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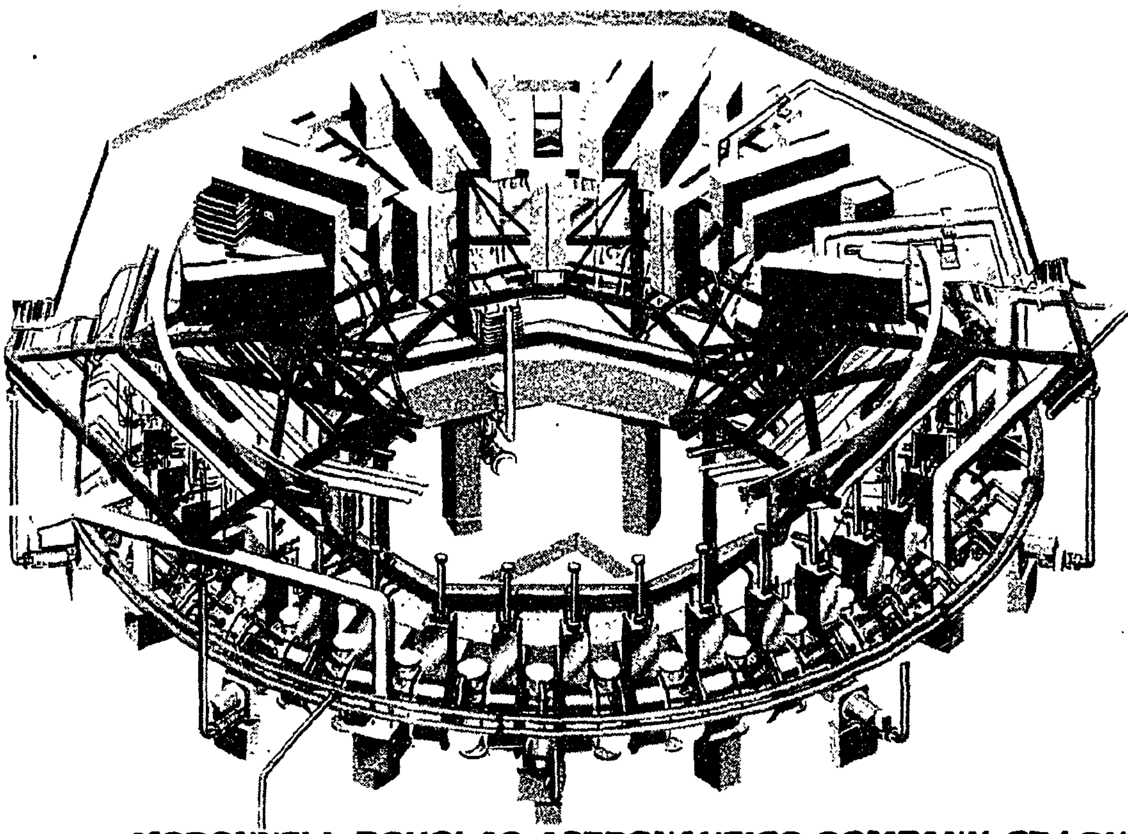
PHASE II — TITLE 1 REPORT.

Volume V. VACUUM-PUMPING SYSTEM



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PRELIMINARY DESIGN REPORT

VACUUM PUMPING SYSTEM

VOLUME V

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LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

AMU	Atomic Mass Units
C	Conductance
CF	Conflat Flange
CFM	Cubic Feet per Minute
CM	Centimeter
GHz	Giga Hertz
Hz	Hertz
K	Degrees Kelvin
KW	Kilowatt
ℓ	Liter
L	Length
LHe	Liquid Helium
LN_2	Liquid Nitrogen
L/S	Liters per Second
m	Milli, i.e., 10^{-3}
M	Mega, i.e., 10^{6}
M	Molecular Weight
MC	Mirror Coil
MLI	Multilayer Insulation
OD	Outer Diameter
ORNL	Oak Ridge National Laboratory
ORVIP	Oak Ridge Valley Industrial Park
P	Power from heating source

LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS (Continued)

R	Major Radius of Torus
R&D	Research and Development
RPM	Revolutions per Minute
S	Pumping Speed
SCCM	Standard Cubic Centimeters per Minute
SCCS	Standard Cubic Centimeters per Second
SS	Stainless Steel
T	Tesla or Temperature
TBD	To Be Determined
TL/S	Torr Liters per Second
torr	Pressure of 1 mm Mercury
UHV	Ultra High Vacuum
UCC-ND	Union Carbide Corporation - Nuclear Division
V	Voltage or Volume
Y-12	ORNL Fusion Facility Location at Oak Ridge

Greek

α	Transmission Probability
λ	Wavelength
λ	Mean Free Path

Subscripts

$\perp$	Perpendicular to flux line
$\parallel$	Parallel to flux line

1.0 INTRODUCTION AND SUMMARY

This report summarizes the TITLE I Preliminary Design of the EBT-P Vacuum Pumping System. The Vacuum Pumping System has been designed by the McDonnell Douglas Astronautics Co. - St. Louis (MDAC). It includes the necessary vacuum pumps and vacuum valves to evacuate the torus, the Mirror Coil Dewars (MC Dewars), and the Gyrotron Magnet Dewars. The pumping ducts, manifolds, and microwave protection system are also included. A summary of the function of each subsystem and a description of its principle components is provided below. The analyses performed during the system design are also identified.

Major contributions to the Vacuum Pumping System Title I design were made by the following persons:

C. F. Dillow	Vacuum System Manager
G. L. Adlon	Vacuum System Design
V. E. Stubblefield	Vacuum System Analysis and Design
R. J. Busam	Mechanical Design

The Vacuum Pumping System consists of five subsystems. They are

- Torus Roughing and Forepumping System
- Primary Torus Pumping System
- MC Dewar Vacuum System
- Gas Flow Monitoring and Control System
- Gyrotron Magnet Dewar Pumping System.

A summary of the function of each subsystem and a description of its principle components is provided below. Also, a summary of the analyses supporting the design of each subsystem is included.

The report is organized in the following manner.

- Purpose and Scope (Section 2) describes the primary objective and deliverables of the TITLE I Design. Definition of the TITLE II Design effort is also provided.
- Design Criteria (Section 3) establishes the design criteria upon which each of the above subsystem designs was based.
- Design Description (Section 4) describes the TITLE I design of each subsystem This includes the physical design, identification of components, subsystem performance, major interfaces and operating characteristics.
- Supporting Analyses (Section 5) includes the analyses and trade studies performed during TITLE I.
- Schedule (Section 6) shows the schedule for completing TITLE II and TITLE III engineering, fabrication, procurement, and installation.

1.1 TORUS ROUGHING AND FOREPUMPING SYSTEM

The Torus Roughing and Forepumping Systems perform the following functions:

- Rough pump the torus to the 10^{-3} torr range
- Foreline pumping of turbomolecular pumps
- Vacuum pumping during cleanup
- Leak detection pumping for gross leaks
- Maintain medium vacuum during standby periods.

A 37CFM two-stage mechanical pump and a 164CFM roots blower is used to evacuate the torus from atmospheric pressure to the 10^{-3} torr range with minimum chance of hydrocarbon contamination. Two roots blowers backed by two-stage mechanical pumps are used for foreline pumping of the five torus turbomolecular pumps. The roots blower and mechanical pumps used for roughing may also be used for plasma driven cleanup in high pressure regimes ($>10^{-4}$ torr) or to maintain a medium vacuum during standby periods. For locating gross leaks, a leak detector will sample the roots blower exhaust.

A protective microwave shield and absorbing duct will protect the rough pumping components, including valves, from the high power microwaves in the torus. Most of the pumps and valves are located outside the device enclosure for protection from the x-ray environment.

Analyses were performed to determine the size of all roughing lines and forelines. Valves were located to allow all functions to be performed and to allow a single roots pump/mechanical pump to provide foreline pumping of multiple turbomolecular pumps. Microwave, x-ray and magnetic field environments were considered in determining the location of all valves and pumps.

1.2 PRIMARY TORUS PUMPING SYSTEM

The Primary Torus Pumping System performs the following functions:

- Pump the torus to a base pressure of 2×10^{-7} torr.
- Remove impurities generated during plasma operation
- Maintain wall pressure between 1×10^{-6} and 1×10^{-4} torr during plasma operation.

Five 3500 liter/sec turbomolecular pumps are included in the Primary Torus Pumping System. These pumps will allow the base pressure of 2×10^{-7} torr to be achieved, after plasma driven cleanup. Each pump can be isolated from the torus during operation by a gate valve. This will allow isolation of a faulty pump. These pumps were selected because of their favorable cost, high pumping speeds, ease of operation, and capability to perform in the EBT-P environment. Turbomolecular pumps can be optimized for radiation resistance (10^7 rads) and are unaffected by the EBT-P stray magnetic fields (6 gauss). They are protected from the thermal effects of the microwave radiation by a microwave shield and an absorbing vacuum duct. Turbomolecular pumps accumulate no hydrogen, thus avoiding potential safety hazards and precluding regeneration requirements.

Pumping speeds of numerous duct and pump combinations and configurations were calculated using a probability analysis method. Microwave attenuation and thermal analyses were performed to design the microwave shield and for cooling the shield and absorbing vacuum duct. Several types of vacuum pumps were considered for use and the rationale for selecting turbomolecular pumps is described.

1.3 MC DEWAR PUMPING SYSTEM

The MC Dewar Pumping System performs the following functions:

- Rough pumping of the MC dewars
- Evacuate MC dewars to the 10^{-5} torr region prior to cooldown
- Pump small helium leaks in the dewars
- Provide foreline pumping for the turbomolecular pumps

The MC Dewar Pumping System is completely independent from the Torus Pumping System. It includes a 37CFM mechanical pump and a 164CFM roots blower for rough pumping the dewars. Four 2200 liter/sec turbomolecular pumps are attached to a manifold which serves all 36 dewars for high vacuum pumping. Appropriate valving is included so that the common dewar manifold can also be used to rough pump the dewars. Two roots blowers backed by two-stage mechanical pumps are used for foreline pumping of the turbopumps. As in the Torus Roughing System, the roughing pumps are located outside the device enclosure for protection from the EBT-P environment.

Numerous vacuum duct configurations were analyzed to determine the most cost effective method of achieving the design criteria. Various numbers, types, and sizes of pumps were considered and several duct and manifold geometries were analyzed.

1.4 GAS FLOW MONITORING AND CONTROL SYSTEM

The Gas Flow Monitoring and Control System performs the following functions:

- Supply hydrogen gas to the plasma and provide pressure control
- Measure and control the flow of up to 3 gases in the plasma

Control of the primary feed gas, hydrogen, is achieved with a piezoelectric valve in a pressure feedback and control loop with a torus ion gage. Its flow is measured with a mass flowmeter. The flows of the two minority species gases are ratiometrically controlled (compared to hydrogen).

1.5 GYROTRON MAGNET DEWAR PUMPING SYSTEM

The Gyrotron Magnet Dewar Pumping System is provided to maintain the vacuum space in the magnet dewar. This will be a maintenance task and will not require dedicated vacuum pumping. A mobile turbomolecular pump cart with a mechanical roughing pump will suffice.

Analyses of the EBT-P environment indicate that this pump should not be used for extended periods inside the device enclosure during plasma operation.

2.0 PURPOSE AND SCOPE

The purpose of this report is to describe the Title I design effort for the EBT-P Vacuum Pumping System. The design and analyses presented in this document evolved from ORNL directed changes subsequent to the Vacuum Pumping System Preliminary Design Review (PDR) held at ORNL in Oak Ridge on November 10, 1981.

Four major efforts were accomplished during Title I and are described in this report.

- Establishment of the Design Criteria, upon which the Title I design is based. (Section 3)
- A Title I design was completed and the details are presented. (Section 4).
- Title I preliminary design drawings are presented. (Section 4) A list of Title I drawings is presented in Figure 2-1. The complete package of Title I drawings is included as an appendix to the volume.
- Trade studies and analyses were performed in support of the Title I design. (Section 5). A list of the Title I trade studies and analyses is presented in Figure 2-2.

The design concepts presented herein will achieve the design criteria formulated during Title I. These design criteria were reviewed with ORNL on 10 and 11 Sept, 1981, and susbsequently approved with some changes. All design criteria changes resulting from the September meeting are reflected in this report.

Several analyses and trade studies (Figure 2-2) were required to verify the capability of the Title I design to achieve the design criteria. These were performed in sufficient detail to select a concept or to verify performance. In many cases further analysis will be required to substantiate the Title II detailed design. These analyses will be Title II efforts.

The depth of the Title I design is sufficient to allow a detailed cost and schedule to be prepared for completing Phase II. The preliminary design drawings (Figure 2-1) establish envelopes and interfaces and depict concepts with sufficient accuracy to allow equipment lists to be prepared so that manhour and material estimates for fabricated items such as ducts, manifolds and microwave shields can be developed.

Presented in Figures 2-3 and 2-4 is a description of the major Title I and Title II design tasks. During Title I, trade studies were completed and concepts selected, with enough analysis performed to lend credibility to the Title I design. In Title II the emphasis will shift to detailed design with analyses performed to predict performance and verify that all design criteria are accomplished. A list of the Title II drawings is presented in Figure 2-5.

Throughout Title I and Title II critical interfaces with the I & C System will be maintained. The capability and performance of the Vacuum Pumping System is critically dependent on vacuum instrumentation (I & C System). This dependance is recognized and mandates close coordination. The details of the I & C vacuum instrumentation is included in Volume VI of this report.

Figure 2-1 Title I Drawings

Drawing No.	Title
70B377006	Microwave Shield Envelope/Installation
70B377009	Installation - Toroidal Vessel Mirror Coil Vacuum System
70B377010	Vacuum Pumping System Toroidal Vessel
70B377011	Vacuum Pumping System Magnet
70B377012	Vacuum System Schematic Mirror Coil
70B377013	Vacuum System Schematic Toroidal Vessel

Figure 2-2 Title I Analyses and Trade Studies

- High Vacuum Pumping Speeds
  A description of the probability method employed and the results obtained.
- Rough Pumping Speeds
  A description of the analytical method and the results.
- Microwave Shield
  A description of how microwave attenuation and molecular conductance are calculated. The thermal performance is described.
- EBT-P Environment
  A description of the x-ray, microwave and magnetic field environments, as they pertain to the Vacuum Pumping System.
- Vacuum Pumps
  A discussion of the types of high vacuum pumps considered for use on EBT-P and a summary of the reason for selecting turbomolecular pumps.
- Cryopump Heat Loads Analysis
  A description of the heat loads analysis used to predict the performance of cryopumps on the torus.
- Gas Loads Analysis
  A description of the analyses to determine the gas loads in the torus and in the MC Dewar.

Figure 2-3 Title I Preliminary Design Tasks of The Vacuum Pumping System

- Establish Design Criteria for the Vacuum Pumping Systems
- Determine Number, Sizes and Types of Vacuum Pumps for Each System
- Identify Valve Locations to Perform All Necessary Functions
- Analyze Environment of Each Component and Establish Envelopes
- Determine Preliminary Duct Sizes to Establish Envelopes
- Perform Prelimary Heat Loads Analysis to Establish Feasibility of Using Liquid Helium Cryopumps and to Determine Cryogenic Requirements
- Establish Preliminary Cooling Configurations for the Microwave Shields and Absorbing Ducts
- Analyze a Manifolded MC Dewar Pumping System
- Interface With I & C System to Ensure All Vacuum System Operations Can Be Performed
- Prepare Title I Design Drawings and Equipment Lists
- Prepare Title I Cost and Schedule Estimate
- Perform A Detailed Cost Comparison of Cryogenic and Turbomolecular Pumped Systems.

Figure 2-4 Title II Final Design Tasks of the Vacuum Pumping System

- Finalize Vacuum Pump Selection; Number, Types, and Speeds
- Analyze Detailed Materials Lists For Vacuum Components and Define Modifications Required.
- Determine Effects of Turbomolecular Pumps on EBT-P Magnetic Field Uniformity.
- Determine Effects of Magnetic Fields on Turbopumps During Off-Normal Conditions (Magnet Quench)
- Finalize Vacuum Duct Sizes
- Design Manifolded Forelines For Turbomolecular Pumps
- Perform Detailed Analyses of Heat Load on Microwave Shield and Absorbing Duct. Design Thermal Protection For Each.
- Define Manufacturing Methods, eg; Welding Specs, Cleaning Procedures, Surface Finishes, and Attachment of Microwave Absorbing Material to Duct.
- Prepare Procurement Specifications Defining Valves and Pumps With Required Modifications
- Interface With the I & C System to Ensure All Vacuum System Operations Can Be Performed.
- Prepare Title II Detailed Design Drawings.

Figure 2-5 Title II Drawings

Title

- VACUUM PUMPING SYSTEM - TOROIDAL VESSEL
  - SCHEMATIC - VACUUM SYSTEM, TORIDAL VESSEL
  - TURBOPUMP INSTALLATION – TOROIDAL VESSEL
    - SUPPORT STRUCTURE ASSY
      - WELD ASSY
      - FITTINGS DETAIL
    - BELLOWS ASSY
    - MICROWAVE SHIELD ASSY
      - FLANGE, DETAILS
      - SHIELD DETAILS
      - COOLING TUBES
    - DUCT ASSY ABSORBING
      - DUCT DETAIL
      - COOLING TUBES
    - ION GAUGE INSTALL
      - MICROWAVE SHIELD
  - ROUGHING LINE/TURBOPUMP FORELINE ASSY'S
    - DUCT ASSY ABSORBING
      - DUCT DETAIL
      - COOLING TUBES
    - PIPE ASSY
    - SUPPORT STRUCTURE ASSY
      - FITTINGS, DETAIL
    - MICROWAVE SHIELD ASSY

Figure 2-5 Title II Drawings (Continued)

Title

- BELLOWS ASSY

- VACUUM PUMPING SYSTEM - MIRROR COIL
  - SCHEMATIC, VACUUM SYSTEM - MIRROR COIL
  - TURBOPUMP INSTALLATION - MIRROR COIL
    - STRUCTURAL SUPPORT ASSY
    - FITTINGS, DETAIL

  - BELLOWS ASSY
  - VACUUM MANIFOLD ASSY
    - WELD ASSY

  - SUPPORT, STRUCTURAL
    - FITTING, DETAIL

- ROUGHING LINE/TURBOPUMP FORELINE ASSY
  - PIPE ASSY
  - SUPPORT STRUCTURE ASSY
  - SUPPORT DETAILS

- MECHANICAL PUMP/BLOWER INST - ROUGHING/FORELINE
  - STRUCTURAL SUPPORT ASSY
    - WELD ASSY
    - FITTING, DETAILS
  - N_2 DILUTION SYSTEM ASSY
  - LN_2 TRAP ASSY (2)
    - WELD ASSYS (2)

  - BELLOWS ASSY

Figure 2-5 Title II Drawings (Continued)

Title

- GYROTRON DEWAR VACUUM INST
  - TURBOMOLECULAR PUMP ASSY - PORTABLE
    - DUCT ASSY, FLEXIBLE
- COOLING SYSTEM, INSTALL TURBOPUMPS - TOROIDAL VESSEL
  - PUMP/COOLER STRUCTURAL ASSY
  - LINE ASSY
  - SUPPORT ASSY
- X-RAY SHIELDS INSTALLATION
  - SHIELDS DETAIL
  - SUPPORT ASSY, STRUCTURAL
- EXHAUST SYSTEM INSTALLATION
  - LINE ASSY
  - SUPPORT ASSY
- GN_2 REPRESSURIZATION SYSTEM INST
  - LINE ASSY
  - SUPPORT ASSY
- GAS FLOW & CONTROL SYS INST (H_2, He, N_2)
  - GAS MANIFOLD ASSY
  - GAS SUPPLY INTERCONNECTING LINES
  - SUPPORT STRUCTURE ASSY
  - SHIELD ASSY, PIEZO VALVE
  - CONTROLLER, GAS SUPPLY VALVE
  - INSTRUMENTATION

3.0 DESIGN CRITERIA

The design criteria for the Vacuum Pumping System are discussed in this section. First, the general design criteria applicable to each of the subsystems are described, then the specific design criteria for each are discussed in detail. A general description of the operating scenarios and capabilities are presented and a detailed description is presented in Section 4.

Design criteria have been derived from various sources including:

- ORNL Reference Design ORNL/TM7191
- EBT-P Request For Proposal
- EBT-P Proposal MDC Report E2229
- Co-ordination with ORNL during Title I (Including meeting of 10 and 11, Sept. 1981)
- MDAC PDC 8 Addressing Design Criteria changes.
- MDAC PDC 12 Regarding Change To Turbomolecular Pumps and Associated Design Criteria Changes

3.1 GENERAL DESIGN CRITERIA

General design criteria for the Vacuum Pumping System are presented below. The criteria discussed are:

- Compatibility with the EBT-P Environment
- Component Selection
- Safety
- Reliability and Maintainability

3.1.1 Environment Compatibility - As discussed in Section 5, the EBT-P environment is quite severe and many components in the Vacuum Pumping System are susceptible to damage. Components in the torus pumping system are protected from the high power ECRH plasma heating by a microwave attenuating screen and absorbing duct as described in Section 5.3.

All components are susceptible to the x-ray environment. The severity of this environment is described in Section 5.4.1. Vacuum valves and pumps, because of their complexity, are fabricated of a variety of materials, many of which are non-metallics. It is these non-metallic materials which are damaged by irradiation. During discussion with vendors, all materials have been reviewed and their susceptibility to x-ray damage evaluated. All roughing pumps and a few roughing system valves are located outside the device enclosure for x-ray protection. They operate in higher flow regimes (higher pressures) and do not experience significantly greater conductance losses.

EBT-P is a magnetic fusion device employing 36 superconducting magnets which produce a maximum field of 4.8 tesla at the center of the mirror coil throat. All vacuum system components must be capable of operating in the stray field produced by these magnets. Furthermore, the presence of the vacuum system components must not introduce errors in the magnetic fields in the plasma region. In reviewing various components, such as valves and pumps, all magnetic materials were noted. Magnetic materials will be present in the Vacuum System components only where necessary. Their effects on the field will be the subject of further analysis.

The ultra high vacuum (UHV) requirement for EBT-P requires a clean environment. All fabricated and procurred parts will be chemically cleaned by recognized procedures and appropriate care will be exercised during installation to ensure a contaminant free environment. The pumping systems are designed to prevent contamination during normal operation and to minimize contamination in off-normal or accident scenarios.

3.1.2 Component Selection - The vacuum pumping system for EBT-P is viewed as a high reliability, low risk system. It is important therefore to select, whenever possible, off-the-shelf hardware whose performance characteristics are well known and documented. A further advantage of such hardware is that prices and delivery times are well established and are not likely to experience large changes.

Many of the materials in vacuum pumps and valves are susceptible to the EBT-P environment. To minimize the adverse effects, off-the-shelf equipment will be procurred with specified material changes. These modifications will of course be coordinated with the vendor to ensure that component reliability and performance are not affected.

3.1.3 Safety - The vacuum pumping system will be designed in accordance with the ORNL approved safety plan. The primary safety concern in the pumping system is associated with hydrogen accumulation from the gas supply system. Valve sequencing and interlocks will be designed to avoid high pressure accumulation of hydrogen. Consideration will also be given to the vacuum failure modes and components will be selected so that a "fail-safe" design philosophy can be employed.

3.1.4 Reliability and Maintainability - The EBT-P Vacuum Pumping System will be designed for maximum reliability and the maintainability of each component will be assessed to maximize machine availability. Reliability will depend on the effects of the EBT-P environment on vacuum components and will be difficult to establish. Data obtained during the elastomer irradiation tests (WBS 6.2.3.2) will provide information necessary to assess the reliability of the components and to establish a maintenance plan to maximize reliability. This maintenance plan must not affect the device duty cycle.

3.2 SPECIFIC DESIGN CRITERIA

The specific design criteria of the Vacuum Pumping System are described below. A brief discussion of the operating capabilities is also included. The individual subsystems are:

- Torus Roughing and Forepumping Systems
- Primary Torus Pumping System
- MC Dewar Pumping System
- Gas Flow Monitoring and Control System
- Gyrotron Magnet Dewar Pumping System

3.2.1 Torus Roughing and Forepumping Systems - The Torus Roughing System is designed to evacuate the torus from atmospheric pressure to the 10^{-3} region. The Forepumping System is used for foreline pumping the high vacuum turbomolecular pumps and for maintenance functions such as leak detection and plasma discharge cleaning. The specific design criteria for the Sytems are:

- A roughing vacuum system shall be provided to initially evacuate the torus from 1 atm to the 10^{-3} torr range.

- The systems shall be selected to minimize the probability of hydrocarbon contamination in the torus.
- Each pumping unit shall be capable of isolation for repair or replacement.

To accomplish these criteria MDAC has proposed a roughing system composed of a roots blower/mechanical pump package for torus rough pumping and two such packages for foreline pumping. Roughing to the 10^{-3} torr range is achieved with the roots blower backed by the two-stage mechanical pump. The blower selected will be of the integral-by-pass variety allowing operation to atmospheric pressure, thus minimizing the probability of contamination. This blower may also be employed during leak detection and system cleanup or during standby periods where ultra high vacuum is not required. Two blower/mechanical pump packages will be used for foreline pumping the five torus turbomolecular pumps. Appropriate valving is included so that each pumping unit can be isolated for repair or replacement.

3.2.2 Primary Torus Pumping System - The Primary Torus Pumping System is designed for high vacuum pumping of the torus prior to initiation of a plasma and for pressure control and impurity removal during plasma operation. The specific design criteria for the Primary Torus Pumping System are:

- A high vacuum system shall be provided to remove impurities released by surface outgassing during operation and to provide sufficient hydrogen pumping speed for pressure control.
- The design goal for the high vacuum system shall be an ultimate pressure of 2×10^{-7} torr in the toroidal vacuum vessel. Pumpdown time from ambient pressure shall be less than 16 hours. This pumpdown time is for a vessel that has undergone plasma wall conditioning and is then briefly exposed to one atmosphere of dry nitrogen. The design goal base pressure (2×10^{-7} torr) shall be provided for start of normal plasma operation within 16 hours of the last shutdown.
- The vacuum system and its associated hydrogen injection system shall be capable of 16 hours of continuous plasma operation in a 24-hour period at a variable wall pressure between 10^{-6} and 5×10^{-5} torr or 8 hours at 1×10^{-4} torr. The wall pressure within each cavity shall not differ by more than 10% from the mean for all cavities, within the anticipated range of plasma parameters.

- Microwave power isolation shall be provided to prevent long-term damage to vacuum system components resulting from exposure to microwave power.
- Single pumps shall be capable of isolation without requiring shutdown of plasma operation.
- Stray magnetic fields generated by electrical components or magnetic materials in the vacuum system shall be included in evaluating the magnetic geometry error field in the plasma region.
- Diffusion pumps or Zr-Al gettering pumps shall not be used.
- The pumping system should provide 10,000 liter/sec hydrogen pumping speed and helium pumping capability.
- Provide for a design upgrade capability in the pumping system requiring five additional turbomolecular pumps.

A turbomolecular pumped system has been designed to achieve these design criteria. A microwave shield and absorbing vacuum duct will protect the vacuum pumps and valves from the microwave energy. Each vacuum pump may be isolated, via valves, for maintenance or replacement. Turbomolecular pumps will not be affected by the steady-state magnetic field. The turbomolecular pumps have magnetic steel parts which may introduce error fields. The magnitude of these errors will be determined during TITLE II design. Radiation resistant pumps will be employed to allow operation in the EBT-P x-ray environment.

3.2.3 MC Dewar Pumping System - The MC Dewar Pumping System is used for evacuation of the MC Dewar vacuum space from atmospheric pressure to the 10^{-5} torr region. It is also used to provide continuous helium pumping in the event that small leaks develop in the internal dewars. The specific design criteria for the MC Dewar Pumping system are:

- A separate vacuum system (roughing and high vacuum) distinct from the Torus Vacuum System shall be provided for the mirror coil dewars.
- Base pressure in the 10^{-5} torr region prior to cooldown.
- 50 liter/sec nitrogen pumping speed at the “worst-case” dewar.
- 1 liter/sec helium pumping speed at the “worst-case” dewar.

- Individually or simultaneously pumping all 36 dewars.
- Pumping with magnets ON.

A turbomolecular pumped system serving the 36 MC Dewars via an UHV manifold and a dedicated roots blower and mechanical roughing pump will achieve these criteria. The necessary valves are provided to allow individual or simultaneous pumping of the MC Dewars. Foreline pumping is provided by roots blowers and mechanical roughing pumps which are separate from the roughing system.

3.2.4 Gas Flow Monitoring and Control System - The Gas Flow Monitoring and Control System provides the hydrogen bleed-in gas to allow pressure control during operation and can provide mixtures with two additional minority species. Flows of each of the gases are measured and controlled. The specific design criteria of the Gas Flow Monitoring and Control System are:

- A system shall be provided to inject H_2 gas continuously or intermittently as required for pressure control during start-up and steady-state plasma operations.
- The impurity level shall be less than 1.0 ppm (total oxygen).
- The hydrogen injection system design shall be integrated with the vacuum system design such that all vacuum system criteria are met.
- The system shall be capable of measuring and controlling the flows of up to three gases into the torus with feedback pressure control.
- The hydrogen injection system shall be compatible with an upgraded Torus High Vacuum System which includes ten turbomolecular pumps.

A system has been designed to meet these criteria. A piezoelectric valve with feedback control to an ion gage controls hydrogen flows. Two minority species flows are measured and controlled in a ratiometric mode.

3.2.5 Gyrotron Magnet Dewar Pumping System - The Gyrotron Magnet Dewar Pumping System is designed to provide rough pumping and high vacuum pumping of the gyrotron dewars. Vacuum pumping will be required only on an intermittant basis. The specific design criteria for this system are:

- Capability to pump the dewar vacuum space to 10^{-4} torr
- Capability to pump helium

A mobile turbomolecular pumping cart will achieve these criteria. It will be capable of pumping a single dewar and isolating it via a high vacuum valve.

4.0 DESIGN DESCRIPTION

4.1 INFLUENCES AND CONSIDERATIONS

As briefly discussed in Section 3.0, and is treated in more depth in Section 5.0, the assessment of x-ray and microwave conditions indicated that the EBT-P environment was not compatible with either the baseline refrigerator-cooled cryopumps or with liquid helium cryopumps.

Considerable discussion was held with the manufacturers of two-stage helium refrigerators. These refrigerators operate on the Gifford-McMahon design principle and are used in cryopumps. The potential for replacing the graphite impregnated teflon piston seals in the two-stage compressor, with a seal material that is more tolerant of x-ray exposure was assessed. Figure 4-1 shows a disassembled two stage refrigerator and the seals.

None of the companies, which included CTI-Cryogenics (Helix Technology Corporation), Balzers, Air Products, and Leybold-Heraeus, were aware of a potential substitute which would seal satisfactorily at 10 to 12K, exhibit minimal wear, and have greater tolerance for x-rays than teflon, without commiting to a research and development program. EBT-P program time constraints and budgetary considerations were not amenable to the possibility of a no-resolution conclusion evolving from such a study.

Studies at ORNL indicated that gaseous helium cryopumps were quite sensitive to the microwave environment. A pump on EBT-S repeatedly exhibited thermal instability, though it was protected by a microwave screen. Also, during the Title I design, the upper operational pressure limit was increased from 1×10^{-5} torr to 1×10^{-4} torr. The additional hydrogen exceeds the capacity of gaseous helium cryopumps. These considerations dictated that alternate high vacuum pumps be considered.

Environmental difficulties were also encountered with turbomolecular pumps, however the problems are potentially resolvable by x-ray hardening the pump. Turbomolecular pumps are used on the torus and on the high vacuum manifold for the MC dewars. The magnetic field in both locations is low enough to allow unshielded installation. The x-ray environment, however, dictates that all turbomolecular pumps, except that on the gyrotrons, be x-

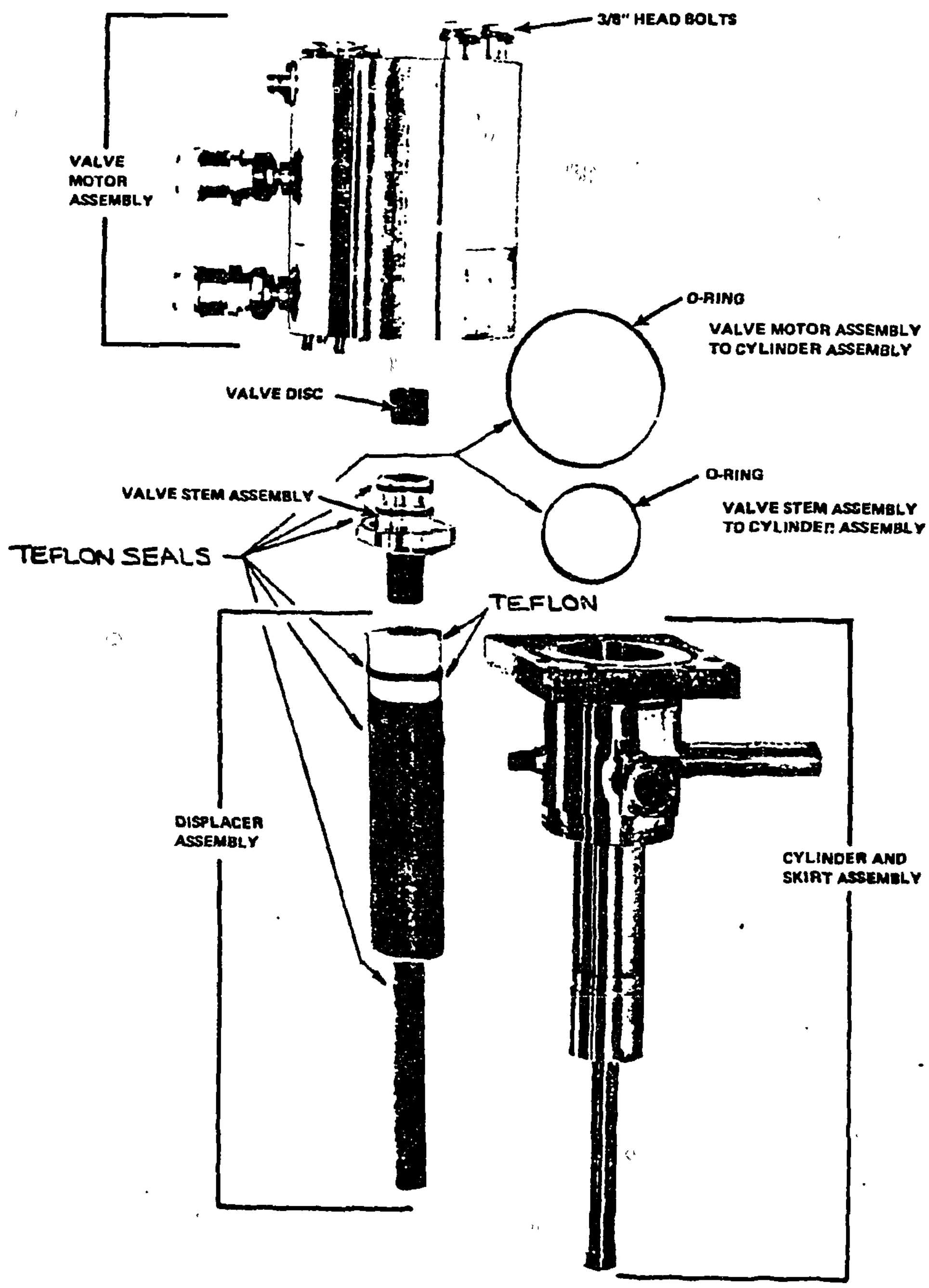


FIGURE 4·1 REFRIGERATOR COOLED CRYOPUMP TWO-STAGE COMPRESSOR ray hardened. The portable pumping station on the gyrotrons will be removed from the device enclosure during plasma operation. A spare pump will be available as a substitute during equipment maintenance or refurbishment operations. It too will be x-ray hardened.

X-ray hardening of a turbomolecular pump to increase component tolerance above the estimated 10^5 rad level, involves using polyimide wire insulation, Viton and metal vacuum seals, and a metal oil reservoir. Leybold-Heraeus has performed such modifications on their turbomolecular pump model TMP3500 for use on TFTR. It was stated by B.D. Abel of Grumman Aerospace Corp, who performed contracted vacuum system design work on the Princeton TFTR, that the nonmetallic materials in the modified pumps increased the radiation dose tolerance to 10^7 rads.

Leybold-Heraeus states that the magnetic fields at the location of the turbomolecular pumps must not exceed 30 gauss in a radial direction or 150 gauss in an axial direction. Balzers requirements are similar for their turbomolecular pumps. As discussed in Section 5.4.3 the EBT-P fields at the pumps will be below these values.

The pumping concepts for the torus and MC Dewars employ turbomolecular pumps. Five 3500 liter/sec turbopumps will be employed on the torus with provisions included for five additional pumps. Four 2200 liter/sec pumps will be used on the high vacuum manifold serving the MC Dewars.

Metal sealed valves were considered for the torus system, but were rejected primarily because of cost considerations. Another factor is the requirement for continued increasing of pneumatic sealing pressure, as the seal in the valve is repeatedly cycled. This requires cycling data to be recorded for each valve and different sealing pressures (due to different numbers of cycles) to be applied to each valve. Aluminum body elastomer sealed valves will be used in all vacuum systems discussed in Section 4.0. There is a test program planned in WBS 6.2.3.2 to evaluate potential problems of small elastomer sealed gate valves in an x-ray environment.

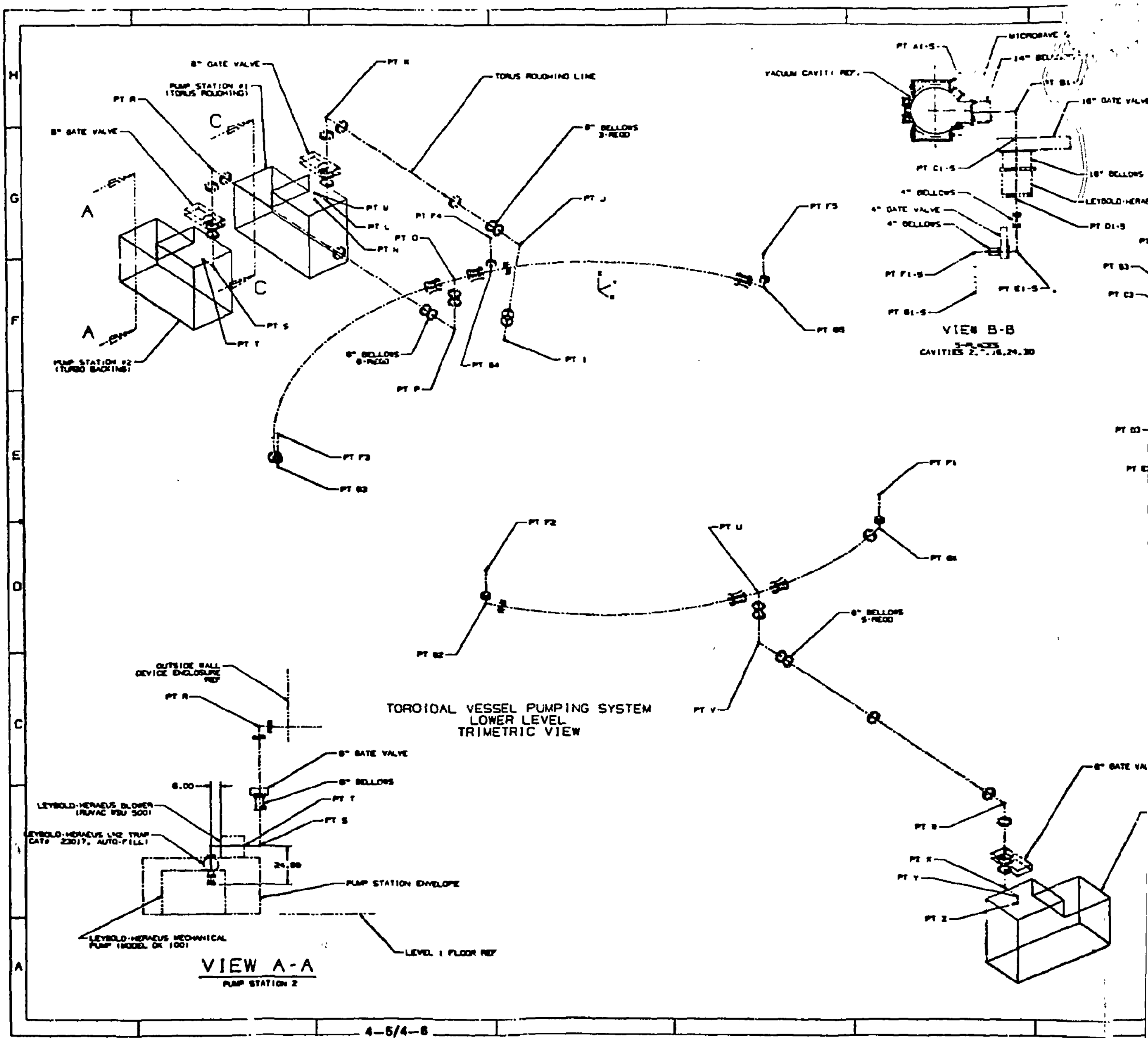
4.2 TORUS ROUGHING AND FOREPUMPING SYSTEM

The roughing system for the EBT-P torus described in this section includes torus roughing and turbomolecular forepumping.

4.2.1 Torus Roughing and Forepumping System Requirements - The MDAC-St. Louis Torus Roughing and Forepumping System design reflects the basic ORNL Reference Design needs. The systems will have the capability for fulfilling each of the following torus system basic vacuum objectives:

- Reduce torus pressure from atmospheric to the 10^{-3} torr range while minimizing the possibility of hydrocarbon contamination reaching the torus.
- The torus forepumping system is used for foreline pumping of the torus high vacuum turbomolecular pumps. The roots blower backing will ensure high hydrogen pumping speeds for the turbomolecular pumps to below 10^{-6} torr.
- The roughing system can be used to pump torus contaminants during cleanup operations.
- The forepumping system will be utilized for leak detection by attaching a helium mass spectrometer leak detector either to the foreline of the torus turbomolecular pump for high sensitivity leak detection or to the outlet of the roots blower for gross leak detection.
- The roughing system can also be used for leak detection purposes.

4.2.2 Torus Roughing and Forepumping Systems Description - The Torus Roughing and Forepumping Systems, Figure 4-2, are comprised of the components shown in Table 4-1. To avoid damage to the roughing system pumps by the excessive x-ray levels in the upgraded configuration, the mechanical pumps and roots blowers have been located outside the bioshield wall on the first level. This eliminates the need for wiring and seal modifications to the pumps which would otherwise experience deterioration due to x-ray exposure. Additionally, this location permits pump maintenance or possible servicing during device operation, should the need arise. As can be seen in Figure 4-2, the vacuum roughing lines pass directly through the wall. Lead shielding will be used in the inside and outside of the device enclosure to minimize a x-ray propagation. The x-ray dose at the pump locations outside the bioshield is calculated to be less than ten rads during the de-


TOROIDAL VESSEL PUMPING SYSTEM
LOWER LEVEL
TRIMETRIC VIEW
VIEW A-A
PUMP STATION 2
VIEW B-B
TORUS ROUGHING LINE
8" GATE VALVE
8" BELLOWS
LEVEL 1 FLOOR REF
PUMP STATION ENVELOPE
4–5/4–6

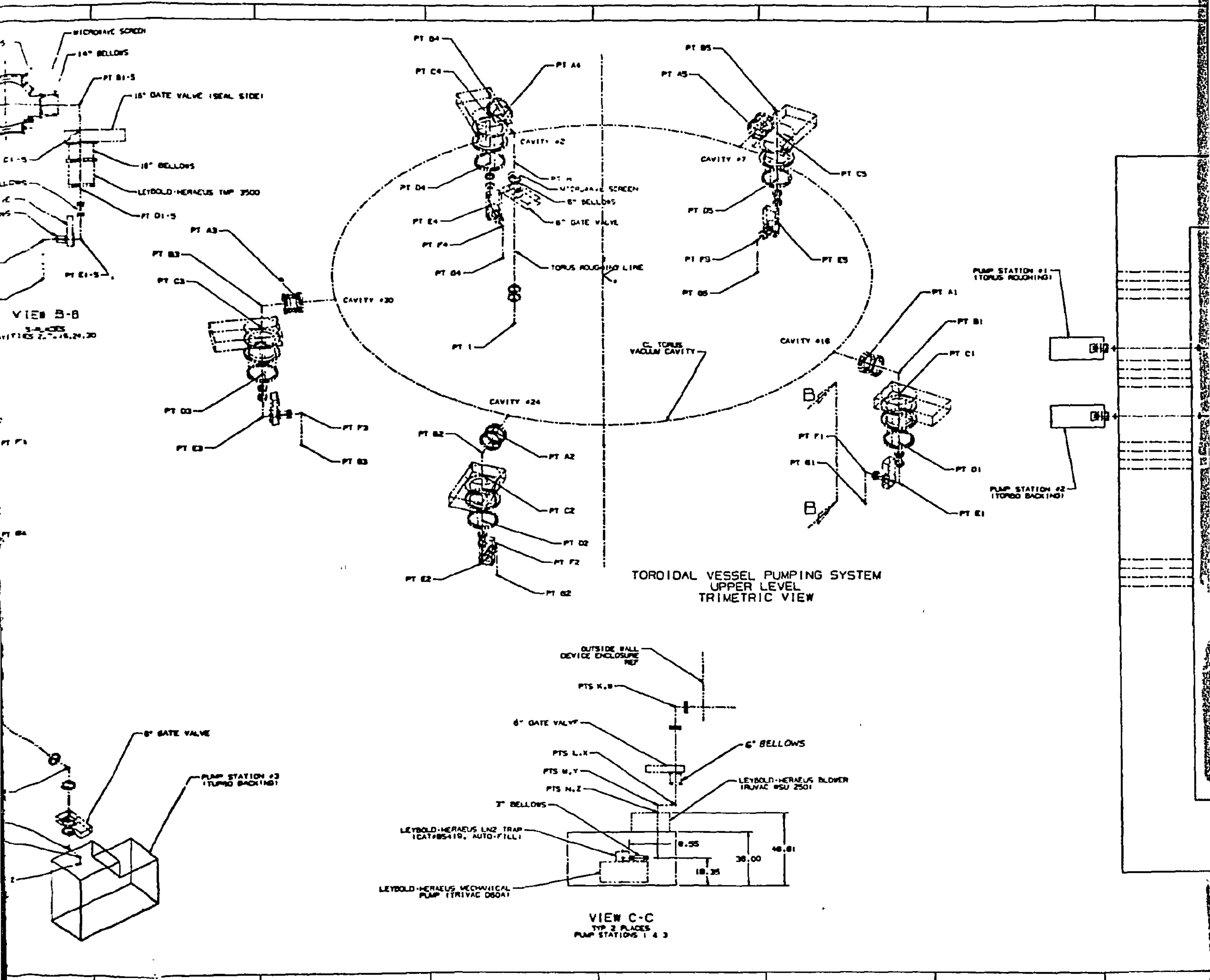
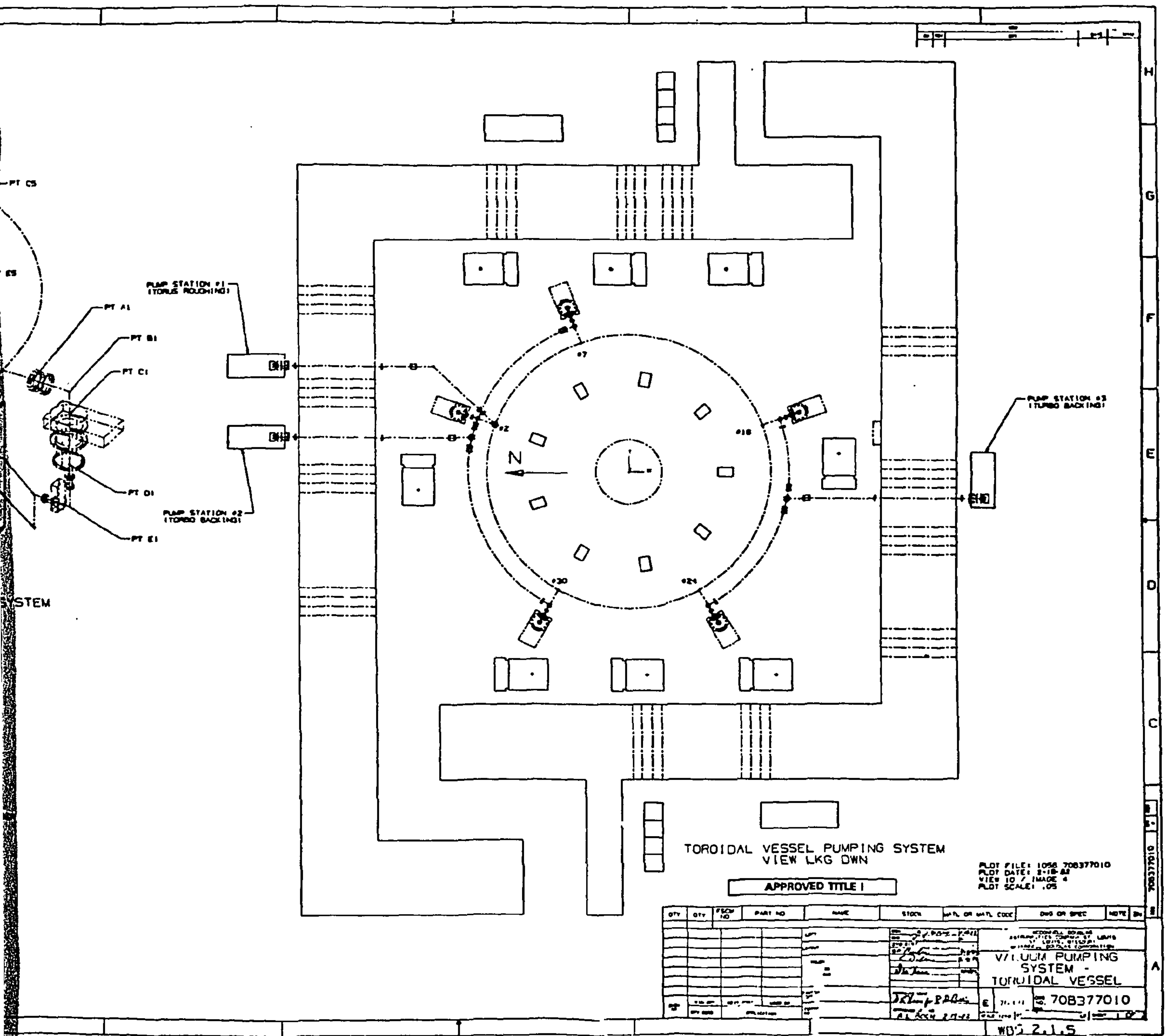

TOROIDAL VESSEL PUMPING SYSTEM
UPPER LEVEL
TRIMETRIC VIEW
VIEW C-C
VIEW B-B
CAVITY #2
CAVITY #7
CAVITY #30
CAVITY #24
PT A4
PT A5
PT C5
PT E5
PT A1
PT B1
PT C1
PT D1
PT E1
PT A2
PT C2
PT D2
PT F2
PT E2
TORUS ROUGHING LINE
6" GATE VALVE
6" BELLOWS
6" GATE VALVE
LEYBOLD-HERAEUS TMP 3500
10" BELLOWS
PUMP STATION #3 (TURBO BACKING)
PUMP STATION #2 (TURBO BACKING)
6" BELLOWS
3" BELLOWS
LEYBOLD-HERAEUS MECHANICAL PUMP (TRIVAC D60A)
VIEW C-C
TYP 2 PLACES
PUMP STATIONS 1 & 3

FIG. 4-2



PT C5
PUMP STATION #1 (TORUS ROUGHING)
PT A1
PT B1
PT C1
PT D1
PT E1
PUMP STATION #2 (TURBO BACKING)
PUMP STATION #3 (TURBO BACKING)
SYSTEM
N
#7
#2
#18
#30
#24
TOROIDAL VESSEL PUMPING SYSTEM
VIEW LKG DWN
APPROVED TITLE I
PLOT FILE: 1056 708377010
VIEW 10 / IMAGE 4
PLOT SCALE: .05
VACUUM PUMPING SYSTEM - TOROIDAL VESSEL
708377010
WBS 2.1.5

FIG. 4-2

vice lifetime. Roughing pumps, such as the roots blower and rotary vane, are designed for use in the viscous through intermediate flow regime. Thus connecting lines can be longer and effectively not cause a loss of pumping speed at the point of use.

The roughing and forepumping systems consist primarily of three roots blowers and three two stage mechanical pumps. A 164 CFM blower backed by a 37 CFM mechanical pump is used for torus roughing. An identical blower and mechanical pump are used for foreline pumping two of the torus turbomolecular pumps. A 331 CFM roots blower with a 65 CFM mechanical pump are used to foreline pump the remaining three torus turbomolecular pumps. During Title II additional device enclosure penetrations will be defined and foreline routing will be planned to allow a future upgrade to ten turbomolecular pumps on the torus.

As seen in Figure 4-2 pump station #1 will be employed for torus roughing. It includes a 164 CFM blower and a 37 CFM mechanical pump. A six-inch diameter line will extend down from cavity #2 and penetrate the floor of the upper level. There, it will continue along the ceiling of the lower level and penetrate the north wall of the device enclosure where it will drop down to the blower and mechanical pump located on the floor of the lower level. A microwave shield is located at the roughing penetration to cavity #2 to prevent the propagation of microwaves to the roughing system components. A valve is located in the roughing line immediately below cavity #2 and another is located at the inlet to the roots blower. A liquid nitrogen cold trap will be located between the roots blower and mechanical pump.

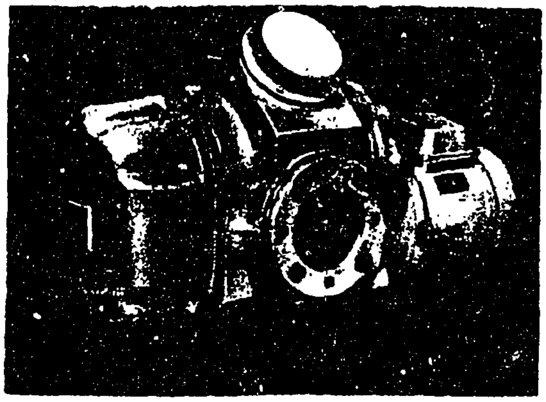
Pump station #3 also employs a 164 CFM blower and a 37 CFM mechanical pump. It serves as the foreline pump for the turbomolecular pumps located on cavity #16 and cavity #24. The turbomolecular pump forelines are attached via four-inch valves and lines to a six-inch manifold which is located at the ceiling of the lower level. A six-inch line, connected to this manifold, passes through the south wall of the device enclosure and drops down to the pumps located on the floor. A valve and flexible bellows are used at this interface. Again, a liquid nitrogen trap is located between the roots blower and the mechanical pump.

Pump station #2 is located adjacent to station #1. It is used to foreline pump three torus turbomolecular pumps on cavities #2, #7 and #30. This pump station includes a 331 CFM roots blower backed by a 65 CFM mechanical pump. Four-inch valves and lines attach the foreline pump port of each turbopump to a common six-inch manifold. This manifold is connected via a six-inch line to the pump station outside the device enclosure on the north wall. The six-inch line is routed along the ceiling of the lower level and attached to a six-inch bellows and valve on the pumping station.

The roots blowers tentatively selected for use are the Leybold-Heraeus WSU-250 and WSU-500. Both pumps are of the integral by-pass variety with sealed drive motors. A typical WSU pump is shown in Figure 4-3. Also shown is a schematic description of the integral by-pass concept. This feature allows a roots blower to operate from atmospheric pressure to blank-off. Operation at high pressure is very desirable because the blower can be used at any time during rough pumping without concern for inlet pressure.

High pressure operation is accomplished in the following manner. Gas is drawn into the inlet by the rotating lobes and compressed to the region of the exhaust. When the exhaust gas flow exceeds the capacity capability of the mechanical backing pump, the excess gas is recycled via a relief-type valve to the inlet. In this manner, the mechanical pump is forced to operate at its maximum capability throughout the rough pumping region, resulting in optimum pump down times. Shown in Figure 4-4 is a comparison of effective pumping speeds of a common roots blower with a mechanical pump and of an integral by-pass blower and mechanical pump with the same rated pumping speeds. The advantage of an integral-bypass pump is evident from the 10 torr cut-on pressure of the common blower, up to atmospheric pressure.

Both blowers also feature a sealed drive motor to eliminate the need for atmospheric shaft seals. These shaft seals, operating at high speeds and under high load, normally limit the ultimate pressure capability of roots blowers. The sealed motor, however, resides inside the vacuum enclosure and requires no shaft seal. Such pumps routinely operate at one to two decades lower pressure than those with shaft seals. The need to pump hydrogen, for which turbomolecular pumps have an inherently low compression ratio, dictates the need for the low foreline pressures offered by the sealed motor roots blowers.



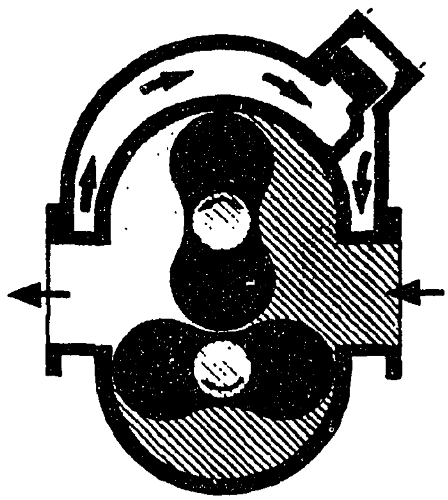


FIGURE 4-3 LEYBOLD-HERAEUS WSU MODEL BLOWER WITH INTEGRAL BY-PASS

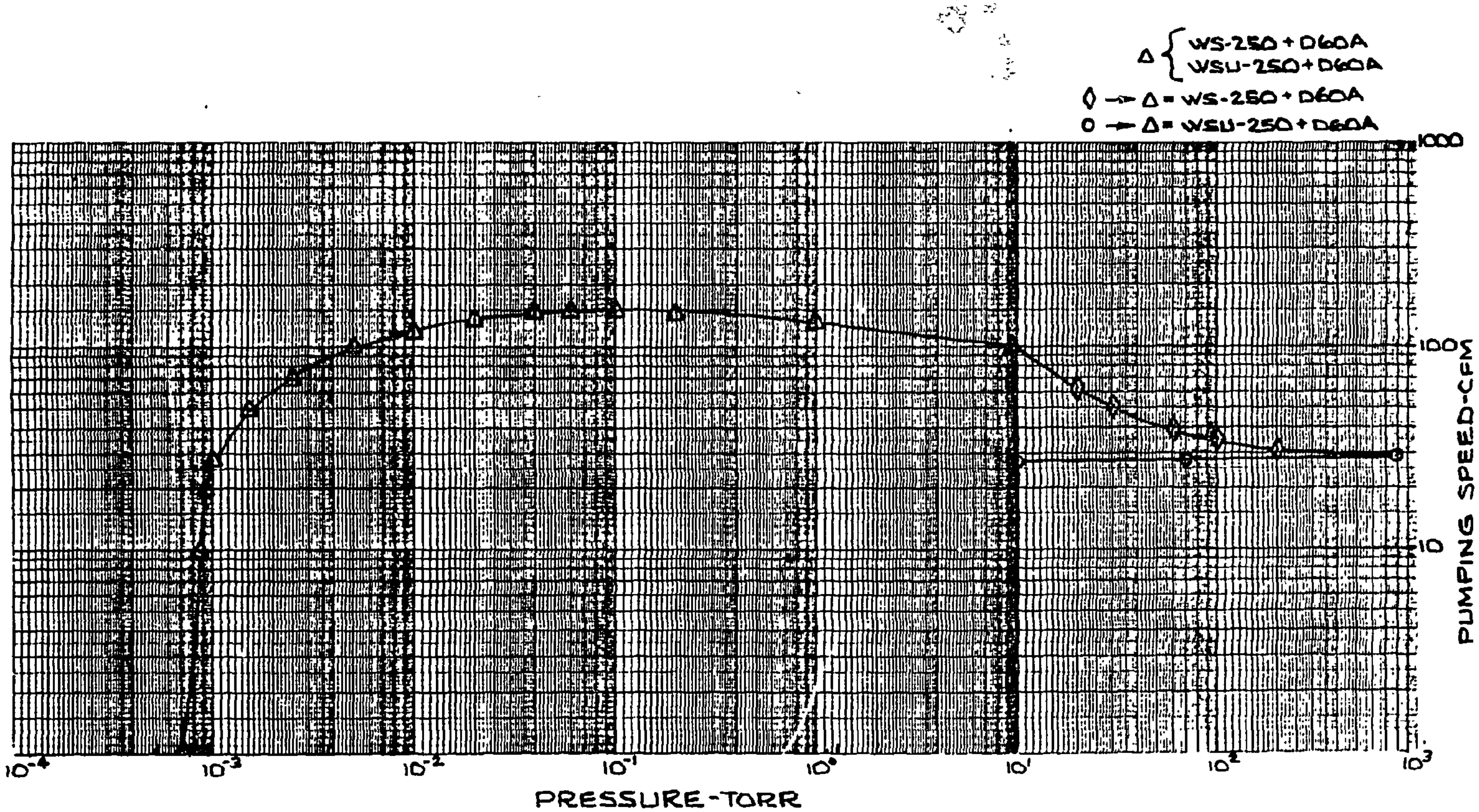


FIGURE 4-4 PERFORMANCE COMPARISON OF WS-250 AND WSU-250 BLOWERS BACKED BY A D60A ROTARY VANE PUMP

A roots blower, backed by a liquid nitrogen trapped two-stage mechanical pump, is a very clean roughing system. Roots blowers have compression ratios which vary directly with the molecular weight of the gas being pumped. Contaminants, which are characterized by high molecular weights, are therefore precluded from backstreaming through the operating blower. The liquid nitrogen trap reduces the contaminant level in the exhaust region of the roots blower.

The performance curves for the WSU-250 and WSU-500 blowers with appropriate mechanical pumps are shown in Figure 4-5. Both pumping systems are capable of operation in the 10^{-4} torr region.

The two stage mechanical pumps and their respective pumping speeds are shown in Figures 4-6 and 4-7. The DK-100 mechanical pump is used with the WSU-500 roots blower for foreline pumping three turbomolecular pumps. It is capable of operating to 1×10^{-4} torr and if the gas ballast is used it can operate to 1×10^{-3} torr. Two D60A mechanical pumps are employed with WSU-250 roots blowers. One is used for torus roughing and the other for foreline pumping two turbopumps. These mechanical pumps are capable of operation to 3×10^{-4} torr without gas ballast. All three pumps are direct drive pumps which do not require bolts. They are provided with gas ballast which is helpful in removing condensible vapors which may condense in the oil vapors, such as water. Exhaust gas from all mechanical pumps will be vented outside the building. Both pumps are designed to prevent back running when first started or when turned off. Also vent valves will be included to prevent contamination from a pump which has been turned off. They will automatically open when the pumps have stopped and pump circuitry is deactivated.

All foreline fabrication will utilize stainless steel tube. Sizing criteria was based upon maximizing roughing system available speed through the intermediate pressure flow range for air and hydrogen at nominally 25°C. The details of the analysis for determining roughing line sizes are presented in Section 5.2. Piping design will enable all sections to be fabricated, cleaned, and helium leak checked at St. Louis. Operations at ORVIP will be limited to bolting flanged connections,except in special cases where building structural details require on-site limited fabrication, such as wall and floor pass-thrus.

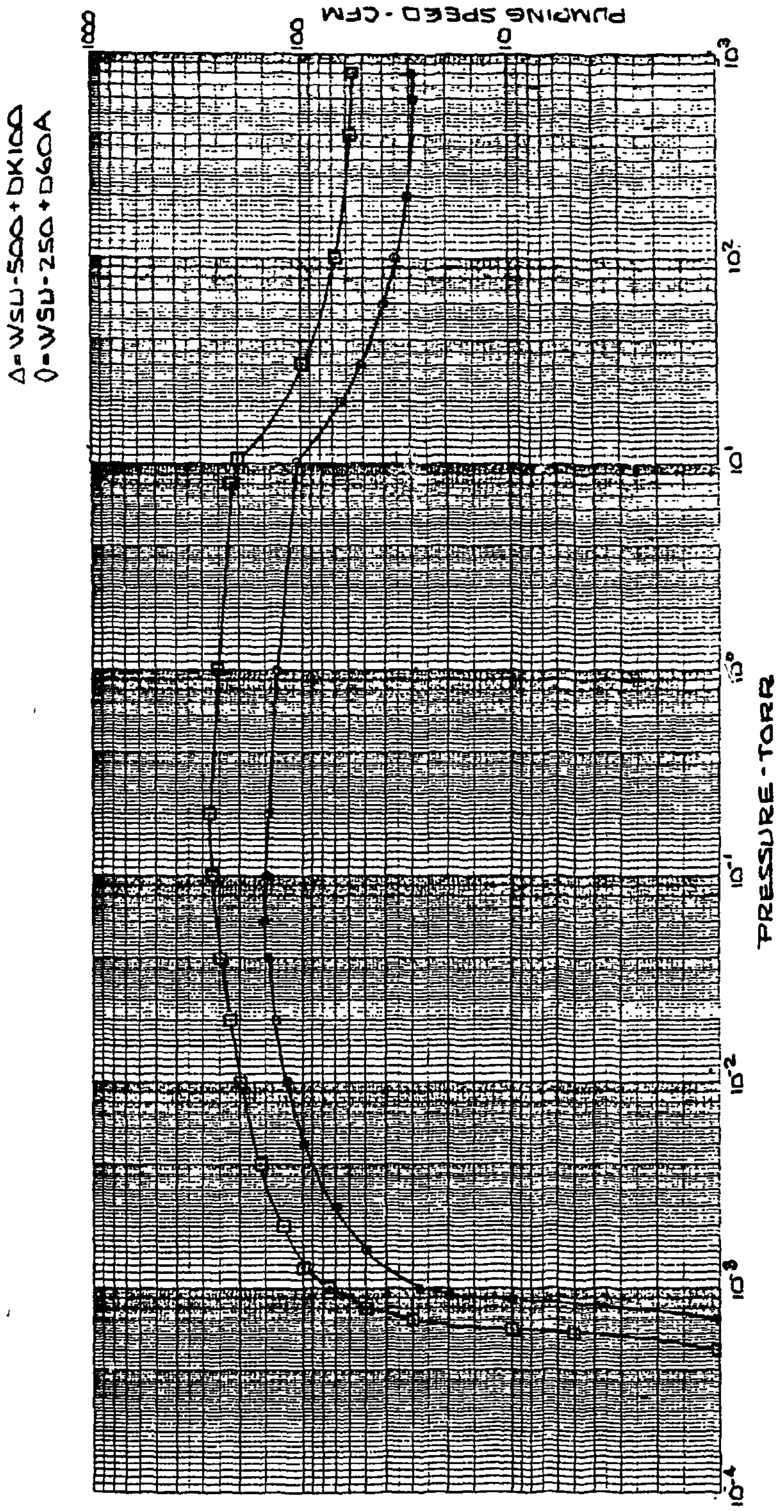
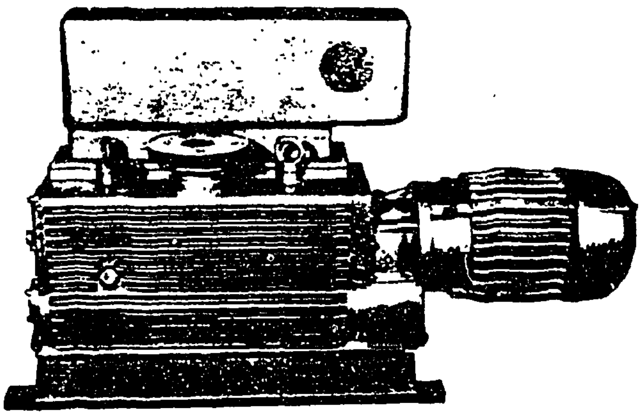


FIGURE 4-5 PERFORMANCE OF WSU-250 AND WSU-500 ROUGHING AND FOREPUMPING SYSTEMS



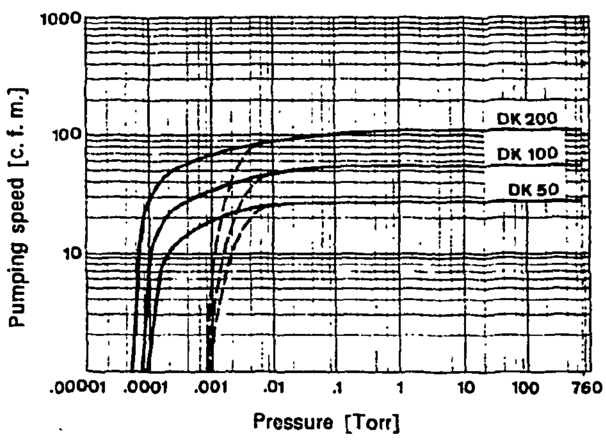


FIGURE 4-6 LEYBOLD-HERAEUS DK-100 TWO-STAGE ROTARY PISTON MECHANICAL PUMP

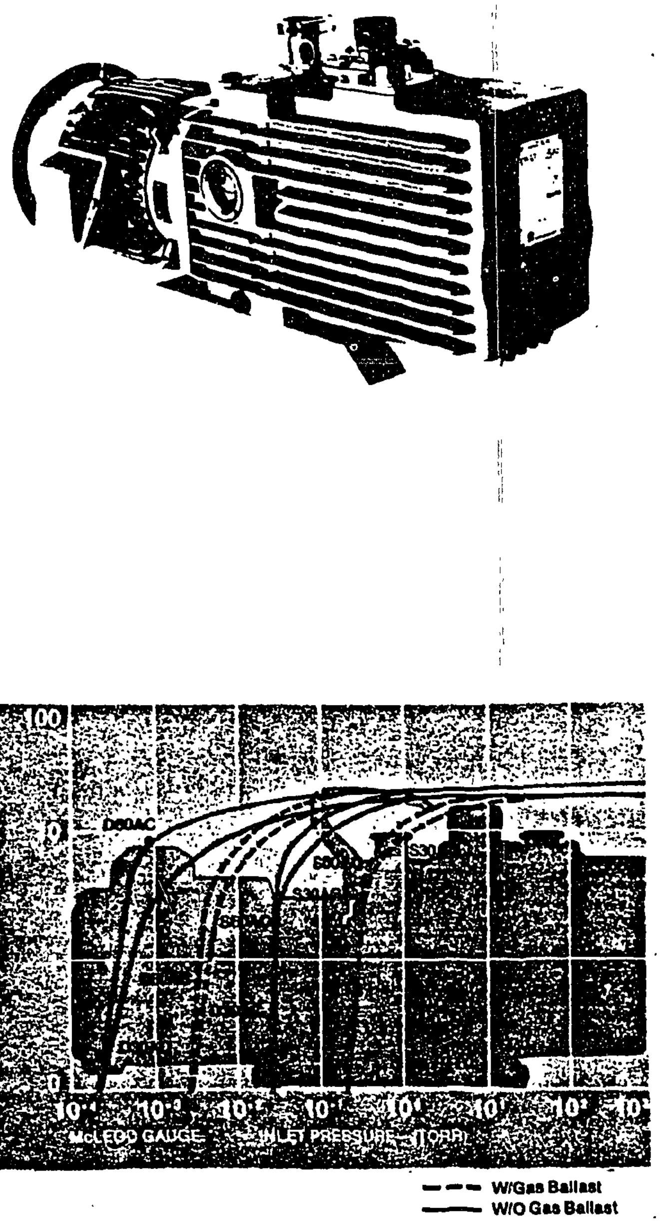


FIGURE 4-7 LEYBOLD-HERAEUS D60A TWO-STAGE ROTARY VANE MECHANICAL PUMP

All flanged tube connections, with the exception of the elastomer sealed aluminum valve interfaces, will utilize Conflat metal seals. Use of the Conflat metal seal in the roughing ducts and manifolds, will eliminate potential areas for seal deterioration due to the x-ray environment. Maintenance activities can thus be minimized or eliminated for the access limited roughing ducts and manifolds. Valves which will require periodic maintenance including seal replacement, will be easily removable without disturbing the balance of the piping. This will be accomplished by including a bellows section where necessary.

