LIGO-G940010-00-R

R&D Program

S. Whitcomb

20 September 1994

LIGO

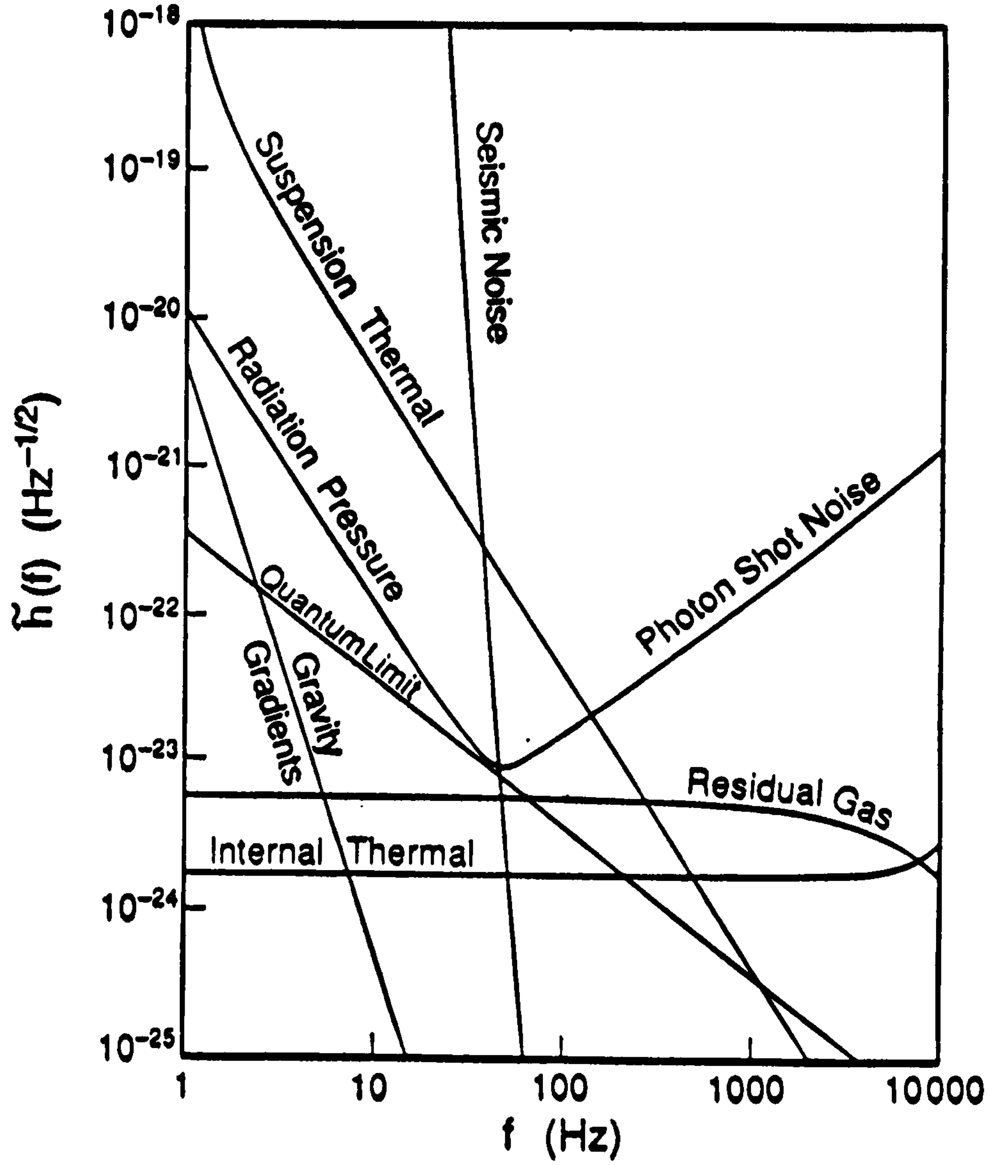
Objectives of the LIGO R&D Program

- Initial Interferometers
  - Develop Detailed Understanding of How Interferometer Design Parameters Affect Fundamental Noise Sources
  - Develop Techniques Required for Initial Interferometer Performance
  - Must Support Interferometer Design Schedule (Subsystem Design Freezes Scheduled Between Dec 1995 and Oct 1996)
- Enhanced or Advanced Interferometers
  - Longer-Term Effort to Build Foundation for Further Sensitivity Improvements

