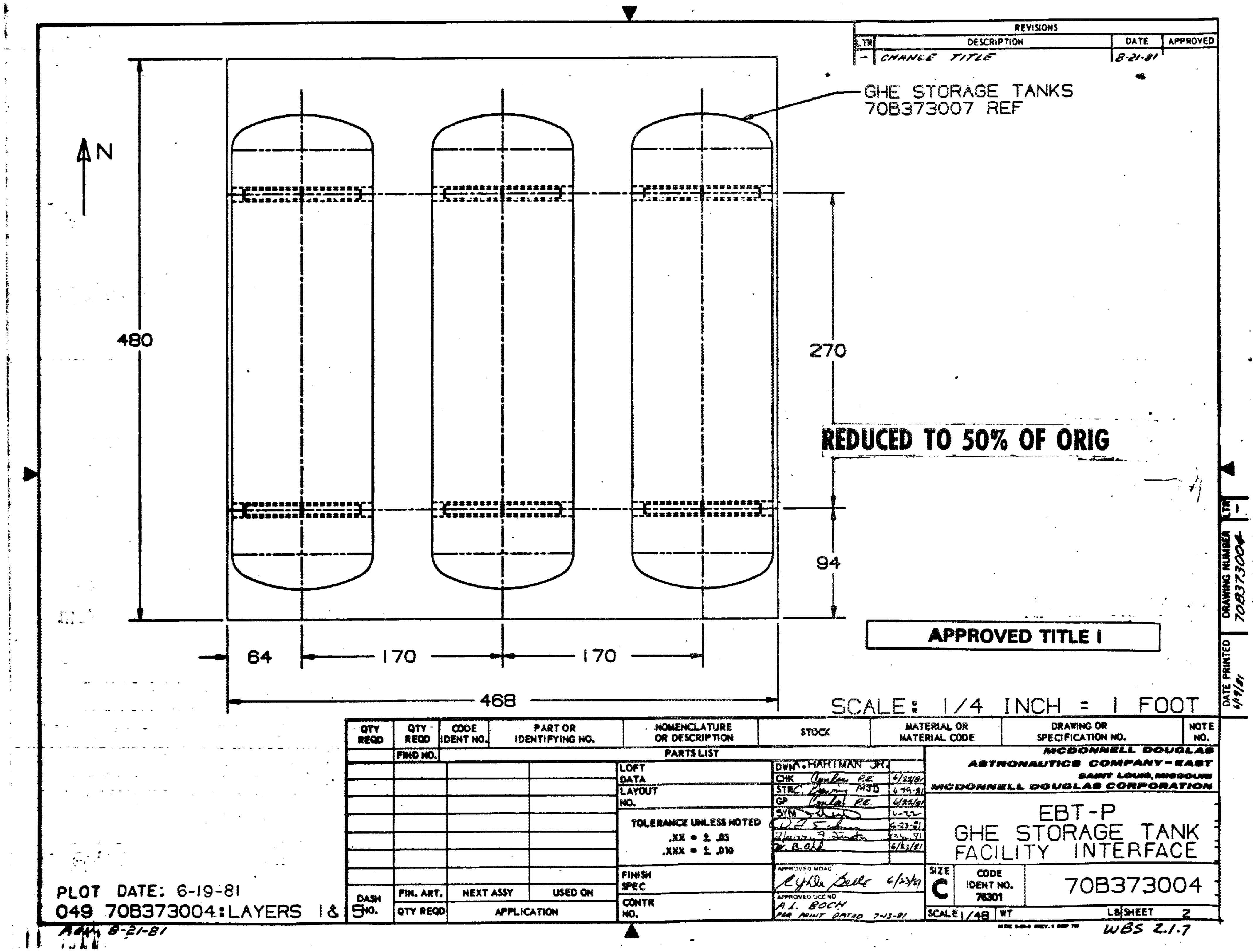
8 2 PL
12 2 PL
VENT
GHE STORAGE TANK
70B373007 REF
APPROX. CAP. = 2,500 CU FT
WT. = 22,000 LBS
120 DIA REF
INLET
OUTLET
70
12
FOUNDATION "A"
68
270
112
DRAIN PLUG
FOUNDATION "B"
APPROVED TITLE I
SCALE: 3/8 INCH = 1 FOOT
TOP OF FOUNDATION "B" IS 6" ABOVE TOP OF FOUNDATION "A"
049 70B373004
LAYERS 1,5&10
PLOT DATE: 6-19-81
REV 8-21-81
TOLERANCE UNLESS NOTED
.XX = ± .03
.XXX = ± .010
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-EAST
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
GHE STORAGE TANK
FACILITY INTERFACE
SIZE C
CODE IDENT NO. 76301
70B373004
SCALE 1/32
SHEET 1 OF 2
DRAWING NUMBER 70B373004
WBS 2.1.7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8-21-81
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N
480
270
94
64
170
170
468
REDUCED TO 50% OF ORIG
APPROVED TITLE I
SCALE: 1/4 INCH = 1 FOOT
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DATE PRINTED 6/19/81
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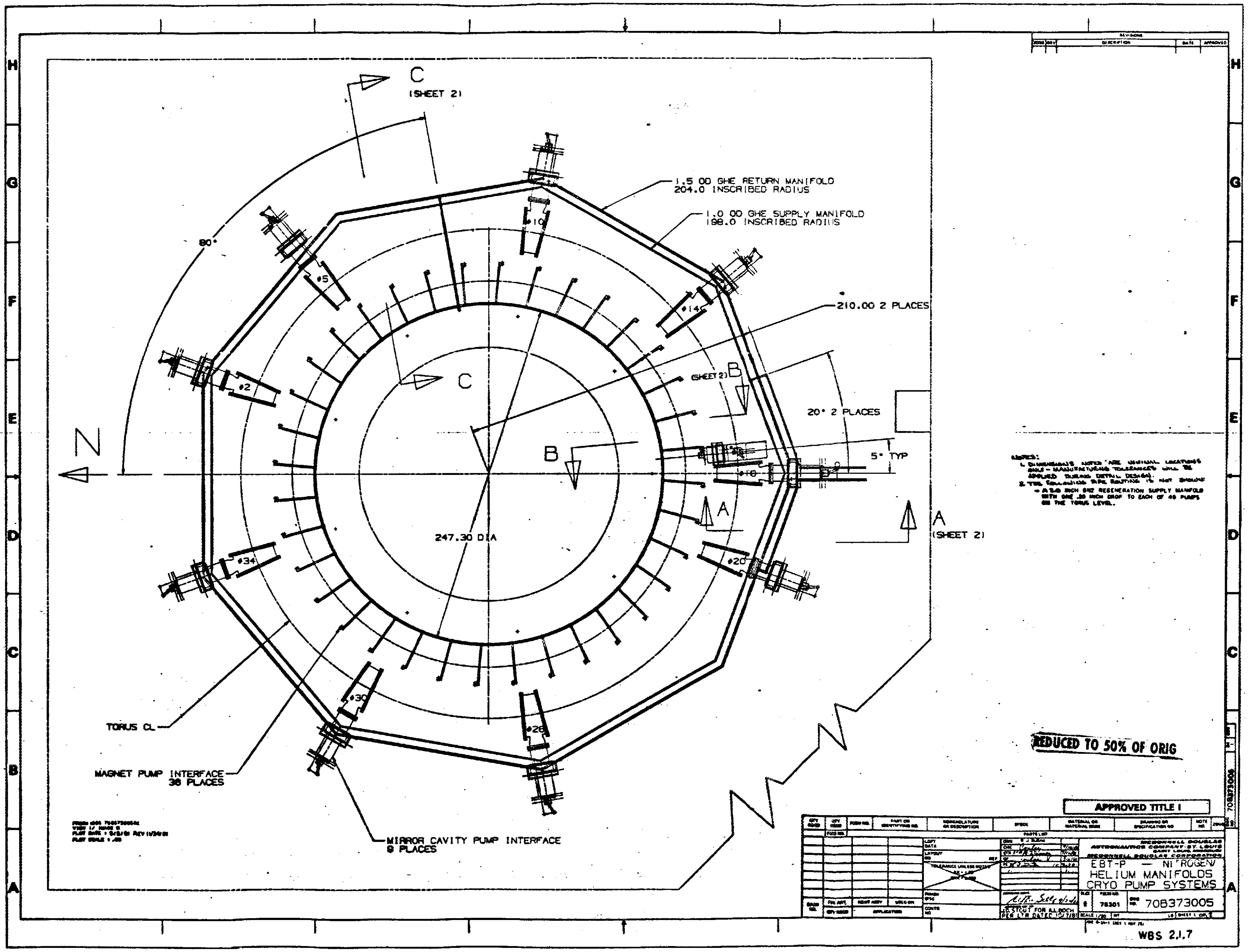
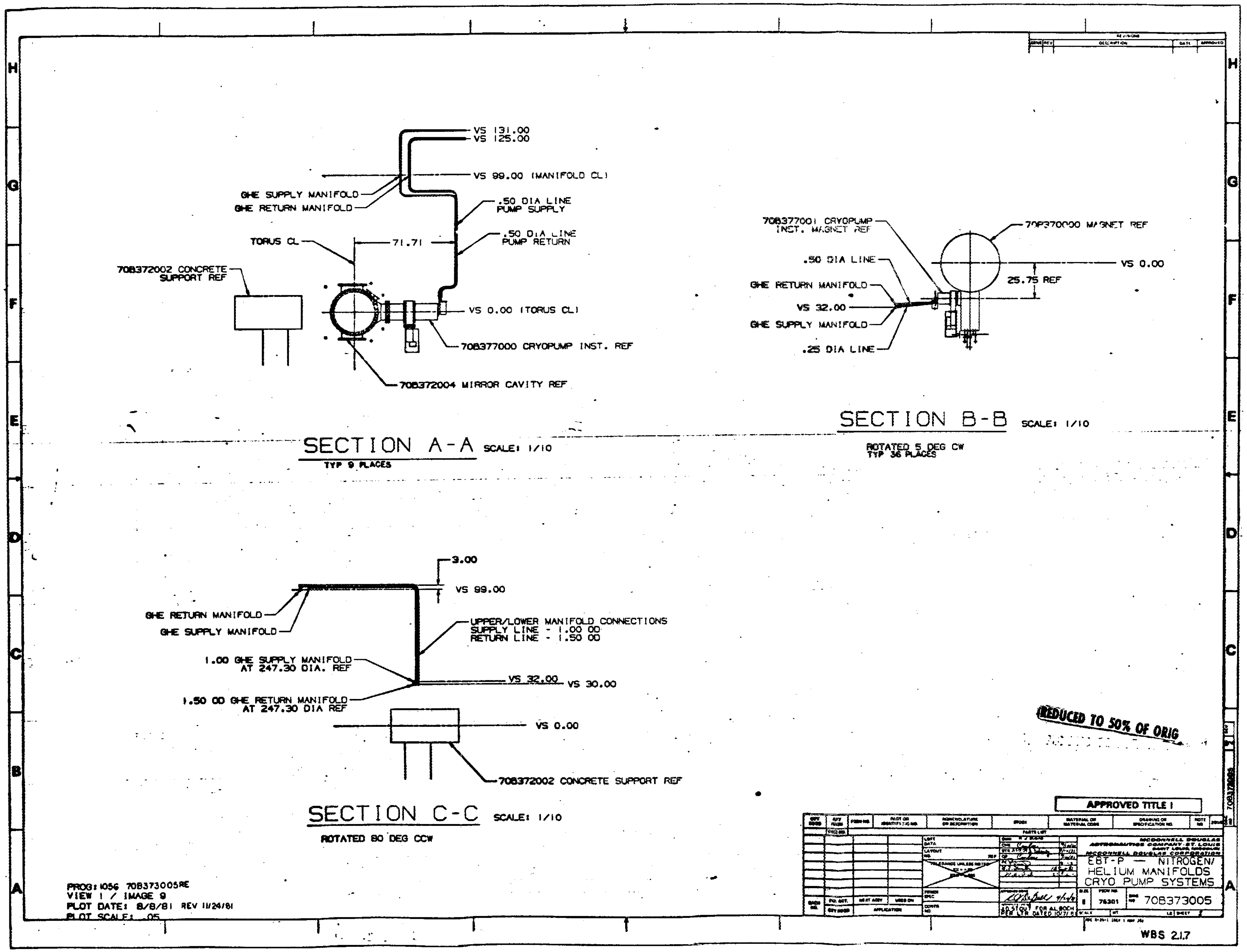
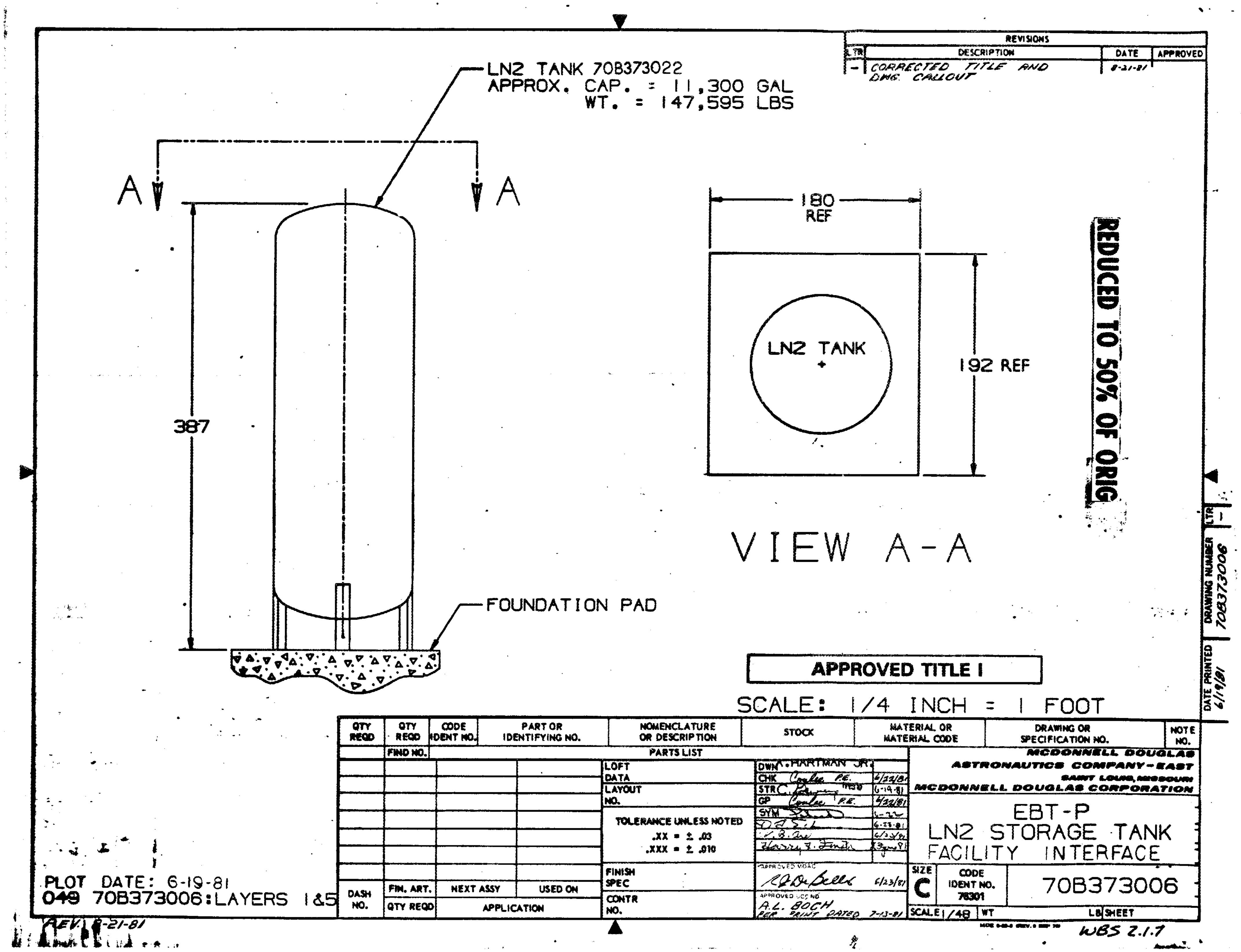
CODE IDENT NO.
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
STOCK
MATERIAL OR MATERIAL CODE
DRAWING OR SPECIFICATION NO.
NOTE NO.
FIND NO.
PARTS LIST
LOFT DATA
LAYOUT NO.
TOLERANCE UNLESS NOTED
.XX = ± .03
.XXX = ± .010
FINISH SPEC
CONTR NO.
DASH NO.
FIN. ART.
NEXT ASSY
USED ON
QTY REQD
APPLICATION
DWN A. HARTMAN JR.
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-EAST
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
GHE STORAGE TANK
FACILITY INTERFACE
SIZE C
CODE IDENT NO. 76301
70B373004
SCALE 1/48
SHEET 2
WBS 2.1.7
PLOT DATE: 6-19-81
049 70B373004:LAYERS 1& 5
AAW 8-21-81


C
(SHEET 2)
1.5 OD GHE RETURN MANIFOLD
204.0 INSCRIBED RADIUS
1.0 OD GHE SUPPLY MANIFOLD
198.0 INSCRIBED RADIUS
210.00 2 PLACES
80°
(SHEET 2) B
20° 2 PLACES
5° TYP
N
B
A
A
(SHEET 2)
247.30 DIA
#2
#5
#10
#14
#16
#20
#26
#30
#34
TORUS CL
MAGNET PUMP INTERFACE
36 PLACES
MIRROR CAVITY PUMP INTERFACE
8 PLACES
REDUCED TO 50% OF ORIG
APPROVED TITLE I
EBT-P — NITROGEN/
HELIUM MANIFOLDS
CRYO PUMP SYSTEMS
78301
70B373005
J.D. STOUT FOR A.L. BOCH
WBS 2.1.7


VS 131.00
VS 125.00
VS 99.00 (MANIFOLD CL)
GHE SUPPLY MANIFOLD
GHE RETURN MANIFOLD
.50 DIA LINE PUMP SUPPLY
.50 DIA LINE PUMP RETURN
TORUS CL
71.71
70B372002 CONCRETE SUPPORT REF
VS 0.00 (TORUS CL)
70B377000 CRYOPUMP INST. REF
70B372004 MIRROR CAVITY REF
SECTION A-A SCALE: 1/10
TYP 9 PLACES
.50 DIA LINE
GHE RETURN MANIFOLD
VS 32.00
GHE SUPPLY MANIFOLD
.25 DIA LINE
VS 0.00
25.75 REF
SECTION B-B SCALE: 1/10
ROTATED 5 DEG CW
TYP 36 PLACES
3.00
VS 99.00
GHE RETURN MANIFOLD
GHE SUPPLY MANIFOLD
UPPER/LOWER MANIFOLD CONNECTIONS
SUPPLY LINE - 1.00 OD
RETURN LINE - 1.50 OD
1.00 GHE SUPPLY MANIFOLD AT 247.30 DIA. REF
1.50 OD GHE RETURN MANIFOLD AT 247.30 DIA REF
VS 32.00
VS 30.00
VS 0.00
70B372002 CONCRETE SUPPORT REF
SECTION C-C SCALE: 1/10
ROTATED 90 DEG CCW
REDUCED TO 50% OF ORIG
APPROVED TITLE I
EBT-P — NITROGEN/HELIUM MANIFOLDS CRYO PUMP SYSTEMS
76301
70B373005
PLOT DATE: 8/8/81 REV 11/24/81
WBS 2.1.7


REVISIONS
LTR
DESCRIPTION
DATE
APPROVED
–
CORRECTED TITLE AND DWG. CALLOUT
8-21-81
LN2 TANK 70B373022
APPROX. CAP. = 11,300 GAL
WT. = 147,595 LBS
A
A
387
FOUNDATION PAD
180
REF
LN2 TANK
192 REF
VIEW A-A
REDUCED TO 50% OF ORIG
APPROVED TITLE I
SCALE: 1/4 INCH = 1 FOOT
QTY REQD
QTY REQD
CODE IDENT NO.
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
STOCK
MATERIAL OR MATERIAL CODE
DRAWING OR SPECIFICATION NO.
NOTE NO.
FIND NO.
PARTS LIST
LOFT DATA
LAYOUT NO.
TOLERANCE UNLESS NOTED
.XX = ± .03
.XXX = ± .010
FINISH SPEC
CONTR NO.
DWN
CHK
STR
GP
SYM
A.L. BOCH
PER PAINT DATED 7-13-81
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-EAST
SAINT LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
LN2 STORAGE TANK
FACILITY INTERFACE
SIZE
C
CODE IDENT NO.
76301
70B373006
SCALE 1/48
WT
LB
SHEET
WBS 2.1.7
DASH NO.
FIN. ART.
NEXT ASSY
USED ON
QTY REQD
APPLICATION
PLOT DATE: 6-19-81
049 70B373006:LAYERS 1&5
REV. 8-21-81
DRAWING NUMBER 70B373006
DATE PRINTED 6/19/81
LTR –

NOTES:

1. TANK SHALL BE IN ACCORDANCE WITH THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME) BOILER AND PRESSURE VESSEL CODE, SECTION VIII, "PRESSURE VESSELS", DIVISION I, LATEST EDITION INCLUDING ADDENDA, EXCEPT AS OTHERWISE STATED. TANK SHALL BE ASME STAMPED.

2. DESIGN REQUIREMENTS:
   - A. TANK SHALL BE CONFIGURED AS SHOWN.
   - B. INTERNAL VOLUME SHALL BE 2500 CUBIC FEET MINIMUM.
   - C. INTERNAL PRESSURE: VACUUM TO 300 PSIG MAX AT 70 DEGREES F. VACUUM TO 335 PSIG MAX AT 130 DEGREES F.
   - D. ALLOWABLE LEAKAGE: 1•10 EXP -7 SCC/SEC OF HELIUM MAXIMUM.
   - E. ELLIPSOIDAL HEADS SHALL BE USED.
   - F. WEIGHT: APPROX. 50,000 LBS REF.
   - G. DRAIN: FLANGE DESIGN, METAL O RING SEALED WITH MATING BLIND FLANGE.
   - H. USEFUL LIFE: 10 YEARS MINIMUM.
   - I. HANDLING/SHIPPING LUGS: AS REQUIRED BY VENDOR.
   - J. INTENDED USE: HELIUM GAS STORAGE.
   - K. TANK MOUNTING FOUNDATION WILL PROVIDE APPROX 1 DEGREE OF PITCH. (AFT MOUNTING LEG 6 INCHES HIGHER THAN FORWARD)
   - L. MANHOLE: SIZE IN ACCORDANCE WITH REQUIREMENTS OF NOTE 1, LOCATE AS SHOWN.