Table 4-1. Torus Roughing and Forepumping System Components

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(5) Vent Device	Vent devices for TMP3500 Turbo-pump	Leybold-Heraeus Inc. #98-273-019
(5) Flanges	Flanges to mate with venting device	NOR-CAL Products Co. ASA flange #ASA-9-000-G bored to 4.01 inch I.D. 304SS
(10) Flanges	Flanges to mate with 4 inch line bellows and elbow	Perkin-Elmer Conflat non-rotatable #262-4040 304SS
(5) Bellows	Bellows assembly for 4 inch foreline	Perkin-Elmer flexible coupling #267-4400 304SS
(5) Elbow	90° elbows for 4 inch foreline	Perkin-Elmer 90° elbow #267-4000 304SS
(5) Flanges	Conflat to ASA flange adapter for 4 inch valve mateup	NOR-CAL Products Co. ASA to CF adapter flange #ASA-9-600-400Z 304SS

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(5) Valve	Foreline valves	Vacuum Research Corp. #4T1EPLS with Viton O-rings limit switches and non-magnetic components
(5) Flanges	Foreline flanges for valve assembly mateup	NOR-CAL Products Co. ASA-9-000 bored to 4.01 inches 304SS
(15) Bolt and Nut Kit	Bolt and nut kit for vent device and 4 inch valve attachment	NOR-CAL Products Co. #BA-9 304SS
(9) Elbow	Elbow for 4 inch line fabrication	NOR-CAL Products Co. #G-2WC-400 304SS
(23) Bolt, Nut and Copper Gasket Kit	For 4 inch foreline conflat flanges	Perkin-Elmer #269-7600 304SS
(30) Flanges	Flanges for bellows and connections on 6 inch manifold	Perkin-Elmer Conflat non-rotatable #262-6040 304SS
(3) Flanges	Flanges for connections on 6 inch manifold	Perkin-Elmer Conflat rotatable #262-6060 and 262-6070 304SS

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(3) Half Nipple	6 inch manifold fabrication	Perkin-Elmer Conflat half-nipple #267-6305 304SS
(13) Bellows	For 6 inch manifold assembly	Perkin-Elmer flexible coupling #267-6400 304SS
(27) Bolt, Nut and Copper Gasket Kit	For 6 inch foreline conflat flanges	Perkin-Elmer #269-7800 304SS
(5) Half Nipples	4 inch foreline fabrication	Perkin-Elmer half nipple #267-4350 304SS
(4) End Caps	4 to 6 inch tube size transition	NOR-CAL Products Co. #G-2W-600 304SS
(3) Blank Flange	4 inch foreline upgrade termination	Perkin-Elmer conflat blank #262-4040 304SS
(9) Flange	6 inch foreline fabrication	NOR-CAL Products Co. ASA flange #ASA11-000 bore to 6.01 inch I.D. 304SS
(12) Flange	6 inch foreline fabrication	NOR-CAL Products Co. ASA flange #ASA11-000G Bore to 6.01 inch I.D. 304SS

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(3) Bellows	6 inch foreline fabrication	Anaconda bellows #6EL45 304SS
(3) Valve	Roughing pump isolation	Vac Research Man Co. 6 inch 94577-101LS with limit switches and viton O-ring
(3) Flange	WSU-500 and WSU-250 Blower inlet adapter	Leybold-Heraeus Inc. rotatable sleeve flange 6 inch Cat. #89542
(3) Flange	WSU-500 and WSU-250 Blower inlet adapter	Leybold-Heraeus Inc. rotatable sleeve flange 3 inch Cat. #89540
(9) Bolt, Nut and Washer Kit	6 inch foreline assembly	NOR-CAL Products Co. bolt and nut kit #BA-11 304SS
(6) Bolt, Nut and Washer Kit	6 inch foreline assembly	NOR-CAL Products Co. bolt and nut kit #BA-6 304SS
(3) Bolt, Nut and Washer Kit	6 inch foreline assembly	NOR-CAL Products Co. bolt and nut kit #BA-9 304SS
(1) Blower	For backing three turbo pumps	Leybold-Heraeus Inc. WSU-500 Cat. #11633-1

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(1) Sealing Disc Set	WSU-500 inlet-outlet seal	Leybold-Heraeus Inc. Cat. #910-181-605
(1) Reducing Tube	WSU-500 blower inlet tube size reduction	Leybold-Heraeus Inc. reducing tube (6 inch to 3 inch) cat. #26995
(1) Elbow	WSU-500 blower outlet elbow	Leybold-Heraeus Inc. 90° elbow cat. #982-780-349
(4) Flange	90° elbow flanges for conversion from 65LF to 3 inch ASA	Leybold-Heraeus Inc. rotatable sleeve flange #89540
(1) Spherical Liquid Nitrogen Trap	Reduction of hydrocarbon back-streaming from backing pump	Leybold-Heraeus Inc. spherical cold trap #23017
(1) Rotary Piston Vacuum Pump	For backing WSU 500 blower	Leybold-Heraeus Inc. DK-100 rotary piston pump #89502-1
(1) Backing Pump Exhaust Filter	For DK-100 pump	Leybold-Heraeus Inc. exhaust filter model AF5-3 #17862-2
(1) Vibration Absorber Set	For DK-100 pump	Leybold-Heraeus Inc. #10155-1

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(3) Sealing Disc	For DK-100 pump inlet and liquid nitrogen trap	Leybold Heraeus Inc. #910-181-605
(3) Bolt, Nut and Washer Kit	3 inch flange assembly	NOR-CAL Products Inc. #BA-9 304SS
(1) Bellows	Separates DK-100 from liquid nitrogen trap	Leybold-Heraeus Inc. #99-105-1013
(2) Bellows	For inlet of D60A vacuum pump	Leybold-Heraeus Inc. corrugated stainless steel metal nose #86785
(2) Blower	For backing two turbo pumps and roughing the torus	Leybold-Heraeus Inc. WSU-250 Cat. #11623-1
(2) Sealing Disc Set	WSU-250 inlet-outlet seal	Leybold-Heraeus Inc. Cat. #910-181-605
(2) Reducing Tube	WSU-250 blower inlet tube size reduction	Leybold-Heraeus Inc. reducing tube (6 inch to 3 inch) cat. #26995
(2) Adapter	WSU-250 blower outlet size reducer	Leybold-Heraeus Inc. KF/ASA adapter cat. #98-278-0441
(6) Clamp	For KF40 ports on LN_2 trap in foreline	Leybold-Heraeus Inc. clamp cat. #18343

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(2) Liquid Nitrogen Trap	Reduction of hydrocarbon back-streaming from backing spring pump D60A	Leybold-Herasus Inc. absorbtion trap cat. #85419
(2) Rotary Vane Vacuum Pump	For backing blower WSU-250	Leybold-Heraeus Inc. D60A complete cat. #895862036
(2) Backing Pump Exhaust Filter	For D60A pump	Leybold-Heraeus Inc. exhaust filter cat. #18915
50 Feet Tube	Foreline fabrication	4 inch O.D. x 3.83 inch I.D. Tube 304SS
200 Feet Tube	Foreline fabrication	6 inch O.D. x 5.83 inch I.D. Tube 304SS
(2) Flanges	Contain microwave shield assembly	Varian conflat flange #954-5062
(1) Flange	Contains microwave shield	Varian double sided conflat flange SPECIAL 8 inch O.D. blank
(1) Bolt, Nut and Washer Set	For 8 inch O.D. conflat flange assembly	Varian SPECIAL 5/16-24 X 3 inch long bolts with nuts, washers

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(1) Gasket Set	For 8 inch O.D. conflat flange assembly	Varian OFHC copper gasket kit #953-5095
(17) Flange	For 1 inch valve attachment	Flowline 1 inch class 150 slip-on flange 304SS
(5) Flange	For 1 inch valve attachment	Flowline 1 inch class 150 lap joint flange 304SS
(5) Stub End	For 1 inch valve attachment	Flowline 1/2 inch schedule 5 stub end 304SS
(14) Valve	Torus isolation, foreline venting, nitrogen inbleed, and leak detection	Vacuum Research Man. Co. one inch valve ITIEPLS with limit switches non-magnetic components and viton O-rings
(1) Valve	Isolates 25 psig nitrogen gas source	Automatic Switch Co. general service valve Cat. #8210C87
(1) Valve	Maintains pressure differential across vacuum valve at one atmosphere	Automatic Switch Co. general service valve Cat. #8210B38
(5) Feet Tube	Fabrication of nitrogen gas line	Ryerson 5/8 inch OD X .035 wall seamless tube 304SS

Table 4-1. Torus Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(25) Feet Pipe	Fabrication of nitrogen gas line	Ryerson 1/2 inch schedule 5 seamless pipe 304SS
(2) Valve	Isolates 25 psig nitrogen gas source	Automatic Switch Co. general service valve Cat. #8210C33
(2) Valve	Maintains pressure differential across vacuum valve at one atmosphere	Automatic Switch Co. general service valve Cat. #8210A21
(40) Feet Tube	Fabrication of nitrogen gas line	Ryerson 3/8 inch O.D. X .028 wall seamless tube 304SS
(2) Valve	For metering gas flow	St. Louis Value and Fitting Nupro Fine Metering Valve #SS-6L with vernier handle #NY-2M-S6

4.2.3 Torus Roughing and Forepumping System Interfaces - The Torus Roughing and Forepumping System has major interfaces with the three systems described below:

- Toroidal Vessel
- Instrumentation and Control
- Utilities

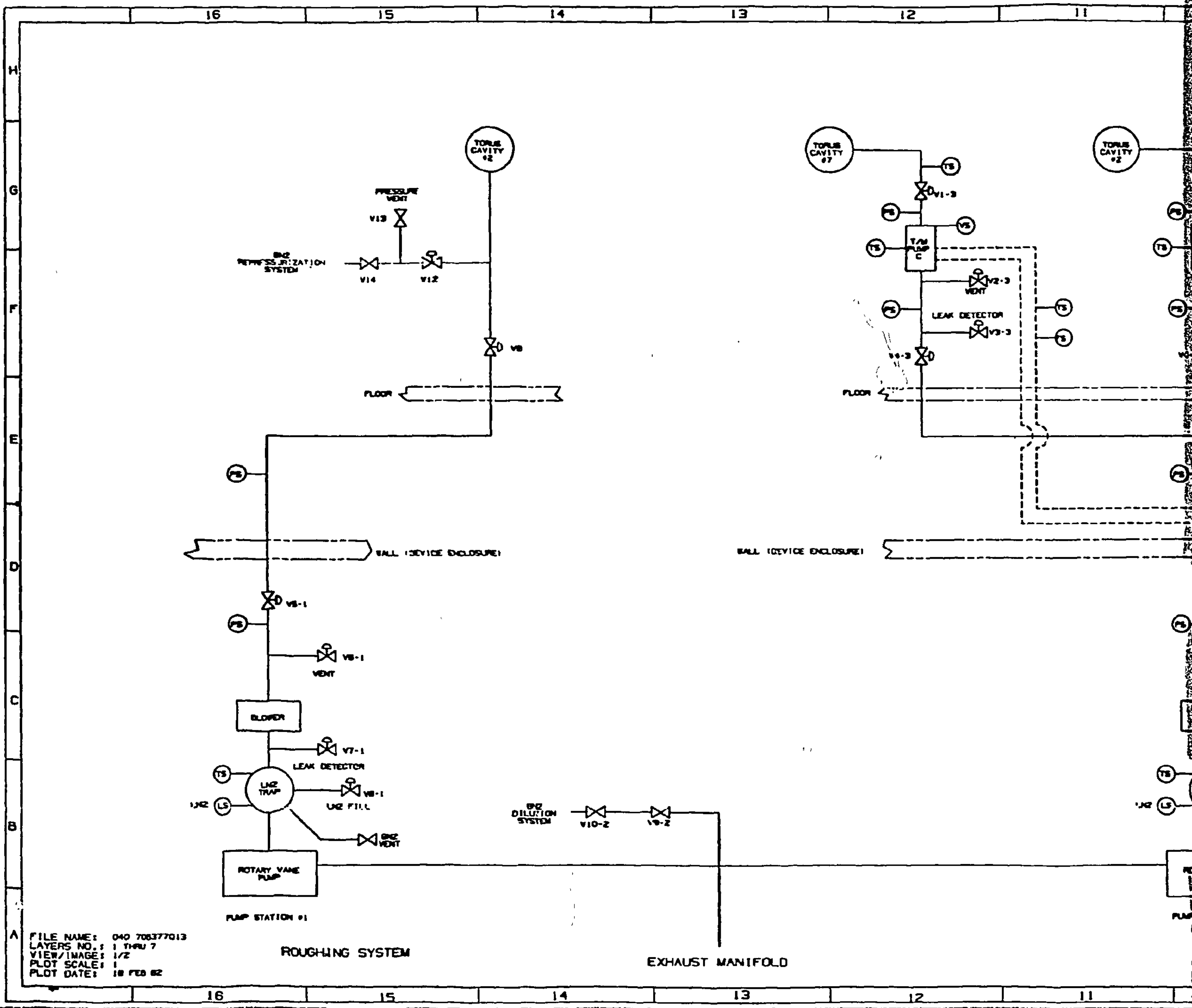
4.2.3.1 Toroidal Vessel - All torus rough pumping from atmospheric pressure will occur at mirror cavity number two. The systems orientation is shown in Figure 4-2. The attachment of roughing system components to cavity two is also shown in Figure 4-2. A microwave shield separates the microwave absorbing duct from the torus bottom port, the details of which are discussed later. Tube connections shown are .085 inch wall thickness. Flanged connections, as discussed earlier, are Conflat metal seals except at the elastomer sealed aluminum valves. The possibility exists for changing the six-inch tube section and bellows to a larger diameter fabricated section and larger bellows, should a detailed design effort indicate the need for greater conductance in the lines. The six-inch standard port V.R.C. valves feature a 6.0 inch inside diameter.

The microwave absorbing duct flange interface with the microwave shield at the torus port will be a metal sealed horsecollar shaped connection. The possibility of the bolted connection successfully loading both metal seals of the three flange assembly will be addressed when the detailed design of the horsecollar flange and seal groove is performed in the Task II design effort, and during the seal development testing (WBS 6.2.3.2).

4.2.3.2 Instrumentation and Control - A schematic of the roughing system valving and pipe manifold pressure status locations is shown on Figure 4-8. All valves will contain limit switches thus assuring that intended valve operations are fulfilled. Automatic backfill valves are also interlocked to the pump circuitry to prevent accidental contamination of the foreline. The following capabilities exist with the indicated configuration.

4.2.3.2.1 Torus Roughing -

- Torus roughdown from atmospheric to the 10^{-3} torr region can be accomplished only with the roughing system at pump station #1.


TORUS CAVITY #2
PRESSURE VENT
V13
GN2 REPRESSURIZATION SYSTEM
V14
V12
V8
FLOOR
WALL (DEVICE ENCLOSURE)
V5-1
V6-1
VENT
BLOWER
V7-1
LEAK DETECTOR
LN2 TRAP
V8-1
LN2 FILL
LN2
GN2 VENT
ROTARY VANE PUMP
PUMP STATION #1
GN2 DILUTION SYSTEM
V10-2
V9-2
TORUS CAVITY #7
V1-3
T/M PUMP C
V2-3
VENT
LEAK DETECTOR
V3-3
V4-3
FILE NAME: 040 703377013
LAYERS NO.: 1 THRU 7
VIEW/IMAGE: 1/2
PLOT SCALE: 1
PLOT DATE: 18 FEB 82
ROUGHING SYSTEM
EXHAUST MANIFOLD

4–25 4–26

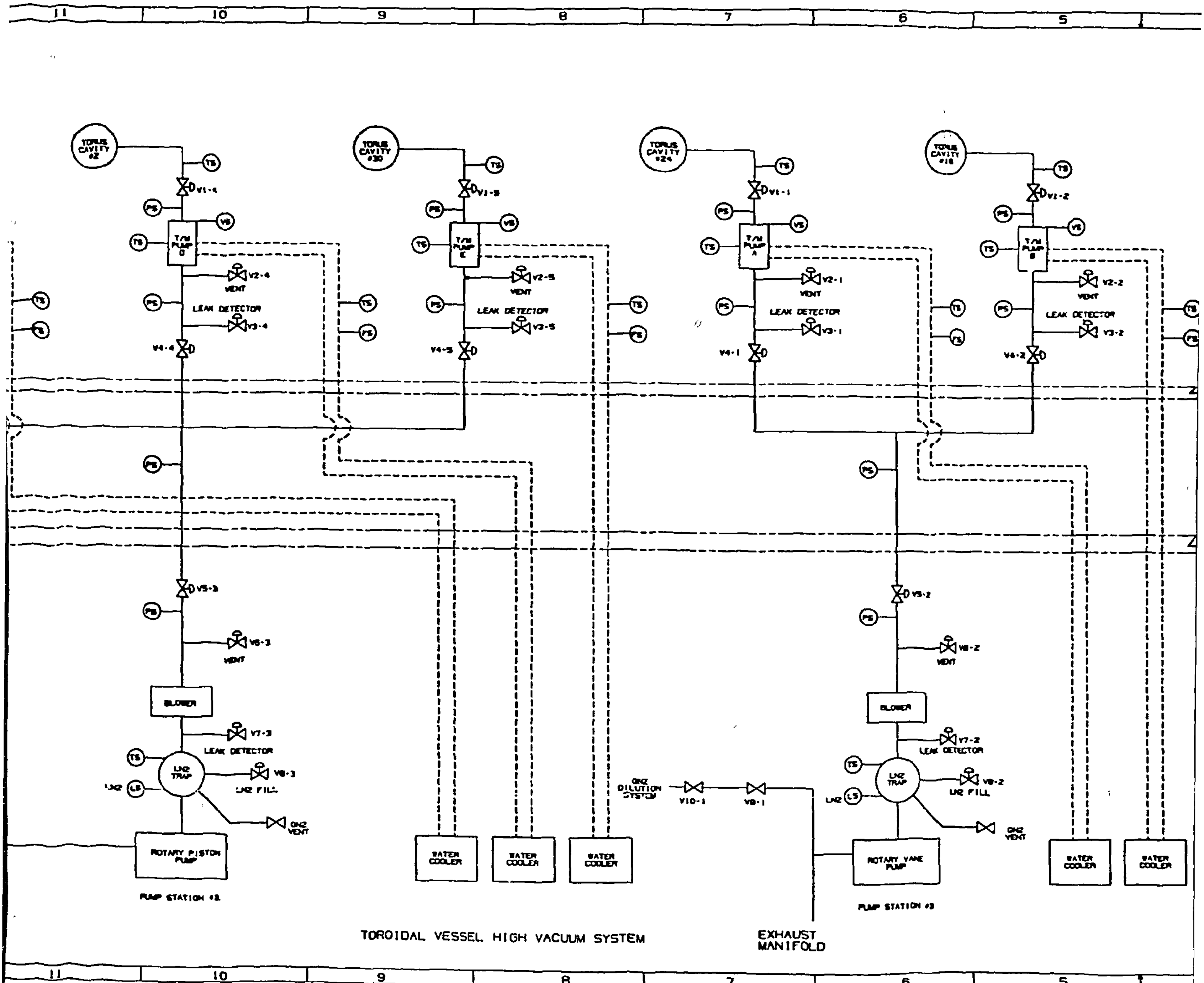

TORUS CAVITY #2
TORUS CAVITY #30
TORUS CAVITY #24
TORUS CAVITY #18
LEAK DETECTOR
VENT
BLOWER
LN2 TRAP
LN2 FILL
GN2 VENT
ROTARY PISTON PUMP
PUMP STATION #2
ROTARY VANE PUMP
PUMP STATION #3
WATER COOLER
GN2 DILUTION SYSTEM
TOROIDAL VESSEL HIGH VACUUM SYSTEM
EXHAUST MANIFOLD

FIG. 4-8

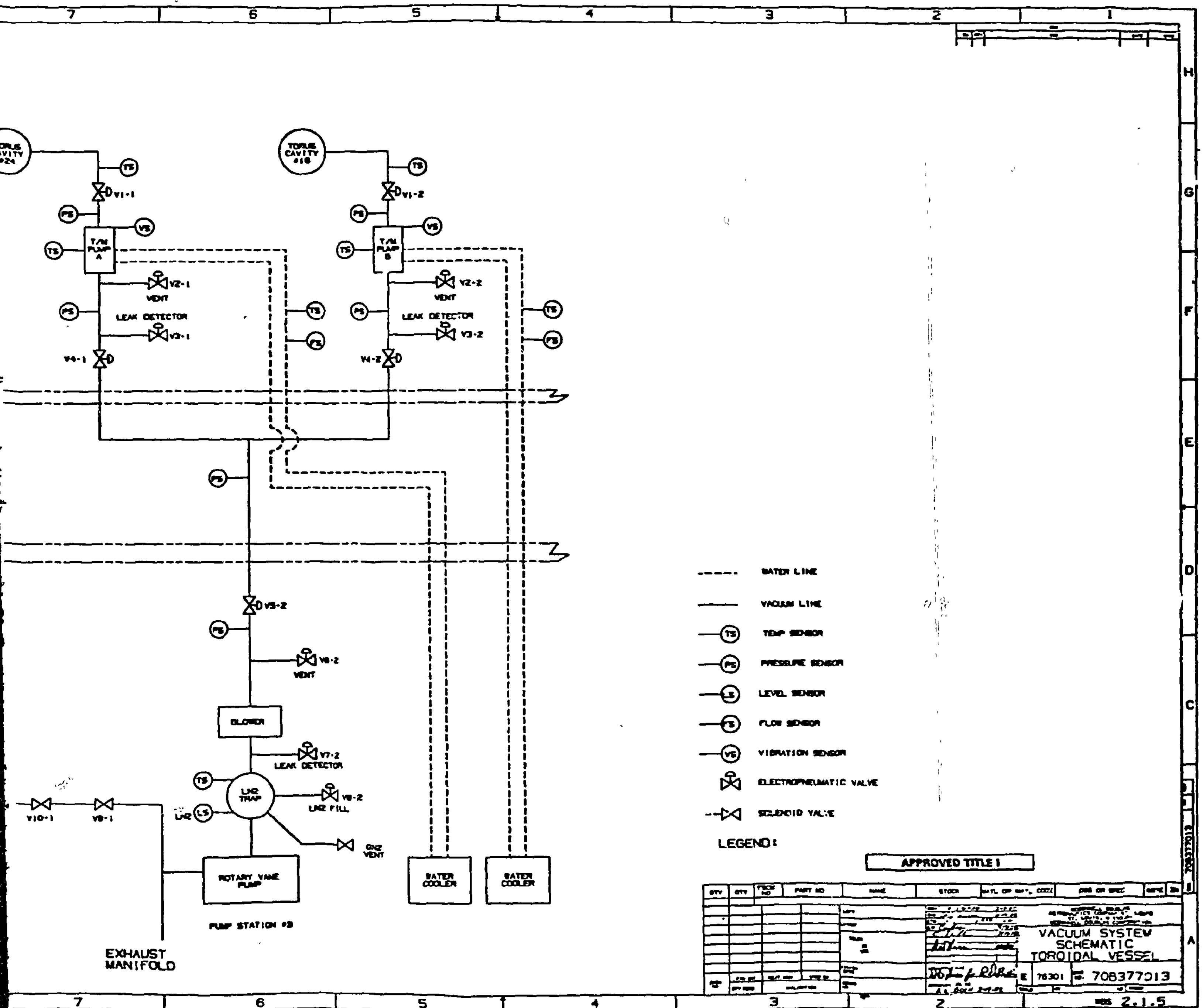

TORUS CAVITY #18
V1-1
V1-2
T/M PUMP A
T/M PUMP B
V2-1
V2-2
VENT
LEAK DETECTOR
V3-1
V3-2
V4-1
V4-2
V5-2
V6-2
BLOWER
V7-2
LEAK DETECTOR
LN2 TRAP
V8-2
LN2 FILL
LN2
V10-1
V9-1
ROTARY VANE PUMP
PUMP STATION #3
EXHAUST MANIFOLD
WATER COOLER
WATER COOLER
WATER LINE
VACUUM LINE
TEMP SENSOR
PRESSURE SENSOR
LEVEL SENSOR
FLOW SENSOR
VIBRATION SENSOR
ELECTROPNEUMATIC VALVE
SOLENOID VALVE
LEGEND:
APPROVED TITLE I
VACUUM SYSTEM SCHEMATIC TOROIDAL VESSEL
76301
708377013
2.1.5

FIG. 4-8

- Startup of the rotary vane pump requires that trap cooldown be initiated and the condensing surface has reached a TBD temperature. Additionally, valves V5-1, V6-1; V7-1, V9 and V12 must be closed.
- The blower will start automatically by means of a circuit interlocked to the rotary vane pump starting circuit.
- The blower, once running, can be manually turned off. However, when off it will electrically deactivate valves V5-1 and V9 and prevent their opening.
- Valves V5-1 and V9 can be opened only if torus pressure is higher than 1×10^{-3} torr the roughing pump system is running and both foreline pressure sensors are at less than 1×10^{-2} torr.
- Valve V9 will not open if valves V1-1 thru V1-5 are open.
- If the trap condensing surface temperature rises above a TBD temperature due to a liquid nitrogen feed failure while running in an isolated mode (valves V9 and V5-1 closed), or while evacuating the torus, valves V9 and V5-1 will close and the roughing system will stop. Air vent valve V6-2 will then open.
- V12 cannot be opened if valves V9, V5-1, and V1-1 thru V1-5 are opened.
- Valve V13 is a normally-open valve with close-sequencing designed so that V12 does not experience more than a one atmosphere pressure differential on the gate.
- Valve V7-1 can be opened only when the system is in a leak detection mode.

4.2.3.2.2 Torus Forepumping -

- Starting of the rotary vane and rotary piston pumps in stations #2 and/or #3 requires that trap cooldown has been initiated and the condensing surface(s) has reached a TBD temperature. Additionally, valves V4-1 thru V4-4, V5-2 and V5-3, V6-2 and V6-3, plus V7-2 and V7-3 must be closed.
- The blower(s) will start automatically by means of a circuit interlocked to the rotary vane pump starting circuit.
- The blower(s) can be stopped after it automatically starts, however it will cause valves V4-1 thru V4-5, plus V5-2 and V5-3 to close.
- If a forepumping station cold trap condensing surface temperature rises above a TBD valve, all open valves permitting pressure reduction in the affected system will close, the pumping system(s) will stop and appropriate vent valves to the affected pumps (eg., V2-1 thru V2-5 plus V6-2 and V6-3) will open.

4.2.3.3 Utilities - All utility requirements air, water and electrical power for the torus vacuum roughing system are identified in Table 4-2. Precise equipment locations are shown in Figures 4-2 and 4-8.

Table 4-2. Torus Roughing and Forepumping System Utilities Requirements

WSU-250 (Quantity 2)	
Electrical	208V 3 Phase 60 Hz 0.8 HP
Cooling	Air Cooled
WSU-500 (Quantity 1)	
Electrical	208V 3 Phase 60 Hz 1.7 HP
Cooling	Air Cooled
DK 100 (Quantity 1)	
Electrical	208V 3 Phase 60 Hz 5 HP
Cooling	Air Cooled
D60A (Quantity 2)	
Electrical	208V 3 Phase 60 Hz 2 HP
Cooling	Air Cooled
Vacuum Valves (Quantity 20)	
Electrical	110V/60 Hz
Air	65 psig

4.2.4 Torus Roughing and Forepumping System Environment - The effects of the EBT-P environment on roughing valves and pumps are discussed below.

4.2.4.1 X-Ray - Thermal, x-ray, and microwave considerations dictate that the basic torus structure be an all metal sealed system. Subsystems, such as the roughing system attached at torus segment two, will utilize metal seals wherever possible to minimize the number of vacuum connections where x-ray damage can occur. The basis for concern with respect to elastomers involves radiation effects which cause hardening, embrittlement, and compression set. The three roots blowers and mechanical pumps, and several valves are located outside the device enclosure to avoid x-ray exposure.

The calculated accumulated radiation doses at key roughing system components inside the device enclosure are approximately 5 x 10^7 rad. It has been mentioned previously that the maximum recommended accumulated dose for Viton elastomers is about 1 x 10^7 rads. At that dose, the elastomer begins to evidence hardening. Therefore, the design includes Conflat seals at all piping connection points except where vacuum valves are located. Other factors considered in choosing the Conflat metal seal for flanged pipe connections, include the difficulties associated with elastomer seal replacement during routine maintenance operations, and with more extensive leak detection requirements. Limiting the use of elastomer seals to only vacuum valves simplifies system maintenance. Failed valves can be replaced by inserting a spare rebuilt and leak checked assembly into the pipe line. It is anticipated, that all valve maintenance and seal replacement will occur during the four week shutdown period allotted for maintenance of the helium liquifier system. Metal sealed valves present other operational problems, as previously discussed (Section 4.1) and cost approximately eight times as much. For these reasons, they are not recommended. The effects of radiation on gate valve seals be studied during the elastomer seal test program in WBS 6.2.3.2.3.

4.2.4.2 Microwaves - There is only one potential area of concern involving microwave damage to elastomers in the roughing system. That area involves the six-inch valve which is separated from the torus by the microwave shield and absorbing duct. Concern can be diminished somewhat due to the fact that the valve is closed throughout plasma operation i.e., during microwave heating. Any supplemental pumping of the torus, necessitating use of the roughing pumps during standby periods, will be performed with microwave power off.

As discussed in Section 5.3.1 the protective microwave shield and absorbing vacuum duct will reduce the microwave power levels in the area of the six-inch gate valve to a few watts. Such power levels will not affect this valve.

4.2.5 Torus Roughing and Forepumping System Performance - The performance of the Torus Roughing and Forepumping System during torus rough pumping and turbomolecular pump operation is discussed in this section.

4.2.5.1 Torus Roughing - The predicted performance of the EBT-P Torus Roughing System is shown in Figure 4-9. Pumpdown from atmospheric will be with a 37CFM two stage rotary vane oil sealed mechanical pump and a 164CFM integral by-pass roots blower with a sealed drive motor. A liquid nitrogen cold trap is located between the mechanical pump and roots blower to minimize contamination of the blower by mechanical pump oil. Torus roughing will commence after verification that the trap is cold and the blower and mechanical pump are rotating. Valve V5-1 will first be opened and the roughing line is evacuated to below 10^{-3} torr. Valve V9 will then be opened to begin torus roughing. The torus pressure will be in the 10^{-3} torr range within approximately 62 minutes at which time the turbomolecular pumps may be operated.

The liquid nitrogen trap will be designed for rapid removal from the foreline while the contaminants remain frozen on the condensing surface. A pre-cleaned replacement trap may then be installed in its place.

The 6-inch O.D. roughing line was sized to maximize the net effective pumping speed of the rotary vane-blower combination for 20°C air in the 10^{-2} torr pressure range. The net effective pumping speed of the 37CFM rotary vane pump and 164CFM blower combination is approximately 89CFM at 10^{-2} torr at the torus / 6-inch line interface. A torus pressure in the 10^{-4} torr range can theoretically be obtained with the roughing system and a gas load design goal of 1×10^{-3} torr liter/sec.

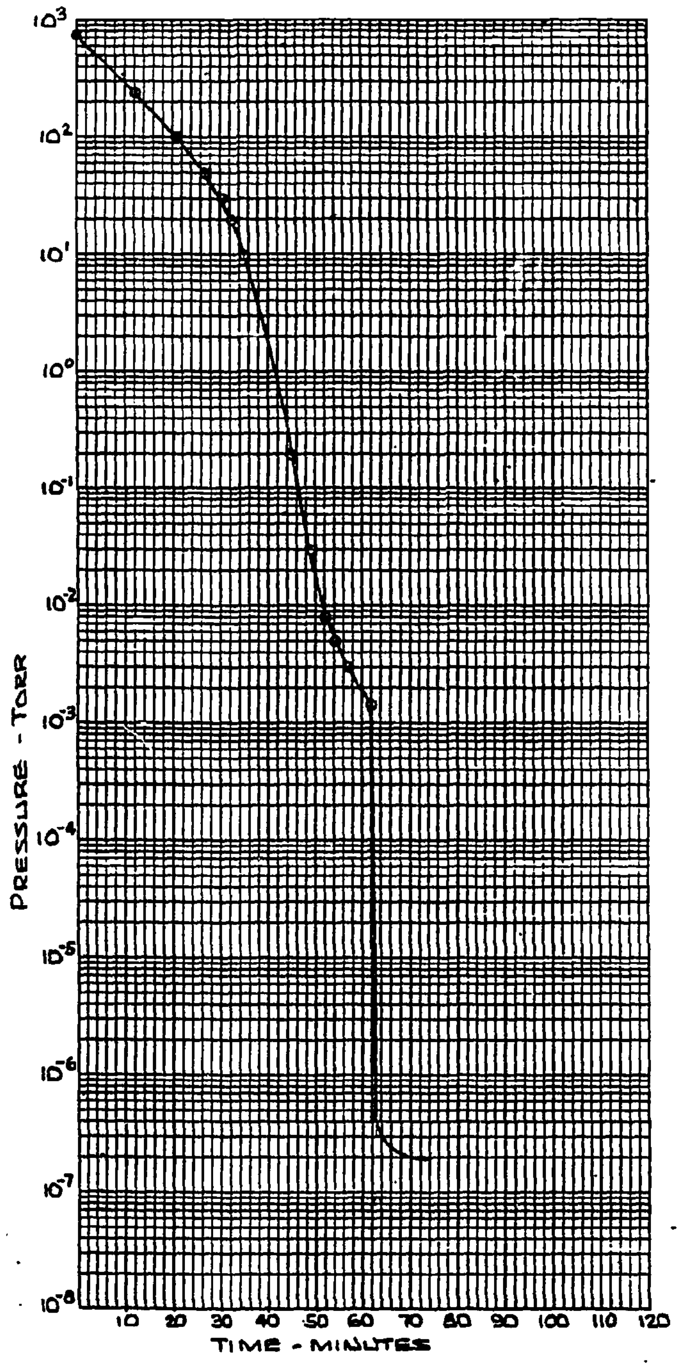


FIGURE 4-9 TORUS ROUGHING PERFORMANCE CURVE

Rough pumping will be terminated when torus pressure reaches the 10^{-3} torr range, unless the system is being used for leak detection. The torus high vacuum turbomolecular pump system will be used to attain torus pressures less than 10^{-3} torr.

4.2.5.2 Torus Forepumping - There are two forepumping systems for the torus turbomolecular pumps. The 65CFM mechanical pump/331CFM blower combination is used to back three turbopumps, and the 37CFM mechanical pump/164CFM blower combination backs two turbo pumps. Both systems will contain a mechanical pump, liquid nitrogen trap, and blower. Startup of pumps in either system will require that the trap condensing surface temperature reach a predetermined value so as to minimize hydrocarbon backstreaming to the blower. Startup of the turbomolecular pump will be dependant upon, along with other interlock signals, the foreline pressure being at or below a specific pressure level.

The liquid nitrogen traps for both of these systems will be designed for rapid removal of the condensing surface in the cooled mode, and replacement with a pre-cleaned trap. System design will permit either turbopump grouping to be shutdown independent of the other for cold trap servicing.

Forepump line sizing was based on a 20°C hydrogen gas load of 1 torr - liter/second uniformly distributed through each pumping station. The line pressure design objective is the intermediate flow range, with 10^{-2} torr as the design goal for foreline discharge pressure at the most remote pump in the manifolded concept shown in Figure 4-2. The net effective pumping speed available at the pumping station #30 discharge is approximately 58 liters per second for hydrogen at 10^{-2} torr. This system uses the 331CFM blower and 65CFM mechanical pump combination. The other forepumping system, which services two turbomolecular pumps, was designed for the same gas load conditions, 0.2 torr - liters/second per turbo pump. This system uses the 164CFM blower and 37CFM mechanical pump. The net effective pumping speed available at pumping station #24 discharge in the 3.83 inch I.D. line is approximately 44 liters per second for hydrogen at 10^{-2} torr. Both of the torus forepumping systems will have a nitrogen inbleed capability to dilute the hydrogen concentration in the roughing pump exhaust.

4.3 PRIMARY TORUS PUMPING SYSTEM

The high vacuum pumping system described in this section is for initial evacuation of the EBT-P torus, plasma stabilization, and impurity control during torus operation.

4.3.1 Torus Pumping System Requirements - The primary requirements of the Torus Pumping System which the turbomolecular pumps fullfill are:

- To produce a torus pressure of 2 x 10^{-7} torr within sixteen hours of initiation of system roughing, while pumping a system maximum allowable air leak of 1 x 10^{-4} torr-liter per sec. and an outgassing load of approximately 1 x 10^{-3} torr-liter/sec.
- Maintain a torus pressure during a sixteen hour burn, of 1 x 10^{-6} torr with a hydrogen bleed-in rate of 0.01 torr-liter per second and 1 x 10^{-5} torr with a hydrogen bleed- in rate of 0.1 torr-liter per second.
- Maintain a torus pressure of 1 x 10^{-4}torr during an eight hour burn with a hydrogen bleed -in rate of 1.0 torr-liter per second.
- The pumping system is not to introduce contamination into the torus.
- The pumping system should not induce vibration into the torus.
- The pumping system should continue to function with a single pump failure, at however, a reduced hydrogen input.
- Total H_2 pumping speed should be a minimum of 10000 l/s.
- The pumping system should be capable of some helium pumping.

Hardware ordered from vendors will have been defined in the purchase orders to meet specific ORNL and MDAC cleanliness specifications. MDAC fabricated hardware will be cleaned per MCAIR process specifications following fabrication, and approved handling and installation procedures will be adhered to thereafter. Prior to shipment, all fabricated components will be helium leak checked per MAC process specifications, to assure that the component leakage does not exceed 1 x 10^{-9} std cc/sec for helium.

4.3.2 Torus Pumping System Description - The torus high vacuum pumping system will consist of five turbomolecular pumps located, as shown in Figure 4-2, on cavities 2, 7, 16, 24 and 30. The net effective pumping speed for hydrogen at each pump station, as detailed in Figure 4-10, is approximately 2022 liters per second. The net effective pumping

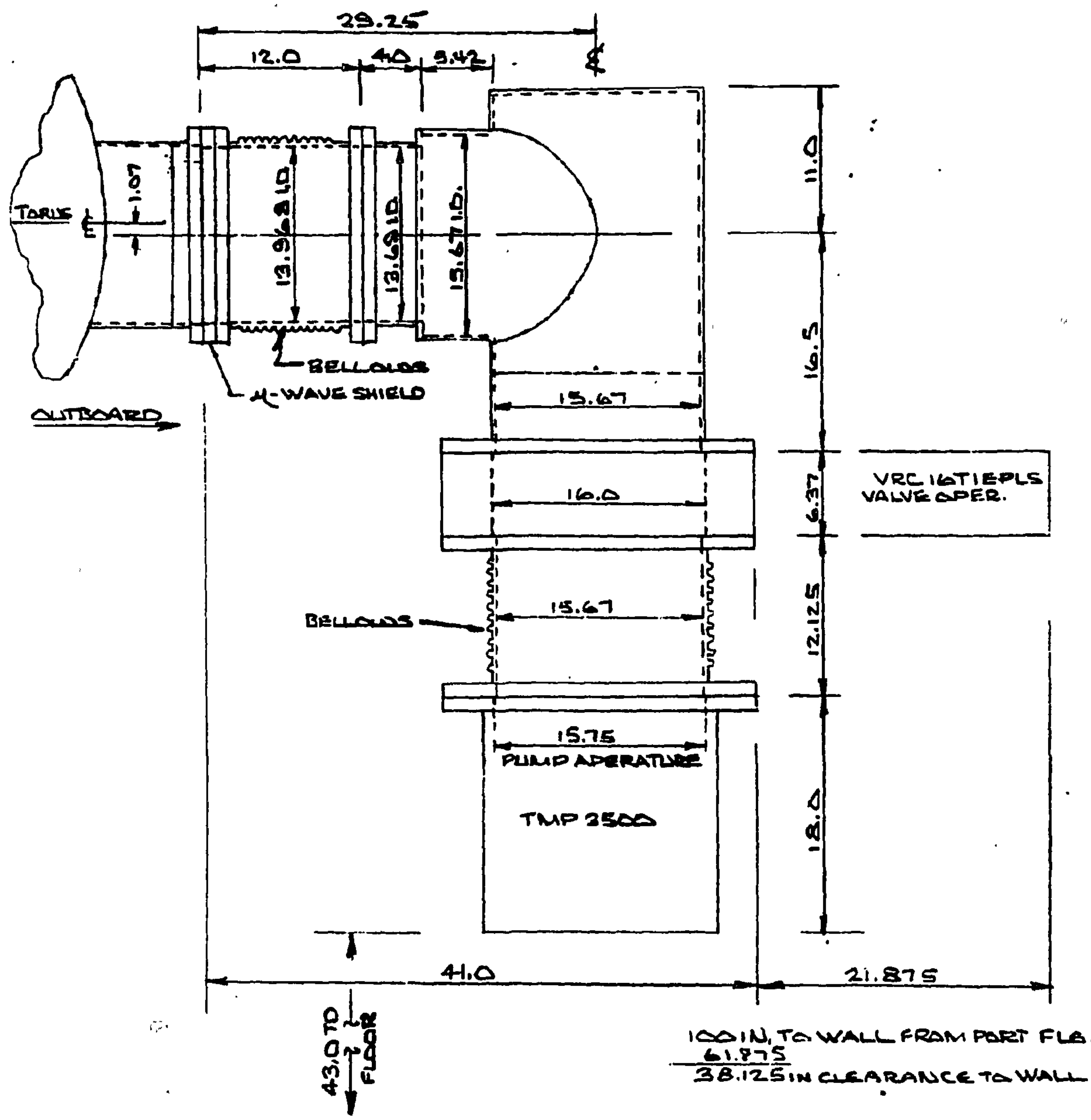


FIGURE 4-10 TORUS HIGH VACUUM PUMPING STATION WITH LEYBOLD-HERAEUS TMP-3500 TURBOMOLECULAR PUMP

speed for air is 1044 liter/sec. The analytical approach for determining this speed is discussed in section 5.1.

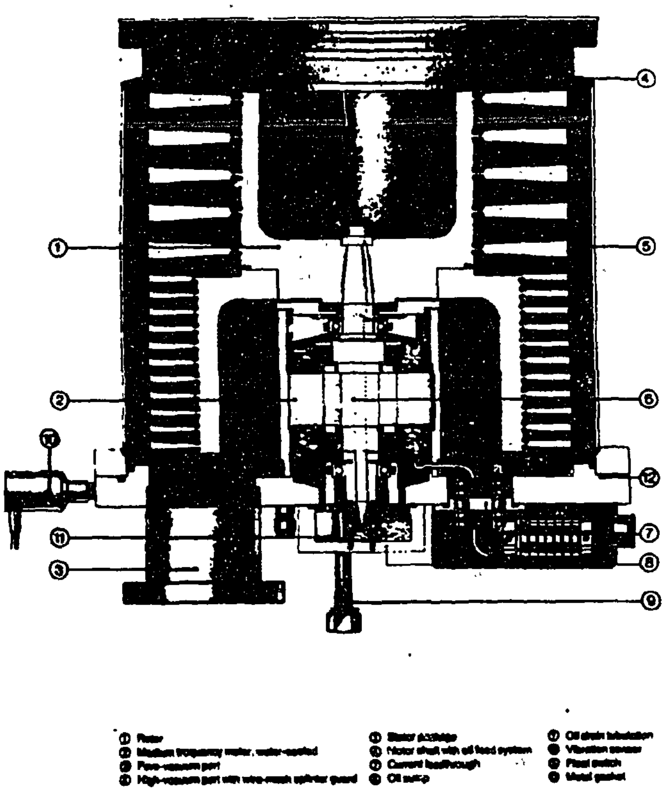
The high vacuum pumping duct assembly is interfaced to the torus via a microwave shield, and a microwave absorbing duct. Details of this assembly are shown in Figure 4-10. Discussions pertaining to molecular conductance calculations for the assembly is in section 5.1.

We have selected the Leybold-Heraeus TMP3500 turbomolecular vacuum pump for use on the EBT-P torus. A picture of the TMP3500 and the vendor's technical data are presented in Figure 4-11. It is a vertically mounted turbopump which operates at 13,500 RPM. The TMP3500 will be radiation hardened, which includes polyimide wire insulation, Viton and metal vacuum seals and a metal oil reservoir. Such pumps are being provided for TFTR and the modifications should increase the radiation tolerance to 10^7 rads. Since it is not feasible to X-ray harden the solid state frequency converter, it will be located outside the device enclosure. The turbomolecular pumps will be provided with vibration monitors to warn of potential failures and with automatic backfill valves to backfill the pump body when it shuts down, to prevent contamination.

Turbomolecular pumps are water cooled, and require cooling water between 20°C and 25°C. During device operation the coolant water in the demineralized water system will reach approximately 46°C. For this reason, a dedicated water coolant system will be supplied for each turbopump. Leybold-Heraeus offers a closed loop system. These water coolers can not be X-ray hardened and will be located outside the device enclosure at each torus forepumping station.

The performance of the TMP3500 is shown in Figure 4-12. It is seen to have a speed of 3500 liter/sec for air and 3300 liter/sec for hydrogen. The TMP3500 renders maximum pumping speed below 4 x 10^{-4} mbar (3 x 10^{-4} torr). Its low compression ratio for hydrogen necessitates a roots blower foreline pump to allow plasma operation at 1 x 10^{-6} torr.

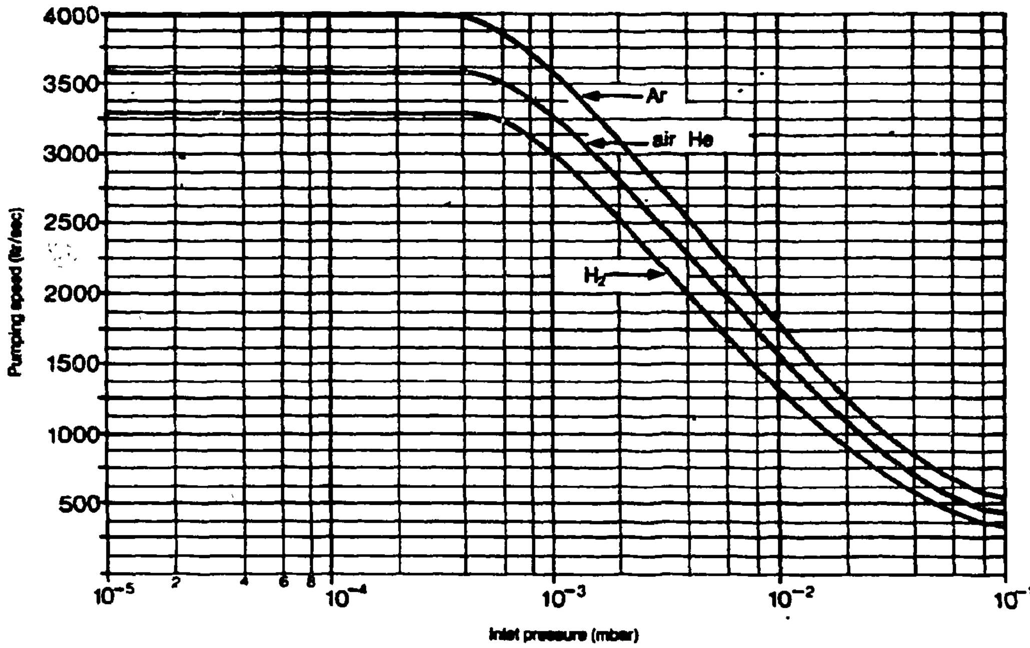
Microwave protection shields will be provided at each of the five high vacuum duct attachment points on the torus. As shown in Figure 4-13, each copper shield will be .0625 inches thick (.16cm), with a series of .045 inch (.11cm) diameter holes set in a triangular pitch,



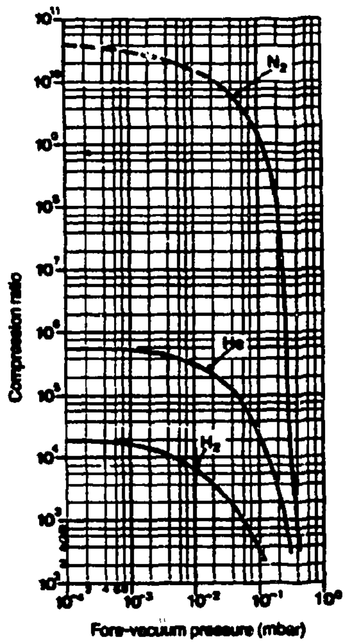
TECHNICAL DATA

[illegible]	
Pumping Speed for Ar—l/sec	4000
Pumping Speed for N_2(air)†—l/sec	3600
Pumping Speed for H_2—l/sec	3300
Pumping Speed for He—l/sec	3600
Inlet Flange Size ASA Version—in.	16
Inlet Flange Size ConFlat Version—in. (O.D.)	N/A
Recommended Backing Pump—type	DK-200
Displacement of Backing Pump—cfm	130
Ultimate Pressure, ASA Version—Torr	<10-[illegible]
Ultimate Pressure, ConFlat Version—Torr	N/A
Compression Ratio for N_2	>10[illegible]:1
Compression Ratio for He	6 x 10[illegible]:1
Compression Ratio for H_2	2 x 10[illegible]:1
Rotational Speed—rpm	15,000
Start Up Time—min	18-20
Oil Fill (approx.)—cc	240
Cooling Water Consumption—gal/hr	14
Cooling Water Connections—in.	½
Bakeout Temp. (pump throat)—°C	120
Allowable Vertical Deviation, Angle—deg	5
Dimensions (approx.)—in.	See Drawing
Weight (approx.)—lbs	352
Vibration Velocity—mm/sec	0.3
[illegible]	
Housing	Stainless Steel
Rotor	Stainless Steel
Stator	Stainless Steel
Gaskets, High Vacuum Side	Viton
Gaskets, Forevacuum Side	Buna N
Oil Reservoir	Acrylic Glass
SOLID-S[illegible]	
Voltage (input) 50-60 Hz—volts	110/220/240
Max. System Input Power Consumption— KVA	1.8
Maximum Output Voltage—volts	3 x 42
Operating Current—amps	13
Start Up Current—amps	*19.0*
Power Consumption Start Up Operation (output)—VA	1250
Power Consumption Continued Operation (output)—VA	860
Overload Current Protection for 115/1/60—amps	13
Output Frequency—Hz	225
Ambient Temp. (range)—°F	32-104
Dimensions with Case (approx.)—in.	17½ x 9¼ x 18¾
Weight (approx.)—lbs	77

FIGURE 4-11 LEYBOLD-HERAEUS TMP-3500 TURBOMOLECULAR PUMP

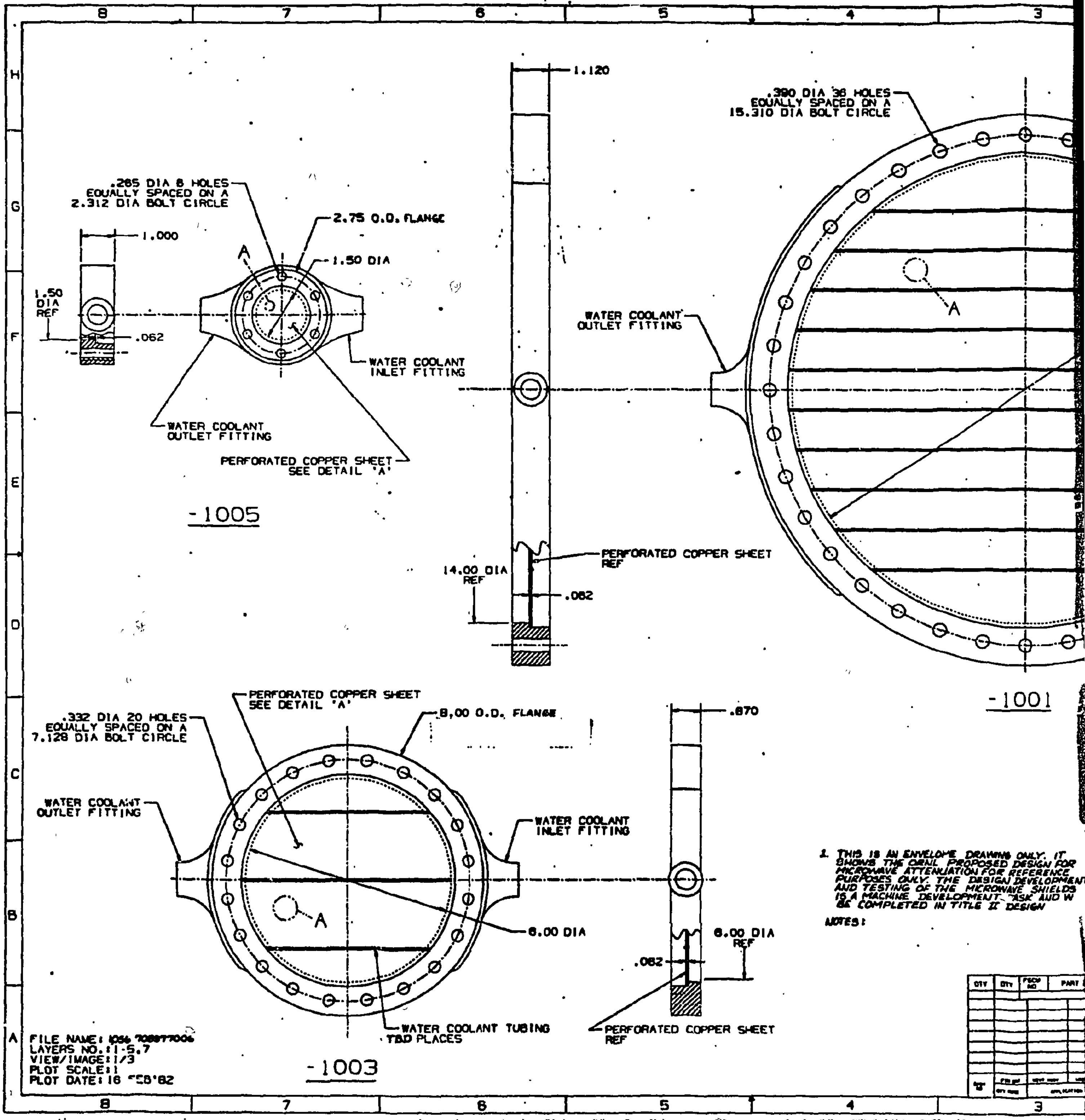


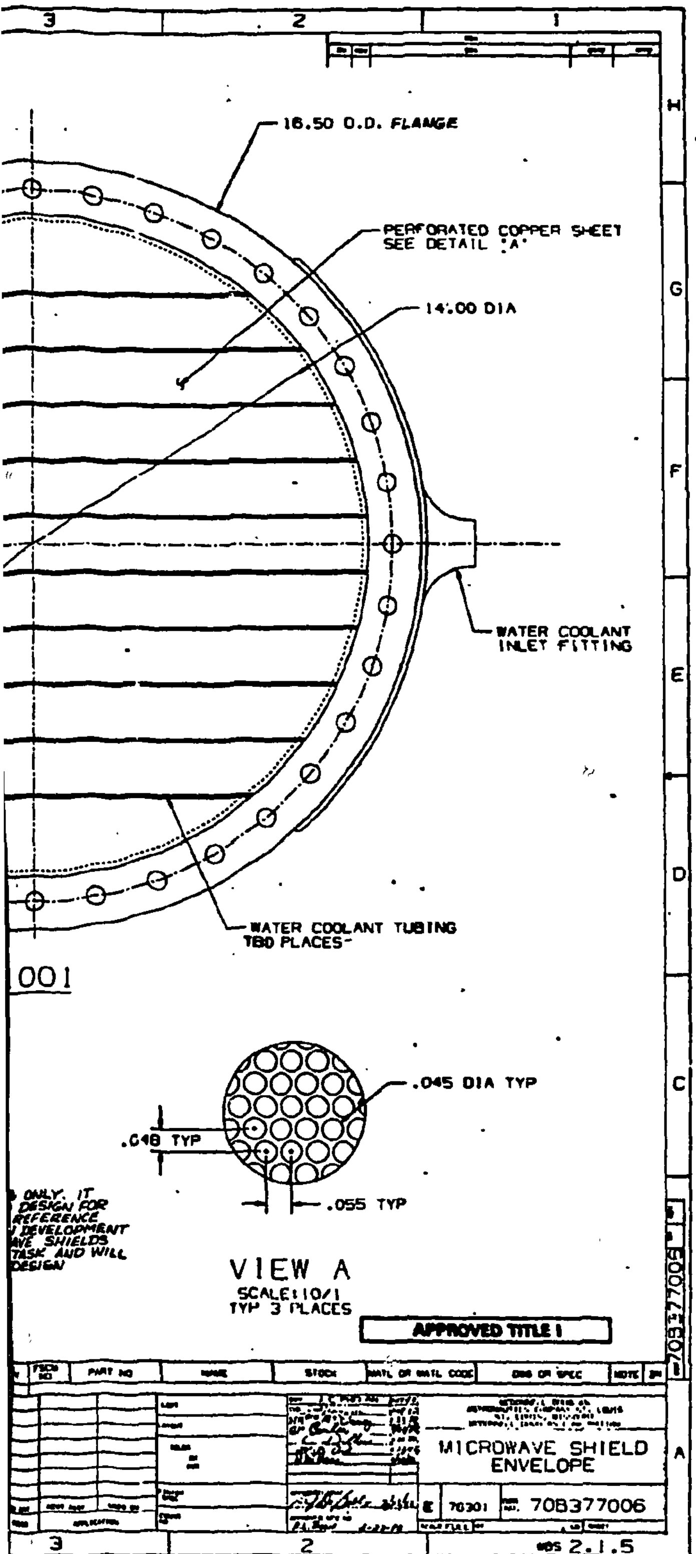
TURBOVAC 3500: Pumping speed (volume flow rate) in ltr/sec. for Ar, air, He, H_2 as a function of inlet pressure in mbar



TURBOVAC 3500:
Compression ratio for N_2, He and H_2 as a function of backing pressure in mbar

FIGURE 4-12 LEYBOLD-HERAEUS TMP-3500 PUMPING SPEED AND COMPRESSION RATIO CURVES


.265 DIA 8 HOLES
EQUALLY SPACED ON A
2.312 DIA BOLT CIRCLE
2.75 O.D. FLANGE
1.000
1.50 DIA
1.50
DIA
REF
.062
WATER COOLANT
INLET FITTING
WATER COOLANT
OUTLET FITTING
PERFORATED COPPER SHEET
SEE DETAIL 'A'
-1005
1.120
PERFORATED COPPER SHEET
REF
14.00 DIA
REF
.062
WATER COOLANT
OUTLET FITTING
.390 DIA 36 HOLES
EQUALLY SPACED ON A
15.310 DIA BOLT CIRCLE
-1001
.332 DIA 20 HOLES
EQUALLY SPACED ON A
7.128 DIA BOLT CIRCLE
PERFORATED COPPER SHEET
SEE DETAIL 'A'
8.00 O.D. FLANGE
WATER COOLANT
OUTLET FITTING
WATER COOLANT
INLET FITTING
6.00 DIA
WATER COOLANT TUBING
TBD PLACES
-1003
.870
6.00 DIA
REF
.062
PERFORATED COPPER SHEET
REF
NOTES:
1. THIS IS AN ENVELOPE DRAWING ONLY. IT SHOWS THE ORNL PROPOSED DESIGN FOR MICROWAVE ATTENUATION FOR REFERENCE PURPOSES ONLY. THE DESIGN DEVELOPMENT AND TESTING OF THE MICROWAVE SHIELDS IS A MACHINE DEVELOPMENT TASK AND W BE COMPLETED IN TITLE II DESIGN
FILE NAME:
LAYERS NO.: 1-5,7
VIEW/IMAGE: 1/3
PLOT SCALE: 1
PLOT DATE: 16 FEB'82



16.50 O.D. FLANGE
PERFORATED COPPER SHEET
SEE DETAIL "A"
14.00 DIA
WATER COOLANT
INLET FITTING
WATER COOLANT TUBING
TBD PLACES
001
.045 DIA TYP
.048 TYP
.055 TYP
VIEW A
SCALE: 10/1
TYP 3 PLACES
APPROVED TITLE I
MICROWAVE SHIELD
ENVELOPE
70301
70B377006
WBS 2.1.5

and having a separation of .055 inch (.14cm) center-to-center. Predicted microwave attenuation for normal incidence is 58.6 db for 28 GHz, 49.8db for 60 GHz, and 41db for 90 GHz. The method for calculating microwave attenuation is presented in Section 5.3.1. Further attenuation will be provided by the absorbent coated duct. The absorbent, possibly a dielectric or graphite material, will be determined in the development program.

Water cooling will be provided on the shield and duct. In addition to heating of the duct walls due to microwave absorption, the duct will also receive additional heat during plasma operation from optical radiation, ions, and neutral particles. The estimated continuous heat load from these sources is 2 KW. As discussed in Section 5.6 this is a "worst case" approximation. Duct shell cooling tubes will be approximately one-inch apart. Shell temperature between the water cooling tubes will be about 100°C, and about 70°C at the tube interface. Microwave shield cooling tubes will be spaced on about 2.12 inch (5.4cm) centers across the face of the perforated shield as shown in Figure 4-13.

The sixteen-inch aluminum gate valve is mounted with the operator on the bottom side to eliminate clearance problems with the microwave distribution manifolds. Valve seals are Viton. Solenoids controlling pneumatic operation of the valve will be mounted on the valve body. Metal air lines will be used between the solenoid control valve and actuator.

The turbomolecular pumps and valves are recessed from direct line-of-sight of the ions and neutral particle heating potential which occurs during plasma burns. Title II design will assess this heating potential to determine if pump body and turbo blade interferences could occur. Should there be no significant problem, the pump mount could be reconfigured to improve pumping speeds.

Operation of the turbomolecular pump system initially requires evacuation of the pump body with the sixteen-inch valve closed. The forepumping system is used to reduce the pump module pressure to about 10^{-2} torr via the foreline valve. At this point the turbomolecular pump will be started and foreline pumping will continue. When high vacuum pumping of the torus is desired (when the torus is below 10^{-2} torr) the sixteen-inch gate valves will be opened.

All seals in the high vacuum pumping duct assembly are Conflat metal seals with the exception of the aluminum valve Viton elastomer seal flange interfaces, and valve body seals.

A part list identifying purchased components of the Primary Torus Pumping System is shown on Table 4-3.

Table 4-3. Torus High Vacuum Pumping System Components

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(5) Flange	Flange for Torus connection	MDC Manufacturing Inc. Rotatable Del-Seal Flange #F16501400R 304SS
(15) Flange	Torus pumping pod valve and bellow flanges	Flowline 16 inch class 150 lap joint flange 304SS
(5) Valve	Turbopump isolation valve	Vacuum Research Co. #16T1EPLS with limit switches Viton O-rings and non-magnetic components.
(5) Bellows	Bellows for vibration isolation	Anaconda bellows 16 inch #16EL45 304SS
(5) Pump	Turbomolecular pump for torus high vacuum	Leybold-Heraeus TMP3500 cat. #85361-1 modified for 1 x 10^8 rad exposure

Table 4-3. Torus High Vacuum Pumping System Components (Continued)

(Quantity) Element	Capacity-Purpose	Identification (Potential Suppliers)
(5) Bolt Set	For flange attachment at torus	MDC Manufacturing Inc. #BA-1650 304SS
(1) Copper Gasket	Gasket set for flange attachment at torus	MDC Manufacturing Inc. #GK-1650
(240) Bolt Nut and Washer assemblies	For 16 inch valve and turbo pump attachment	1 inch -8NC x 3.25 inch long bolts with washers and nuts 304SS
(5) Turbo Pump Control Cable	Connects frequency converter to turbo pump	Leybold-Heraeus Inc. 165 foot long cable
(30 foot) Pipe	Pump pod fabrication	16 inch schedule 5 pipe 304SS
(3 foot) Pipe	Pump pod fabrication	14 inch schedule 5 pipe 304SS
(5) Copper Disc	Microwave shield material	.062 thick copper x 14 inch diameter discs
(5) Stainless Steel Disc	Pod closure	.5 inch thick x 16 inch diameter 304SS
(5) Backout Jacket	For outgassing TMP3500	Leybold-Heraeus Inc. #85367-1

Table 4-3. Torus High Vacuum Pumping System Components (Continued)

(Quantity) Element	Capacity-Purpose	Identification (Potential Suppliers)
(5) Water Cooling Unit	Provides cooling water to TMP3500	Leybold-Heraeus Inc. #99239003
(5) Water Flow Switch	Cooling water flow interlock to TMP3500	Leybold-Heraeus Inc. #85326
(5) Bellows	Pumping pod isolation from mirror cavity	Metal Bellows Corp., 1000 series 1401K x 12 inch 340SS
(10) Flange	Flange for bellows installation	MDC Manufacturing Inc. non-rotatable conflat #F16501400
(2) Copper Gasket Set	For flanged bellows assembly	MDC Manufacturing Inc., OFHC copper gasket set #GK-1650
(10) Bolt Set	For flanged bellows assembly	MDC Manufacturing Inc., bolt set #BA-1650
(5) Flange	For mounting microwave shield	MDC Manufacturing Inc., double-sided flange #FD16501400

4.3.3 Torus Pumping System Interfaces - The Primary Torus Pumping System has major interfaces with the following three systems, which are discussed below.

- Toroidal Vessel
- Instrumentation and Control
- Utilities

4.3.3.1 Toroidal Vessel - The turbomolecular pumps will be mounted on cavities 2, 7, 16, 24, and 30 on the outboard side 1.02 inches below the torus horizontal midplane. The stainless steel pumping duct interfaces with a round port having a 14.0 inch inside diameter flange employing a Conflat surface. The microwave shield is mounted inside a double faced Conflat flange containing cooling water tube connections to the shield. This segment is thus easily replaceable in the event of a failure. The microwave absorbing duct flange, which mates with the microwave shield flange contains a Conflat seal, while the flange on the other end, which mates with the aluminum valve body elastomer seal is smooth faced.

Provisions have been made for adding five turbomolecular pumps at some future time. In the upgraded mode, pumps will be located on cavities 5, 12, 20, 27, and 34. The five baseline pumps will remain on the cavities noted above. The selected cavities from the upgraded configuration use foreline segements identical to those in the baseline, thus minimizing the additional costs. Drawings depicting the upgrade configuration are a TITLE II effort.

The turbomolecular pumps will be vibration isolated via two sixteen-inch bellows, to minimize vibration being transmitted to the torus, which may interfere with diagnostic measurements. The details of the isolation system and mechanical supports will be developed during Title II.

4.3.3.2 Instrumentation and Control - Control of the Primary Torus Pumping System for both automatic and manual sequencing modes will be available in the control room only. The torus roughing and high vacuum pumping system control schematic is shown in Figure 4-8. The following operational limits and requirements are imposed on the torus turbomolecular pump system.

- All vacuum valves will have limit switches for positive identification of position status.
- The turbomolecular pump torus isolation gate valves (V1-1 thru V1-5) must be closed to initiate roughing of the torus by pump station #1.
- The turbomolecular pump torus isolation gate valves (V1-1 thru V1-5) must be closed to initiate roughing of the torus turbopumps via their respective foreline pumps.
- Pressure inside the turbopump must reach the 10^{-2} torr level prior to starting the pumps.
- Starting the turbomolecular pumps is independent of torus pressure status and can be performed manually or automatically from the control room.
- The turbopumps will not start unless their respective flow sensor and temperature sensor interlocks in the water coolers are satisfied.
- Opening of the sixteen-inch isolation valve on each pumping module is interlocked and requires a close signal from the limit switches on the automatic vent valves (V2-1 thru V2-5) and the leak detection valves (V3-1 thru V3-5).
- A torus pressure greater than TBD torr during plasma burn or cleanup will cause the gas flow inbleed to be terminated and the turbopump sixteen-inch isolation valves to close. Isolation valves to the roughing system (valves V9 and V5-2) can be opened.
- LN_2 liquid levels will be monitored and maintained automatically in the foreline pump cold traps.
- Torus pumping can proceed with fewer than five turbopumps.
- Turbomolecular pumps A, B, C, D or E can be used independant of one another, or in any combination of two or more, to maintain a high vacuum in the torus so long as their respective forepumping systems (pump stations #2 and 3) are operating.
- Starting of the rotary vane and rotary piston pumps in stations #2 and/or #3 requires that trap cooldown has been initiated and the condensing surface(s) has reached a TBD temperature. Additionally, valves V4-1 thru V4-4, V5-2 and V5-3, V6-2 and V6-3, plus V7-2 and V7-3 must be closed.
- The blower(s) will start automatically by means of a circuit interlocked to the rotary vane pump starting circuit.
- The blower(s) can be stopped after it automatically starts, however it will cause valves V4-1 thru V4-5, plus V5-2 and V5-3 to close.

- Turbomolecular pumps A, B, C, D and E will not start unless valves V1-1 thru V1-5 and V2-1 thru V2-5 are closed, the forepumping stations #2 and #3 are operating, foreline pressures are less than 1 x 10^{-2} torr, the water coolers are operating, and valve V4-1 thru V4-4 plus V5-2 and V5-3 are open.
- Valves V3-1 thru V3-5 plus V7-2 and V7-3 can be opened as needed when the torus system is in a leak detection mode and the appropriate forepumping plus turbomolecular pump combination is operating.
- If a forepumping station cold trap condensing surface temperature rises above a TBD value, all open valves permitting pressure reduction in the affected system will close, the pumping system(s) will stop and appropriate vent valves to the affected pumps (eg., V2-1 thru V2-5 plus V6-2 and V6-3) will open.
- Valves V1-1 thru V1-5 cannot be opened unless torus pressure is in the 10^{-3} torr region, inlet pressure to the turbomolecular pump(s) is less than 1 x 10^{-5} torr, the appropriate pumping systems are operating and V9 and V12 are closed.
- A temperature sensor located near the attachment point of valves V1-1 thru V1-5 to the elbow will cause plasma generation to be terminated if the temperature at that location exceeds a TBD value.
- A temperature sensor located on the inlet flange of each turbomolecular pump (A, B, C, D, E) will terminate plasma generation and/or pump bakeout if temperature at that location exceeds a TBD value.
- If a mechanical failure occurs in a turbmolecular pumps activating the vibration sensor, gas flow for plasma generation will be terminated the affected pump will shutdown and the appropriate valves in the V1 and V4 series will close and it's V2 series vent valve will open.
- If turbomolecular pump water cooler fails to provide adequate cooled water, the appropriate valves in the V1 and V4 series will close, the turbomolecular pump will shutdown and its V2 series vent valve will open.

4.3.3.3 Utilities - Requirements are shown in Table 4-4 for the torus turbomolecular pump installation.

TABLE 4-4. Utility Requirements for the Torus High Vacuum System

Turbomolecular Pumps (Quantity 5)	
Electrical	220V/20 Amps/60 Hz
Cooling	Integral Refrigerator
Water Cooling Unit (Quantity 5)	
Electrical	110V/7A/60 Hz
Valves (Quantity (5)	
Electrical	110V/53mAmp
Air	65 psi

4.3.4 Torus Pumping System Environment - The considerations of the EBT-P x-ray, magnetic field and microwave environments on the design of the Primary Torus Vacuum System are presented below.

4.3.4.1 X-Ray

The calculated 10 year accumulated x-ray close in the vicinity of a torus turbopump station on the outboard side is approximately 5 x 10^7 rads. Conflat seals will be used where the pump duct attaches to the torus. The sixteen-inch and four-inch vacuum valves in each pump station contain polyethylene air supply lines between the solenoid and pneumatic operator which will have to be changed to stainless steel or copper tubing.

As indicated above, the 10 year accumulated x-ray dose in the vicinity of the ten-inch valve which isolates the turbopump from the torus is approximately 5 x 10^7 rad. Viton begins to demonstrate hardening and thus a lack of memory when it experiences an accumulated dosage of about 1 x 10^7 rad. There are no other serious considerations at this location, such as thermal extremes or microwave damage. The x-ray deterioration is considered tolerable because it can be managed through routine maintenance activities. Substituting the 16 inch elastomer sealed valve with an all metal sealed unit represents a significant cost increase. The metal seals in such valves would also require frequent replacement and are thus not considered to be of significant advantage for EBT-P.

Piping runs which incorporate valves will be designed with sufficient flexibility via bellows to facilitate valve substitution.

4.3.4.2 Magnetic Fields - Turbomolecular vacuum pumps are sensitive to stray magnetic fields. Leybold-Heraeus states that the maximum field to which the TMP3500 may be subjected is 30 gauss in the radial direction and 150 gauss axially. The EBT-P field strength at the turbo pump is calculated (Section 5.4.3) to be 6 gauss. Each of the sixteen and four-inch aluminum valves in the high vacuum duct assembly contain solenoids for controlling pnuematic operation of the disc and carriage assembly. The solenoid manufacturer feels that if the magnetic fields surrounding the valve are uniform, there will be no need to mount them remotely or provide shielding.

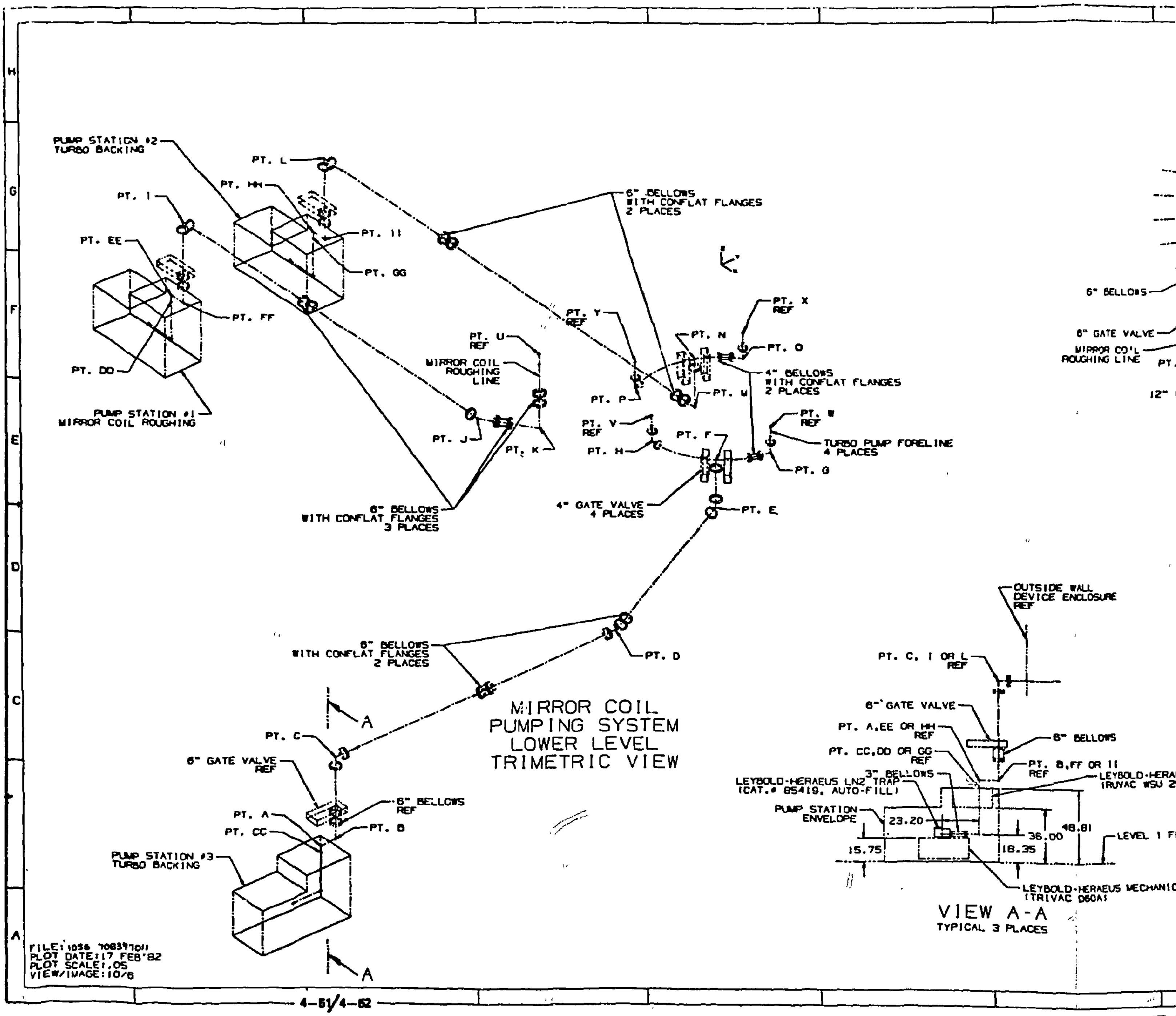
Turbomolecular vacuum pumps have internal electrical motors and other magnetic material in their construction. Their effects on the EBT-P fields will be determined during Title II Design. An additional Title II activity is to determine the magnitude of the magnetic field during off-normal conditions, such as a quench, and to assess the impact on the vacuum system components.

4.3.4.3 Microwaves - Turbomolecular pumps and vacuum isolation valves in each pumping station are protected by a microwave attenuating screen. A discussion of the attenuation capabilities and physical characteristics of the microwave protection system are presented in sections 4.3.2. and 5.3.1. As previously discussed, the recommended shield and absorbing duct will limit microwave power in the vicinity of the valves to only a few watts.

4.3.5 Torus Pumping System Performance - The performance of the Primary Torus Vacuum System during initial pumpdown and during plasma operation are discussed.

4.3.5.1 Torus Pumpdown - Base Pressure - The roughing system, reference section 4.2 will be utilized to attain a torus pressure in the range of 10^{-2} to 10^{-3} torr before the turbomolecular pumps are valved into the torus. The high vacuum pumps must further reduce the pressure to 2×10^{-7} torr.