1989 PROPOSAL

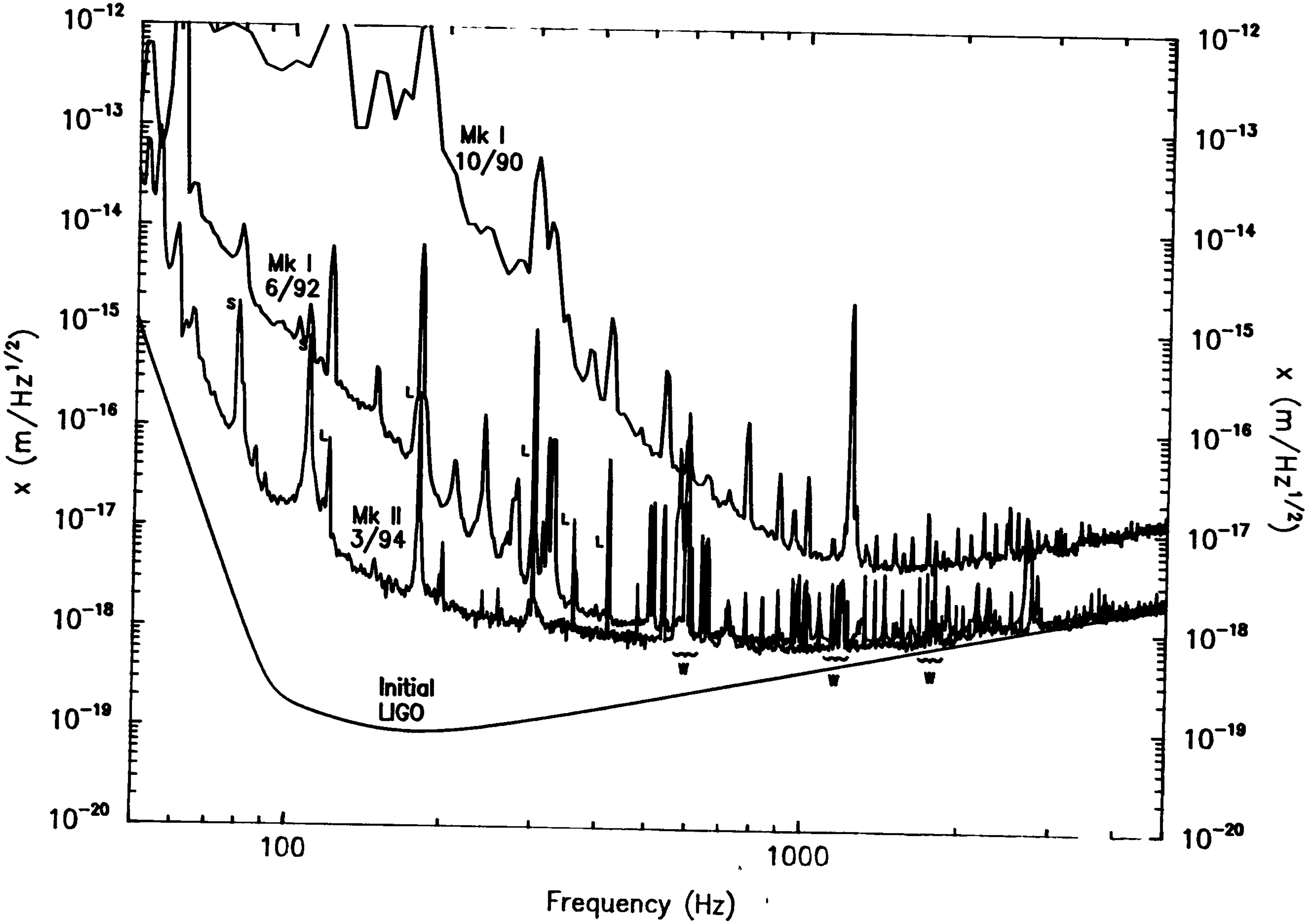
A Noise Budget For First LIGO Detectors

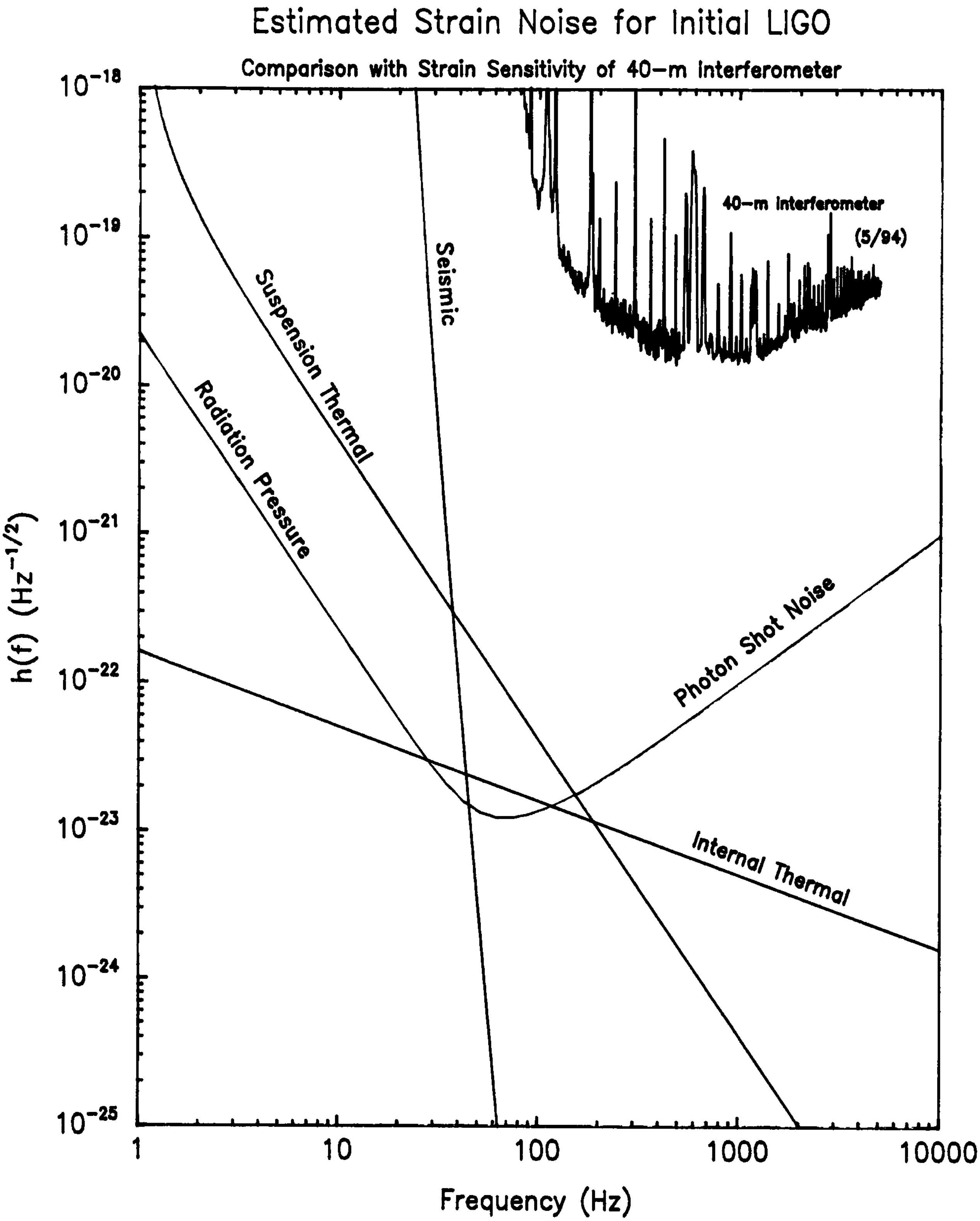
- 5 Watt Laser
- Mirror Losses 50 ppm
- Recycling Factor of 30
- 10 kg Test Masses
- Suspension Q=10^7