3. MATERIAL: TANK SHALL BE FABRICATED FROM THE FOLLOWING MATERIALS:
   TANK: SA 285, GRADE C OR SA 516, GRADE 70 CARBON STEEL.
   STRUCTURE: SA 36 CARBON STEEL

4. FINISH: TANK SHALL BE EPOXY PRIMED/PAINTED, USING A WATERPROOF PRIMER, 2 MILS MINIMUM THICKNESS, IN ACCORDANCE WITH VENDOR PROCESS SPECIFICATIONS TO INSURE OUT DOOR CORROSION PROTECTION FOR A PERIOD OF 5 YEARS MINIMUM. FINAL TANK COLOR WILL BE 13711 PER FED-STD 595 (COLOR: LIGHT TAN).

5. ENVIRONMENT: TANK WILL BE INSTALLED OUTDOORS.
   - A. TEMPERATURE RANGE: -20 DEGREES F TO 130 DEGREES F.
   - B. RADIATION: NONE
   - C. WIND LOAD: 100 MPH MAX.
   - D. SEISMIC LOAD: UNIFORM BUILDING CODE SEISMIC ZONE 2, LATEST ISSUE AND ADDENDA.

6 (flag) SAFETY: THE SAFETY VENT DEVICE SHALL CONSIST OF A BURST DISK AND SPRING LOADED RELIEF VALVE MOUNTED IN PARALLEL. THE BURST DISK AND RELIEF VALVE SHALL BE FLANGE MOUNTED AND EMPLOY A METAL O RING SEAL.

7. CLEANING: INTERNAL TANK CLEANING SHALL BE IN ACCORDANCE WITH VENDOR PROCESS SPECIFICATIONS AS REQUIRED FOR HELIUM USAGE.

8 (flag) MARKING: THE FOLLOWING INFORMATION SHALL BE ADDED TO THAT REQUIRED BY THE ASME CODE ON A PERMANENTLY ATTACHED METAL NAME PLATE LOCATED AS SHOWN:
   MDAC DWG NO. 70B373007
   CONTRACT NO. 22X-21-099C
   VOLUME: (ENTER TO NEAREST CUBIC FOOT)

9. TESTING:
   - A. HYDROSTATIC TESTING SHALL BE DONE AT 500 PSIG PLUS 50 MINUS 0 PSIG. NO DETRAMENTAL DEFORMATION SHALL RESULT FROM HYDROSTATIC TESTING.
   - B. LEAK RATE AFTER HYDROSTATIC TEST SHALL NOT EXCEED THAT SPECIFIED IN 2.D. AT 335 PSIG.
   - C. OTHER TESTING SHALL BE PERFORMED AS REQUIRED BY NOTE 1.

10. MAINTAINABILITY: MAINTAINABILITY SHALL BE LIMITED TO REPAINT AT 5 YEAR, MINIMUM, INTERVALS.

11. PACKAGING: PACKAGING SHALL BE IN ACCORDANCE WITH VENDOR PROCESS SPECIFICATIONS TO PREVENT DAMAGE DURING SHIPMENT. TANK SHALL BE EQUIPPED WITH A PRESSURE GAGE AND CHARGING VALVE AND SHALL BE CHARGED WITH 2 PSIG, WITH -60 DEGREE F. DEW POINT, HELIUM GAS DURING SHIPMENT.

12. DOCUMENTATION:
   - A. THE FOLLOWING DOCUMENTATION SHALL BE SUBMITTED FOR MDAC APPROVAL WITHIN 90 DAYS OF CONTRACT APPROVAL:
     - DETAIL DRAWINGS
     - DESIGN CALCULATIONS
     - VENDOR MATERIAL FINISH SPECIFICATIONS
     - VENDOR WELD SPECIFICATIONS/PROCEDURES
     - VENDOR CLEANING SPECIFICATIONS/PROCEDURES.
     - VENDOR REPAIR SPECIFICATIONS/PROCEDURES
     - LEAK TEST SPECIFICATIONS/PROCEDURES
   - B. THE FOLLOWING INFORMATION SHALL BE SHIPPED ALONG WITH THE TANK:
     - HYDROSTATIC TEST RESULT
     - RECORD OF ALL REPAIR WORK
     - RECORD OF MATERIAL OF CONSTRUCTION
     - ACTUAL (CALCULATED/ESTIMATED) WEIGHT
   - C. THE FOLLOWING INFORMATION WILL BE AVAILABLE ON REQUEST:
     - MATERIAL CERTIFICATIONS
     - HEAT TREAT RECORDS
     - ASME CODE CERTIFICATIONS
     - WELD INSPECTION RECORDS
     - ASME DATA SHEET U-2

13 (flag) OUTLET WELD NIPPLE SHALL BE SA 304 L STAINLESS STEEL, 3.0 OD, .203 WALL THICKNESS.

14. TANK SHALL BE DELIVERED WITH A SPARE SET OF SEALS AND GASKETS.

PROG. 1056 70B373007RE
LAYER 1
PLOT DATE: 9/28/81
PLOT SCALE: 1/1
REVISED: 11/24/81

REDUCED TO 50% OF ORIG

SPECIFICATION CONTROL DRAWING

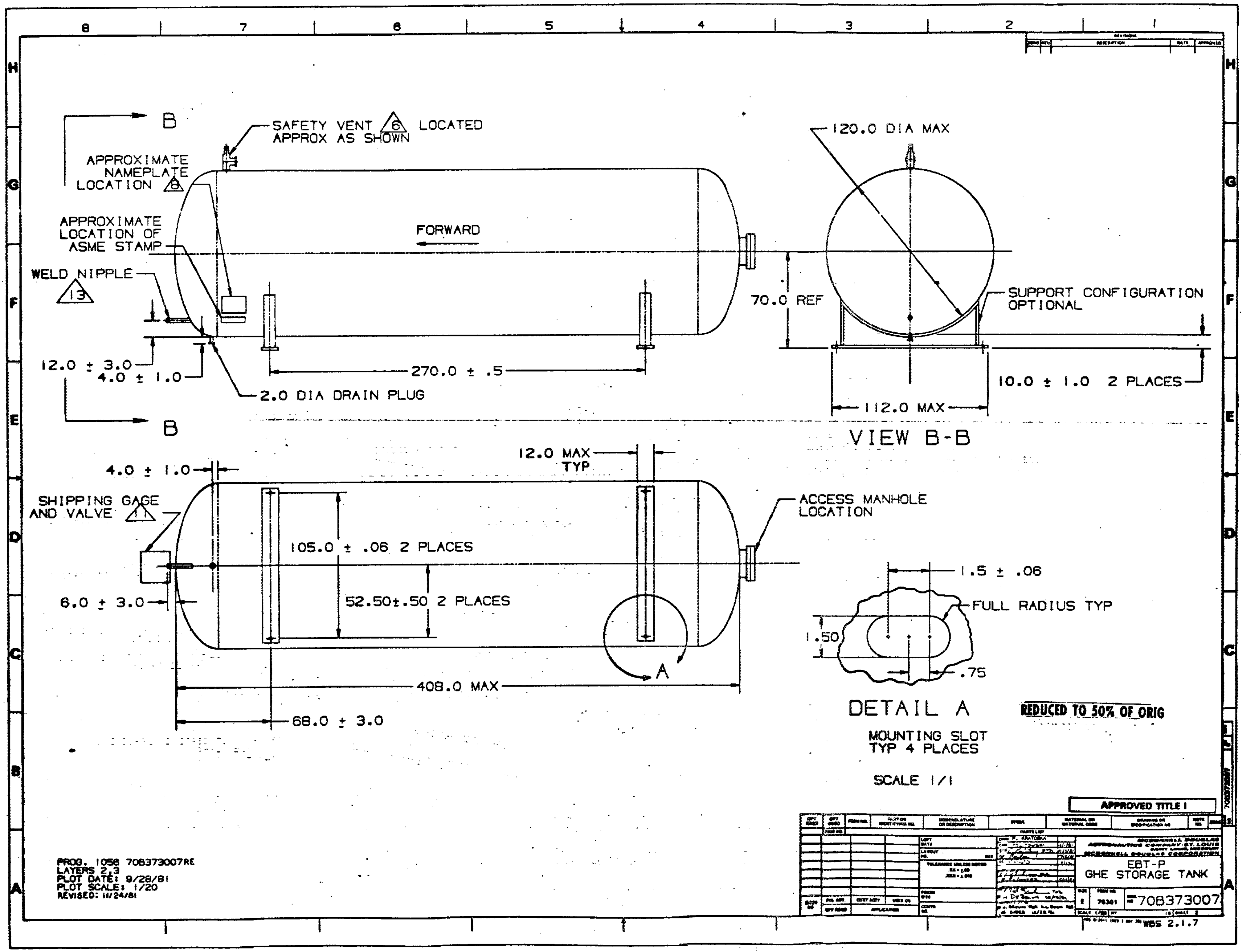
APPROVED TITLE I

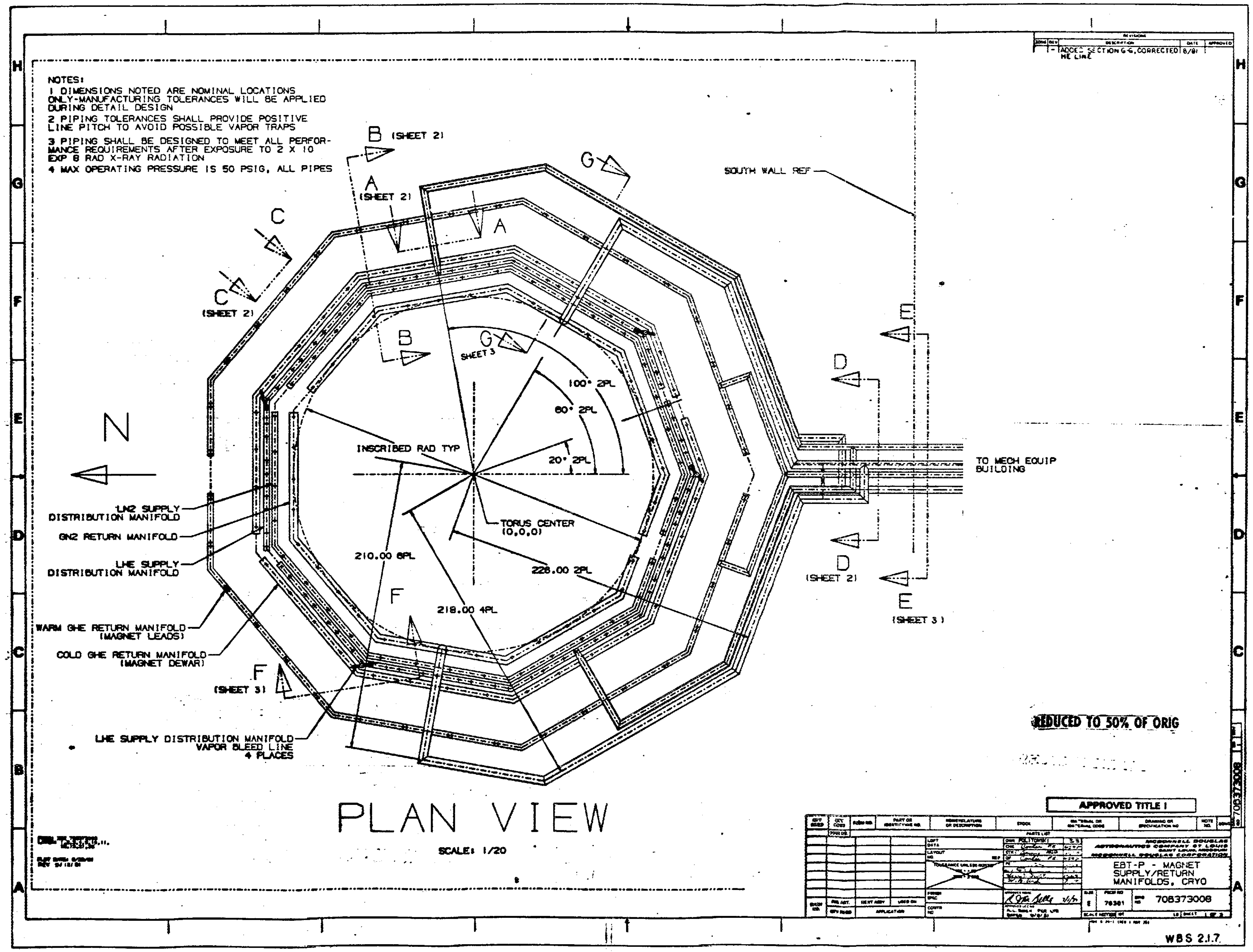
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
MCDONNELL DOUGLAS CORPORATION

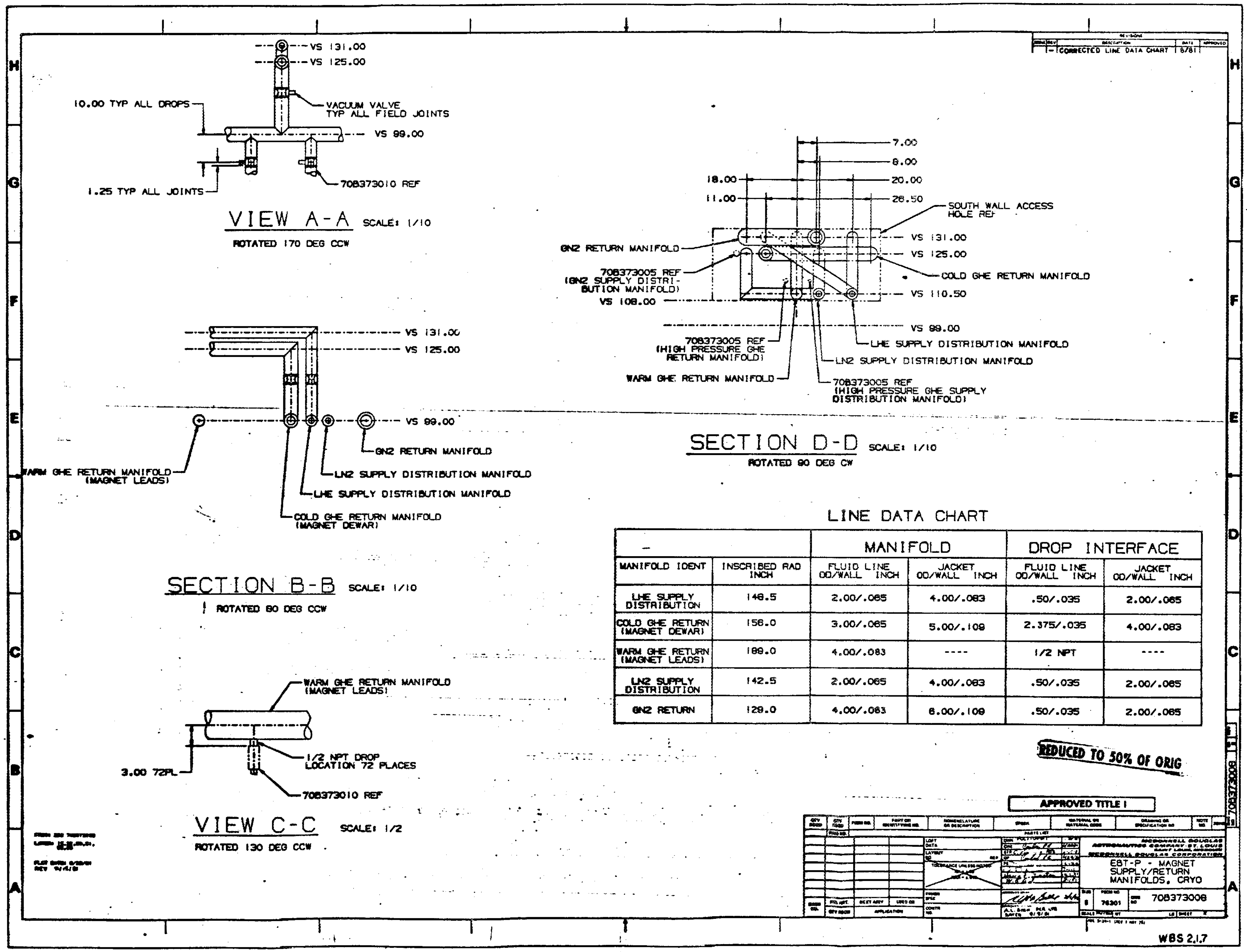
EBT-P
GHE STORAGE TANK

76301 70B373007

WBS 2.1.7

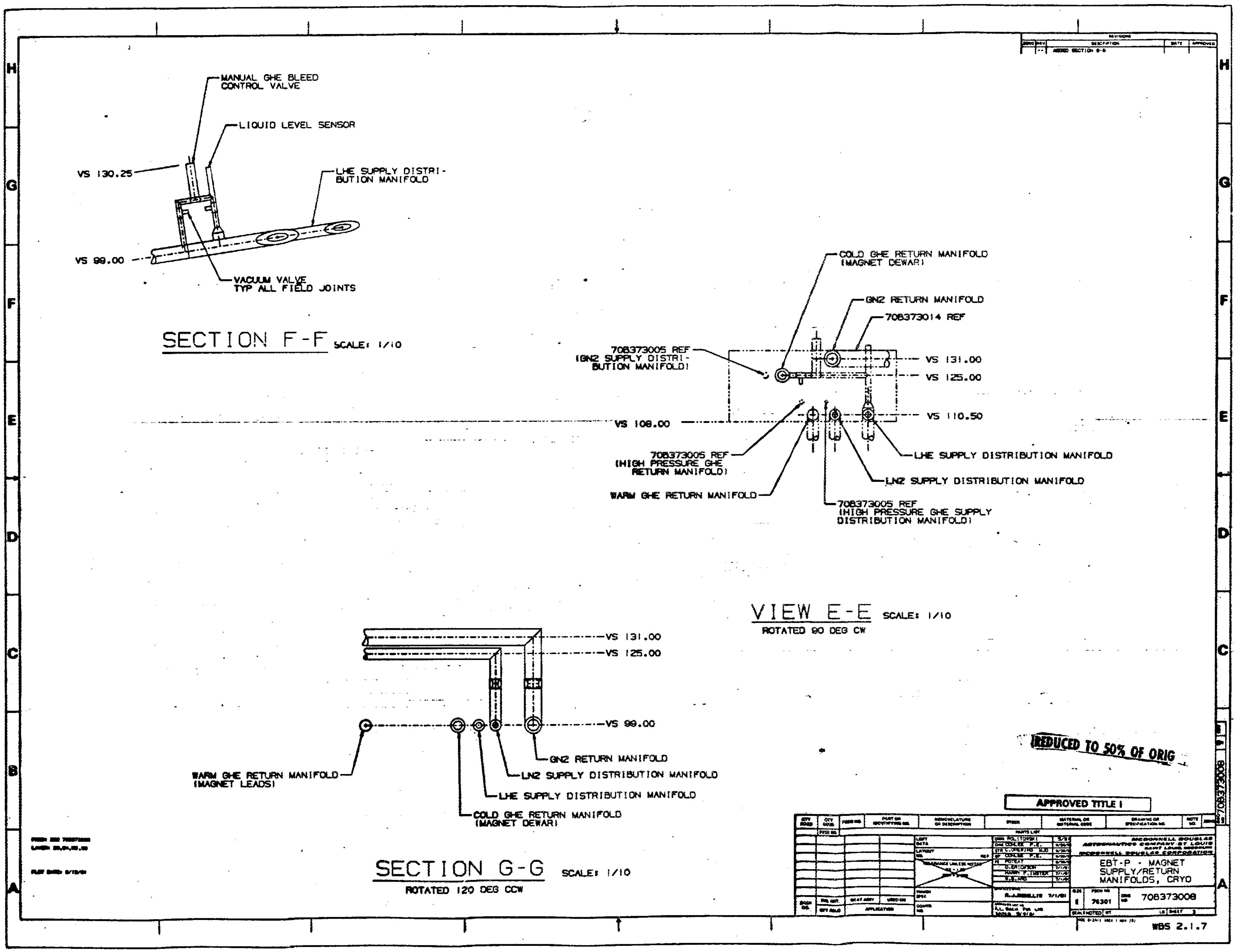

SAFETY VENT 6 LOCATED APPROX AS SHOWN
APPROXIMATE NAMEPLATE LOCATION 8
APPROXIMATE LOCATION OF ASME STAMP
WELD NIPPLE 13
FORWARD
120.0 DIA MAX
70.0 REF
SUPPORT CONFIGURATION OPTIONAL
12.0 ± 3.0
4.0 ± 1.0
270.0 ± .5
2.0 DIA DRAIN PLUG
10.0 ± 1.0 2 PLACES
112.0 MAX
VIEW B-B
4.0 ± 1.0
12.0 MAX TYP
SHIPPING GAGE AND VALVE 11
ACCESS MANHOLE LOCATION
105.0 ± .06 2 PLACES
52.50±.50 2 PLACES
6.0 ± 3.0
1.5 ± .06
FULL RADIUS TYP
1.50
.75
408.0 MAX
68.0 ± 3.0
DETAIL A
MOUNTING SLOT TYP 4 PLACES
SCALE 1/1
REDUCED TO 50% OF ORIG
APPROVED TITLE I
EBT-P
GHE STORAGE TANK
70B373007
WBS 2.1.7
PROG. 1056 70B373007RE
LAYERS 2,3
PLOT DATE: 9/28/81
PLOT SCALE: 1/20
REVISED: 11/24/81