The torus pumping system consists of five turbomolecular pumps located on the torus as shown in Figure 4-2, and have a combined effective hydrogen speed of 1.0×10^4 liters/sec


PUMP STATION #2
TURBO BACKING
PT. L
PT. HH
PT. I
PT. II
PT. EE
PT. GG
PT. FF
PT. DD
PUMP STATION #1
MIRROR COIL ROUGHING
6" BELLOWS
WITH CONFLAT FLANGES
2 PLACES
PT. Y
REF
PT. X
REF
PT. N
PT. O
PT. U
REF
MIRROR COIL
ROUGHING
LINE
4" BELLOWS
WITH CONFLAT FLANGES
2 PLACES
PT. P
PT. M
PT. J
PT. K
PT. V
REF
PT. H
PT. F
PT. W
REF
TURBO PUMP FORELINE
4 PLACES
PT. G
6" BELLOWS
WITH CONFLAT FLANGES
3 PLACES
4" GATE VALVE
4 PLACES
PT. E
6" BELLOWS
WITH CONFLAT FLANGES
2 PLACES
PT. D
MIRROR COIL
PUMPING SYSTEM
LOWER LEVEL
TRIMETRIC VIEW
A
PT. C
6" GATE VALVE
REF
PT. A
PT. CC
6" BELLOWS
REF
PT. B
PUMP STATION #3
TURBO BACKING
FILE: 1056 70839701
PLOT DATE: 17 FEB'82
PLOT SCALE: .05
VIEW/IMAGE: 10/6
A
OUTSIDE WALL
DEVICE ENCLOSURE
REF
PT. C, I OR L
REF
6" GATE VALVE
PT. A, EE OR HH
REF
6" BELLOWS
PT. CC, DD OR GG
REF
PT. B, FF OR II
REF
LEYBOLD-HERAEUS LN2 TRAP
(CAT.# 85419, AUTO-FILL)
3" BELLOWS
PUMP STATION
ENVELOPE
23.20
36.00
48.81
LEVEL 1 FL
15.75
18.35
LEYBOLD-HERAEUS MECHANIC
(TRIVAC D60A)
VIEW A-A
TYPICAL 3 PLACES
6" BELLOWS
6" GATE VALVE
MIRROR COIL
ROUGHING LINE
12"
4-51/4-82

FI

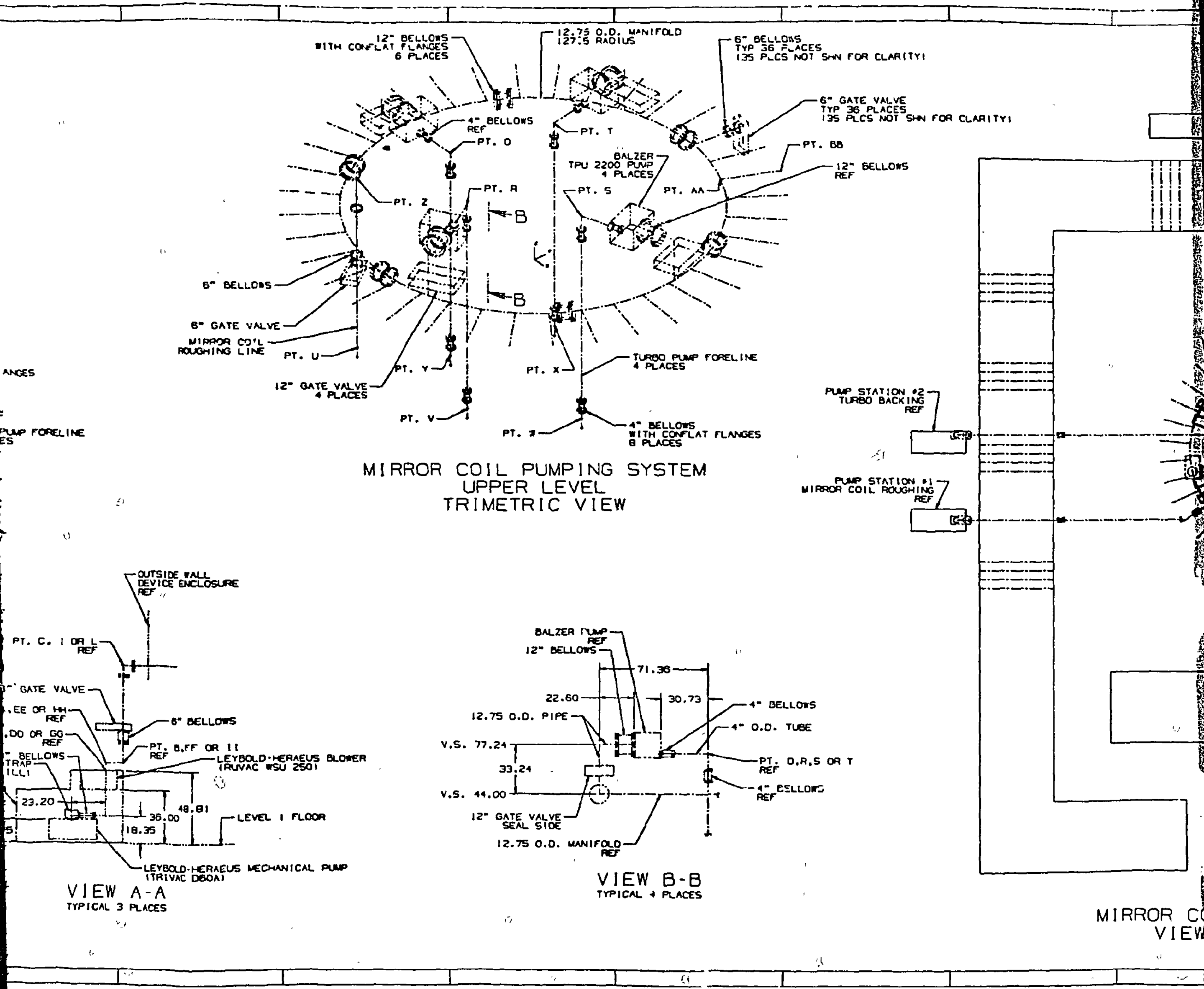

12" BELLOWS WITH CONFLAT FLANGES 6 PLACES
12.75 O.D. MANIFOLD 127.5 RADIUS
6" BELLOWS TYP 36 PLACES (35 PLCS NOT SHN FOR CLARITY)
6" GATE VALVE TYP 36 PLACES (35 PLCS NOT SHN FOR CLARITY)
4" BELLOWS REF
PT. Q
PT. T
PT. BB
BALZER TPU 2200 PUMP 4 PLACES
12" BELLOWS REF
PT. R
PT. S
PT. AA
PT. Z
6" BELLOWS
6" GATE VALVE
MIRROR COIL ROUGHING LINE
PT. U
PT. Y
PT. X
TURBO PUMP FORELINE 4 PLACES
12" GATE VALVE 4 PLACES
PT. V
PT. W
4" BELLOWS WITH CONFLAT FLANGES 8 PLACES
MIRROR COIL PUMPING SYSTEM
UPPER LEVEL
TRIMETRIC VIEW
PUMP STATION #2 TURBO BACKING REF
PUMP STATION #1 MIRROR COIL ROUGHING REF
OUTSIDE WALL DEVICE ENCLOSURE REF
PT. C, I OR L REF
GATE VALVE
EE OR HH REF
DD OR GG REF
BELLOWS
TRAP
6" BELLOWS
PT. B,FF OR II REF
LEYBOLD-HERAEUS BLOWER (RUVAC WSU 250)
23.20
36.00
48.81
18.35
LEVEL I FLOOR
LEYBOLD-HERAEUS MECHANICAL PUMP (TRIVAC D60A)
VIEW A-A
TYPICAL 3 PLACES
BALZER PUMP REF
12" BELLOWS
71.38
22.60
30.73
12.75 O.D. PIPE
4" BELLOWS
4" O.D. TUBE
V.S. 77.24
33.24
V.S. 44.00
PT. Q,R,S OR T REF
4" BELLOWS REF
12" GATE VALVE SEAL SIDE
12.75 O.D. MANIFOLD REF
VIEW B-B
TYPICAL 4 PLACES
MIRROR C
VIEW

FIG. 4-14

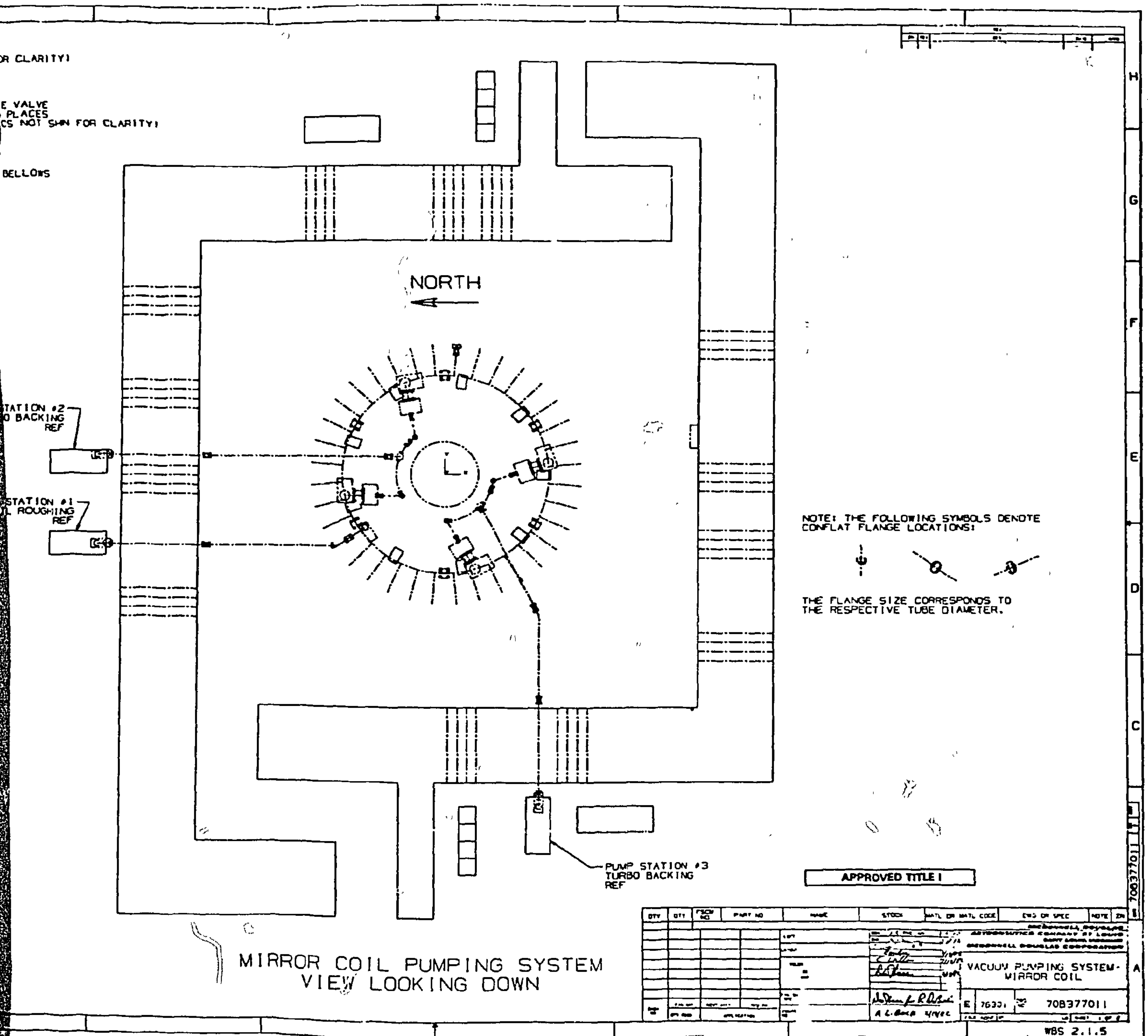

NORTH
PUMP STATION #3
TURBO BACKING
REF
NOTE: THE FOLLOWING SYMBOLS DENOTE
CONFLAT FLANGE LOCATIONS:
THE FLANGE SIZE CORRESPONDS TO
THE RESPECTIVE TUBE DIAMETER.
APPROVED TITLE I
MIRROR COIL PUMPING SYSTEM
VIEW LOOKING DOWN
VACUUM PUMPING SYSTEM-
MIRROR COIL
708377011
WBS 2.1.5

FIG. 4-14

and nitrogen speed of 5 x 10^3 liter/sec. The predicted torus gas loads are discussed in section 5.7. These gas loads, when combined with the system nitrogen pumping speed yield a predicted base pressure for the EBT-P torus of 2 x 10^{-7} torr. The calculated time to reach the 2 x 10^{-7} torr pressure is shown in Figure 4-14.

4.3.5.2 Hydrogen Pumping During Burn - The five torus turbomolecular pumps will be the only pumping source for H_2 during plasma operation. The design criteria require a hydrogen pumping speed of 10000 ℓ/s betweem 1 x 10^{-6} and 1 x 10^{-4} torr.

The table below lists the minimum capabilites which the turbomolecular pump system will fulfill.

H_2 Feed Rate TL/S	Torus Pressure Torr	Plasma Burn Time Hrs
.01	1 x 10^{-6}	16
.1	1 x 10^{-5}	16
1.0*	1 x 10^{-4}	8

* Added at 11 September 1981 Design Criteria Review at ORNL

4.4 MC DEWAR PUMPING SYSTEM

The MC Dewar Pumping System consists of a roughing system, and a manifolded high vacuum pumping system serving the 36 superconducting magnets. This pumping system is completely independent of the torus vacuum system.

4.4.1 MC Dewar Roughing and Forepumping - The basic purposes of the roughing and forepumping systems are to reduce pressure in the MC dewar insulating space from atmospheric to the 10^3 torr region and to provide foreline pumping for the four high vacuum turbomolecular pumps.

4.4.1.1 Roughing and Forepumping Requirements - Requirements imposed upon these systems dedicated to the MC dewars are:

- The rough pumping system must have the capability for reducing dewar insulating pressure from atmospheric to the 10^{-3} torr range. This application will occur during end-of-the-year maintenance operations on the helium liquifier system. During this time it is tentatively assumed all high vacuum valve elastomer seals will be replaced, thus pressure in all systems will have been returned to atmospheric.
- It must be capable of evacuating the high vacuum pumping manifold and the turbomolecular pumps without affecting the pressure status of the MC dewars.
- It must be capable of foreline pumping the high vacuum turbopumps.

4.4.1.2 Roughing System Description - The MC dewar roughing system is comprised of three 164 CFM root blowers backed by three 37 CFM rotary vane vacuum pumps. The system functions independent of the torus roughing system. As with the torus system these pumps will be located outside the bioshield wall. This location is necessary to eliminate any need for equipment modifications which would be required if the equipment were exposed to the radiation environment inside the device enclosure. The pumping systems locations are shown in Figure 4-14. Equipment identification is listed in Table 4-5.

Table 4-5. MC Dewar Roughing and Forepumping System Components

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(4) Flange with Pipe	Turbopump outlet size modifier	Balzers #BP217128-X 304SS
(4) Flange	Turbopump outlet size modifier	Perkin Elmer non-rotatable CF flange #262-4050 bore to 3.0 inch I.D. 304SS
(4) Seals	For turbopump outlet port	Balzers BP213195-T Viton
(14) Bellows	4 inch foreline expansion-contraction	Perkin-Elmer flexible coupling #2674400304SS
(24) Flanges	4 inch foreline fabrication	Perkin-Elmer non-rotatable conflat flange #262-4040 304SS
(28) Bolts, Nuts and Washer Sets	4 inch foreline assembly	Perkin-Elmer assembly kit model no. 269-1010 304SS
(2) Tee	6 inch foreline fabrication	Nor-Cal Products Co. Tee #G-7W-600V 304SS
(4) End Cap	Foreline tube size conversion	Nor-Cal Products Co. end cap #G-2W-600 304SS

Table 4-5. MC Dewar Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(8) Bellows	6 inch foreline fabrication	Perkin-Elmer flexible coupling #2676400 304SS
(18) Flanges	6 inch foreline fabrication	Perkin-Elmer conflat non-rotatable #2626040 304SS
(3) Copper Gasket Kit	4 inch foreline assembly	Perkin-Elmer gasket model #268-4000
(2) Copper Gasket Kit	6 inch foreline assembly	Perkin-Elmer gasket model #268-6000
(17) Bolt, Nut and Washer Set	6 inch foreline assembly	Perkin-Elmer assembly kit model no. 269-1210
(100) Feet Tube	Foreline fabrication	4 inch O.D. X 3.83 inch I.D. 304SS tube
(148) Feet Tube	Foreline fabrication	6 inch O.D. X 5.83 inch I.D. 304SS tube
(12) Flange	6 inch foreline fabrication	Nor-Cal Products Co. ASA flange #ASA11-000 bore to 6.01 inch I.D. 304SS

Table 4-5. MC Dewar Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(9) Flange	6 inch foreline fabrication	Nor-Cal Products Co. ASA flange #ASA11-000G Bore to 6.01 inch I.D. 304SS
(3) Bellows	6 inch foreline fabrication	Anaconda bellows #6EL45 304SS
(3) Valve	Backing pump isolation	Vac Research Man., Co. 6 inch 94577-101LS with limit switches and viton O-ring
(3) Flange	WSU-250 Blower inlet adapter	Leybold-Heraeus Inc. rotatable sleeve flange 6 inch Cat. #89542
(3) Flange	WSU-250 Blower inlet adapter.	Leybold-Heraeus Inc rotatable sleeve flange 3 inch Cat. #89540
(9) Bolt, Nut and Washer Kit	6 inch foreline assembly	Nor-Cal Products Co bolt and nut kit #BA-11 304SS
(6) Bolt, Nut and Washer Kit	6 inch foreline assembly	Nor-Cal Products Co. bolt and nut kit #BA-6 304SS

Table 4-5. MC Dewar Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(3) Bolt, Nut and Washer Kit	6 inch foreline assembly	Nor-Cal Products Co. bolt and nut kit #BA-9 304SS
(3) Blower	For backing turbo pumps	Leybold-Heraeus Inc. WSU-250 Cat. #11623-1
(3) Sealing Disc Set	WSU-250 inlet-outlet seal	Leybold-Heraeus Inc. Cat. #910-181-605
(3) Reducing Tube	WSU-250 blower inlet tube size reduction	Leybold-Heraeus Inc. reducing tube (6 inch to 3 inch) Cat. #26995
(3) Adapter	WSU-250 blower outlet size reducer	Leybold-Heraeus Inc. KF/ASA Adapter #98-278-0441
(6) Clamp	For KF40 ports on LN_2 trap in foreline	Leybold-Heraeus Inc. Clamp Cat. #18343
(3) Liquid Nitrogen Trap	Reduction of hydrocarbon back-streaming from backing pump	Leybold-Heraeus Inc. adsorbtion trap Cat. #85419

Table 4-5. MC Dewar Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(3) Rotary Vane Vacuum Pump	For backing blower WSU-250	Leybold-Heraeus Inc. D60A complete Cat. #895-862-336
(3) Backing Pump Exhaust Filter	For D60A pump	Leybold-Heraeus Inc. exhaust filter Cat. #18915
(7) Vent Valves	For foreline venting and nitrogen inbleed	Vacuum Research Man. Co. 1 inch 1T1EPLS with limit switch and Viton O-rings
(4) Valves	Isolate each turbo foreline	Vacuum Research Man. Co. 4 inch valve #4T1EPLS with limit switches and Viton O-rings
(8) Flanges	Attachment of 4 inch valves	Nor-Cal Products Co. 4 inch ASA flange #ASA-9-000 bore to 4.01 inch I.D. 304SS
(8) Bolt, Nut and Washer Kit	Attachment of 4 inch valves	Nor-Cal Products Co. Bolt and Nut Kit #BA-9 304SS

Table 4-5. MC Dewar Roughing and Forepumping System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(8) Flanges	For foreline venting and nitrogen inbleed	One-inch class 150 lap joint flange 304SS
(7) Stub Ends	For foreline venting and nitrogen inbleed	One-inch schedule 5 stub end 304SS

The pumps selected for use are the Leybold-Heraeus WSU-250 integral bypass, sealed motor roots blower backed by a Leybold-Heraeus D60A two-stage rotary vane mechanical pump.

A 37CFM mechanical pump and 164CFM roots blower is used for roughing the 36 MC dewars through the high vacuum manifold. Identical roughing systems are used for foreline pumping the four high vacuum turbomolecular pumps.

Pump station number one is used for dewar roughing and is located outside the north wall of the device enclosure. It is isolated from the roughing line with a six-inch bellows and gate valve. The six-inch roughing line continues through the device enclosure wall, along the ceiling of the lower level, and up to the twelve-inch manifold located above the second level floor. This manifold serves the 36 MC dewars via six-inch lines extending from the manifold radially outward to each dewar. A valve is employed on each dewar to allow simultaneous or individual pumping.

A six-inch gate valve is located at the point where the roughing line attaches to the manifold. This valve allows the roughing line to be isolated from the manifold when roughing operations are not being performed. This is necessary since the twelve-inch manifold also serves as the high vacuum pumping manifold.

Pump stations number two and three are located outside the north and west walls of the device enclosure on the lower level. Each station consists of a 164CFM roots blower backed by a 37CFM rotary vane mechanical pump, and each is used to provide foreline pumping for two 2200 liter/sec turbomolecular pumps.

As shown in Figure 4-14 both pump stations are isolated from the roughing lines by six-inch bellows and valves. The lines penetrate the device enclosure, continue along the ceiling of the first level and then are connected via four-inch manifolds to pairs of turbomolecular pumps. Each turbomolecular pump is equipped with a four-inch gate valve on its foreline pumping port.

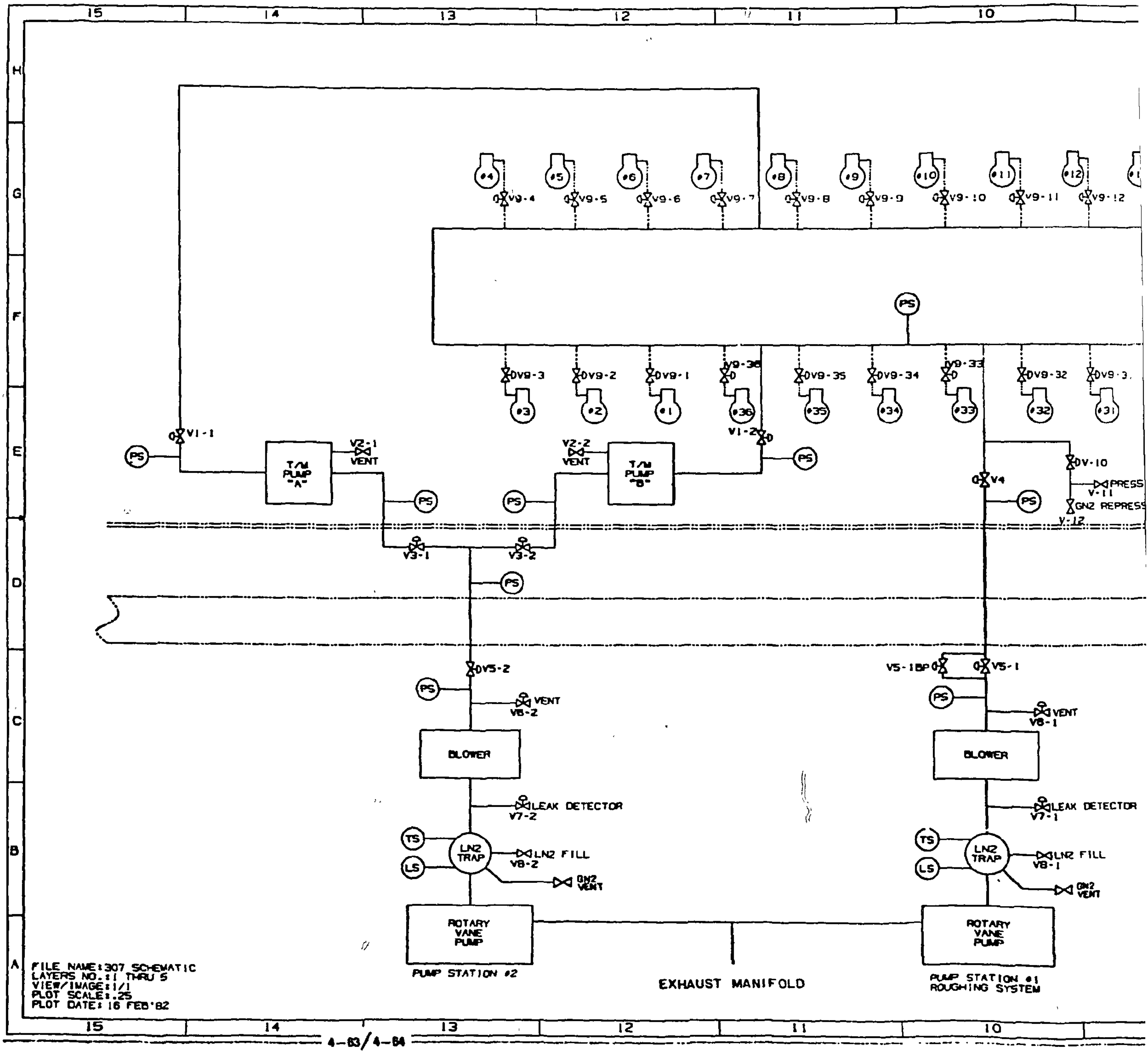
Liquid nitrogen cold traps are located between the roots blower and rotary vane mechanical pumps in each pumping station. Each trap is provided with automatic liquid nitrogen fill provision including liquid level sensors and solenoid fill valves. Bellows are provided to facilitate removal and cleaning of each trap.

Detailed description of the WSU-250 integral bypass roots blower with sealed drive motor and of the D60A two-stage rotary vane mechanical pump are provided in Section 4.2.2. Their performance and technical data is also provided.

All vacuum lines will be prefabricated, cleaned, and leak checked in St. Louis. ORVIP site operations will be limited to maintaining cleanliness of components during installation and leak checking the completed assembly. Bellows are employed throughout the roughing lines and forelines to facilitate assembly and provide for expansion and contraction. They are also located where required for valve removal during maintenance periods.

4.4.1.3 Roughing System Interfaces - The MC dewar roughing system interfaces with four systems as described below:

- MC Dewar
- Instumentation and Control
- Cryogenics
- Utilities


15
14
13
12
11
10
H
G
F
E
D
C
B
A
#4
#5
#6
#7
#8
#9
#10
#11
#12
V9-4
V9-5
V9-6
V9-7
V9-8
V9-9
V9-10
V9-11
V9-12
PS
DV9-3
DV9-2
DV9-1
V9-36
DV9-35
DV9-34
V9-33
DV9-32
#3
#2
#1
#36
#35
#34
#33
#32
#31
V1-1
V1-2
T/M PUMP "A"
T/M PUMP "B"
V2-1 VENT
V2-2 VENT
V3-1
V3-2
V4
DV-10
PRESS V-11
GN2 REPRESS V-12
DV5-2
V5-1BP
V5-1
VENT V6-2
VENT V6-1
BLOWER
LEAK DETECTOR V7-2
LEAK DETECTOR V7-1
TS
LS
LN2 TRAP
LN2 FILL V8-2
LN2 FILL V8-1
GN2 VENT
ROTARY VANE PUMP
PUMP STATION #2
EXHAUST MANIFOLD
PUMP STATION #1 ROUGHING SYSTEM
FILE NAME:307 SCHEMATIC
LAYERS NO.:1 THRU 5
VIEW/IMAGE:1/1
PLOT SCALE:.25
PLOT DATE: 16 FEB'82
4–83/4–84

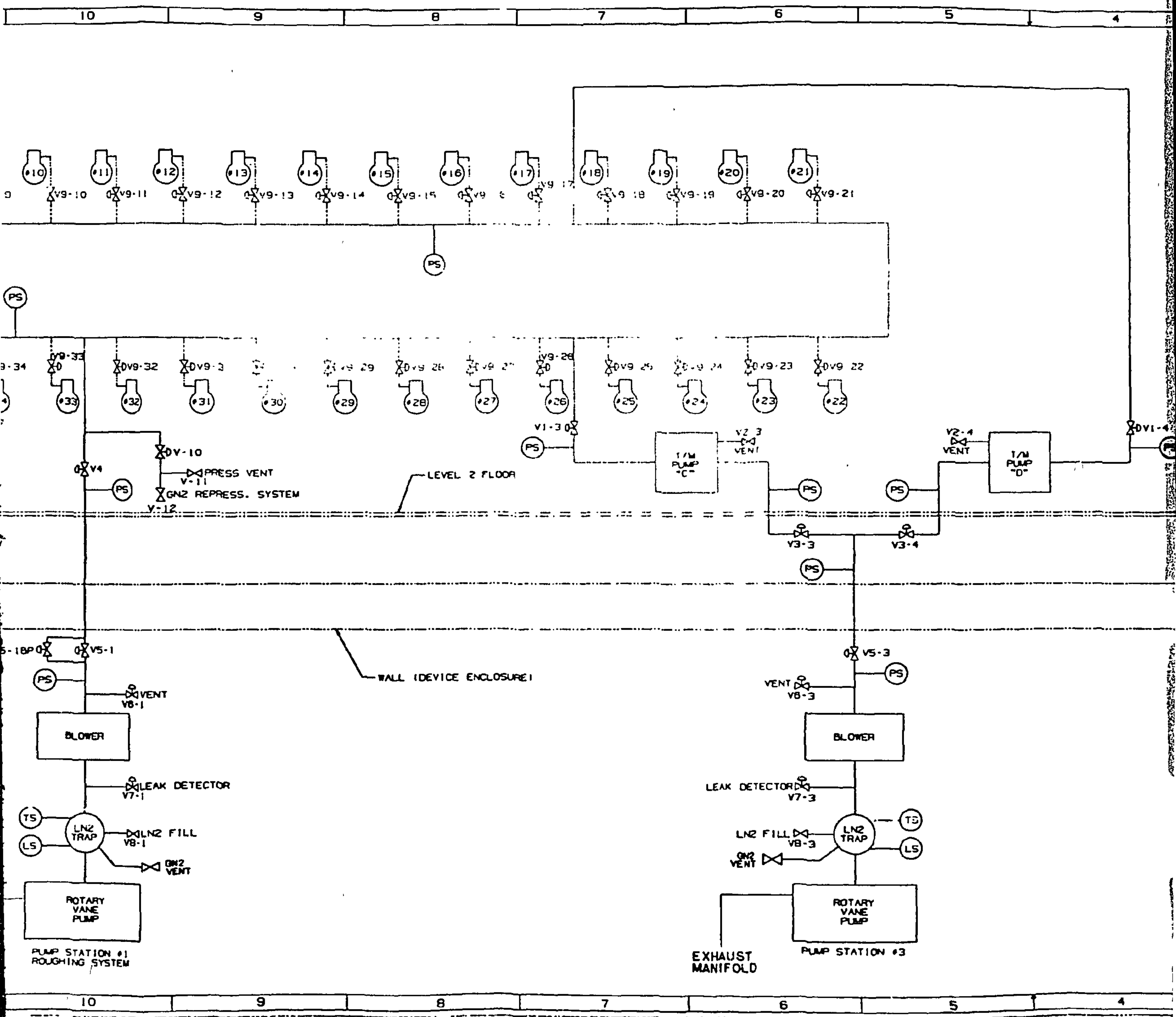

PS
V9-10
V9-11
V9-12
V9-13
V9-14
V9-15
V9-28
DV9-32
V9-33
DV1-4
V1-3
V2-3
VENT
V2-4
T/M PUMP "C"
T/M PUMP "D"
V4
DV-10
PRESS VENT
V-11
GN2 REPRESS. SYSTEM
V-12
LEVEL 2 FLOOR
V3-3
V3-4
V5-1
V5-3
WALL (DEVICE ENCLOSURE)
VENT
V6-1
V6-3
BLOWER
LEAK DETECTOR
V7-1
V7-3
TS
LS
LN2 TRAP
LN2 FILL
V8-1
V8-3
GN2 VENT
ROTARY VANE PUMP
PUMP STATION #1 ROUGHING SYSTEM
PUMP STATION #3
EXHAUST MANIFOLD

FIG. 4-15

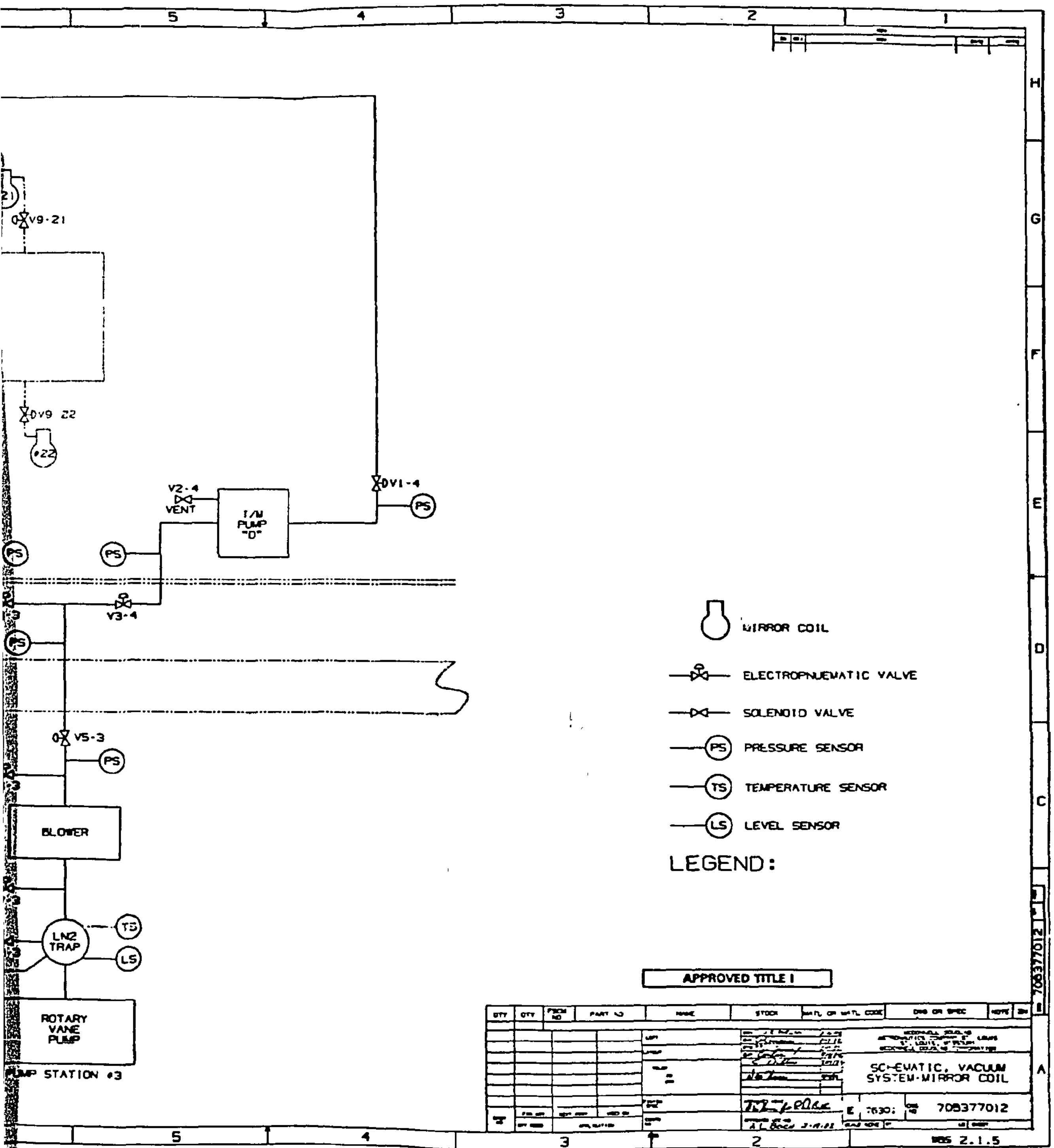

V9-21
DV9 22
#22
V2-4
VENT
T/M PUMP "D"
DV1-4
PS
V3-4
V5-3
BLOWER
LN2 TRAP
TS
LS
ROTARY VANE PUMP
PUMP STATION #3
MIRROR COIL
ELECTROPNUEMATIC VALVE
SOLENOID VALVE
PRESSURE SENSOR
TEMPERATURE SENSOR
LEVEL SENSOR
LEGEND:
APPROVED TITLE I
SCHEMATIC, VACUUM SYSTEM-MIRROR COIL
76301
705377012
WBS 2.1.5

FIG. 4-15

4.4.1.3.1 MC Dewar - The roughing system interfaces with each MC dewar at the inboard six-inch vacuum isolation valve located near the top of the stack, 44 inches above the magnet axis. The valve will be furnished by MDAC to the mirror coil vendor. It will contain a Viton elastomer seal at the flange interface with the six-inch bellows. The valve will be electropneumatically operated and can be activated only from the control room. The bellows facilitates valve removal for seal replacement during the annual maintenance period.

4.4.1.3.2 - Instrumentation and Control - The 36 MC dewars and the high-vacuum manifold can be evacuated from atmospheric to the 10^3 torr region torr only with the roughing system, pump station #1. The schematic of the MC dewar pumping system is presented in Figure 4-15.

- Starting of the rotary vane pump at station #1 requires that trap cooldown has been initiated and the condensing surface has reached a TBD temperature. Additionally, valve V5-1, V5-1BP, V6-1, V7-1, V4 and V10 must be closed.
- The blower(s) will start automatically by means of a circuit interlocked to the rotary vane pump starting circuit.
- The roughing blower can be stopped after it automatically starts, however it will cause valves V5-1, V5-1BP, and V4 to close.
- Valves V5-1 and V4 can be opened only if the MC dewar high vacuum manifold pressure is within TBD torr and TBD torr, the roughing pump system is running, both foreline pressure sensors are at less than 1 X 10^{-2} torr, and valves V1-1 thru V1-4 are closed. If the manifold pressure is higher than TBD, valve V5-1 will not open and V5-1BP will open to control rate of pump down.
- During evaucation of all the MC dewar insulating volumes from atmospheric pressure, valves V9-1 thru V9-36 will initially be opened when the insulating volumes and the high vacuum manifold are at atmospheric pressure. Valves V4 and V5-1BP will then be opened to reduce pressure in all of the insulating volumes simultaneously at a controlled rate. At a high vacuum manifold pressure of TBD, V5-1BP will close and V5-1 will open.
- Valves V5-1 by-pass (V5-1BP) and V5-1 are interlocked to a pressure sensor in the high vacuum manifold. The pressure at which either of the two valves can be utilized for a mirror coil roughing scenerio is TBD.

- If the trap condensing surface temperature rises above a TBD temperature due to a liquid nitrogen feed failure while running in an isolated mode (Valves V4, V5-1 and V5-1BP are closed), or while evacuating the MC dewars and/or high vacuum manifold, valves V9-1 thru V9-36 and/or V4, V5-1 and V5-1BP will close. The roughing system will stop and valve V6-1 will open.
- Valve V10 cannot be opened if valves V4, V5-1 and/or V5-1BP, V9-1 thru V9-36, and V1-1 thru V1-4 are opened.
- Valve V11 is a normally-open valve with close sequencing circuitry designed so that V10 does not experience more than a one atmosphere pressure differential on the gate.
- Valve V7-1 can be opened only when the system is in a leak detection mode.
- In the event that one or more MC dewars should require evacuation from atmospheric pressure while the remaining MC dewars are at less than 10^{-3} torr, it will be necessary to repressurize the high vacuum manifold to atmospheric. Only those V9 valves associated with the affected mirror coils will be opened for evacuation at a controlled rate thru V5-1BP with pump station #1.
- Starting of the rotary vane pumps in stations #2 and/or #3 requires that trap cooldown has been initiated and the condensing surface(s) has reached a TBD temperature. Additionally, valves V3-1 thru V3-4, V5-2 and V5-3, V6-2 and V6-3, plus V7-2 and V7-3 must be closed.
- The forepump blower(s) can be stopped after it automatically starts, however it will cause valves V3-1 thru V3-4, V5-2 and V5-3, to close.
- Following evacuation of the MC dewar insulating volumes to the 10^{-3} torr region with the roughing system station #1, valves V9-1 thru V9-36 are to remain open for further pressure reduction by the turbomolecular pump system.
- If a forepumping or roughing pump station cold trap condensing surface temperature rises above a TBD value, all open valves permitting pressure reduction in the affected system will close, the appropriate pumping system(s) will stop, and vent valves to the effected pumps (eg. V2-1 thru V2-4 and V6-1 thru V6-3) will open.

4.4.1.3.3 Cryogenics - The three liquid nitrogen traps in the pumping stations require liquid nitrogen. Liquid nitrogen is required whenever the rotary vane pumps are operating to prevent oil contamination of the roots blower. The level is automatically maintained with a liquid level sensor and solenoid fill valve provided with each trap. Total LN_2 consumption is estimated to be 8 liters per day per trap.

4.4.1.3.4 Utilities - All utility requirements for the MC Dewar Roughing System are shown in Table 4-6.

Table 4-6. MC Dewar Roughing System Utilities Requirements

WSU 250 (Quantity 3)	
Electrical	208V, 3 Phase, 60 Hz 0.8HP
Cooling	Air Cooled
D60A (Quantity 3)	
Electrical	208V, 3 Phase, 60 Hz 2 HP
Cooling	Air Cooler
Valves (Quantity 48)	
Electrical	110V/60 Hz
Air	65 psig

4.4.1.4 Roughing System Environment - The susceptibility of the MC dewar roughing system components to the x-ray and magnetic field environments is discussed below. MC dewar vacuum components do not interface with microwave power.

4.4.1.4.1 X-Ray - All roughing pumps will be isolated outside the bioshield wall where there will not be a potential for x-ray deterioration of equipment. Conflat metal seals will be used wherever possible on roughing line connections to eliminate seal maintenance problems. An exception to this will be the use of Viton elastomer seals at vacuum valve flanged connections. Elastomer o-rings will also be used on the main gate seal in the valves and for other internal seals. System design will facilitate the removal of these valves for refurbishment during the planned year end maintenance cycle on the helium liquifier system. The predicted accumulated ten year x-ray dose for the valves within the torus area is approximately 5 x 10^7 rad.

4.4.1.4.2 Magnetic Field - The roughing system pumps and some valves are located outside the bioshield wall, and thus not affected by the torus magnetic field. Other components of the system, such as roughing lines, manifolds, and flanges, are non-magnetic stainless steel and are neither influenced by nor influence the torus magnetic field. All vacuum valves are aluminum. Solenoid valves supplying the vacuum valve air operators will not, according to the solenoid valve manufacturer, be affected by the magnetic field if the field surrounding the solenoid is uniform.

4.4.1.5 Roughing and Forepumping System Performance

4.4.1.5.1 MC Dewar Roughing - The purpose of the roughing system is to reduce the pressure in the MC dewars from atmospheric to the 10^{-3} torr range. Design considerations for purposes of sizing the blower-assisted roughing system included a leakage and outgassing value of 5 X 10^{-3} TL/S per MC dewar each of which has a 40 liter volume in the insulation space, and a 10^{-3} torr range pressure objective.

The roughing system (Figure 4-14 pump station #1) is located outside the bioshield wall on the north side. It consists of a 37CFM rotary vane pump, liquid nitrogen trap, and 164CFM blower in series. The system is connected to the high vacuum manifold with a 5.83 inch I. D. tube. Two valves in series, V5-1 and V4, isolate the roughing system from the manifold. V4, which is located near the high vacuum manifold interface, excludes the roughing line inside surface area from experiencing the manifold high vacuum environment. Included in the roughing line at the pumping station location is a bypass valve V5-1BP. This bypass line will be designed to control the pressure reduction within the MC dewar insulating volume, so that the multi-layered insulation does not become displaced from its designed position due to gas flow turbulance.

A leak detection attachment point, valve V7-1, is located downstream of the blower. This valve will be operational only when the roughing system is in a leak detection mode.

The liquid nitrogen trap will be designed for rapid removal from the foreline while the contaminants remain frozen on the condensing surface. A pre-cleaned replacement trap will then be installed in its place. Maximum operating time between cleaning is TBD.

The effective pumping speed available at the 5.83 inch I. D. tube - 12 inch pipe high vacuum manifold interface for air at 20°C is approximately 85CFM at a pressure in the 10^{-2} torr range. Until the effects of the MC dewar multi-layered insulation are defined, the roughing times through the bypass line for the insulating volumes cannot be calculated. However, if this concern were ignored, a pressure in the 10^{-3} torr range for the total MC dewar system volume could be realized in approximately 30 minutes. Reference Figure 4-16.

4.4.1.5.2 MC Dewar Forepumping - Pumping stations #2 and #3, which are designed to back the four high vacuum turbomolecular pumps, are basically identical in hardware configuration to the roughing system at station #1. An exception is that a bypass line is not required at the V5 series valves for stations #2 and #3.

Each pumping station can effectively back both turbomolecular pumps. In the event of a turbopump failure or shutdown because of reduced pumping speed requirements, the particular section of vacuum line involving the turbopump can be isolated while the pumping station backs the other turbopump. The two pumping stations operate independent of one another.

The 5.83 inch and 3.83 inch I. D. tubing which connects the pumping stations to the turbomolecular pumps, results in an effective pumping speed for air at 20°C of approximately 53CFM at the turbopump discharge connection for the most remote turbopump pumping station combination.

4.4.2 MC Dewar High Vacuum Pumping System - A discussion of the design of the MC dewar high vacuum pumping system is provided below.

4.4.2.1 High Vacuum Pumping Requirements - The following criteria establish the basis for design of the MC dewar vacuum pumping system:

- The pumps must be capable of operation with the mirror coil "on"
- Pumping speed available to the most remote MC dewar in the twelve-inch diameter manifold system must be 50 ℓ/s or greater for nitrogen.
- Base pressure in the dewar insulating volume must be in the 10^{-5} torr region.

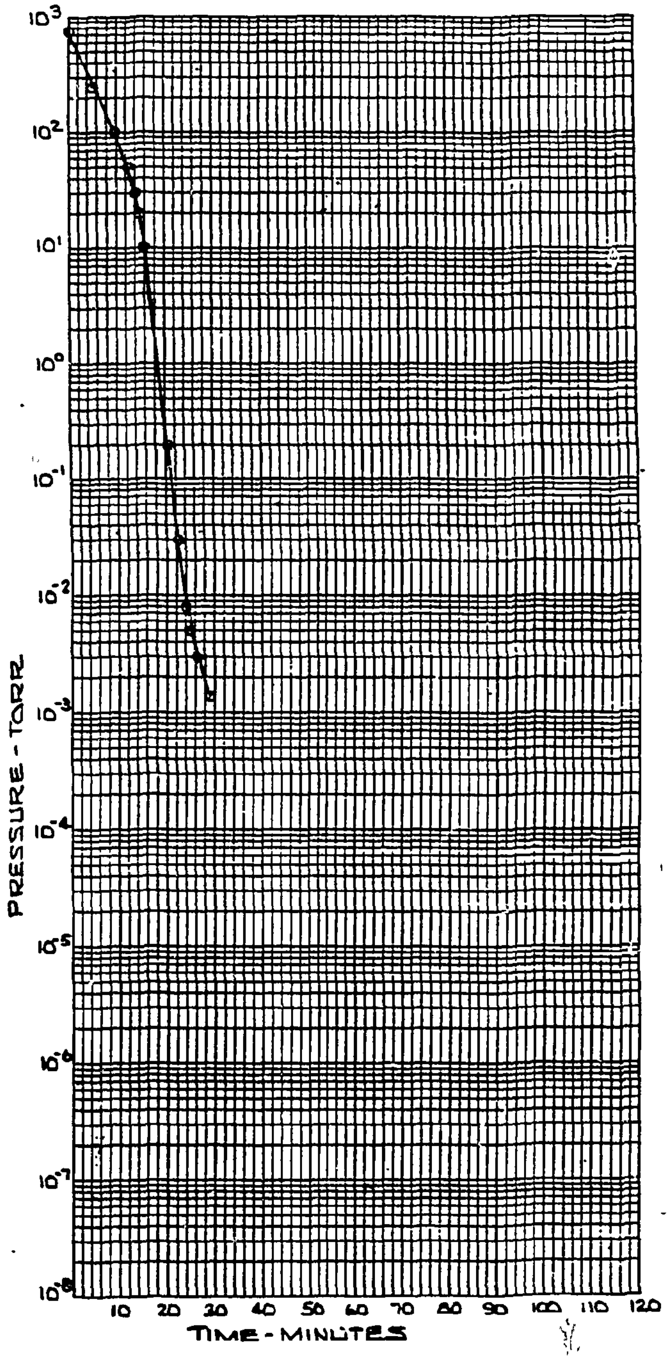


FIGURE 4-16 MC DEWAR ROUGHING PERFORMANCE CURVE

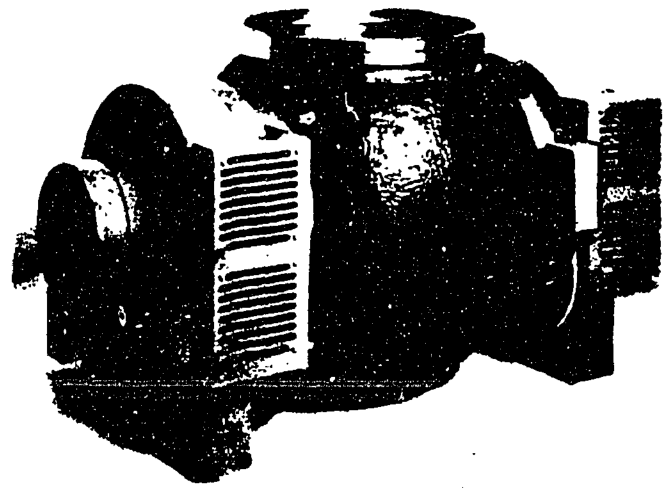
- A minimum of one liter/sec helium pumping speed is required at the most remote dewar.
- The high vacuum system must function independent of the torus pumping system.
- Any number of MC dewars up to 36, can be pumped simultaneously.

4.4.2.2 High Vacuum Pumping System Description - The system will consist of four 2,200 liter/sec turbomolecular pumps equally spaced on a twelve-inch schedule five pipe manifold, as shown in Figure 4-14.

The 255 inch major diameter manifold is located inboard of the mirror coils. Each mirror coil is connected to the manifold with a six-inch pipe containing a bellows and vacuum isolation valve. The net effective pumping speed for nitrogen for the most remote MC dewar with respect to any given pumping station, is greater than 50 ℓ/s. Details of the high vacuum pumping speed calculations are described in detail in Section 5.1 of this report. Assuming the maximum allowable outgassing rate and leak rate stated to be 5 x 10^{-3} TL/S per MC dewar, as discussed in Section 5.7, the base insulating pressure for the most remote MC dewar will be in the 10^{-5} torr range.

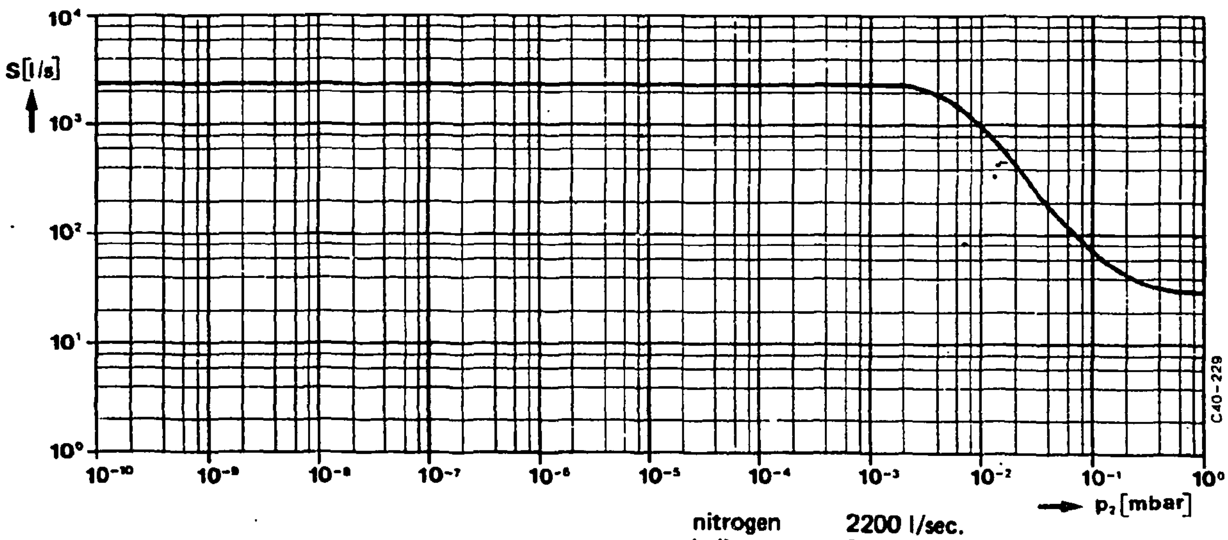
The 10 inch turbomolecular pumps will be isolated from the manifold with a twelve-inch vacuum valve containing Viton elastomer seals. These valves are necessary to allow individual pump isolation for repair or replacement. A Conflat metal seal will connect the turbomolecular pump to the mating flange. All other flanged connections on the twelve inch manifold will use Conflat metal seals. Each turbomolecular pump will contain an ionization gauge on its inlet and a thermistor gage on its foreline.

The Balzers TPU-2200 has been tentatively selected for use on the MC dewar manifold. A picture of the vacuum pump and its performance curve are presented in Figure 4-17. The TPU-2200 is a horizontal shaft turbomolecular pump. This geometry allowed the pumps to be located closer to the manifold, and thus provide higher pumping speeds, than vertical turbomolecular pumps. A twelve-inch Conflat flange on the inlet provides a 9.84 inch diameter pumping inlet. As shown in Figure 4-17 the TPU-2200 can be provided with air cooling. The electronic frequency converter can sense vibration and will automatically shut down the turbomolecular pump to prevent catastrophic failure if an out of tolerance vibra-



TPU 2200 – air-cooled version

VOLUME FLOW RATE



nitrogen	2200 l/sec.
helium	3200 l/sec
hydrogen	2800 l/sec.

Volume flow rate for N_2 as a function of the pressure

FIGURE 4-17 BALZERS TPU-2200 TURBOMOLECULAR PUMP tion is sensed. This will normally indicate the need for bearing replacement. The pump body is automatically vented when the pump is shut down.

A major advantage of the Balzers turbomolecular pump is that the main bearings can be replaced without returning the pump to the factory for re-balancing. This is very desirable from an operational standpoint. The TPU 2200 has an air pumping speed of 2200 liter/sec from 10^{-9} to 2 x 10^{-3} torr. The helium pumping speed in this range is 3200 liter/sec.

All equipment utilized in the high vacuum pumping system is identifed in Table 4-7.

4.4.2.3 High Vacuum Pumping System Interfaces - The major interfaces of the MC dewar high vacuum pumping system are described below. The following systems interfaces are discussed:

- MC dewar
- Instrumentation and Control
- Utilities

4.4.2.3.1 MC Dewar - The insulating vacuum volume of each mirror coil will be connected to the twelve-inch diameter high vacuum manifold with a six-inch line. A six-inch vacuum valve, furnished by MDAC to the mirror coil vendor, is the interface point of the manifold system installation. The valve is located on an inboard port on the mirror coil stack, 44 inches above the torus centerline. Both faces of the valve body, as well as the moving gate assembly contain Viton elastomer seals. Viton seals were selected for two reasons. First, the aluminum valve body is not compatible with metal seals. Secondly, the dynamic seals in the valve assembly must be elastomers and are likely to fail from radiation effects before static seals. The cost and complexities associated with metal sealed gate valves were discussed in Section 4.1 and preclude their use. Static and dynamic elastomer seals will be replaced at the same time.

4.4.2.3.2 Instrumentation and Control - The basic design approach considers the mirror coil high vacuum pumping system to be continuously available for pumping helium originating from small leaks in the internal dewar. As safeguards to inadvertant operations, the following safeguards must be observed the schematic for the MC dewar pumping system was presented in Figure 4-15.

- Turbomolecular pumps A, B, C or D can be used independent of one another, or in any combination of two or more, to maintain a high vacuum in the manifold and MC dewars so long as their respective forepumping systems (pump stations #2 and 3) are operational.
- Starting of the rotary vane pumps in stations #2 and/or #3 requires that trap cooldown has been initiated and the condensing surface(s) has reached a TBD temperature. Additionally, valves V3-1 thru V3-4, V5-2 and V5-3, V6-2 and V6-3, plus V7-2 and V7-3 must be closed.
- The blower(s) will start automatically by means of a circuit interlocked to the rotary vane pump starting circuit.
- The blower(s) can be stopped after it automaticaly starts, however it will cause valves V3-1 thru V3-4, V5-2 and V5-3, to close.
- Turbomolecular pumps A, B, C, and D cannot be started unless valves V1-1 thru V1-4 and V2-1 thru V2-4 are closed, the water coolers are operating, the forepumping systems stations #2 and #3 are operating, and foreline pressures are less than 1 x 10^{-2} torr.
- Following evacuation of the MC dewar insulating volumes to the 10^{-3} torr region with the roughing system station #1, valves V9-1 thru V9-36 are to remain open for further pressure reduction by the turbomolecular pump system.
- Valves V1-1 thru V1-4 cannot be opened unless their respective turbomolecular pumps and forepumping systems are operating, inlet pressure to the turbomolecular pumps is 1 x 10^{-5} torr or less, the high vacuum manifold pressure is in the 10^{-3} torr region, and valve V4 is closed.
- When all MC dewars are cooled to operating temperature and the mirror coil system is in either an ON or OFF mode, valves V9-1 thru V9-36 may be opened or closed independent of one another for pressure maintenance in the dewar insulating volume if any one or more turbomolecular pumping systems is operating, its respective inlet valve V1-1 thru V1-4 is opened, and manifold pressure is 1 X 10^{-5} torr or less.

- If a forepumping or roughing pump station cold trap condensing surface temperature rises above a TBD value, all open valves permitting pressure reduction in the affected system will close, the pumping system(s) will stop and vent values to the effected pumps (eg. V2-1 thru V2-4 and V6-1 thru V6-3) will open.
- The liquid nitrogen trap in each forepumping system has an automatic level maintenance capability.
- All vacuum valves have limit switches for positive identification of position status.
- All control of the mirror coil vacuum system will be available from the control room only.

Table 4-7. MC Dewar High Vacuum System Components

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(36) Mirror Coil Vacuum Valves	Isolates mirror coil from high vacuum manifold	Vac. Research Man. Co. 6 inch 94577-101LS with limit switches and Viton O-rings.
(36) Bellows	Connects high vacuum manifold to mirror coil	Anaconda 6 inch type 6EL11 304SS
(36) Mirror Coil H.V. Line Flanges	For joining mirror coil bellows to the manifold	Varian conflat non-rotatable style 10 inch O.D. X special 6.645 inch I.D. 304SS
(36) Mirror Coil H.V. Line Flanges	For joining mirror coil bellows to valve	Standard 6 inch class 150 lap joint O.D. and drill 304SS

Table 4-7. MC Dewar High Vacuum System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(36) Mirror Coil H.V. Line Flanges	For joining mirror coil bellows to manifold	Varian conflat rotatable style 10 inch O.D. X special 6.645 inch I.D. 304SS
(4) Copper Gasket Sets	For Varian flanges	Varian gasket set 953-5096 (10 per set)
(36) Screw, Nut and Washer Sets	For Varian flanges	Varian set 953-5049 304SS
(36) Bolt, Nut and Washer Sets	For bellows attachment to 6 inch valve	Nor-Cal Products Co. kit No. BA-11 304SS
(72) Feet Pipe	High vacuum manifold connection to mirror coil	6 inch schedule 5 pipe 304SS
105 Feet Pipe	High vacuum manifold and turbopump attachment	12 inch schedule 5 pipe 304SS
(10) Bellows	High vacuum manifold expansion-contraction	Anaconda 12 inch type 12EL11 304SS
(22) Flanges	For high vacuum manifold and turbopump bellows attachment	Varian conflat non-rotatable special 16.5 inch O.D. X 12.76 inch I.D. 304SS

Table 4-7. MC Dewar High Vacuum System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(4) Flanges	Turbo pump adapter	Varian conflat non-rotatable special 16.5 inch O.D. X 10.09 inch I.D. 304SS
(14) Flanges	For high vacuum manifold and turbo pump bellows attachment	Varian conflat rotatable special 16.5 inch O.D. X 12.76 inch I.D. 304SS
(2) Copper Gasket Sets	For 16.5 inch O.D. conflat flanges	MDC Manufacturing Inc. #GK1650
(20) Bolt Sets	For 16.5 inch O.D. conflat flanges	MDC manufacturing Inc. #BA-1650 304SS
(8) Flanges	For attachment of 12 inch valves	Flowline Corp. 12 inch series 15 lap joint flange 340SS
(4) Valves	Turbo pump isolation	Vacuum Research Man. Co. 12 inch 94582-101LS with limit switches and Viton O-rings.
(4) Turbomolecular Pump	Mirror coil high vacuum	Balzers TPU 2200 with 1 X 10^8 rad capability and with DN 250 conflat flange on inlet

Table 4-7. MC Dewar High Vacuum System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(4) Air Cooler Sets	Cooling turbo pump	Balzers air cooler #PM201028
(4) Drive Electronics	Turbo pump control	Balzers #PMC01230
(4) Splintershield	Protect turbo pump inlet	Balzers #PM006126
(4) Automatic Vent Control	Vent turbo to atmospheric pressure	Balzers #PMC01061
(4) Vent Valve	Admit air to turbo pump	Balzers #PMZ01000
(4) Air Drier	Dries turbo pump venting air	Balzers Z00120
(4) Power Cables 164 feet long	Connects drive electronics to turbo pump	Balzers special order
(4) Flanges	Adapts 12 inch line to TPU-2200 inlet	Balzers conflat non-rotatable #BP416106-R 304SS
(4) Tube	Adapts 12 inch line to TPU-2200 inlet	10.08 inch O.D. X 9.92 inch I.D. X 6 inch long 304SS fabricated tube
(4) Bolt Sets	Flange attachment to TPU-2200 inlet	Balzers #BN845014 304SS

Table 4-7. MC Dewar High Vacuum System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
[illegible] Copper Gasket Set	TPU 2200 inlet flange	Balzers #BN845322-T
(4) Input Plug	Turbo power input	Balzers #PM001164T
(4) Output Plug	Turbo power feedback	Balzers #PM001165T
(4) Flanges	Turbo outlet port with 63 conflat flange	Balzers #BP414307R 304SS
(2) Bolt Set	Turbo outlet port with 63 conflat flange	Balzers #BN845012T 304SS
(2) Bolt Set	Turbo outlet port with 16 conflat flange	Balzers #BN845010T 304SS
(1) Copper Gasket Set	Turbo outlet port with 63 conflat flange	Balzers #BN845037T
(2) Copper Gasket Set	Turbo outlet port with 16 conflat flange	Balzers #BN845035T

4.4.2.3.3 Utilities - Utilities requirements for the MC Dewar high vacuum pumps are shown in Table 4-8.

Table 4-8. MC Dewar High Vacuum Utilities Requirements

TPU-2200 (Quantity 4)	
Electrical	220V/25A/60 Hz
Cooling	Air Cooled
Vacuum Valves (Quantity 4)	
Electrical	110V/60 Hz
Air	65 Psig

4.4.2.4 High Vacuum Pumping Environment - The effects of the x-ray and magnetic field environments on the MC dewar high vacuum components is discussed in this section.

4.4.2.4.1 X-Ray - The ten year accumulated x-ray dose potential is calculated to be 4 x 10^7 rad in the vicinity of the turbomolecular pumps on the twelve-inch manifold. All flanged connections, with the exception of the vacuum valves, utilize Conflat metal seals. The valves will contain Viton elastomer seals which require replacement after an accumulated dose level of 1 x 10^7 rads. It is planned that valve seals will be replaced once every year during the year end maintenance cycle. The valve vendor will be required to change the polyethylene air supply lines to stainless steel or copper.

The Balzers turbomolecular pumps can be ordered with modifications to increase their radiation resistance. The insulation in the motor windings is polyimide. Conflat flanges are provided in the inlet and outlet ports and metal seals are utilized on the automatic vent valve. Also, Fomblin oil is used in the pump and a metal oil reservoir is used in place of the standard plastic reservoir. The modified Balzers pump is resistant to dose levels up to 1 x 10^8 rads.

4.4.2.4.2 Magnetic Field - No problems are anticipated with respect to turbopump operation in the magnetic field at the twelve-inch manifold location. The field strength at this location is less than two gauss, which is comparable to the earth's field and will thus not affect the turbomolecular pumps. Magnetic fields during off-normal condition, such as during a quench, will be determined during Title II and their effects on the high vacuum components will be assessed.

Each of the twelve-inch aluminum valves in the high vacuum duct assembly contain solenoids for controlling pneumatic operation of the disc and carriage assembly. The solenoid manufacturer feels that if the magnetic fields surrounding the valve are uniform, there will be no need to mount them remotely or provide shielding.

4.4.2.5 High Vacuum Pumping Performance - The performance of the MC Dewar high vacuum pumps is discussed in this section.

4.4.2.5.1 Mirror Coil Pumping - Adequacy of the pumping system design is predicated on having received an evacuated and outgassed mirror coil from the vendor at the EBT-P site. These pumping situations are imposed on the system design.

- Repump each mirror coil insulating pressure to the 10^{-5} torr range, following installation, assuming pressure was raised to one atmosphere of nitrogen for transport and handling.
- Reduce helium partial pressure arising from LHe internal dewar leaks in each mirror coil dewar during operation and standby periods if required.
- Following vacuum valve refurbishment at the end of each operational year, the pressures in each of the MC dewars must be reduced from atmospheric to the 10^{-5} torr range in about two weeks.

Calculations in Section 5.1 of this report illustrate the method used to determine pumping speed of the manifolded system. A net effective nitrogen pumping speed greater than 50 ℓ/s has been calculated for the "worst case" magnet-pump pod combination, assuming all four pumps are evacuating the manifold and magnet assembly as shown in Figure 4-14. If a magnet has a combined leak and outgassing rate of 5×10^{-3} TL/S, it will be possible to achieve a 10^{-5} torr range insulating pressure in each MC dewar within approximately two weeks. As noted in Section 5.7, it is assumed that the MC dewars can be heated to 100°C to accelerate the degassing process. The net effective helium pumping speed for the "worst case" magnet-pump pod combination, assuming all four pumps are evacuating the manifold and magnet assembly, is greater than 100 ℓ/s.

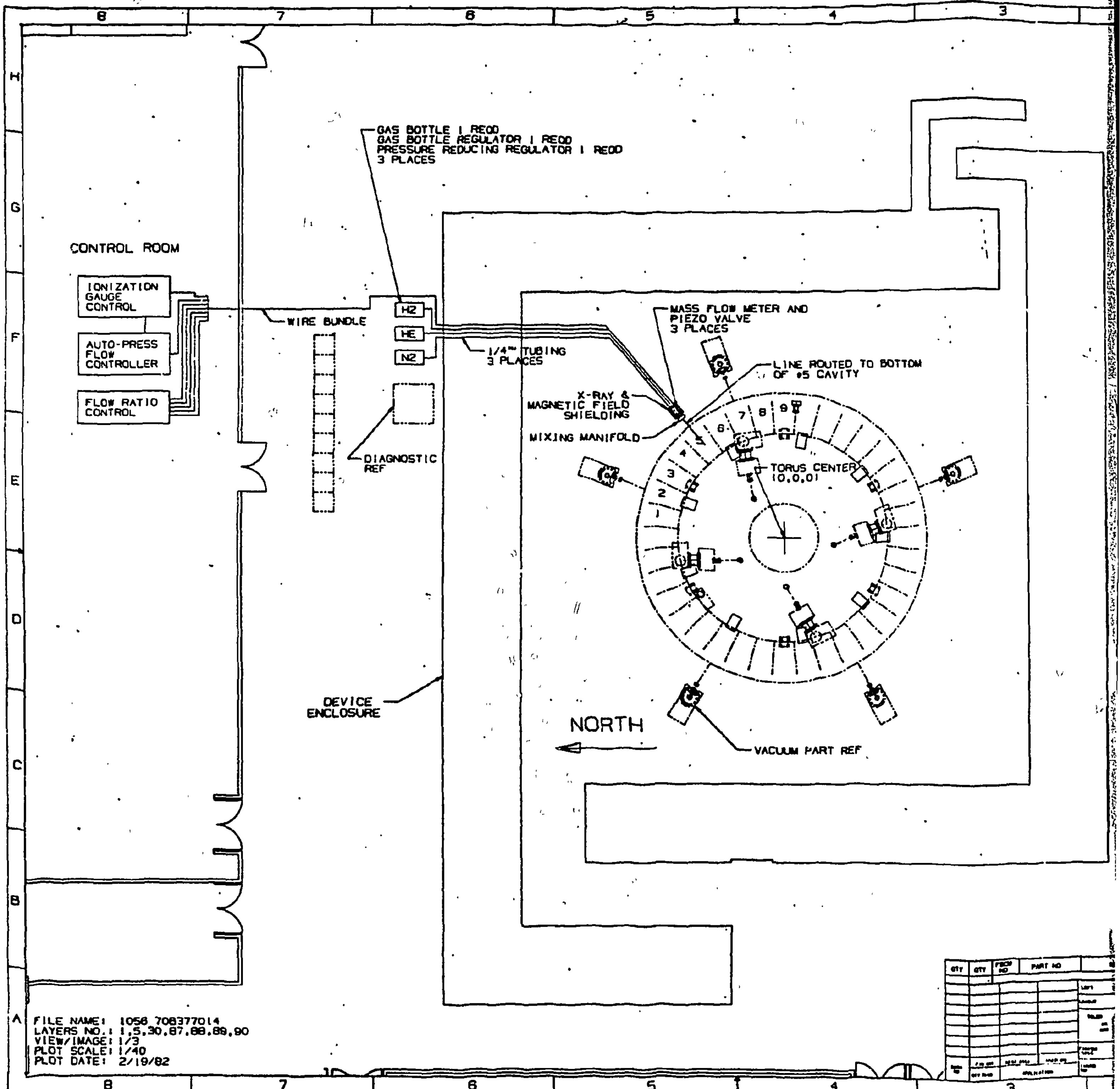
4.5 GAS FLOW MONITORING AND CONTROL SYSTEM

The system described in the EBT-P proposal is a single gas injection system. It has the capability for controlling a GH_2 inbleed to the torus for initiating a plasma. The controller is linked to a pressure measurement circuit, having a feedback to the controller. The flow monitoring and control system defined by ORNL on 21 September 1981, has the capability for inbleeding three gases simultaneously.

4.5.1 Gas Flow Requirements - The gas flow monitoring and control system must be capable of measuring and controlling the flow of up to three gases simultaneously during plasma operation. It must operate in this manner for up to 16 continuous hours in the 1 x 10^{-6} to 1 x 10^{-4} torr pressure region. The gas system must also be capable of intermittant flow, with a fast response valve and feed-back loop, during start-up of plasma operation. Two of the bleed gases are minority species and must be ratiometrically controlled. The minority species concentrations will be on the order of 0.1 percent to 1.0 percent. All gases must be high purity with oxygen concentration less than 1.0 PPM.

4.5.2 Gas Flow Description - Due to the brief time available between the preliminary design review and receipt of the proposed system concept from ORNL, it was not possible to appraise the merits of this technique versus other commerically available systems. The system concept is shown in Figure 4-18 and equipment requirements are identified in Table 4-9.

The baseline system combined an automatic pressure controller with an ionization gauge and piezoelectric valve. It has the capability to inbleed hydrogen at a rate commensurate with torus pressure requirements and system pumping speed. Torus pressure is held constant by a pressure signal feedback from the ionization gauge to the controller which in turn controls hydrogen flow by modulating the piezoelectric valve. In order to gain hydrogen mass flow information for expansion of the baseline system, a Tylon mass flowmeter having a capability of up to 200 SCCM of H_2 can be added along with a flow monitor and ratio controller. Each of the two additional gas species will require a piezo valve and mass flow meter slaved to the flow controller. The pressure controller will be the master unit of the gas inbleed system with the flow controller slaved to it. Based on the desired torus pressure during burn, the flow controller will inbleed up to three gas species, two of which


GAS BOTTLE 1 REQD
GAS BOTTLE REGULATOR 1 REQD
PRESSURE REDUCING REGULATOR 1 REQD
3 PLACES
CONTROL ROOM
IONIZATION GAUGE CONTROL
AUTO-PRESS FLOW CONTROLLER
FLOW RATIO CONTROL
WIRE BUNDLE
H2
HE
N2
1/4" TUBING 3 PLACES
DIAGNOSTIC REF
MASS FLOW METER AND PIEZO VALVE 3 PLACES
LINE ROUTED TO BOTTOM OF #5 CAVITY
X-RAY & MAGNETIC FIELD SHIELDING
MIXING MANIFOLD
TORUS CENTER (0,0,0)
DEVICE ENCLOSURE
NORTH
VACUUM PART REF
FILE NAME: 1056 708377014
LAYERS NO.: 1,5,30,87,88,89,90
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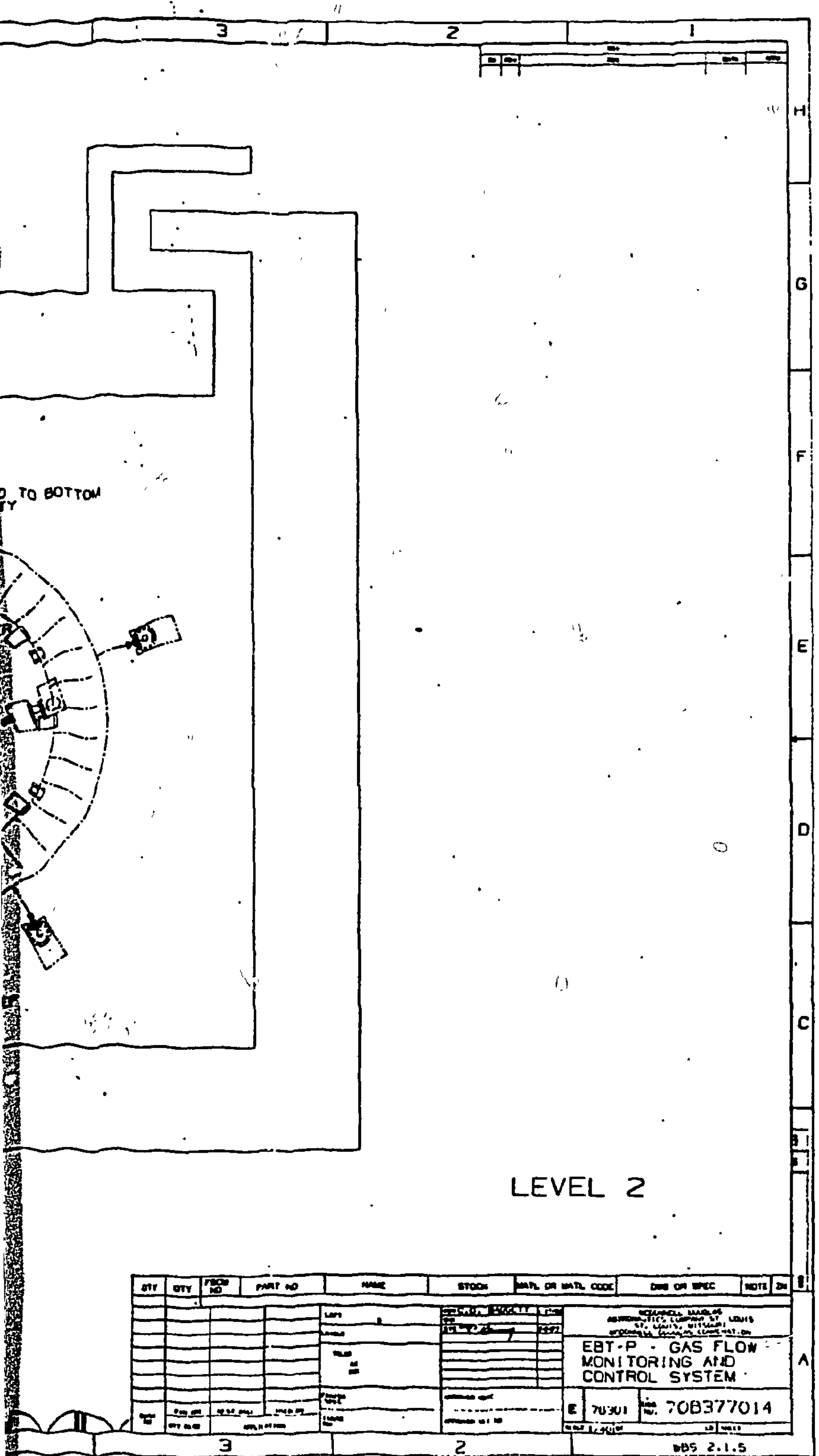
PLOT SCALE: 1/40
PLOT DATE: 2/19/82



TO BOTTOM
LEVEL 2
EBT-P - GAS FLOW
MONITORING AND
CONTROL SYSTEM
70301
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BBS 2.1.5

wili be ratioed to the hydrogen flow. Pressure excursions within the torus will be sensed by the ionization gauge. That information will be fed to the pressure controller, which in turn will output a signal to the flow controller. The flow controller will then modulate flows of whichever gas species are being inbled, maintaining proper flow ratios. Gas species number two requires a flow meter with a capability of up to 3 SCCM, and species number three requires a flow capability of up to .3 SCCM.

Research quality gases will be supplied from pressurized K bottles which will require precise pressure regulation to maintain desired inbleed values. A 2830 liter K bottle of H_2 will be adequate for more than 60 days of burn conditions. All gas bottles will be located outside the bioshield wall at the gas line feed penetration through the wall.

Table 4-9. Gas Flow Monitoring and Control System Components

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(1) Gas Bottle Regulator	Regulates down-stream gas pressure	Rego Welding Products dual stage regulator for hydrogen #2067HY
(1) Gas Bottle Regulator	Regulates down-stream gas pressure	Rego Welding Products dual stage regulator for helium #2067H
(1) Gas Bottle Regulator	Regulates down-stream gas pressure	Rego Welding Products dual stage regulator for nitrogen #2068

Table 4-9. Gas Flow Monitoring and Control System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(3) Pressure Reducing Regulator	Maintain piezo valve inlet pressure at approximately and atmosphere	Fisher Controls Co. Pressure reducing regulator type 66Z with carbon steel body and 2 inch class 150 flanged inlet and outlet
(1) Mass Flow Sensor	Control hydrogen flow	Vacuum General flow sensor #TMFS-01-1000
(1) Mass Flow Sensor	Control flow of minority gas #1	Vacuum General flow sensor #TMFS-01-0010
(1) Mass Flow Sensor	Control flow of minority gas #2	Vacuum General flow sensor #TMFS-01-0001
(2) Gas Leak Valve	Admits gas to Torus	Veeco piezoelectric gas leak valve PV-10 #4021-000-00 with SPECIAL 100 foot cable
(1) Gas Leak Valve	Admits gas to Torus	Veeco piezoelectric gas leak valve SPECIAL PV-10 #4021-000-00 modified for through put of 2.0 torr lets per second at one atmosphere differential with SPECIAL 100 foot cable.