LIGO

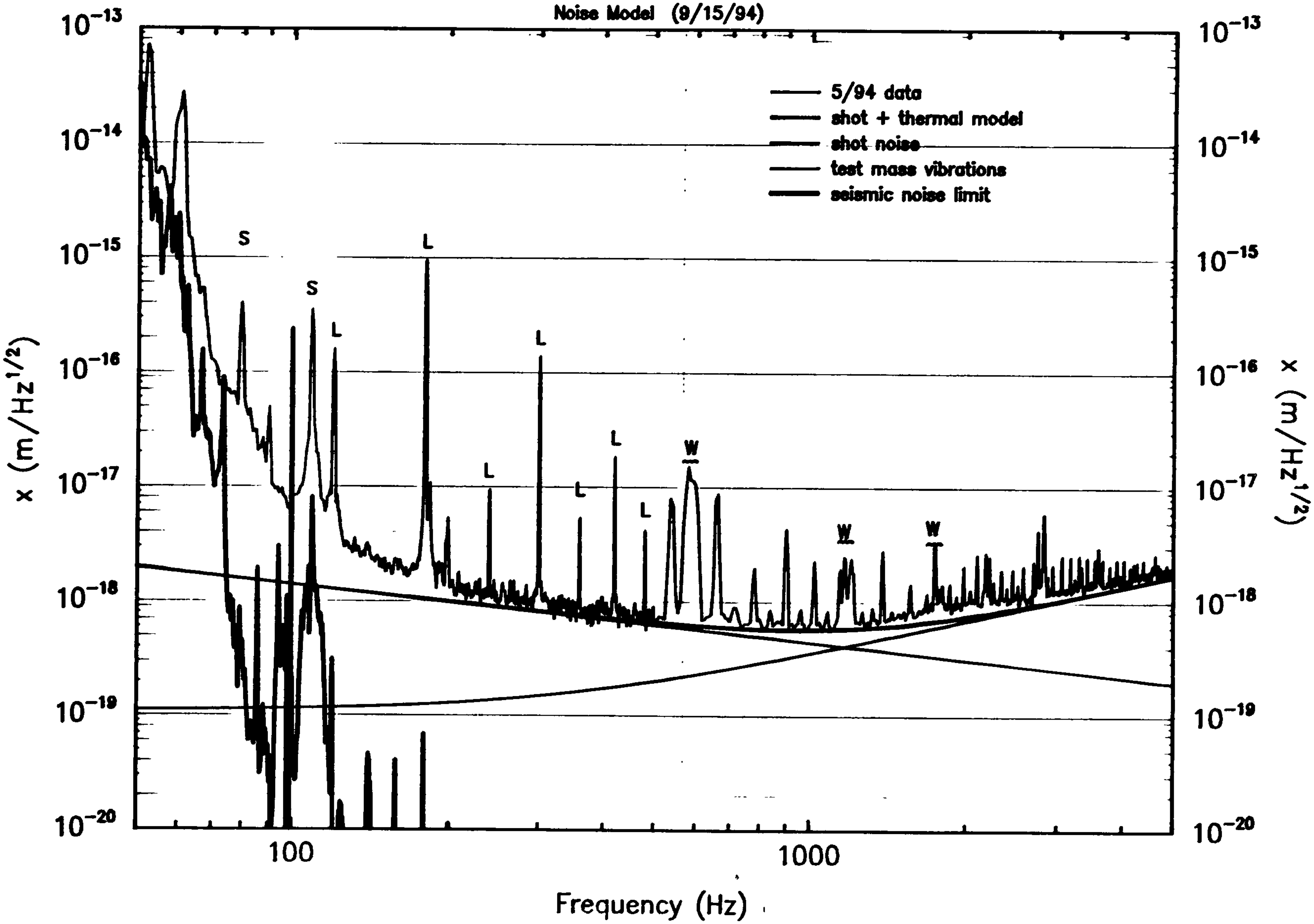
Displacement Sensitivity of Caltech 40 m Interferometer




Estimated Strain Noise for Initial LIGO
Comparison with Strain Sensitivity of 40-m Interferometer
40-m Interferometer
(5/94)
Seismic
Suspension Thermal
Radiation Pressure
Photon Shot Noise
Internal Thermal
h(f) (Hz^-1/2)
10^-18
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
1
10
100
1000
10000
Frequency (Hz)

straincomp

Displacement Sensitivity of 40-Meter Interferometer



mk2theory2

Where Do We Stand?