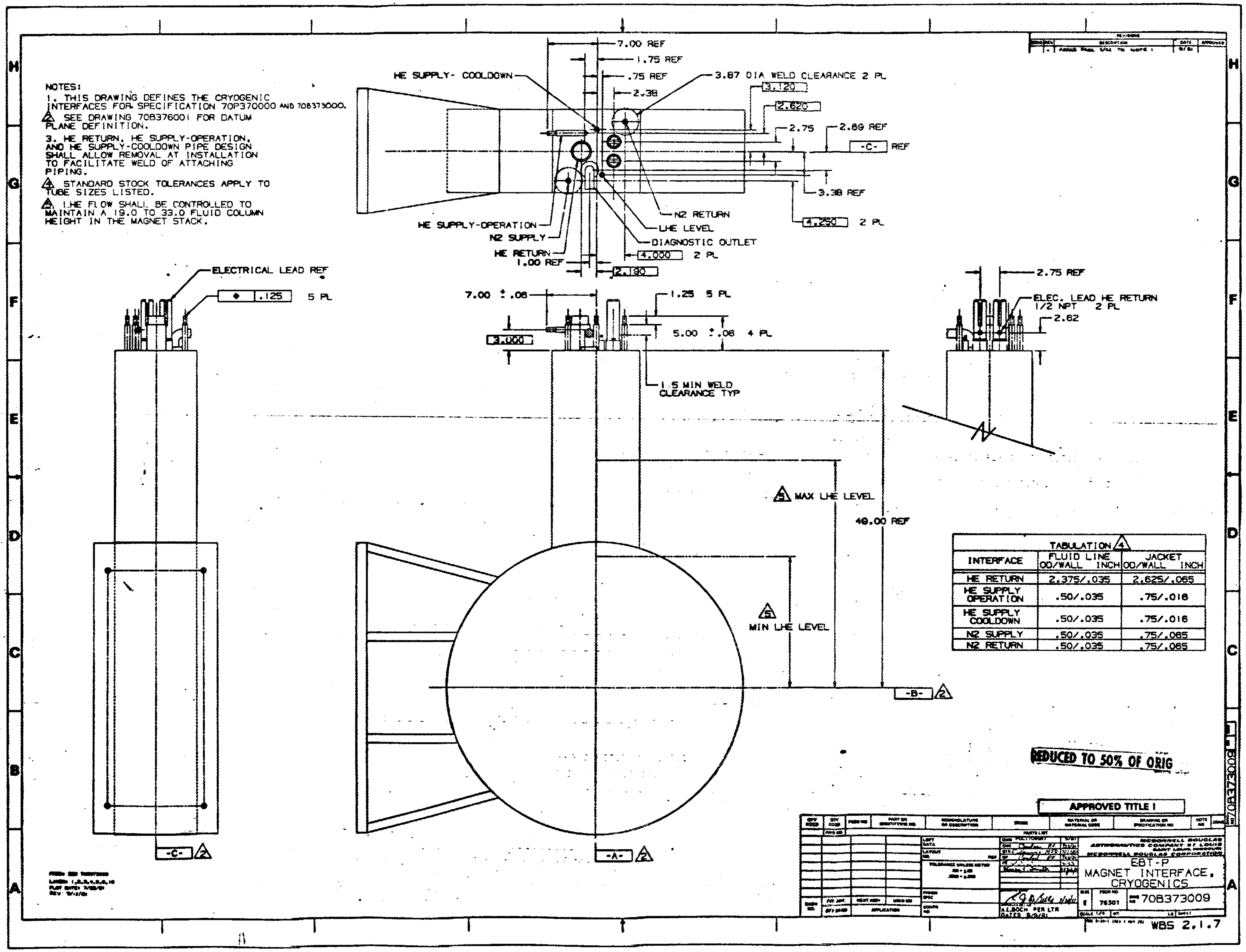

NOTES:
1 DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY-MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN
2 PIPING TOLERANCES SHALL PROVIDE POSITIVE LINE PITCH TO AVOID POSSIBLE VAPOR TRAPS
3 PIPING SHALL BE DESIGNED TO MEET ALL PERFORMANCE REQUIREMENTS AFTER EXPOSURE TO 2 X 10 EXP 8 RAD X-RAY RADIATION
4 MAX OPERATING PRESSURE IS 50 PSIG, ALL PIPES
B (SHEET 2)
A (SHEET 2)
C (SHEET 2)
G
SOUTH WALL REF
SHEET 3
100° 2PL
60° 2PL
20° 2PL
INSCRIBED RAD TYP
TORUS CENTER (0,0,0)
210.00 6PL
226.00 2PL
218.00 4PL
N
LN2 SUPPLY DISTRIBUTION MANIFOLD
GN2 RETURN MANIFOLD
LHE SUPPLY DISTRIBUTION MANIFOLD
WARM GHE RETURN MANIFOLD (MAGNET LEADS)
COLD GHE RETURN MANIFOLD (MAGNET DEWAR)
F (SHEET 3)
LHE SUPPLY DISTRIBUTION MANIFOLD VAPOR BLEED LINE 4 PLACES
TO MECH EQUIP BUILDING
D (SHEET 2)
E (SHEET 3)
PLAN VIEW
SCALE: 1/20
REDUCED TO 50% OF ORIG
APPROVED TITLE I
ADDED SECTION G-G, CORRECTED HE LINE
EBT-P - MAGNET SUPPLY/RETURN MANIFOLDS, CRYO
76301
708373008
WBS 2.1.7



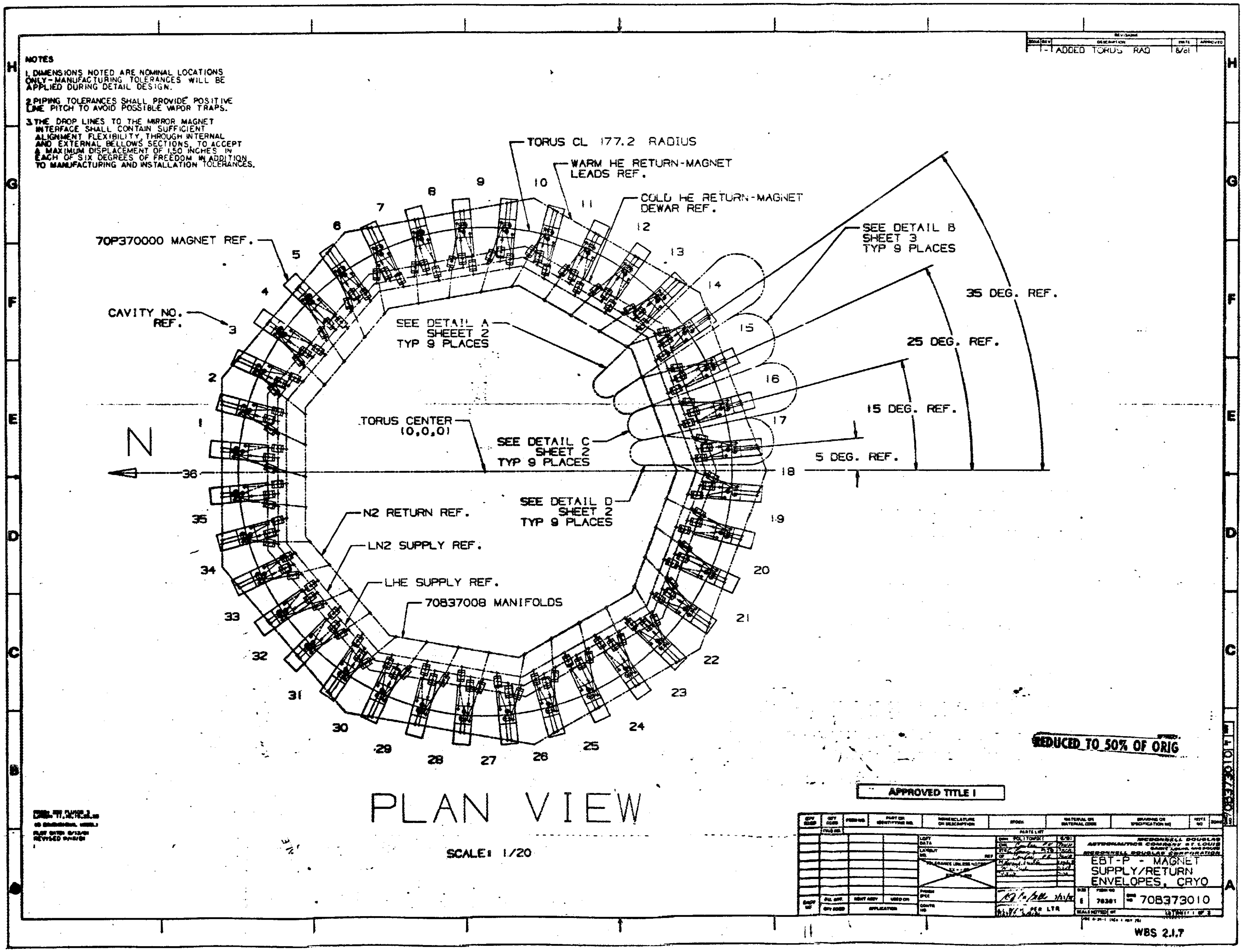
LINE DATA CHART

—		MANIFOLD		DROP INTERFACE	
MANIFOLD IDENT	INSCRIBED RAD INCH	FLUID LINE OD/WALL INCH	JACKET OD/WALL INCH	FLUID LINE OD/WALL INCH	JACKET OD/WALL INCH
LHE SUPPLY DISTRIBUTION	148.5	2.00/.065	4.00/.083	.50/.035	2.00/.065
COLD GHE RETURN (MAGNET DEWAR)	156.0	3.00/.065	5.00/.109	2.375/.035	4.00/.083
WARM GHE RETURN (MAGNET LEADS)	189.0	4.00/.083	----	1/2 NPT	----
LN2 SUPPLY DISTRIBUTION	142.5	2.00/.065	4.00/.083	.50/.035	2.00/.065
GN2 RETURN	129.0	4.00/.083	8.00/.109	.50/.035	2.00/.065

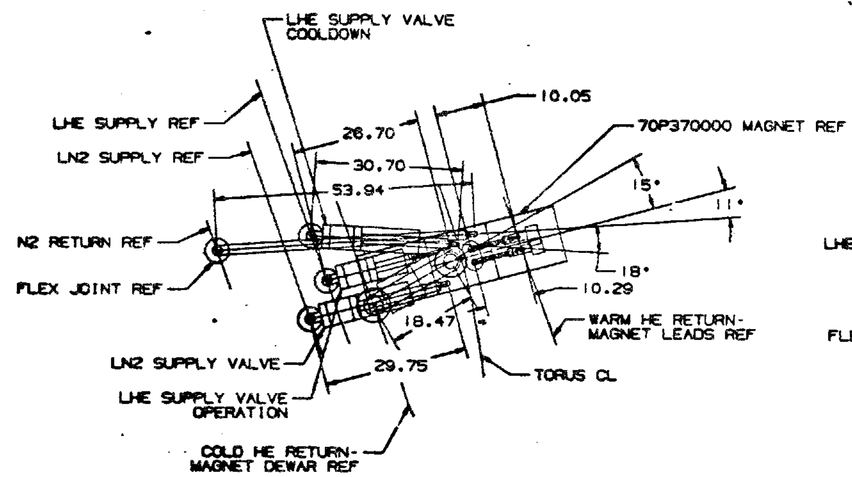

MANUAL GHE BLEED CONTROL VALVE
LIQUID LEVEL SENSOR
VS 130.25
LHE SUPPLY DISTRIBUTION MANIFOLD
VS 99.00
VACUUM VALVE TYP ALL FIELD JOINTS
SECTION F-F SCALE: 1/10
COLD GHE RETURN MANIFOLD (MAGNET DEWAR)
GN2 RETURN MANIFOLD
708373014 REF
708373005 REF (GN2 SUPPLY DISTRIBUTION MANIFOLD)
VS 131.00
VS 125.00
VS 108.00
VS 110.50
708373005 REF (HIGH PRESSURE GHE RETURN MANIFOLD)
LHE SUPPLY DISTRIBUTION MANIFOLD
LN2 SUPPLY DISTRIBUTION MANIFOLD
WARM GHE RETURN MANIFOLD
708373005 REF (HIGH PRESSURE GHE SUPPLY DISTRIBUTION MANIFOLD)
VIEW E-E SCALE: 1/10
ROTATED 90 DEG CW
VS 131.00
VS 125.00
VS 99.00
GN2 RETURN MANIFOLD
LN2 SUPPLY DISTRIBUTION MANIFOLD
WARM GHE RETURN MANIFOLD (MAGNET LEADS)
LHE SUPPLY DISTRIBUTION MANIFOLD
COLD GHE RETURN MANIFOLD (MAGNET DEWAR)
SECTION G-G SCALE: 1/10
ROTATED 120 DEG CCW
REDUCED TO 50% OF ORIG
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
EBT-P · MAGNET SUPPLY/RETURN MANIFOLDS, CRYO
76301
708373008
WBS 2.1.7



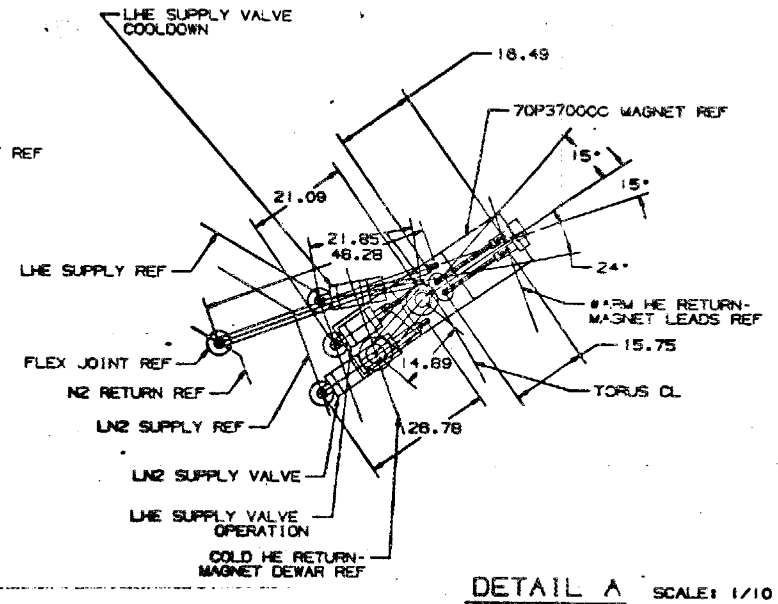
TABULATION (4)				
INTERFACE	FLUID LINE OD/WALL INCH	JACKET OD/WALL INCH
HE RETURN	2.375/.035	2.625/.065
HE SUPPLY OPERATION	.50/.035	.75/.016
HE SUPPLY COOLDOWN	.50/.035	.75/.016
N2 SUPPLY	.50/.035	.75/.065
N2 RETURN	.50/.035	.75/.065


NOTES
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY - MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
2. PIPING TOLERANCES SHALL PROVIDE POSITIVE LINE PITCH TO AVOID POSSIBLE VAPOR TRAPS.
3. THE DROP LINES TO THE MIRROR MAGNET INTERFACE SHALL CONTAIN SUFFICIENT ALIGNMENT FLEXIBILITY, THROUGH INTERNAL AND EXTERNAL BELLOWS SECTIONS, TO ACCEPT A MAXIMUM DISPLACEMENT OF 1.50 INCHES IN EACH OF SIX DEGREES OF FREEDOM IN ADDITION TO MANUFACTURING AND INSTALLATION TOLERANCES.
ADDED TORUS RAD
TORUS CL 177.2 RADIUS
WARM HE RETURN-MAGNET LEADS REF.
COLD HE RETURN-MAGNET DEWAR REF.
70P370000 MAGNET REF.
CAVITY NO. REF.
SEE DETAIL B SHEET 3 TYP 9 PLACES
SEE DETAIL A SHEEET 2 TYP 9 PLACES
35 DEG. REF.
25 DEG. REF.
15 DEG. REF.
5 DEG. REF.
TORUS CENTER (0,0,0)
SEE DETAIL C SHEET 2 TYP 9 PLACES
SEE DETAIL D SHEET 2 TYP 9 PLACES
N
N2 RETURN REF.
LN2 SUPPLY REF.
LHE SUPPLY REF.
70837008 MANIFOLDS
PLAN VIEW
SCALE: 1/20
REDUCED TO 50% OF ORIG
APPROVED TITLE I
EBT-P - MAGNET SUPPLY/RETURN ENVELOPES, CRYO
70B373010
WBS 2.1.7

REV	DESCRIPTION
–	CORRECTED LINE DATA CHART



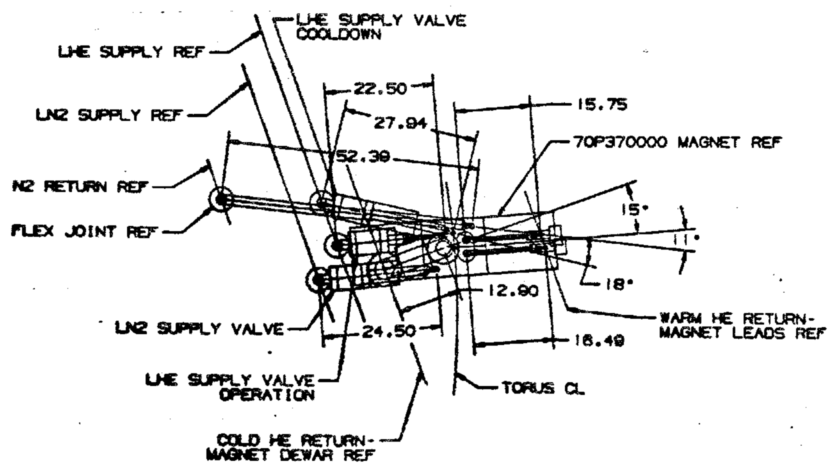
DETAIL C SCALE: 1/10
TYPICAL 9 PLACES
(SHEET 1)



DETAIL A SCALE: 1/10
TYPICAL 9 PLACES
(SHEET 1)

LINE DATA CHART

	MANIFOLD INTERFACE		MAGNET INTERFACE	
LINE IDENT	FLUID LINE OD/WALL INCH	JACKET OD/WALL INCH	FLUID LINE OD/WALL INCH	JACKET OD/WALL INCH
LHE SUPPLY OPERATION	.50/.035	2.00/.065	.50/.035	.75/.016
LHE SUPPLY COOLDOWN	.50/.035	2.00/.065	.50/.035	.75/.016
COLD HE RETURN MAGNET DEWAR	2.375/.035	4.00/.083	2.375/.035	2.625/.065
WARM HE RETURN MAGNET LEADS	.50 ID/.80 OD FLEX LINE 1/2 NPT	----	.50 ID/.80 OD FLEX LINE 1/2 NPT	----
LN2 SUPPLY	.50/.035	2.00/.065	.50/.035	.75/.065
N2 RETURN	.50/.035	2.00/.065	.50/.035	.75/.065



DETAIL D SCALE: 1/10
TYPICAL 9 PLACES
(SHEET 1)