Table 4-9. Gas Flow Monitoring and Control System Components (Continued)

(Quantity) Element	Purpose	Identification (Potential Suppliers)
(1) Pressure Gauge	Senses torus pressure	Granville-Phillips Bayard-Alpert Ion garage #274018
(1) Ionization Gauge Controller	Readout for Bayard-Alpert gauge	Granville-Phillips Ion gauge controller #271004
(1) 100 Feet Ionization Gauge Cable	Collector and gauge cable set	Granville-Phillips special length (100 feet) of cable set for ionization gauge #274018
(1) Gas Flow/Ratio Control	Mass flow control	Vacuum General Standard controller #77-44 three-gas flow/ratio control
(3) Mass Flow Sensor Cables	Connects flow sensors to flow/ratio controller	Vacuum General flow sensor cable each 100 foot long SPECIAL #CB-101
(1) Automatic Pressure Controller	Controls Torus pressure during gas inbleed	Veeco automatic pressure controller model APC-1000
80 Feet Tube	Connect gas bottles to flow valves	Ryerson 304 stainless steel tube 1/4 inch O.D. x .035 inch wall

4.5.3 Gas Flow Interfaces - The major interfaces with the Gas Flow Monitoring and Control System are described below.

4.5.3.1 Torus - Gas will be inbled at mirror cavity number four from a single feed line attached to the torus with a Conflat flange. The segments of the flow control system located within the torus environment, will be the gas feed line, ionization gauge, piezo valves, flow meters, and a gas mixing manifold. All other components will be located outside the bioshield on the torus level.

4.5.3.2 Instrumentation and Control - The flow control system will be located outside the bioshield wall on the torus level. Modifications to the controllers will permit remote operation from the control room. Capability will be provided for both manual and automatic pressure control.

4.5.4 Gas Flow Environment

4.5.4.1 X-Ray - Because of the location of the flow control system outside the bioshield wall, there will be no potential degradation of that part of the system due to x-rays originating from the torus. Components located adjacent to the torus will be shielded as necessary.

4.5.4.2 Magnetic Field - Magnetic shielding will be provided for the ionization gauge tube and other components on mirror cavity four.

4.5.5 Gas Flow Performance - The gas system will provide monitoring and control of three gases. Typical gases in combinations of three will be hydrogen, helium, neon, and nitrogen. The main gas feed in any combination will be hydrogen. Any two of the aforementioned gases will be inbled with hydrogen and then ratios controlled with respect to the hydrogen. Ratio control ranges will be as follows:

a. Hydrogen - primary feed.
b. Gas 2 - ratio control as low as 1 part per 100 of the hydrogen mass flow.
c. Gas 3 - ratio control as low as 1 part per 1000 of the hydrogen mass flow.

Each gas can also be independently inbled and controlled. These controlled gas inbleeds to the torus cavity will occur through the 1 x 10^{-6} to 1 x 10^{-4} torr pressure range. Any pumping speed variation during burn will cause the hydrogen inbleed to adjust accordingly to maintain the desired torus pressure. The flow rates of gases two and three, which are slaved to a flow monitor and controller, will adjust accordingly to maintain their pre-set flow ratios with respect to the hydrogen input. Hydrogen inbleed can be varied from less than .02TL/S to in excess of 2.0TL/S.

Both automatic and manual control of the hydrogen inbleed will be possible. In the event of a system perturbation either during plasma manual startup or during a stable automatic operating mode, gas inbleed can be terminated within approximately 2 μsec by the fast acting piezoelectric valves.

4.6 GYROTRON MAGNET DEWAR PUMPING SYSTEM

The roughing and high vacuum pumps used to maintain the vacuum in the gyrotron magnet dewars are described below.

4.6.1 Gyrotron Magnet Dewar Requirements - The function of the pumping system is to produce an insulating vacuum and to degass the multilayered insulation surrounding the magnet dewar. A base pressure in the 10^{-5} torr region is required for the insulating jacket space before LN_2 and LHe fill. The pumping system should not have the potential for introducing contaminants into the dewar insulating space. Following the achievement of a stable insulating pressure condition the pumping system will be removed from the gyrotron, because system components are not compatible with the torus x-ray environment. It there are indications of a pressure rise within the dewar, the portable unit can be used to reestablish the base pressure during torus non-operational modes. Details of the vacuum port have not been fully addressed by the gyrotron supplier.

4.6.2 Gyrotron Magnet Dewar - Both roughing and high vacuum pumping will be provided by a portable turbomolecular pumping unit. This system can be utilized to establish the base pressure and can then be removed from the gyrotron upon achieving a stable pressure condition. Each dewar insulating space will be pumped individually, with LN_2 and LHe fill being initiated at the conclusion of vacuum servicing. The portable turbopump system will also be available for vacuum pumping diagnostic assemblies following their attachment to the torus. Both the backing and turbomolecular pumps are air cooled. Utility needs for the portable unit are limited to electrical power only. Details of the gyrotron dewar and insulating requirements are not available at this point, making it impossible to define pumping speed needs. It is tentatively assumed that a turbomolecular pump speed of approximately 500 ℓ/s air will be adequate to achieve the 10^{-5} torr base pressure. Figure 4-19 shows a representative pumping unit setup for the gyrotron. Provisions will be included for attachment of a helium leak detector to validate the seal integrity of both the gyrotron and pumping unit. Equipment identification is shown on Table 4-10.

Table 4-10. Gyrotron Magnet Dewar High Vacuum System

Element	Capacity-Purpose	Identification
(1) Portable Pumping Unit	Reduce dewar insulating pressure to 10^{-5} torr range	Balzers portable turbomolecular pumping unit, type TSU 510, with DUO 030 A backing pumps and TPG 060 Pirani vacuum gauge readout and TPR010 gauge heads.

4.6.3 Gyrotron Magnet Dewar Interfaces - The interfaces of the gyrotron dewar pump with the other systems are described below.

4.6.3.1 Gyrotron Magnet Dewar - A vacuum valve is required at the interface between the insulating vacuum and room environment. X-ray dose predictions indicated that the valve will experience an accumulated level of less than 1 x 10^7 rad during a ten year exposure. A standard elastomer sealed vacuum valve incorporating Viton o-ring seals at each flange face can be utilized at the dewar insulating volume interface. A portable turbomolecular pumping system will attach directly to the dewar vacuum isolation valve.

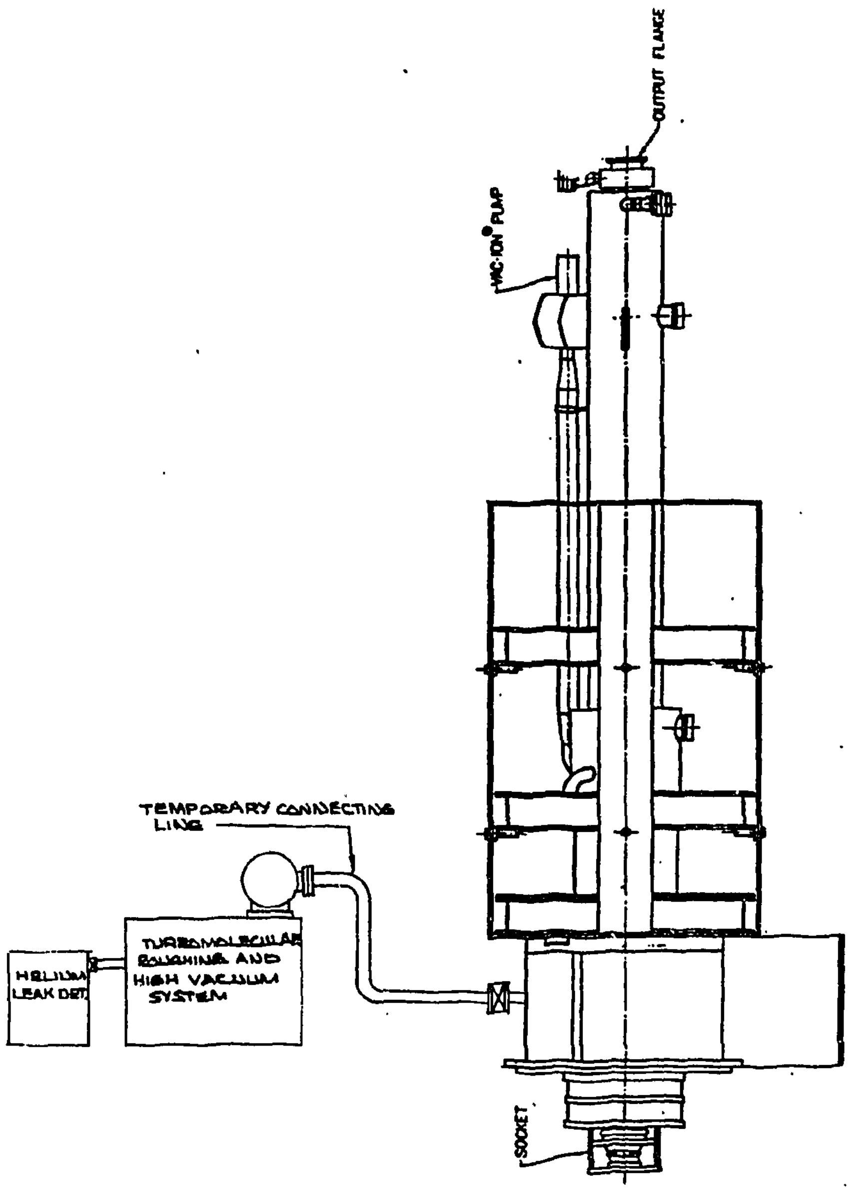

FIGURE 4-19 GYROTRON MAGNET DEWAR PORTABLE HIGH VACUUM PUMPING SYSTEM

4.6.3.2 Instrumentation and Control - Pumping operations will be manually controlled at the gyrotron site. Initiation of pumping on the gyrotron will require on-site manual activation of the dewar vacuum isolation valve. This valve will have a hand operator which can be locked in the closed position to secure the dewar following attainment of the base pressure and a satisfactory cryogenic cooldown. Dewar temperature and pressure can be monitored in the torus control room. The portable pumping unit will contain pressure gauging to identify its status prior to initiating gyrotron pumping.

4.6.3.3 Utilities - Requirements for the portable 500 ℓ/s turbomolecular pumping system are 220V, 3 Phase, 1.5 KW electrical power. No other services are required.

4.6.4 Gyrotron Magnet Dewar Environment

4.6.4.1 X-Ray and Magnetic Field - Current information indicates there will not be a need to provide a dedicated pumping system for each gyrotron. Dewar vacuum pumping needs will be fulfilled with a portable turbomolecular system to maintain the gyrotron dewar vacuum space during periods when the torus is not operational. The pumping unit will not be inside the bioshield enclosure during torus operations, and thus will not be exposed to x-ray or magnetic field environments.

4.6.5 High Vacuum Pumping Performance - Insufficient information is available concerning the gyrotron dewar insulating volume and surface area, to predict pumping performance characteristics.

5.0 SUPPORTING ANALYSES

Presented in this section are the details of the various trade studies and analyses performed in the support of the TITLE I Preliminary Design of the Vacuum Pumping System. The major analyses and trade studies discussed are:

- High Vacuum Pumping Speed Calculations
- Roughing Speed Calculations
- Microwave Shield Design
- EBT-P Environment Definition
- High Vacuum Pumps Considered
- Heat Loads Analysis
- Gas Loads Analysis

5.1 HIGH VACUUM PUMPING SPEEDS

The design of the torus and MC dewar pumping systems required analyses of numerous configurations to optimize the number and size of vacuum pumps and the sizes of ducts and manifolds. The effects of the microwave protection screen were also determined. The methods of analyses and results obtained for the various configurations are presented in this section.

5.1.1 High Vacuum Pumping Speed Analysis Methods - For the high vacuum pumping system, the relevant pressures are well within the range corresponding to molecular flow, in which the mean free path of the gas molecules being pumped is larger than the dimensions of the vacuum enclosure. This justifies neglecting the intermolecular collisions in pumping speed calculations since their effect will be much smaller than the effect of collisions of the molecules with enclosure walls. The walls are assumed to be rough, on a molecular scale, so that the probability that a molecule reflected from the wall will travel along a given direction is proportional to the cosine of the angle between the direction and the normal to the wall at the point of collision. The velocity direction of the molecule after a wall collision is thus independent of the velocity direction of the molecule before the collision.

System pumping speeds in the molecular flow pressure range are a function of the vacuum pump employed and of the geometrical arrangement of the walls of the vacuum chamber and ducts. Vacuum pumps are characterized by their pumping speed. Pumping speed for a pump is defined in terms of the ultimate pressure a pump is capable of producing at its inlet with a known gas load at or near the inlet. The basic equation is

$$S = Q/P \qquad \text{(Eq. 5-1)}$$

where S is the pumping speed of the pump, measured in liters/second; Q is the rate at which gas is being introduced at the inlet, measured in torr-liters/second; and P is the ultimate steady-state pressure, measured in torr. This speed (S) is closely related to the pumping speed reported by manufacturers in characterizing vacuum pumps, as discussed in the next section.

However, the net effective pumping speed for a vacuum system also depends on the ductwork which connects the chamber to the pump. The ductwork generally consists of a combination of duct elements, each of which can be individually characterized for vacuum calculation purposes. It is then necessary to combine the characteristics of the individual elements in an appropriate way so that the performance of the vacuum system as a whole can be predicted.

The problem of characterizing individual duct elements for calculation of pumping speed and also the problem of finding the net effect of several combined elements (with given properties) are both very difficult mathematically and no exact solutions are available, except for special cases. The performance of a vacuum system can be measured experimentally, or it can be found via computerized Monte Carlo calculations, which amount to a simulated experiment. However, both these methods are too expensive and time consuming to use when selecting a design from among many candidates. For performing such trade studies, approximations are necessary to predict characteristics of a vacuum system from knowledge of the vacuum pumps and ductwork elements which make up the system.

Parameters similar to those used in the description of vacuum pumps are used to describe an element of ductwork. The conductance C, measured in liters/second, is the net rate Q per unit difference in pressure ΔP at which gas will flow through the element from the high pressure inlet to the low pressure outlet. If A represents the inlet area of the element in cm^2, then the conductance is given by the expression

$$C = \alpha A f, \qquad \text{(Eq. 5-2)}$$

where f is the factor describing the mobility of the gas molecules given by $f = 3.638\sqrt{T/M}$ in the units used here, and where α is the probability that a molecule which enters the inlet orifice will leave the element via its outlet orifice without first being reflected back through the inlet orifice.

To calculate the effective pumping speed for a vacuum system, it is first necessary to obtain appropriate values of the transmission probability for the individual elements of the ductwork, and then to combine correctly the probability values of elements making up the system. The capture probability of the particular pump is determined, as described below. It is combined with the transmission probability of the ductwork to yield an overall pumping probability for the system. Once this overall pumping probability is calculated, the net effective pumping speed can be calculated.

After a presentation of the method for determining the pump capture probability, duct element transmission probabilities will be dealt with on a case-by-case basis. We then discuss procedures for combining the probability values of the individual elements. Finally two special duct elements, the tapered tube and manifold, are discussed.

5.1.1.1 Vacuum Pumps - The pumping speed S can itself be considered as the product of three factors,

$$S = \alpha_p A f \qquad \text{(Eq. 5-3)}$$

where A is the pump inlet area, usually expressed in square centimeters, and α_p is the probability that a molecule entering the pump inlet will be captured by the pump rather than be allowed to eventually reenter the vacuum chamber. The factor f describes the mobility of the molecules being pumped and is again given by $3.638\sqrt{T/M}$, where T is the Kelvin temperature and M is the appropriate molecular weight in AMU. For this analysis, T was taken as 300K and M was taken as 2 for hydrogen or as ~ 30 for air or nitrogen.

Closely related to the actual pumping speed S of vacuum pumps is a specification speed S′ quoted by the pump manufacturer. The capture probability α_p, which was required for these analyses, was obtained in two steps from the quoted pumping speed: 1) the first approximation α_p', was taken as S′/Af and 2) the corrected value α_p was taken as:

$$\alpha p = \frac{\alpha_p'}{1 + \alpha_p'/_2} .$$

This correction is required because of the standardized procedure used by pump manufacturers to measure the pumping speed, in which the gauge measuring the ultimate pressure P attained by the pump is mounted close to the pump inlet in such a way that it reports a pressure somewhat lower than that obtained in the chamber[5-1].

Turbomolecular pumps and other pumps with a well defined throat are treated for conductance calculation purposes as a tubular conductance with inlet orifice coincident with the pump inlet, with outlet orifice in a perfect vacuum, and with transmission probability equal to the capture probability of the pump.

Vacuum pumps which are not appendage pumps, such as the cryopumps considered in this study, were handled somewhat differently. When such pumps were placed directly in the ductwork, it was assumed that the pumping speed quoted by the manufacturer was the effective pumping speed with an inlet orifice of diameter and location the same as that of the tubing immediately before the pumps. In other cases the pump was placed in a recessed section of ductwork to preclude a direct path to cryogenic surfaces for hot ions and neutrals. These cases were treated by assuming that the pressure P in the recessed ductwork surrounding the pump was given by P = Q/S; where S is the pumping speed quoted by the manufacturer and Q is an assumed gas load from the chamber to be evacuated. The conductance C of the remaining ductwork between the chamber and the section containing the pump was then calculated. The pressure P_e in the chamber followed from the definition of the conductance: $P_e = P + Q/C$. Finally, the effective pumping speed S_e at the chamber was obtained from $S_e = Q/P_e$. The assumed gas load Q is cancelled out in the final step; its actual value does not affect S_e.

5.1.1.2 Tubes of Constant Circular Cross Section - The transmission probability for a tube of constant circular cross section is determined by the ratio of its length to its diameter. Since constant cross section means that the entrance orifice and exit orifice have the same area, symmetry considerations show that the transmission probability for such a tube will be independent of direction. Clausing[5-4] calculated the transmission probability for this case from kinetic theory and tabulated his results as a function of the tube length to its radius. The procedure used in these calculations was to find the length to radius ratio of the tube-shaped conductance element in question, and then obtain the transmission probability by linear interpolation from Clausing's table. According to Roth[5-6], Clausing's results are also given by the expression

$$\alpha = 1.33(15+6(L/a))/(20+19(L/a)+3(L/a)^2) \qquad \text{(Eq. 5-4)}$$

where L/a is the length to radius ratio of the tube. This formula gives results which differ by no more than 1 1/2% from Clausing's tabulated values, and it was also used.

5.1.1.3 Mitered Right Angle Elbows - These right angle elbows are the kind formed by cutting through a section of straight tubing at a 45° angle, then rotating one of the pieces 180° about its axis and 90° about an axis in the plane of the cut and at right angles to the tube axis, and finally rejoining the pieces to give an elbow with an abrupt 90° change in the direction of the tubing axis. Transmission probabilities for such an elbow were found from interpolation of tabular data generated by D. H. Davis[5-7] using Monte Carlo techniques. Elbows for which one or both of the arms was too long for Davis' table to apply directly were handled as an elbow in series with straight tubing.

5.1.1.4 Bends in Tubing - Conductance elements which change the direction of the tubing axis via a bend with a finite radius were assigned a transmission probability equal to the probability for the corresponding element without the bend.

5.1.1.5 Perforated-Plate Microwave Shields - To protect pumps from incident microwave energy it is necessary to install shielding. Such shielding in these designs included perforated plates made of an electrically conductive material. These plates also unavoidably constitute an impedance to gas flow. Their transmission probability α was calculated as the product of two factors: (i) the probability A_H/A that a given incident molecule would enter one of the holes in the plate, where A_H is the total cross sectional area of the holes drilled in the plate of original cross-sectional area A, and (ii) the probability α_H that a molecule entering one of the holes on the upstream side will exit on the downstream side. The value for α_H is obtained by treating the hole as a short cylindrical pipe of length equal to the plate thickness.

5.1.1.6 Methods of Combining Probabilities - Having determined the transmission probabilities of each duct element and the capture probability of the vacuum pump, the problem that remains is to combine these elements, with different cross-sectional areas, in a manner which gives the net pumping probability of the pumping system (the duct/pump combination). This net pumping probability is defined as the probability that a molecule which enters the vacuum duct, from the chamber, will be pumped before re-entering the chamber. Vacuum conductance elements interconnected in series and parallel form systems whose effective conductance was traditionally calculated in the same way that effective conductances are calculated for series and parallel electrical networks. The effective conductance C_e for a parallel combination of elements with individual conductances C_1, and C_2 was taken to be

$$C_e = C_1 + C_2 \qquad \text{(parallel) (Eq. 5-5)}$$

for parallel combinations, and to be $1/C_e = 1/C_1 + 1/C_2$ for series combinations. This approximation works well only in the case of parallel conductances since the analogy on which it is based breaks down in the case of series connections due to interactions between the two conductances in the vacuum system case.

Our treatment for a series combination of conductances is based on the work of Oatley[5-2], who handled the interaction between two series-connected conductance elements A and B such as those shown in Fig. 5-1(a) in terms of their transmission probabilities α_1, α_2. This reasoning ran as follows:

"Of the N molecules entering A, $N\alpha_1$ pass into B and $N(1-\alpha_1)$ are turned back to the reservoir from which they came. Of the $N\alpha_1$ entering B, $N\alpha_1\alpha_2$ emerge from the right-hand end of B, while $N\alpha_1 (1-\alpha_2)$ return to A. Of these, $N\alpha (1-\alpha_2) (1-\alpha_1)$ enter B once again

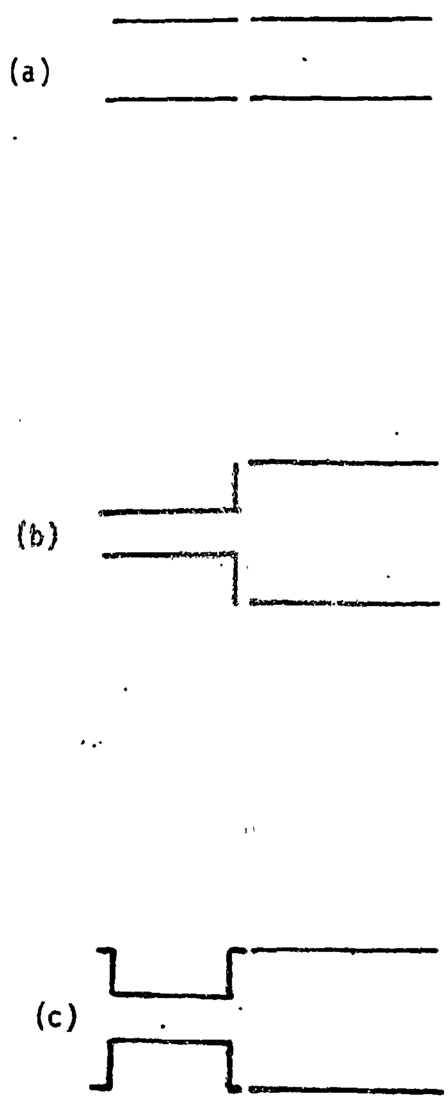

FIGURE 5-1 COMBINATIONS OF TWO CONDUCTANCES, EACH OF CONSTANT CROSS SECTION

and $N\alpha_1\alpha_2 (1-\alpha_1)(1-\alpha_2)$ emerge from the right-hand end of B. Proceeding in this way, we see that the total number of molecules passing through the tube from left to right is given by the infinite series

$$N\alpha = N\alpha_1\alpha_2 [1 + (1-\alpha_1)(1-\alpha_2) + (1-\alpha_1)^2 (1-\alpha_2)^2 + \ldots]$$

$$= \frac{N\alpha_1 \alpha_2}{\alpha_1 + \alpha_2 - \alpha_1\alpha_2}$$

whence

$$\frac{1}{\alpha} = \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1 \right) \qquad \text{(Eq. 5-6)}$$

This treatment is for the case where both individual conductances A and B have equal and constant cross sections. Oatley also derived an expression for the equivalent conductance of two series connected elements with constant but unequal cross sections (Fig. 5-1(b) by considering the physically equivalent case in which the element with the smaller cross section is modified by the addition at both ends of a flange and an infinitesimally short tube of the same diameter as that of the larger element, as shown in Fig. 5-1-(c). Since the added tubes are infinitesimal, the total conductance is the same in Figs. 5-1(b) and 5-1(c), but the added tubes in the second figure enable the problem to be treated as two successive tubes of equal diameter. The transmission probability of the first tube in Fig. 5-1(b), where it is treated as an element of diameter D_1, is α_1. In Fig. 5-1(c), where this same tube has been modified by the addition of an infinitesimally short tube on each end, it is treated as an element of diameter D_2. Its transmission probability is given by

$$\alpha_{1D_2} = \frac{D_1^2}{\left(D_2^2 \right)} \alpha_1$$

On the left hand side of this equation, the extra subscript D_2 specifies that the element is being treated as though it had that larger diameter. On the right hand side the first factor gives the probability that a molecule entering the left-hand infinitesimal tube will also enter the section with diameter D_1, and the second factor is the probability that a molecule entering the D_1 section will emerge at the right-hand end.

Oatley's equation for two tubes of equal cross section then applies to the system of Figure 5-1(c)

$$\frac{1}{\alpha_{eq_{D_2}}} = \frac{D_2^2}{D_1^2 \alpha_1} + \frac{1}{\alpha_2} - 1 \qquad \text{(Eq. 5-7)}$$

On the left hand side of this equation, the subscript "eq" specifies that we are concerned with the equivalent transmission probability for the entire conductance combination and the subscript "D_2" specifies that we are treating the combination as though its inlet diameter were D_2. Invoking the fact that the conductance is the same for the system for both the original case in which the first tube is considered to be of diameter D_1, and the second case in which it is considered to be of diameter D_2, we have

$$C_{D_1} = \alpha_{eq_{D_1}} A_1 f = \alpha_{eq_{D_1}} \pi D_1^2 f = \qquad \text{(Eq. 5-8)}$$

$$C_{D_2} = \alpha_{eq_{D_2}} A_2 f = \alpha_{eq_{D_2}} \pi D_2^2 f$$

from which

$$\frac{1}{\alpha_{eqD_1}} = \frac{D_1^2}{D_2^2} \frac{1}{\alpha_{eq_{D_2}}} = \frac{1}{\alpha_1} + \frac{D_1^2}{D_2^2} \frac{1}{\alpha_2} - \frac{D_1^2}{D_2^2} \qquad \text{(Eq. 5-9)}$$

For an arbitrary number N of series connected elements of constant internal diameter, we can use Eq. 5-6 successively to obtain

$$\frac{1}{\alpha_{eq}} = \left(\sum_{i=1}^{N} \frac{1}{\alpha_i} \right) - (N - 1) \qquad \text{(Eq. 5-10)}$$

For an arbitrary number N of series connected elements of various internal diameters $D_1, D_2, ..., D_N$ as shown in Fig. 5-2(a), we can extend Oatley's treatment by adding infinitesimally short tubes of internal diameter equal to the maximum D_{max} of $D_1, D_2, ..., D_N$ as shown in Fig. 5-2(b). We have for the effective transmission probability for the arrangement considered as having inlet diameter D_{max} as shown in Fig. 5-2(b)

$$\frac{1}{\alpha_{eqD_{max}}} = \left(\sum_{i=1}^{N} \frac{D_{max}^2}{D_i^2} \frac{1}{\alpha_i} \right) - (N - 1) \qquad \text{(Eq. 5-11)}$$

and since we have $D_1^2 \alpha_{eqD_1} = D_{max}^2 \alpha_{eqD_{max}}$, we get for the effective transmission probability α_{eqD_1} of the system, considered as having inlet diameter D_1, the expression:

$$\frac{1}{\alpha_{eqD_1}} = \left(\sum_{i=1}^{N} \frac{D_1^2}{D_i^2} \frac{1}{\alpha_i} \right) - \frac{D_1^2}{D_{max}^2}(N - 1) \qquad \text{(Eq. 5-12)}$$

This is one equation which was used together with the transmission probabilities of the individual elements to calculate effective transmission probabilities in the various candidate pumping systems. Additionally, certain rules and procedures were used to account for special items such as frustums and manifolds. Before moving to discuss these rules and procedures, we pause to consider the philosophy behind Eq. 5-12. In the course of these considerations we will develop and discuss one other equation used to calculate effective transmission probabilities.

As Oatley himself points out, certain simplifying assumptions are made in the logic leading to Eqs. 5-6, 5-11, and 5-12, so that these expressions are only approximations. Perhaps the chief assumption is that the probability of transmission α_i for the ith element is independent of the (i−1)th element which is upstream of it. In fact, this is not necessarily the case. For example, if the ith element is a cylindrical tube and the (i−1)th element is a large sphere, the value of α_i obtained will be appropriate for molecules entering the inlet of the ith element with randomly directed velocities. On the other hand, if the (i−1)th element is a cylinder whose axis lies along the same line as that of the ith element, the velocities of molecules entering the ith element will tend to be bunched in the axial direc-

(a)

(b)

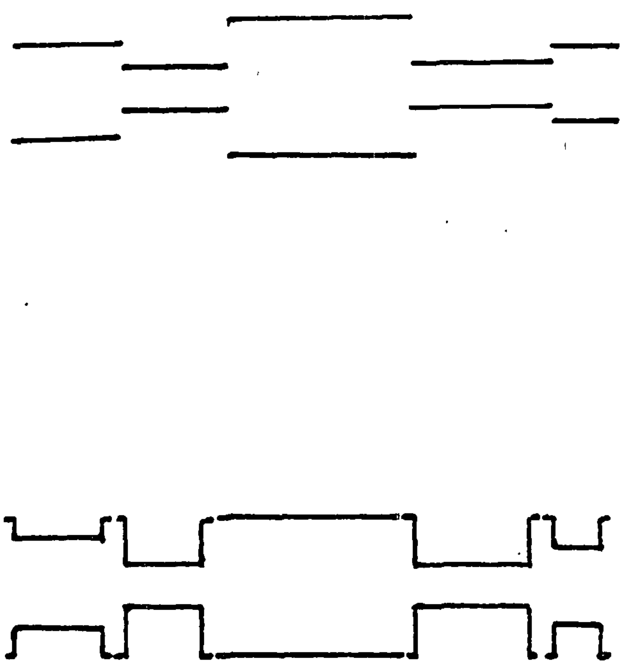

FIGURE 5-2 COMBINATIONS OF SEVERAL CONDUCTANCES, EACH OF CONSTANT CROSS SECTION

tion. The probability α_i that the average molecule will go through the ith element is thus increased, since many molecules have been "aimed" by the (i−1)th tube so that they will not collide at all with the walls of the ith tube.

Since Eqs. 5-6, 5-11, and 5-12 are only approximations, one would expect a lack of accuracy in the results which would grow more pronounced with increasing number N of elements. Ballance[5-3] compared α for a tube with length = 10 units to the α predicted by Eq. 5-10 for a series connection of identical elements of the same radius and same total length and with element lengths equal to 5, 2, 1, and 1/2 units, respectively. The percentage error of the predicted value of α of the series combination ranged from 5.4% for N=2 to 14.6% for N=20. Correct values for the transmission probability for each individual element and for the 10 unit long tube were obtained from a procedure due to Clausing[5-4]. Using Ballance's results as a guide, we expect the transmission probability for a series connection of, roughly, ten elements which is predicted by equation 5-12 to be accurate only to within 10 to 20 percent. Despite the limited accuracy of equation 5-12, however, one would expect that the relative merit of candidate conductance systems should be properly predicted if calculations are performed the same way for each system.

Any system of vacuum ductwork with an orifice on each end should have the property that the conductance from the first orifice to the second is equal to the conductance in the reverse direction, since otherwise the ductwork would be like a pump when immersed in a gas. Since the conductance is given by equation 5-2, C = αAf, it is seen that the product αA of the area A of an orifice and the probability α that a molecule entering the ductwork via this orifice will exit via the other orifice has the same value for both orifices. For example, in Fig. 5-1(b), we must have $D_1^2\alpha_R = D_2^2\alpha_L$ where α_R and α_L are the total transmission probabilities to the right and to the left, respectively. It is seen that equation 5-12 satisfies this condition since it predicts

$$\alpha A_1 = \pi r_1^2\ \alpha = \pi \left(\Sigma \frac{1}{r_i^2} \frac{1}{\alpha_i} - \frac{1}{r_{max}^2} (N-1) \right)^{-1}$$

and since nothing in this expression for αA depends on the direction of molecular motion for which the probability α is being calculated. This is because for any individual duct element, the product $r_i^2 \alpha_i$ must have the same value when one end is considered as the inlet as it has when the other end is considered as the inlet. Otherwise the individual element itself would act like a pump.

Another self-consistency check which can be applied to equation 5-12, or indeed to any rule for calculating the total transmission probability α for a series connection of duct elements each of which has the known transmission probability α_i, is to see whether the associative property is satisfied. For example, if we have a series of five duct elements, one way to calculate the total α would be to apply equation 5-12 directly to all five elements, obtaining

$$\frac{1}{\alpha} = \sum_{i=1}^{5} \frac{r_1^2}{r_i^2} \frac{1}{\alpha_i} - \frac{r_1^2}{r_{max}^2} (4) \qquad \text{(Eq. 5-13)}$$

Alternatively, we could first combine the 3rd and 4th element into an equivalent conductance α_{3+4}, letting R = larger of r_3 and r_4:

$$\frac{1}{\alpha_{3+4}} = \frac{1}{\alpha_3} + \frac{r_3^2}{r_4^2} \frac{1}{\alpha_4} - \frac{r_3^2}{R^2}$$

and then again use equation 5-12 to combine this equivalent conductance with the 1st, 2nd, and 5th elements, obtaining

$$\frac{1}{\alpha_1} = \frac{1}{\alpha_1} + \frac{r_1^2}{r_2^2} \frac{1}{\alpha_2} + \frac{r_1^2}{r_3^2} \left(\frac{1}{\alpha_{3+4}} \right) + \frac{r_1^2}{r_5^2} \frac{1}{\alpha_5} - \frac{r_1^2}{r_{max}^2} (3) =$$

$$\frac{1}{\alpha_1} + \frac{r_1^2}{r_2^2} \frac{1}{\alpha_2} + \frac{r_1^2}{r_3^2} \frac{1}{\alpha_3} + \frac{r_1^2}{r_4^2} \frac{1}{\alpha_4} - \frac{r_1^2}{R^2} + \frac{r_1^2}{r_5^2} \frac{1}{\alpha_5} - \frac{r_1^2}{r_{max}^2} (3)$$

This will give the same result as equation 5-13 only if the maximum r_{max} of all 5 inlet radii is equal to R, the larger of r_3 and r_4. To this extent the reasoning behind equation 5-

12 is not self-consistent. However, the ambiguity represents only a fraction of the last term of equation 5-12, and this term is itself the "correction term" which Oatley added to the older formula

$$\frac{1}{\alpha} = \sum_{i=1}^{N} \frac{1}{\alpha_i}$$

following from the electrical circuit analogy mentioned earlier. As already stated, equation 5-12 is only an approximation; consequently, it should perhaps not be expected to have exact self-consistency. Furthermore, the ambiguity is smallest when r_{max} is approximately the same as the other element radii, and this is the general rule in practical vacuum systems.

In view of all these considerations, the fact that the transmission probability for a total system depends, in this approximation, on the order in which transmission probabilities for its individual elements are combined is unlikely to cause trouble. Nevertheless, we followed the policy of first combining the α's of all adjacent elements for which there was no discontinuity in internal radius r_i, and only then applying equation 5-12. This policy helped ensure that the order in which the α's of individual elements was combined was the same in calculations of the total transmission probability for rival ductwork system designs, and hence it helped ensure that the merit ranking of the rival systems was correct.

An alternative to equation 5-12 was found recently which is based on extensions of Oatley's ideas contributed by Fustoss and Toth (reference 5) and by Ballance (reference 4). The basic idea of these extensions is to suppose that each individual conductance element in the series can have a transmission probability to the right α_{iR} different from the probability α_{iL} for motion to the left. Referring to Fig. 5-3, suppose that we seek the total transmission probability α_{TR} to the right side of the series connection of two elements. Following the approach of Oatley and Ballance, we focus attention on N molecules enter-

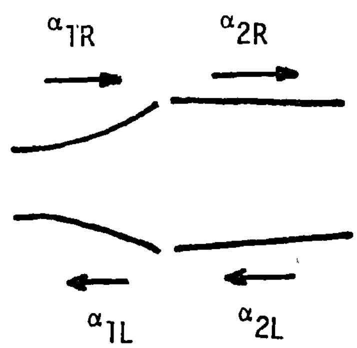

FIGURE 5-3 COMBINATIONS OF CONDUCTANCES WITH VARYING CROSS SECTIONS

ing the left-hand end of the combination. The number eventually emerging from the right-hand end will be given by:

$$N\alpha_{TR} = N\alpha_{1R}\alpha_{2R} + N\alpha_{1R}\alpha_{2R}\ (1-\alpha_{2R})\ (1-\alpha_{1L}) + N\alpha_{1R}\alpha_{2R}\ (1-\alpha_{2R})^2\ (1-\alpha_{1L})^2 + \cdots$$

$$= N\alpha_{1R}\alpha_{2R}\left(\frac{1}{1-(1-\alpha_{2R})\ (1-\alpha_{1L})}\right)$$

so that we find

$$\alpha_{TR} = \frac{\alpha_{1R}\alpha_{2R}}{\alpha_{2R} + \alpha_{1L} - \alpha_{2R}\ \alpha_{1L}} \qquad \text{(Eq. 5-14)}$$

For a series of 3 or more conductances, we can find an expression for the total probability by using Eq. 5-14 repeatedly: first to find the equivalent conductance of the rightmost 2 conductances; second to find the result of that conductance and the third conductance from the right, and so on. In this way, we find for the total conductance of n series conductances

$$\frac{1}{\alpha_{TR}} = \frac{1}{\alpha_{1R}} + \sum_{i=2}^{N}\left(\prod_{j=1}^{i-1}\frac{\alpha_{jL}}{\alpha_{jR}}\right)\left(\frac{1}{\alpha_{iR}} - 1\right) \qquad \text{(Eq. 5-15)}$$

Here $\prod_{j=1}^{i-1}\frac{\alpha_{jL}}{\alpha_{jR}}$ is shorthand notation for the product consisting of (i−1) factors

$$\frac{\alpha_{1L}}{\alpha_{1R}}\ \frac{\alpha_{2L}}{\alpha_{2R}}\ \frac{\alpha_{3L}}{\alpha_{3R}} \cdots \frac{\alpha_{i-1L}}{\alpha_{i-1R}}$$

Eq. 5-15 is the alternative to Eq. 5-12. If we let A_{iL} and A_{iR} stand for the areas of the left and right side orifices of conductance element i, then both alternative equations satisfy the consistency requirement that $A_{1L}\ \alpha_{TR} = A_{nR}\alpha_{TL}$, where α_{TL} is the probability for gas motion to the left found by using Eq. 5-12 or Eq. 5-15 to calculate the combined probability of the n conductances taken in reverse order. Unlike Eq. 5-12, however, Eq. 5-15 is also "associative" in that the final answer α_T is unchanged if we first combine, say, 3 of the n probabilities into an equivalent probability and then combine that equivalent probability with the (n−3) remaining ones.

Consider a series of n conductances which have no discontinuity between cross sections in adjacent elements so that $A_{iR} = A_{(i+1)L}$ as in Fig. 5-3. Then the general rule that $A_{iL}\alpha_{iR} = A_{iR}\alpha_{iL}$ means that equation 5-15 can be written in the form

$$\frac{1}{\alpha_{TR}} = \frac{1}{\alpha_{1R}} + \sum_{i=2}^{N} \frac{A_{1L}}{A_{iL}} \left(\frac{1}{\alpha_{iR}} - 1 \right) .$$

This is the form in which Fustoss and Toth give the expression. If we allow discontinuities in cross section between adjacent elements as in Fig. 5-1(b), then we must revert to the form given in Eq. 5-15 containing α_{iL} and α_{iR} explicity. Furthermore, we need to account for the extra orifice encountered by a molecule crossing a junction with discontinuity in cross section. This is done by inserting another conductance element for conductance calculation purposes. For example, the series in Fig. 5-1(b) is modified by an inserted conductance as in Fig. 5-4. The inserted conductance is cone-shaped and removes the discontinuity in cross section for calculation purposes. It is thought of as having vanishingly small length with $\alpha_R = 1$ and $\alpha_L = D_1^2/D_2^2$. Addition of such conductance elements thus enables the use of Eq. 5-15 to calculate the effective conductance of systems with discontinuities in cross section between elements.

Equation 5-12 was used to analyze nearly all the candidate systems as described in Section 5.1.2 below. Equation 5-15, together with the procedure shown in Fig. 5-4 for handling cross section discontinuities was found late in the effort and was used to reanalyze those candidate systems which had been shown by Equation 5-12 to be most desirable at that time. For these cases, the total transmission probabilities predicted were essentially the same as those earlier predicted in Eq. 5-12. Subsequently, Equation 5-15 was used exclusively.

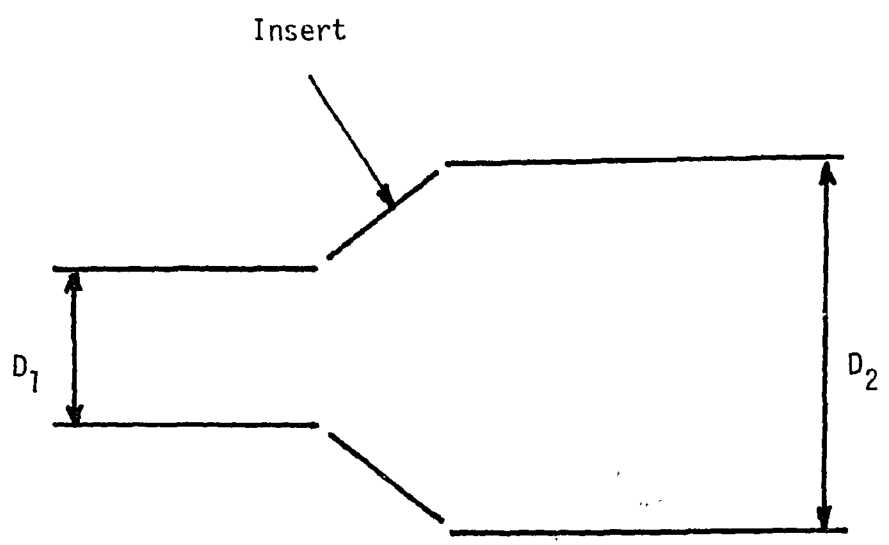

FIGURE 5-4 INSERTED CONDUCTANCE AT A CROSS SECTION DISCONTINUITY

As mentioned above, each type of individual conductance element was assigned transmission probabilities α_{iR} and α_{iL} by a method suited to its type.

5.1.1.7 Manifold Pumps - Several of the candidate vacuum systems use manifolded ductwork, which can involve typically 24 pumps connected to a manifold which in turn is connected to each of 36 magnet dewars. Methods used for calculating the effective pumping speeds at each of the dewars rely on symmetry arguments. For example, the 24 pump manifold system was treated by supposing that pumps were located halfway between dewar pairs, with every third dewar pair not having an associated pump. This situation is shown schematically in Fig. 5-5.

If each dewar has the same gas load and each pump the same speed, then there should be no net gas flow across the dotted lines in Fig. 5-5. For pumping speed calculation purposes the entire system can then be considered as consisting of 12 identical disconnected subsystems, bounded by the dotted lines in the figure, each having three dewars and two pumps. The dewar located between the two pumps in each of these sub-systems enjoys more efficient pumping than the two outer dewars; it is these two "worst case" dewars, farthest from pumps, for which the speed was calculated.

Directing our efforts at just one of the 12 sub-systems, we first suppose that each dewar represents a gas load Q. Then each pump is required to pump a throughput given by 1 1/2 Q. We consider only the left hand half of the subsystem; the right half is equivalent by symmetry. We calculate the conductance C_{JP} between the point J and the pump, and find the pressure P_J at the junction from the expression $C_{JP} = 3Q/2 \div (P_J - P_P)$ with the assumption that the pressure P_P at the downstream end is zero. The conductance C_{JP} includes the pump capture probability as a final effective conductance element as discussed in Section 5.1.1.1.

To complete the pumping speed calculation for the outer dewars in the sub-system, we calculate the conductance C_{DJ} between the left-most outer dewars and the junction J.

We calculate the pressure P_D in the dewar using this conductance value from $(P_D - P_J) = Q \div C_{DJ}$, obtaining $P_D = Q/C_{DJ} + 3Q/2C_{JP}$. The effective pumping speed at the dewar is then given by the basic equation $S = Q/P$ so that $1/S = 1/C_{DJ} + 3/2C_{JP}$.

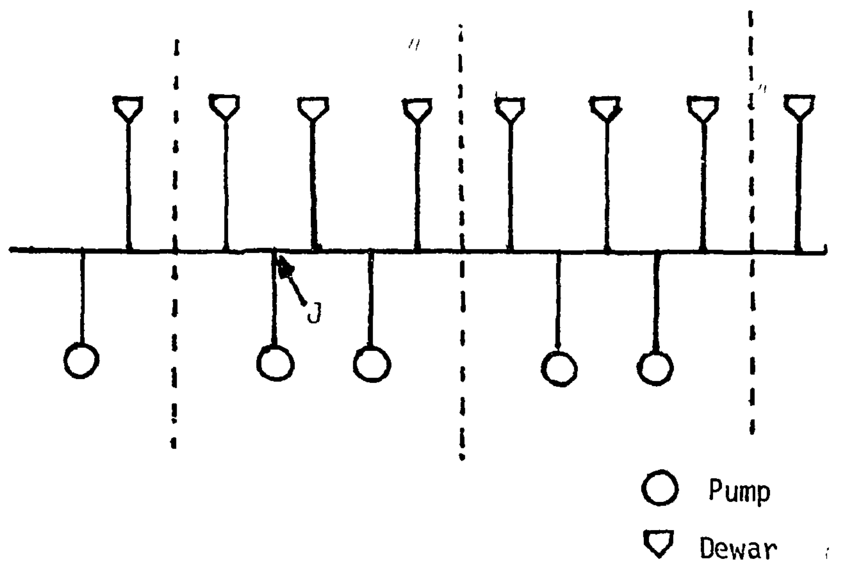

FIGURE 5-5 MANIFOLDED PUMP SYSTEM

5.1.1.8 Tapered Tubes of Circular Cross Section - Conductance elements shaped like a truncated right circular cone are encountered as adaptors between tubes of differing cross sectional area. The transmission probability for such elements clearly is dependent on the direction of the molecular motion. The transmission probabilities are determined by the ratios R_1/R_2 and L_1/R_2, where L_1 is the axial length and R_1 and R_2 are the radii of the large and the small end; respectively. For R_1/R_2 up to 2.5 and for L_1/R_2 up to 4 the transmission probabilities α_{12} in the direction from the large end to the small end are given by a graph on page 104 of reference 5-1. Transmission probabilities α_{21} from the small to the large end are calculated from the principle that $\pi R_1{}^2\alpha_{12} = \pi R_2{}^2\alpha_{21}$. For tapered tubes outside the range of this graph a formula given by Roth[5-6] for the equivalent diameter of a tapered pipe of circular cross section was used:

$$R_{eq} = (2R_1{}^2R_2{}^2/(R_1+R_2))^{1/3}$$

R_{eq} is the radius for a cylindrical pipe having the same length and conductance as the tapered pipe. The value of this conductance was found using Eq. 5-4 and Eq. 5-2 with $A = \pi R_{eq}{}^2$. Next α_{12} was found from this conductance using Eq. 5-2 with $A = \pi R_1{}^2$. This value of α_{12} was compared with the value predicted by the graph in reference 1 for the L_1/R_2 and R_1/R_2 in its range closest to the actual conditions. Finally the smaller of these α_{12} values was used to represent the tapered tube.

However, having found the transmission probability of the tapered tube one cannot proceed directly with the application of Eq. 5-12, since this operation refers to each element as characterized both by its transmission probability and by its cross-sectional diameter. The diameter of the cross section of a tapered tube depends on the location of the cross section. Furthermore, the transmission probability depends on which end of the tapered tube is to be considered the upstream end. If equation 5-12 is to be used, it is thus necessary to follow some sort of procedure to resolve these ambiguities. The procedure used for these vacuum system conductance calculations, using eq. 5-12, was to treat all tapered tubes as follows: (i) Calculate the effective transmission probability α_o for the conductance element combination between the tapered tube and pump for flow moving in the upstream direction away from the pump, (ii). Combine α_o with the upstream transmission probability α_{tt} of the tapered tube to get the equivalent probability α_{eu} for the tapered tube and all conductances downstream of it and for flow moving in the upstream direction. The diameter used in eq. 5-12 to describe the tapered tube in this step is the diameter of its downstream end. (iii) Convert α_{eu} to the equivalent downstream transmission probability α_{ed} of the tapered tube and all conductance elements after it. This is done by use of the equality α_{eu} x (pump inlet area) = α_{ed} x (area of upstream end of tapered tube). (iv) Proceed with equation 5-12, treating the tapered tube and everything downstream of it as a single conductance with probability α_{ed} and diameter equal to that of the upstream end of the tapered tube.

5.1.2 Analysis of Configurations - In Section 5.1.1 a method was described for analyzing vacuum pumping systems. The systems analyzed during the Title I design of the Vacuum Pumping System are presented in this section. In order to optimize the design the number, size and type of vacuum pumps were varied. Duct lengths and diameters were also varied. Manifold systems were analyzed with varying numbers of pumps and different manifold geometries. Integral pumping system in which the MC dewars and torus shared high vacuum pumps were also analyzed. Many of the configurations analyzed are presented in this section. Others, which were only slightly different from those presented were analyzed but are not included herein. For clarity these analyses are separated into three major groups.

- Primary Torus Vacuum Systems
- MC Dewar Vacuum Systems
- Integral Pumping Systems

In the torus and MC dewar analyses, several configurations were considered using Cryotorr 7 and Cryotorr 10 gaseous helium cryopumps. These were the baseline pumps for the MC dewars and torus respectively. However, during the course of the Title I design these pumps were found to be unsuitable for use due to their susceptibility to x-rays, as discussed in Section 5.4.1. The analyses are presented for comparison to other systems.

It should be noted that standard components were used wherever possible in pumps, valves, flanges, piping, elbows, bellows, etc. For this reason, uniform diameters are not always maintained throughout the ducts and manifolds.

5.1.2.1 Primary Torus Pumping Systems - Eight configurations were analyzed for the torus pumping system. All configurations employed a single vacuum pump per duct, with each vacuum duct penetrating the torus on the outboard side of the torus at the horizontal midplane. A valve and microwave shield are included in each duct. Five different vacuum pumps were analyzed and, accordingly, this section is organized as follows:

- Crytorr-10 Pump Systems - Torus
- Crytorr-7 Pump System - Torus
- Liquid Helium BPK-2000 System - Torus
- Turbomolecular TMP1500 System - Torus
- Turbomolecular TMP3500 System - Torus

All calculations pertaining to the torus are the net effective hydrogen pumping speed of the appropriate duct/pump configuration. It is assumed that the hydrogen is at room temperature. To determine the speeds for other gases, the capture probability for the pump must be calculated and combined with the vacuum duct transmission probability to yield a net pumping probability. The atomic mass of the gas should then be substituted, as in Equation 5-3, to obtain the net effective pumping speed for the gas of interest.

5.1.2.1.1 Cryotorr-10 Pump Systems - Torus - The baseline vacuum pump was the CTI Cryotorr-10. It has a hydrogen pumping speed of 3000 liter/sec. Three different configurations utilizing this pump were analyzed and the results were:

- Baseline Design - 1860 liter/sec
- Baseline Design with Direct Plasma View Prevented By Adding a Right Angle Duct - 1770 liter/sec
- Baseline Design with Direct Plasma View Prevented by Adding a Right Angle Duct. The Straight 12 Inch Long Absorbing Duct Removed - 1840 liter/sec.

A schematic of the baseline pumping configuration is shown in Figure 5-6. The Cryotorr-10 pump and a 11.5 inch inside diameter gate valve are attached to an 11.5 inch diamter, 12 inch long microwave absorbing duct. The duct is connected to the torus at the microwave shield. This system exhibits the highest pumping speed, 1860 liter/sec, for those analyzed. Six such pumps would be required to meet the design goal of 10,000 liter/sec.

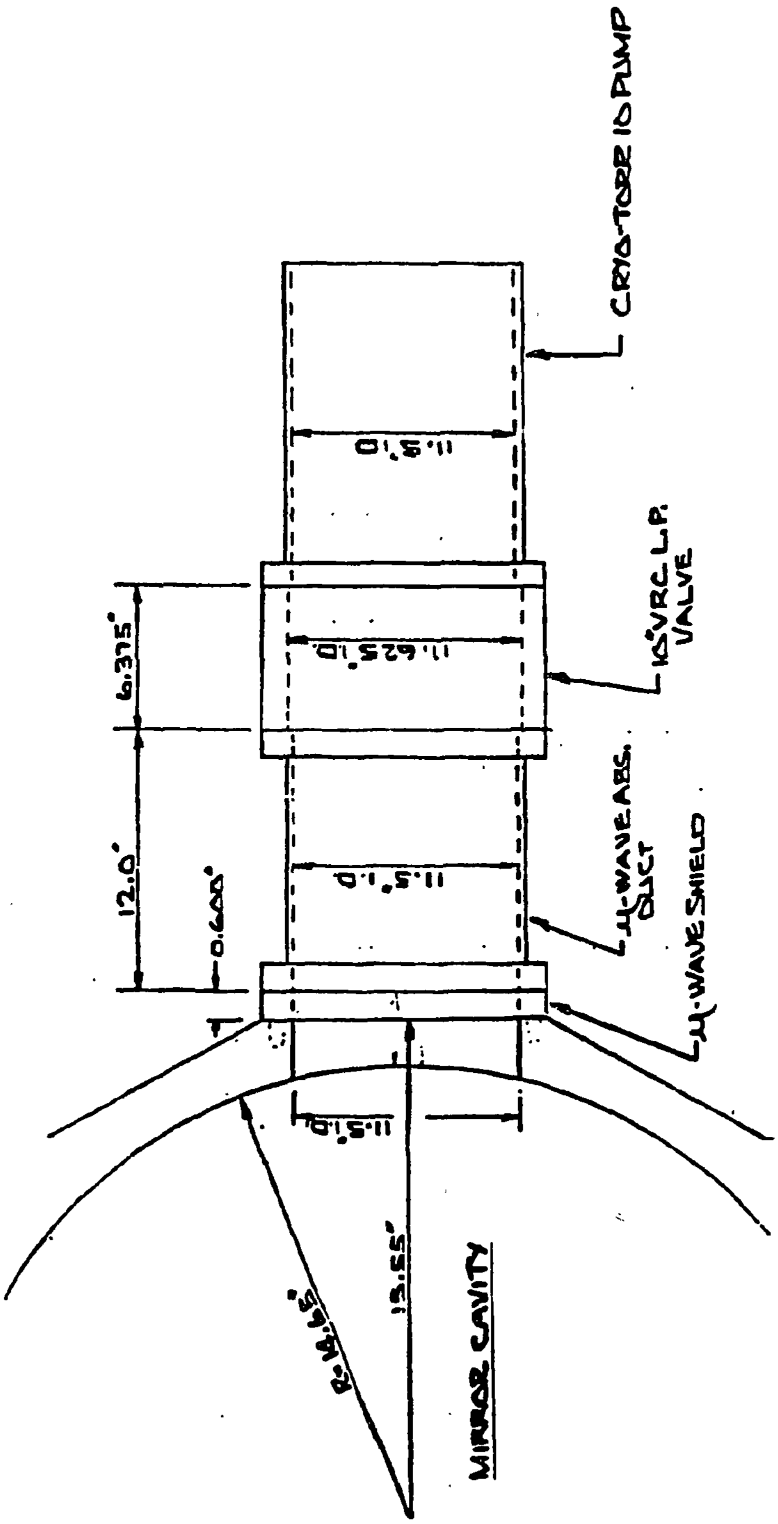

FIGURE 5-6 BASELINE TORUS HIGH VACUUM SYSTEM

Shown in Figure 5-7 is a modified version of the baseline design. A Cryotorr-10 pump is vertically mounted with a right angle elbow used to optically shield the cryopump from the plasma and minimize the incident heat loads. The configuration is identical to that just described except that a 11.5 inch diameter right angle elbow connects the Cryotorr-10 to the gate valve. The pumping speed of this configuration was calculated to be 1770 liter/sec. Six such pumps would be required to meet the design goal of 10,000 liter/sec.

This optically tight configuration was modified as shown in Figure 5-8. The 12 inch long microwave absorbing duct was removed and the elbow is coated with the absorbing material. This is considered to be adequate protection for the cryopump, and gate valve. Removal of this section of duct increases the pumping speed to 1840 liter/sec. Six pumps would be required to achieve the design goal of 10,000 liter/sec. This configuration is the best of the Cyrotorr-10 pumping systems because of the high pumping speed and the protection it offers from the plasma thermal environment.

5.1.2.1.2 Cryotorr-7 Pump System - Torus - An analysis of a torus pumping system using a CTI Cryotorr-7 vacuum pump was performed. It has a hydrogen pumping speed of 1000 liters/sec.

The configuration analyzed is shown in Figure 5-9. A Cryotorr-7 has an inlet diameter of 7.88 inches. The 11.5 inch diameter duct and valve were retained to maximize the efficiency of this configuration. No straight section of absorbing duct is employed. A coated elbow will provide sufficient protection from the thermal enviroment of the plasma. The resulting pumping speed is 766 liter/sec. Fourteen such pumps would be required.

5.1.2.1.3 Liquid Helium Cryopump Systems - Torus - Analyses were performed on liquid helium cryopumped systems. The vacuum pump considered is a Leybold Heraeus liquid helium cryopump, BPK 2000. It has a hydrogen pumping speed of 7000 liter/sec. The BPK 2000 utilizes an internal liquid helium dewar for operation at 4.2 K and must thus be vertically mounted. Two configurations were analyzed and the results were:

- Mounted inside duct with plasma view - 2690 liter/sec
- Recessed with no plasma view - 2210 liter/sec.

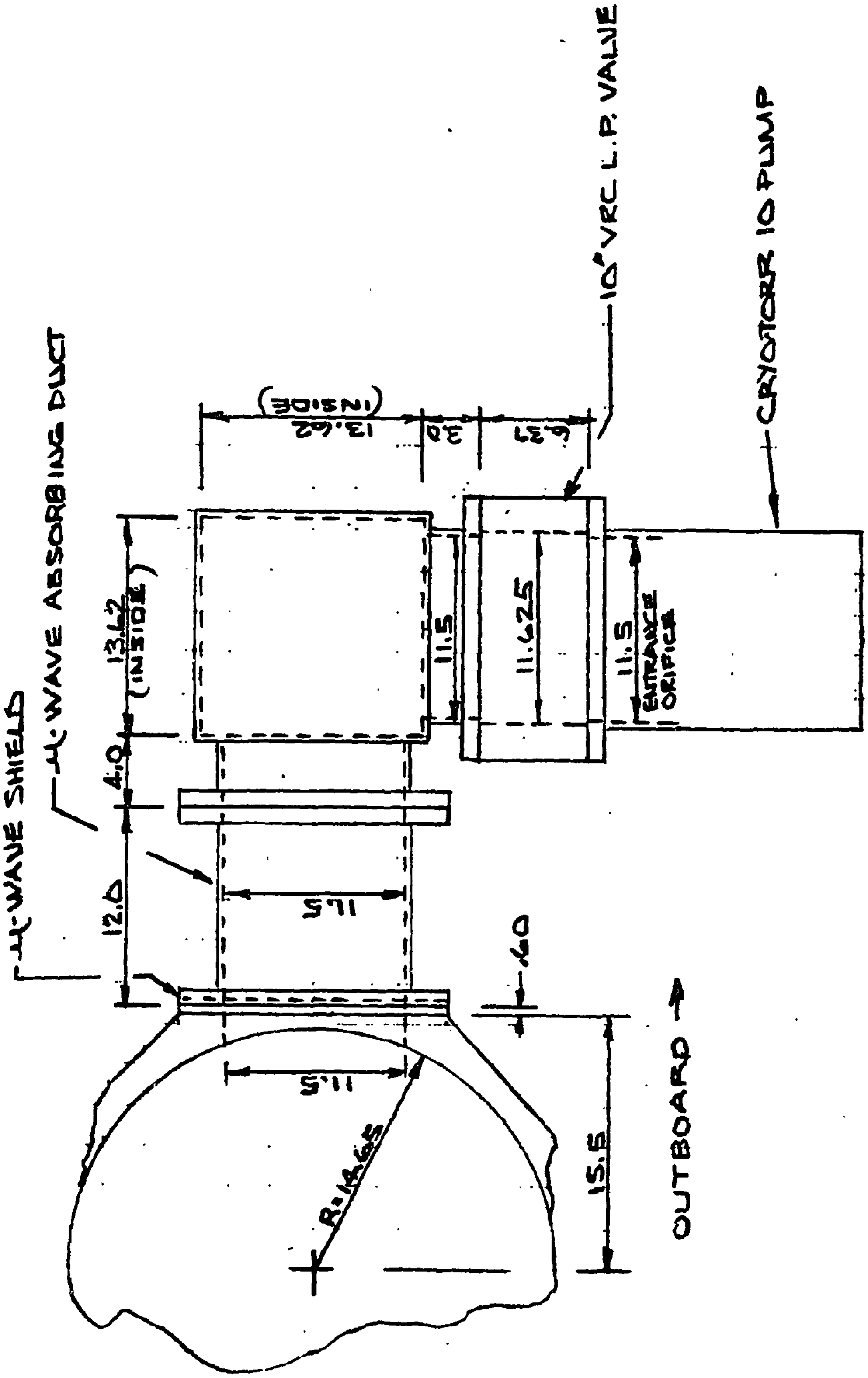

FIGURE 5-7 TORUS HIGH VACUUM SYSTEM WITH ELBOW FOR OPTICALLY SHIELDING THE CRYOTORR-10

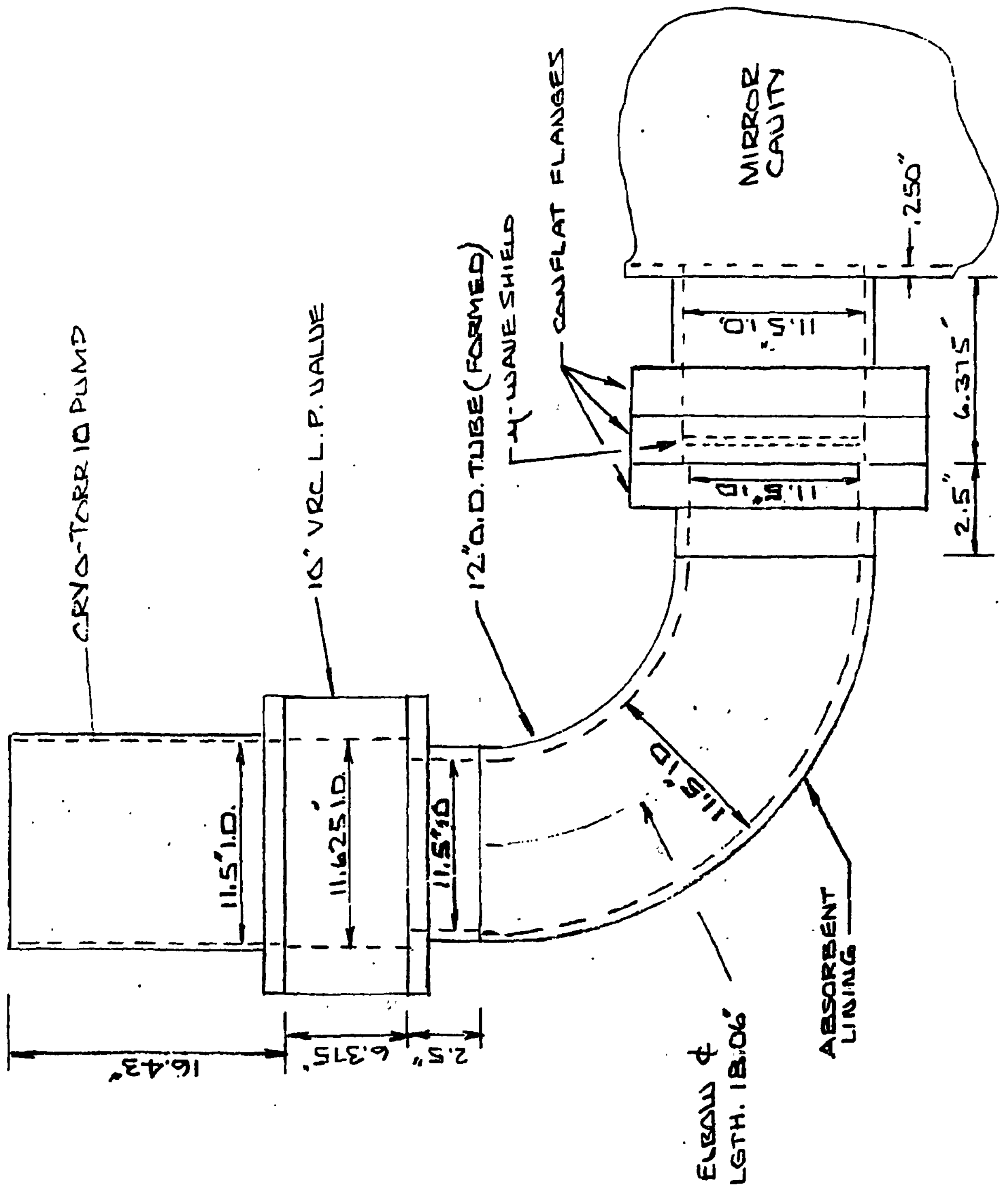

FIGURE 5-8 TORUS HIGH VACUUM SYSTEM WITH MICROWAVE ABSORBING DUCT REMOVED AND CRYOTORR-10 PUMP

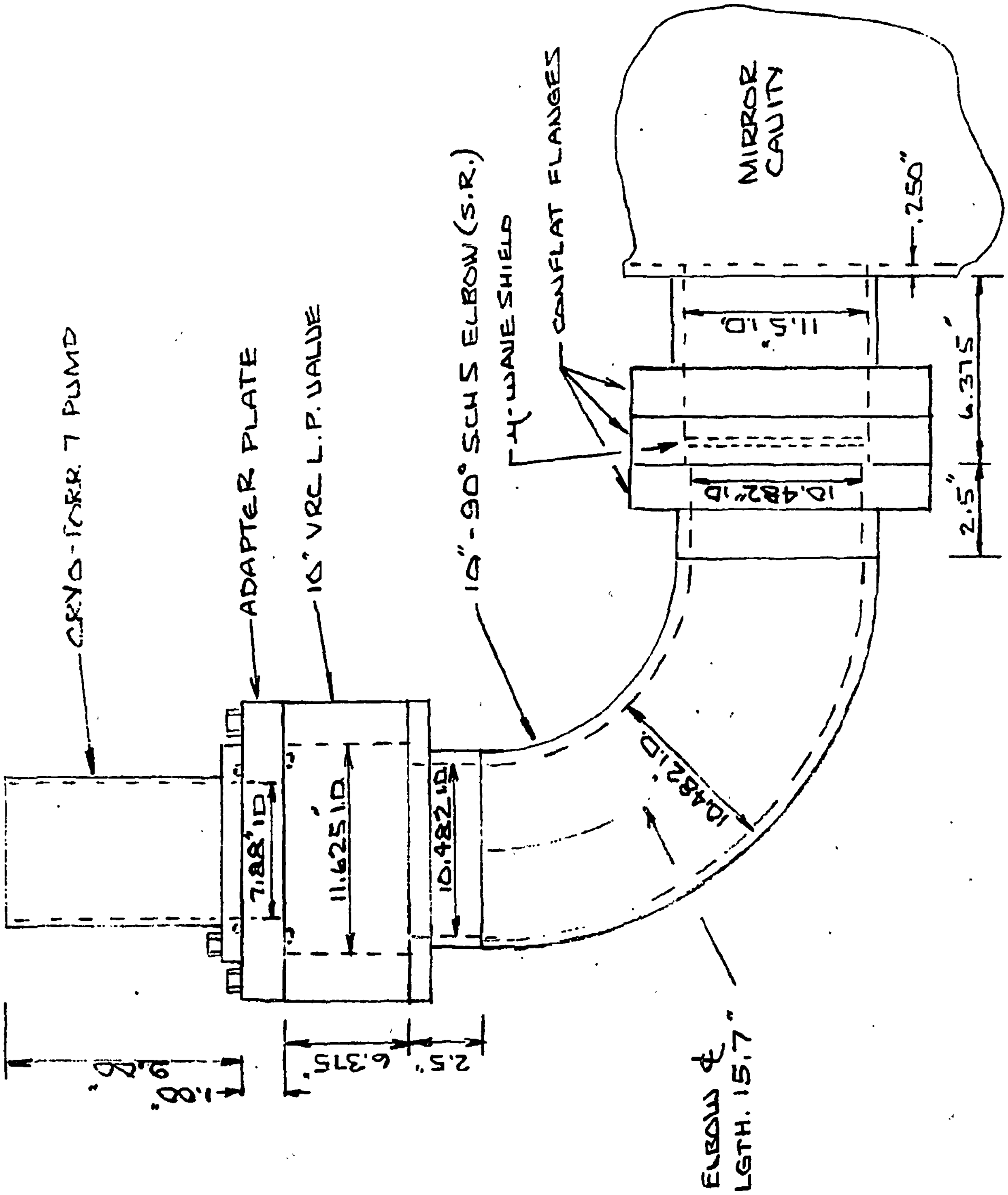

FIGURE 5-9 TORUS HIGH VACUUM SYSTEM WITH MICROWAVE ABSORBING DUCT REMOVED AND CRYOTORR-7 PUMP

Presented in Figure 5-10 is the configuration in which the BPK 2000 is attached to a 10.48 inch diameter right angle elbow and extends into the elbow. An 11.62 inch valve and 11.5 inch diameter, 12.0 inch long microwave absorbing duct connect the elbow to the torus, with the microwave shield located at the duct to torus interface. The net effective pumping speed of this configuration is 2690 liter/sec. Four cryopumps are required to obtain the design goal of 10,000 liter/sec.

A second configuration is presented in Figure 5-11. The duct, microwave shield, valve and elbow are identical to those described in the preceeding system. The only difference is that the BPK 2000 is recessed to reduce the plasma view and thus the heat load incident on the cryogenic surfaces. The pumping speed of this system was calculated to be 2210 liter/sec. Five such pumps are required to achieve the design goal.

5.1.2.1.4 Turbomolecular TMP1500 System - Torus - A configuration employing a Leybold Heraeus TMP1500 turbomolecular pump was analyzed. It has a hydrogen pumping speed of 1020 liter/sec. The TMP 1500 must be vertically mounted.

The configuration which was analyzed is shown in Figure 5-12. The 10.3 inch inlet TMP1500 pump is connected to a 10.75 inch vibration isolation bellows and a 10.48 inch diameter elbow. The elbow is connected to the torus via a 11.625 inch valve, an 11.5 inch diameter duct and a microwave shield. In this configuration the pump is in a magnetic field below 35 gauss. A pumping speed of 874 liter/sec was calculated for this configuration. Twelve of these pumps would be required to pump the EBT-P torus.

5.1.2.1.5 Turbomolecular TMP 3500 System - Torus - The final torus pumping system to be described uses Leybold Heraeus TMP3500 turbomolecular pumps. The TMP3500 is a larger pump, with a 15.75 inch pump inlet and a hydrogen speed equal to 3300 liters/sec. It must also be vertically mounted.