(Fundamental Noise Sources)

- Seismic Noise
  - Passive Seismic Isolation Stack Understood
  - Stacks with Softer Elastomer in Preparation
  - Significant Reduction in Seismic Background at Remote Sites
  - Projected to Meet Initial LIGO Goal
- Thermal Noise
  - Improvements in Quanitative Understanding
  - Suspension Requirements Relaxed, Internal Mode Requirements Tightened
  - Current Suspension Design Projected to Meet LIGO Goal
- Shot Noise
  - LIGO Goal 10× Better than Best Demonstrated
  - Requires Characterization and Integration Of Different Electro-Optical Components and Subsystems (Photodetectors, Modulators, Laser Stabilization, . . .)
  - High Power Shot Noise Experiment Underway at MIT

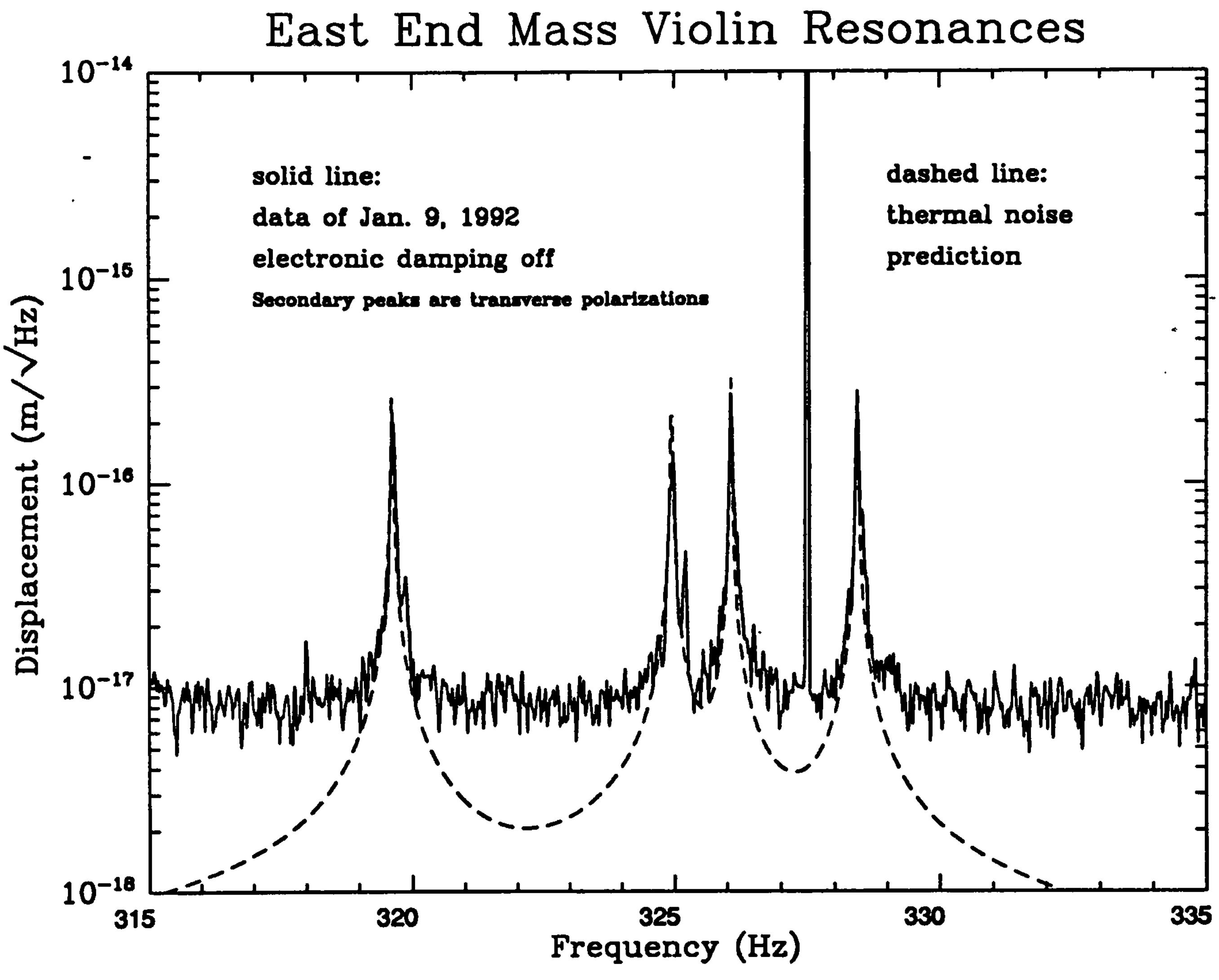
Where Do We Stand?

(Interferometer Technology)

- Laser Stabilization
  - Laser Requirements (Power, Stability) Established
  - Prototype Developed and Tested
- Input Optics
  - Mode Cleaner Requirements Established
  - LIGO-Scale Laboratory Model Built and Undergoing Test
- Length Control
  - Tabletop Experiments Have Demonstrated Concept
  - Computer Modeling (to Scale to LIGO Scale) Underway
  - Tests on 40–m Interferometer Beginning
- Alignment Control
  - Computer Model of Interferometer Used to Set Requirements
  - Single Cavity Demonstration of Concept Completed
  - Tabletop Model of Full Interferometer Underway