REDUCED TO 50% OF ORIG

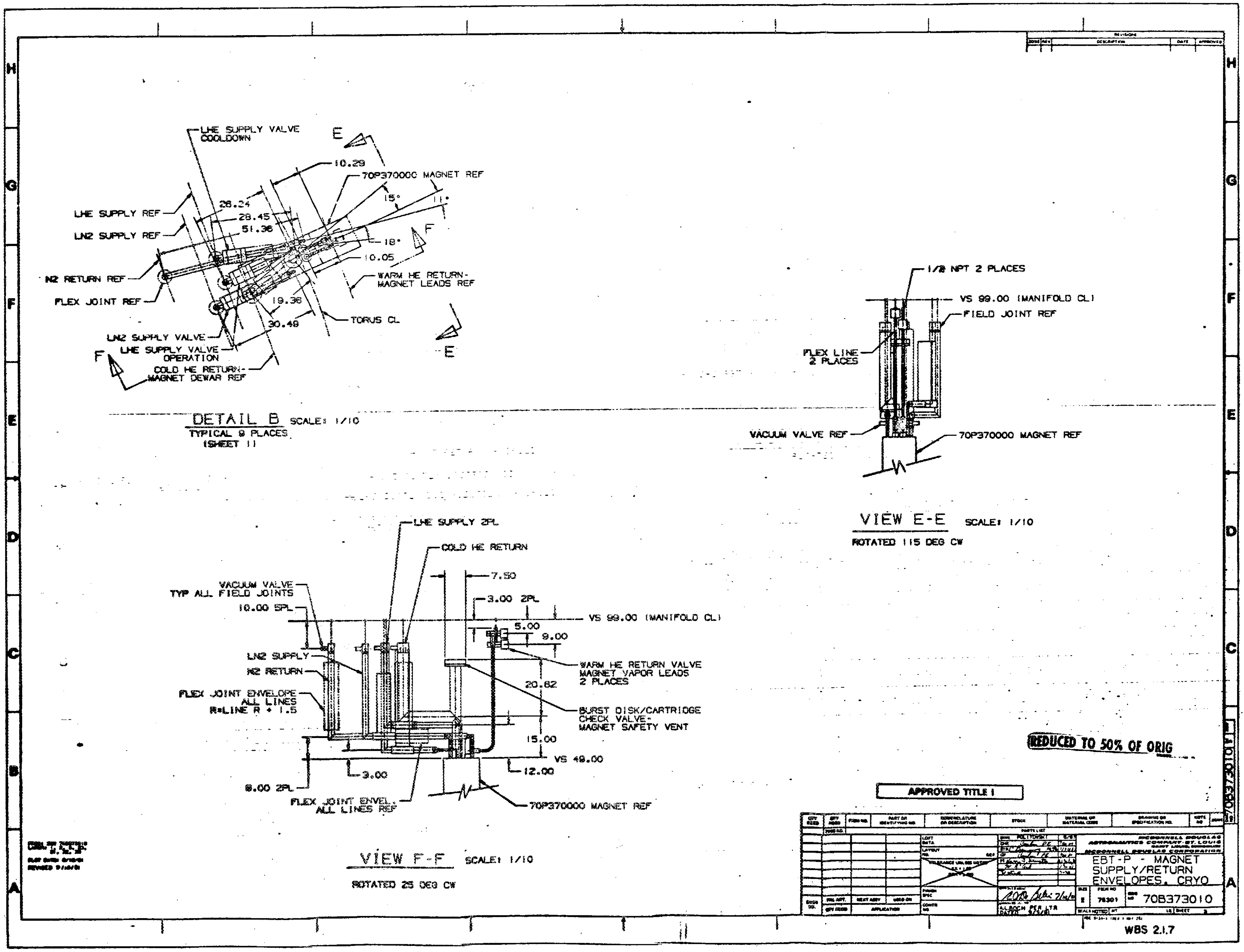
APPROVED TITLE I

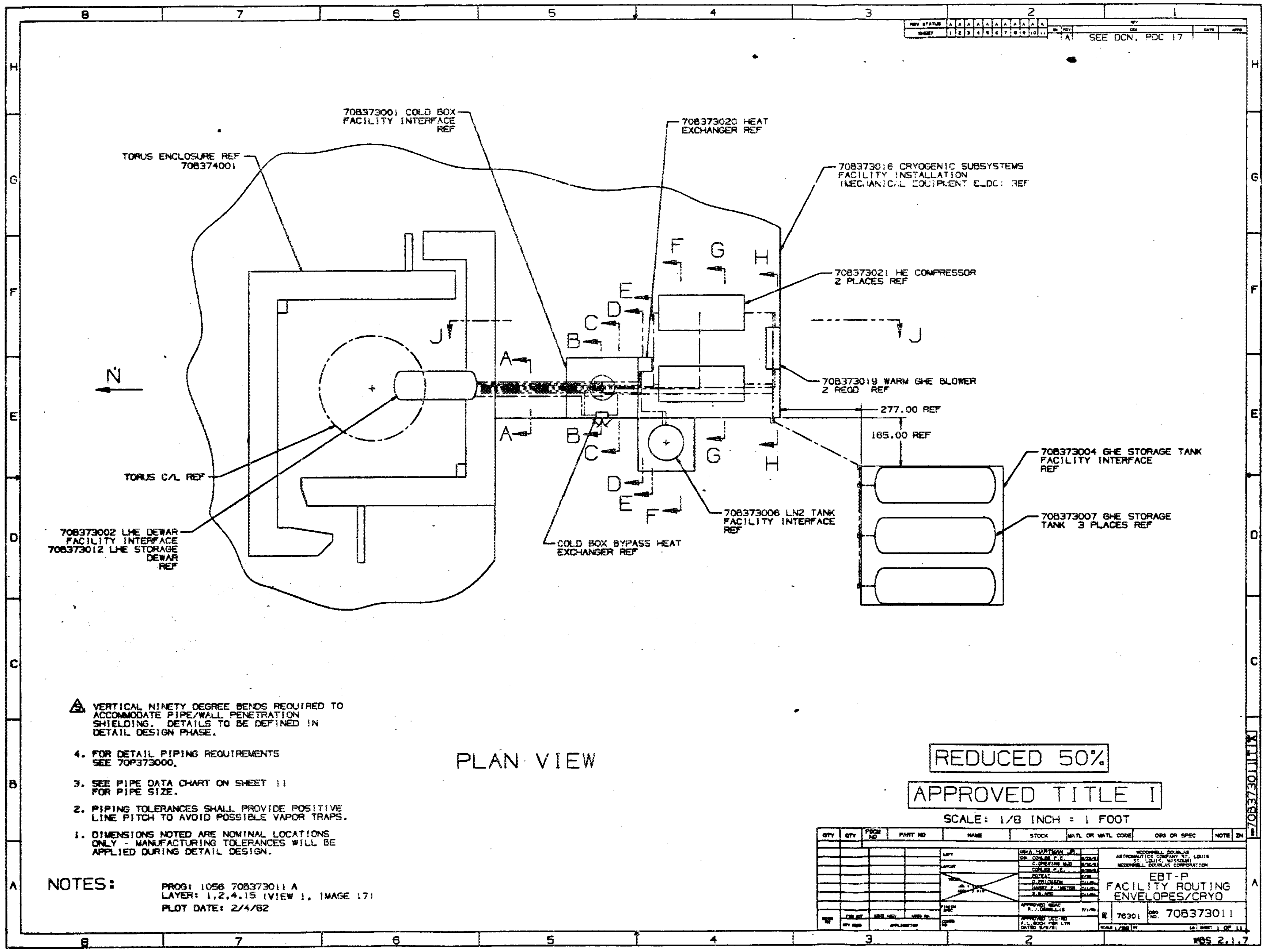
McDONNELL DOUGLAS

EBT-P - MAGNET SUPPLY/RETURN ENVELOPES, CRYO

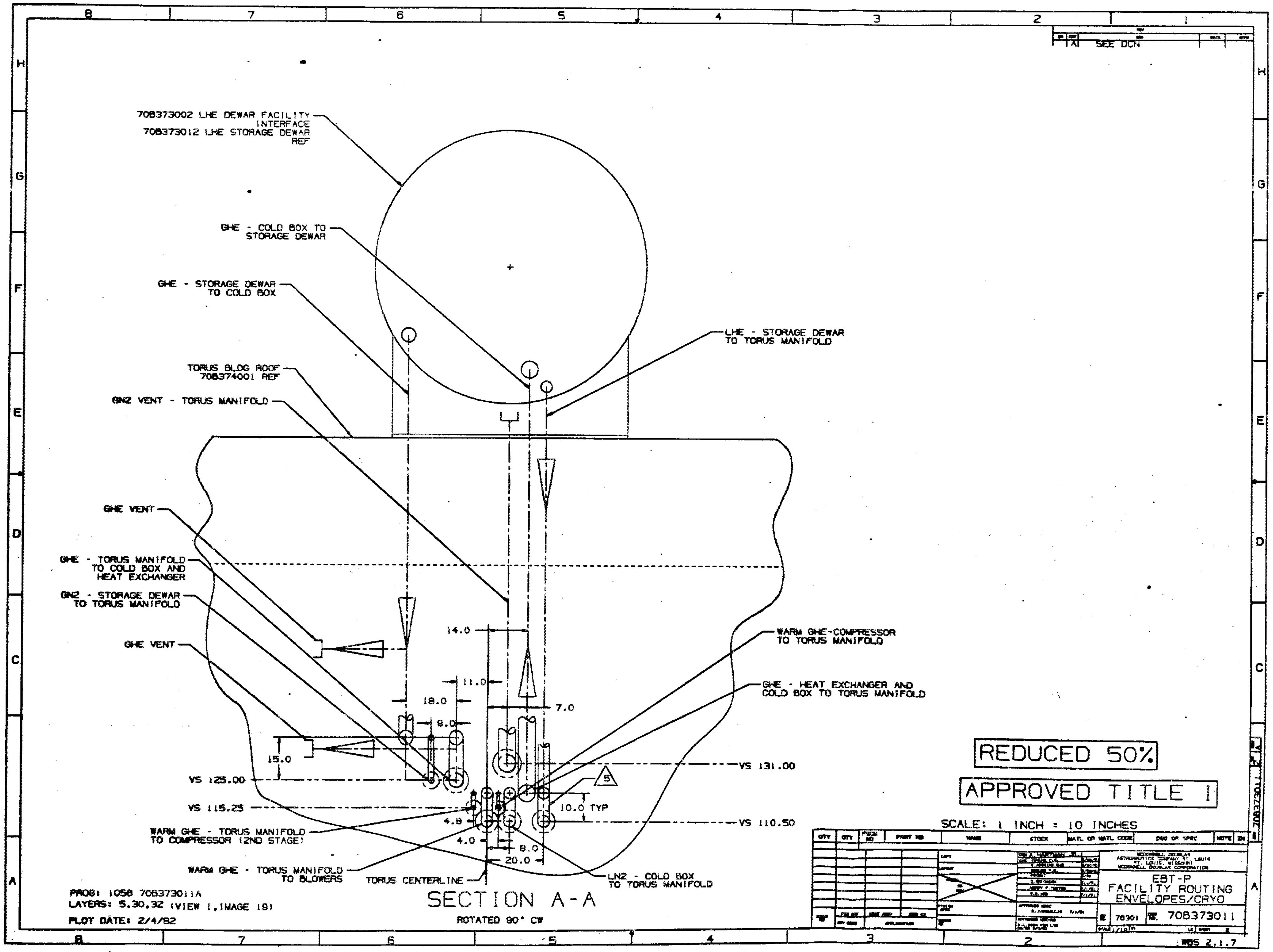
76301 70B373010

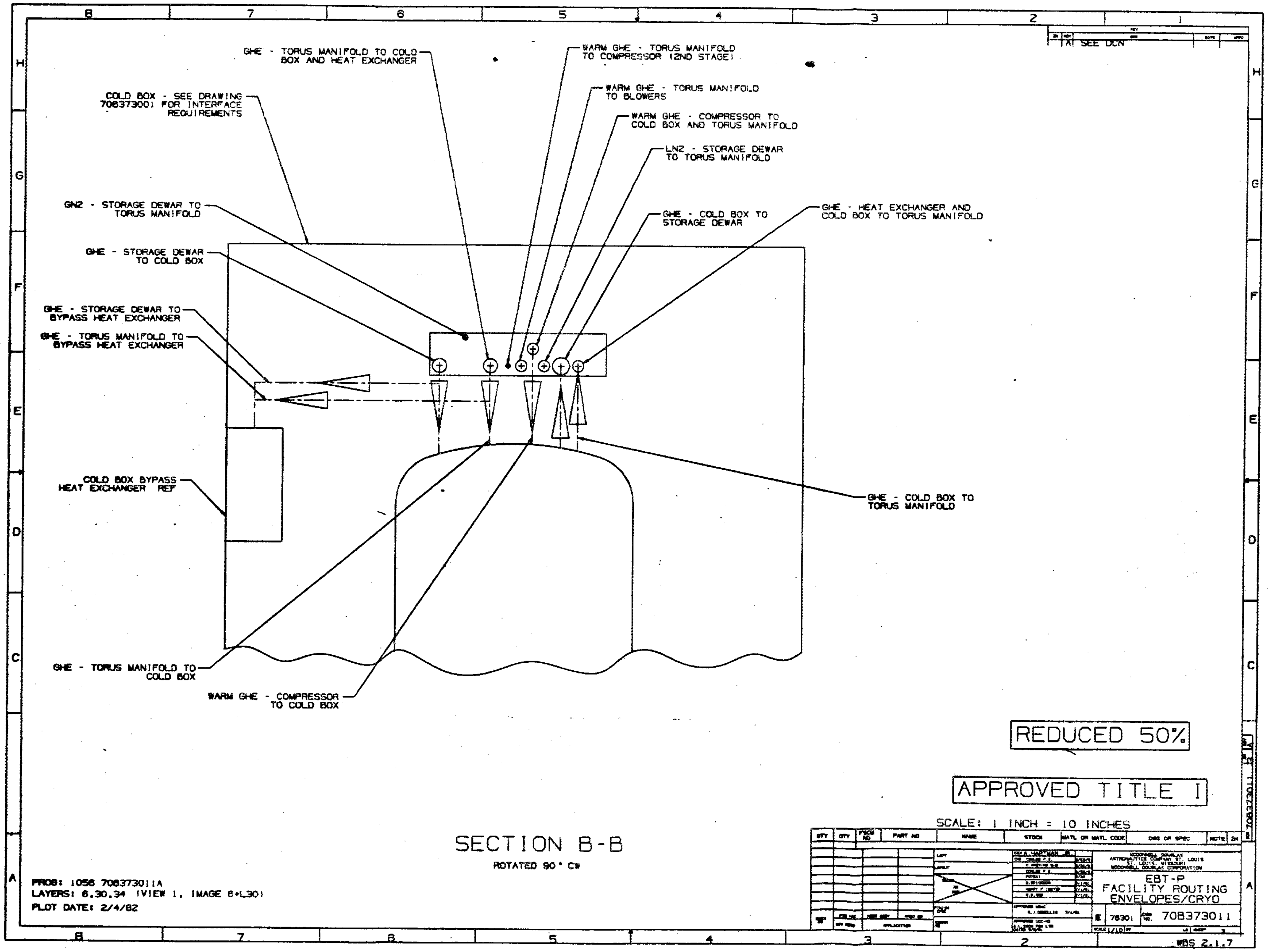
WBS 2.1.7

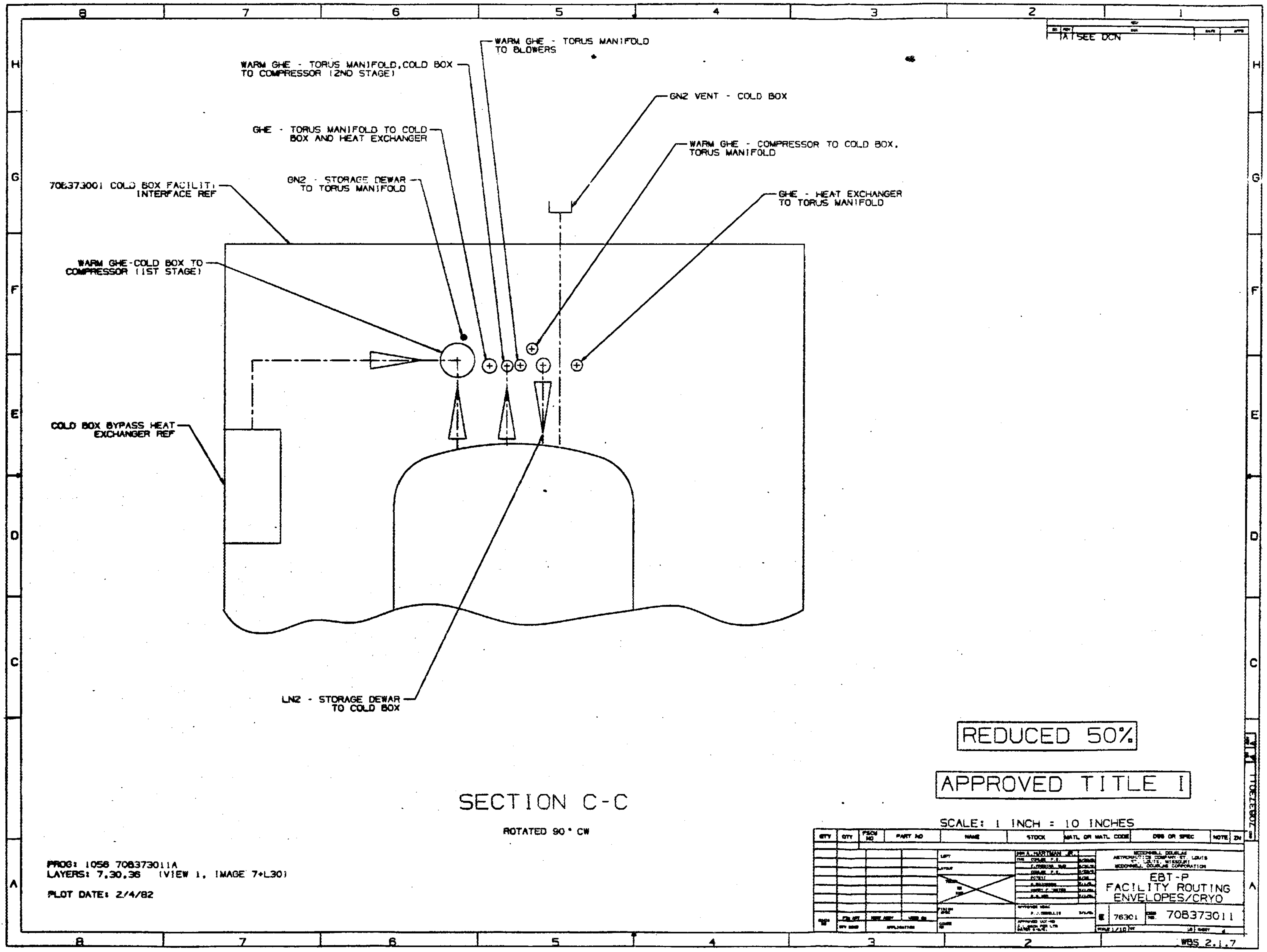

LHE SUPPLY VALVE COOLDOWN
E
10.29
70P370000 MAGNET REF
15°
LHE SUPPLY REF
LN2 SUPPLY REF
26.24
28.45
51.36
18°
F
10.05
N2 RETURN REF
WARM HE RETURN-MAGNET LEADS REF
FLEX JOINT REF
19.36
30.49
TORUS CL
LN2 SUPPLY VALVE
LHE SUPPLY VALVE OPERATION
COLD HE RETURN-MAGNET DEWAR REF
DETAIL B SCALE: 1/10
TYPICAL 9 PLACES (SHEET 1)
1/2 NPT 2 PLACES
VS 99.00 (MANIFOLD CL)
FIELD JOINT REF
FLEX LINE 2 PLACES
VACUUM VALVE REF
70P370000 MAGNET REF
VIEW E-E SCALE: 1/10
ROTATED 115 DEG CW
LHE SUPPLY 2PL
COLD HE RETURN
7.50
3.00 2PL
VACUUM VALVE TYP ALL FIELD JOINTS
10.00 5PL
VS 99.00 (MANIFOLD CL)
5.00
9.00
LN2 SUPPLY
N2 RETURN
WARM HE RETURN VALVE MAGNET VAPOR LEADS 2 PLACES
20.82
FLEX JOINT ENVELOPE ALL LINES R=LINE R + 1.5
BURST DISK/CARTRIDGE CHECK VALVE-MAGNET SAFETY VENT
15.00
VS 49.00
3.00
12.00
8.00 2PL
FLEX JOINT ENVEL. ALL LINES REF
70P370000 MAGNET REF
VIEW F-F SCALE: 1/10
ROTATED 25 DEG CW
REDUCED TO 50% OF ORIG
APPROVED TITLE I
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
EBT-P - MAGNET SUPPLY/RETURN ENVELOPES, CRYO
76301
70B373010
WBS 2.1.7