Figure 5-13 illustrates the configuration. The TMP3500 is connected via a 15.67 inch i.d. bellows to a 16 inch i.d. gate valve. The valve is mounted at the bottom of a 15.67 inch i.d. elbow. The inlet of the elbow is connected to the torus via a 4 inch length of 13.69 inch i.d. pipe, a 12 inch length of 14 inch i.d. bellows with .016 inch wall thickness, and an adapter of axial length 7.09 inches, inlet area 94.4 square inches, and outlet area 153.9

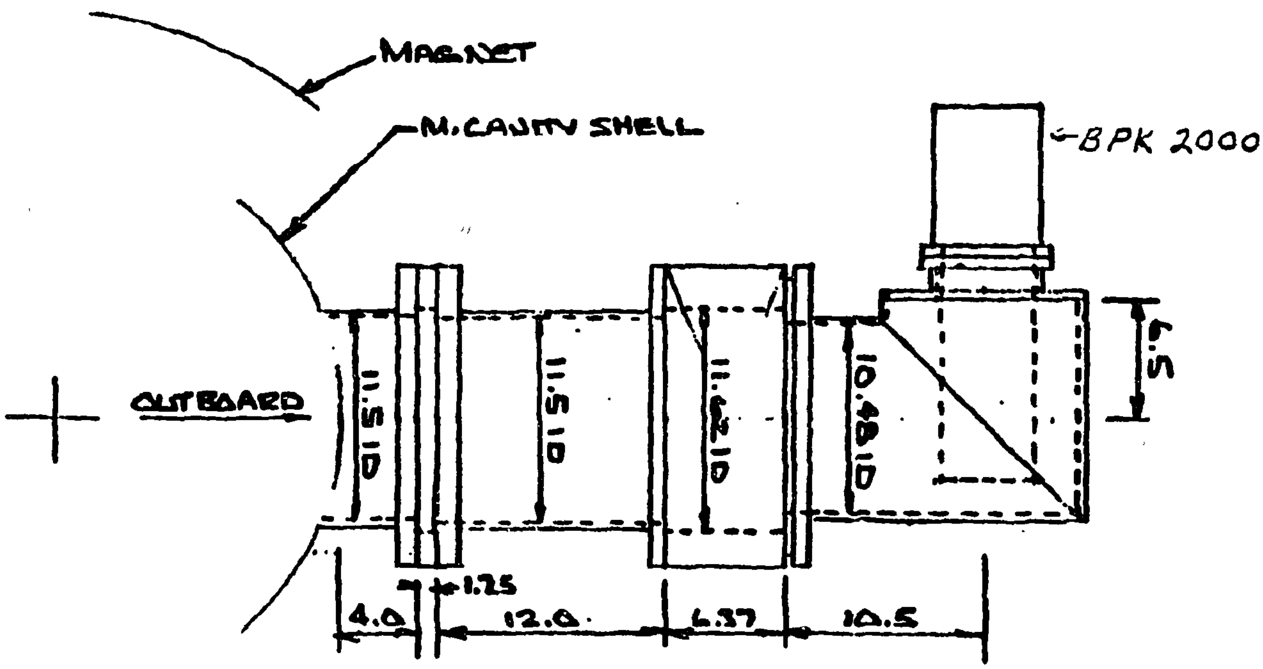

FIGURE 5-10 TORUS HIGH VACUUM SYSTEM WITH BPK-2000 LHe CRYOPUMP

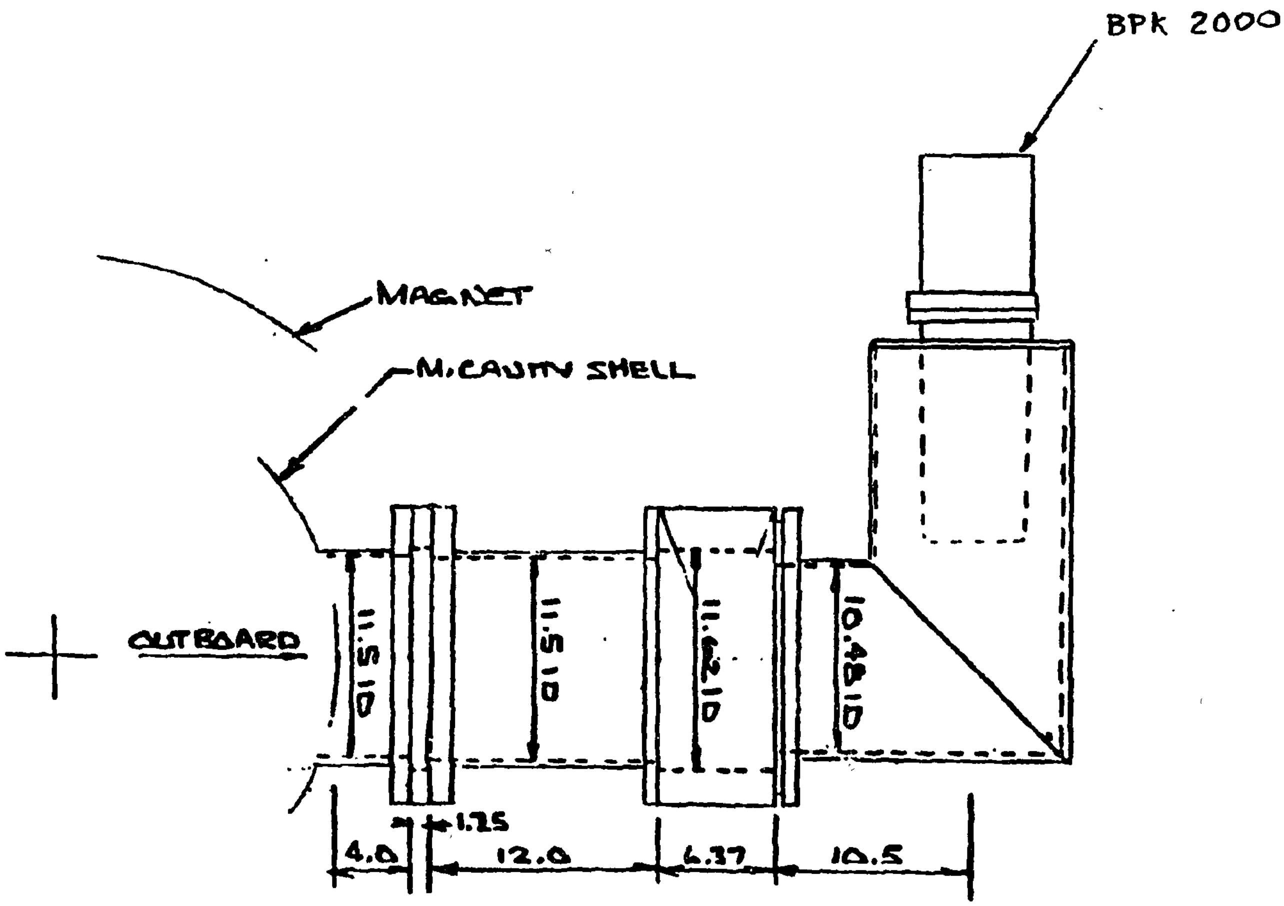

FIGURE 5-11 TORUS HIGH VACUUM SYSTEM WITH RECESSED BPK-2000 CRYOPUMPS

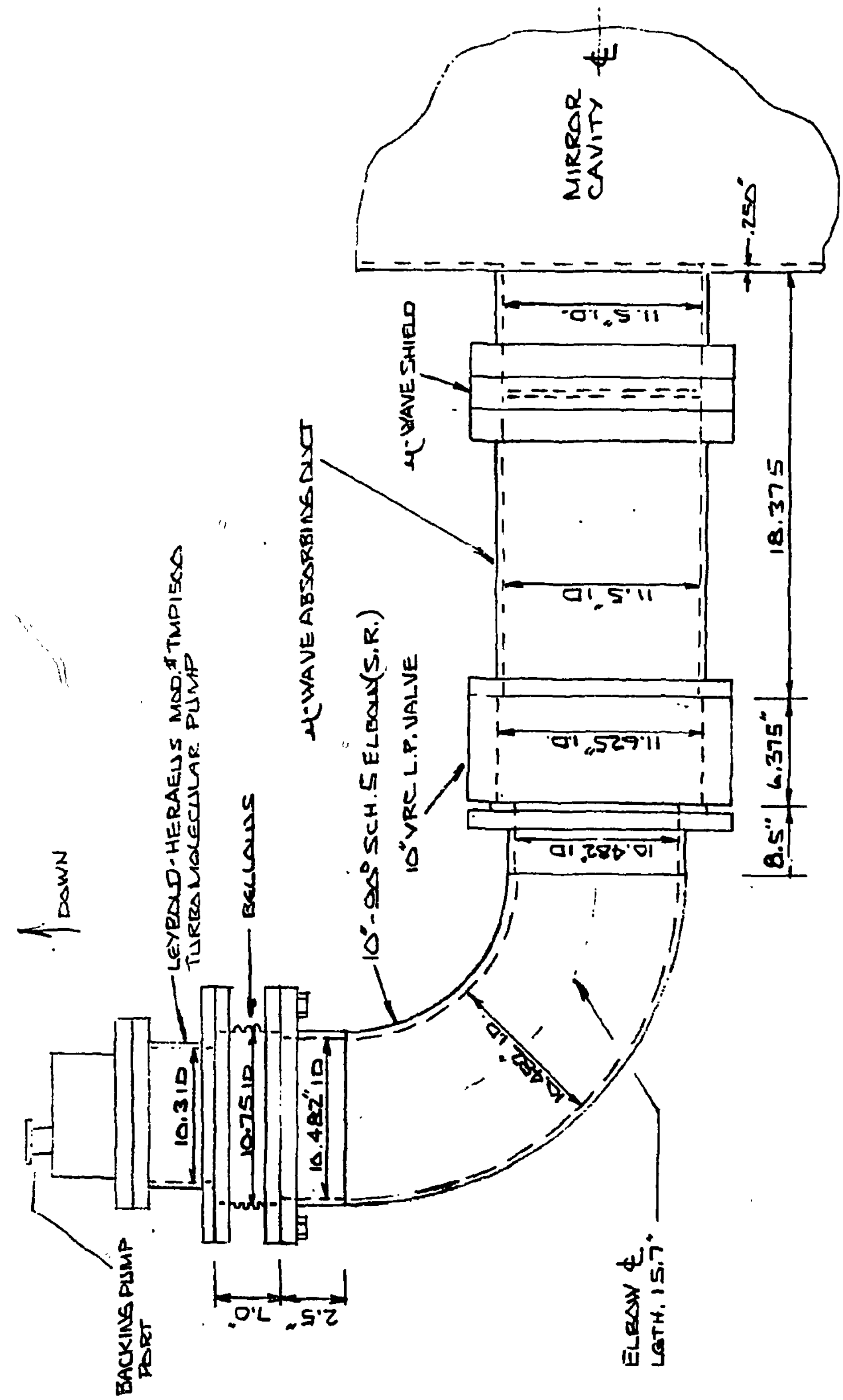

FIGURE 5-12 TORUS HIGH VACUUM SYSTEM WITH TMP1500 TURBOMOLECULAR PUMP

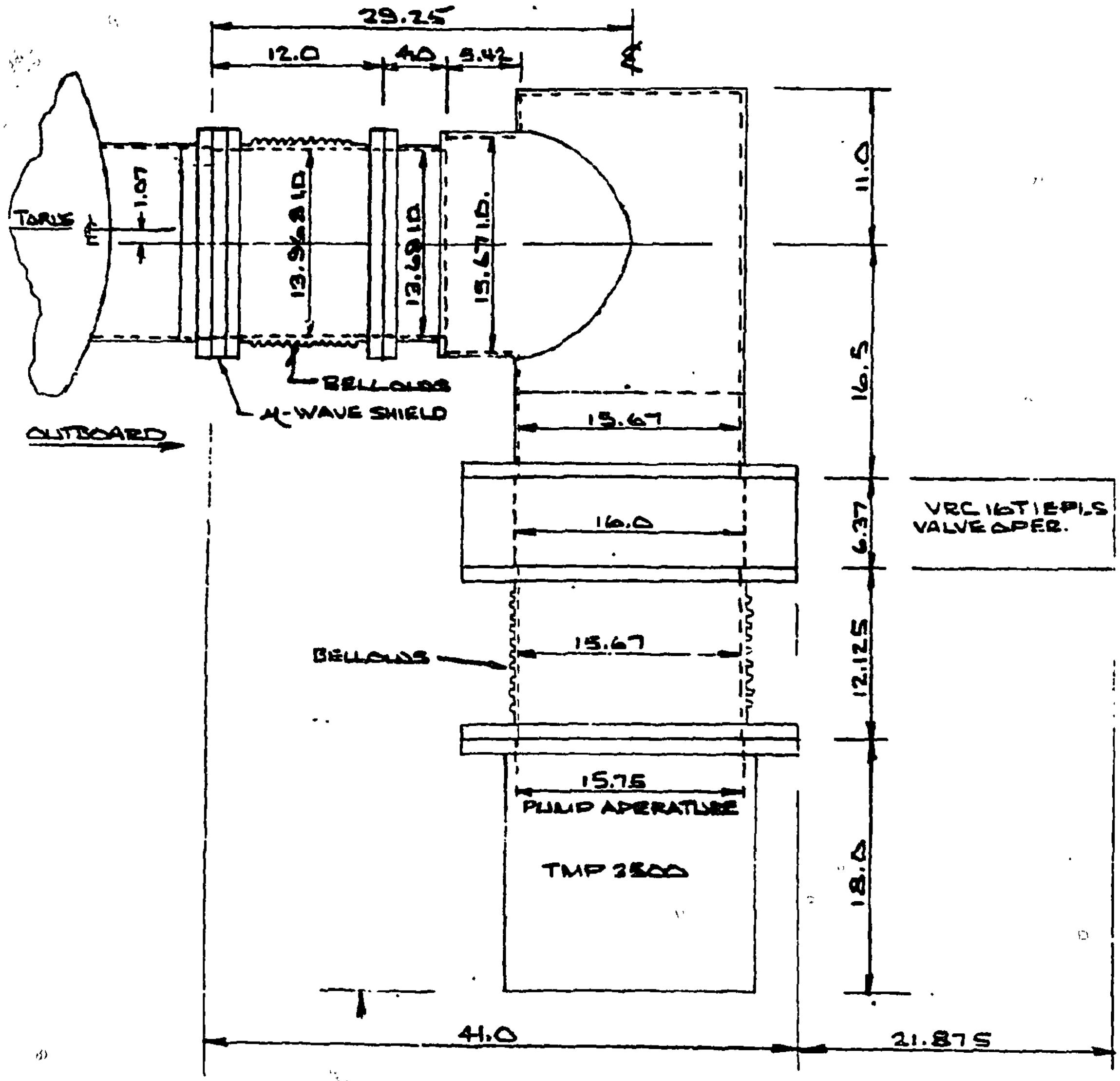

FIGURE 5-13 RECOMMENDED EBT-P TORUS HIGH VACUUM SYSTEM

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square inches. Calculations predict a net effective hydrogen pumping speed at the torus equal to 2020 liters/sec for each TMP3500 connected in this configuration. Each TMP3500 produces a nitrogen pumping speed of 1040 liter/sec. for the system.

This is the configuration recommended for use on the EBT-P Primary Torus Pumping System, with five pumps to be connected initially and with provision to add up to five additional TMP3500 pumps later. Five such pumps are required to provide 10,000 liter/sec hydrogenpumping speed at the torus.

5.1.2.2 MC Dewar Vacuum System - Nineteen different pumping systems employing five different types of vacuum pumps were analyzed and will be described. One configuration, the baseline design, featured a dedicated cryopump with a gate valve attached to each MC dewar stack. All others were manifolded systems with different numbers, types, and sizes of vacuum pumps attached to the manifold. The manifold location was varied, inboard and outboard, as well as the diameter of the manifold and of the connecting vacuum ducts. Five types of vacuum pumps were analyzed and accordingly this section is organized as follows:

- Cryotorr 7 Pump System - MC Dewar
- Turbomolecular TMP1500 Systems - MC Dewar
- Turbomolecular TMP3500 Systems - MC Dewar
- Liquid Helium Cryopump BPK-2000 Systems - MC Dewar
- Turbomolecular TPU2200 System - MC Dewar

All calculations performed for the MC dewars are the net effective pumping speed for air at 300°K. In manifold systems, the speed was calculated for the "worst-case" MC dewar, because the pumping speed for a particular dewar varies according to its proximity to the pumps on the manifold. To determine the pumping speeds of other gases of interest, such as helium, the capture probability of the pump must be determined and then the overall pumping probability of the duct/manifold/pump geometry calculated as discussed in Section 5.1.1. Finally, the net effective speed can be calculated using the atomic mass of the gas of interest.

Most of the configurations analyzed had pumping speeds far higher than the design goal of 50 liter/sec on each magnet dewar. This was due to a change in the design criteria in October which reduced the required pumping speed from 500 liter/sec to 50 liter/sec.

As previously noted, standard size lines, bellows, valves, elbows, flanges, reducers, etc. are used wherever possible.

5.1.2.2.1 Cryotorr-7 Pump System - MC Dewar - A schematic of the baseline pumping configuration of the MC dewar is presented in Figure 5-14. A CTI Cryotorr-7 gaseous helium cryopump is dedicated to each magnet dewar. It has an air pumping speed of 1000 liter/sec at its 7.75 inch diameter inlet. The Cryotorr-7 is attached, via a 7.125 inch inside diameter gate valve and a 7.125 inch penetration, to the top of the magnet stack. The pumping speed for air was calculated to be 665 liter/sec., which is far higher than the present design goal of 50 liter/sec. Other configurations employing this pump were not analyzed because its low tolerance level for x-rays (Section 5.4.1) precluded its use on EBT-P.

5.1.2.2.2 Turbomolecular TMP1500 System - MC Dewar - Analyses were performed on manifolded systems employing the Leybold Heraeus TMP1500 turbomolecular pump. It has a pumping speed for air of 1450 liter/sec and must be vertically mounted. Four configurations employing the pump were analyzed. All were manifolded systems on the inboard side of the torus. One configuration assumed 36 pumps on the manifold; three assumed 12 pumps. The manifold diameter was varied from 10.48 inches to 12.44 inches. A summary of the results is presented below.

- 10.482 inch manifold; 12 TMP1500 - 81 liter/sec
- 12.438 inch manifold; 12 TMP1500 - 123 liter/sec
- 12.438 inch manifold; 36 TMP1500 - 318 liter/sec
- 12.438 inch manifold; 12 TMP1500 on short drop duct - 192 liter/sec.

A schematic of the configuration with a 10.482 inch manifold is shown in Figure 5-15. A plan view of the manifolded MC dewar system is shown in Figure 5-16. A duct, approximately four feet long with a 7.125 inch inside diameter gate valve and a 6.4 inch diameter bellows connects each of the thirty-six magnet dewars to the 10.482 inch manifold on the

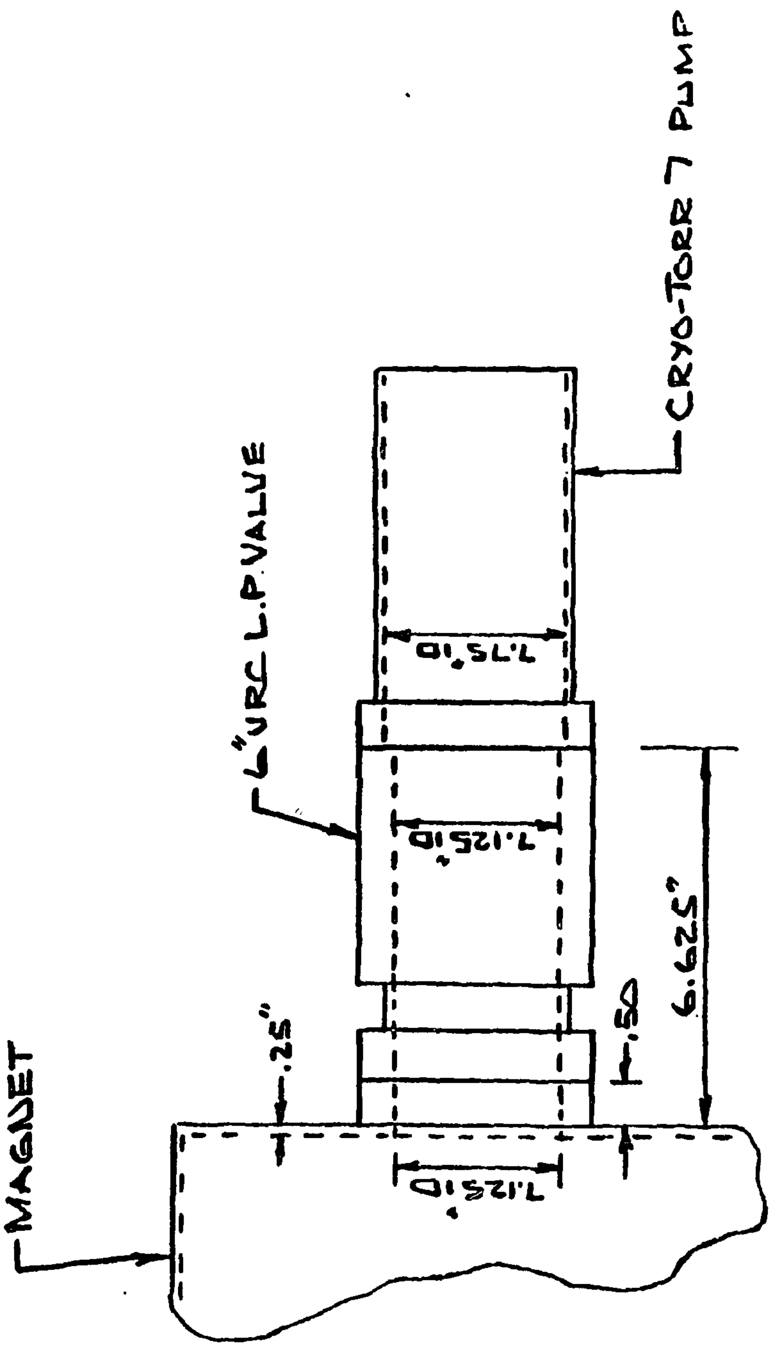


FIGURE 5-14 BASELINE MC DEWAR VACUUM SYSTEM

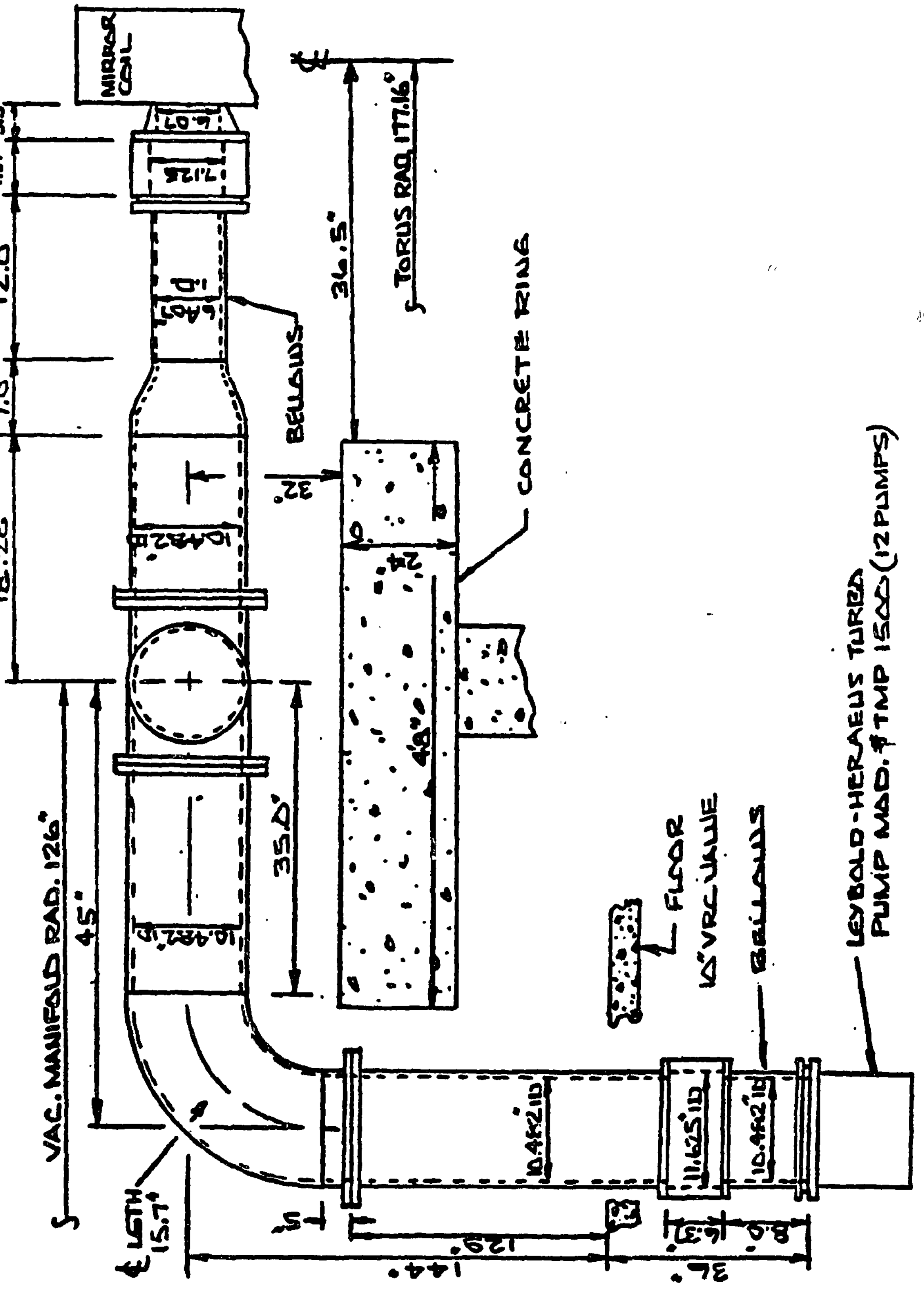


FIGURE 5-15 MC DEWAR TMP 1500 SYSTEM WITH 10.48 INCH MANIFOLD

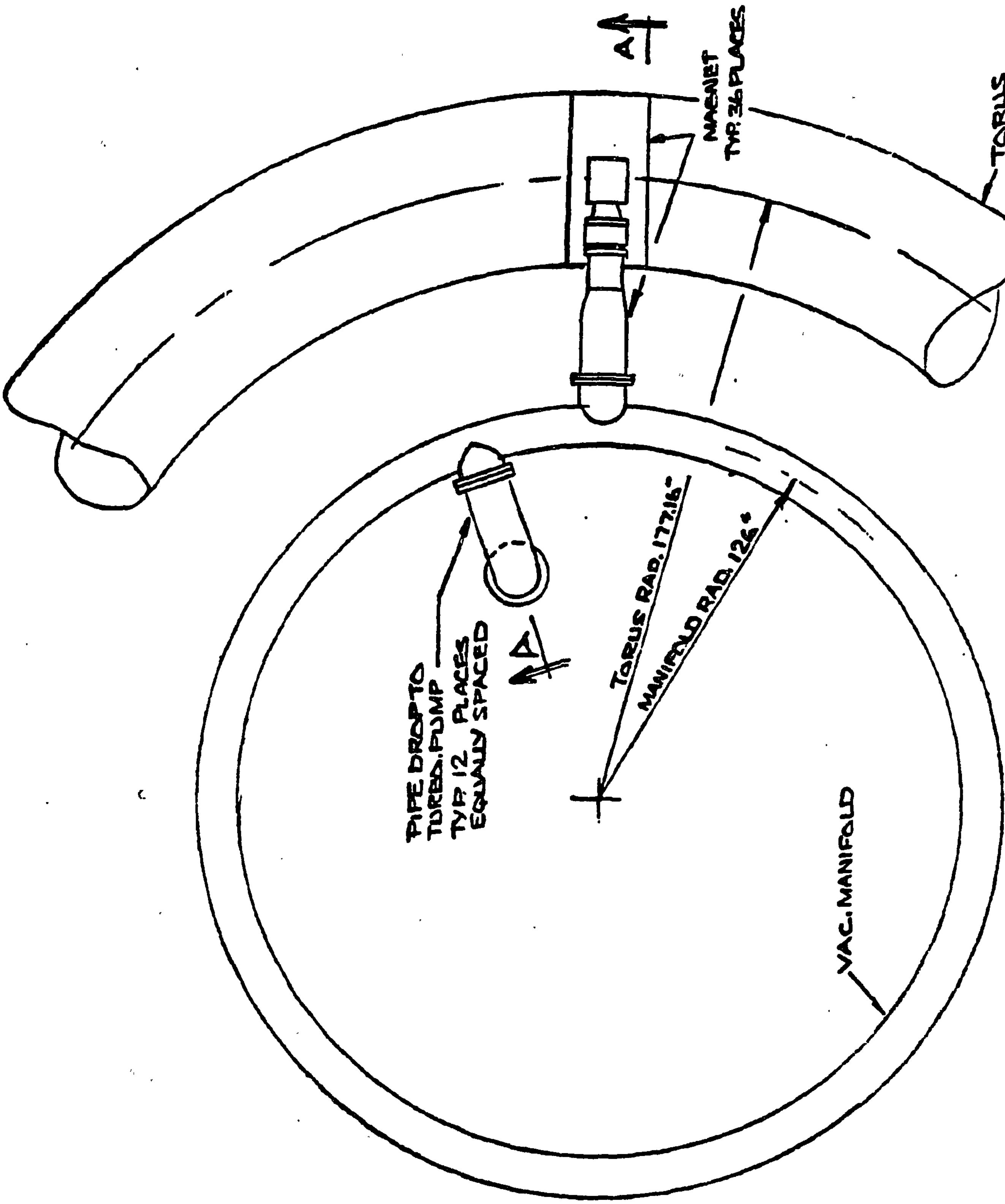


FIGURE 5-16 PLAN VIEW OF 10.48 INCH MANIFOLD SYSTEM

inboard side. In twelve places a 10.482 inch duct with a right angle elbow continues inboard, clearing the concrete bucking ring, and dropping to below the concrete floor level where the TMP1500 is attached. A vibration isolation bellows and an 11.625 inch gate valve isolate each turbomolecular pump from the vacuum manifold. The turbomolecular pump was located below the floor level in an attempt to minimize the effects of the x-ray and high magnetic field environments near the torus. This configuration has a pumping speed for air of 81 liter/sec.

The manifold diameter was increased to 12.44 inches as shown in Figure 5-17. The valve and bellows at each magnet stack are unchanged. Twelve turbomolecular pumps are attached via inboard ducts to the manifold. These duct and elbow diameters are increased to 12.44 inches and a 12.0 inch diamter valve and 12.4 inch bellows are located immediately above the TMP1500. The pumping speed of this configuration is 123 liter/sec for air at the farthest MC dewar. To determine the effect of more pumps, a calculation was performed assuming that 36 TMP1500 turbomolecular pumps were mounted on the inboard side of the 12.44 inch diameter manifold with the identical components shown in Figure 5-17. The pumping speed for air increased to 318 liter/sec with the addition of 24 TMP1500 pumps.

A variation of the configuration employing the 12.44 inch inboard manifold is shown in Figure 5-18. Again a 7.125 inch gate valve and 6.4 inch bellows with a short section of 12.44 inch pipe connect each MC dewar to the manifold. Twelve TMP1500 pumps are on the inboard side immediately below the concrete bucking ring, rather than below the floor as in the other configuration. The drop length of this duct is 137 inches less than that shown in Figure 5-17. This configuration was analyzed after it was determined that the EBT-P environment for the above floor location was hardly different from that for the below floor location. The valve and isolation bellows attached to the TMP1500 are unchanged. The pumping speed of this configuration is 192 liter/sec for air.

5.1.2.2.3 Turbomolecular TMP3500 Systems - MC Dewar - Analyses were performed on manifolded systems using the Leybold Heraeus TMP3500 turbomolecular pump. The TMP3500 has a pumping speed for air of 3500 liter/sec and it must be vertically mounted. It has an inlet diameter of 15.75 inches. Five configurations were considered, two with inboard manifolds and three with outboard manifolds. The inboard manifolds are 15.67 inch diameter and the outboard manifolds are 12.44 inch diameter. Twelve TMP3500

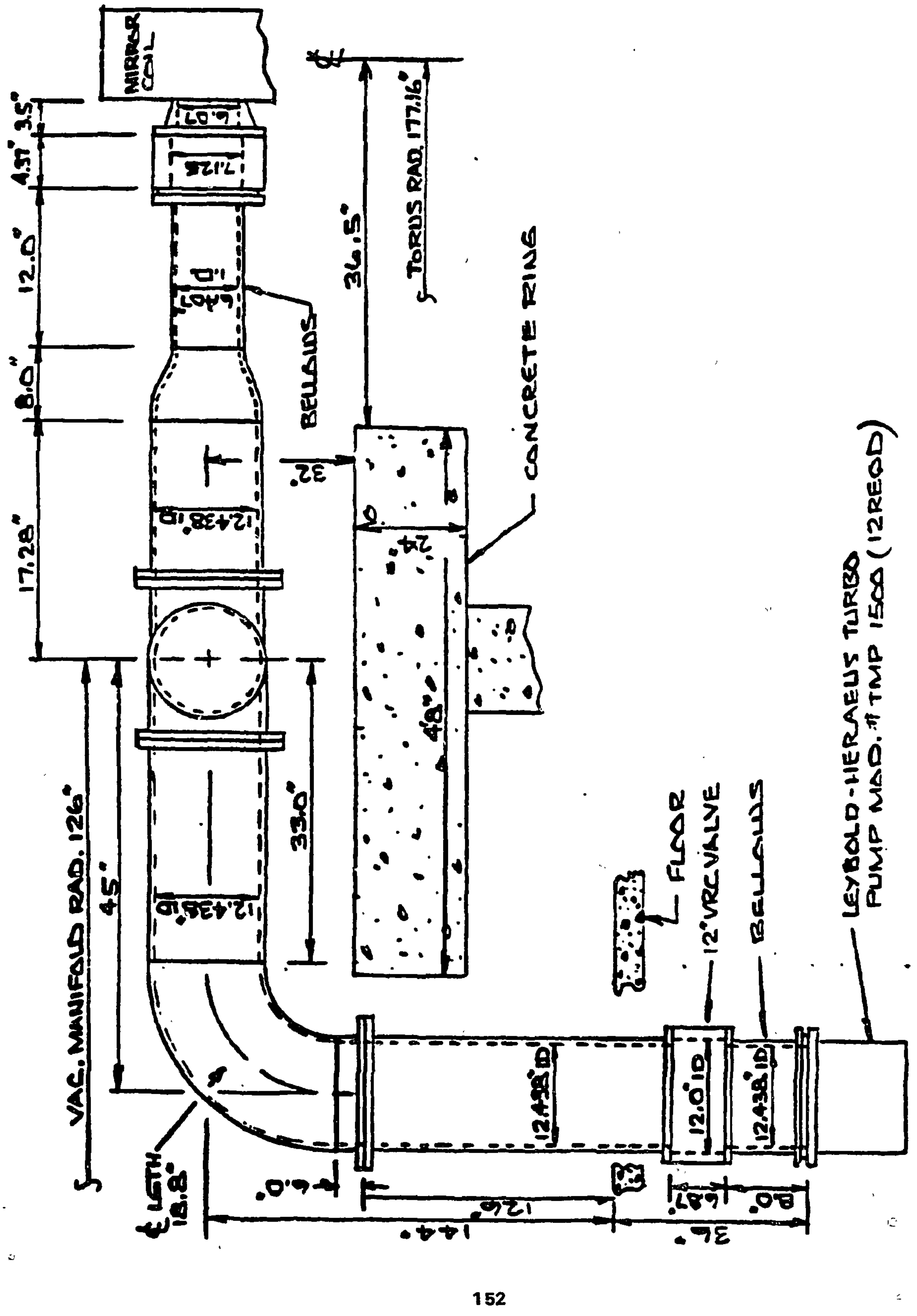


FIGURE 5-17 MC DEWAR TMP 1500 SYSTEM WITH 12.44 INCH MANIFOLD

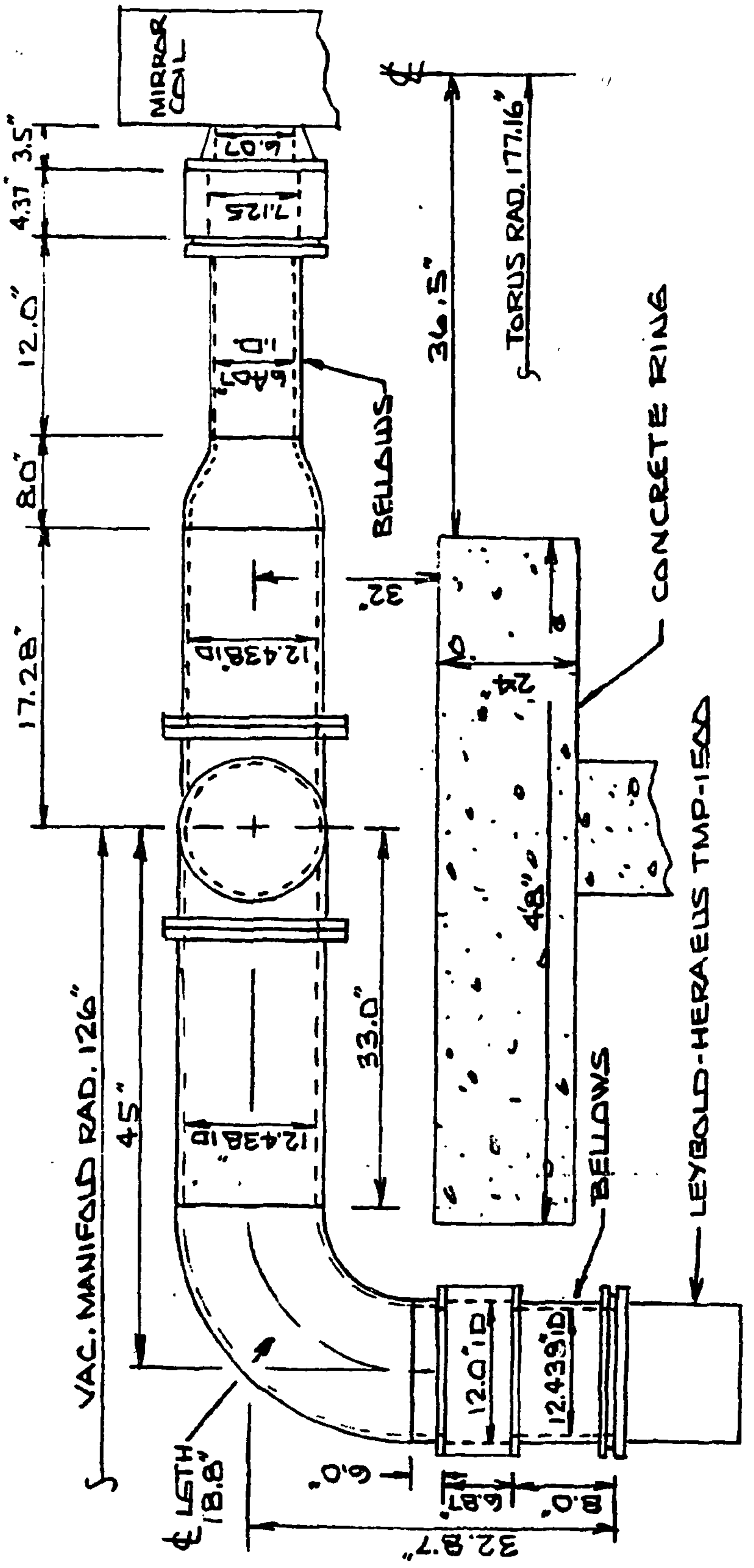


FIGURE 5-13 MC DEWAR TMP 1500 SYSTEM WITH 12.44 INCH MANIFOLD AND PUMP ABOVE FLOOR

pumps were used in all five configurations. The principle changes in these configurations were associated with increasing valve and connecting line diameters on the outboard systems and shortening the drop lengths on the inboard ducts. The following is a summary of the results.

- 15.67 inch manifold inboard; TMP3500 below floor-270 liter/sec
- 15.67 inch manifold inboard; TMP3500 at bucking ring-365 liter/sec
- 12.44 inch manifold outboard; TMP3500-175 liter/sec
- 12.44 inch manifold outboard, 12.44 inch duct; TMP3500-233 liter/sec
- 12.44 inch manifold outboard, 12.44 inch duct, 8 inch valve; TMP3500-316 liter/sec.

The first configuration, shown in Figure 5-19, features an inboard manifold, 15.67 inch diameter, to which each of the 36 MC dewars are connected. Twelve TMP3500 turbomolecular pumps are employed as shown in the plan view, Figure 5-20. A 7.125 inch inside diameter gate valve and a 6.4 inch bellows connect each magnet dewar, via a 15.67 inch line, to the manifold. The pumps are connected to the manifold with a 15.67 inch line and elbow, a 16 inch gate valve, and a 15.67 inch vibration isolation bellows. As shown, the TMP3500 is mounted on a long duct below the floor level. The pumping speed of this system for air is 270 liter/sec for the farthest MC dewar.

A similar configuration is shown in Figure 5-21. The only difference in this system is the short drop length due to locating the TMP1500 at the level of the bucking ring. This configuration was considered after it was found that the x-ray and magnetic field environments at the bucking ring level were not significantly different from those below the floor. The drop length is reduced by approximately 130 inches with this change. The pumping speed for air is increased to 365 liter/sec.

Presented in Figure 5-22 is a system in which a 12.44 inch diameter manifold is located outboard of the torus. Numerous interferences were encountered in the outboard position. The microwave distribution manifold, as shown, forced the vacuum pumps farther outboard than desired. As seen in the plan view, Figure 5-23, the manifold is not continuous around the torus as in the case of the inboard manifolds. Rather, a ducting system is shown in which a single pump serves three MC dewars. Since each of the TMP3500 turbomolecular pumps is isolated from the other eleven pumps, isolation gate valves at the

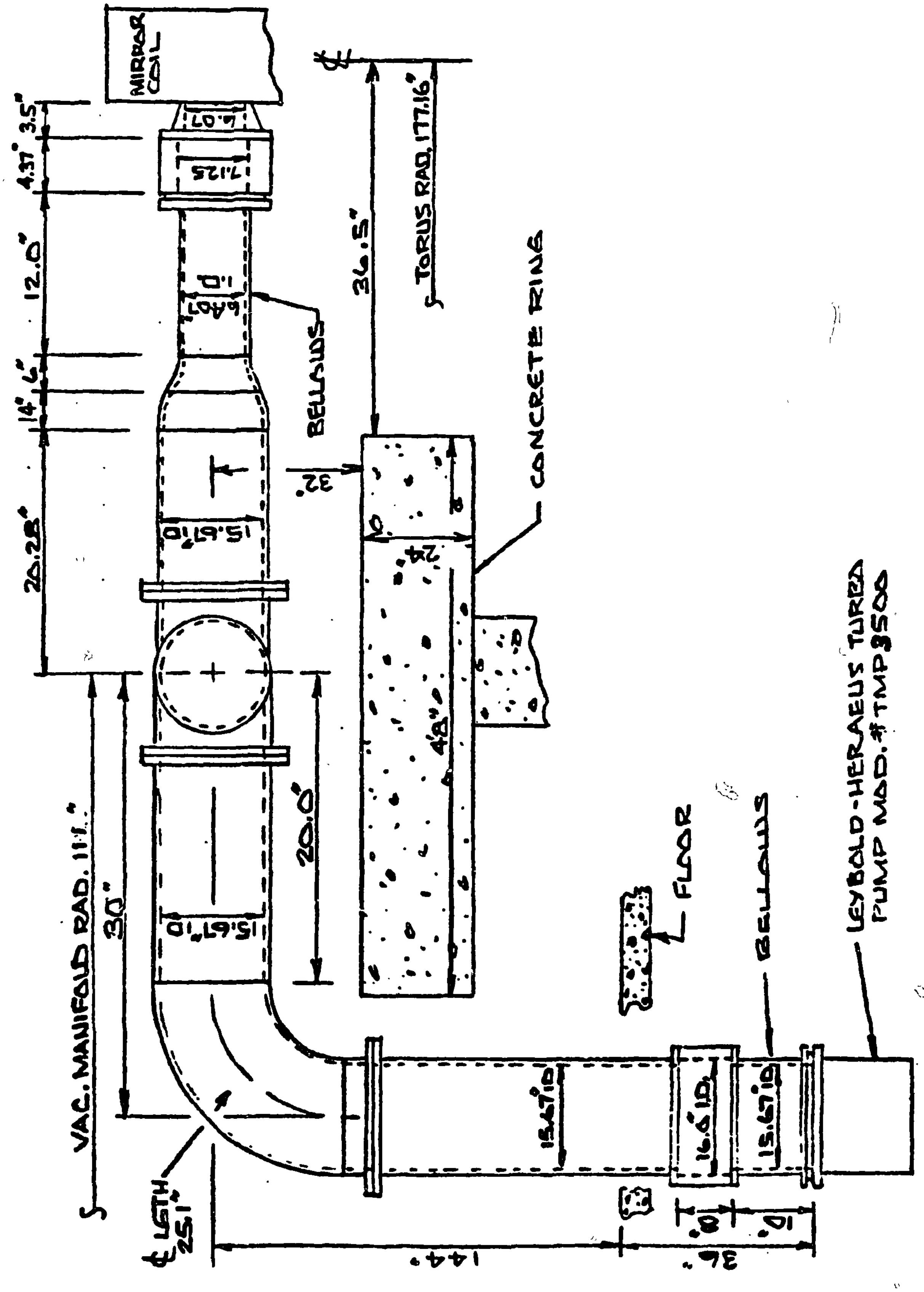


FIGURE 5-19 MC DEWAR TMP 3500 SYSTEM WITH INBOARD MANIFOLD AND PUMP BELOW FLOOR

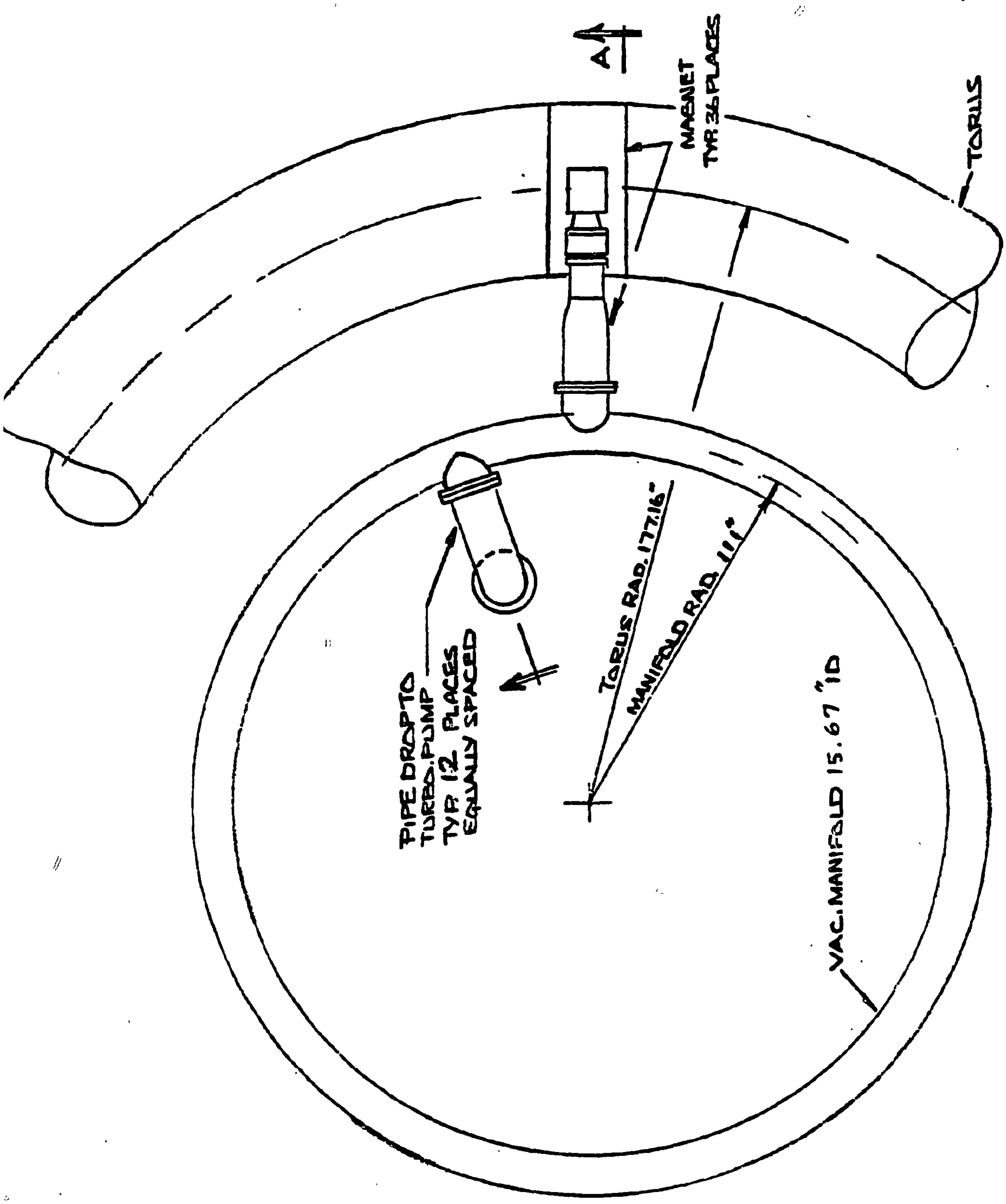


FIGURE 5-20 MC DEWAR TMP 3500 SYSTEM, INBOARD MANIFOLD - PLAN VIEW

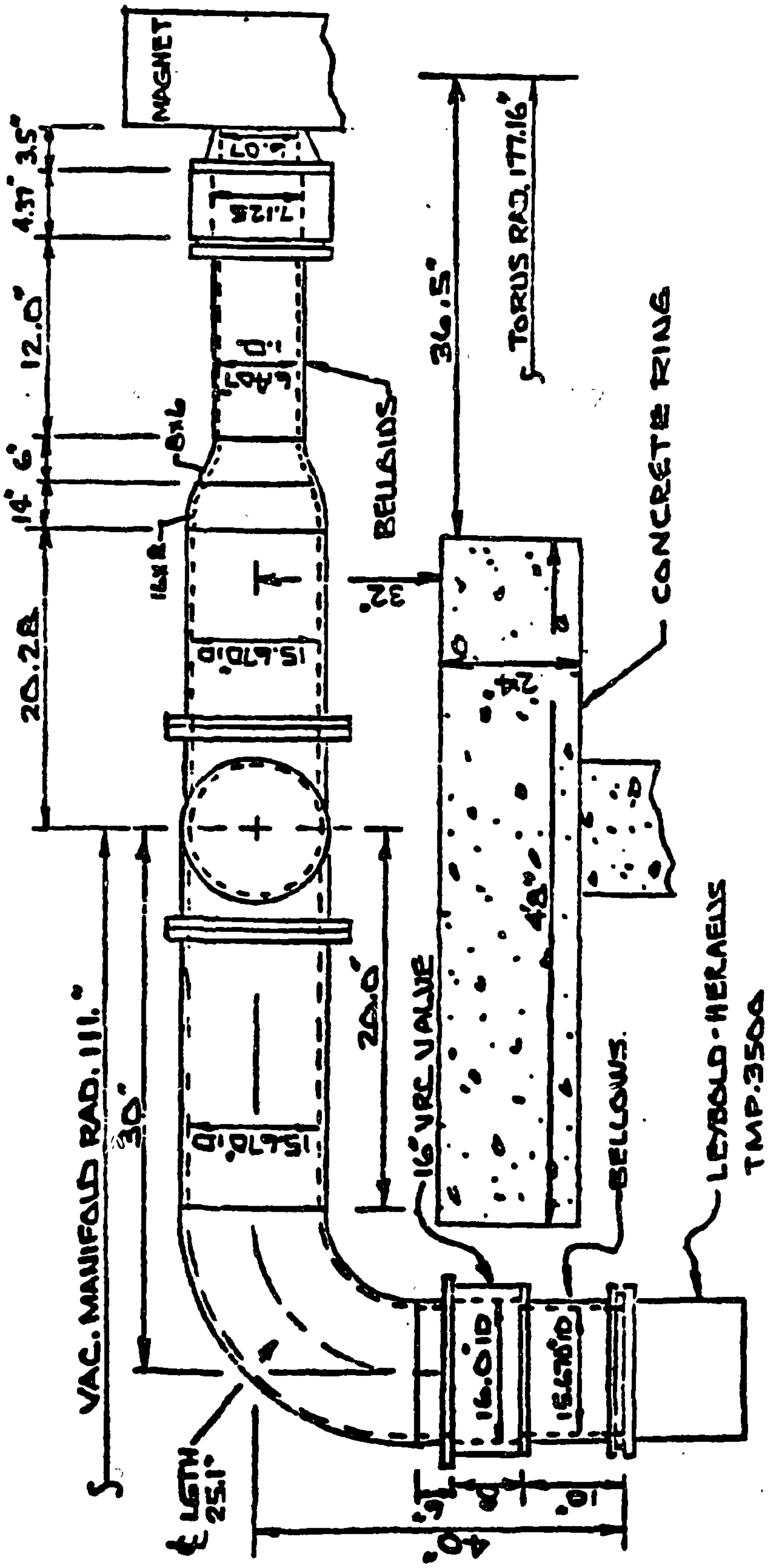


FIGURE 5-21 MC DEWAR INBOARD MANIFOLD SYSTEM WITH TMP 3500's at BUCKING RING

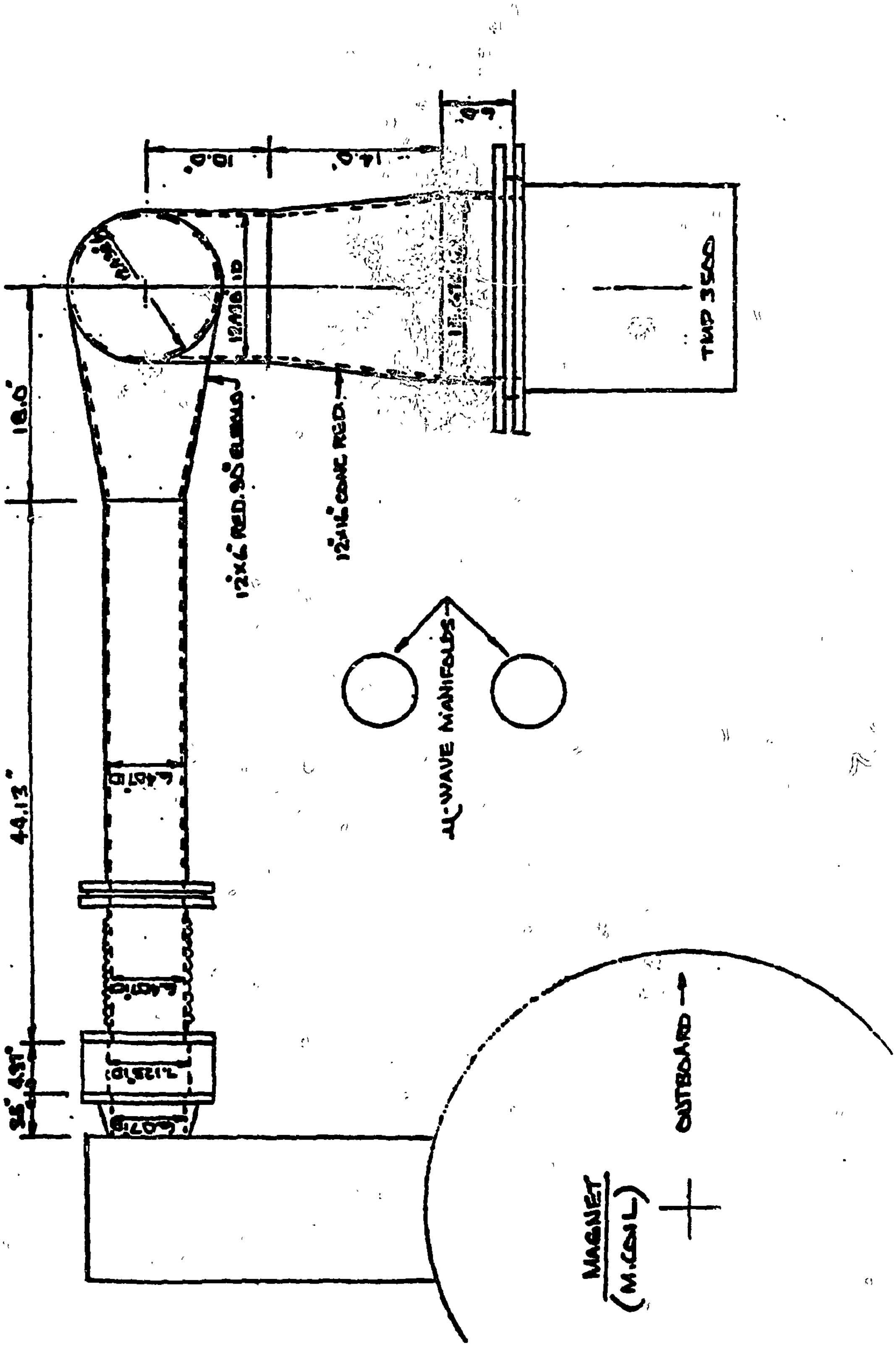


FIGURE 5-22 MC DEWAR TMP 3500 OUTBOARD MANIFOLD SYSTEM WITH 6.4 INCH DUCTS

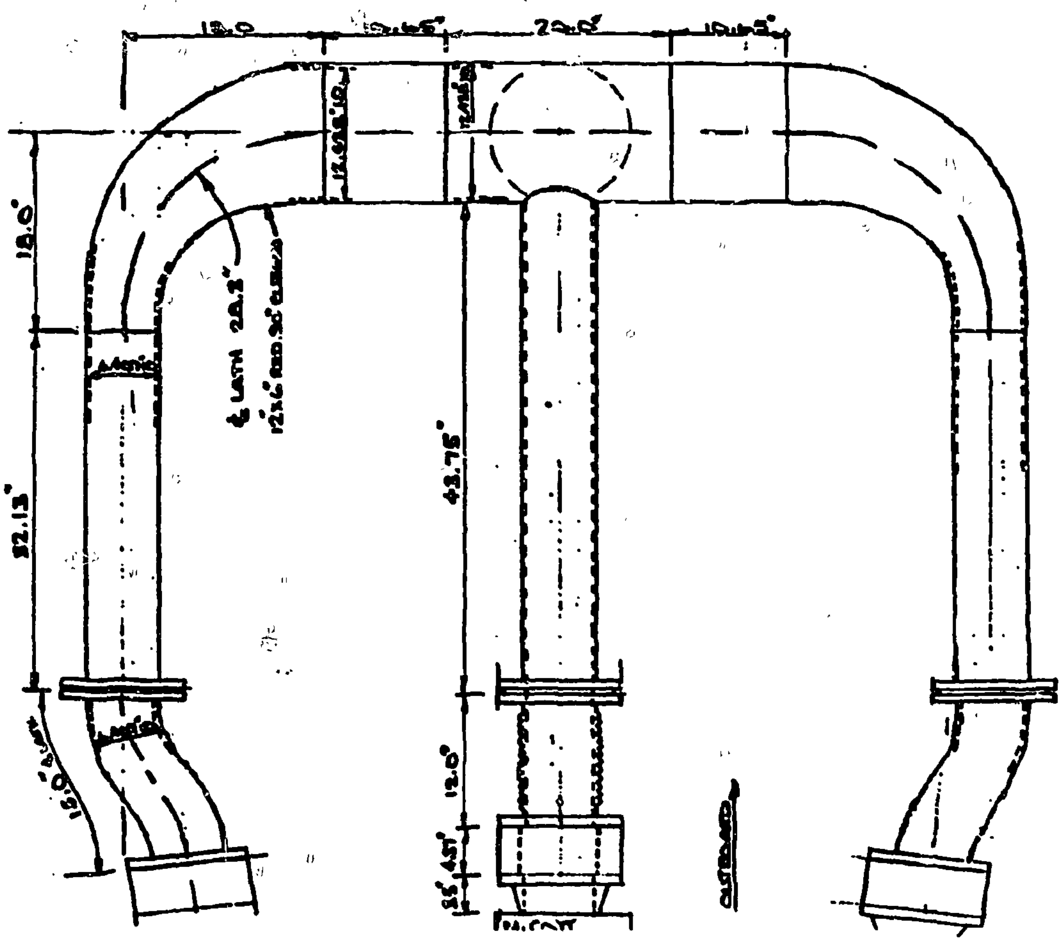


FIGURE 5-23 PLAN VIEW OF MC DEWAR TMP 3500 OUTBOARD MANIFOLD SYSTEM WITH 6.4 INCH DUCTS

pump are not required. Only the 7.125 inch gate valve at each dewar is needed. Vacuum ducts and bellows, 6.4 inch diameter, connect a set of three dewars into a 12.44 inch diameter manifold to which the TMP3500 is attached via a conical reducer. The pumping speed of this system is 175 liter/sec for air.

To enhance the pumping speed, the connecting duct diameters were increased to 12.44 inches as shown in Figure 5-24. The gate valves and bellows at the MC dewars were not changed. Neither was the conical reducer connecting the TMP3500 to the 12.44 inch diameter manifold. This change increases the pumping speed for air to 233 liter/sec.

Another modification was made, as shown in Figure 5-25. The valve on the MC dewar was enlarged. Its diameter was increased from 7.125 inches to 8.01 inches. The diameter of the bellows connecting the valve to the duct was also increased from 6.4 inch diameter to 8.65 inch diameter. The duct, manifold and reducer were not changed. The resulting pumping speed for air was 316 liter/sec.

5.1.2.2.4 Liquid Helium Cryopump BPK-2000 Systems-MC Dewar - Analyses were performed on seven configurations employing the Leybold Heraeus BPK-2000 liquid helium cryopump. It has a pumping speed for air of 2000 liter/sec. The BPK-2000 features an internal liquid helium dewar used in a "pool-boiling" mode at atmospheric pressure, and thus must be vertically mounted with the fill tubes oriented upward. All geometries considered employed manifolds, two outboard and five inboard. Manifold diameters from 8.41 inch to 15.69 inch were analyzed. Connecting duct sizes were varied from 6.5 inch to 8.0 inch diameter. The number of BPK-2000 cyropumps was varied from 4 to 24. A summary of the results is shown below:

- Outboard 12.44 inch manifold, 18 pumps, 6.5 inch duct; 309 liter/sec
- Outboard 12.44 inch manifold, 24 pumps, 8 inch duct; 508 liter/sec
- Inboard 13.69 inch manifold, 24 pumps, 6.5 inch duct; 309 liter/sec
- Inboard 13.69 inch manifold, 24 pumps, 8 inch duct; 499 liter/sec
- Inboard 15.67 inch manifold, 24 pumps, 8 inch duct; 548 liter/sec
- Inboard 8.41 inch manifold, 4 pumps, 6.5 inch duct; 79 liter/sec
- Inboard 10.48 inch manifold, 4 pumps, 6.5 inch duct; 91 liter/sec

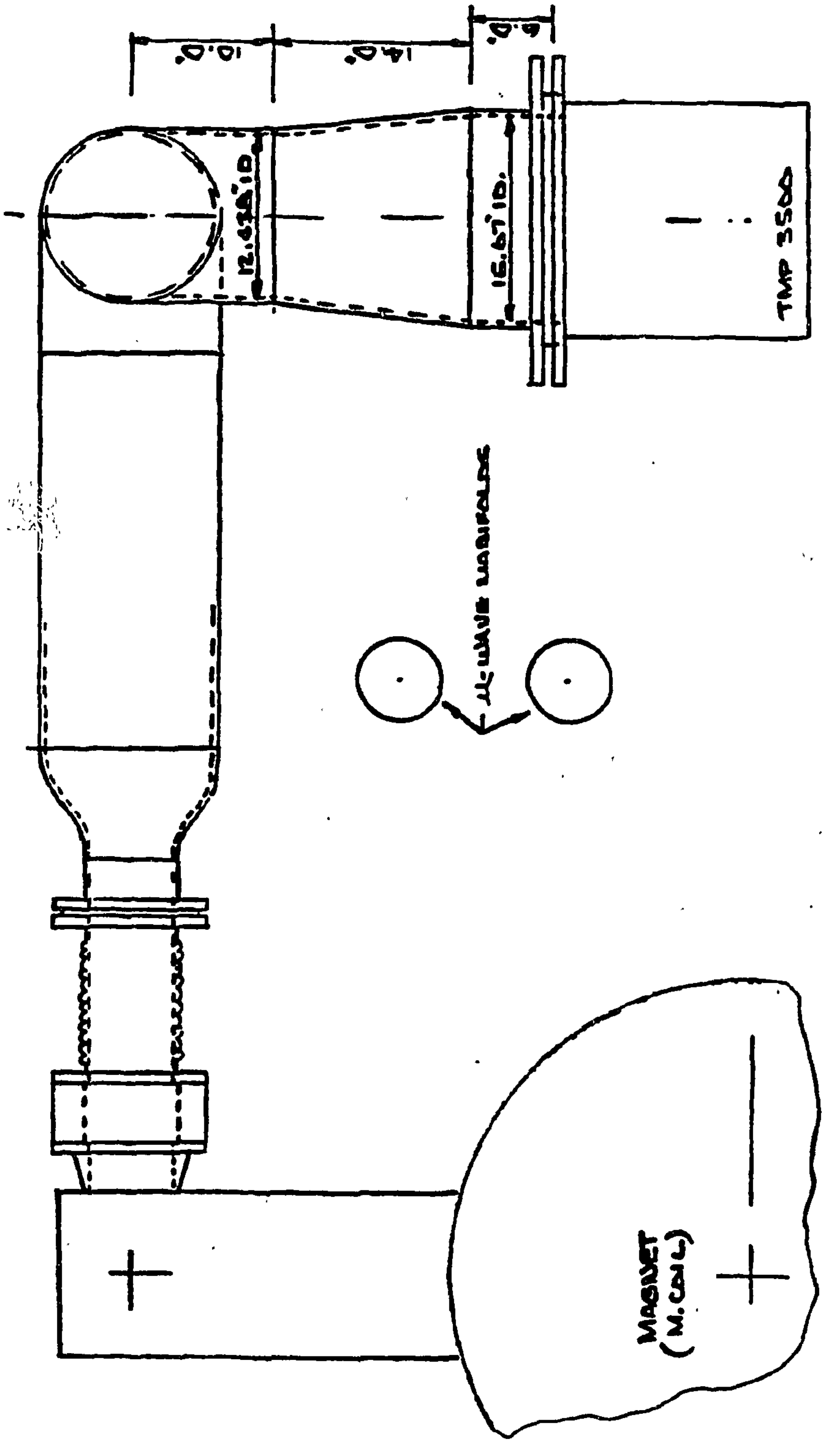


FIGURE 5-24 MC DEWAR TMP 3500 OUTBOARD MANIFOLD SYSTEM WITH 12.44 INCH DUCTS

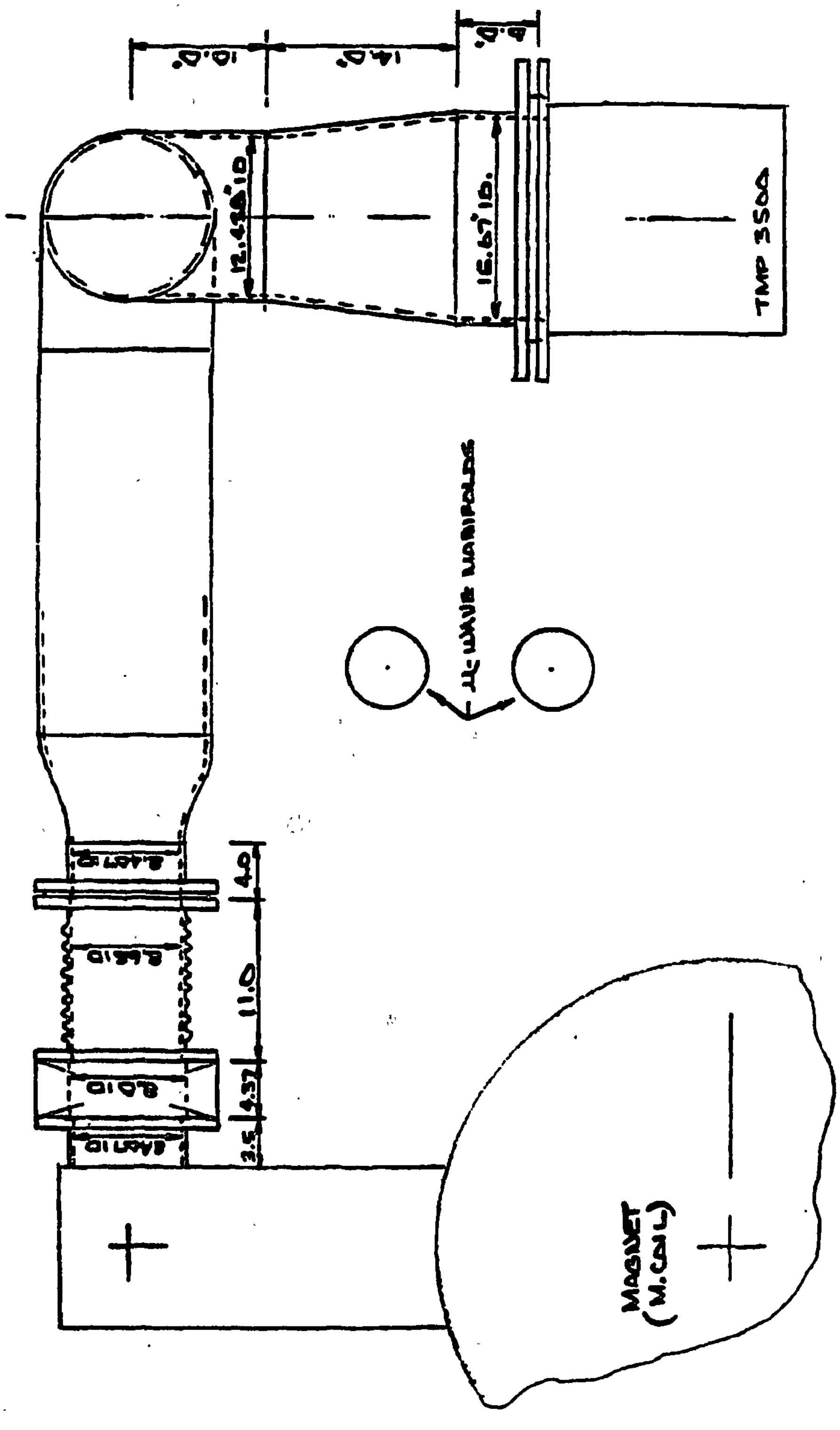


FIGURE 5-25 MC DEWAR TMP 3500 OUTBOARD MANIFOLD SYSTEM WITH 12.44 INCH DUCTS AND 8.07 INCH VALVES

The configuration presented in Figure 5-26 is a manifolded system with eighteen BPK-2000 pumps located around the torus as shown in Figure 5-27. The 12.44 inch diameter manifold is continuous around the outboard side and is connected to each of the 36 MC dewars via a 7.125 inch inside diameter gate valve and a 6.62 inch bellows. The BPK-2000 is vertically mounted and the cryopump array extends into the manifold. The pumping speed of this configuration, for air, is 309 liter/sec at the farthest MC dewar.

An attempt to improve the capability of this configuration is shown in Figure 5-28. Twenty-four pumps are located on the same outboard manifold. The valve size at the MC dewar is increased to 8.0 inches inside diameter and the bellows diameter is 8.64 inches. These modifications increase the pumping speed to 508 liter/sec for air.

Presented in Figure 5-29 is an inboard manifold system. A plan view is shown in Figure 5-30. A 13.69 inch diameter manifold is connected to each magnet dewar via a 7.125 inch diameter valve and a 6.4 inch bellows. Twenty-four pumps are equally spaced around the manifold and provide an air pumping speed of 309 liter/sec for the "worst-case" dewar.

This system was modified as presented in Figure 5-31. The connecting duct between each MC dewar and the 13.69 inch diameter manifold was enlarged. An 8.0 inch inside diameter gate valve and an 8.6 inch bellows are provided. Twenty-four BPK-2000 pumps are retained. The pumping speed increases to 499 liter/sec for air.

Another attempt to improve the pumping speed of the inboard manifold system is shown in Figure 5-32. The manifold diameter is increased to 15.67 inches and the connecting duct to the MC dewar retains the 8.0 inch gate valve and 8.6 inch diameter bellows. Twenty-four BPK-2000 cryopumps are vertically mounted and evenly spaced around the manifold. The net pumping speed of this configuration for air is 548 liter/sec at the farthest MC dewar.