Suspension Thermal Noise

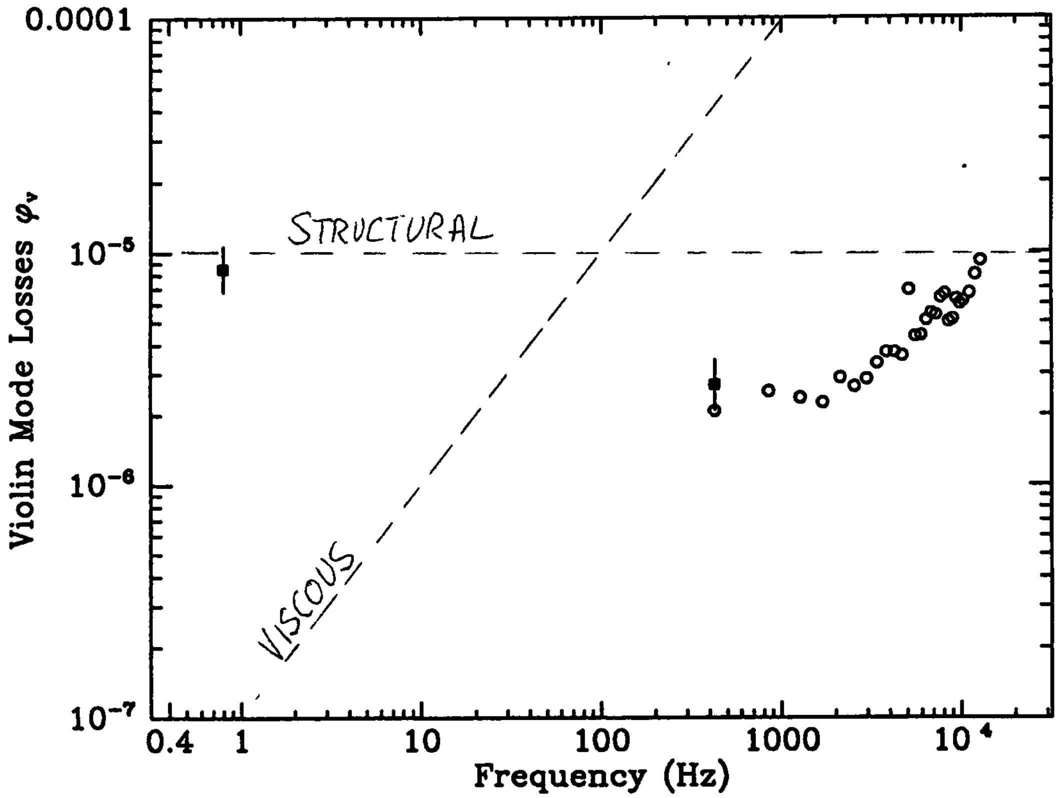
Observation of Thermal Noise in Violin Modes of 40–m Test Mass Suspensions



LIGO

Suspension Thermal Noise

- **Have Established Link Between Loss Mechanisms in Pendulum Mode and Violin Modes**
- **Makes Violin Q Measurements an Important Diagnostic for Suspension Thermal Noise**

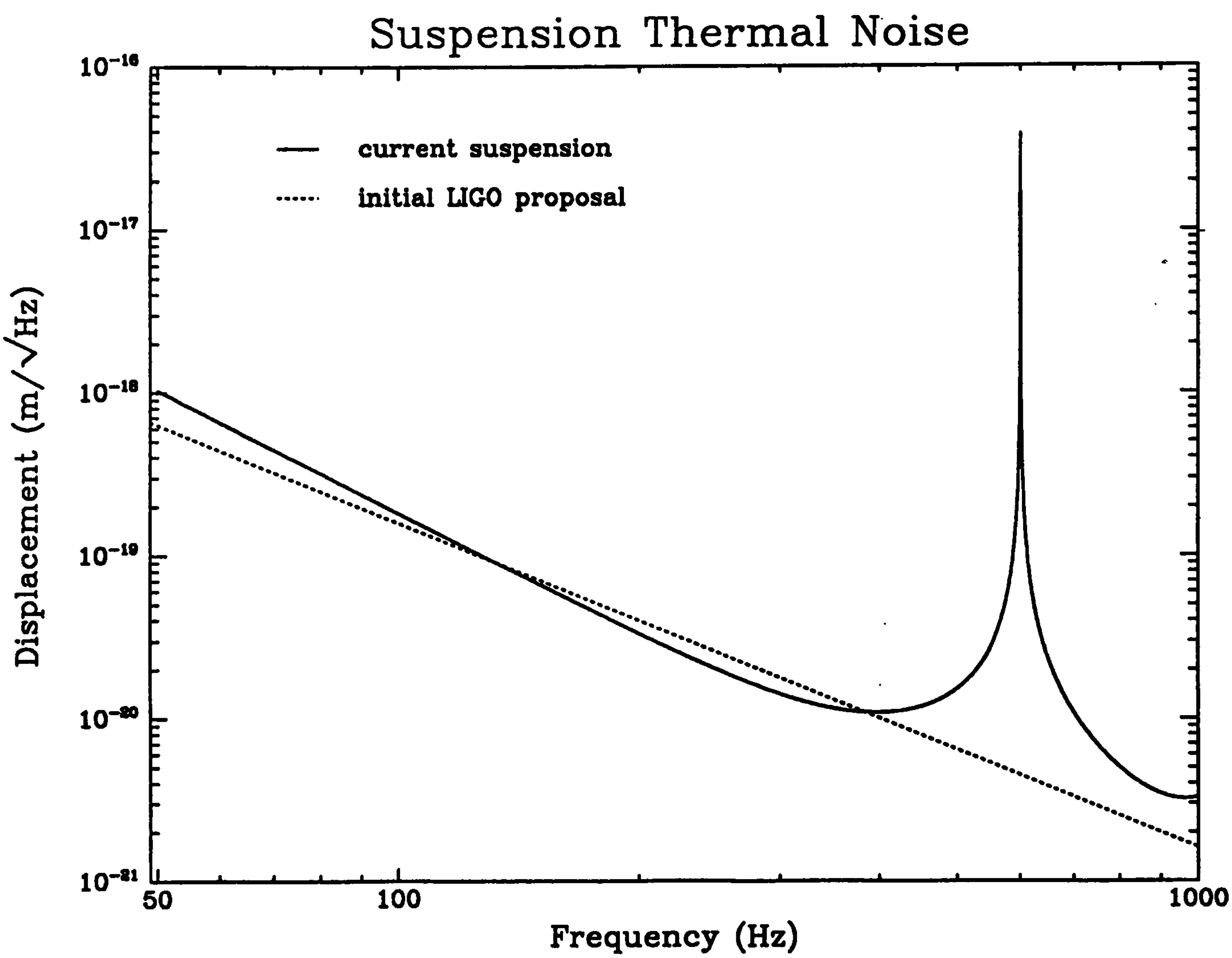


- **Data for Steel Wire Suspension System Indicate Best Model for Thermal Noise Uses Frequency Independent Loss Function**