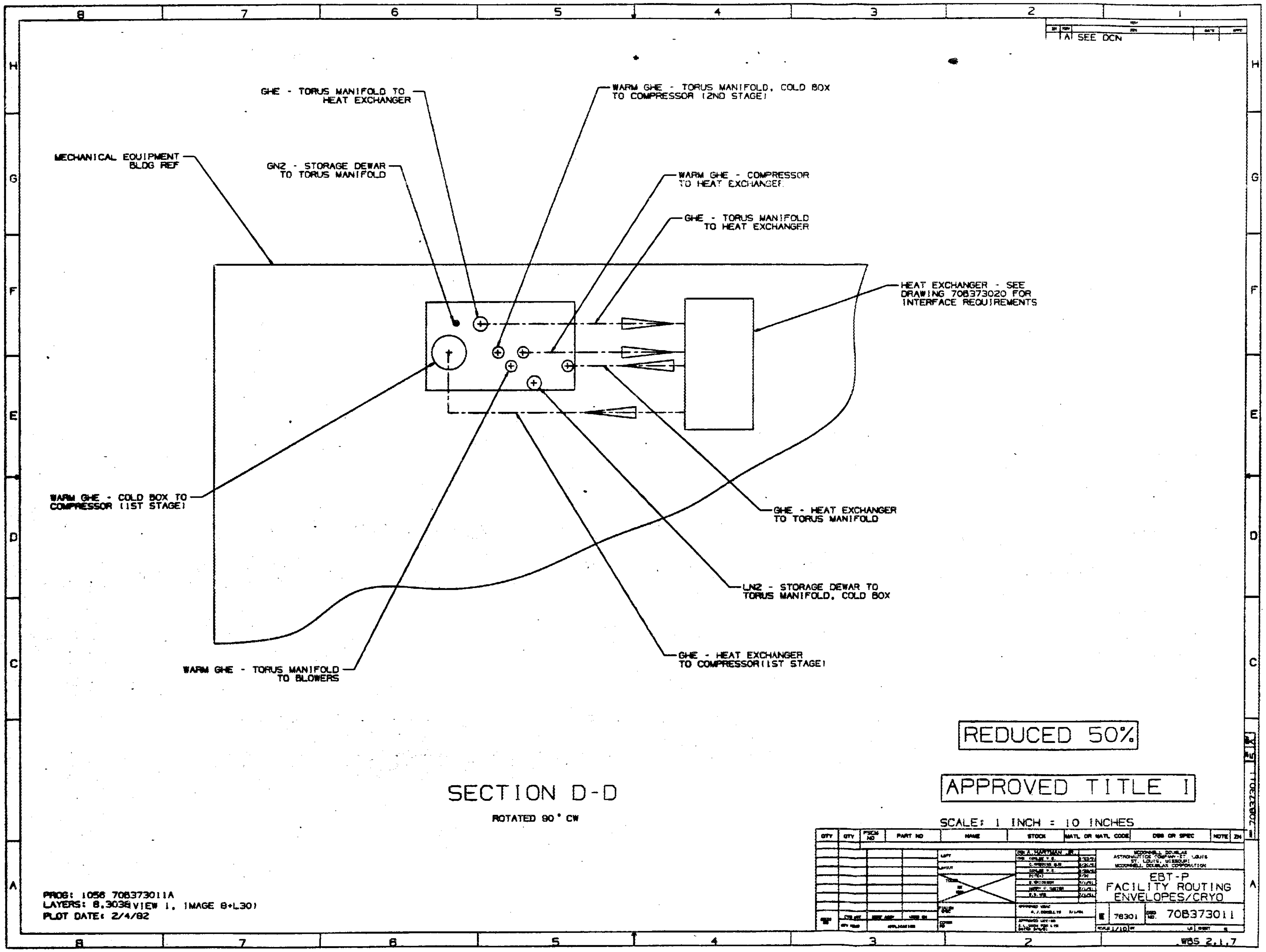


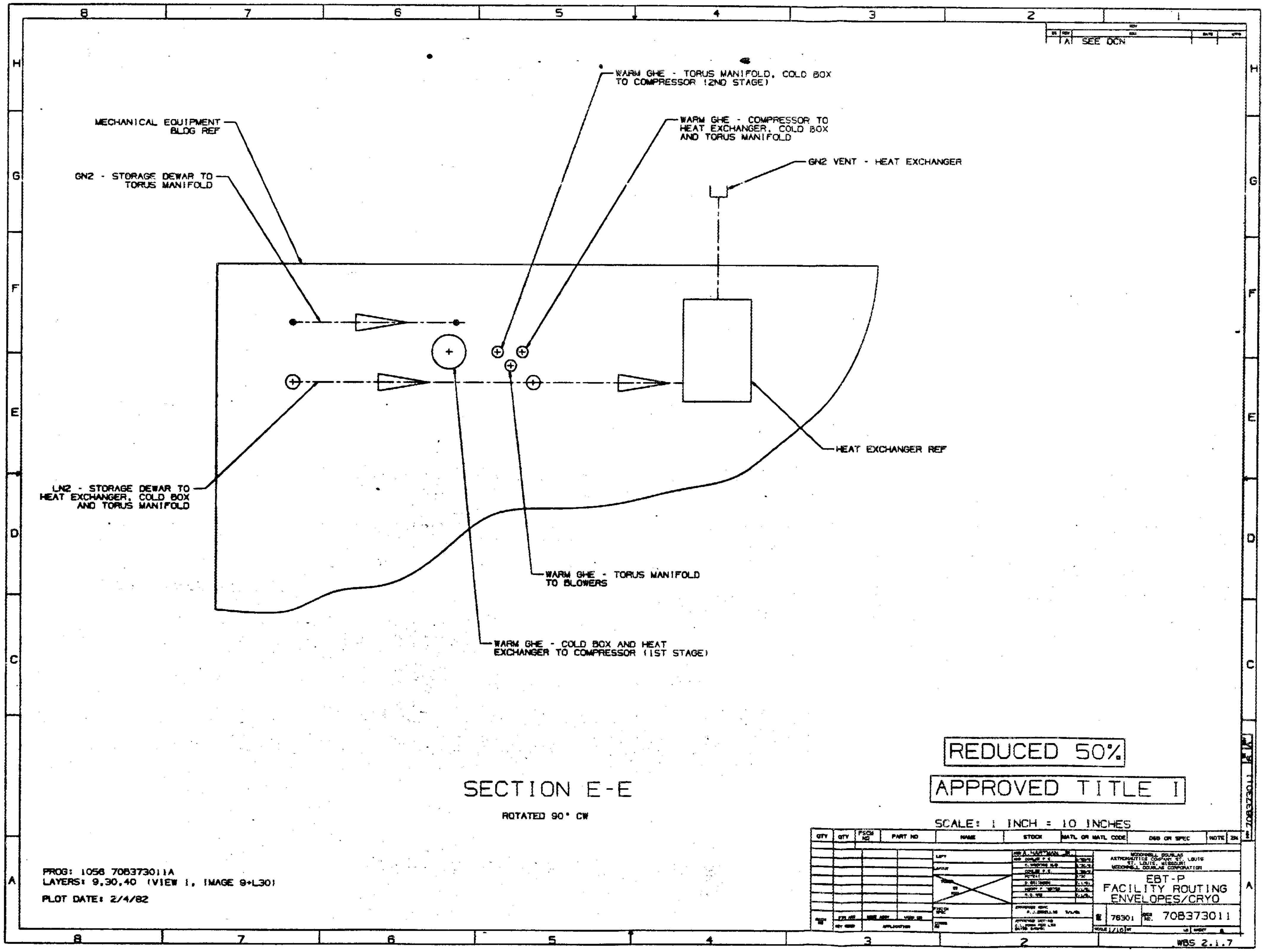
SEE DCN, PDC 17
708373001 COLD BOX FACILITY INTERFACE REF
708373020 HEAT EXCHANGER REF
TORUS ENCLOSURE REF 708374001
708373016 CRYOGENIC SUBSYSTEMS FACILITY INSTALLATION (MECHANICAL EQUIPMENT BLDG) REF
708373021 HE COMPRESSOR 2 PLACES REF
708373019 WARM GHE BLOWER 2 REQD REF
277.00 REF
165.00 REF
708373004 GHE STORAGE TANK FACILITY INTERFACE REF
708373007 GHE STORAGE TANK 3 PLACES REF
708373006 LN2 TANK FACILITY INTERFACE REF
COLD BOX BYPASS HEAT EXCHANGER REF
TORUS C/L REF
708373002 LHE DEWAR FACILITY INTERFACE
708373012 LHE STORAGE DEWAR REF
N
PLAN VIEW
VERTICAL NINETY DEGREE BENDS REQUIRED TO ACCOMMODATE PIPE/WALL PENETRATION SHIELDING. DETAILS TO BE DEFINED IN DETAIL DESIGN PHASE.
4. FOR DETAIL PIPING REQUIREMENTS SEE 70P373000.
3. SEE PIPE DATA CHART ON SHEET 11 FOR PIPE SIZE.
2. PIPING TOLERANCES SHALL PROVIDE POSITIVE LINE PITCH TO AVOID POSSIBLE VAPOR TRAPS.
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY - MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
NOTES:
PROG: 1056 708373011 A
LAYER: 1,2,4,15 (VIEW 1, IMAGE 17)
PLOT DATE: 2/4/82
REDUCED 50%
APPROVED TITLE I
SCALE: 1/8 INCH = 1 FOOT
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
76301
708373011
WBS 2.1.7

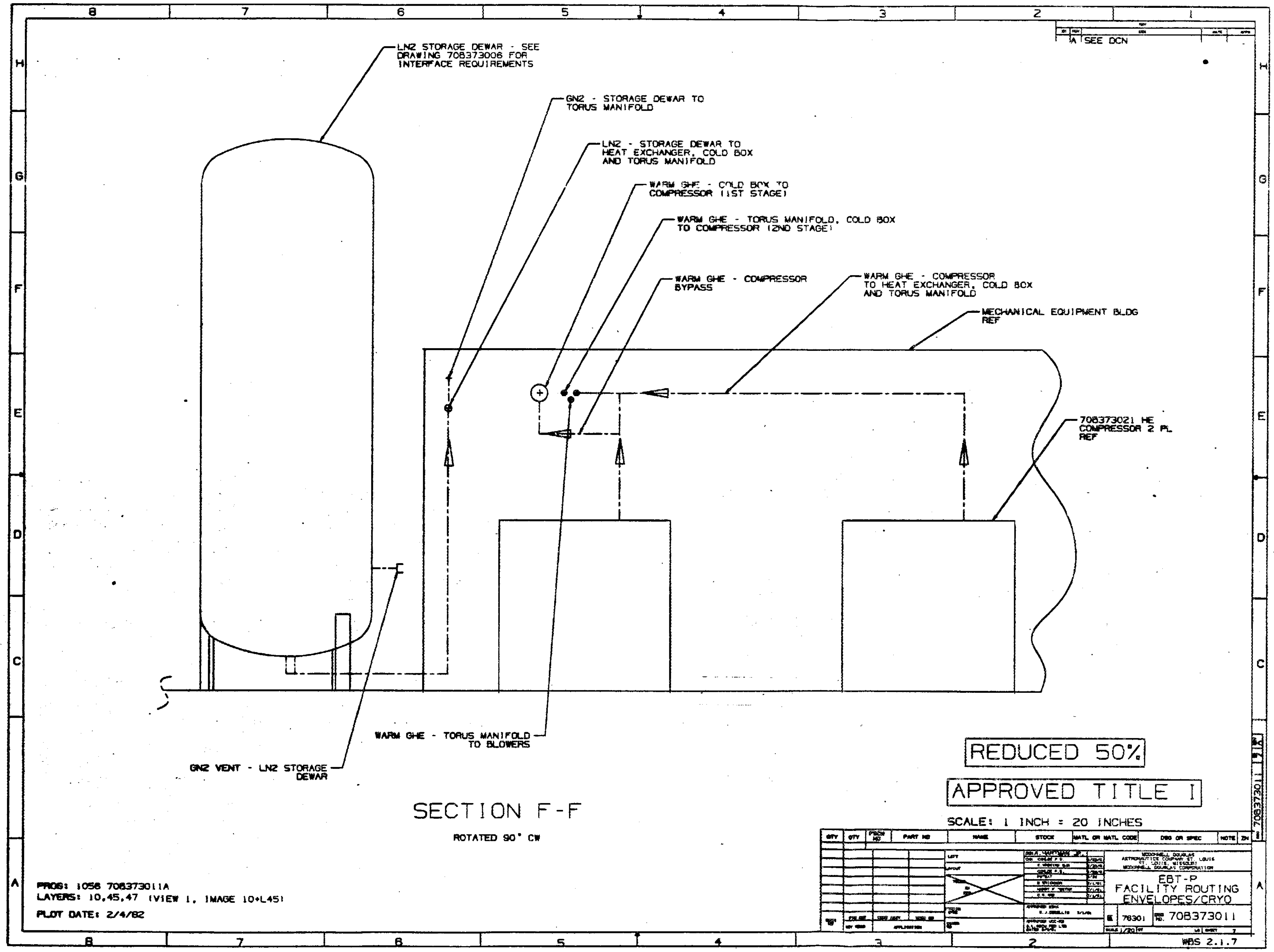

708373002 LHE DEWAR FACILITY INTERFACE
708373012 LHE STORAGE DEWAR REF
GHE - COLD BOX TO STORAGE DEWAR
GHE - STORAGE DEWAR TO COLD BOX
TORUS BLDG ROOF 708374001 REF
GN2 VENT - TORUS MANIFOLD
LHE - STORAGE DEWAR TO TORUS MANIFOLD
GHE VENT
GHE - TORUS MANIFOLD TO COLD BOX AND HEAT EXCHANGER
GN2 - STORAGE DEWAR TO TORUS MANIFOLD
GHE VENT
WARM GHE-COMPRESSOR TO TORUS MANIFOLD
GHE - HEAT EXCHANGER AND COLD BOX TO TORUS MANIFOLD
14.0
11.0
18.0
8.0
7.0
15.0
VS 125.00
VS 131.00
VS 115.25
10.0 TYP
VS 110.50
4.8
4.0
8.0
20.0
WARM GHE - TORUS MANIFOLD TO COMPRESSOR (2ND STAGE)
WARM GHE - TORUS MANIFOLD TO BLOWERS
TORUS CENTERLINE
LN2 - COLD BOX TO TORUS MANIFOLD
SECTION A-A
ROTATED 90° CW
PROG: 1058 708373011A
LAYERS: 5,30,32 (VIEW 1,IMAGE 19)
PLOT DATE: 2/4/82
REDUCED 50%
APPROVED TITLE I
SCALE: 1 INCH = 10 INCHES
SEE DCN
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
76301
708373011
WBS 2.1.7

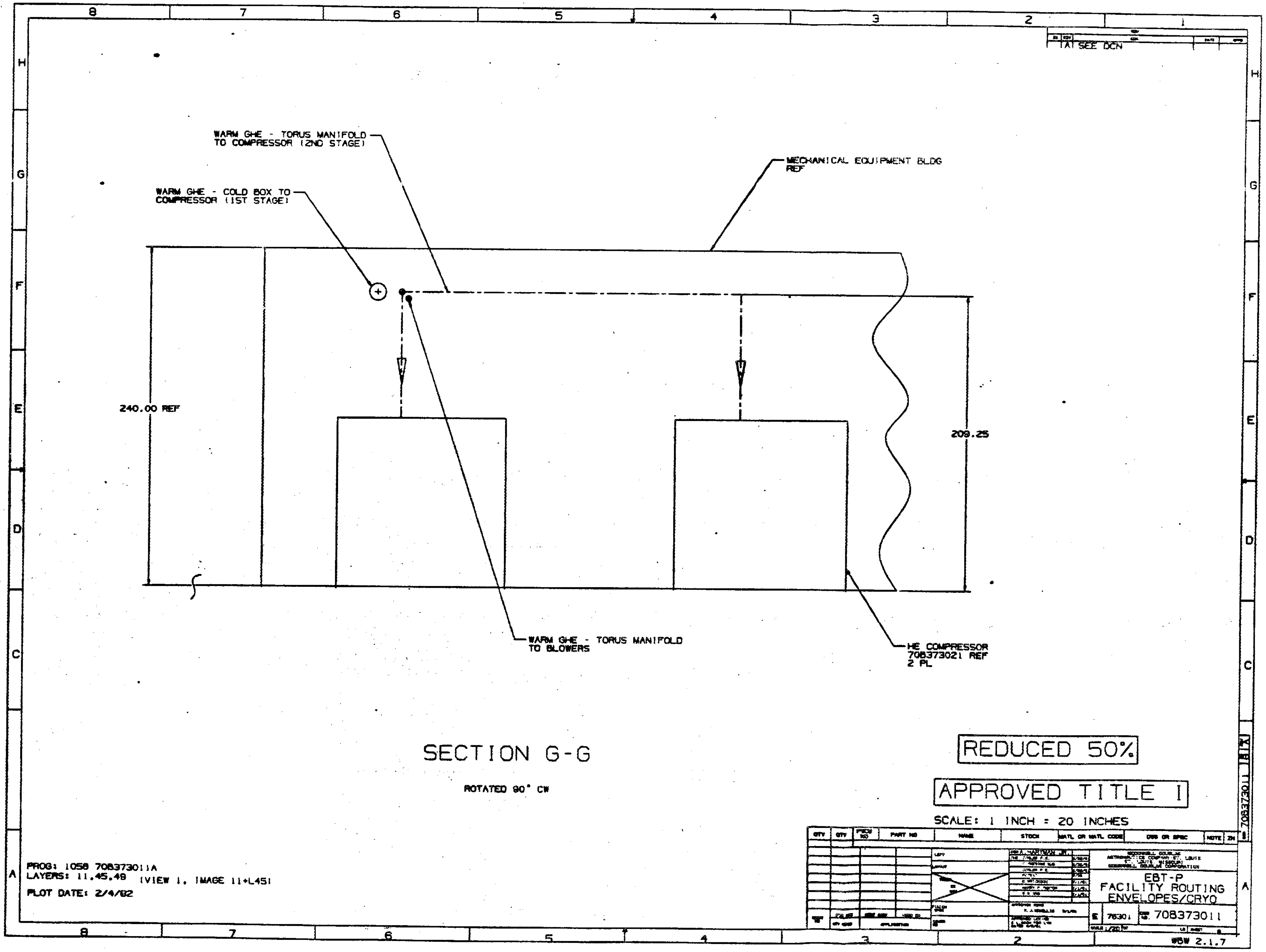

GHE - TORUS MANIFOLD TO COLD BOX AND HEAT EXCHANGER
WARM GHE - TORUS MANIFOLD TO COMPRESSOR (2ND STAGE)
WARM GHE - TORUS MANIFOLD TO BLOWERS
WARM GHE - COMPRESSOR TO COLD BOX AND TORUS MANIFOLD
LN2 - STORAGE DEWAR TO TORUS MANIFOLD
GHE - COLD BOX TO STORAGE DEWAR
GHE - HEAT EXCHANGER AND COLD BOX TO TORUS MANIFOLD
COLD BOX - SEE DRAWING 70B373001 FOR INTERFACE REQUIREMENTS
GN2 - STORAGE DEWAR TO TORUS MANIFOLD
GHE - STORAGE DEWAR TO COLD BOX
GHE - STORAGE DEWAR TO BYPASS HEAT EXCHANGER
GHE - TORUS MANIFOLD TO BYPASS HEAT EXCHANGER
COLD BOX BYPASS HEAT EXCHANGER REF
GHE - COLD BOX TO TORUS MANIFOLD
GHE - TORUS MANIFOLD TO COLD BOX
WARM GHE - COMPRESSOR TO COLD BOX
A SEE DCN
REDUCED 50%
APPROVED TITLE I
SCALE: 1 INCH = 10 INCHES
SECTION B-B
ROTATED 90° CW
PROB: 1056 70B373011A
LAYERS: 6,30,34 (VIEW 1, IMAGE 6+L30)
PLOT DATE: 2/4/82
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
EBT-P FACILITY ROUTING ENVELOPES/CRYO
78301
70B373011
WBS 2.1.7

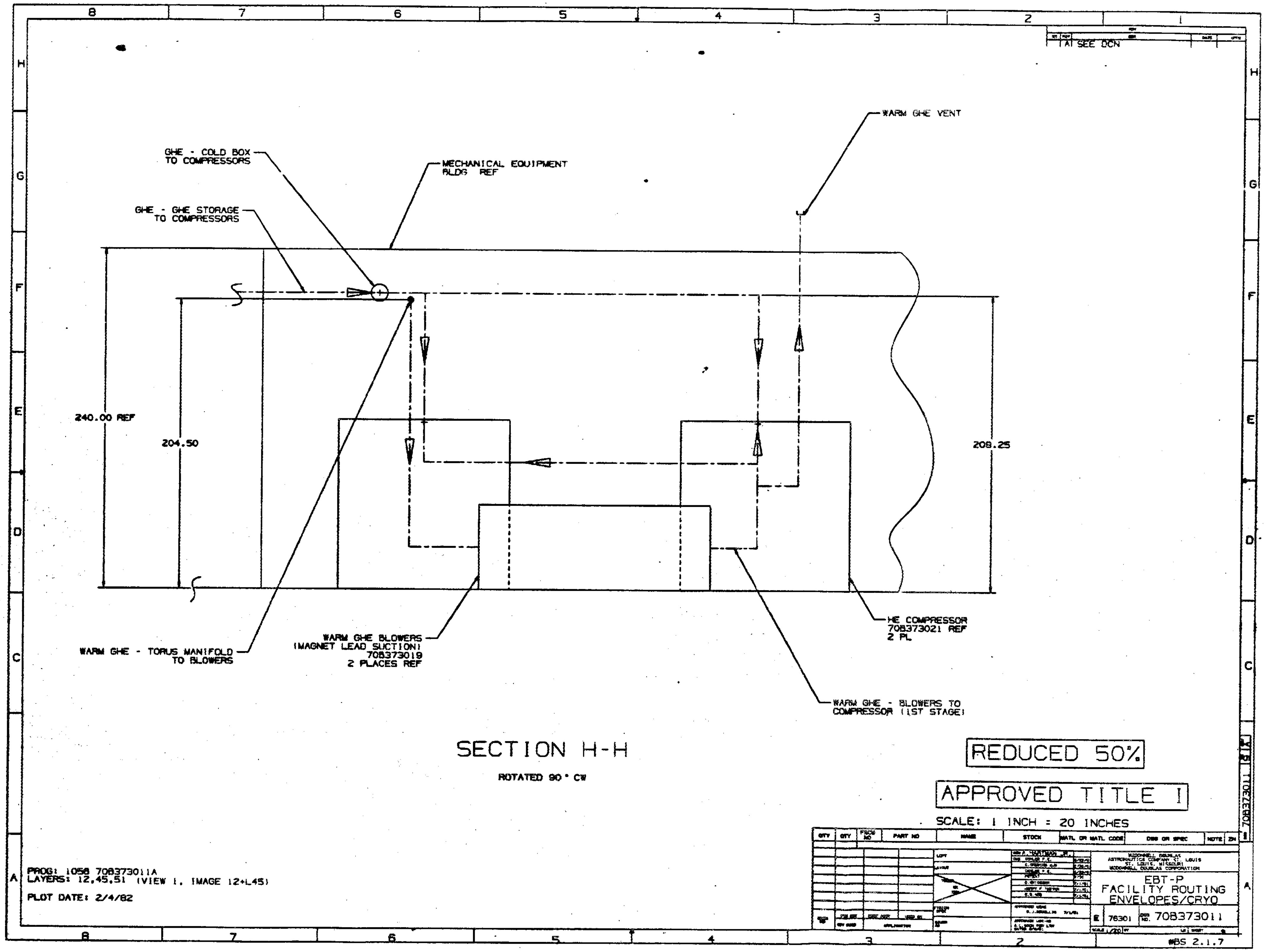

WARM GHE - TORUS MANIFOLD TO BLOWERS
WARM GHE - TORUS MANIFOLD,COLD BOX TO COMPRESSOR (2ND STAGE)
GN2 VENT - COLD BOX
GHE - TORUS MANIFOLD TO COLD BOX AND HEAT EXCHANGER
WARM GHE - COMPRESSOR TO COLD BOX, TORUS MANIFOLD
708373001 COLD BOX FACILITY INTERFACE REF
GN2 - STORAGE DEWAR TO TORUS MANIFOLD
GHE - HEAT EXCHANGER TO TORUS MANIFOLD
WARM GHE-COLD BOX TO COMPRESSOR (1ST STAGE)
COLD BOX BYPASS HEAT EXCHANGER REF
LN2 - STORAGE DEWAR TO COLD BOX
REDUCED 50%
APPROVED TITLE I
SECTION C-C
ROTATED 90° CW
SCALE: 1 INCH = 10 INCHES
PROG: 1058 708373011A
LAYERS: 7,30,36 (VIEW 1, IMAGE 7+L30)
PLOT DATE: 2/4/82
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
76301
708373011
WBS 2.1.7