Presented in Figure 5-33 is an inboard manifold system with four BPK-2000 cryopumps. A plan view is shown in Figure 5-34. The manifold diameter is 8.41 inches and it is connected to each MC dewar via a 7.125 inch gate valve and a 6.41 inch bellows. Each BPK-2000 pump is isolated with a 12.0 inch inside diameter gate valve to allow separate regeneration

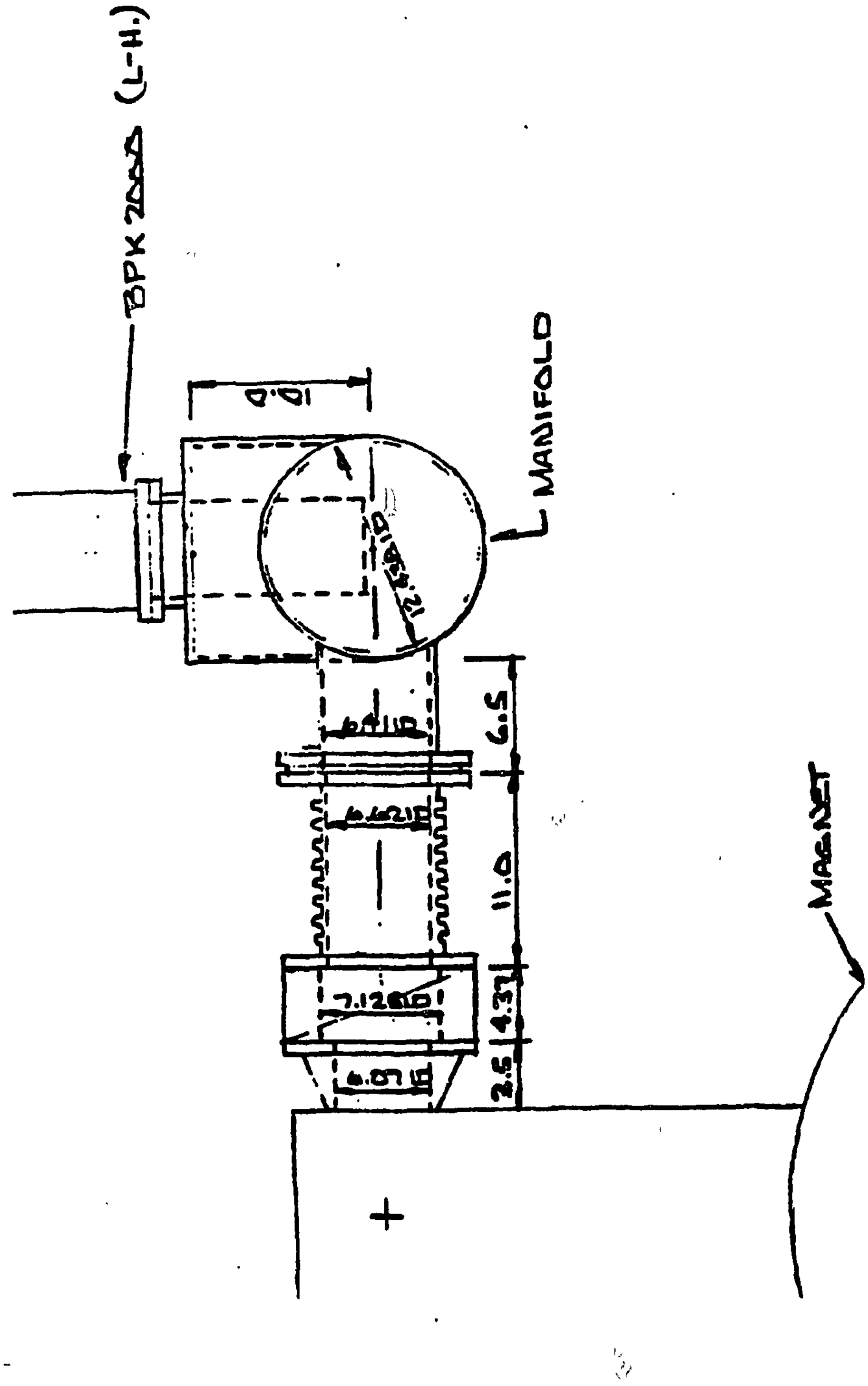


FIGURE 5-26 MC DEWAR OUTBOARD 12.44 INCH MANIFOLD SYSTEM WITH 18 BPK-2000 PUMPS AND 6.5 INCH DUCTS

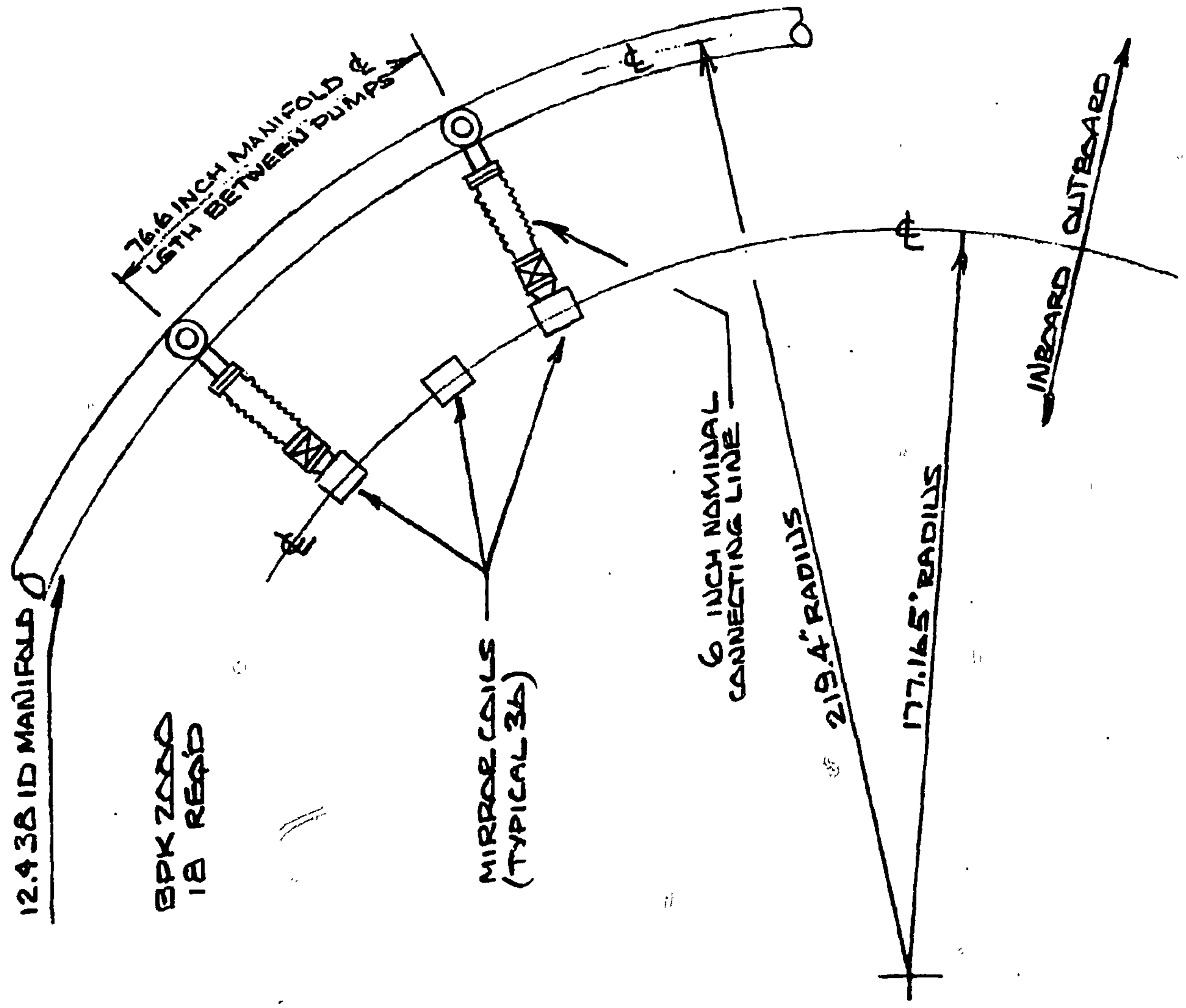


FIGURE 5-27 PLAN VIEW OF MC DEWAR, OUTBOARD 12.44 INCH MANIFOLD SYSTEM WITH 18 BPK-2000 PUMPS

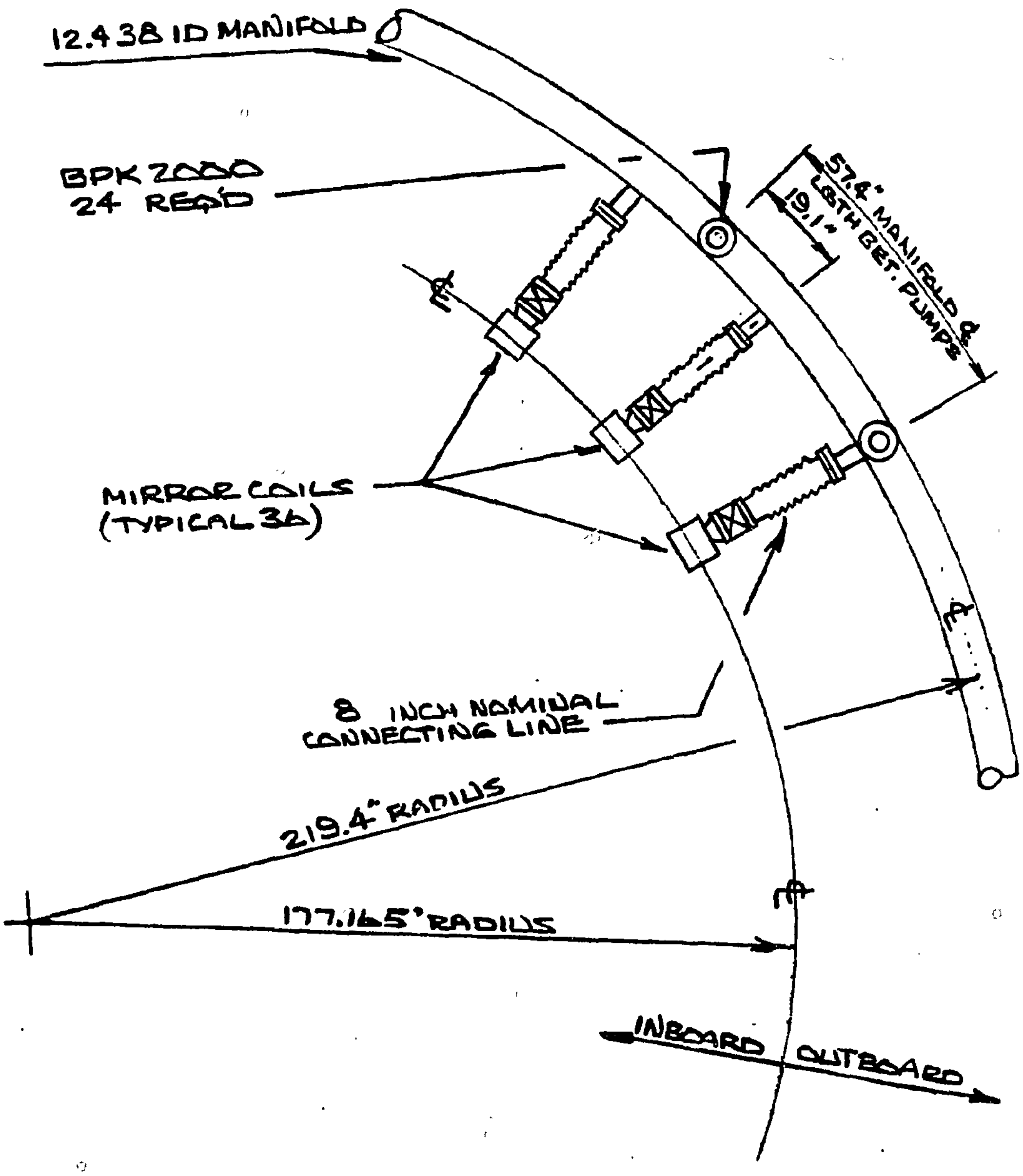


FIGURE 5-28 PLAN VIEW OF MC DEWAR, OUTBOARD 12.44 INCH MANIFOLD SYSTEM WITH 24 BPK-2000 PUMPS AND 8 INCH NOMINAL DUCTS

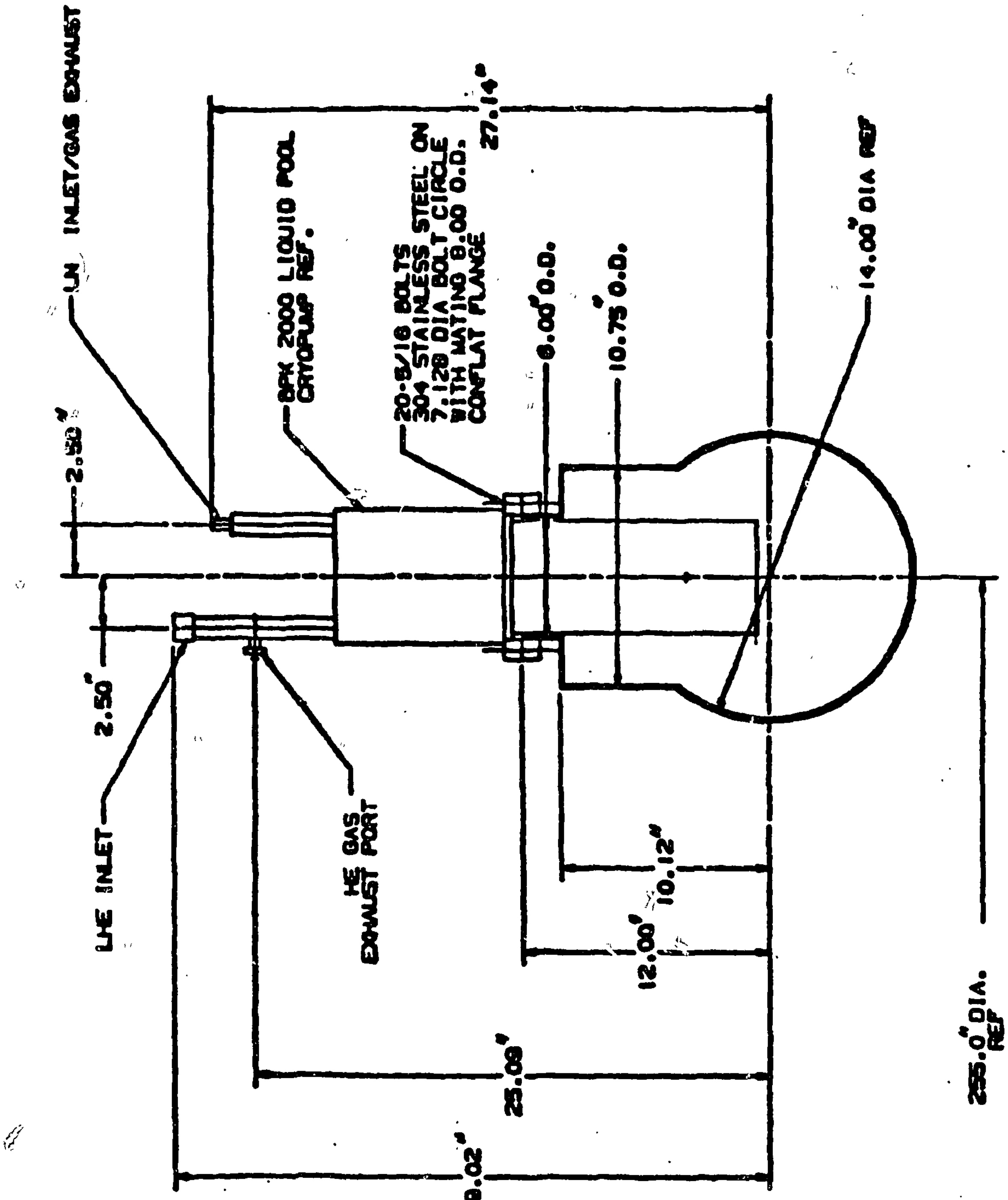


FIGURE 5-29 MC DEWAR, INBOARD 13.69 INCH I.D. MANIFOLD SYSTEM WITH 24 BPK-2000 PUMPS AND 6.5 INCH DUCTS

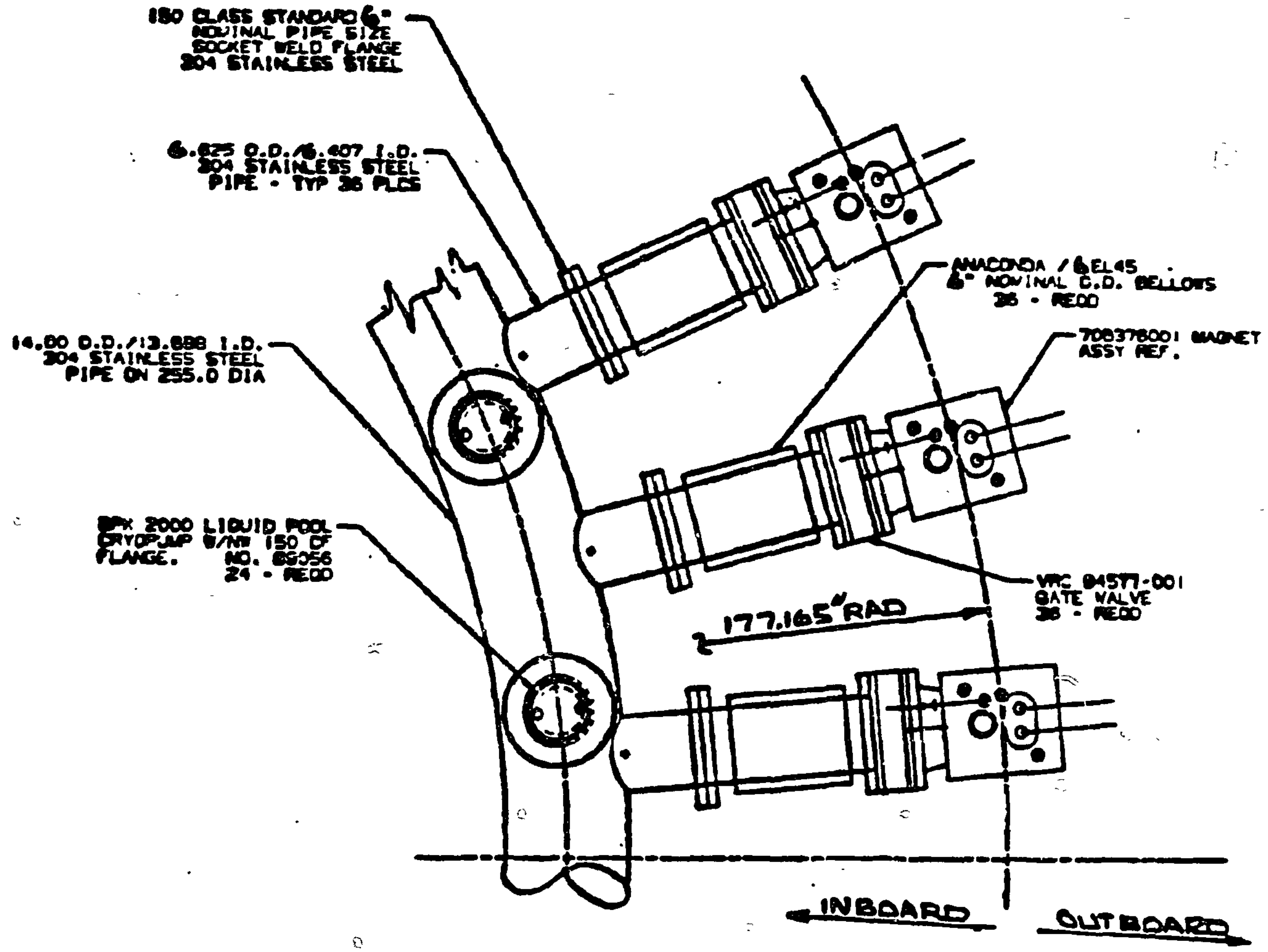


FIGURE 5-30 PLAN VIEW OF MC DEWAR, INBOARD 13.69 INCH I.D. MANIFOLD SYSTEM WITH 24 BPK-2000 PUMPS AND 6.5 INCH DUCTS

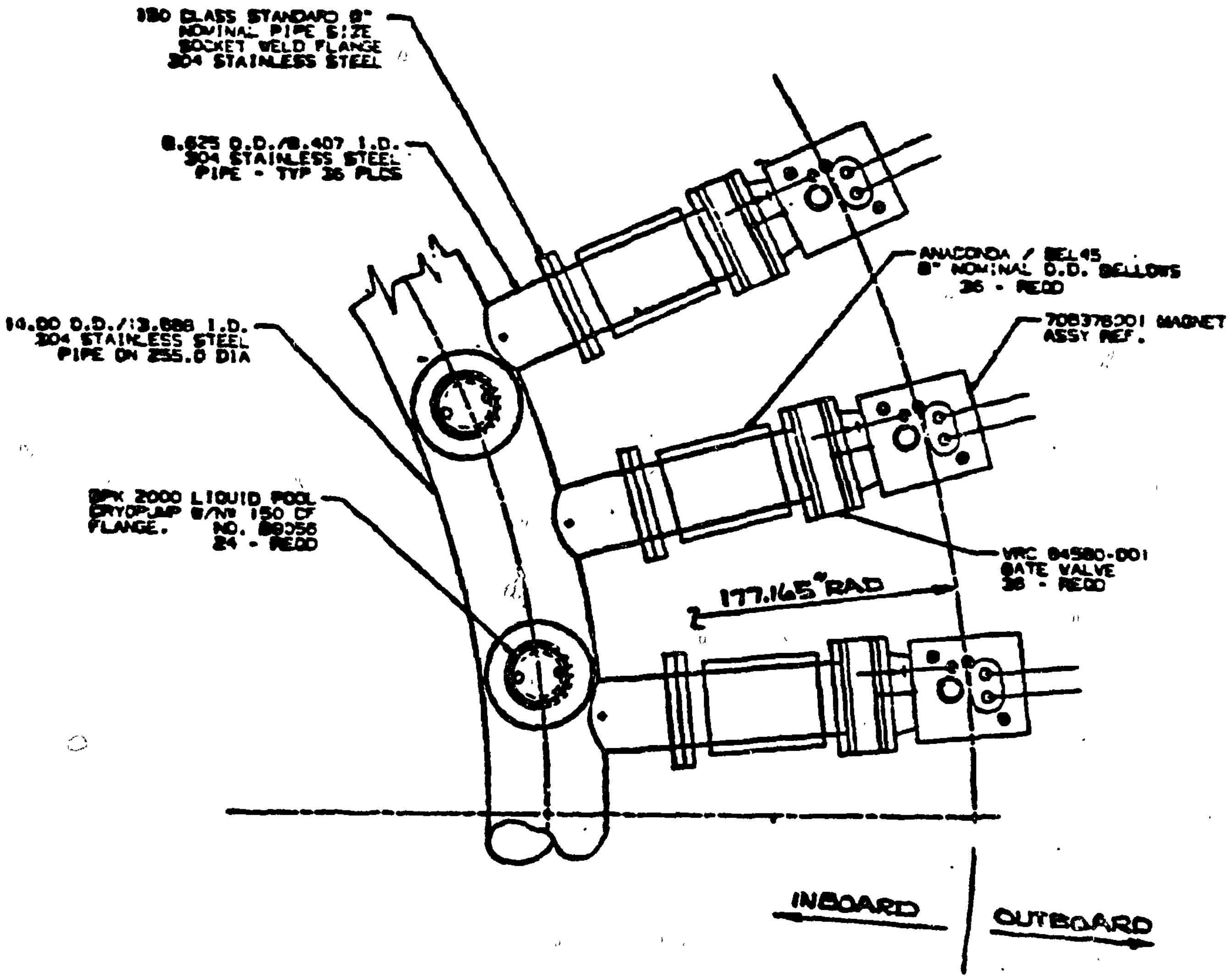


FIGURE 5-31 MC DEWAR, INBOARD 13.69 INCH I.D. MANIFOLD SYSTEM WITH 24 BPK-2000 PUMPS AND 8 INCH DUCTS

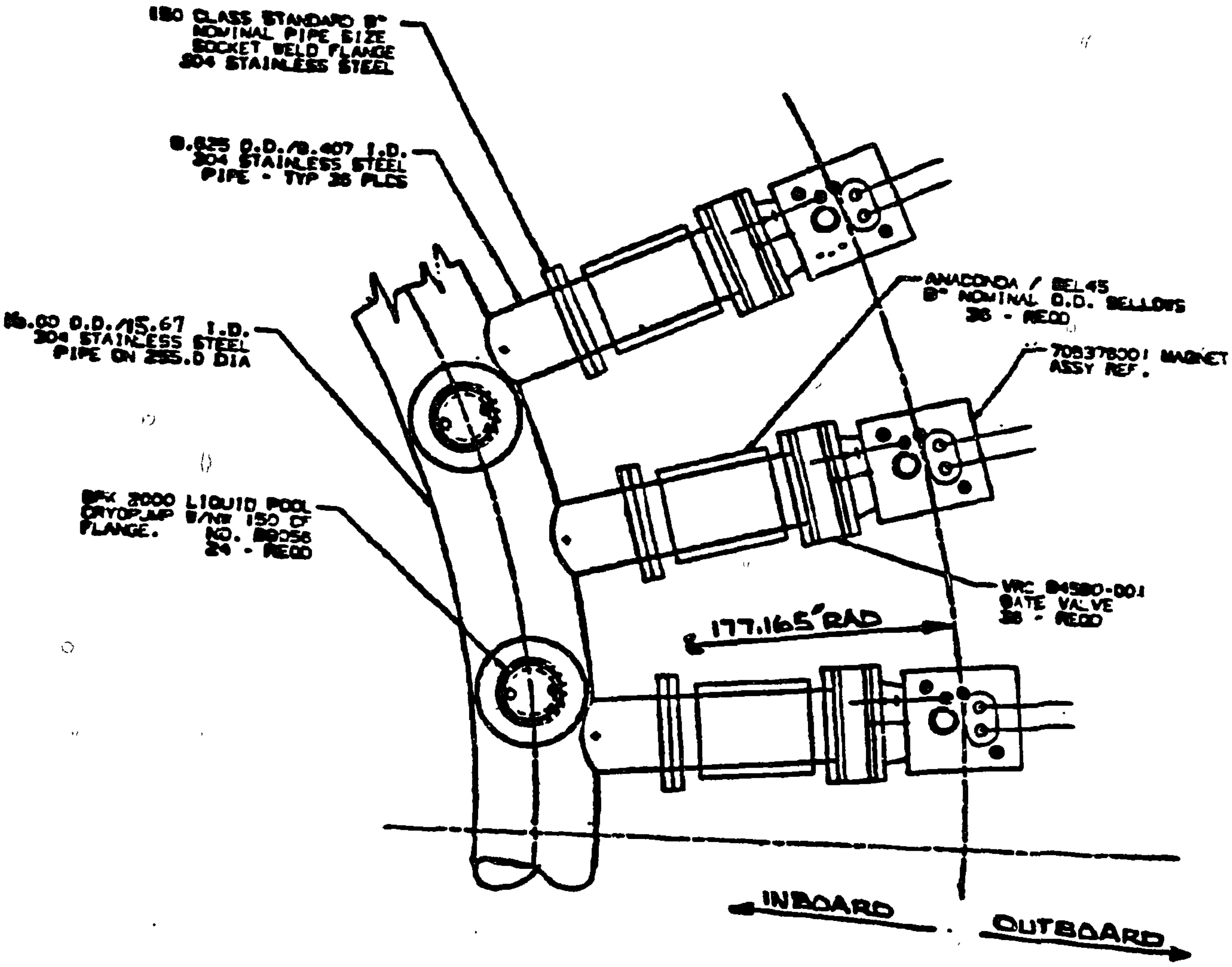


FIGURE 5-32 MC DEWAR, INBOARD 15.67 INCH MANIFOLD WITH 24 BPK-2000 PUMPS AND 8 INCH DUCTS

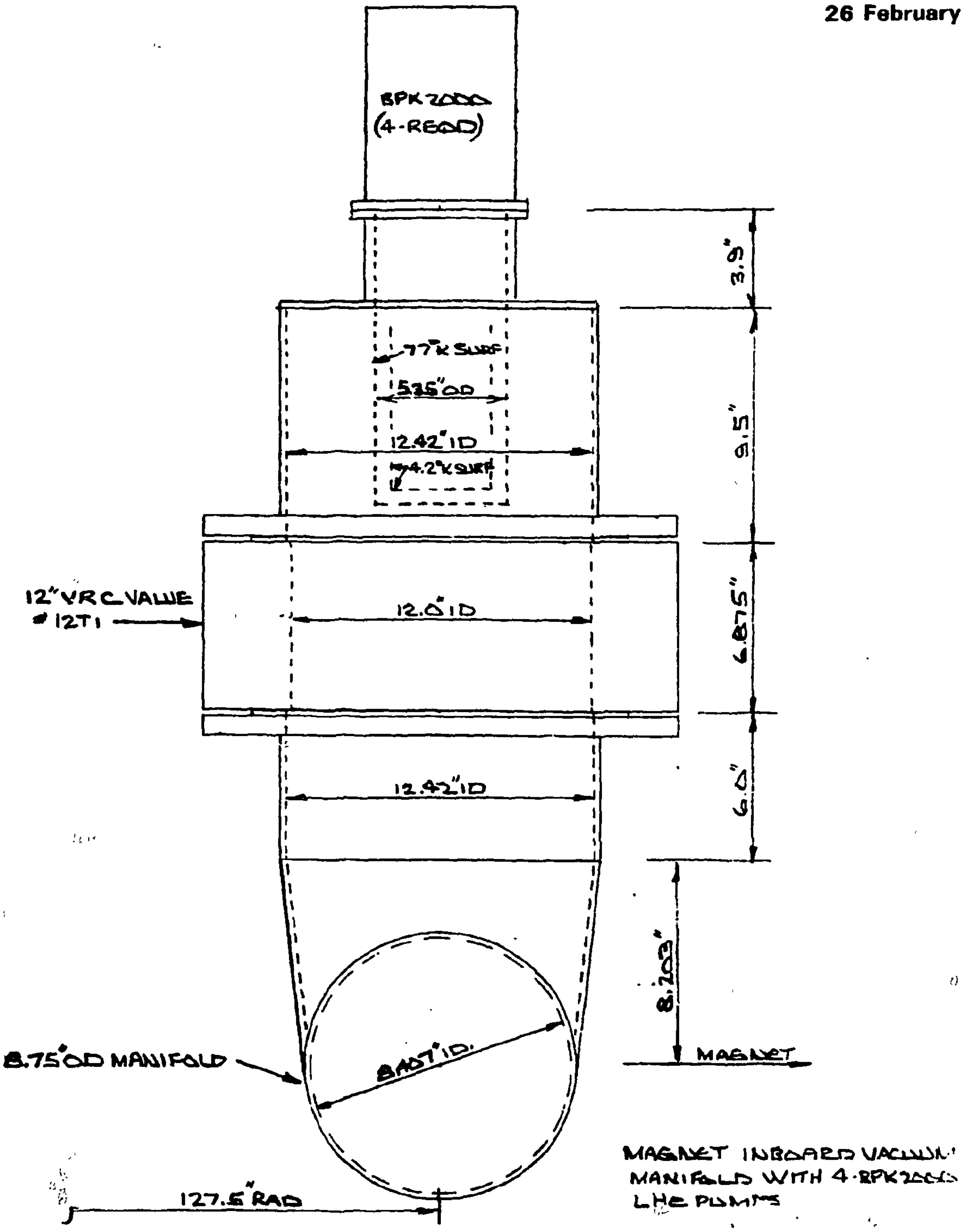


FIGURE 5-33 MC DEWAR, INBOARD 8.41 INCH MANIFOLD WITH 4 BPK-2000 PUMPS AND 6.5 INCH DUCTS

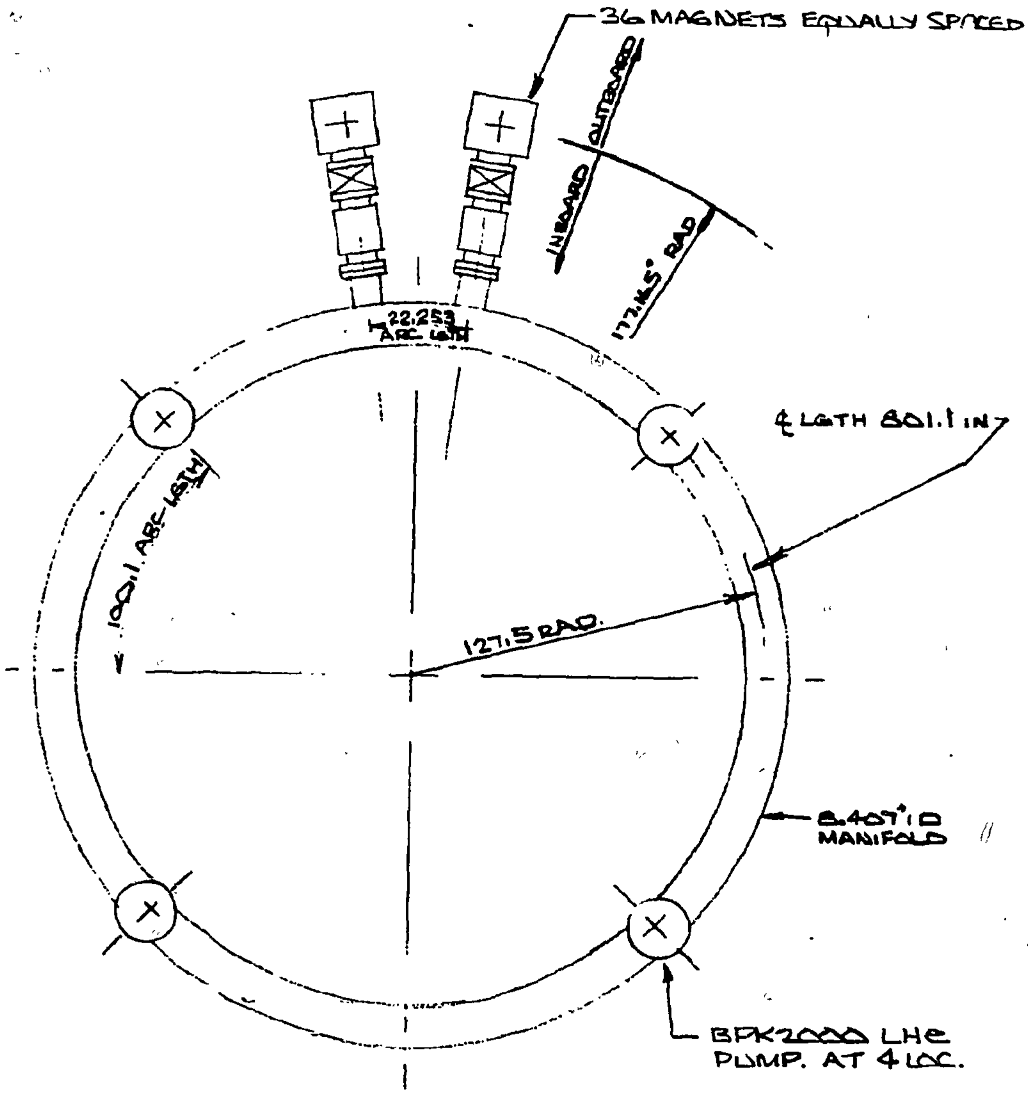


FIGURE 5-34 PLAN VIEW OF 8.41 INCH MANIFOLD SYSTEM WITH 4 BPK-2000 PUMPS AND 6.5 INCH DUCTS FOR MC DEWAR

of the cryopumps. A reducer is used to connect each manifold to the gate valve. The pumping speed of this configuration is 79 liter/sec for air.

The final system analyzed is presented in Figure 5-35. It is an inboard manifold system with four BPK-2000 pumps isolated by 12.0 inch gate valves. The manifold diameter has been increased to 10.48 inches. The connections to the MC dewar are unchaged from the previous configuration. The resulting pumping speed for air is 91 liter/sec.

5.1.2.2.5 Turbomolecular TPU-2200 System - MC Dewar - Two configurations were analyzed employing the Balzers TPU-2200 turbomolecular pump. Since the TPU-2200 is horizontally mounted, it can be mounted closer to the MC dewars, residing in the superstructure on the inboard side. The vertically mounted pumps can not be mounted in this manner. The TPU-2200 has an inlet diameter of 9.84 inches and a pumping speed for air of 2200 liter/sec. A summary of the results for these two configurations follows:

- Inboard 15.67 inch manifold, 24 pumps, nominal 8 inch diameter connections from dewar to manifold; 533 liter/sec.
- Inboard 12.42 inch manifold, 4 pumps, nominal 6 inch diameter connections from dewar to manifold; 70 liter/sec.

The four pump system with nominal 6 inch i.d. dewar connections is the recommended pumping system for the EBT-P MC Dewars. As discussed in Section 5.1.2.2, the pumping speed requirements for the MC Dewars were reduced near the end of Title I. The current design goal of 50 liter/sec for air is exceeded by the 72.5 liter/sec speed of the chosen system.

The first system analyzed is presented in Figure 5-36. Twenty-four TPU-2000 turbomolecular pumps are spaced around a 15.67 inch diameter manifold. Each of the 36 MC dewars are connected to the manifold, via an 8.01 inch inside diameter gate valve, an 8.4 inch diameter bellows, and a reducer. Each TPU-2200 turbomolecular pump is isolated from the manifold with a 12.0 inch gate valve. This system has a pumping speed for air of 533 liter/sec.

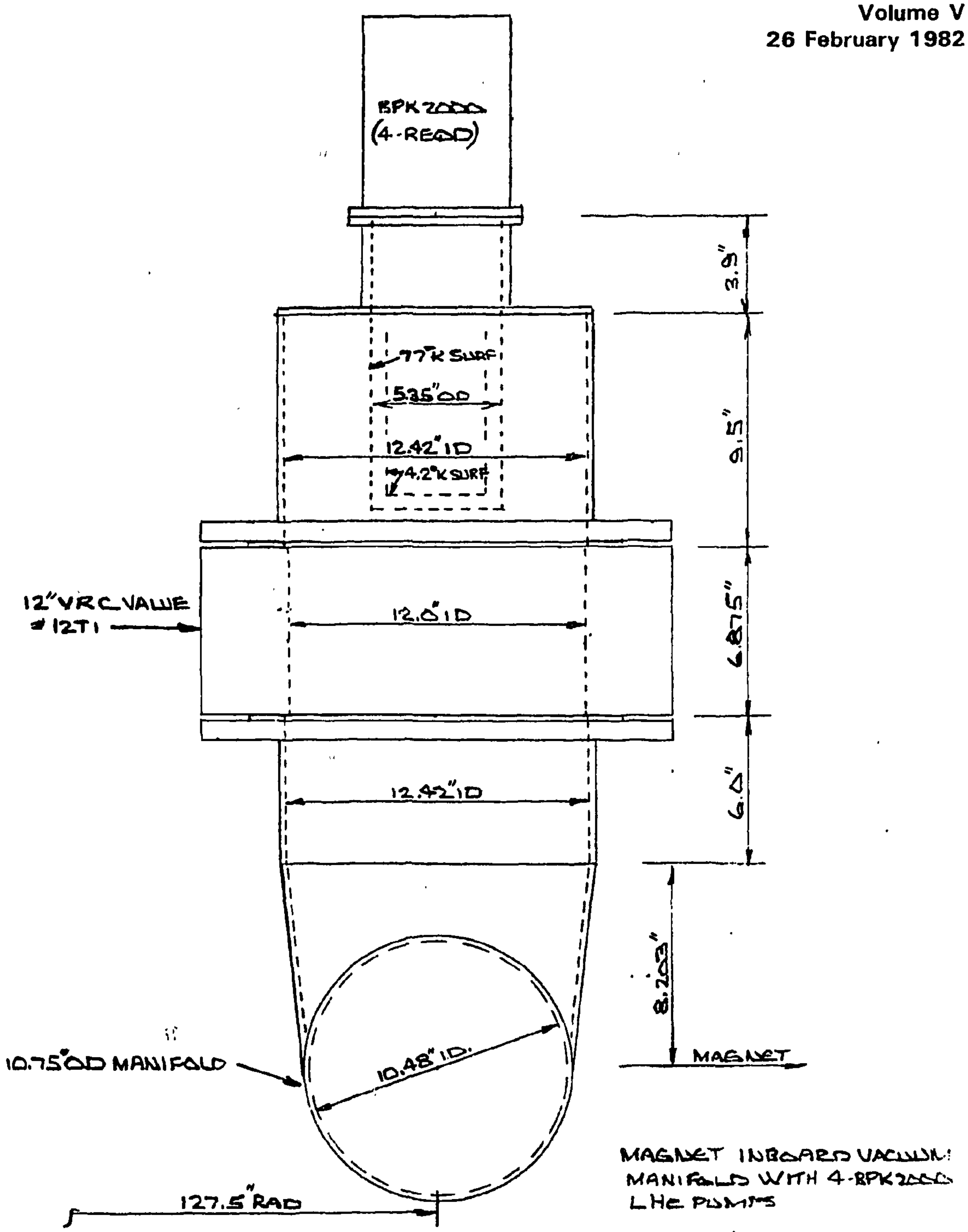


FIGURE 5-35 MC DEWAR, INBOARD 10.48 INCH MANIFOLD WITH 4 BPK-2000 PUMPS AND 6.5 INCH DUCTS

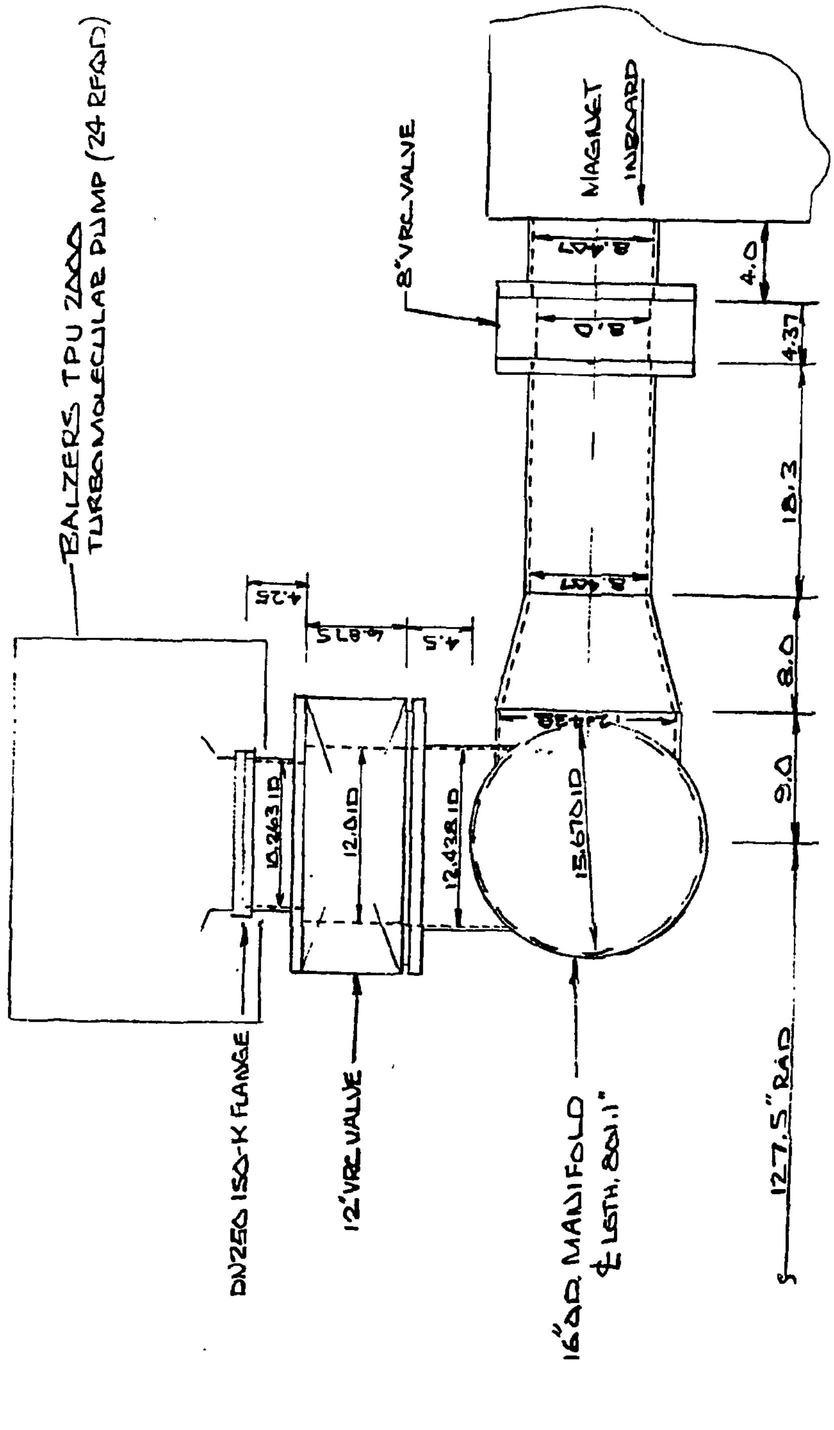


FIGURE 5-36 MC DEWAR, INBOARD 15.67 INCH MANIFOLD WITH 24 TPU-2200 PUMPS AND NOMINAL 8 INCH DUCTS

The configuration of the second system using a TPU-2200 is shown in cross section in Figure 5-37 , and in plan view in Figure 4-15. The manifold is positioned inboard and has a diameter of 12.42 inches. Each magnet dewar is connected to the manifold via a 3.5 inch length of 6.07 i.d. duct, a 7.125 inch i.d. gate valve, a 14.875 inch length, 6.407 inch i.d. bellows, and a 14.571 inch length of duct which also has a 6.407 inch i.d. Four pumps are placed around the manifold in positions only roughly symmetric, as shown in Figure 4-15. Each of these four pumps is connected to the manifold via a 5 inch length of 9.84 i.d. adapter, a 9.25 inch length of 12.42 inch i.d. bellows, and an asymmetric right angle elbow of i.d. 12.42 inches and total axial length 53.4 inches. In the long side of the elbow, 10.75 inches from the manifold, a 12 inch i.d. valve is placed. The calculated nitrogen pumping speed for the dewar most distant from a pump was found to be 70 liters/sec. For helium, the speed calculated was 150 liters/sec. This is the configuration recommended for use as the EBT-P MC Dewar Pumping System.

5.1.2.3 Integral Pumping Systems - Four configurations of integral pumping systems were analyzed and are presented in this section. An integral system is one in which common high vacuum pumps serve both the torus and the MC dewars. Two different vacuum pumps were analyzed, the Leybold Heraeus TMP3500 turbomolecular pump and the Leybold Heraeus BPK-2000 liquid helium cryopump. The TMP3500 has an inlet diameter of 15.75 inches and must be mounted vertically. Its pumping speed for air is 3500 liter/sec and for hydrogen is 3000 liter/sec. The BPK-2000 has an air pumping speed of 2000 liter/sec and a hydrogen pumping speed of 7000 liter/sec and must also be vertically mounted. Pumping speeds are reported as air pumping speeds for the MC dewars and as hydrogen pumping speeds for the torus.

5.1.2.3.1 Turbomolecular TMP3500 System - Integral - A cross-section view of the integral configuration employing the TMP3500 is presented in Figure 5-38. A TMP3500 is connected via a reducer, a 10.75 inch diameter bellows, a 11.625 inch gate valve, and a 11.5 inch diameter pipe to the torus. This is repeated on eleven cavities around the torus to give a torus total pumping speed of 20,000 liter/sec for hydrogen. Extending upward at these eleven pumps are ducts which connect to eleven 11.625 inch inside diameter gate valves. The gate valves in turn are connected to a 12.44 inch diameter manifold which passes completely around the outboard side of the torus. This manifold is connected to each of the 36 MC dewars by a 8.65 inch bellows and a 8.0 inch gate valve. A

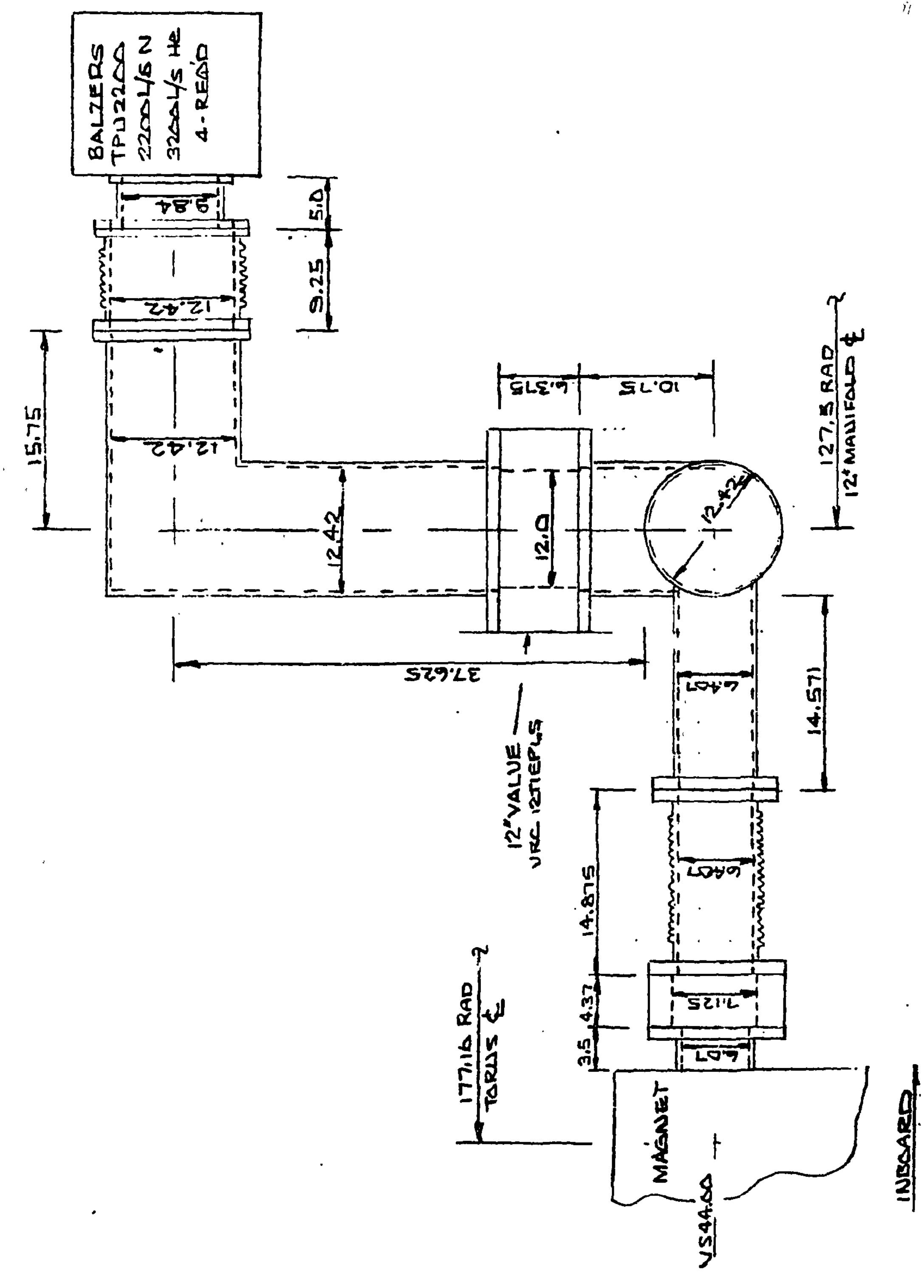


FIGURE 5-37 MC DEWAR, INBOARD 12.42 INCH MANIFOLD WITH 4 TPU-2200 PUMPS AND NOMINAL 6 INCH DUCTS

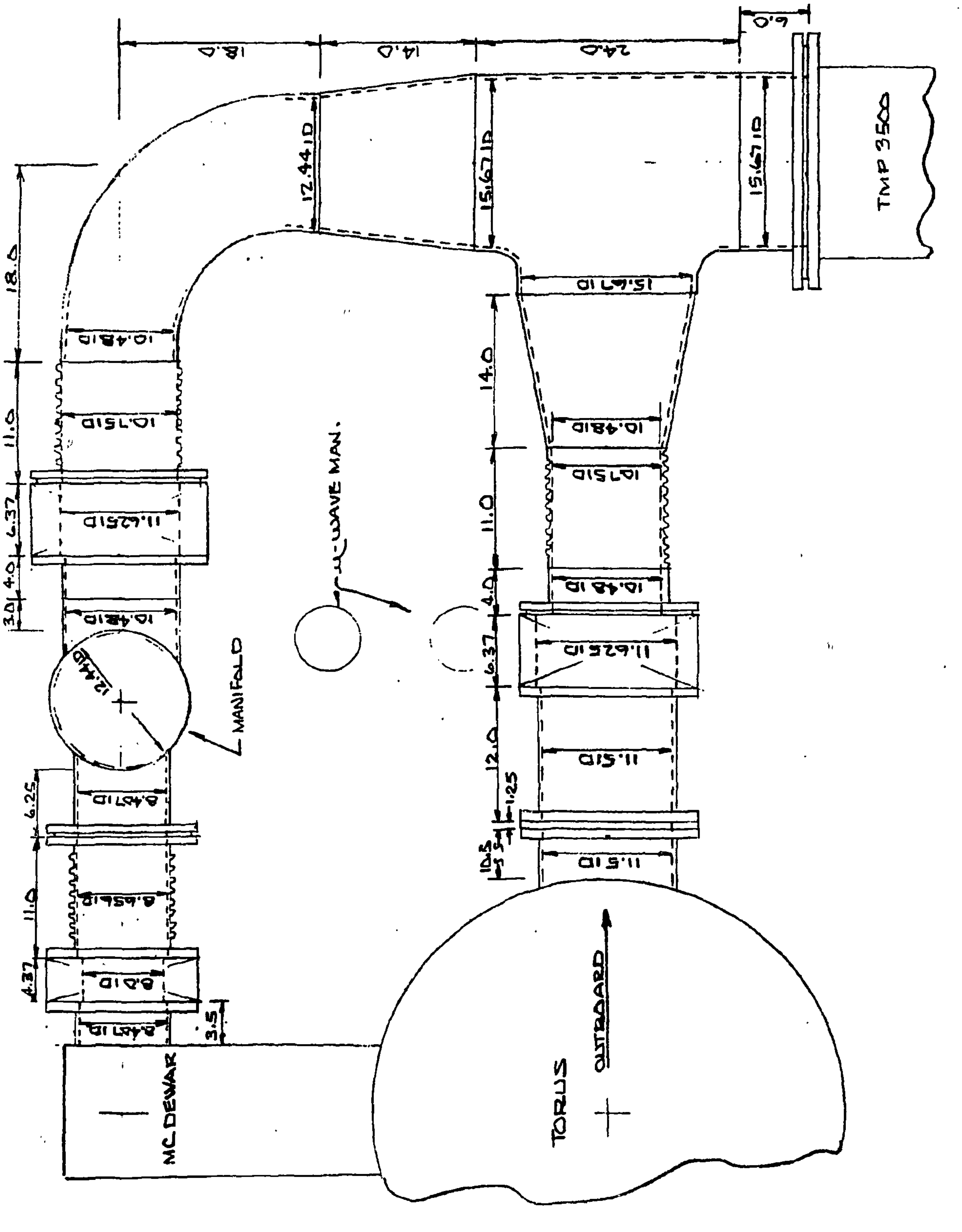


FIGURE 5-38 INTEGRAL TMP 3500 SYSTEM WITH MC DEWAR DUCTS 8 INCHES (NOMINAL)

plan view is presented in Figure 5-39. Each pump has a speed of 1820 liter/sec for hydrogen at the torus and a speed for air of 551 liter/sec at the "worst-case" MC dewar.

An analysis of an identical system with smaller connections to the MC Dewars was also performed. The configuration analyzed is presented in Figure 5-40. As shown, the gate valves at the MC Dewar stack are reduced to 7.125 inch diameter and the bellows are reduced to 6.6 inch diameter. The pumping speeds at the torus are unchanged; they remain 1820 liter/sec for hydrogen. The air pumping speed at the farthest MC dewar is, however, reduced to 349 liter/sec.

5.1.2.3.2 Cryopump BPK-2000 System - Integral - A cross-section view of an integral pumping system employing the BPK-2000 liquid helium cryopump is presented in Figure 5-41. This system connects to the torus in only eight locations, compared to eleven for the TMP3500. Eight ducts therefore extend up to the 12.44 inch diameter manifold at the top of the MC dewar stack. These ducts are nominally 10.5 inch diameter and each is isolated from the manifold with an 11.62 inch diameter gate valve. The manifold is on the outboard side and is continuous around the torus. Each of the 36 MC dewars are connected to the manifold via a 8.0 inch gate valve and a 8.66 inch diameter bellows. A plan view is shown in Figure 5-42. The resulting pumping speed at each of the eight torus inlets is 2753 liter/sec for hydrogen. The "worst-case" magnet dewar has an air pumping speed of 473 liter/sec.

A nearly identical system, shown in Figure 5-43, was analyzed. The only difference from the previous configuration is the smaller gate valve and bellows connecting the 36 MC dewars to the manifold. The valve diameters in this system are 7.125 inches and the bellows diameters are 6.62 inches. The torus pumping speed remains at 2753 liter/sec for hydrogen. However, the pumping speed for the farthest MC dewar is reduced from 473 liter/sec to 306 liter/sec for air.

5.2 ROUGH PUMPING ANALYSIS

This section describes the methods used in sizing the lines which connect the turbomolecular pumps to the forepumping systems and roughing pumps to the torus and MC dewar high vacuum manifold.

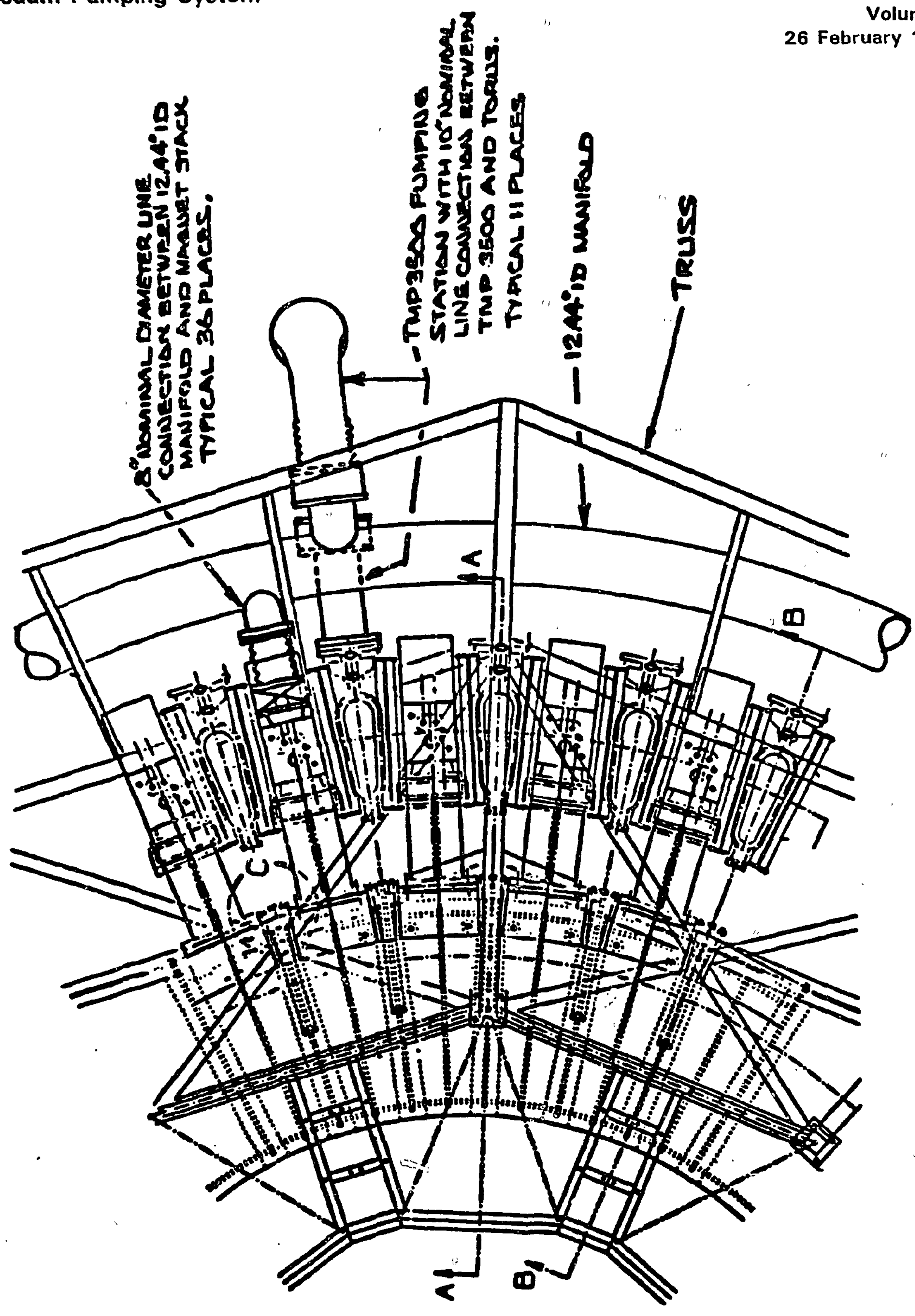


FIGURE 5-39 PLAN VIEW OF INTEGRAL TMP 3500 SYSTEM WITH 8 INCH MC DEWAR DUCTS

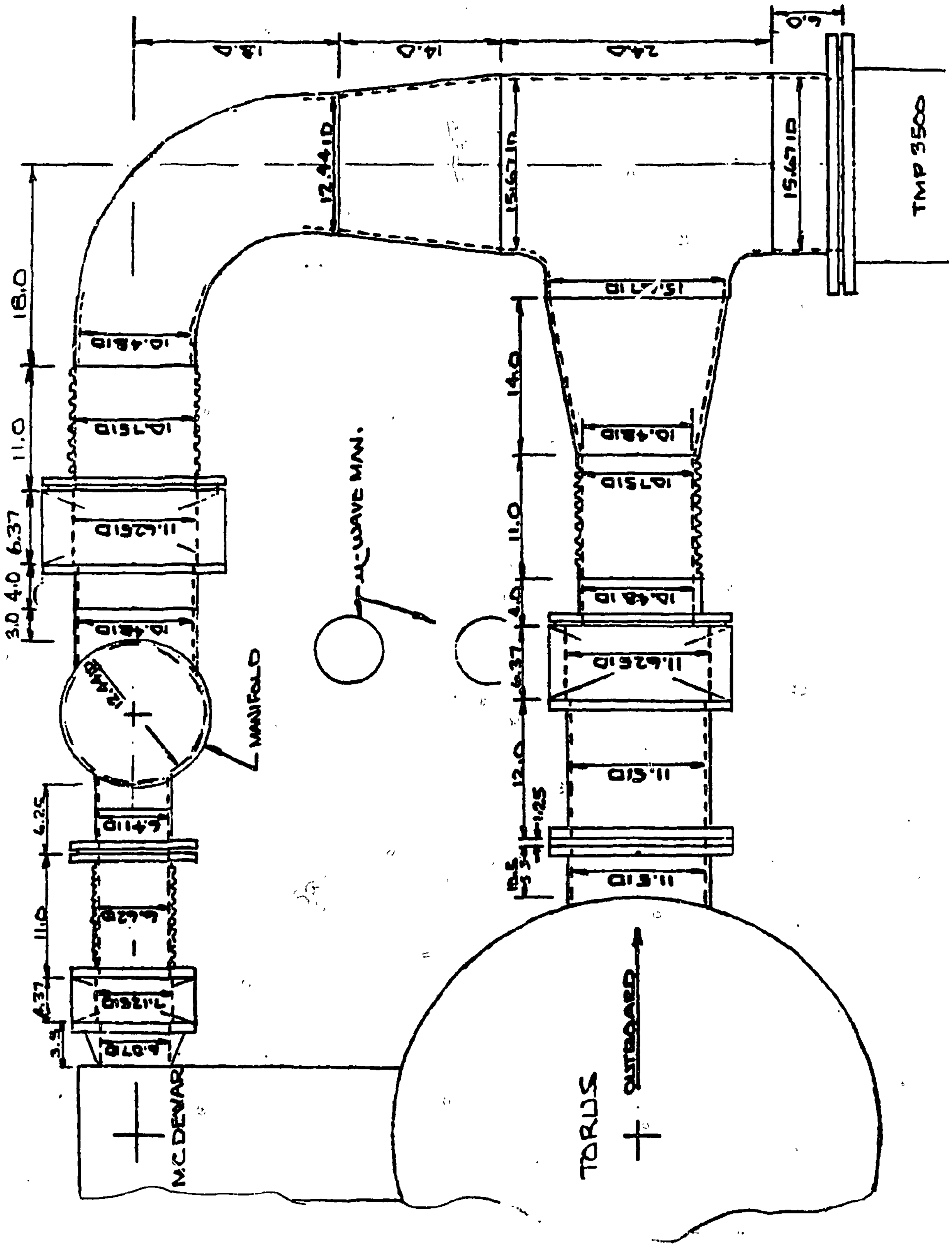


FIGURE 5-40 INTEGRAL TMP 3500 SYSTEM WITH 6.5 INCH DIAMETER (NOMINAL) DEWAR DUCTS

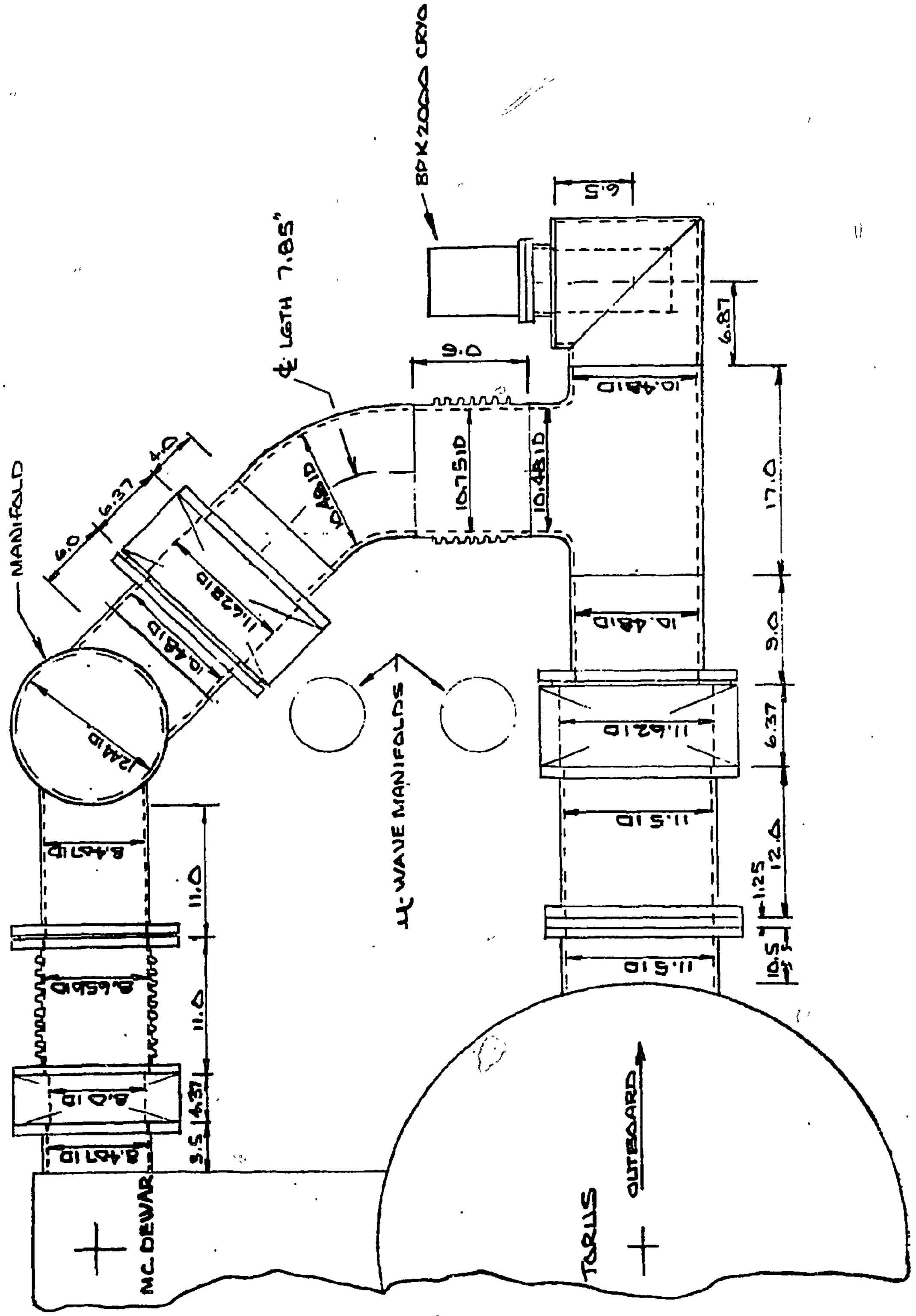


FIGURE 5-41 INTEGRAL BPK-2000 SYSTEM WITH 8 INCH VALVE AND 8.65 INCH BELLOWS IN MC DEWAR LINE

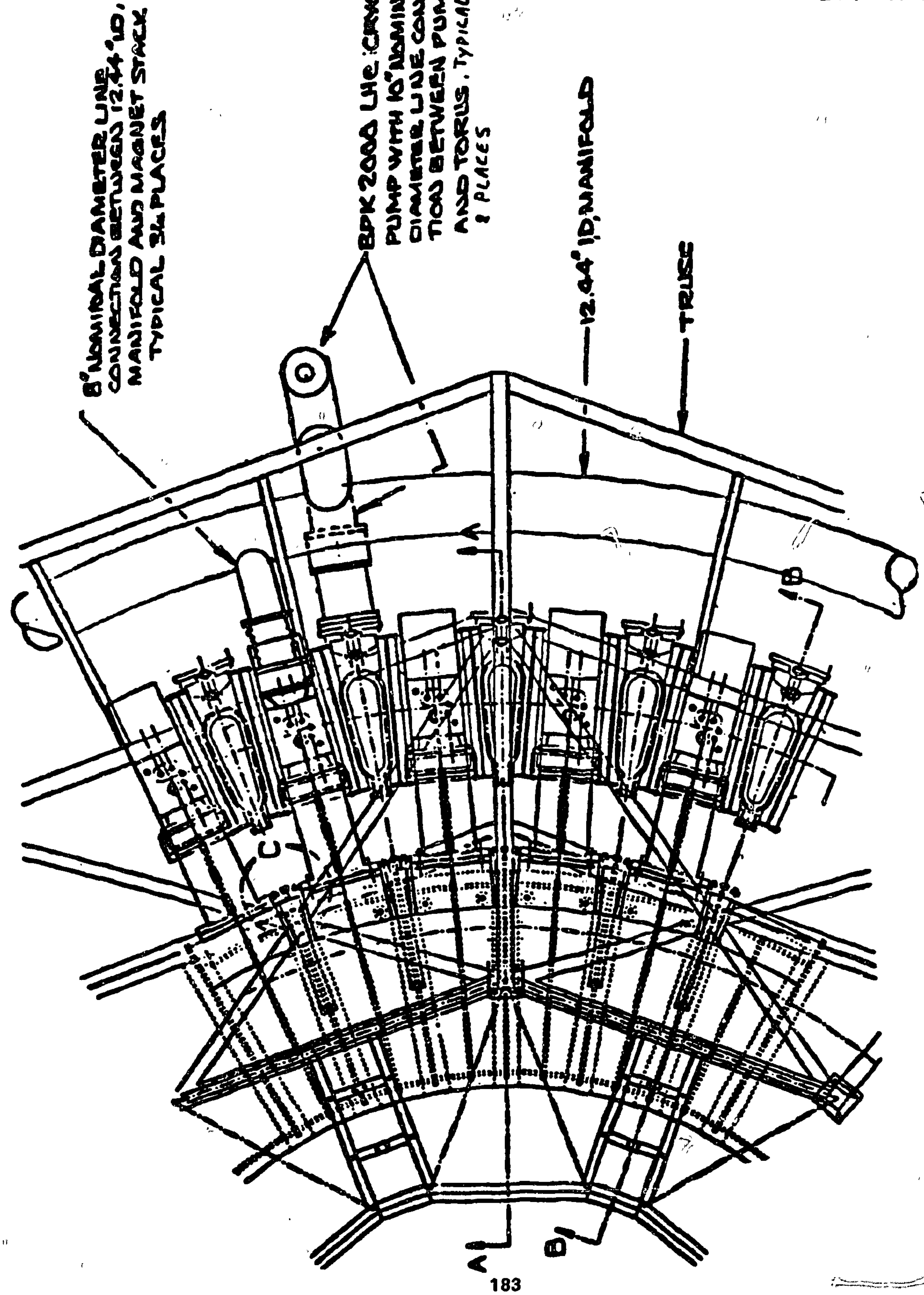


FIGURE 5-42 PLAN VIEW OF INTEGRAL BPK-2000 SYSTEM

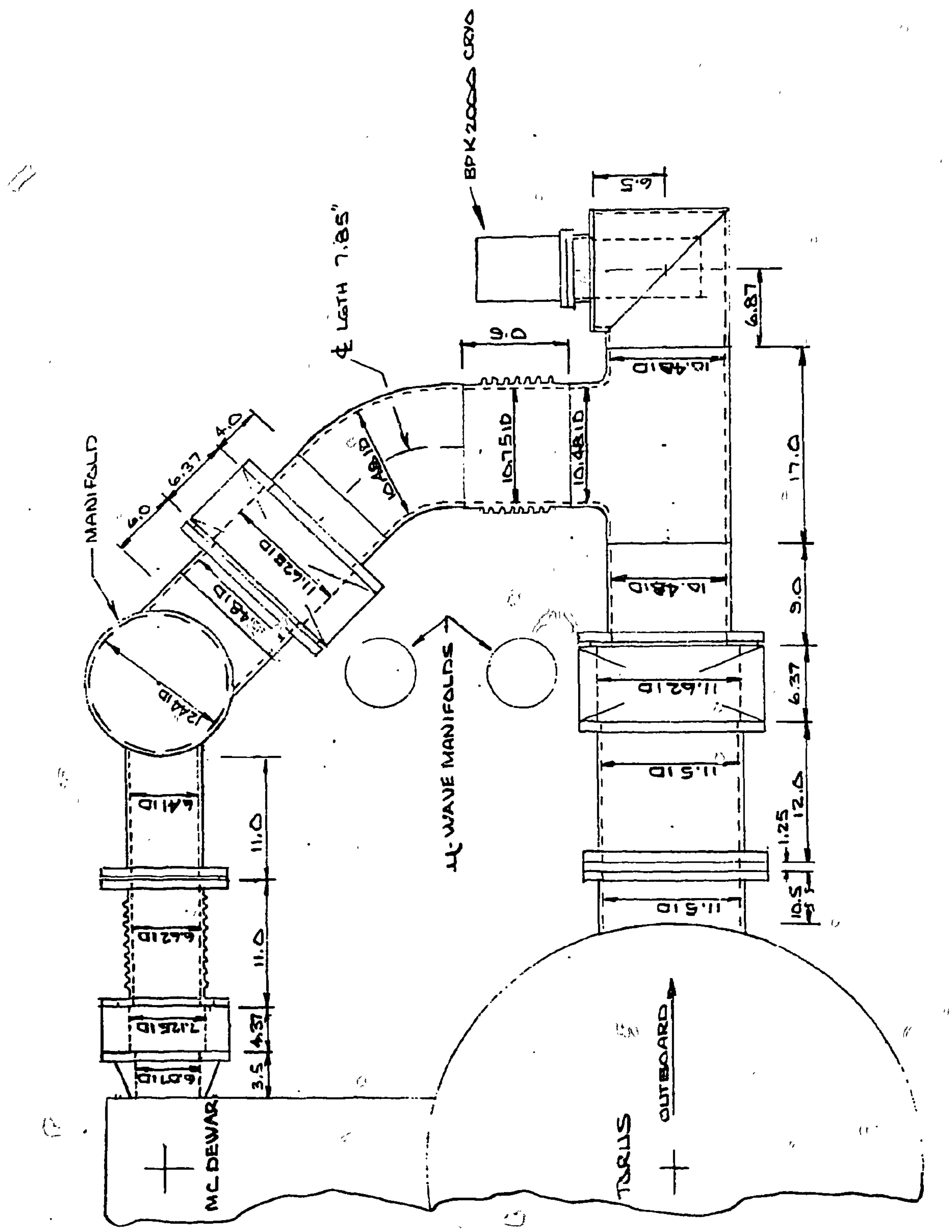


FIGURE 5-43 INTEGRAL BPK-2000 SYSTEM WITH 7.125 INCH VALVE AND 6.62 INCH BELLOWS IN MC DEWAR LINE

5.2.1 Analyses Method - The assumptions employed in the pumping systems analyses include:

- The gas to be pumped was assumed to be air at room temperature.
- Gas lines were sized for the intermediate pressure range.
- Roughing pump capability in the required turbomolecular pump fore-vacuum pressure range was optimized.
- Net effective pumping speed of the vacuum pump and roughing line assembly was made nearly equal to the vendor rated speed of the pump for that pressure range.

Determination of pipe line sizing in the intermediate flow range was done with equations taken from Vacuum Technology by A. Roth[5-6]. The baseline consideration was to maintain the mean free path of air at 25°C less than the inside diameter of selected lines and within the intermediate flow range. Equation 2.58, from Roth,

$$\lambda = \frac{5 \times 10^{-3}}{P}$$

defines the mean free path for ambient temperature air with P in torr and λ in cm.

Gas flow in the intermediate range is described by the Knudsen number, the ratio of the pipe inside diameter to the mean free path. Roth's Equation 3.9 defines intermediate flow as occuring when

$$1 < \frac{D}{\lambda} < 110$$

where D and λ are expressed in the same units. The turbomolecular pump foreline pressure range, where the roughing pump capability must be maximized, is approximately 1×10^{-3} to 4×10^{-2} torr. A pipe size can be chosen and the intermediate pressure limits determined for conductance in that range.

For air at ambient temperature, Roth's equation 3.216 defines the average upper pressure limit of the intermediate flow range as being

$$\bar{P}_u = \frac{5.55 \times 10^{-1}\ \text{torr-cm}}{D}$$

The average lower pressure limit of the intermediate flow range is given by equation 3.220.

$$\bar{P}_l = \frac{5.5 \times 10^{-3}\ \text{torr- cm}}{D}$$

D is the pipe inside diameter.

The selected pipe diameter and its average pressure, $\bar{P}$, in the intermediate gas flow range can then be introduced, along with the piping design length, into Knudsen's general equation 3.193,

$$C = \frac{(C_1 D^4 \bar{P} + C_2 D^3)/L}{L}$$ where C is in liter/sec

$C_1 = \pi/128\eta$ where η is the viscosity of the gas

D = tube inside diameter

$\bar{P}$ = average pressure in the intermediate range

$C_2 = 3.81 \times 10^3\ (T/M)^{1/2}$ where T and M are the gas temperature and molecular weight.

L = tube length.

The conductance of each line length C_a, C_b, etc. was determined by the above approach and the tubing system conductance, C_s, by equation 3.23,

$$1/C_s = 1/C_a + 1/C_b + ...$$

Net effective pumping speed in liters/second of the tubing and roughing pump assembly is given by

$$Snet = Spump \times C_s/(Spump + C_s)$$

5.2.2 Results of Analysis - In this section, the pumping configurations recommended for the Torus Roughing System and the forepump section of the Torus High Vacuum System are presented. The Mirror Coil Dewar system is also discussed. Elements in these configurations were sized using the intermediate flow analysis methods discussed in Section 5.1.

5.2.2.1 Torus Roughing System - The Torus Roughing System is shown in Figure 4-2. The 164 cubic feet per minute blower is backed by a 37 CFM rotary vane pump. Between the blower and the rotary vane pump is a liquid nitrogen cooled trap to prevent contamination of the blower and torus by mechanical pump oil. This blower and rotary vane pump combination is connected to cavity number 2 of the torus by a 6 inch o.d. roughing line. The calculated value for the effective pumping speed at the interface between the torus and the 6 inch line is approximately 89 cubic feet per minute at 10^{-2} torr. This interface is at the "horsecollar" shaped port located at the bottom of cavity 2 and shown in Figure 5-44.

5.2.2.2 Foreline Pumping for the Torus Turbomolecular Pumps - As shown in Figure 4-2, there are two forepumping systems for the five two pumps used in the torus high vacuum system. The first forepump system consists of a 331 CFM blower backed by a 65 CFM mechanical rotary piston pump, and supplies forepumping for the three turbopumps on cavities 2, 7, and 30 respectively. The second system consists of a 164 CFM blower backed by a 37 CFM rotary vane pump, and services the two turbopumps at cavities 16 and 24.

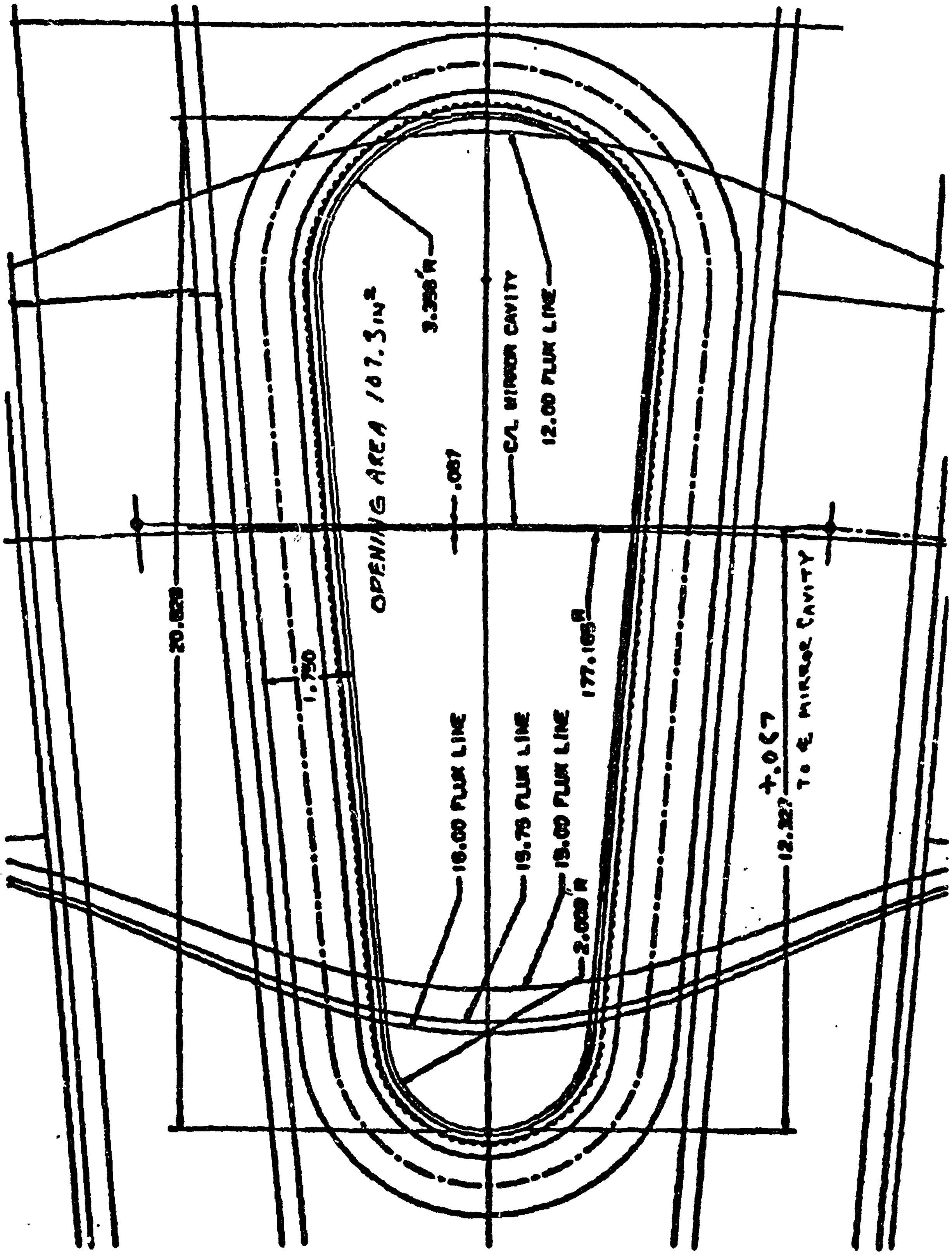


FIGURE 5-44 "HORSECOLLAR" PORT AT TORUS-ROUGHING LINE INTERFACE

The design hydrogen gas load of the system is one torr-liter per second uniformly distributed through each of the five turbopumps. Both foreline pumping systems were sized to produce a discharge pressure of 10^{-2} torr at the turbomolecular pump farthest from the blower. For the first system, the pumping speed at the discharge of the turbomolecular pump attached to cavity number 30 was calculated to be 58 liters per second for hydrogen at 10^{-2} torr. For the second system, the corresponding speed was 44 liters per second at the turbopump discharge of cavity number 24.

5.2.2.3 Mirror Coil Dewar Roughing - The roughing system is shown in Figure 4-14. It consists of a 164 cubic feet per minute blower backed by a 37 CFM rotary vane pump. A liquid nitrogen cooled trap is located between the blower and rotary vane pump to minimize the potential for hydrocarbon contamination reaching the MC dewar system. A 5.83 inch I.D. diameter tube is used to connect the roughing systems to the high vacuum manifold at point Z, reference Figure 4-14. The effective pumping speed where the 5.83 inch line intersects the 12.42 inch I.D. high vacuum manifold is approximately 85 CFM for 20°C air at 10^{-2} torr.