LIGO

Suspension Thermal Noise For LIGO Interferometers

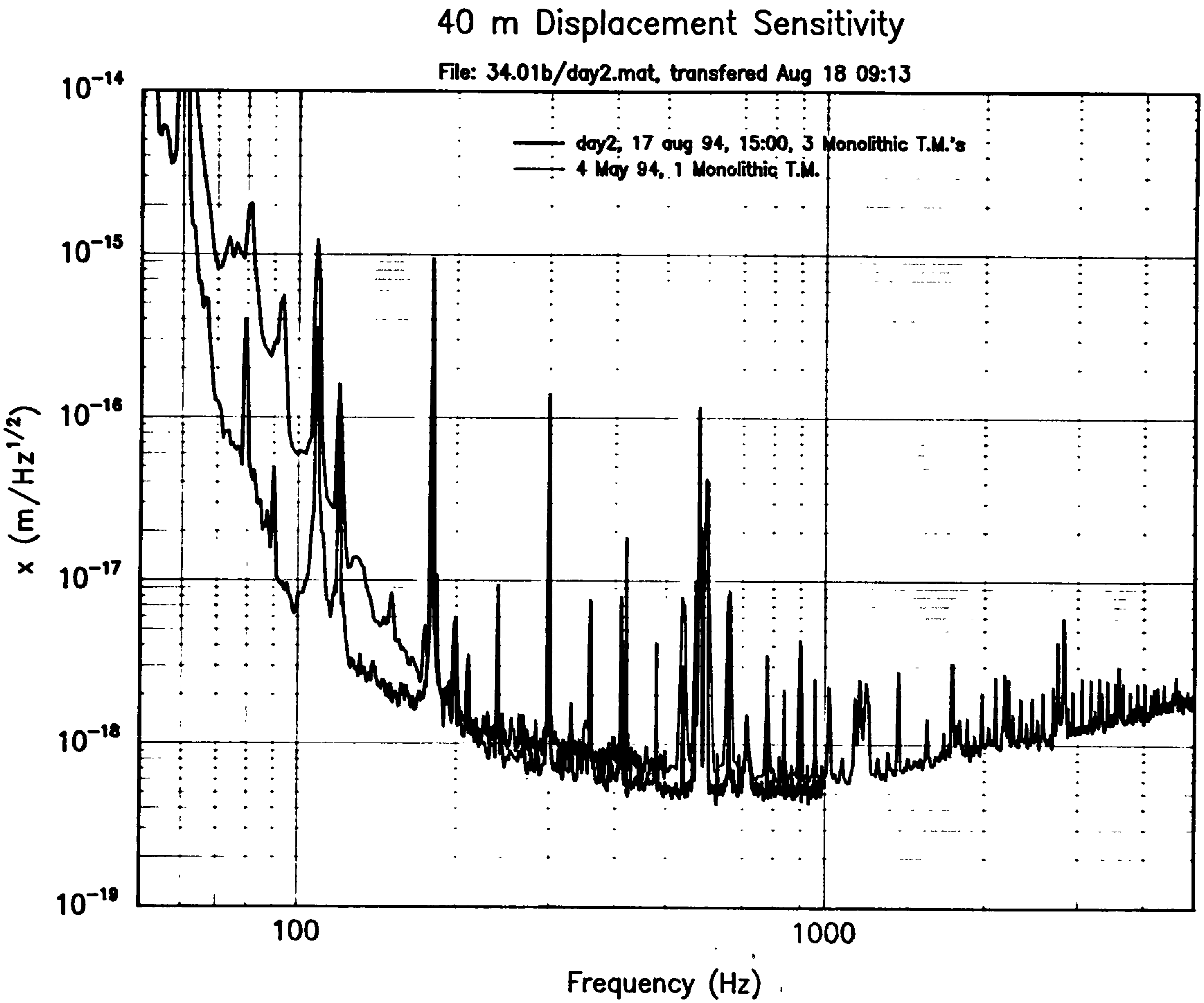
- **Projected Thermal Noise for LIGO Interferometers**
  - **Model Suspension System Using Frequency Independent Loss Function**
  - **Use Current 40–m Suspension Design (Standoff on Test Mass and Clamps at Suspension Point)**



LIGO

Thermal Noise From Test Mass Internal Modes

- Evidence From 40–m Interferometer Lends Some Support to Frequency Independent Loss Function For Internal Modes of Test Masses
  - Persistent Mid-frequency Noise (Both Before and After Mark II Rebuild)
  - Consistent with Expected Spectral Shape
  - Level Consistent with Observed Level within Uncertainty of Calculation (approx. factor of 2)
  - Observed in 40–m Noise Spectrum due to Low Q's in Compound Test Masses
- Conclusive Test (Replacement of Test Masses with Lower Loss Monolithic Test Masses) Underway



40 m Displacement Sensitivity
File: 34.01b/day2.mat, transfered Aug 18 09:13
day2, 17 aug 94, 15:00, 3 Monolithic T.M.'s
4 May 94, 1 Monolithic T.M.
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
x (m/Hz$^{1/2}$)
100
1000
Frequency (Hz)

Suspension Development Plans

- Design of New Test Mass Suspension for 40–m Interferometer Underway
  - Incorporates Techniques Developed to Simultaneously Achieve Low Losses in Suspension and Internal Modes
  - Controls Compatible with LIGO Design
  - Prototype Planned to be Installed and Tested by Spring 1995
  - All 40–m Interferometer Suspensions Replaced by End of 1995
- Design of Suspension Test Stand for LIGO Test Masses Underway
  - Measure Suspension and Internal Mode Q's
  - Confirm Scaling From 40–m Test Masses to LIGO Test Masses
  - Complete First Measurements By March 1995
- Support Design for LIGO Suspensions
  - Completion Scheduled 7/95

Shot Noise

$$\delta h(f) \approx \frac{1}{L} \left(\frac{\partial \phi}{\partial x}(f) \right)^{-1} \delta\phi(f)$$

PROPERTY OF INTERFEROMETER OPTICAL CONFIGURATION (MIRROR R'S, ETC.)