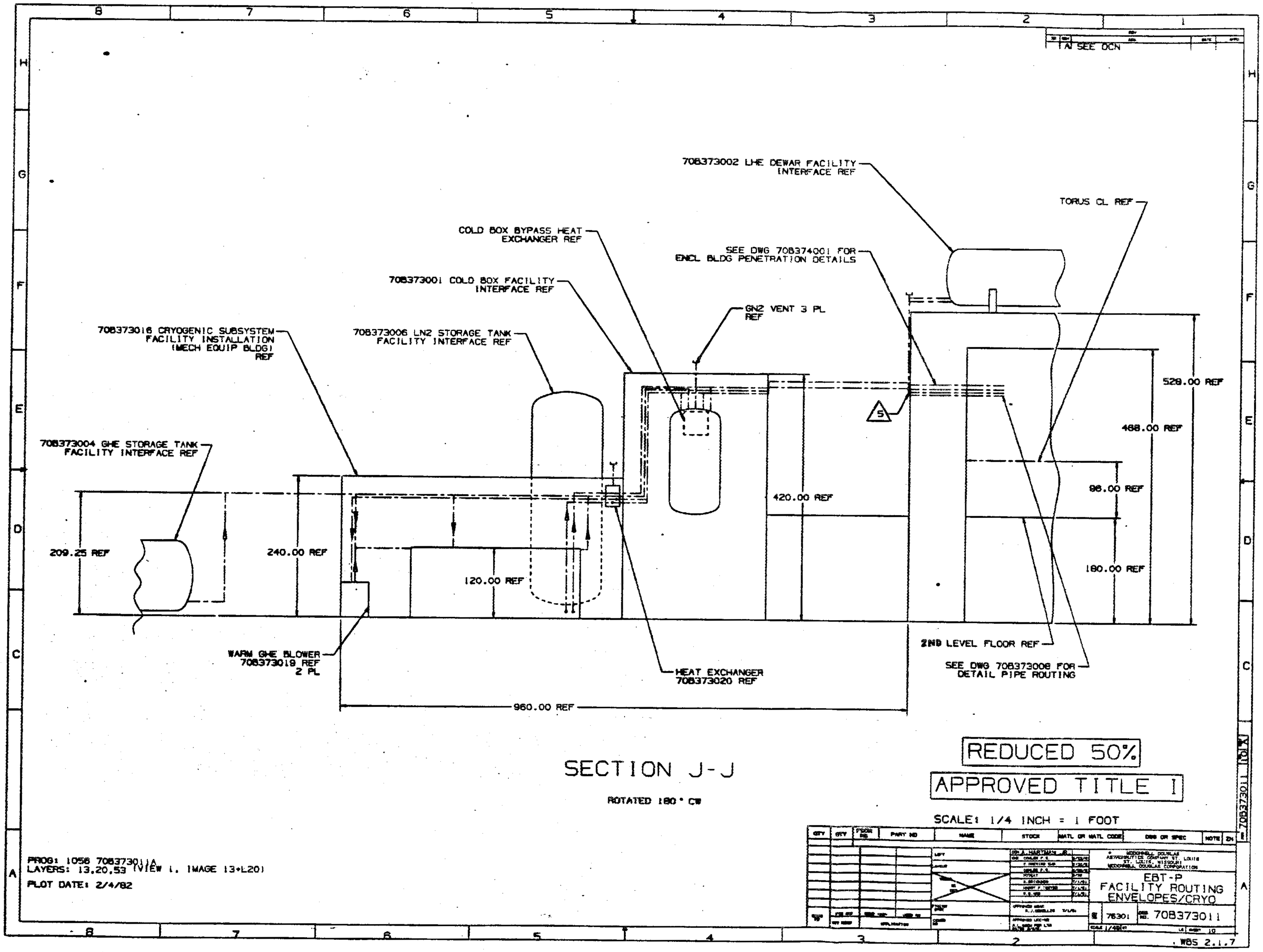

A SEE DCN
GHE - TORUS MANIFOLD TO HEAT EXCHANGER
WARM GHE - TORUS MANIFOLD, COLD BOX TO COMPRESSOR (2ND STAGE)
MECHANICAL EQUIPMENT BLDG REF
GN2 - STORAGE DEWAR TO TORUS MANIFOLD
WARM GHE - COMPRESSOR TO HEAT EXCHANGER
GHE - TORUS MANIFOLD TO HEAT EXCHANGER
HEAT EXCHANGER - SEE DRAWING 70B373020 FOR INTERFACE REQUIREMENTS
WARM GHE - COLD BOX TO COMPRESSOR (1ST STAGE)
GHE - HEAT EXCHANGER TO TORUS MANIFOLD
LN2 - STORAGE DEWAR TO TORUS MANIFOLD, COLD BOX
WARM GHE - TORUS MANIFOLD TO BLOWERS
GHE - HEAT EXCHANGER TO COMPRESSOR (1ST STAGE)
REDUCED 50%
APPROVED TITLE I
SECTION D-D
ROTATED 90° CW
SCALE: 1 INCH = 10 INCHES
EBT-P FACILITY ROUTING ENVELOPES/CRYO
78301
70B373011
WBS 2.1.7
PROG: 1056 70B373011A
LAYERS: 8,3038 VIEW 1, IMAGE 8+L30)
PLOT DATE: 2/4/82


A SEE DCN
WARM GHE - TORUS MANIFOLD, COLD BOX TO COMPRESSOR (2ND STAGE)
WARM GHE - COMPRESSOR TO HEAT EXCHANGER, COLD BOX AND TORUS MANIFOLD
GN2 VENT - HEAT EXCHANGER
MECHANICAL EQUIPMENT BLDG REF
GN2 - STORAGE DEWAR TO TORUS MANIFOLD
HEAT EXCHANGER REF
LN2 - STORAGE DEWAR TO HEAT EXCHANGER, COLD BOX AND TORUS MANIFOLD
WARM GHE - TORUS MANIFOLD TO BLOWERS
WARM GHE - COLD BOX AND HEAT EXCHANGER TO COMPRESSOR (1ST STAGE)
SECTION E-E
ROTATED 90° CW
REDUCED 50%
APPROVED TITLE I
SCALE: 1 INCH = 10 INCHES
PROG: 1056 708373011A
LAYERS: 9,30,40 (VIEW 1, IMAGE 9+L30)
PLOT DATE: 2/4/82
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
76301
708373011
WBS 2.1.7


SEE DCN
LN2 STORAGE DEWAR - SEE DRAWING 708373006 FOR INTERFACE REQUIREMENTS
GN2 - STORAGE DEWAR TO TORUS MANIFOLD
LN2 - STORAGE DEWAR TO HEAT EXCHANGER, COLD BOX AND TORUS MANIFOLD
WARM GHE - COLD BOX TO COMPRESSOR (1ST STAGE)
WARM GHE - TORUS MANIFOLD, COLD BOX TO COMPRESSOR (2ND STAGE)
WARM GHE - COMPRESSOR BYPASS
WARM GHE - COMPRESSOR TO HEAT EXCHANGER, COLD BOX AND TORUS MANIFOLD
MECHANICAL EQUIPMENT BLDG REF
708373021 HE COMPRESSOR 2 PL REF
WARM GHE - TORUS MANIFOLD TO BLOWERS
GN2 VENT - LN2 STORAGE DEWAR
SECTION F-F
ROTATED 90° CW
REDUCED 50%
APPROVED TITLE I
SCALE: 1 INCH = 20 INCHES
PROG: 1056 708373011A
LAYERS: 10,45,47 (VIEW 1, IMAGE 10+L45)
PLOT DATE: 2/4/82
QTY
QTY
PART NO
NAME
STOCK
MATL OR MATL CODE
DWG OR SPEC
NOTE
ZN
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
ST. LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
76301
708373011
WBS 2.1.7


WARM GHE - TORUS MANIFOLD TO COMPRESSOR (2ND STAGE)
WARM GHE - COLD BOX TO COMPRESSOR (1ST STAGE)
MECHANICAL EQUIPMENT BLDG REF
240.00 REF
209.25
WARM GHE - TORUS MANIFOLD TO BLOWERS
HE COMPRESSOR 70837302I REF 2 PL
SECTION G-G
ROTATED 90° CW
REDUCED 50%
APPROVED TITLE I
SCALE: 1 INCH = 20 INCHES
PROG: 1058 70837301IA
LAYERS: 11,45,49 (VIEW 1, IMAGE 11+L45)
PLOT DATE: 2/4/82
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
70837301I
WBW 2.1.7


A SEE DCN
WARM GHE VENT
GHE - COLD BOX TO COMPRESSORS
MECHANICAL EQUIPMENT BLDG REF
GHE - GHE STORAGE TO COMPRESSORS
240.00 REF
204.50
208.25
WARM GHE - TORUS MANIFOLD TO BLOWERS
WARM GHE BLOWERS (MAGNET LEAD SUCTION) 708373019 2 PLACES REF
HE COMPRESSOR 708373021 REF 2 PL
WARM GHE - BLOWERS TO COMPRESSOR (1ST STAGE)
SECTION H-H
ROTATED 90° CW
REDUCED 50%
APPROVED TITLE I
SCALE: 1 INCH = 20 INCHES
PROG: 1058 708373011A
LAYERS: 12,45,51 (VIEW 1, IMAGE 12+L45)
PLOT DATE: 2/4/82
QTY
QTY
FSCM NO
PART NO
NAME
STOCK
MATL OR MATL CODE
DWG OR SPEC
NOTE
ZN
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS ST. LOUIS, MISSOURI MCDONNELL DOUGLAS CORPORATION
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO
E
76301
DWG NO. 708373011
WBS 2.1.7


708373002 LHE DEWAR FACILITY INTERFACE REF
TORUS CL REF
COLD BOX BYPASS HEAT EXCHANGER REF
SEE DWG 708374001 FOR ENCL BLDG PENETRATION DETAILS
708373001 COLD BOX FACILITY INTERFACE REF
GN2 VENT 3 PL REF
708373016 CRYOGENIC SUBSYSTEM FACILITY INSTALLATION (MECH EQUIP BLDG) REF
708373006 LN2 STORAGE TANK FACILITY INTERFACE REF
528.00 REF
468.00 REF
708373004 GHE STORAGE TANK FACILITY INTERFACE REF
420.00 REF
96.00 REF
209.25 REF
240.00 REF
120.00 REF
180.00 REF
2ND LEVEL FLOOR REF
WARM GHE BLOWER 708373019 REF 2 PL
HEAT EXCHANGER 708373020 REF
SEE DWG 708373008 FOR DETAIL PIPE ROUTING
960.00 REF
SECTION J-J
ROTATED 180° CW
REDUCED 50%
APPROVED TITLE I
SCALE: 1/4 INCH = 1 FOOT
PROG: 1056 708373011A
LAYERS: 13,20,53 (VIEW 1, IMAGE 13+L20)
PLOT DATE: 2/4/82
EBT-P FACILITY ROUTING ENVELOPES/CRYO
708373011
WBS 2.1.7

PIPE DATA CHART

(DIMS INCLUDE PIPE TO INSIDE ENCL SOUTH WALL)

LINE IDENTIFICATION	FLUID LINE O.D./WALL INCH	JACKET O.D./WALL INCH	APPROXIMATE LENGTH FT
LIQUID HELIUM			
LHE - STORAGE DEWAR TO TORUS MANIFOLD	2.0/.065	4.0/.083	25
GASEOUS HELIUM			
GHE - COLD BOX TO STORAGE DEWAR	4.0/.083	6.0/.109	45
GHE - TORUS MANIFOLD, STORAGE DEWAR TO COLD BOX	3.0/.065	5.0/.109	45
GHE - STORAGE DEWAR TO COLD BOX	3.0/.065	5.0/.109	45
GHE - HEAT EXCHANGER, COLD BOX TO TORUS MANIFOLD	2.0/.065	4.0/.083	61
GHE - VENT 2 PLACES	3.0/.065	----	3
WARM GHE - COMPRESSOR TO HEAT EXCHANGER, COLD BOX, TORUS MANIFOLD	4.0/.083 ***	----	80
WARM GHE - TORUS MANIFOLD TO BLOWERS	4.0/.083	----	117
WARM GHE - TORUS MANIFOLD ,COLD BOX TO COMPRESSOR (2ND STAGE)	4.0/.083 **	----	100
WARM GHE - COLD BOX TO COMPRESSOR (1ST STAGE)	12.0/.156	----	73
WARM GHE - BLOWERS TO COMPRESSOR (1ST STAGE)	4.0/.083	----	24
WARM GHE - GHE STORAGE TO COMPRESSOR (1ST STAGE)	3.0/.203	----	100
WARM GHE - COMPRESSOR BYPASS	4.0/.083	----	10
WARM GHE - VENT	12.0/.156	----	12
LIQUID NITROGEN			
LN2 - STORAGE DEWAR TO HEAT EXCHANGER, COLD BOX, TORUS MANIFOLD	3.0/.065 *	5.0/.109	80
LN2 - STORAGE DEWAR TO HEAT EXCHANGER, COLD BOX (TEED OFF PIPE TO TORUS MANIFOLD)	2.0/.065	4.0/.083	6
GASEOUS NITROGEN			
GN2 - STORAGE DEWAR TO TORUS MANIFOLD	2.0/.065	----	80
GN2 VENT - TORUS MANIFOLD	4.0/.065	6.0/.109 (TERMINATE VACUUM JACKET AT TORUS ENCLOSURE OUTSIDE WALL)	20
GN2 VENT - HEAT EXCHANGER, LN2 STORAGE DEWAR AND COLD BOX	INCLUDED IN EQUIPMENT SPECIFICATION 70P373000		

* 3.0/.065 FLUID LINE,5.0/.109 JACKET PIPE REDUCED TO 2.0/.065 FLUID LINE, 4.0/.083 JACKET AT COLD BOX

** 1.5 OD, .049 WALL PIPE INCREASED TO 4.0 OD, .083 WALL AT COLD BOX

*** 4.0 OD, .083 WALL PIPE REDUCED TO 1.0 OD, .035 WALL AT COLD BOX

PROG: 1056 70B373011A
LAYERS: 55,25 (VIEW 1,IMAGE 14+L25)
PLOT DATE: 2/4/82

A SEE DCN

REDUCED 50%

APPROVED TITLE I

QTY	QTY	FSCM NO	PART NO	NAME	STOCK	MATL OR MATL CODE	DWG OR SPEC	NOTE	ZN

A. HARTMAN JR.
COMLEE F.E.
C. GREEING
COMLEE F.E.
HARRY F. WEBER
APPROVED
R.J. DEBELLIS
APPROVED UCC-ND
A.L. BOCH PER LTR

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
ST. LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