5.2.2.4 Mirror Coil Turbomolecular Pump Forepumping System - The forepumping systems shown in Figure 4-14, consist of a 164 CFM blower backed by a 37 CFM rotary vane pump. A liquid nitrogen cooled trap separates the two pumps in each of the installations to minimize the potential for rotary vane pump hydrocarbon contamination reaching the MC dewar system. Each forepumping system backs two TPU-2200 turbomolecular pumps. 3.83 inch I.D. lines attached to the discharge ports of the two turbopumps are manifolded together and connected to the forepumping system with a 5.83 inch I.D., common line. The effective pumping speed at the turbopump outlet for the longest length combination of 3.83 and 5.83 inch I.D. lines in 53 CFM for air at 10^{-2} torr.

5.3 MICROWAVE SHIELD

In this section the perforated plate designed to shield the vacuum pumps and ion gauges from microwave energy is described. The means used to calculate its microwave shielding effectiveness are presented in Section 5.3.1. The action of the microwave shield as an impedance in the Vacuum Pumping System was discussed in Section 5.1.1.5; the treatment in Section 5.3.2 below is limited to the effect of this impedance on pressures measured by ion gauges. Finally, Section 5.3.3 describes the heat transfer analysis performed to determine the shield cooling requirements.

5.3.1 Microwave Attenuation - The microwave shield is made of a 1/16" thick metal plate in which circular holes on an equilateral triangular lattice are drilled.

The transmission coefficient of such a plate is given in reference 5-8 by

$$T = (1 - j[A + B \tanh(\beta L)])^{-1} - (1 - j\,[A + B \coth(\beta L)])^{-1}$$

where A and B are functions of the spacing and size of the circular openings. They are given by

$$A = 12\left(\frac{4}{3}\left(\frac{\lambda}{d}\right)^{2} - 1\right)^{1/2}\left[\left(J_1'\left(\frac{4\pi}{\sqrt{3}}\frac{a}{d}\right)\Big/\left(1-\left(\frac{4\pi a}{1.841\sqrt{3}\,d}\right)^{2}\right)\right]^{2} - \left(12\Big/\left(\frac{4}{3}\left(\frac{\lambda}{d}\right)^{2}-1\right)^{1/2}\right)\left[J_1\left(\frac{4\pi}{\sqrt{3}}\frac{a}{d}\right)\Big/\left(\frac{4\pi}{\sqrt{3}}\frac{a}{d}\right)\right]^{2}$$

and

$$B = 0.33\left(\frac{d}{a}\right)^{2}\left(\left(\frac{.293\lambda}{a}\right)^{2} - 1\right)^{1/2}$$

and the quantity β is given by

$$\beta = \frac{2\pi}{\lambda}\left(\left(\frac{.293\lambda}{a}\right)^{2} - 1\right)^{1/2}$$

In these expressions a is the radius of the circular holes, d is the center-to-center spacing between them, the J's denote Bessel functions, λ is the microwave wavelength, and 2ℓ is the plate thickness. The present microwave shield design has a = .0225 inch, d = .055 inch, and 2ℓ = .0625 inch.

A graph of the attenuation in dB as a function of plate thickness is shown in Fig. 5-45 for a plate having the above values of a and d. The microwave frequency is shown as a parameter.

This microwave shield design was originally selected to provide sufficient shielding for cryogenic pumps. Since the recommended pumps are turbomolecular pumps, it was considered worthwhile to investigate a modified shield with the radius of the circular holes increased to a = .0275 inch. The center-to-center distance d was also increased to .065 inch; the thickness was not changed. The modifications gave smaller attenuation for transmitted microwave energy, 38 dB compared to 50 dB for 60GHz calculations. On the other hand, the calculated value of the vacuum conductance increased by a factor of 1.2 for the microwave shield alone. However, the effective pumping speed at the torus depends on the conductance of all elements between the torus and the pump, not just the microwave shield. This means that the factor of improvement in the pumping speed arising from the above modification to the shield is considerably smaller than 1.2. It was found to be only 1.03 in the typical case tested. Further study showed that completely omitting the microwave shield produced less than a 16% improvement in the pumping speed for the case studied. Consequently the shield design with a = .0225 inch and a d = .055 inch was retained.

The required microwave attenuation is not yet known. The attenuation required is a function of the level of microwave power incident on the ducts. This in turn depends on the Q of the cavity and the microwave absorption of the plasma, neither of which is presently well defined.

5.3.2 Ion Gauge Effects of the Microwave Shield - Ion gauges are degassed before operation. This means that the elements and walls of an operating ion gauge are able to absorb incoming gas molecules. In addition the ionization processes can lead to further sorption of active gases at the hot elements and to ionic pumping of even the noble gases, so that an operating ion gauge acts like a pump. Both these pumping mechanisms eventually saturate for a continuously operating gauge, due to the descrption of previously pumped gas at the same rate at which fresh gas is being pumped.

To avoid damage to the ion gauges from microwave energy present in the torus, it is necessary to install a microwave shield in the tubulation connecting the ion gauge to the torus.

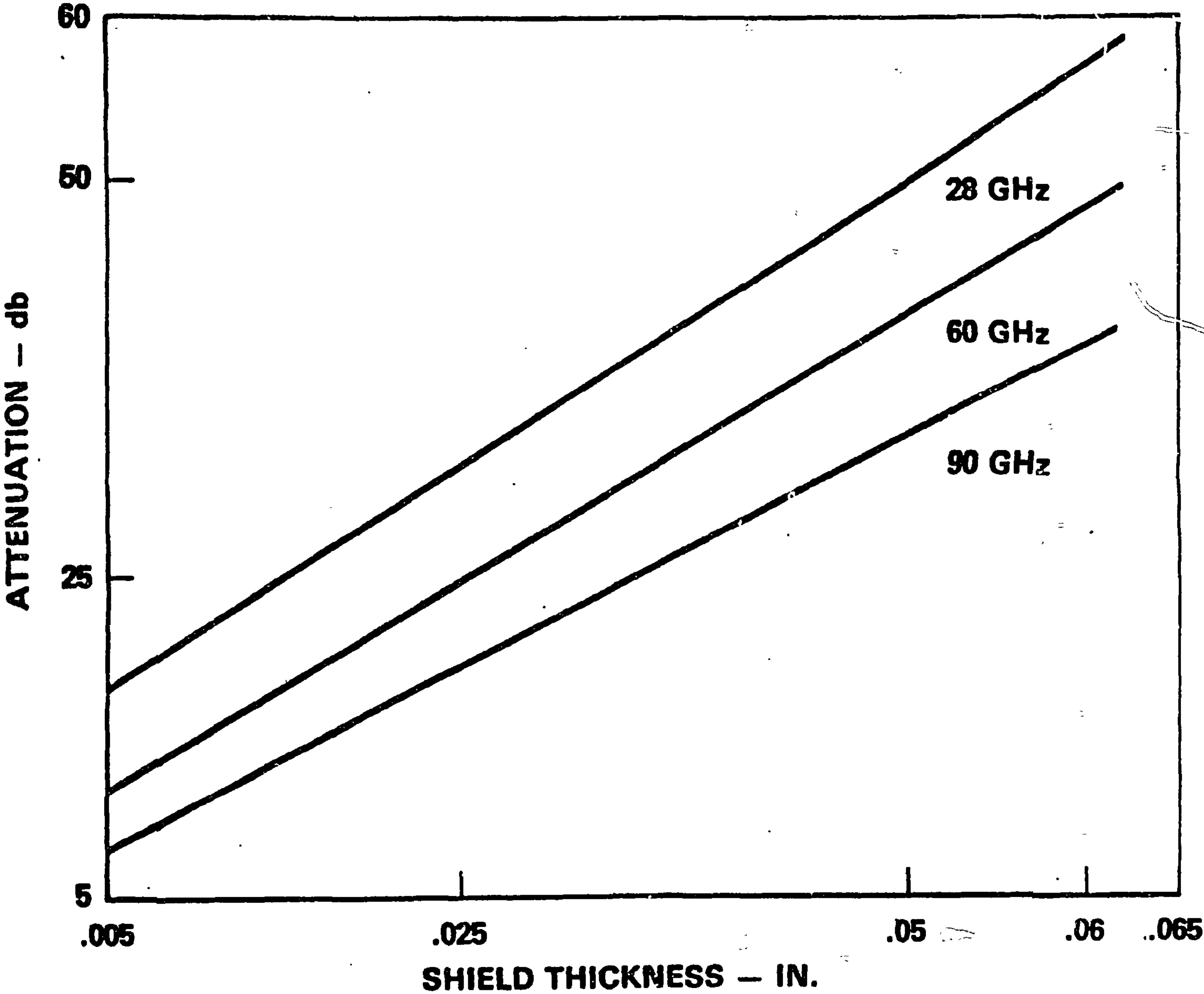


FIGURE 5-45 ATTENUATION OF MICROWAVES VERSUS SHIELD THICKNESS FOR A METAL SHIELD HAVING .045" HOLES ON A TRIANGULAR LATTICE WITH .055" HOLE CENTER SEPARATION

When there is any kind of impedance to gas flow between a pumping ion gauge and the chamber whose pressure is to be measured, the pressure in the ion gauge will be lower than the chamber pressure, resulting in an inaccurate pressure measurement. These effects can be taken into account, at least approximately, in the following manner. Suppose that the ion gauge has an effective pumping speed S and that it registers a pressure P_g when connected through a conductance C to a chamber whose actual pressure is P_a. We can express the effective throughput Q of the ion gauge as $Q = SP_g$. This is also the throughput of the conductance C so that we have $Q = C(P_a - P_g)$.

Solving these two equations for the ratio P_g/P_a yields $P_g/P_a = C/(S + C)$. The conductance C of the connecting tube and microwave shield can be calculated as already described in 5.1, and hence the correction factor to be applied to the pressure P_g, indicated by the gauge, may be determined if its effective pumping speed S is known. This pumping speed is, typically, 2 liter/sec for nitrogen from sorption, and .2 liters/sec for nitrogen from ionic pumping [5-1]. A representative value of the conductance C can be found by calculating the conductance of a segment of microwave shield perforated plate, where the segment is in the form of a circle of diameter 1.36 inches, comparable to the diameter of the flange mounting of a typical ion gauge. The conductance of such a segment for nitrogen at room temperature is ~30 liters/second; combined with the gauge nitrogen pumping speeds mentioned above this implies that the gauge readings will be ~7% too low. The inclusion of three inches length of tubing of internal diameter 1.36" in the value of the conductance C decreases it to ~20 liters/second and implies that the gauge reading will be ~10% too low.

The correction factor for EBT-P will be different because the primary gas species is hydrogen, not nitrogen. This will probably tend to increase both the conductance C and the gauge pumping speed S. Further, the effective temperature of the hydrogen will be greater than room temperature; this will also tend to increase the conductance C. The net effect is expected to be an error somewhat smaller than was calculated for nitrogen.

The fact that the ion gauge acts like a pump also implies a time delay in the response of the gauge reading P_g to an abrupt change in the chamber pressure P_a. The 1/e time constant for pressure change in a volume V with pumping speed S is given by [5-1]

$$\tau = V/S$$

For reasonable values of V and S associated with the gauge, this predicts time constants on the order of 50 milliseconds or less.

5.3.3 Thermal Performance of the Microwave Shield - To determine the cooling requirements for the microwave shield, the heat load was assumed[5-9] to be 5 w/cm^2. As previously discussed, the microwave shield is 60 percent transparent, resulting in a total heat load of 1.98 kw in the large 35.56 cm diameter shield at the vacuum pumping duct. Such a heat load requires an active cooling system. Presented in Figure 5-46 is the proposed cooling system.

Seven copper tubes with .109 cm. I.D. are brazed to the shield and fed with water from a manifold around the outer edge of the shield. A minimal mass flow rate of .048 kg/sec is necessary to remove the 1.98 kw load. This flow rate results in a flow velocity of 7.1 m/sec. The necessary tube spacing would be 5.4 cm between tube centerlines to keep the shield below 200°C. The heat transfer coefficient is 4.5 w/(cm^2 deg C).

A similar thermal analysis was performed to determine the cooling requirements of the 6 inch diameter roughing line shield and of the small 1.36 inch diameter microwave shield which protects the ion gage. A single coolant loop around the circumference of the shield was found to provide adequate cooling for the ion gauge shield. For the roughing line shield, three .109 cm I.D. copper tubes with a water mass flow rate of .0174 kg/sec are recommended to handle the .36 kw load. This produces a flow velocity of 6.1 m/sec and a heat transfer coefficient of 3.9 w/(cm^2 deg C). The spacing between tube centers is 5 cm.

5.4 EBT-P ENVIRONMENT

In this section the accumulated X-ray dose, the steady state microwave power, and the magnetic field strength in the neighborhood of the torus are described. A general defini-

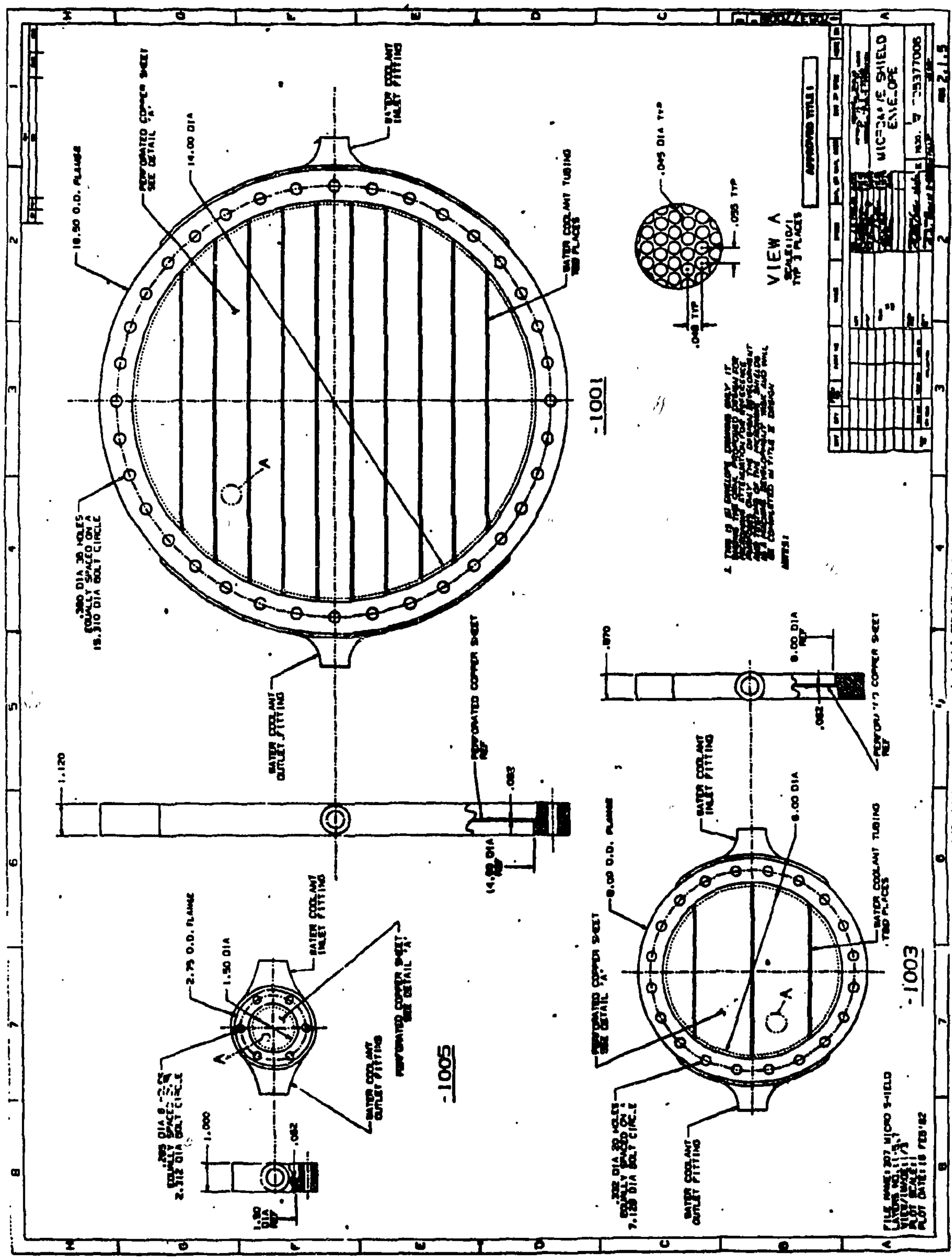


FIGURE 5-46 MICROWAVE SHIELD AND COOLING SYSTEM

tion of the potential problems associated with each of these aspects of the EBT-P environment is provided; in particular potential incompatibilities are identified for vacuum system hardware such as seals, valves, solenoid actuators, electronics, and pumps. These considerations ruled out gaseous helium cryopumps because of incompatibility with X-rays. Turbomolecular pumps were usable, but presented potential problems related to interactions between the pump and the magnetic fields in EBT-P.

5.4.1 X-Rays - Large quantities of high energy X-rays result from bremsstrahlung emission by the ring electrons. This emission arises in approximately equal parts via direct emission from electrons in the ring and via scattered emission from electrons scattered out of the ring and impinging on the wall or the limiter. These X-rays are potentially damaging to elastomers present in seals and valves, to oil, insulation, motors, and electronics present in some types of pumps, and to solenoid actuators in valves. The X-ray dose a component receives is determined by the amount of X-ray power generated combined with the amount of shielding the item in question receives from placement and the geometry of the system, and of course, by the "ON" time of the plasma. The damage to a component is primarily a function of the materials from which the component is fabricated.

A point source model[5-10] was developed to predict the X-ray dose at the 76 cm vacuum seal between cavity segments of the torus. The vacuum seals are essentially unshielded; consequently they are subject to X-ray energy in amounts dependent primarily on the source distribution and intensity.

Figure 5-47 shows the cumulative dose received by these seals over the 10 year project life with allowance for the initial low power period. Although the quantitative dose values shown in Fig. 5-47 depend on the assumption of the point source model that the X-ray energy is emitted by a point at the cavity center, the time dependence of the cumulative dose does not depend on such an assumption. Consequently a similar time dependence is to be expected for doses to equipment calculated later in this discussion by other models. If the plasma impurity level is assumed to be 2% aluminum, sputtered from the limiter, the point source model predicts a dose rate at the seals of 8.4 rad/sec for full power (7MW microwave power) conditions.

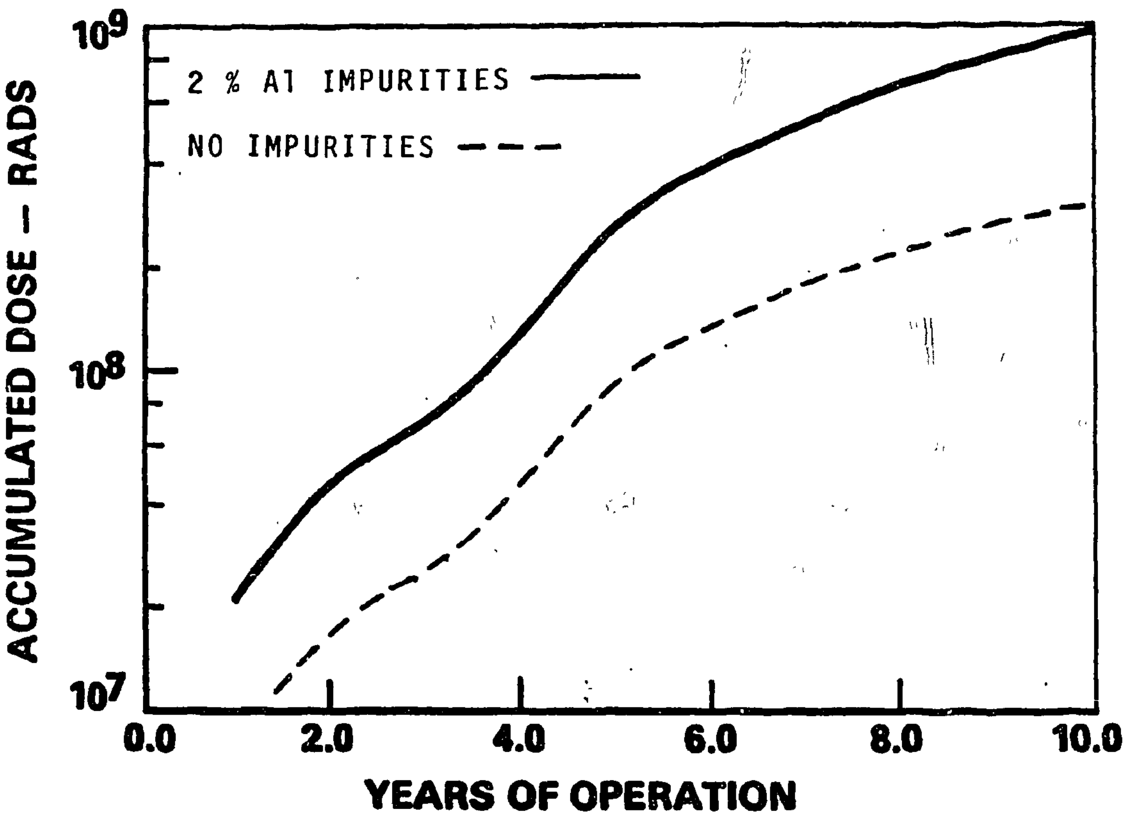


FIGURE 5-47 CUMULATIVE X-RAY DOSE RECEIVED BY VACUUM SEALS BETWEEN TORUS CAVITY SEGMENTS

The two curves shown in Fig. 5-47 represent the cumulative dose with and without plasma impurities. The top curve, representing plasma impurities of 2%, is more realistic here. If the limiter material is changed from aluminum to some other material, the atomic number of the sputtered material may be expected to increase, and an increased rate of X-ray generation from each impurity ion will result. On the other hand, the sputtering rate may decrease in which case the total number of X-ray source impurity ions would decrease. The total X-ray power tradeoff will be evaluated if the limiter material is changed.

The point source model mentioned above assumes that the X-rays are emitted by a source at the center of the cavity. This approximation is based on the locations of the direct and scattered X-ray sources, which are roughly distributed over the surface of a sphere centered at the cavity center. When allowance is made for the detailed asymmetries in the X-ray source distributions, it turns out that the inboard side of the seals receives an above average amount of the power and can be a 'hot spot'.

A somewhat improved analysis[5-11] assuming X-ray sources in all 36 cavities and attempting to account for the non-uniformity of source distribution in each cavity was performed. This analysis treats 77% of the X-rays as originating on the electron rings and 23% as originating on the limiters. A total of just under 100 watts X-ray power is expected from each cavity based on these calculations. The location of the valve and pump for the torus high-vacuum system is shown in Fig. 5-48. Also shown on this figure are the X-ray dose rates predicted by the improved model. The dose at the turbomolecular pump shown in Fig. 5-43 is expected to be somewhat lower; in the neighborhood of $3x10^7$ rads. The remainder of the torus roughing system and the dewar roughing system are outside the concrete enclosure and the expected ten year dose for both is less than 10 rads. These calculations also predict that the ten-year dose at the dewar high-vacuum valve and pump will be on the order of $5x10^7$ rads.

Early in the EBT-P design gaseous helium cryopumps were considered for use. These pumps have an integral refrigerator which cools internal pumping surfaces in two stages to 80K and 10K. The refrigerator is in the vacuum pump enclosure. However, such pumps are incompatible with the X-ray environment due to the presence of several components within the refrigerator which are made of Teflon. The radiation resistance of Teflon is extremely poor (on the order of 10^4 rads). Further investigation showed that the four major

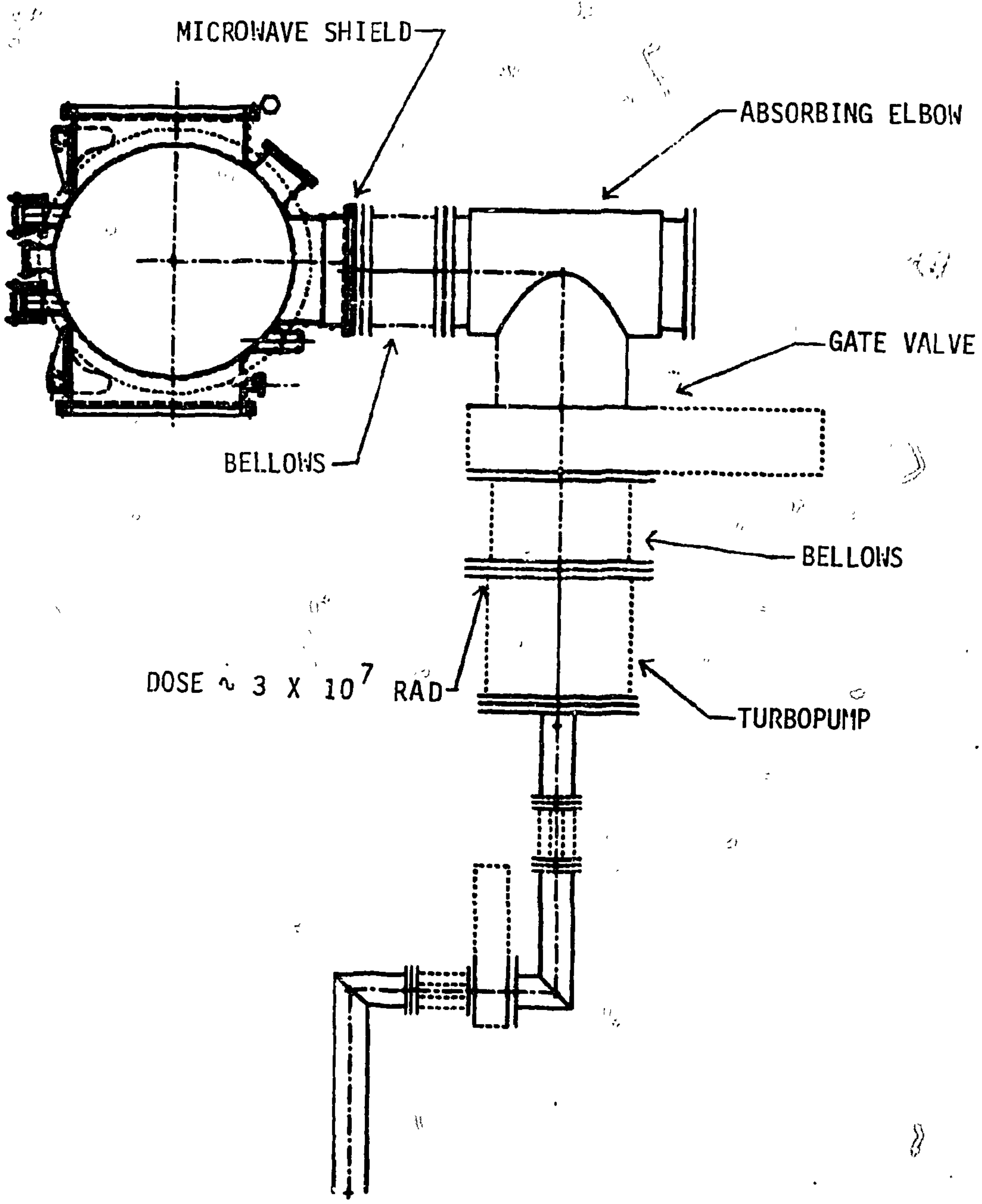


FIGURE 5-48 VALVE AND PUMP LOCATION FOR TORUS HIGH VACUUM SYSTEM

manufacturers of such cryopumps use Teflon parts. One part, the seal on a piston in the refrigerator, is particularly critical and in the opinion of all four manufacturers, could not be replaced with a different material without a significant amount of development. For these reasons, gaseous helium cryopumps were no longer considered for use on EBT-P.

5.4.2 Microwave Environment - The microwave energy injected into the plasma, up to 7 MW total power, represents a potential problem for vacuum seals, pumps, and elastomers in valves which are unshielded. For the fully upgraded power configuration of the power, calculations give 16 W/cm^2 as a conservative estimate of the power flux on the walls of the chamber[5-10]. The same calculations showed that the amount of power reaching the torus seals could be estimated as .20 watts/centimeter, not serious for metal seals but large enough to cause overheating in o-ring seals and preclude their use.

Since microwaves are effectively stopped by metal walls, the only items susceptible to microwave damage, other than the primary vacuum seals, are the valves, pumps, and instrumentation, for which there are paths for microwave access along vacuum ducts. The ducts to the ion gauges and to the pumping system are protected by microwave shields described in section 5.3. These shields are shown by calculations in that section to decrease the microwave power by a factor of 2.5×10^{-4} for 90 GHz microwaves and by a larger factor for lower frequencies. This is adequate shielding for prevention of heat damage to valve components and ion gauges, but because of the large size of vacuum ducts the microwave power past the shield can still be on the order of half a watt, which is an undesirable heat load on cryogenic pumps. Turbopumps are recommended; furthermore in the selected design these pumps are recessed so that they do not have a direct view of the microwave shield, and the duct walls past the shield have a microwave absorbent coating. Hence the heat load arising from microwave energy is deposited on the vacuum duct before reaching the pump. This is also true of the much larger heat load due to hot neutrals from the torus, which tend to reach thermal equilibrium with the walls after a few reflections. The ducts are actively cooled to minimize the radiative heat load to the pumps. Thermal performance of the microwave shield is discussed in section 5.3.3, and an analysis of the heat loads which would impact cryopumps is presented in section 5.6.

It is recognized that microwaves could represent a serious problem for liquid helium cryopumps. The biggest unknowns at present are the electric field strength in the cavity, which is dependent on the cavity Q and the synchrotron power generated by the plasma. The potential for microwave and synchrotron radiation heating of the pumps was a major factor in the selection of turbomolecular pumps rather than cryopumps.

5.4.3 Magnetic Fields - The EBT-P environment includes large magnetic fields on the order of 4.6 Tesla at the coil center. Stray fields represent a potential source of interference for solenoid valve actuators and turbomolecular pumps.

Computer programs[5-12] were developed which use elliptical integrals to evaluate these fields. The programs model each of 36 coils as a 10 x 20 matrix of current rings. A separate analysis was performed to evaluate error fields arising from current leads and the helicity in the coil. These error fields are expected to be trivial in comparison to those from the current rings. Since 300 series steels have been specified throughout, error fields arising from ferromagnetic effects are also expected to be trivial, in comparison to those from the current rings.

The valves in the torus and MC dewar vacuum systems are operated electro-pneumatically. The pneumatic actuators are controlled by solenoid operated valves. As discussed in Section 4, the manufacturer of these valves feels that if the magnetic fields in the vicinity of the valve are uniform, there will be no need to mount them remotely or to provide shielding.

Turbomolecular pumps, because of their high rotation rates and metallic construction, can tolerate only limited magnetic field strengths. The most critical effect is rotor heating by the action of eddy currents and the resulting thermal expansion leading to imbalance and clearance problems[5-13]. Literature from one manufacturer (Leybold-Heraeus) specifies 3 X 10^{-3} Tesla (30 gauss) as the maximum tolerable field; this figure was confirmed in conversation with their representatives. The value of the magnetic field predicted by computer analysis for the turbopump locations was 1.3 gauss for the TMP 3500 and less than 1 gauss for the TPU-2200. These results indicate that no magnetic shielding of the turbopumps is necessary. However, these predicted fields correspond to normal operating conditions, and off-normal events need to be analyzed. One example of such an event is the quench of a toroidal field magnet followed by failure of one of the current breakers designed to shutdown the rest of the toroidal field magnets. Calculations have not been performed for this scenario (or for other off-normal events), but it is felt that magnetic fields of perhaps 40 gauss could result at the turbopump locations for on the order of 5 minutes. The impact of such events on potential requirements for magnetic shielding of the turbomolecular pumps will be investigated as part of the Title II design effort.

Another aspect of this problem is that the turbomolecular pump contains large internal parts - the internal housing, main rotor shaft, and the motor core - made of ferromagnetic steel parts which could potentially perturb the EBT-P fields. This is unlikely to be a problem, at least under normal conditions, due to the low values of the magnetic field at the turbopump locations.

5.5 VACUUM PUMPS

In this section we will discuss the types of high vacuum pumps which were considered. The working principles and inherent speed of each type of pump will be described, along with pertinent cost and environment requirements.

5.5.1 Refrigerated Cryopumps - In the refrigerated cryopump, the condenser is cooled by a built-in refrigerator which uses gaseous helium as its working fluid. The temperature achieved at the condenser is in the range 12K-20K. Neon, hydrogen, and helium, being noncondensible at these temperatures, are cryosorbed by a sorbing material such as activated charcoal in the pump; all other gases are cryocondensed.

Because of saturation of the absorbing material in refrigerated cryopumps, such pumps have a limited capacity to pump hydrogen (as well as helium and neon). Evidence of the onset of saturation includes a gradual drop in the pumping speed or rise in the condenser temperature. The pump should then be regenerated; typically this is accomplished by allowing the condenser to warm to $\sim$ 300 K while being rough pumped. Depending on the pump size and design, the cryosorption capacity for hydrogen is in the range 4,000 to 40,000 torr-liters for pumps with speeds for N_2 in the range 600 to 18,000 liters/second.

Figure 5-49 illustrates an appendage type refrigerated cryopump. The built-in refrigerator is two-stage. The first stage at 80K cools the baffle and shield. These elements radiate far less energy to the 12K surface than would room temperature surfaces; the heat they ab-

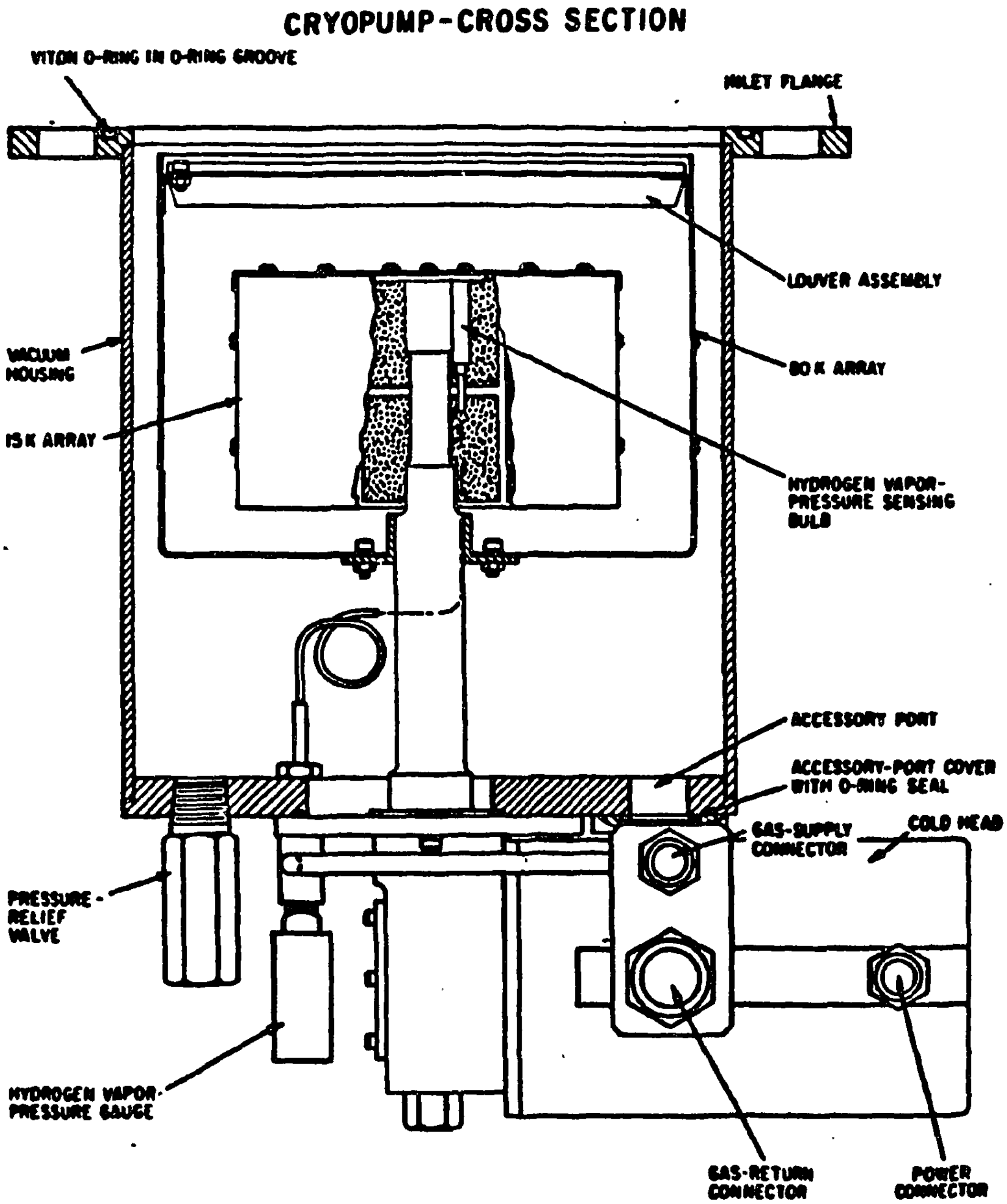


FIGURE 5-49 APPENDAGE-TYPE REFRIGERATED CRYOPUMP

sorb from the incoming stream of molecules and flanges is comparatively easy for the refrigeration system to extract because of the relatively high temperature of the elements. The second stage of the refrigeration system cools the 12K surface on the underside of which is the coating of active sorbing material, typically activated charcoal. As mentioned above, the 12K surface will pump all gases not already pumped by the shield and baffles except He, Ne, and H_2; these are absorbed by the sorbing material.

The helium gas, used as the working fluid in the two-stage refrigerator, is in a closed-loop system, so that the only utility needed to operate this type pump is electrical power. This leads to a lower operating cost than is available with other types of cryopumps, as well as a less complicated installation. On the other hand, the two-stage cryogenic refrigerator is high-technology equipment, which one would not expect to tolerate a harsh environment. In particular, x-rays impinging on the refrigerator in the EBT-P application would cause unacceptable damage to its Teflon seals (Section 5.4.1). For this reason refrigerated cryopumps were not selected.

5.5.2 Liquid Helium Cryopumps - Liquid helium cryopumps are of two types. Liquid pool cryopumps are equipped with a tank containing liquid helium from an external supply. The outer surface of the tank is the cryosorption surface. It is generally shielded by liquid nitrogen cooled baffles to reduce the liquid helium consumption, which for the pump shown in Fig. 5-50, with hydrogen speed of 7,000 liters/sec, is .035 liters/hour at 4.2K and pressures below 10^{-5} Torr. In contrast, continuous flow liquid-helium cryopumps have as their cryosorption surface a heat exchanger through which liquid helium from an external dewar is supplied. The helium evaporates in the exchanger, cooling it to temperatures comparable to those for the liquid-pool cryopumps. The cold helium gas from the exchanger is used to cool the baffle and shields which prevent an excessive heat load on the exchanger. Consequently continuous-flow liquid helium cryopumps do not customarily require liquid nitrogen for their operation, unlike liquid pool cryopumps. On the other hand, continuous flow cryopumps have a liquid helium consumption rate perhaps an order of magnitude greater. Furthermore, a continuous flow system is normally characterized by higher liquid helium consumption rates associated with the supply lines and valves to the pump. This is because the supply lines for the liquid pool cryopumps normally need to operate only once per day, since the LHe holding time for such a pump is typically ~30 hours. In contrast, the distribution system servicing a continuous flow cryopump needs to

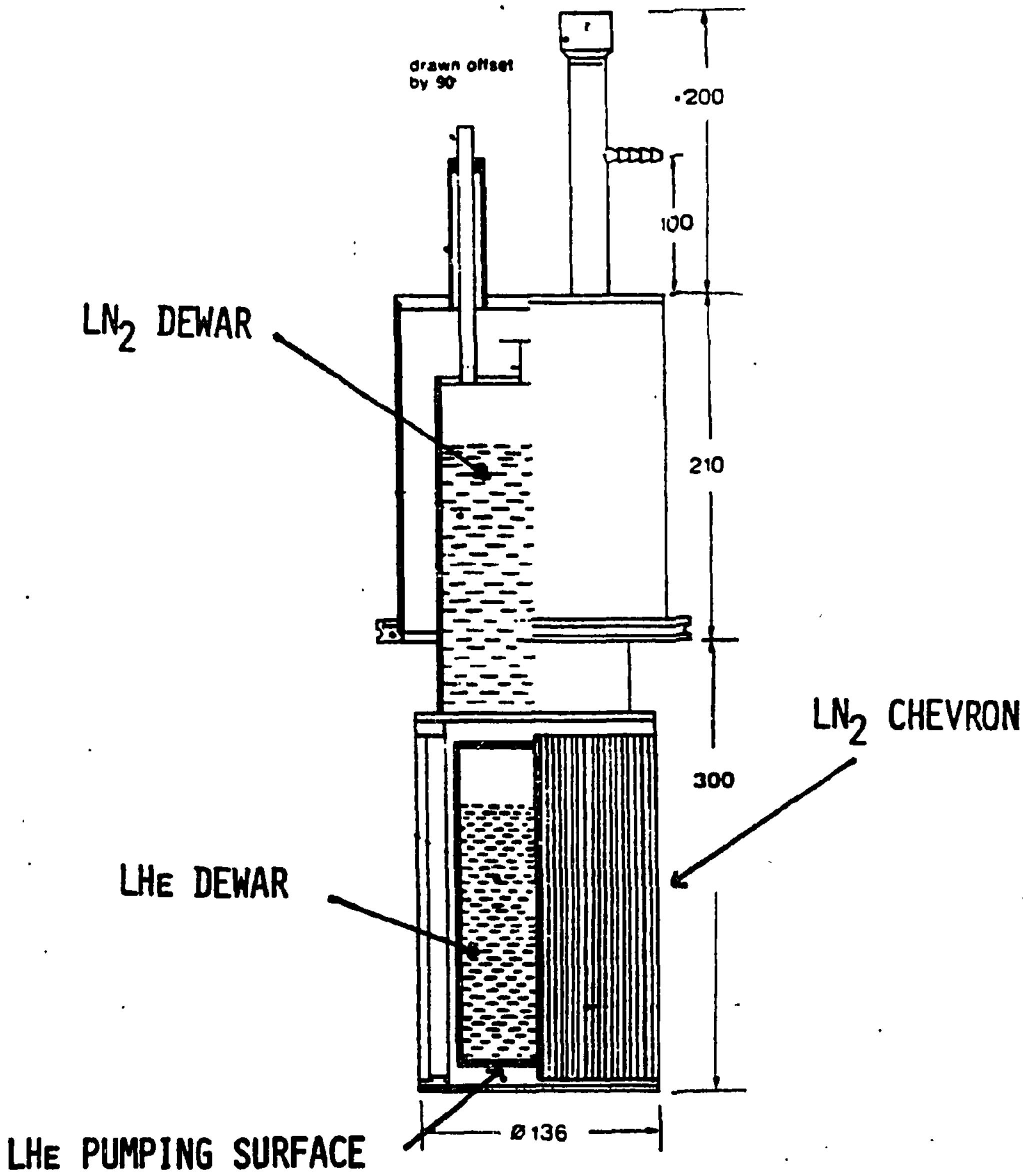


FIGURE 5-50 LIQUID POOL LHe CRYOPUMP

constantly supply a trickle of LHe. However, this contrast in the supply line operation may vanish in the present application for two reasons: (i) the LHe holding time for the liquid pool pump may decrease dramatically due to heat loads from the torus and from hydrogen recycling between the nitrogen cooled and helium cooled surfaces, and (ii) the supply line design needs to prevent accidental regeneration. Consequently there may be a need for a continuous trickle of LHe in both types of pump, and at least some of the lower helium consumption advantage of the liquid pool pump is lost. Nevertheless, since the pumping performance of continuous flow cryopumps seems to show no advantage over that of liquid pool cryopumps, the continuous flow cryopumps were excluded from consideration.

The liquid pool cryopump shown in Fig. 5-50 was then considered for use on the EBT-P project. Having no moving parts, it is of simple and reliable design. It is also free of Teflon seals and has good tolerance for x-rays and magnetic fields, provided excessive heat loads are avoided. The speed of this pump is 2,250 liter/sec for N_2, and 7,000 liter/sec for H_2. Helium pumping can be provided on the cryopump by coating a portion of the LHe dewar with activated charcoal. The helium speed depends on the surface area coverage of the sorption material

Disadvantages of the liquid helium cryopump system include the lack of availability of such pumps on an off-the-shelf basis. Furthermore, there are potential heat load problems which are difficult to define. One such problem is the heat load due to microwave energy, which depends on the Q-factor of the torus cavity. A related problem is the possible difficulty in achieving LHe hold times in the cryopump dewars to equal or exceed the desired 16 hours to prevent unwanted pump regeneration.

5.5.3 Turbomolecular Pumps - These pumps operate on the molecular drag principle. Molecules striking a solid surface under high vacuum conditions are not specularly reflected; instead the reflection process is more nearly described as a momentary absorption followed by a re-emission of the molecule at an angle independent of its incident angle. Further, compared to the incident molecule, the velocity of the emitted molecule has on the average picked up a component from the surface itself, if the surface is in motion.

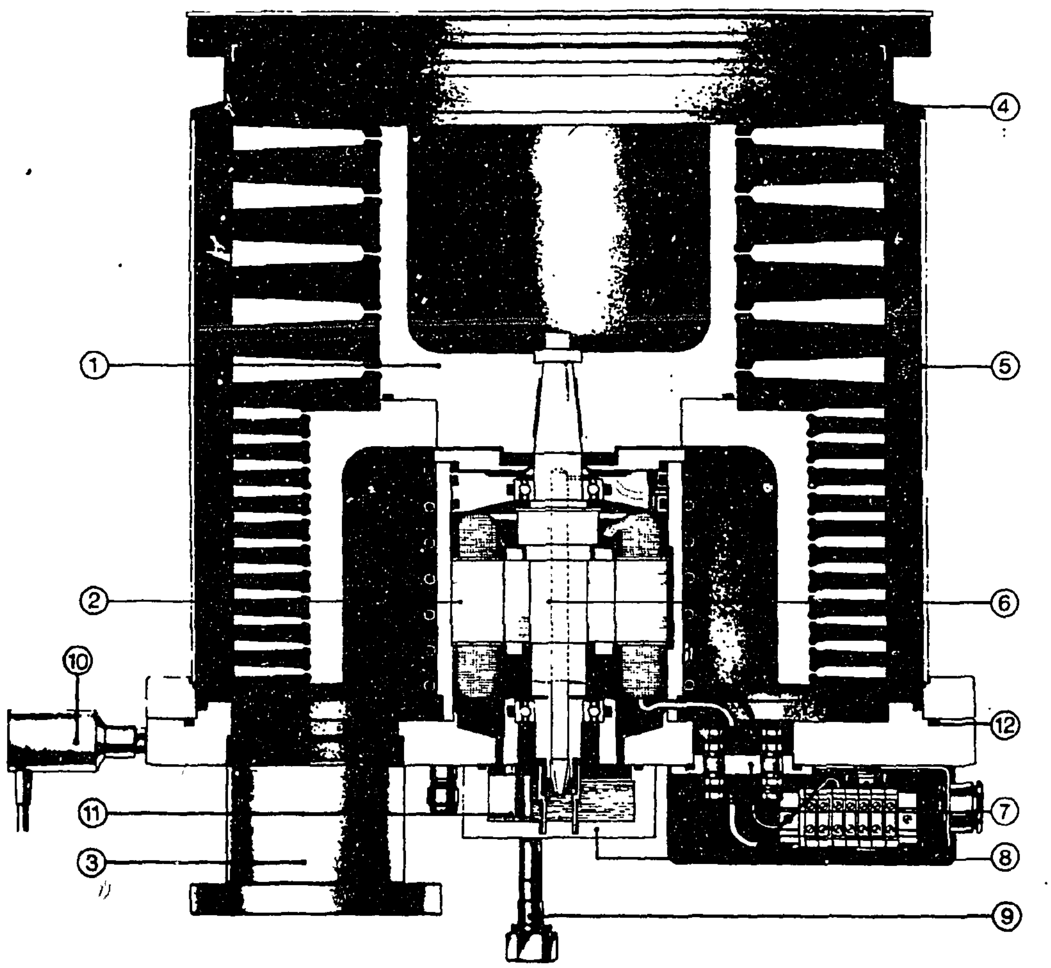
In the turbomolecular pump, vanes are rotating at such high speeds that the surface speed is comparable to that of the incident molecule, and are so oriented that a condensed and re-emitted molecule tends to move from the inlet area to the outlet area, so that pumping occurs. Gas at the turbopump outlet is removed by a foreline mechanical pump. It can be shown that the ratio of the outlet pressure to the inlet pressure varies exponentially as the surface velocity and mass of the molecule, and exponentially as the inverse of the temperature and of the spacing between the moving vanes and the stationary pump walls.

For this reason an efficient turbomolecular pump has vanes rotating at tens of thousands of revolutions per minute and positioned very near stationary vanes.

A Leybold Heraeus turbomolecular pump is illustrated in Fig. 5-51. The inlet diameter is 15 3/4". Because a single rotor cannot develop a sufficiently large pressure differential, there are 31 rotors, effectively connected in series. The rotor speed is 15,000 RPM. As mentioned above, heavier molecules are more efficiently pumped. This means the turbopump will have a very high pumping speed for hydrocarbons and is hence a "clean" pump. The molecular mass dependence is also reflected in the capture probabilities of this type pump for elementary gases: .06 for H_2, .09 for He, and .25 for N_2. The pumping speeds for the pump in Fig. 5-51 for He, H_2, and N_2 respectively was 3,600, 3,300, and 3,600 ℓ/sec. This turbomolecular pump was selected for use on the EBT-P high vacuum system. Compared to cryogenic pumps, the TMP can tolerate higher heat loads, does not require regeneration, and is available off-the-shelf.

A disadvantage attendant on the high speed large rotor forming the heart of the turbomolecular pump is sensitivity to harsh environments. The rotors are susceptible to damage by any particulates which find their way into the pump, and can tolerate only a limited magnetic field, on the order of 30 gauss or less for smaller turbopumps. The turbopump must be mounted vertically and has motors with insulation potentially susceptible to radiation damage from x-rays. This risk also applies to motor lubricants and seals. Detailed discussions of the effects of the x-ray and magnetic field environments on turbopumps are described in Sections 5.4.1 and 5.4.3 respectively.

5.5.4 Diffusion Pumps - Diffusion pumps work by means of a high velocity stream of vapor directed away from the pump inlet. The vapor is produced by boiling the pump working fluid by heating it at the bottom of the pump. It moves up through a stack to the



① Rotor
② Medium frequency motor, water-cooled
③ Fore-vacuum port
④ High-vacuum port with wire-mesh splinter guard
⑤ Stator package
⑥ Motor shaft with oil feed system
⑦ Current leadthrough
⑧ Oil sump
⑨ Oil drain tubulation
⑩ Vibration sensor
⑪ Float switch
⑫ Metal gasket

FIGURE 5-51 LEYBOLD-HERAEUS TMP3500 TURBOMOLECULAR PUMP top of the pump, where it is directed outward and downward by a cap. The downward stream of vapor sweeps along with it molecules of the gas to be pumped which diffuse into the stream from the inlet. The stream then strikes the pump walls, which are in close contact with cooling coils. The vapor thus condenses on the cold walls and runs back as a liquid to the boiler at the bottom, to begin the process anew. The pumped gas molecules are removed from the high pressure region at the bottom of the pump by a foreline pump.

A multistage diffusion pump is shown schematically in Fig. 5-52. The top stage is designed to provide a high pumping speed and provide a relatively small pressure difference. Progressively lower stages provide small pumping speeds, while each one supports a progressively larger pressure differnce.

The working fluid in this typical pump can be either oil or mercury. Its desirable properties include low vapor pressure, inertness, low ability to dissolve gases, and high molecular weight.

For the EBT-P project, however, diffusion pumps have serious disadvantages. The greatest disadvantage is probably the potential of either type of pump fluid to contaminate the system and cause a difficult cleanup problem. Mercury can also become amalgamated with many metals and is toxic. Both characteristics complicate its use or cleanup. In the case of the MC dewars, contamination of the MLI with even thin films of organic pump oils could cause significant problems. X-rays may initiate changes in the molecular structure of the organics and cause significant changes in surface emittances. For these reasons, diffusion pumps were eliminated from consideration.

5.5.5 Summary of Vacuum Pump Considerations - Several types of vacuum pumps were considered for use on EBT-P. Table 5-1 summarizes the pumps considered and salient features of each. Turbomolecular pumps were identified as the best candidate. They offer good pumping performance for air, hydrogen, and helium at a total system cost comparable to other systems. They are clean, reliable, and readily available as off-the-shelf components. They have a good tolerance for heat loads. X-ray and magnetic field tolerance of these pumps is sufficiently high for normal operating conditions. Effects of off-normal conditions may require shielding of the pumps. As already mentioned, the question of off-normal conditions will be investigated as part of the Title II effort.

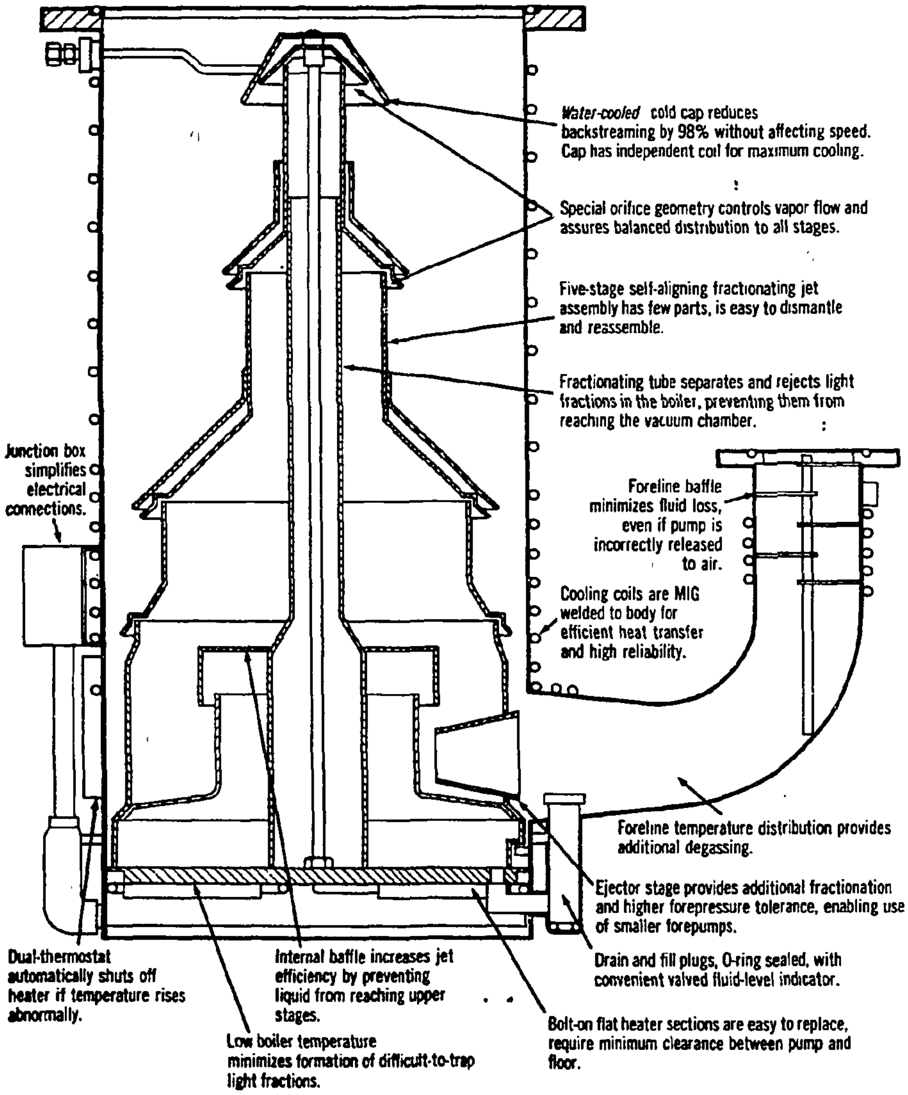


FIGURE 5-52 SCHEMATIC OF A MULTISTAGE DIFFUSION PUMP

	CAPTURE PROBAB.	RELIABILITY/ MAINTAIN-ABILITY	ENVIRONMENT X-RAY	ENVIRONMENT THERMAL	OPERATING PRESSURE RANGE	SPACE & AUX. EQPT. REQUIRED	MAGNETIC FIELD TOLERANCE	COMMENTS
CRYOPUMPS GASEOUS HELIUM	- .10 .33	INTEGRAL REFRIGERATOR MAINTENANCE REQUIRED. ENVIRONMENT IS CRITICAL.	10^4 RAD LIMIT DUE TO TEFLON COMPONENTS	CANNOT TOLERATE HIGH HEAT LOADS	10^{-3} TO 10^{-9} TORR	HELIUM COMPRESSOR REQUIRED	HIGH FIELDS CAN AFFECT ELECTRICAL MOTOR	REQUIRES REGENERATION.
CRYOPUMPS LIQUID POOL	HE H N .10 .15 .18	NO MOVING PARTS, NO WORKING FLUIDS-CARE REQUIRED TO AVOID INADVERTENT REGENERATION.	COMPONENTS NOT AFFECTED BY X-RAYS	CANNOT TOLERATE LARGE HEAT LOADS, WILL REQUIRE SHIELDING, COOLING, ETC.	2×10^{-3} TO 10^{-11} T	REFRIGERATION EQPT, THERMAL SHIELDING	HIGH TOLERANCE	MUST BE REGENERATED DUE TO LIMITED CAPACITY. AVAILABLE IN LARGE SIZES.
TURBOPUMPS OIL LUBRICATED	(TMP 3500) .091 .058 .25	HIGH ≈ ROTATING COMPONENTS TYP. 15k RPM	LUBRICANTS, PUMPOILS, SEALS, MOTOR INSULATION, ELECTRONICS CAN BE DAMAGED. TURBOVAC PUMPS SUITABLE FOR RADIATION LOAD UP TO 10^8 RAD	NOT CRITICAL USED IN BAKED OUT SYSTEMS	HI PRESS END 10^{-3} T LOW PRESS END ~ 10^{-11} T	REQUIRE VERTICAL MOUNT	TURBOPUMP ROTORS HAVE FIELD LIMITS ≤ 30 GAUSS	LARGEST SIZE ≈ 16" ID. NO CONSENSUS THAT SIZE OR CAPRO CAN BE MUCH BETTERED.
DIFFUSION PUMPS	CPRO FOR HE ≈ 1/2 CAPRO FOR N_2 ON PUMP TESTED $S_{H2} \geq 1.2 \times S_{AIR}$	OIL CAN BECOME CONTAMINATED OR BREAK INTO SMALLER MOLECULES. MERCURY BECOMES AMALGAMATED W/MANY METALS (3)	SEALS, FLUIDS, FOREPUMPS ALL SUSCEPTIBLE	NOT CRITICAL	HI PRESS END 10^{-3}T LOW PRESS END 10^{-7} CAN GET TO 10^{-11} W/TRAP	MERCURY DIFF. PUMP REQUIRES A REFRIGERATED TRAP	NO PROBLEM	CLEANUP OF A CONTAMINATED SYSTEM COULD BE EXTREMELY COMPLICATED.
	.14 .1 .3	ANY BACK STREAMING DIFFUSION PUMP OIL WOULD CAUSE A TOUGH CLEANUP JOB IN THE TORUS			VARIAN D-I PUMPS 10^{-2} TO $<10^{-10}$ (5 p.13)			

TABLE 5-1 SUMMARY OF CHARACTERISTICS OF VACUUM PUMPS CONSIDERED FOR USE ON EBT-P

5.6 CRYOPUMP THERMAL ANALYSIS

The baseline vacuum pumps were gaseous helium cryopumps. As discussed in Section 5.5.1 thermal and x-ray environments precluded their use. Because of their tolerance to x-rays, liquid helium cryopumps were considered for use. ORNL and MDAC were however aware of potential thermal problems. These problems are addressed in this section.

The thermal environment surrounding the liquid helium cryopump, illustrated in Figure 5-50, controls the operating efficiency of the pump. The heat flux incident on and transmitted through the microwave shield shown in Figure 5-46 increases the duct temperature, putting a thermal load on the cryopump system. Three methods of predicting the heat flux on the shield were examined. These methods produced loads ranging from 1.7 to 3.3 kw. Reference 5-9 states that the steady state heat flux for the cavity and all surfaces created by ports is 5 w/cm^2, producing the 3.3 kw load which was used for this analysis.

This 3.3 kw of power is assumed to be produced by neutral particles, ions, and radiative heat. Of this power, 60% passes through the microwave shield. The microwave power that passes through the shield is less than 1% of the neutral particle, ion and radiative power due to the shield attenuation factor of .01% or greater for the frequencies produced in EBT-P. The total power incident on the duct is therefore 2 kw. The power distribution in the duct is based on radiation shape factors and results in incident fluxes on the walls of 0.25 w/cm^2 from the shield up to and including the front flange, 0.06 w/cm^2 from the flange to the rear closure plate, and 1.18 w/cm^2 on the rear closure plate. The cryopump and surrounding pod are not in direct sight of the plasma and receive no direct heating from it.

The above fluxes require an active cooling system on the duct to keep it below the 100°C necessary for structural integrity and low helium boil off rates. Copper tubes wrapped and brazed to the duct cool it to 100°C if the following spacings are observed: 8 cm between centerlines from the shield up to and including the front flange, 20 cm from the flange to the rear closure plug, and 7.5 cm on the rear closure plug. The portion of the pod immediately surrounding the pump requires no active cooling since it receives no direct heating.

The performance of the helium cryopump was predicted assuming the following radiation properties, as shown in Figure 5-53. The helium tank sides, the baffle inner wall and the baffle bottom inside and out are highly reflective with emissivities of 0.03. The outer baffle wall, the helium tank bottom, and duct walls are all blank and have an emissivity of 1.0, while the pod wall has an emissivity of 0.1. These emissivities, in conjunction with the 100°C duct walls, produce a heat leak from the LN_2 baffles to the wall of 1 watt with a maximum ΔT from the LN_2 tank to the bottom of the baffle of 17K. Heat losses from the helium tank to the baffle are .02 watts which result in a 75% boil-off of the 1.25 liters of helium in 30 hours. The ΔT for a 1/4 full helium tank from the 4.2K helium to the top of the tank is less than .1K.

It is recognized that the above analysis does not include certain other heat loads which exist. These heat loads are not well defined and could be quite large, even dominant. Perhaps the largest of these loads is the heat transport due to hydrogen reflux between the helium - cooled and the liquid nitrogen - cooled cryogenic surfaces. Particle heat load from the plasma, via particles not completely thermalized in wall collisions prior to reaching the pump, could also be large. These effects, coupled with the necessity of avoiding inadvertent regeneration of the cryopumps during a liquid helium dewar refill, would almost certainly require continuous flow liquid helium supply to the cryopumps.

5.7 GAS LOADS ANALYSIS

Both the Torus Vacuum System and the Mirror Coil Dewar Vacuum System will reach a pressure inversely proportional to the pumping speed and directly proportional to the gas load. The gas load in either case can be thought of as the sum of a contribution Q_O due to outgassing and a contribution Q_L due to leaks. However, sealing techniques are sufficiently developed to enable the neglect of Q_L, since it is expected to be much smaller than the outgassing load in both the torus and mirror coil dewar systems.

5.7.1 Torus Gas Loads - The significant sources of outgassing loads in the torus vacuum system include the surface of the torus itself ($80m^2$ area), the surface of the limiter (approximately $30m^2$), and the surface of the vacuum ducts between the torus and the pumps. Surfaces of the torus and limiter can be cleaned by the plasma, so that an outgassing rate of nominally (10^{-10}) torr liter/sec cm^2 can be anticipated. Combined with

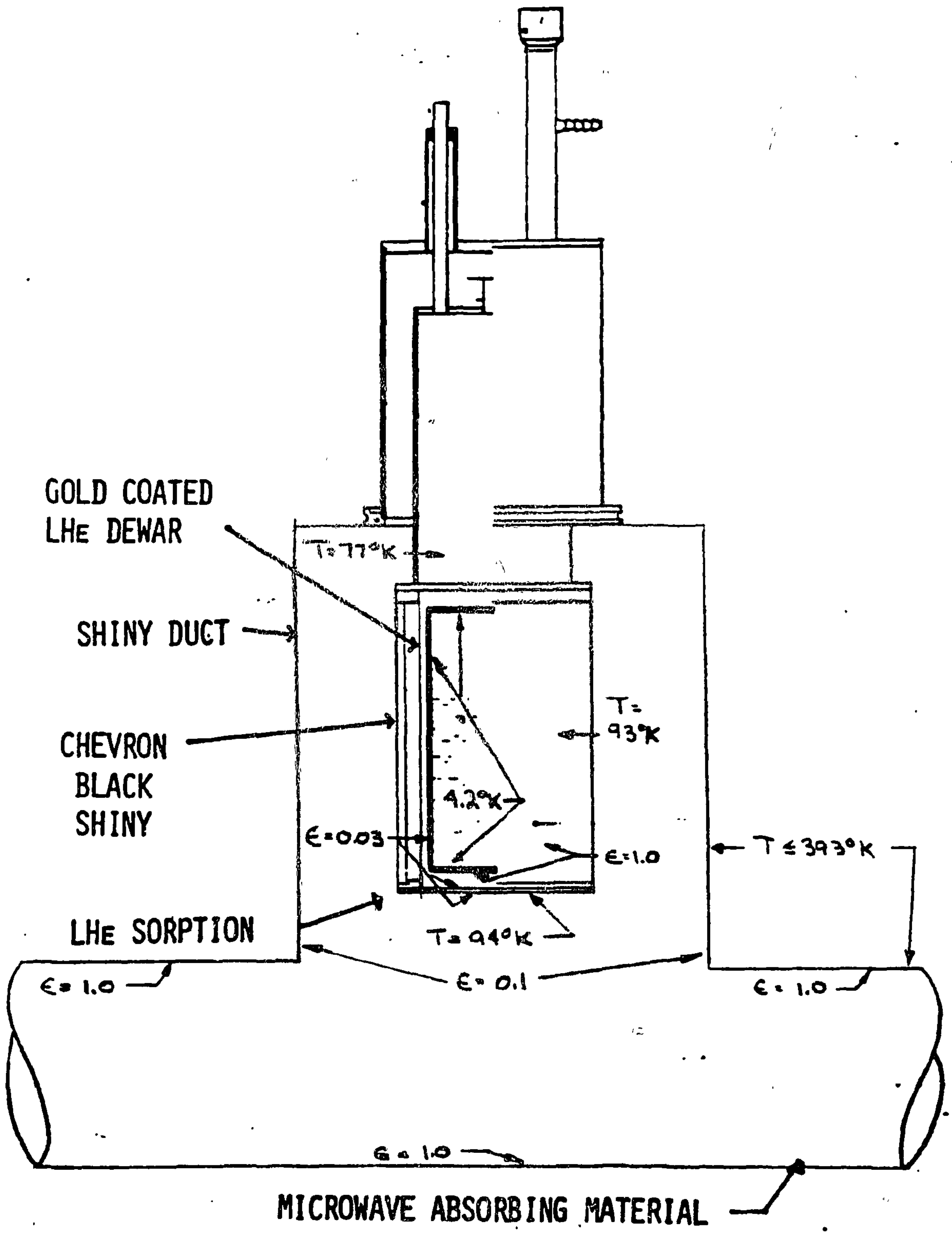


FIGURE 5-53 RADIATIVE ENVIRONMENT IN THE LHe CRYOPUMP

the surface area of the torus and limiters this implies a gas load from the torus prop... of about (1.1×10^{-4}) torr liter/sec.

The vacuum ducts, with a total surface area of about $13 m^2$, also contribute to the gas load in the Torus Vacuum System. However, the vacuum system ducts cannot be cleaned by the plasma due to their location behind the microwave shield. Furthermore, the microwave absorbing coating on the ducts downstream of the microwave shield may well provide a powderlike, large total surface area component with unknown outgassing properties. Consequently the gas load from the duct system can't be defined at present. This gas load will be evaluated in Machine R&D (WBS 6.2.3.2). These tests may indicate a necessity to heat the ducts in order to reach the gas load design goal for the torus, which is 1×10^{-3} torr liter/sec. This translates into an outgassing rate of the microwave absorbing duct of 7.0×10^{-9} torr-liter/sec-cm^2.

5.7.2 Mirror Coil Dewar Gas Loads - In the case of the mirror coil dewar, the chief source of gas load is surface outgassing in the multi-layer insulation. The effective surface area of the MLI is approximately 250 m^2 per dewar. The outgas load is expected to be in the range 1×10^{-9} to 1×10^{-10} torr liter/sec cm^2. This outgassing load will be time and temperature dependent. The dewars are capable of being heated to 100°C, a high enough temperature to provide a light bakeout to accelerate the degassing of the MC dewar. When the outgassing rate is reduced to the levels noted above, the total gas load from the dewar will be between 2.5×10^{-3} and 2.5×10^{-4} torr liter/sec.

The minimum pumping speed at the dewar for helium will be at least one liter per second. The helium gas load seems likely to impose more stringent requirements on the pumping system than the air load. This results from inability to locate, and hence to repair, small leaks in the dewar. Another complication is the presence of liquid helium in the dewar, which causes the gas load from leaks which it contacts to be increased by a factor of 100 over the load which would result from gaseous helium.

6.0 SCHEDULE

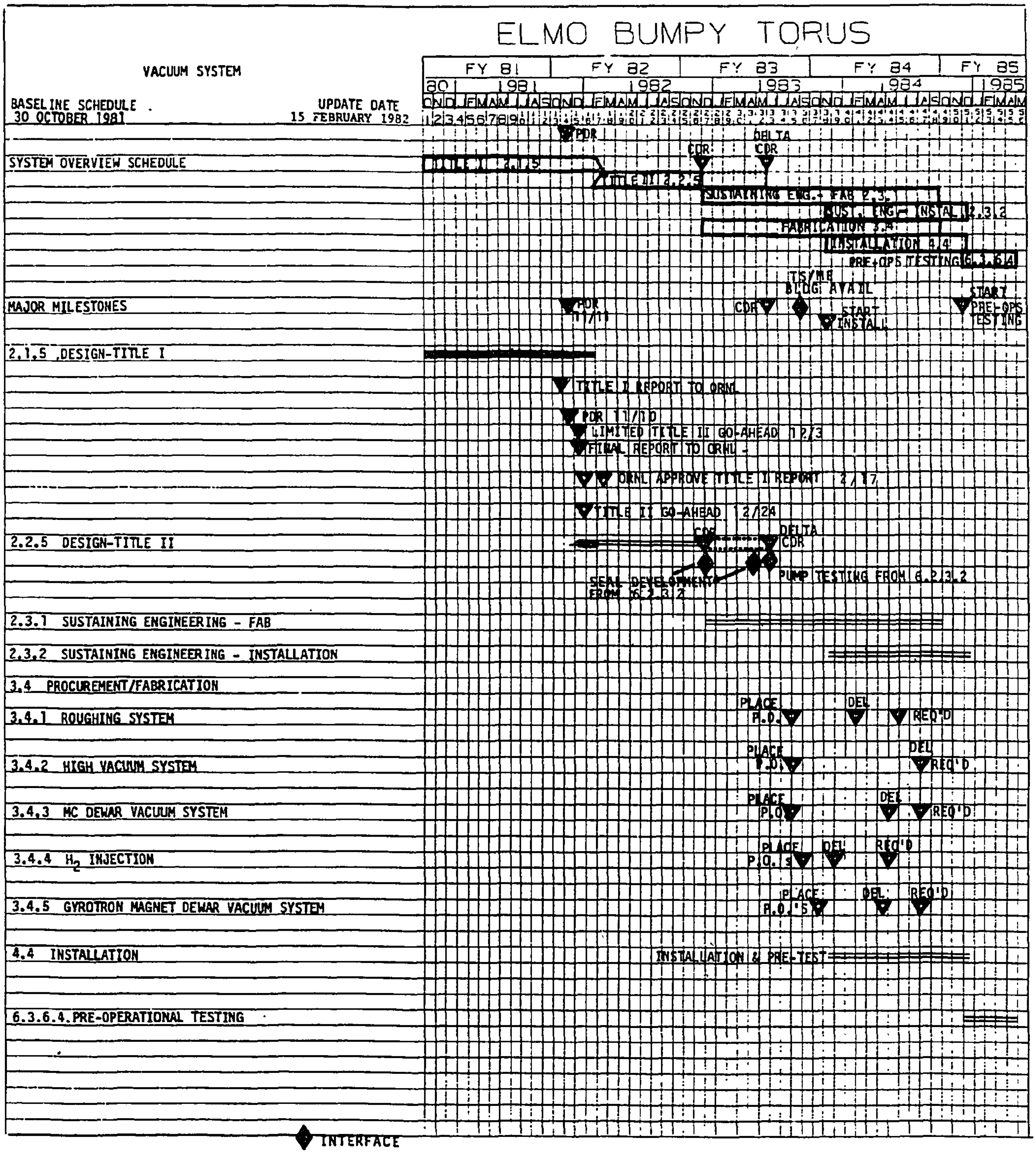
The schedule for completing Phase II of the Vacuum Pumping System is presented in Figure 6-1. Several major milestones are shown, as listed below:

• Preliminary Design Review	11 Nov 81
• CDR	1 Dec 82
• Delta CDR	1 Jun 83
• Start Installation	15 Nov 83
• Start Pre-Ops Testing	1 Dec 84

Assuming that limited Title II Go-Ahead is authorized on 17 Feb 1982, as shown on the schedule, it appears as though there will be no major obstacles to meeting this schedule. This schedule is based upon the timely completion of several tasks in WBS 6.2.3.2. These include the following:

- Design of the microwave shield
- Verification of the vacuum pump
- Development of the microwave absorbing material

No long lead procurements are anticipated. The procurred vacuum system components will be off-the-shelf vacuum hardware. Some components, such as the radiation resistant turbomolecular pumps, will be modified by the vendor. MDAC will perform some fabrication, including roughing and regeneration lines and microwave shields and absorbing ducts. The vacuum system components not required for subassembly at MDAC-STL will be shipped directly to ORNL, where final assembly will take place.


ELMO BUMPY TORUS
VACUUM SYSTEM
BASELINE SCHEDULE
30 OCTOBER 1981
UPDATE DATE
15 FEBRUARY 1982
FY 81
FY 82
FY 83
FY 84
FY 85
80
1981
1982
1983
1984
1985
SYSTEM OVERVIEW SCHEDULE
PDR
CDR
DELTA CDR
TITLE I 2.1.5
TITLE II 2.2.5
SUSTAINING ENG.+ FAB 2.3.1
SUST. ENG.+ INSTAL 2.3.2
FABRICATION 3.4
INSTALLATION 4.4
PRE+OPS TESTING 6.3.6.4
MAJOR MILESTONES
PDR 11/11
CDR
TS/ME BLDG AVAIL
START INSTALL
START PRE-OPS TESTING
2.1.5 DESIGN-TITLE I
TITLE I REPORT TO ORNL
PDR 11/10
LIMITED TITLE II GO-AHEAD 12/3
FINAL REPORT TO ORNL
ORNL APPROVE TITLE I REPORT 2/17
TITLE II GO-AHEAD 12/24
2.2.5 DESIGN-TITLE II
CDR
DELTA CDR
SEAL DEVELOPMENT FROM 6.2.3.2
PUMP TESTING FROM 6.2.3.2
2.3.1 SUSTAINING ENGINEERING - FAB
2.3.2 SUSTAINING ENGINEERING - INSTALLATION
3.4 PROCUREMENT/FABRICATION
3.4.1 ROUGHING SYSTEM
PLACE P.O.
DEL
REQ'D
3.4.2 HIGH VACUUM SYSTEM
PLACE P.O.
DEL
REQ'D
3.4.3 MC DEWAR VACUUM SYSTEM
PLACE PLO
DEL
REQ'D
3.4.4 H2 INJECTION
PLACE P.O.'s
DEL
REQ'D
3.4.5 GYROTRON MAGNET DEWAR VACUUM SYSTEM
PLACE P.O.'S
DEL
REQ'D
4.4 INSTALLATION
INSTALLATION & PRE-TEST
6.3.6.4 PRE-OPERATIONAL TESTING
INTERFACE

7.0 REFERENCES

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5-9 Communication from A.L. Boch to Roy DeBellis, June 23, 1981

5-10. *Vacuum Vessel Seals and Wall Material Trade Study,* 1 June 1981.