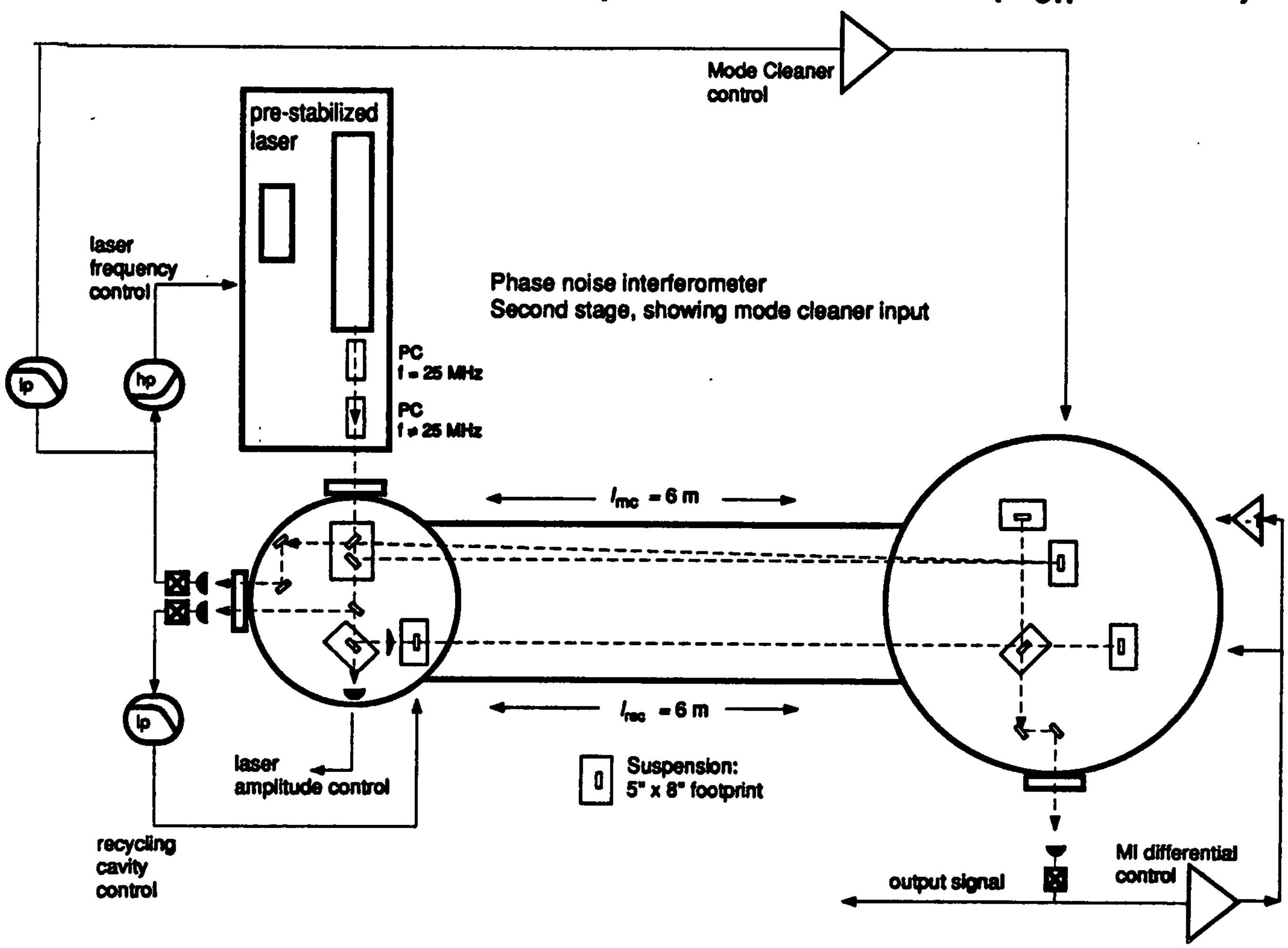
DETERMINED PRIMARILY BY EFFECTIVE OPTICAL POWER

- Achieving Shot-Noise Limited Phase Sensitivity Requires Understanding and Control of All Other Optical Sources of Noise
  - Laser Noise
  - Photodiode Uniformity
  - Modulator-Induced Noise
  - Scattered Light