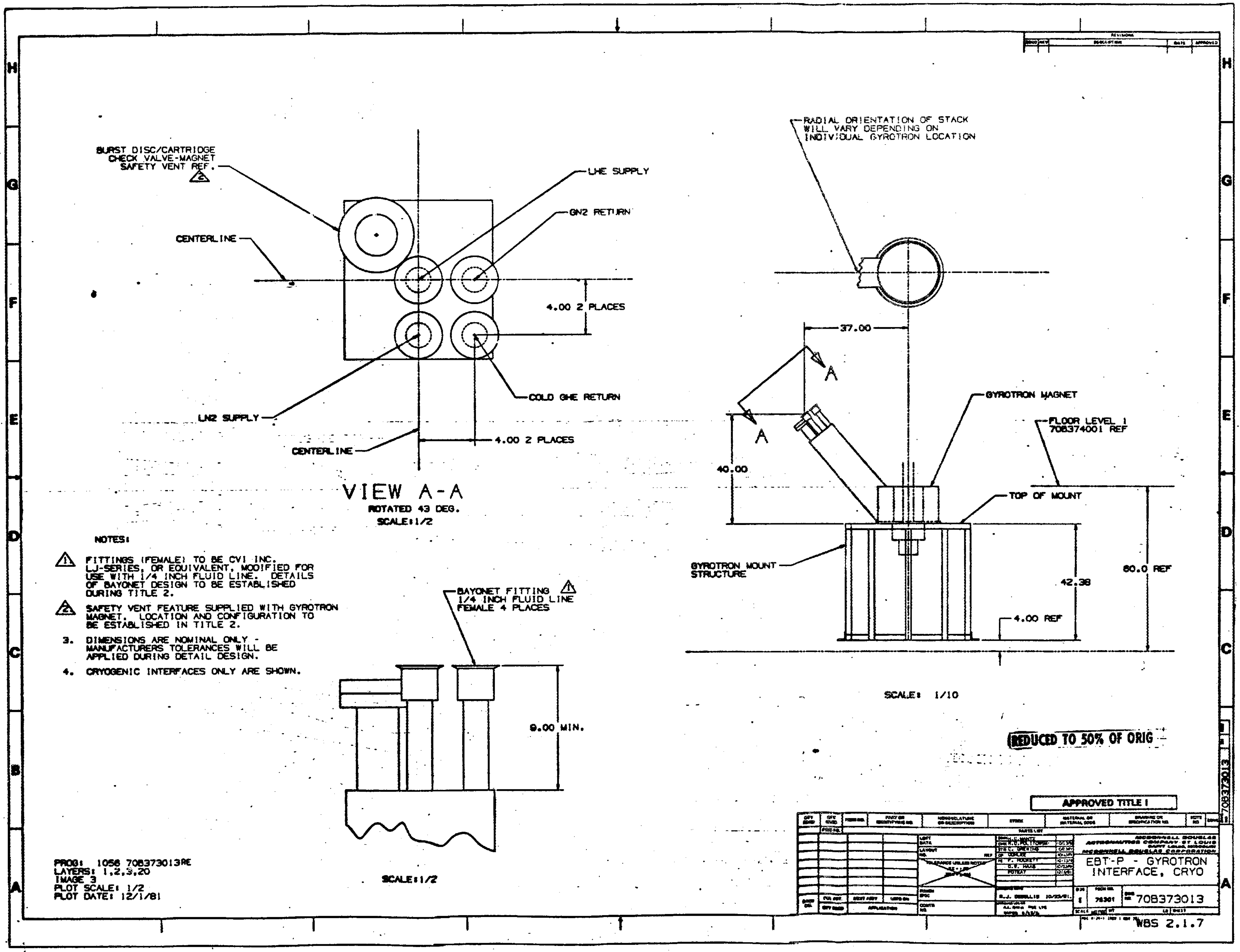
EBT-P
FACILITY ROUTING
ENVELOPES/CRYO

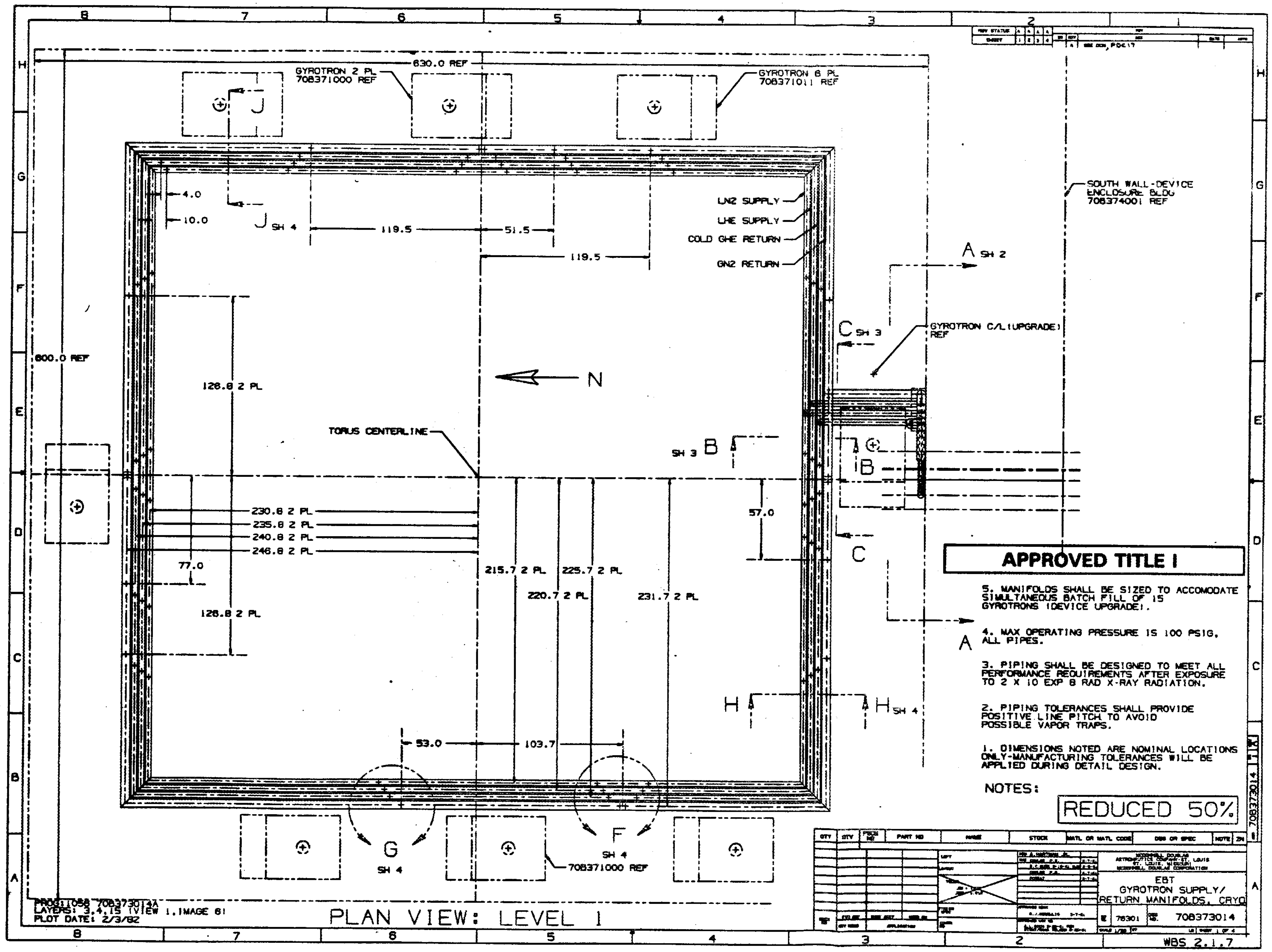
E 76301 DWG NO. 70B373011

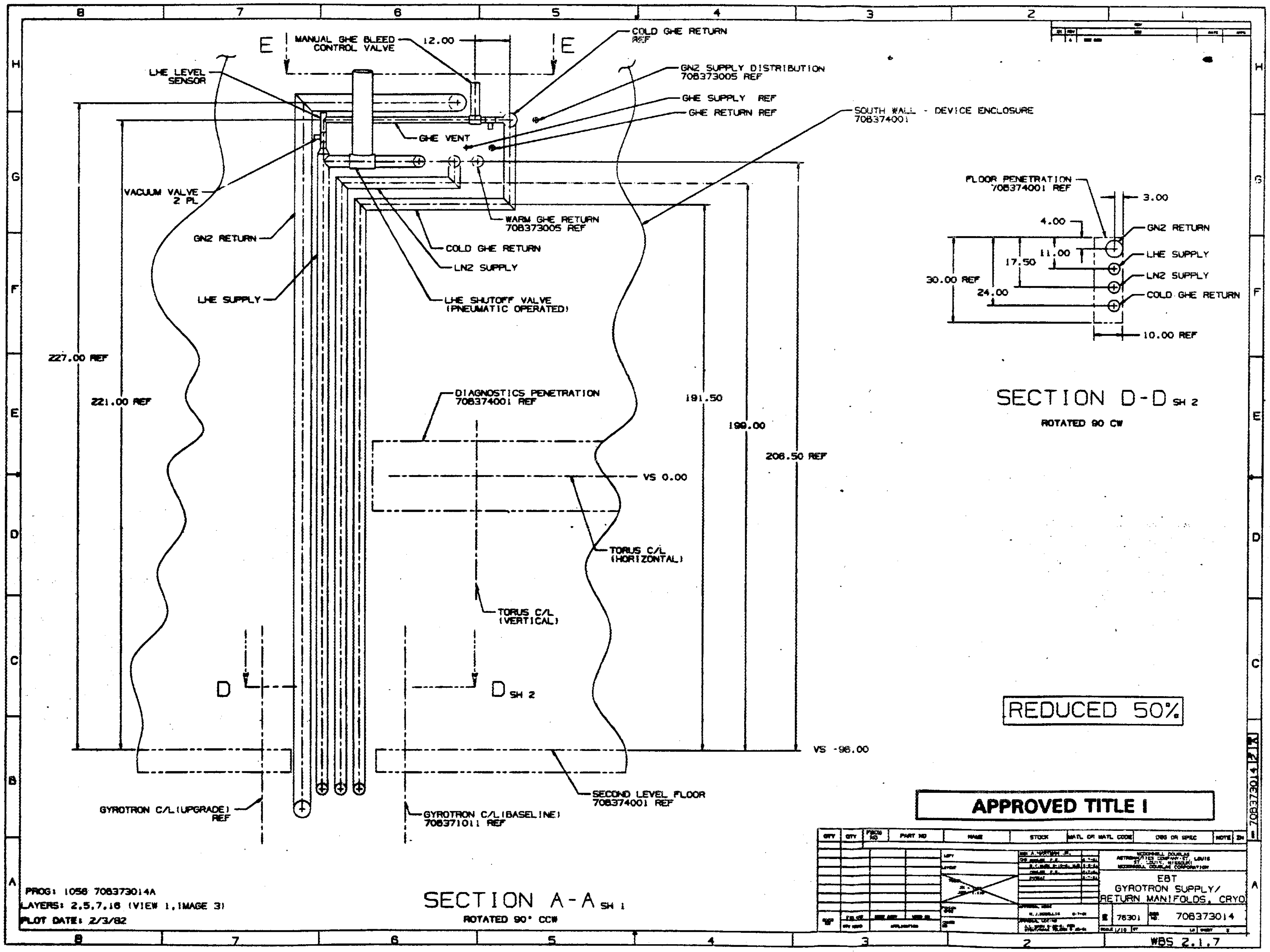
SCALE 1/1

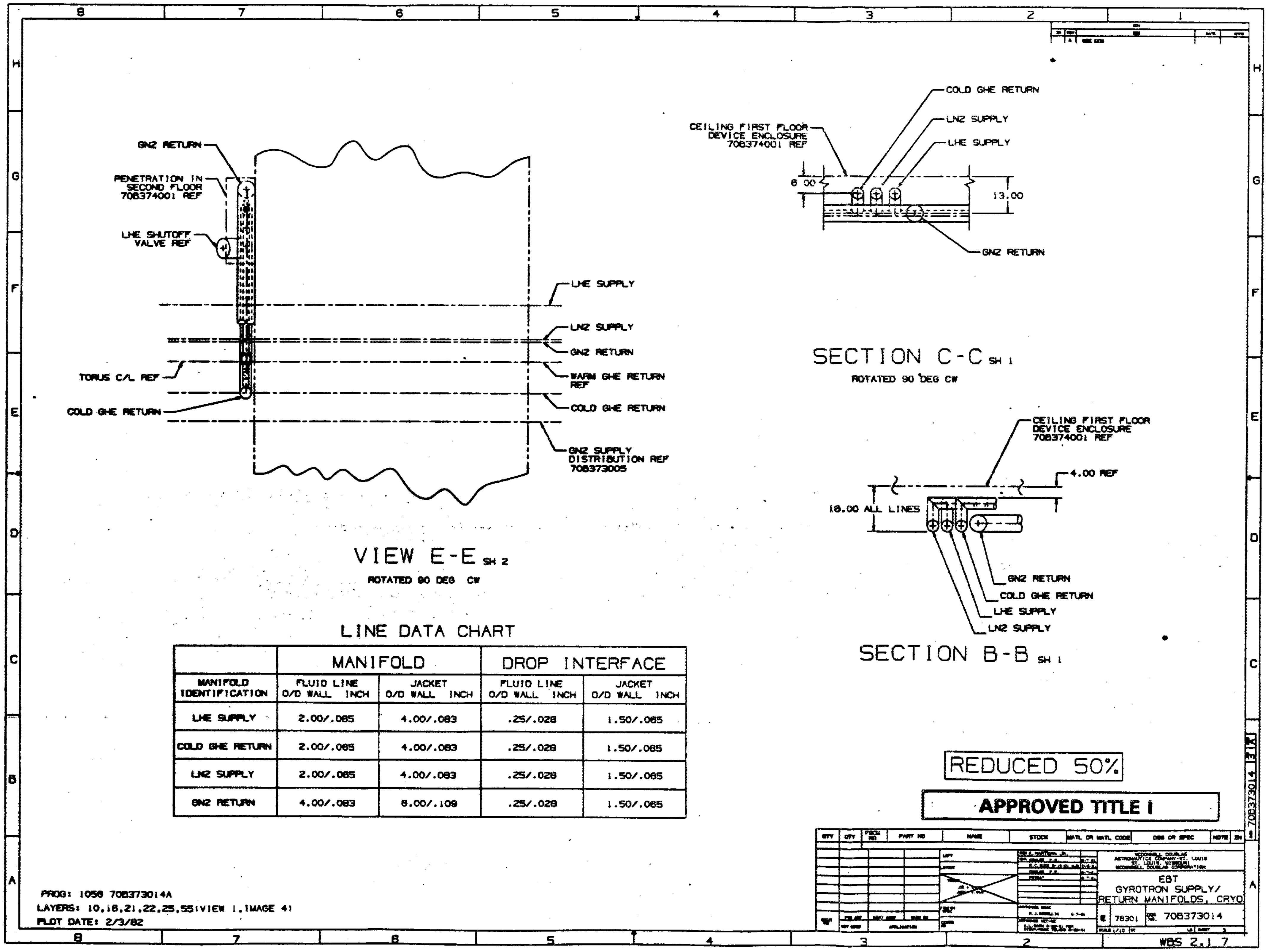
WBS 2.1.7

70B373011


BURST DISC/CARTRIDGE CHECK VALVE-MAGNET SAFETY VENT REF.
LHE SUPPLY
GN2 RETURN
CENTERLINE
4.00 2 PLACES
COLD GHE RETURN
LN2 SUPPLY
CENTERLINE
4.00 2 PLACES
VIEW A-A
ROTATED 43 DEG.
SCALE: 1/2
NOTES:
1. FITTINGS (FEMALE) TO BE CVI INC. LJ-SERIES, OR EQUIVALENT, MODIFIED FOR USE WITH 1/4 INCH FLUID LINE. DETAILS OF BAYONET DESIGN TO BE ESTABLISHED DURING TITLE 2.
2. SAFETY VENT FEATURE SUPPLIED WITH GYROTRON MAGNET. LOCATION AND CONFIGURATION TO BE ESTABLISHED IN TITLE 2.
3. DIMENSIONS ARE NOMINAL ONLY - MANUFACTURERS TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
4. CRYOGENIC INTERFACES ONLY ARE SHOWN.
BAYONET FITTING 1/4 INCH FLUID LINE FEMALE 4 PLACES
9.00 MIN.
SCALE: 1/2
RADIAL ORIENTATION OF STACK WILL VARY DEPENDING ON INDIVIDUAL GYROTRON LOCATION
37.00
A
A
GYROTRON MAGNET
FLOOR LEVEL 1 708374001 REF
40.00
TOP OF MOUNT
GYROTRON MOUNT STRUCTURE
42.38
80.0 REF
4.00 REF
SCALE: 1/10
REDUCED TO 50% OF ORIG
APPROVED TITLE I
PROG: 1056 708373013RE
LAYERS: 1,2,3,20
IMAGE 3
PLOT SCALE: 1/2
PLOT DATE: 12/1/81
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST. LOUIS
MCDONNELL DOUGLAS CORPORATION
EBT-P - GYROTRON INTERFACE, CRYO
76301
708373013
WBS 2.1.7

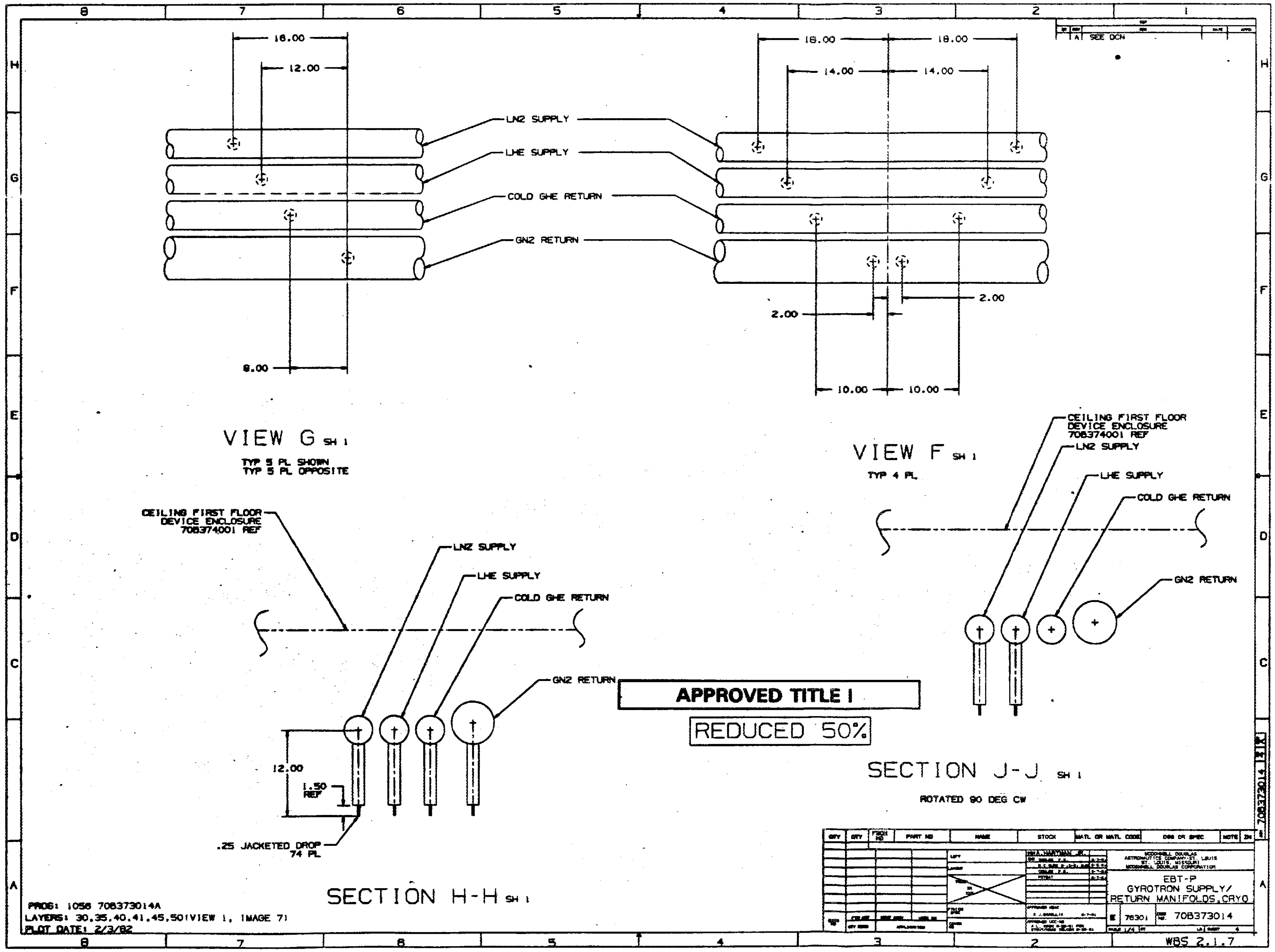

630.0 REF
GYROTRON 2 PL
708371000 REF
GYROTRON 6 PL
708371011 REF
SOUTH WALL-DEVICE ENCLOSURE BLDG 708374001 REF
LN2 SUPPLY
LHE SUPPLY
COLD GHE RETURN
GN2 RETURN
119.5
51.5
119.5
4.0
10.0
A SH 2
C SH 3
GYROTRON C/L (UPGRADE) REF
600.0 REF
128.8 2 PL
N
TORUS CENTERLINE
SH 3 B
B
230.8 2 PL
235.8 2 PL
240.8 2 PL
246.8 2 PL
57.0
77.0
215.7 2 PL
225.7 2 PL
220.7 2 PL
231.7 2 PL
C
A
H
H SH 4
53.0
103.7
G SH 4
F SH 4
708371000 REF
APPROVED TITLE I
5. MANIFOLDS SHALL BE SIZED TO ACCOMODATE SIMULTANEOUS BATCH FILL OF 15 GYROTRONS (DEVICE UPGRADE).
4. MAX OPERATING PRESSURE IS 100 PSIG, ALL PIPES.
3. PIPING SHALL BE DESIGNED TO MEET ALL PERFORMANCE REQUIREMENTS AFTER EXPOSURE TO 2 X 10 EXP 8 RAD X-RAY RADIATION.
2. PIPING TOLERANCES SHALL PROVIDE POSITIVE LINE PITCH TO AVOID POSSIBLE VAPOR TRAPS.
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY-MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
NOTES:
REDUCED 50%
EBT
GYROTRON SUPPLY/ RETURN MANIFOLDS, CRYO
708373014
WBS 2.1.7
LAYERS: 3,4,15 (VIEW 1, IMAGE 6)
PLOT DATE: 2/3/82
PLAN VIEW: LEVEL 1

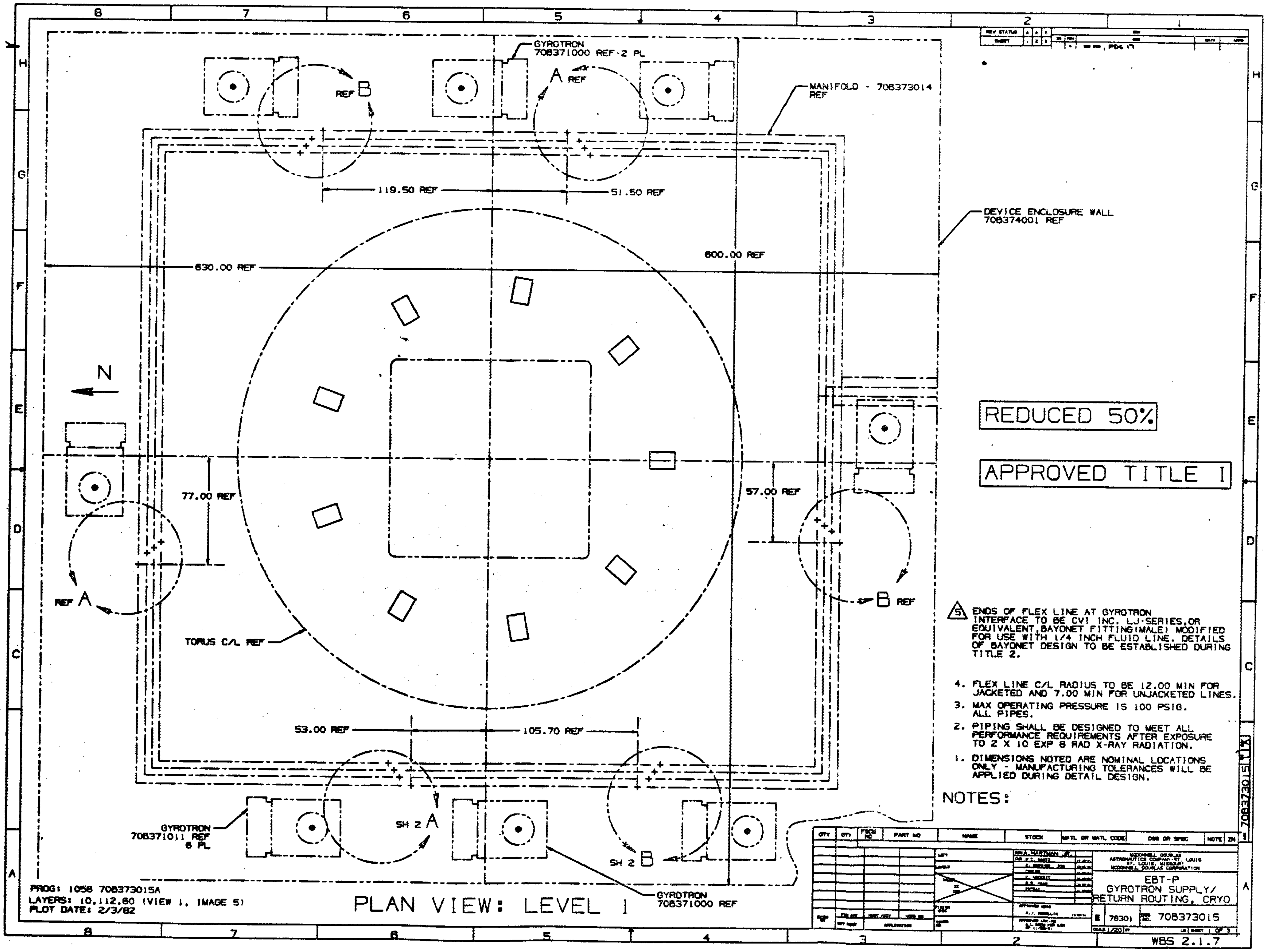

MANUAL GHE BLEED CONTROL VALVE
12.00
COLD GHE RETURN REF
GN2 SUPPLY DISTRIBUTION 708373005 REF
GHE SUPPLY REF
GHE RETURN REF
SOUTH WALL - DEVICE ENCLOSURE 708374001
LHE LEVEL SENSOR
GHE VENT
VACUUM VALVE 2 PL
GN2 RETURN
WARM GHE RETURN 708373005 REF
COLD GHE RETURN
LN2 SUPPLY
LHE SUPPLY
LHE SHUTOFF VALVE (PNEUMATIC OPERATED)
227.00 REF
221.00 REF
DIAGNOSTICS PENETRATION 708374001 REF
191.50
199.00
206.50 REF
VS 0.00
TORUS C/L (HORIZONTAL)
TORUS C/L (VERTICAL)
VS -98.00
SECOND LEVEL FLOOR 708374001 REF
GYROTRON C/L (UPGRADE) REF
GYROTRON C/L (BASELINE) 708371011 REF
FLOOR PENETRATION 708374001 REF
3.00
4.00
11.00
17.50
30.00 REF
24.00
GN2 RETURN
LHE SUPPLY
LN2 SUPPLY
COLD GHE RETURN
10.00 REF
SECTION D-D SH 2
ROTATED 90 CW
REDUCED 50%
APPROVED TITLE I
SECTION A-A SH 1
ROTATED 90° CCW
PROG: 1056 708373014A
LAYERS: 2,5,7,16 (VIEW 1,IMAGE 3)
PLOT DATE: 2/3/82
EBT
GYROTRON SUPPLY/ RETURN MANIFOLDS, CRYO
76301
708373014
WBS 2.1.7