5-11 EBT-P Shielding Meeting, MDC, St. Louis, 9 July 1981

5-12 Technical Memorandum 256.5144, McDonnell Aircraft Corp., 15 Dec. 1978

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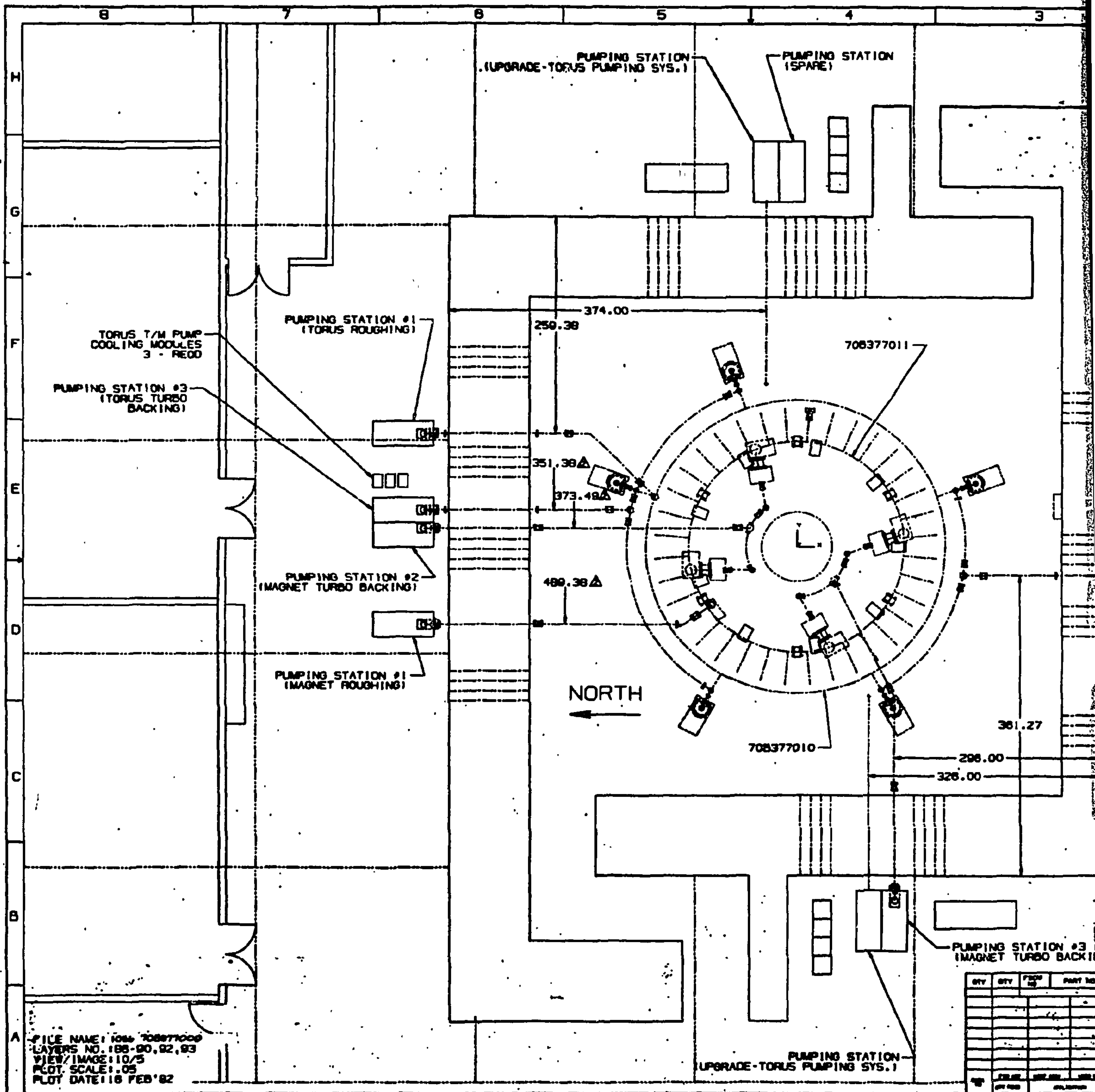
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(UPGRADE-TORUS PUMPING SYS.)
PUMPING STATION
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250.38
708377011
PUMPING STATION #1
(TORUS ROUGHING)
TORUS T/M PUMP
COOLING MODULES
3 - REQD
PUMPING STATION #3
(TORUS TURBO
BACKING)
351.38
373.49
489.38
PUMPING STATION #2
(MAGNET TURBO BACKING)
PUMPING STATION #1
(MAGNET ROUGHING)
NORTH
708377010
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326.00
PUMPING STATION #3
(MAGNET TURBO BACKI
PUMPING STATION
(UPGRADE-TORUS PUMPING SYS.)
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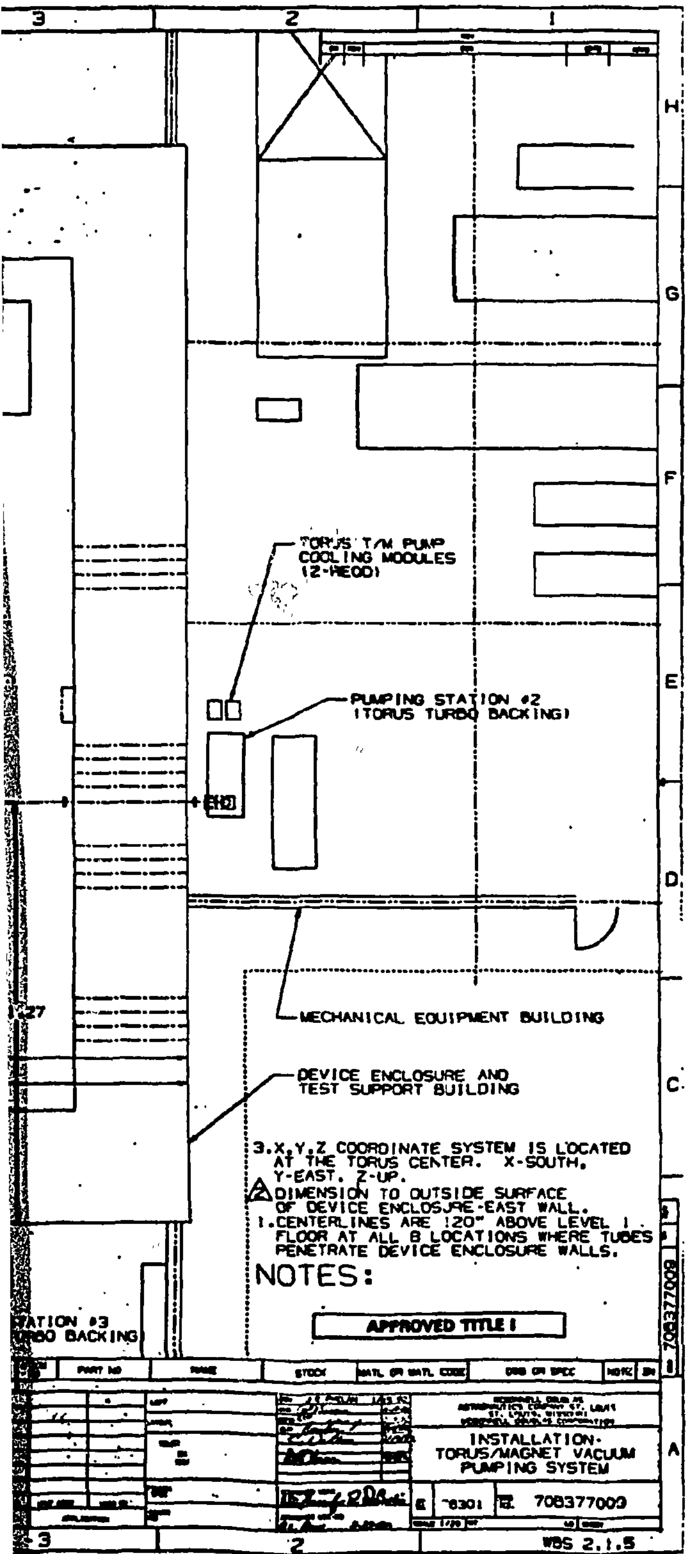
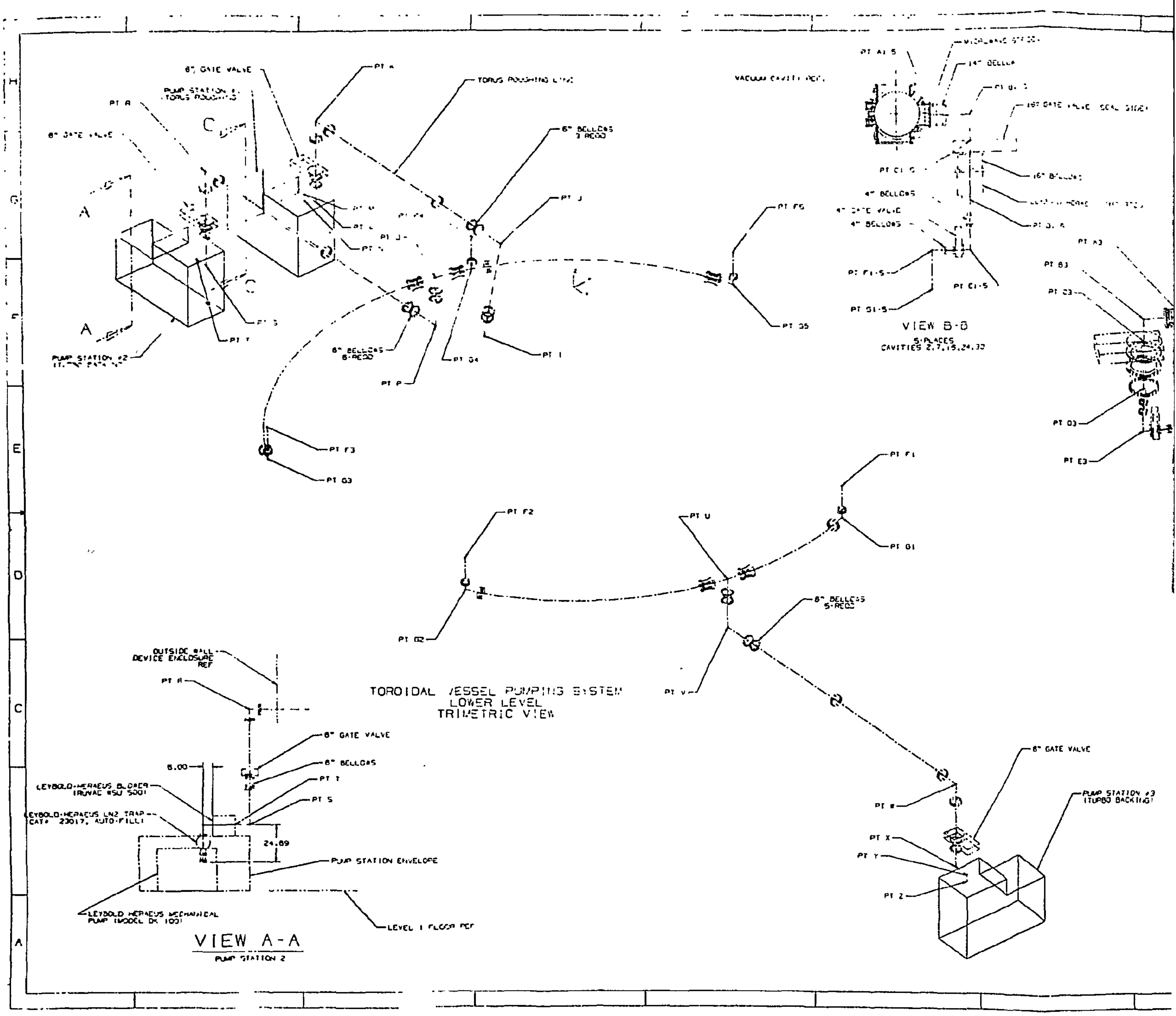
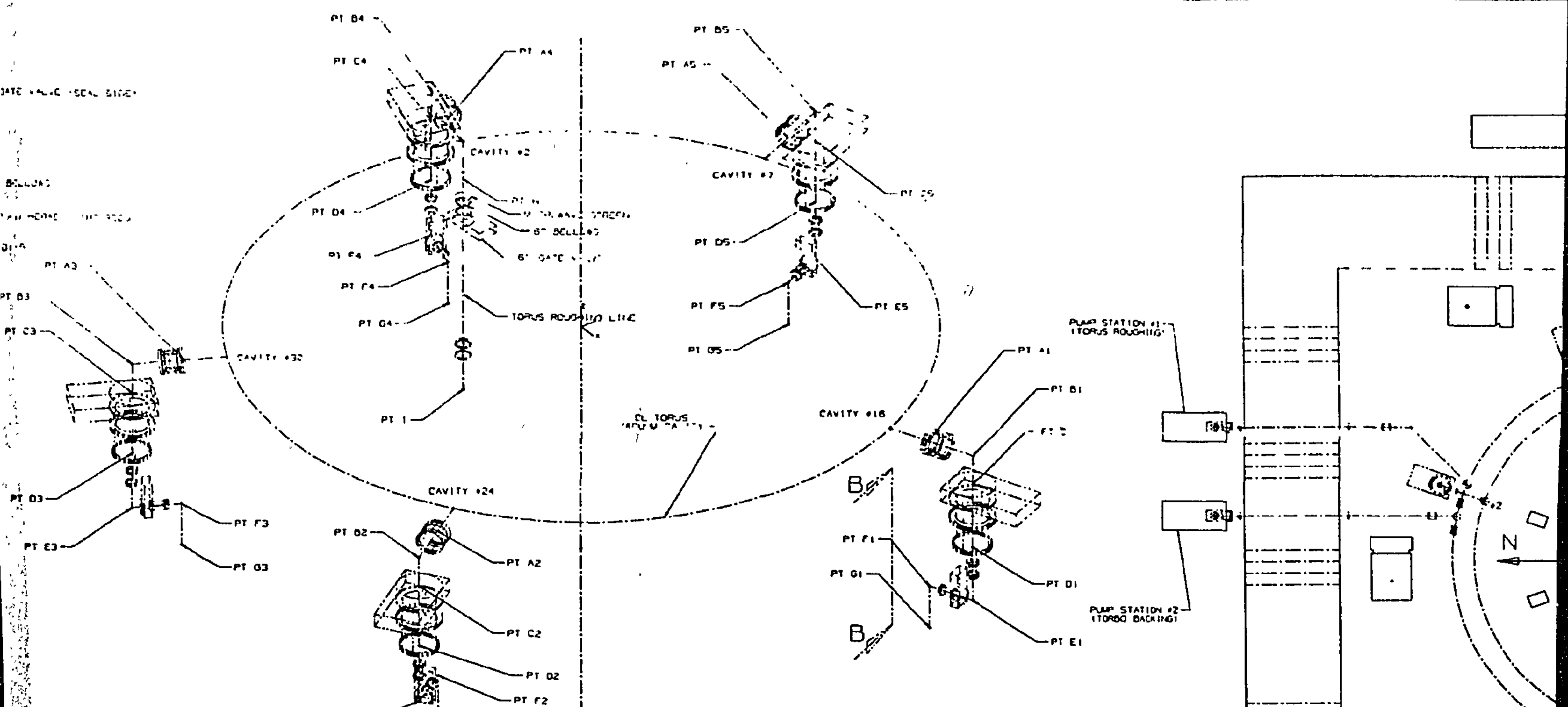
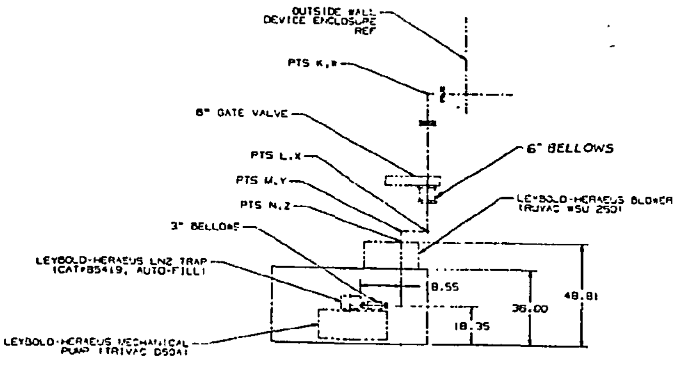
VIEW/IMAGE: 10/5
PLOT SCALE: .05
PLOT DATE: 18 FEB '82


TORUS T/M PUMP COOLING MODULES (2-REQD)
PUMPING STATION #2 (TORUS TURBO BACKING)
MECHANICAL EQUIPMENT BUILDING
DEVICE ENCLOSURE AND TEST SUPPORT BUILDING
ATION #3
RBO BACKING
3. X,Y,Z COORDINATE SYSTEM IS LOCATED AT THE TORUS CENTER. X-SOUTH, Y-EAST, Z-UP.
2 DIMENSION TO OUTSIDE SURFACE OF DEVICE ENCLOSURE-EAST WALL.
1. CENTERLINES ARE 120" ABOVE LEVEL 1 FLOOR AT ALL 8 LOCATIONS WHERE TUBES PENETRATE DEVICE ENCLOSURE WALLS.
NOTES:
APPROVED TITLE I
PART NO
STOCK
DWG OR SPEC
INSTALLATION-
TORUS/MAGNET VACUUM
PUMPING SYSTEM
76301
708377009
WBS 2.1.5

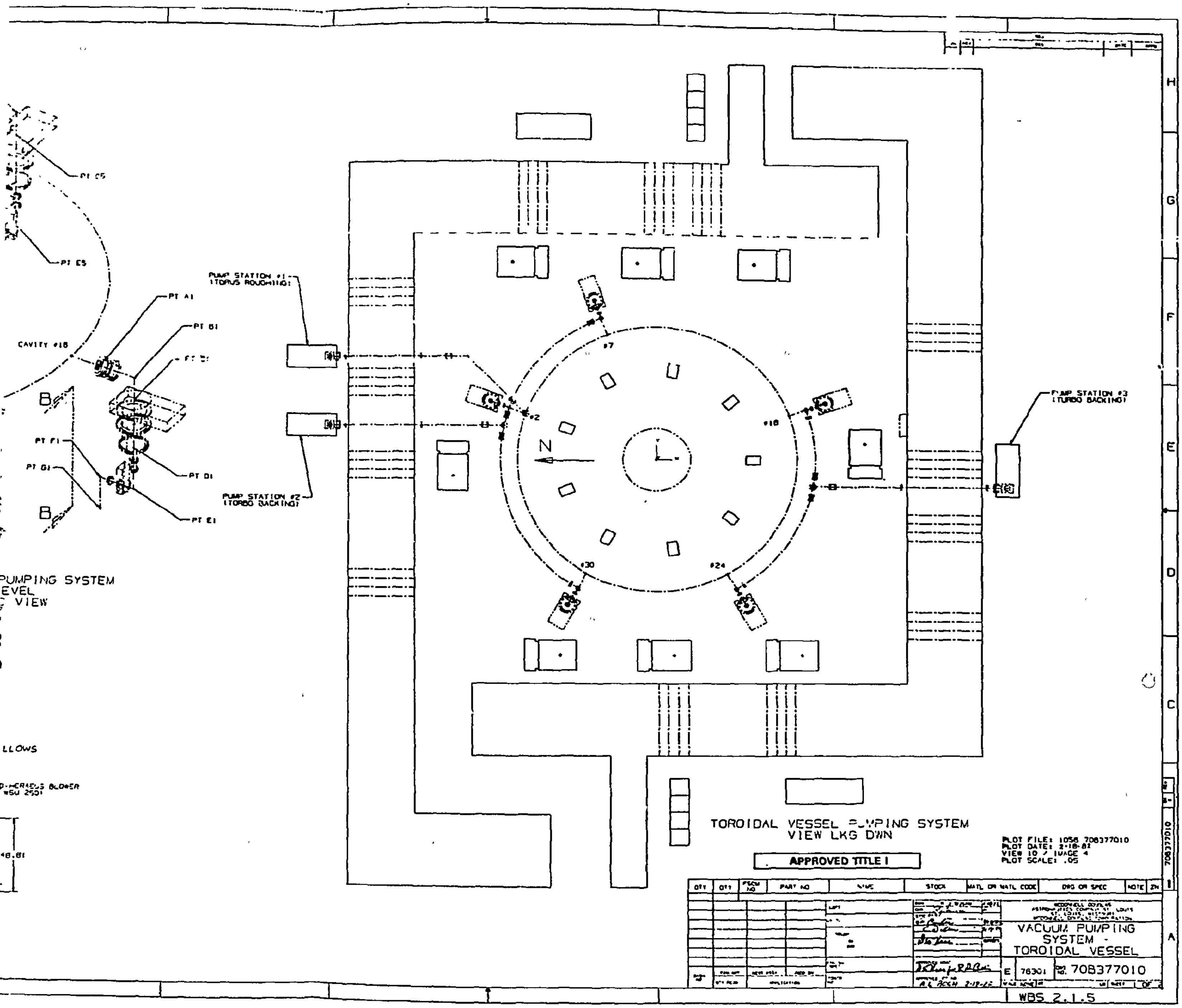

TOROIDAL VESSEL PUMPING SYSTEM
LOWER LEVEL
TRIMETRIC VIEW
VIEW B-B
VIEW A-A
6" GATE VALVE
TORUS ROUGHING LINE
6" BELLOWS
PT F3
PT G3
PT F2
PT U
PT F1
PT D1
PT D2
PT V
6" GATE VALVE
PUMP STATION #3 (TURBO BACKING)
PT X
PT Y
PT Z
6" BELLOWS
PT T
PT S
PUMP STATION ENVELOPE
LEVEL 1 FLOOR REF
24.89
6.00
PT D3
PT E3
PT G5
PT F5
PT I
PT P



TOROIDAL VESSEL PUMPING SYSTEM
UPPER LEVEL
TRIMETRIC VIEW



VIEW C-C
TYP 2 PLACES
PUMP STATIONS 1 & 3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PT E5
PT A1
PT B1
CAVITY #18
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PUMP STATION #2 (TURBO BACKING)
PUMP STATION #3 (TURBO BACKING)
N
#7
#2
#18
#30
#24
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EVEL
VIEW
LLOWS
TOROIDAL VESSEL PUMPING SYSTEM
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APPROVED TITLE I
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PLOT SCALE: .05
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SYSTEM -
TOROIDAL VESSEL
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76301
708377010
WBS 2.1.5

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J	-242.508	138.819	-158.000
K	-429.000	138.819	-158.000
L	-429.000	138.819	-222.000
M	-441.000	138.819	-222.000
N	-441.000	138.819	-227.188
O	-194.959	44.819	-117.000
P	-194.959	44.819	-158.000
Q	NOT USED		
R	-429.000	44.819	-158.000
S	-429.000	44.819	-232.375
T	-438.500	44.819	-232.375
U	188.981	-34.729	-117.000
V	188.981	-34.729	-158.000
W	432.000	-34.729	-158.000
X	432.000	-34.729	-222.000
Y	444.000	-34.729	-222.000
Z	444.000	-34.729	-227.188

END PTS.	X	Y	Z
D4	-211.688	77.040	-57.613
D5	-77.040	211.688	57.613
E1	211.688	77.040	-91.000
E2	112.625	-195.072	-91.000
E3	-112.625	-195.072	-91.000
E4	-211.686	77.040	-91.000
E5	-77.040	211.686	-91.000
F1	187.938	68.404	-91.000
F2	100.000	-173.205	-91.000
F3	-100.000	-173.205	-91.000
F4	-187.938	68.404	-91.000
F5	-68.404	187.938	-91.000
G1	187.938	68.404	-117.000
G2	100.000	-173.205	-117.000
G3	-100.000	-173.205	-117.000
G4	-187.938	68.404	-117.000
G5	-68.404	187.938	-117.000
H	-188.481	80.594	-19.500

END PTS.	X
A1	187.
A2	99.
A3	-99.
A4	-187.
A5	-68.
B1	211.
B2	112.
B3	-112.
B4	-211.
B5	-77.
C1	211.
C2	112.
C3	-112.
C4	-211.
C5	-77.
D1	211.
D2	112.
D3	-112.

END PTS.	TUBE LENGTH (CENTERLINE DISTANCE)	TUBE O.D.
G4 • O	25.00 (200.00 RAD)	6.00
G3 • O	245.00 (200.00 RAD)	6.00
G2 • U	175.00 (200.00 RAD)	6.00
G1 • U	105.00 (200.00 RAD)	6.00
U • V	39.00	6.00
V • W	235.00	6.00
W • X	66.00	6.00
X • Y	12.00	6.00
Y • Z	5.19	3.00

END PTS.	TUBE LENGTH (CENTERLINE DISTANCE)	TUBE O.D.
A1-5 • B1-5	23.00	12.00/18.00
B1-5 • C1-5	18.93	18.00
C1-5 • D1-5	38.00	18.00
D1-5 • E1-5	35.00	4.30
E1-5 • F1-5	25.25	4.30
F1-5 • G1-5	26.00	4.00
H • I	138.00	6.00
I • J	108.00	6.00
J • K	187.00	6.00
K • L	66.00	6.00
L • M	12.00	6.00
M • N	5.19	3.00
O • P	39.00	6.00
P • Q	234.00	6.00
R • S	76.375	6.00
S • T	9.50	3.00
G5 • O	210.00 (200.00 RAD)	6.00

2. ALL FLANGES TO BE C
THOSE MATING GATE V
THESE SYMBOLS DENOT

1. X,Y,Z COORDINATE SY
TORUS CENTER. X - S

NOTES:

QTY | QTY | FSCM NO | PART NO

FILE NAME: 1096 708377010
LAYERS NO.: 50,51
VIEW/IMAGE: 10/5
PLOT SCALE: .05
PLOT DATE: 2/18/82

Y	Z
80.594	-156.000
138.819	-156.000
138.819	-156.000
138.819	-222.000
138.819	-222.000
138.819	-227.188
44.819	-117.000
44.819	-156.000
44.819	-156.000
44.819	-232.375
44.819	-232.375
-34.720	-117.000
-34.720	-156.000
-34.720	-156.000
-34.720	-222.000
-34.720	-222.000
-34.720	-227.188

END PTS.	X	Y	Z
D4	-211.666	77.040	-57.613
D5	-77.040	211.666	57.613
E1	211.666	77.040	-91.000
E2	112.625	-195.072	-91.000
E3	-112.625	-195.072	-91.000
E4	-211.666	77.040	-91.000
E5	-77.040	211.666	-91.000
F1	187.938	68.404	-91.000
F2	100.000	-173.205	-91.000
F3	-100.000	-173.205	-91.000
F4	-187.938	68.404	-91.000
F5	-68.404	187.938	-91.000
G1	187.938	68.404	-117.000
G2	100.000	-173.205	-117.000
G3	-100.000	-173.205	-117.000
G4	-187.938	68.404	-117.000
G5	-68.404	187.938	-117.000
H	-166.481	60.594	-19.500

END PTS.	X	Y	Z
A1	187.268	68.160	-1.070
A2	99.642	172.586	-1.070
A3	-99.642	-172.586	-1.070
A4	-187.268	68.160	-1.070
A5	-68.160	187.268	-1.070
B1	211.666	77.040	-1.070
B2	112.625	-195.072	-1.070
B3	-112.625	-195.072	-1.070
B4	-211.666	77.040	-1.070
B5	-77.040	211.666	-1.070
C1	211.666	77.040	-18.000
C2	112.625	-195.072	-18.000
C3	-112.625	-195.072	-18.000
C4	-211.666	77.040	-18.000
C5	-77.040	211.666	-18.000
D1	211.666	77.040	-57.613
D2	112.625	-195.072	-57.613
D3	-112.625	-195.072	-57.613

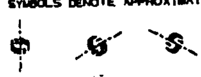
TUBE O.D.
6.00
8.00
8.00
6.00
6.00
8.00
6.00
6.00
3.00

END PTS.	TUBE LENGTH (CENTERLINE DISTANCE)	TUBE O.D.
A1-5 + B1-5	23.00	12.00/18.00
B1-5 + C1-5	16.93	16.00
C1-5 + D1-5	38.00	16.00
D1-5 + E1-5	35.00	4.00
E1-5 + F1-5	25.25	4.00
F1-5 + G1-5	26.00	4.00
H + I	156.00	6.00
I + J	108.00	6.00
J + K	187.00	6.00
K + L	88.00	6.00
L + M	12.00	6.00
M + N	5.18	3.00
O + P	38.00	6.00
P + Q	234.00	6.00
R + S	78.375	6.00
S + T	9.50	3.00
G5 + O	210.00 (200.00 RAD)	6.00

NOTES:

1. X,Y,Z COORDINATE SYSTEM IS LOCATED AT THE TORUS CENTER. X - SOUTH, Y - EAST, Z - UP.

2. ALL FLANGES TO BE CONFLAT TYPE FLANGES EXCEPT THOSE MATING GATE VALVES WILL BE A.S.A. 150 SERIES. THESE SYMBOLS DENOTE APPROXIMATE FLANGE LOCATIONS



APPROVED TITLE I

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

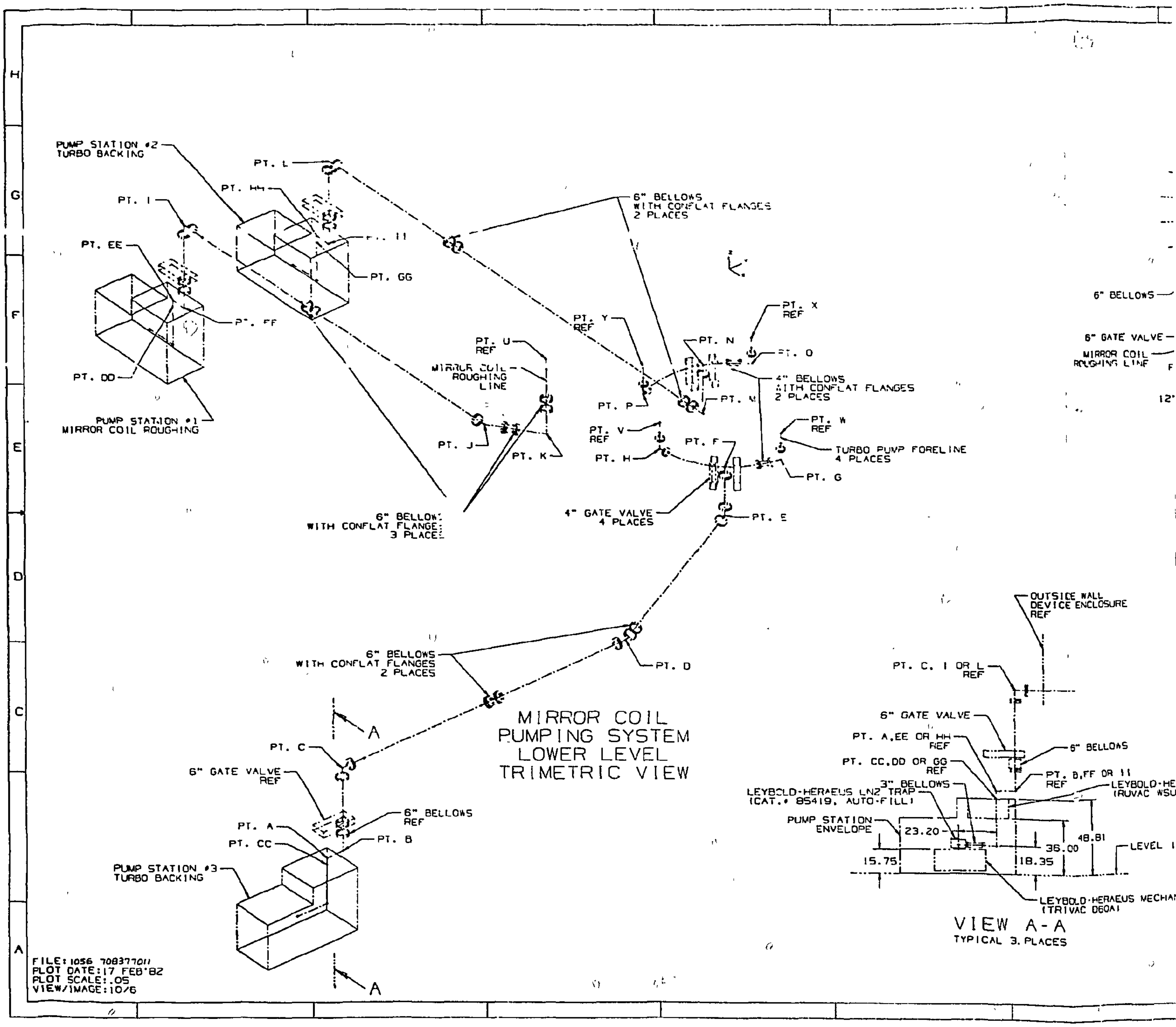
McDONNELL DOUGLAS ASTRONAUTICS COMPANY - ST. LOUIS

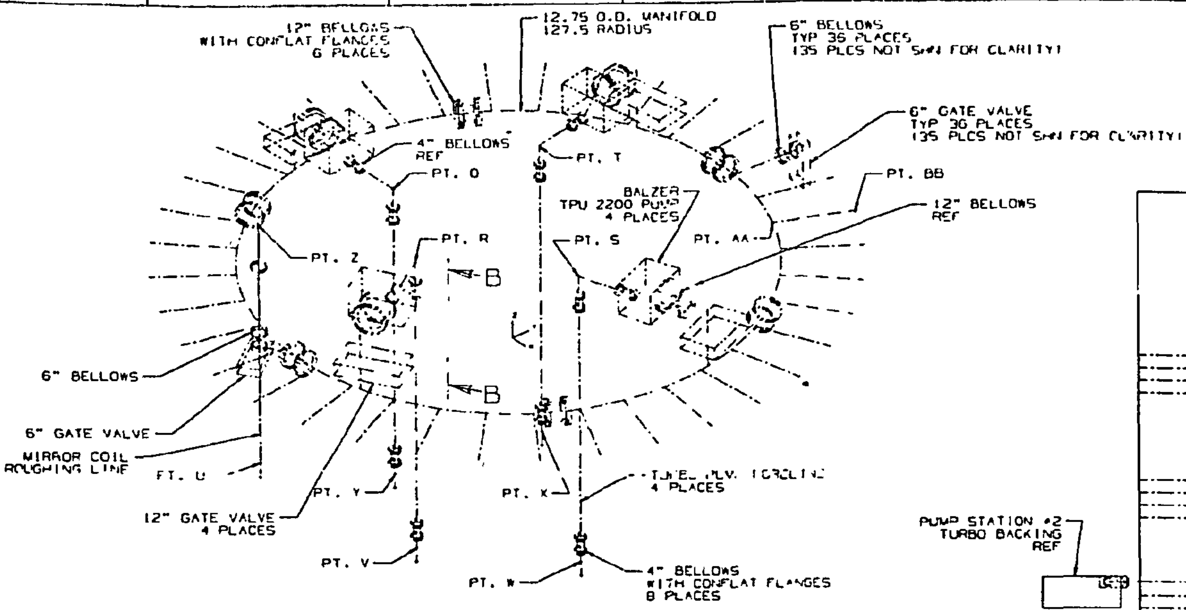
VACUUM PUMPING SYSTEM - TOROIDAL VESSEL

E 70B377010

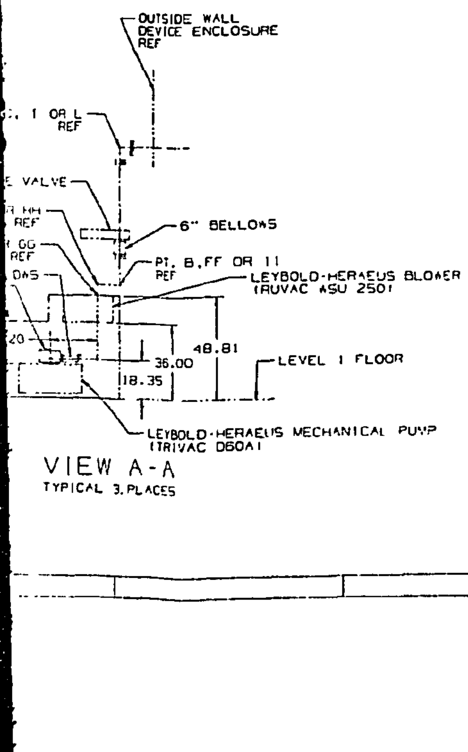
SHEET 2 OF 2

WBS 2.1.5

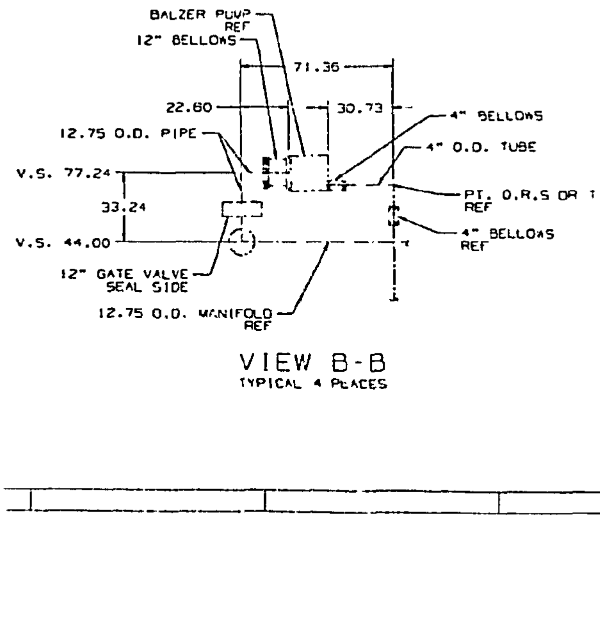

PUMP STATION #2
TURBO BACKING
PT. L
PT. HH
PT. I
PT. EE
PT. GG
PT. FF
PT. DD
PUMP STATION #1
MIRROR COIL ROUGHING
6" BELLOWS
WITH CONFLAT FLANGES
2 PLACES
PT. X
REF
PT. N
PT. O
PT. Y
REF
PT. U
REF
MIRROR COIL
ROUGHING
LINE
4" BELLOWS
WITH CONFLAT FLANGES
2 PLACES
PT. P
PT. M
PT. V
REF
PT. W
REF
PT. J
PT. K
PT. H
PT. F
TURBO PUMP FORELINE
4 PLACES
PT. G
6" BELLOWS
WITH CONFLAT FLANGES
3 PLACES
4" GATE VALVE
4 PLACES
PT. E
6" BELLOWS
WITH CONFLAT FLANGES
2 PLACES
PT. D
MIRROR COIL
PUMPING SYSTEM
LOWER LEVEL
TRIMETRIC VIEW
PT. C
6" GATE VALVE
REF
6" BELLOWS
REF
PT. A
PT. CC
PT. B
PUMP STATION #3
TURBO BACKING
FILE: 1056 70837701I
PLOT DATE: 17 FEB'82
PLOT SCALE: .05
VIEW/IMAGE: 10/6
6" BELLOWS
6" GATE VALVE
MIRROR COIL
ROUGHING LINE
OUTSIDE WALL
DEVICE ENCLOSURE
REF
PT. C, I OR L
REF
6" GATE VALVE
PT. A,EE OR HH
REF
6" BELLOWS
PT. CC,DD OR GG
REF
3" BELLOWS
PT. B,FF OR II
REF
LEYBOLD-HERAEUS LN2 TRAP
(CAT.# 85419, AUTO-FILL)
PUMP STATION
ENVELOPE
23.20
48.81
36.00
15.75
18.35
LEVEL
LEYBOLD-HERAEUS MECHA
(TRIVAC D60A)
VIEW A-A
TYPICAL 3 PLACES



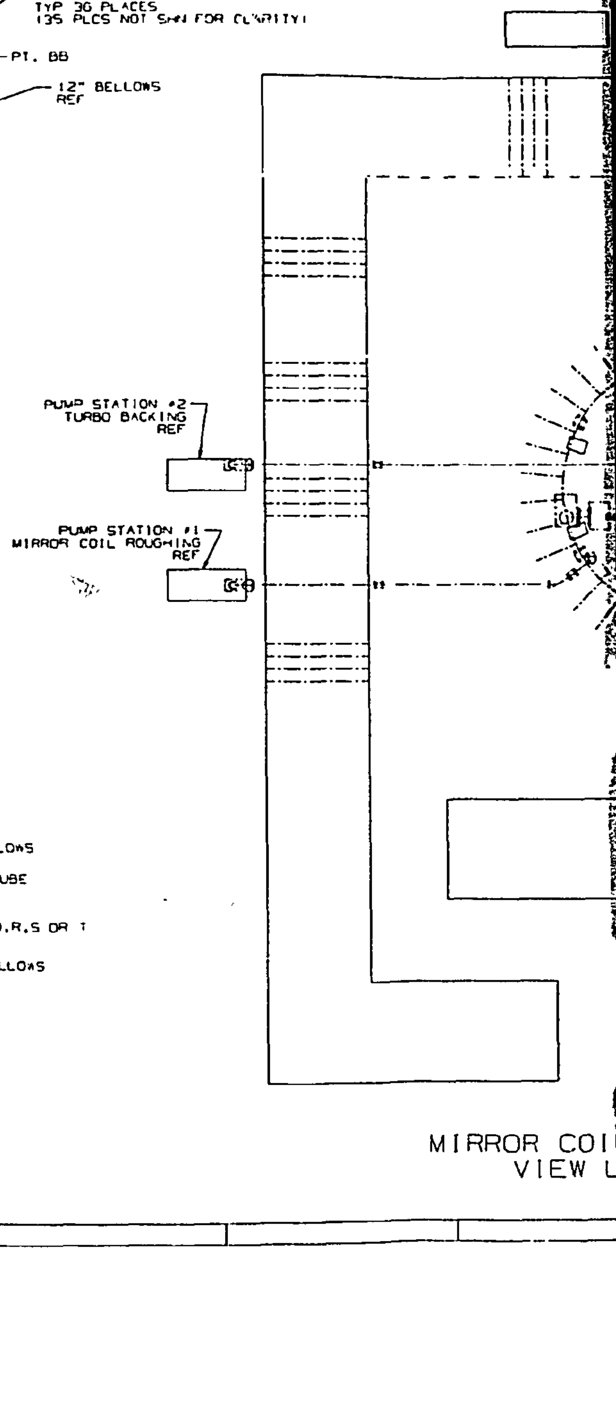
MIRROR COIL PUMPING SYSTEM
UPPER LEVEL
TRIMETRIC VIEW



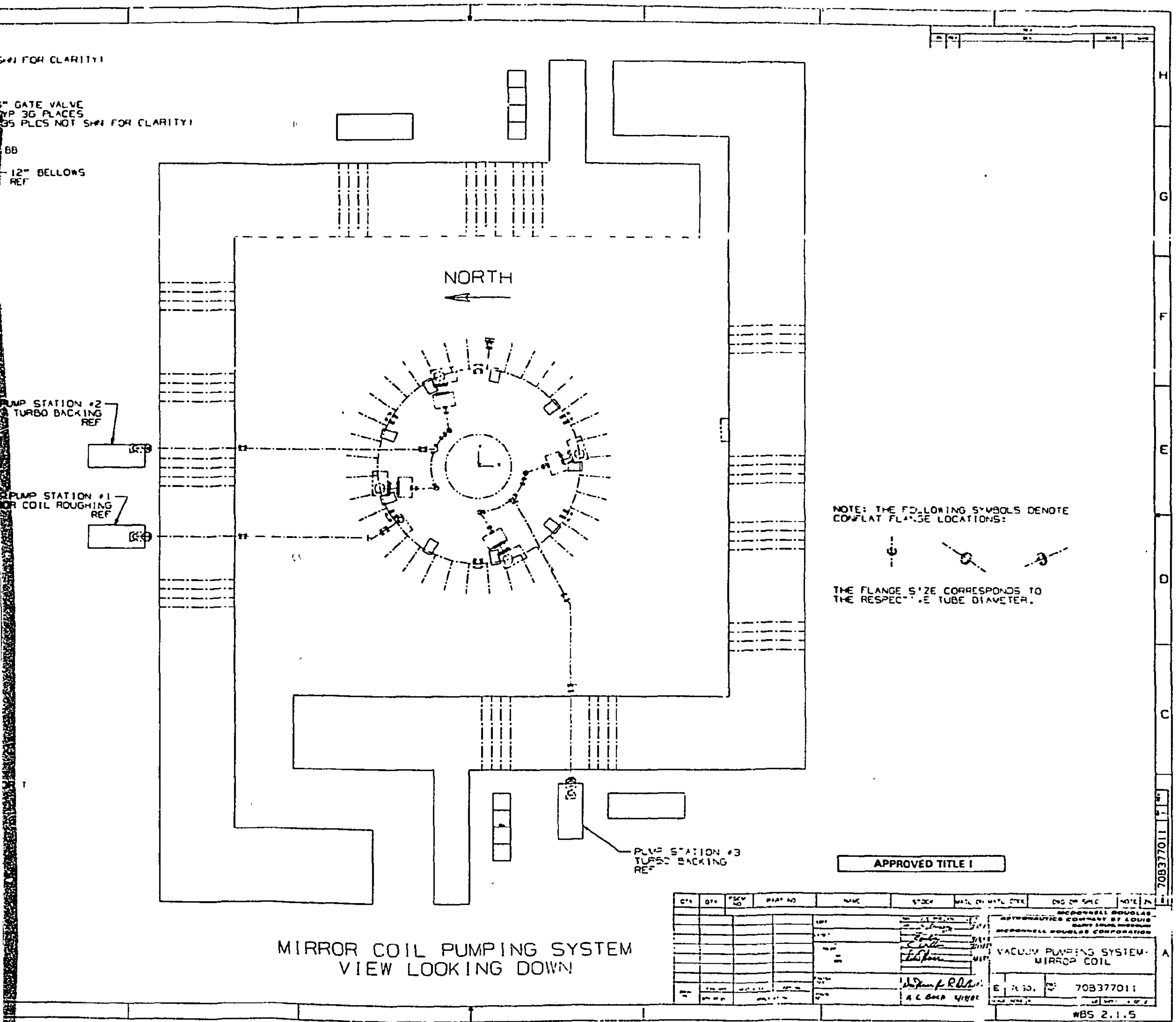
VIEW A-A
TYPICAL 3 PLACES



VIEW B-B
TYPICAL 4 PLACES



MIRROR COI
VIEW L



SHN FOR CLARITY)
" GATE VALVE
TYP 36 PLACES
35 PLCS NOT SHN FOR CLARITY)
BB
12" BELLOWS
REF
NORTH
PUMP STATION #2
TURBO BACKING
REF
PUMP STATION #1
COIL ROUGHING
REF
NOTE: THE FOLLOWING SYMBOLS DENOTE CONFLAT FLANGE LOCATIONS:
THE FLANGE SIZE CORRESPONDS TO THE RESPECTIVE TUBE DIAMETER.
PUMP STATION #3
TURBO BACKING
REF
APPROVED TITLE I
MIRROR COIL PUMPING SYSTEM
VIEW LOOKING DOWN
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY ST LOUIS
MCDONNELL DOUGLAS CORPORATION
VACUUM PUMPING SYSTEM-MIRROR COIL
70B377011
WBS 2.1.5

END PTS.	TUBE LENGTH • (CENTERLINE DISTANCE)	TUBE O.D.
A-B	12.00	6.00
B-C	66.00	6.00
C-D	232.74	6.00
D-E	157.43	6.00
E-F	39.00	6.00
F-G	36.41	4.00
F-H	47.36	4.00
I-J	295.64	6.00
J-K	41.30	6.00
L-M	370.32	6.00
M-N	39.00	6.00
N-O	41.89	4.00
N-P	41.89	4.00
G-S	188.18	4.00
H-R	188.18	4.00
P-Q	188.18	4.00
O-T	188.18	4.00
K-Z	200.00	6.00
AA-BB	40.04 (TYP 36 PLCS)	6.00
CC-A	5.19	3.00
DD-EE	5.19	3.00
GG-HH	5.19	3.00

PTS.	X	Y	Z
A	115.000	-426.000	-222.000
B	115.000	-414.000	-222.000
C	115.000	-414.000	-156.000
D	115.000	-181.262	-156.000
E	44.065	-40.721	-156.000
F	44.065	-40.721	-117.000
G	59.420	-8.319	-117.000
H	2.125	-59.962	-117.000
I	-429.000	-93.380	-156.000
J	-133.362	-93.380	-156.000
K	-99.527	-69.689	-156.000
L	-429.000	22.506	-156.000
M	-55.619	22.506	-156.000
N	-55.619	22.506	-117.000
O	-36.914	47.300	-117.000
P	-52.991	-28.140	-117.000
Q	-52.991	-28.140	71.180
R	2.125	-59.962	71.180

PTS.	
S	59
T	-3
U	-9
V	2
W	59
X	-3
Y	-5
Z	-9
AA	53
BB	70
CC	11
DD	-44
EE	-44
FF	-42
GG	-44
HH	-44
II	-42

FILE NAME: 1056 70837701
LAYERS NO.
VIEW/IMAGE: 10/8
PLOT SCALE: .05
PLOT DATE: 17 FEB'82

PTS.	X	Y	Z
S	59.420	-8.318	71.180
T	-36.914	47.300	71.180
U	-99.527	-69.689	-96.000
V	2.125	-59.962	-96.000
W	59.420	-8.318	-96.000
X	-36.914	47.300	-96.000
Y	-52.991	-28.140	-96.000
Z	-99.527	-69.690	44.000
AA	53.883	115.554	44.000
BB	70.803	151.838	44.000
CC	115.000	-426.000	-227.188
DD	-441.000	-93.380	-227.188
EE	-441.000	-93.380	-222.000
FF	-429.000	-93.380	-222.000
GG	-441.000	22.506	-227.188
HH	-441.000	22.506	-222.000
II	-429.000	22.506	-222.000

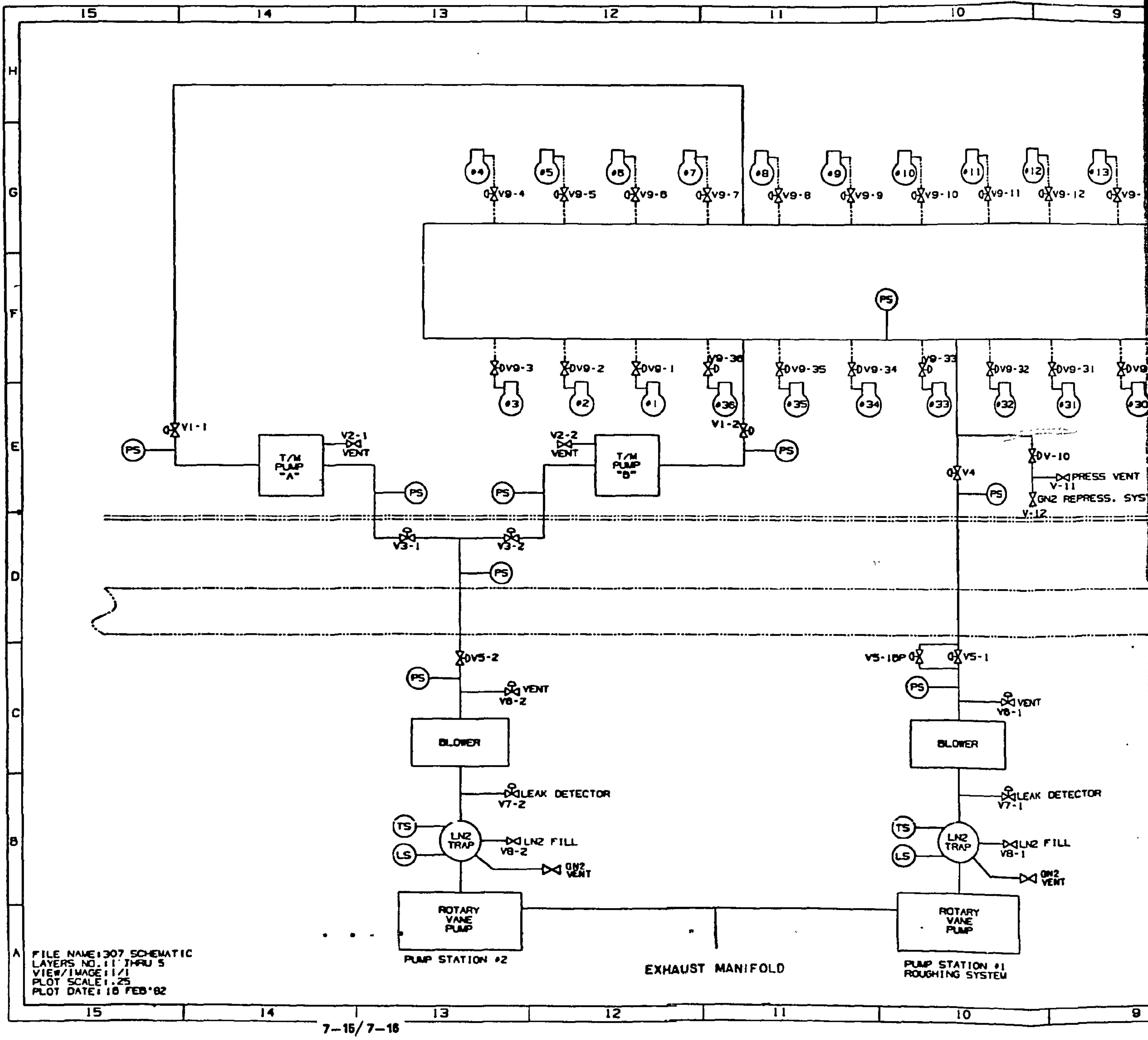
APPROVED TITLE I

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

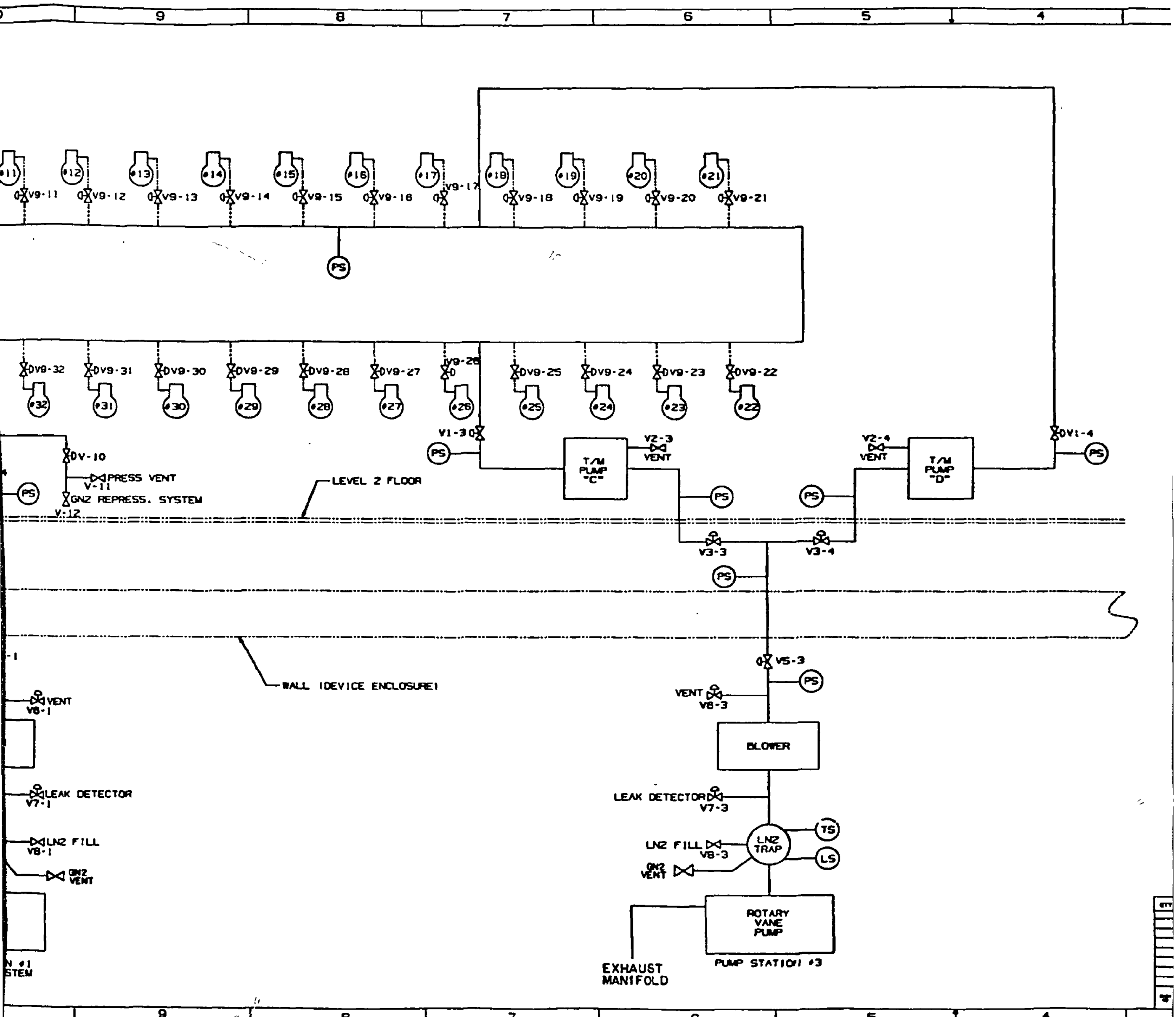
VACUUM PUMPING SYSTEM-MIRROR COIL

708377011

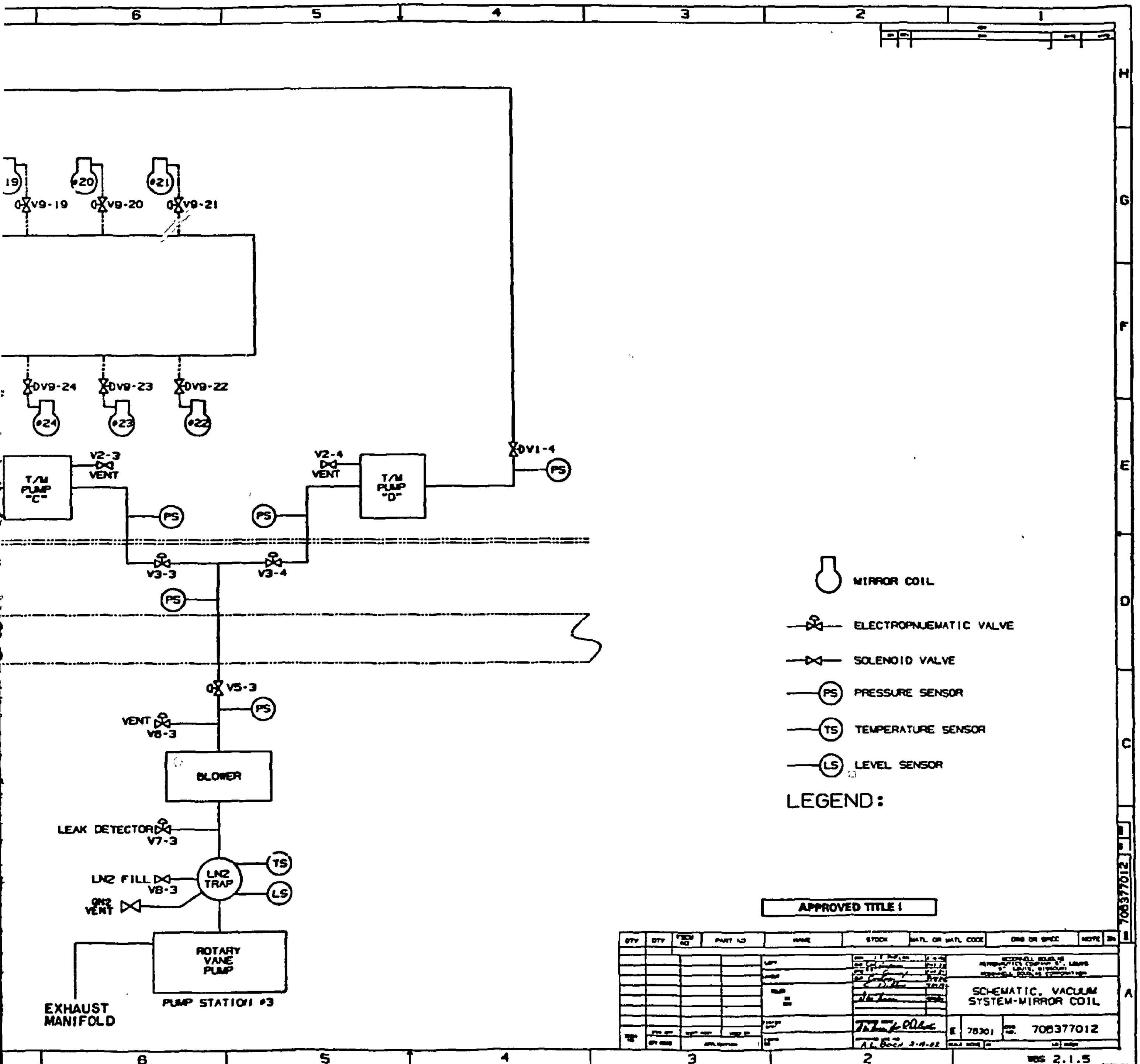
2.1.5


T/M PUMP "A"
T/M PUMP "B"
V1-1
V1-2
V2-1 VENT
V2-2 VENT
V3-1
V3-2
V4
DV-10
PRESS VENT V-11
GN2 REPRESS. SYST V-12
DV5-2
V5-1
V5-18P
VENT V6-2
VENT V6-1
BLOWER
LEAK DETECTOR V7-2
LEAK DETECTOR V7-1
LN2 TRAP
LN2 FILL V8-2
LN2 FILL V8-1
GN2 VENT
ROTARY VANE PUMP
PUMP STATION #2
PUMP STATION #1 ROUGHING SYSTEM
EXHAUST MANIFOLD
FILE NAME:307 SCHEMATIC
LAYERS NO.:1 THRU 5
VIEW/IMAGE:1/1
PLOT SCALE:.25
PLOT DATE: 18 FEB'82

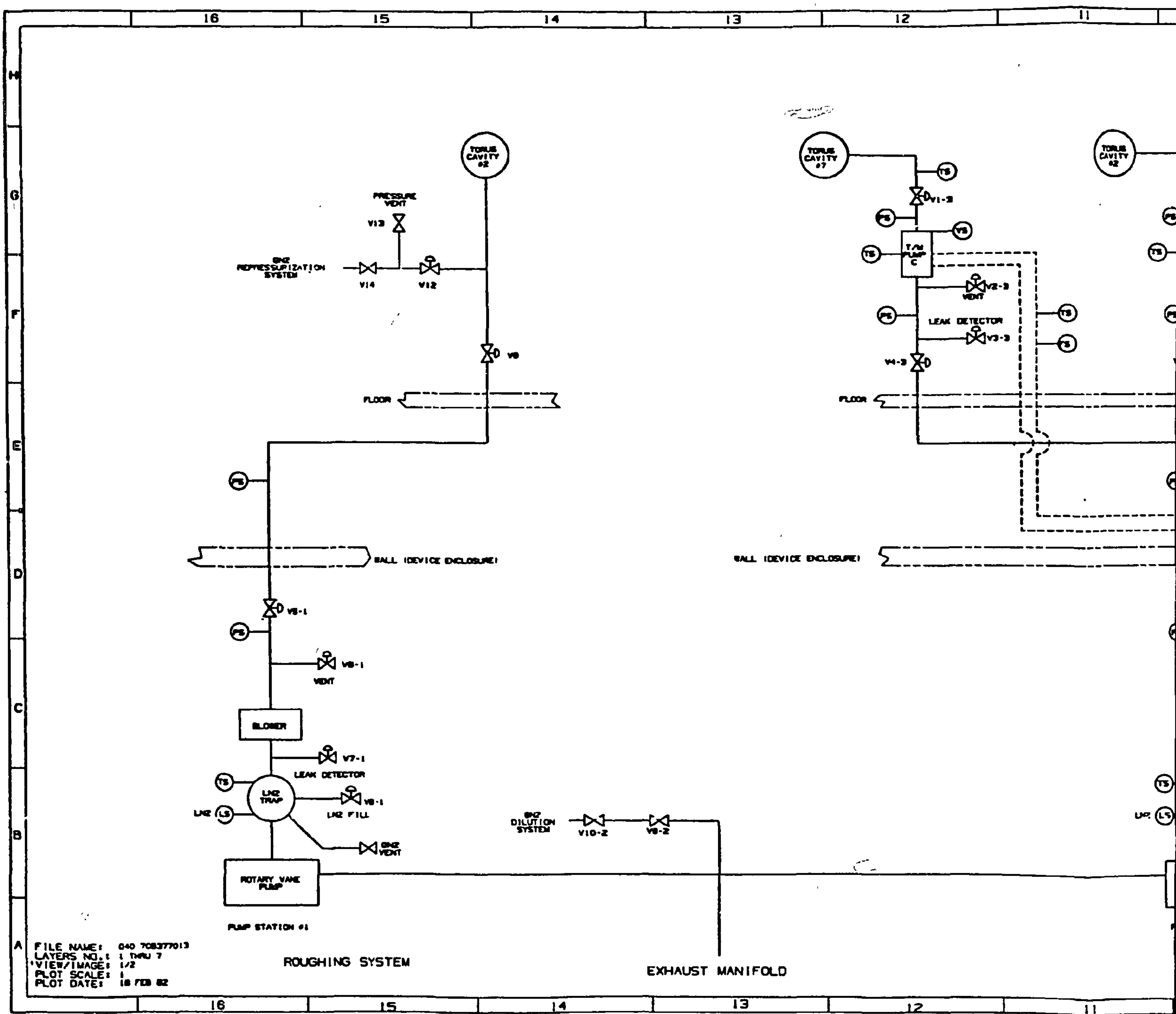
7–15/7–16



9
8
7
6
5
4
V9-11
V9-12
V9-13
V9-14
V9-15
V9-16
V9-17
V9-18
V9-19
V9-20
V9-21
PS
DV9-32
DV9-31
DV9-30
DV9-29
DV9-28
DV9-27
V9-26
DV9-25
DV9-24
DV9-23
DV9-22
V1-3
T/M PUMP "C"
V2-3 VENT
V2-4 VENT
T/M PUMP "D"
DV1-4
DV-10
PRESS VENT V-11
GN2 REPRESS. SYSTEM V-12
LEVEL 2 FLOOR
V3-3
V3-4
V5-3
WALL (DEVICE ENCLOSURE)
VENT V6-1
VENT V6-3
BLOWER
LEAK DETECTOR V7-1
LEAK DETECTOR V7-3
LN2 FILL V8-1
LN2 FILL V8-3
GN2 VENT
LN2 TRAP
TS
LS
ROTARY VANE PUMP
PUMP STATION #3
EXHAUST MANIFOLD

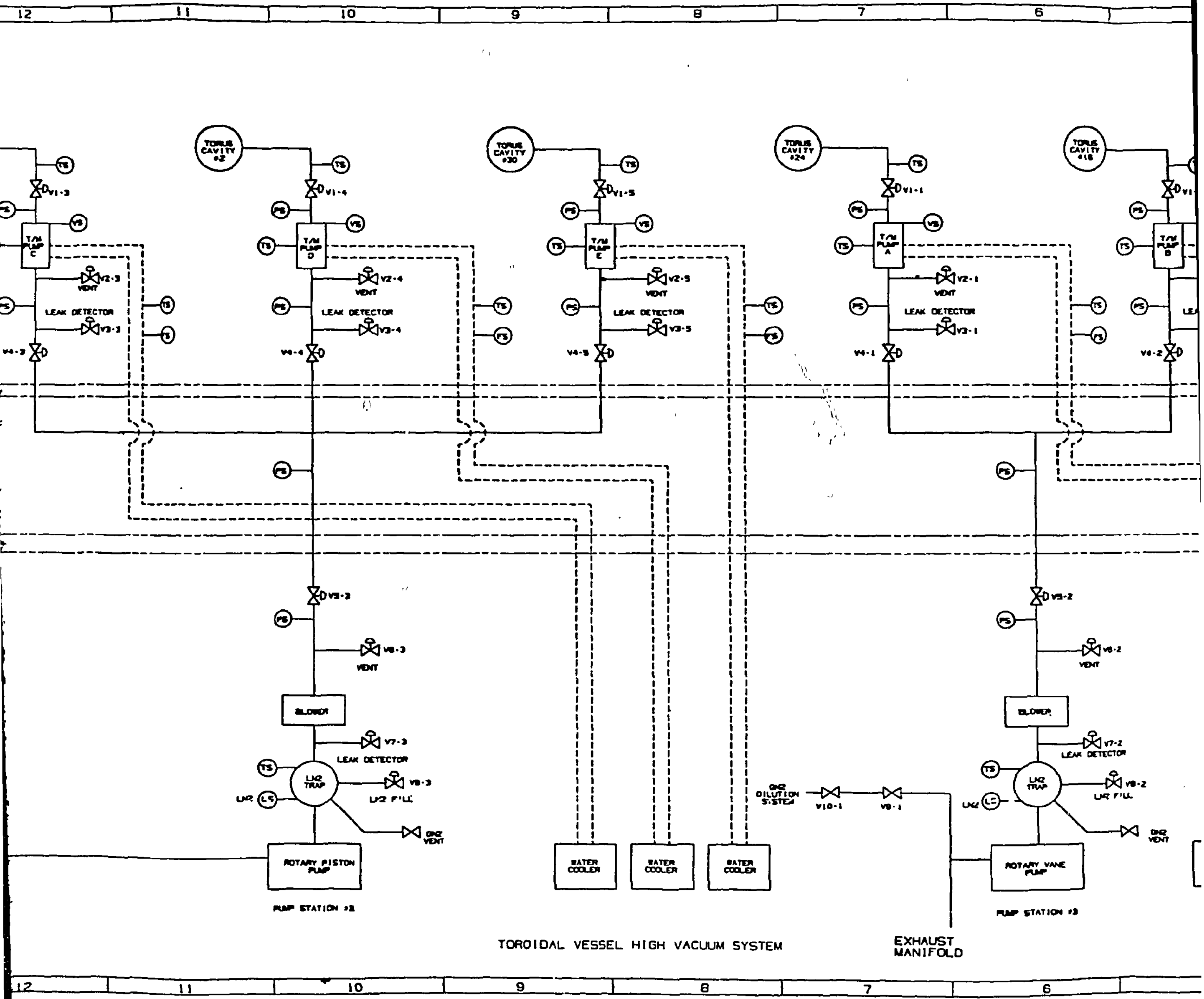


V9-19
V9-20
V9-21
DV9-24
DV9-23
DV9-22
#20
#21
#24
#23
#22
T/M PUMP "C"
T/M PUMP "D"
V2-3 VENT
V2-4 VENT
DV1-4
PS
V3-3
V3-4
V5-3
VENT V6-3
BLOWER
LEAK DETECTOR V7-3
LN2 FILL V8-3
GN2 VENT
LN2 TRAP
TS
LS
ROTARY VANE PUMP
PUMP STATION #3
EXHAUST MANIFOLD
MIRROR COIL
ELECTROPNUEMATIC VALVE
SOLENOID VALVE
PRESSURE SENSOR
TEMPERATURE SENSOR
LEVEL SENSOR
LEGEND:
APPROVED TITLE I
SCHEMATIC, VACUUM SYSTEM-MIRROR COIL
78301
708377012
WBS 2.1.5

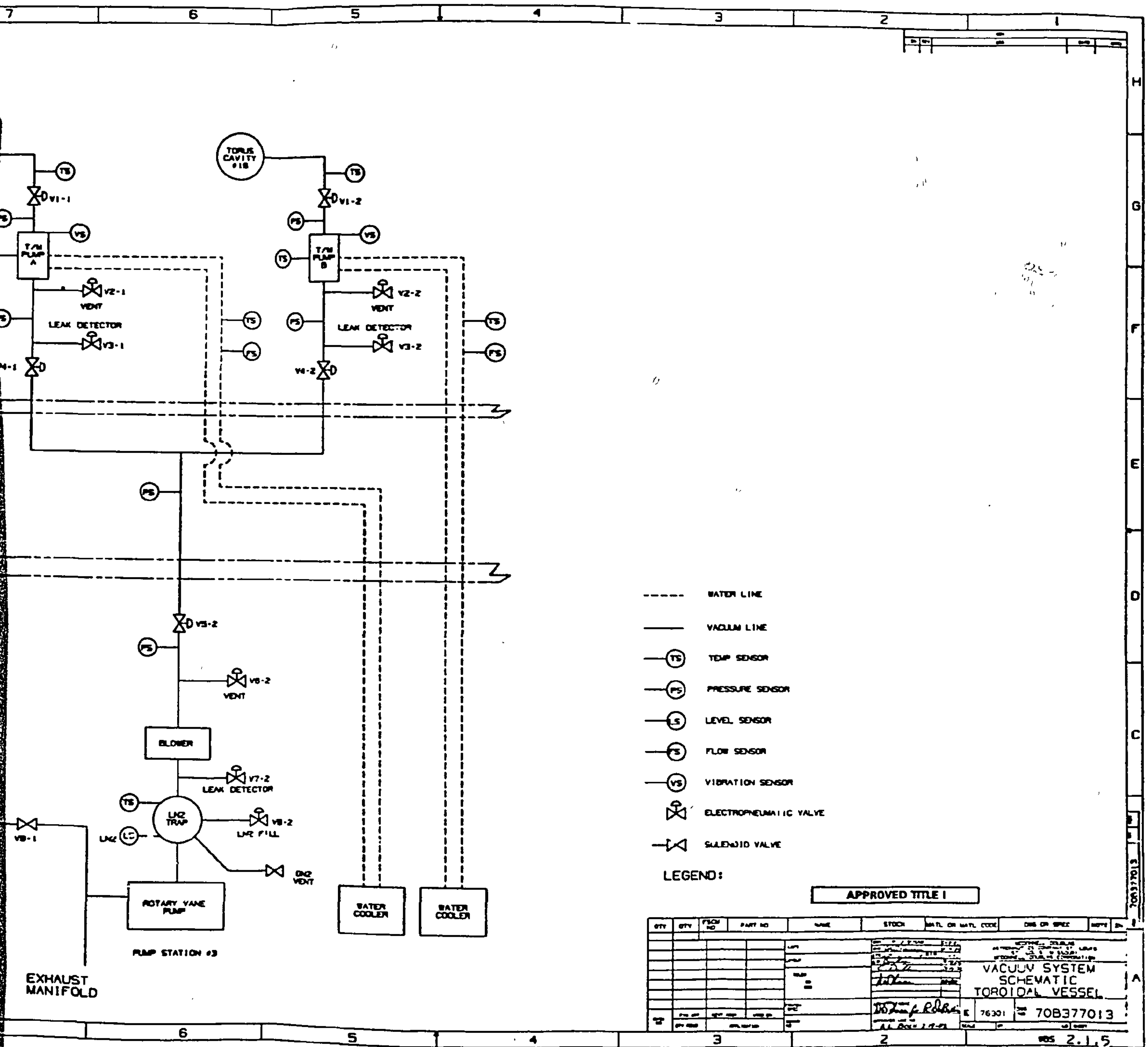


16
15
14
13
12
11
TORUS CAVITY #2
PRESSURE VENT
V13
GN2 REPRESSURIZATION SYSTEM
V14
V12
FLOOR
WALL (DEVICE ENCLOSURE)
BLOWER
VENT
LEAK DETECTOR
V7-1
LN2 TRAP
LN2 FILL
GN2 VENT
ROTARY VANE PUMP
PUMP STATION #1
TORUS CAVITY #7
T/M PUMP C
V1-3
V2-3
V3-3
V4-3
GN2 DILUTION SYSTEM
V10-2
FILE NAME:
LAYERS NO.:
VIEW/IMAGE:
PLOT SCALE:
PLOT DATE:
ROUGHING SYSTEM
EXHAUST MANIFOLD

7–17/7–18



TOROIDAL VESSEL HIGH VACUUM SYSTEM



TORUS CAVITY #18
VI-1
VI-2
T/M PUMP A
T/M PUMP B
V2-1
V2-2
VENT
LEAK DETECTOR
V3-1
V3-2
V4-2
V5-2
V6-2
VENT
BLOWER
V7-2
LEAK DETECTOR
LN2 TRAP
V8-2
LN2 FILL
V9-1
LN2
GN2 VENT
ROTARY VANE PUMP
PUMP STATION #3
EXHAUST MANIFOLD
WATER COOLER
WATER COOLER
WATER LINE
VACUUM LINE
TEMP SENSOR
PRESSURE SENSOR
LEVEL SENSOR
FLOW SENSOR
VIBRATION SENSOR
ELECTROPNEUMATIC VALVE
SOLENOID VALVE
LEGEND:
APPROVED TITLE I
VACUUV SYSTEM
SCHEMATIC
TOROIDAL VESSEL
76301
70B377013
WBS 2.1.5