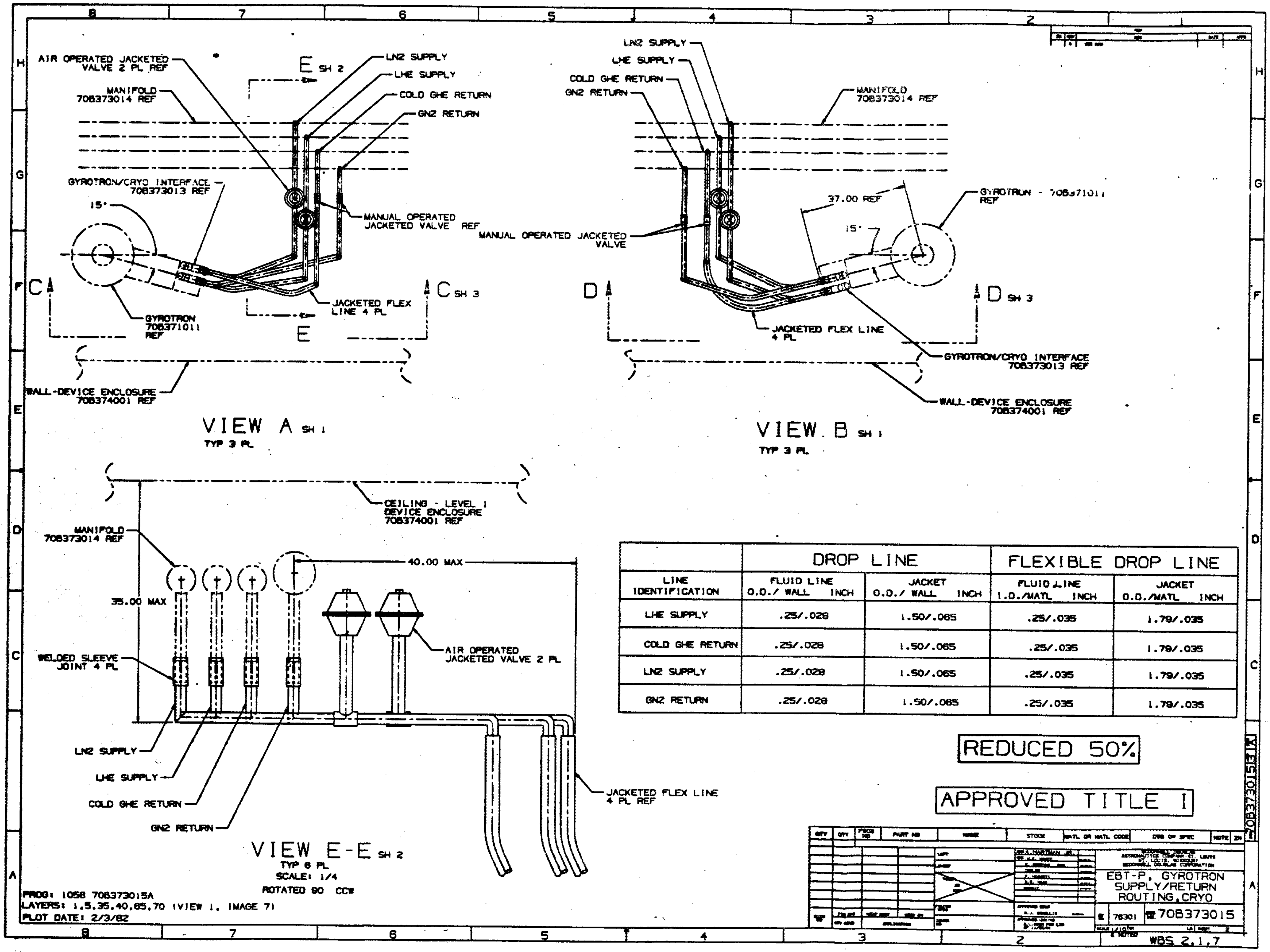


LINE DATA CHART

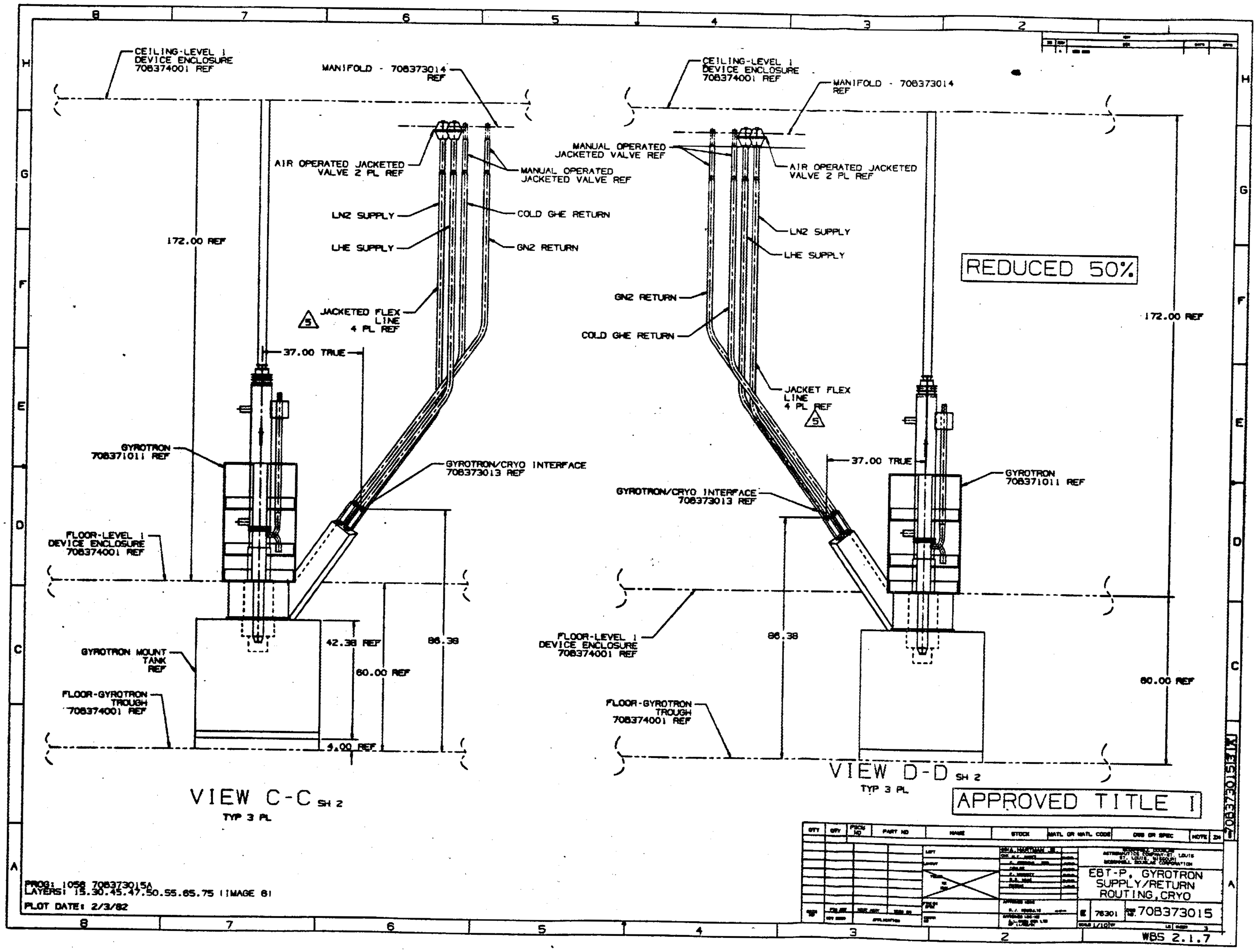
	MANIFOLD		DROP INTERFACE	
MANIFOLD IDENTIFICATION	FLUID LINE O/D WALL INCH	JACKET O/D WALL INCH	FLUID LINE O/D WALL INCH	JACKET O/D WALL INCH
LHE SUPPLY	2.00/.065	4.00/.083	.25/.028	1.50/.065
COLD GHE RETURN	2.00/.065	4.00/.083	.25/.028	1.50/.065
LN2 SUPPLY	2.00/.065	4.00/.083	.25/.028	1.50/.065
GN2 RETURN	4.00/.083	6.00/.109	.25/.028	1.50/.065

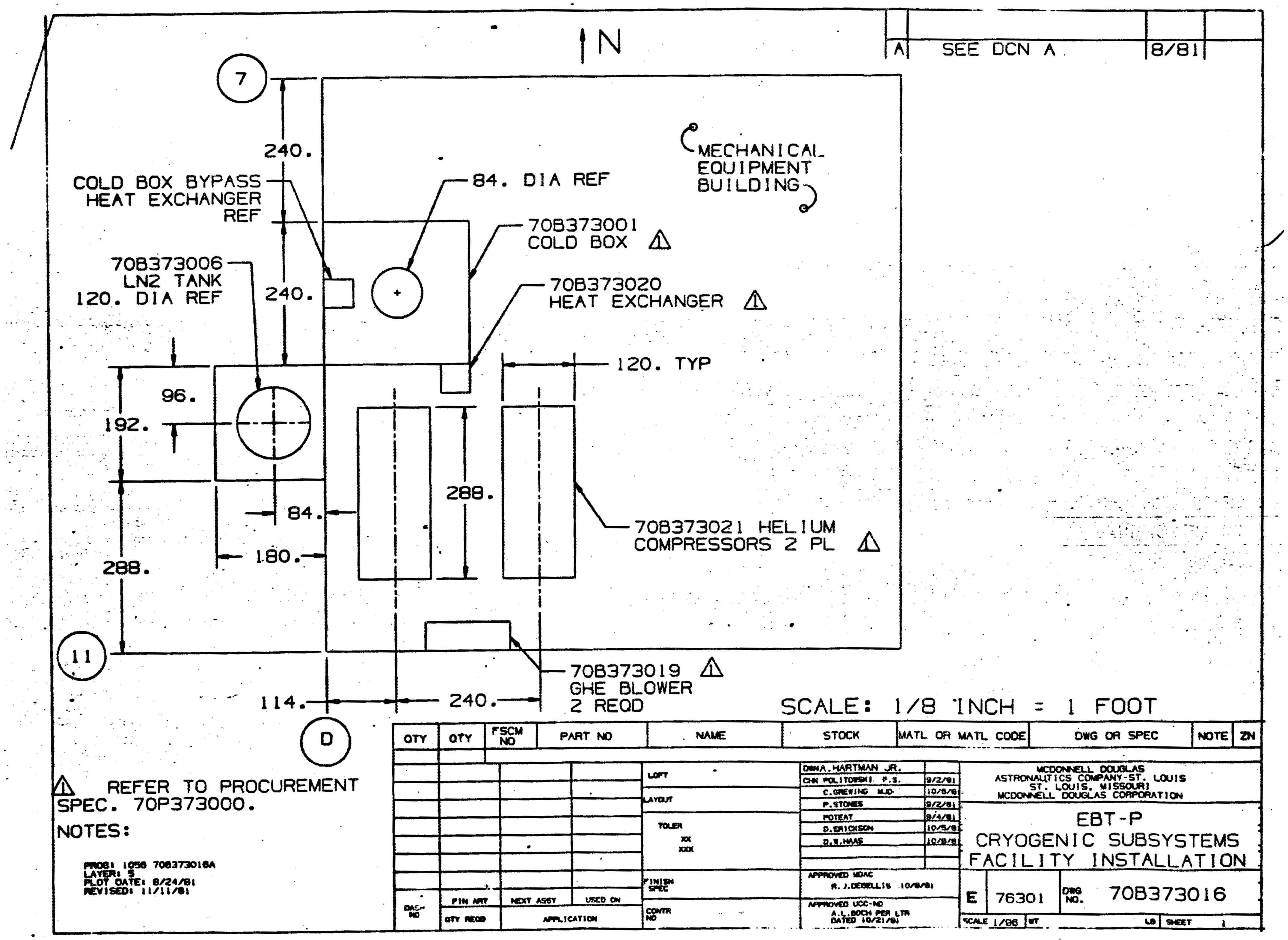

VIEW G SH 1
TYP 5 PL SHOWN
TYP 5 PL OPPOSITE
VIEW F SH 1
TYP 4 PL
LN2 SUPPLY
LHE SUPPLY
COLD GHE RETURN
GN2 RETURN
CEILING FIRST FLOOR DEVICE ENCLOSURE 708374001 REF
APPROVED TITLE I
REDUCED 50%
SECTION J-J SH 1
ROTATED 90 DEG CW
SECTION H-H SH 1
.25 JACKETED DROP 74 PL
EBT-P
GYROTRON SUPPLY/
RETURN MANIFOLDS,CRYO
708373014
WBS 2.1.7

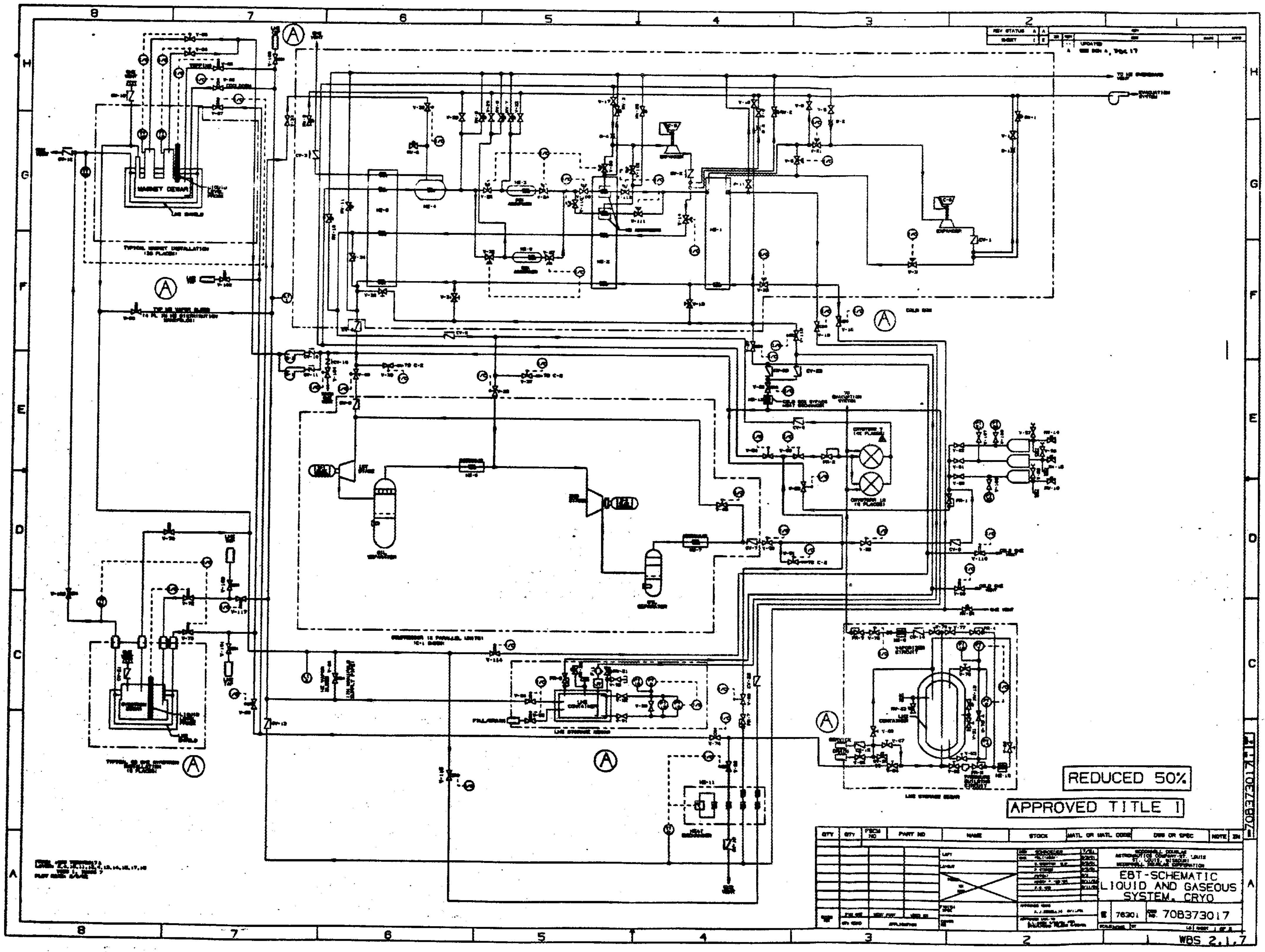

GYROTRON 708371000 REF-2 PL
MANIFOLD - 708373014 REF
119.50 REF
51.50 REF
DEVICE ENCLOSURE WALL 708374001 REF
630.00 REF
600.00 REF
N
77.00 REF
57.00 REF
REF A
B REF
TORUS C/L REF
53.00 REF
105.70 REF
SH 2 A
SH 2 B
GYROTRON 708371011 REF 6 PL
GYROTRON 708371000 REF
REDUCED 50%
APPROVED TITLE I
5 ENDS OF FLEX LINE AT GYROTRON INTERFACE TO BE CVI INC. LJ-SERIES,OR EQUIVALENT,BAYONET FITTING(MALE) MODIFIED FOR USE WITH 1/4 INCH FLUID LINE. DETAILS OF BAYONET DESIGN TO BE ESTABLISHED DURING TITLE 2.
4. FLEX LINE C/L RADIUS TO BE 12.00 MIN FOR JACKETED AND 7.00 MIN FOR UNJACKETED LINES.
3. MAX OPERATING PRESSURE IS 100 PSIG. ALL PIPES.
2. PIPING SHALL BE DESIGNED TO MEET ALL PERFORMANCE REQUIREMENTS AFTER EXPOSURE TO 2 X 10 EXP 8 RAD X-RAY RADIATION.
1. DIMENSIONS NOTED ARE NOMINAL LOCATIONS ONLY - MANUFACTURING TOLERANCES WILL BE APPLIED DURING DETAIL DESIGN.
NOTES:
PROG: 1058 708373015A
LAYERS: 10,112,80 (VIEW 1, IMAGE 5)
PLOT DATE: 2/3/82
PLAN VIEW: LEVEL 1
EBT-P
GYROTRON SUPPLY/
RETURN ROUTING, CRYO
76301
708373015
WBS 2.1.7



LINE IDENTIFICATION	DROP LINE: FLUID LINE O.D./WALL INCH	DROP LINE: JACKET O.D./WALL INCH	FLEXIBLE DROP LINE: FLUID LINE I.D./MATL INCH	FLEXIBLE DROP LINE: JACKET O.D./MATL INCH
LHE SUPPLY	.25/.028	1.50/.065	.25/.035	1.79/.035
COLD GHE RETURN	.25/.028	1.50/.065	.25/.035	1.79/.035
LN2 SUPPLY	.25/.028	1.50/.065	.25/.035	1.79/.035
GN2 RETURN	.25/.028	1.50/.065	.25/.035	1.79/.035


CEILING-LEVEL 1 DEVICE ENCLOSURE 708374001 REF
MANIFOLD - 708373014 REF
AIR OPERATED JACKETED VALVE 2 PL REF
MANUAL OPERATED JACKETED VALVE REF
LN2 SUPPLY
COLD GHE RETURN
LHE SUPPLY
GN2 RETURN
172.00 REF
JACKETED FLEX LINE 4 PL REF
37.00 TRUE
GYROTRON 708371011 REF
GYROTRON/CRYO INTERFACE 708373013 REF
FLOOR-LEVEL 1 DEVICE ENCLOSURE 708374001 REF
GYROTRON MOUNT TANK REF
42.38 REF
86.38
60.00 REF
FLOOR-GYROTRON TROUGH 708374001 REF
4.00 REF
VIEW C-C SH 2
TYP 3 PL
JACKET FLEX LINE 4 PL REF
REDUCED 50%
VIEW D-D SH 2
TYP 3 PL
APPROVED TITLE I
PROG: 1058 708373015A
LAYERS: 15.30.45.47.50.55.65.75 (IMAGE 8)
PLOT DATE: 2/3/82
EBT-P, GYROTRON SUPPLY/RETURN ROUTING, CRYO
76301
708373015
WBS 2.1.7


A SEE DCN A 8/81
N
7
240.
COLD BOX BYPASS
HEAT EXCHANGER
REF
84. DIA REF
MECHANICAL
EQUIPMENT
BUILDING
70B373001
COLD BOX
70B373006
LN2 TANK
120. DIA REF
240.
70B373020
HEAT EXCHANGER
120. TYP
96.
192.
288.
84.
180.
288.
70B373021 HELIUM
COMPRESSORS 2 PL
11
70B373019
GHE BLOWER
2 REQD
114.
240.
D
SCALE: 1/8 INCH = 1 FOOT
REFER TO PROCUREMENT
SPEC. 70P373000.
NOTES:
PROB: 1056 70B373016A
LAYER: 5
PLOT DATE: 8/24/81
REVISED: 11/11/81
QTY
QTY
FSCM NO
PART NO
NAME
STOCK
MATL OR MATL CODE
DWG OR SPEC
NOTE
ZN
LOFT
LAYOUT
TOLER
XX
XXX
FINISH SPEC
CONTR NO
DASH NO
FIN ART
NEXT ASSY
USED ON
QTY REQD
APPLICATION
DWN A. HARTMAN JR.
CHK POLITOWSKI P.S. 9/2/81
C.GREWING MJD 10/6/81
P.STONES 9/2/81
POTEAT 9/4/81
D.ERICKSON 10/5/81
D.W.HAAS 10/9/81
APPROVED MDAC
R. J.DEBELLIS 10/9/81
APPROVED UCC-ND
A.L.BOCH PER LTR
DATED 10/21/81
MCDONNELL DOUGLAS
ASTRONAUTICS COMPANY-ST. LOUIS
ST. LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION
EBT-P
CRYOGENIC SUBSYSTEMS
FACILITY INSTALLATION
E
76301
DWG NO.
70B373016
SCALE 1/96
WT
LB
SHEET 1


REDUCED 50%
APPROVED TITLE I
QTY
QTY
PART NO
NAME
STOCK
EBT-SCHEMATIC
LIQUID AND GASEOUS
SYSTEM, CRYO
76301
70B373017
WBS 2.1.7

NOTES:

1. THERE ARE 51 CRYOTORR 7 PUMPS REQD FOR DEVICE UPGRADE.

2. THIS DRAWING DOES NOT SHOW ALL DETAILS NECESSARY FOR A COMPLETE SYSTEM OPERATION. SPECIFICALLY DETAILS HAVE BEEN OMITTED FROM THE COMPRESSOR SKIDS AND COLD BOX. CERTAIN ELEMENTS OF THE SYSTEM, SUCH AS THE 80°K ADSORBERS HE-3 AND HE-9, MAY REQUIRE RELOCATION TO OPERATE PROPERLY.

LEGEND

- BLOWER
- CHECK VALVE
- HEAT EXCHANGER
- JOULE THOMPSON VALVE
- MANUAL VALVE
- EXTENDED STEM MANUAL VALVE
- EXTENDED STEM MANUAL VALVE WITH LIMIT SWITCH
- VACUUM JACKETED MANUAL VALVE
- PNEUMATIC OPERATED VALVE
- VACUUM JACKETED PNEUMATIC OPERATED VALVE
- VAC JACKETED PNEU OPERATED VALVE WITH LIMIT SWITCH
- THREE WAY VALVE
- RELIEF VALVE
- PRESSURE REGULATOR
- ORIFICE
- STRAINER
- LOCALLY MOUNTED
- PANEL MOUNTED
- BURST DISK
- CAP
- MECHANICAL JOINT
- BAYONET
- ELECTRICAL SWITCH
- ELECTRICAL LINE
- FILTER
- CRYOGENIC ACCESS PORT (BAYONET WITH CAP)

B	BLOWER
C	COMPRESSOR
CV	CHECK VALVE
F	FILTER
HE	HEAT EXCHANGER
I/C	INSTR. & CONTROL
M	MOTOR
O	ORIFICE
PI	PRESSURE INDICATOR
PR	PRESSURE REGULATOR
PT	PRESSURE TRANSDUCER
RV	RELIEF VALVE
TT	TEMP TRANSDUCER
V	VALVE

(A)

REDUCED 50%

APPROVED TITLE I

QTY	QTY	FSCM NO	PART NO	NAME	STOCK	MATL OR MATL CODE	DWG OR SPEC	NOTE	ZN

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-ST. LOUIS
ST. LOUIS, MISSOURI
MCDONNELL DOUGLAS CORPORATION

EBT-SCHEMATIC
LIQUID AND GASEOUS
SYSTEM, CRYO

E 76301 DWG NO. 708373017

WBS 2.1.7