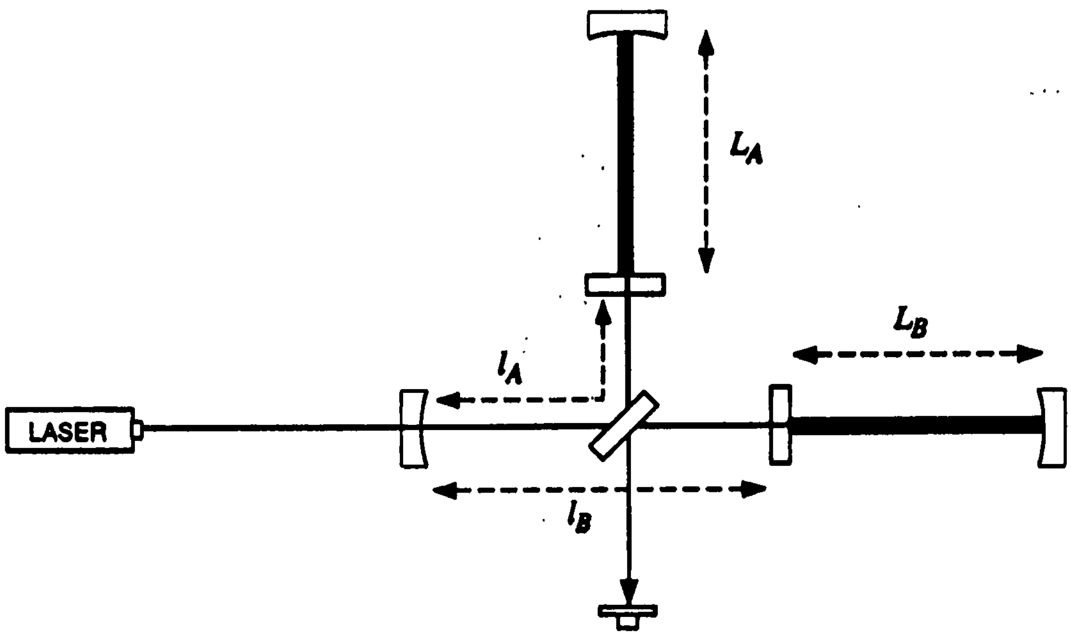
LIGO Requirement	10^{-10} rad/$\sqrt{\text{Hz}}$
Current 40-m Interferometer	10^{-8} rad/$\sqrt{\text{Hz}}$
MPQ Garching	10^{-9} rad/$\sqrt{\text{Hz}}$

Phase Noise Demonstration

- Goal is to Develop and Demonstrate Technology for Shot-Noise Limited Phase Measurements at Initial LIGO Interferometer Power Levels
    - Requires Development and Testing of Modulators and Photodetectors.
- Build Up 5–m Interferometer in Stages toward Full Recombined, Recycled Operation
    - Begin with Simple Michelson Interferometer Using LIGO Readout Scheme ($P_{eff} \sim 1$ W)
    - Add Recycling Mirror ($P_{eff} \sim 15$ W)
    - Reconfigure with Input Mode Cleaner ($P_{eff} \sim 70$ W)



Optical Configuration Investigations



- Must Control at Least Four Critical Lengths
  - Need to Specify Placement of Pick-offs, Photodetectors, and Modulators to Extract Required Control Signals
- In 1991, Started Efforts to Build and Test Two Possible Schemes in Tabletop Experiments For Comparison with Model Predictions of Performance
  - Test Signal Sizes, Servoloop Stability
  - Look for Gaps in Models
  - Not Practical to Test Noise Performance

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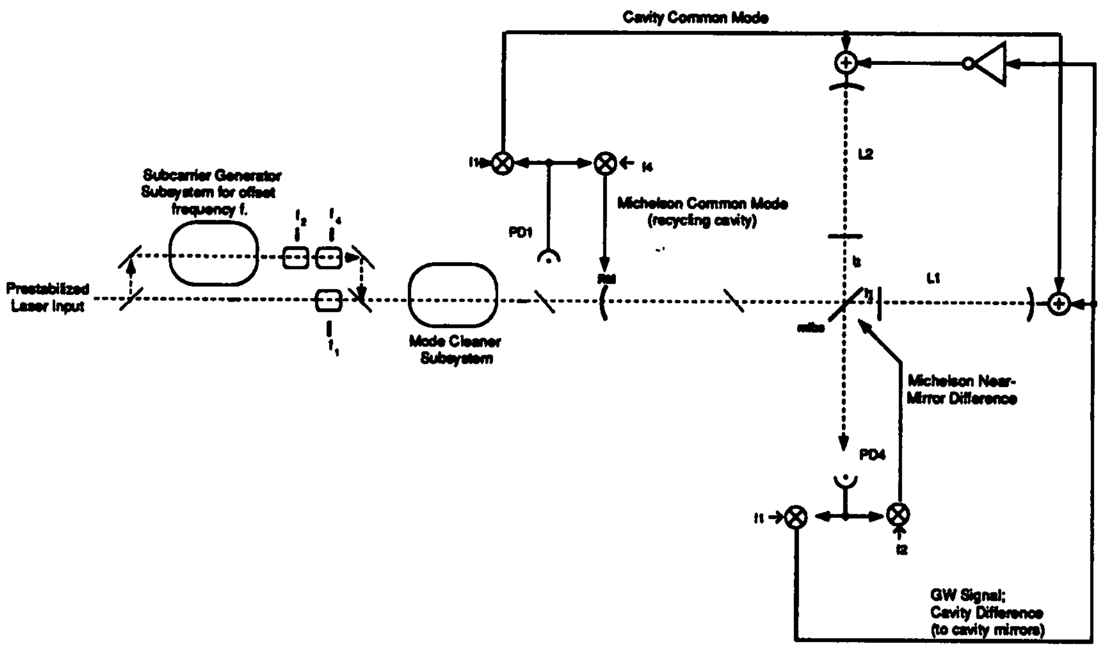
LIGO Optical Configuration

- **Have Selected Optical Configuration for LIGO Interferometers**
- **Selected Configuration Incorporates Major Elements From Both Schemes**
  - **Asymmetry Between Arms for Gravitational Wave Readout**
  - **Single Sideband (Frequency-Shifted Subcarrier) for Auxiliary Length Readout**



LIGO

Plans for Optical Configuration Development

- Modeling
  - Optical Model for Recombined, Recycled Interferometer (Including Region Far From Resonance) In Progress
  - Incorporate Control Loops to Investigate Operational Performance and Lock Acquisition Stategy
- Experimental Verification On 40–m Interferometer
  - Reconfigure 40–m Interferometer
    - Optical Recombination of Two Arms (April 1995)
    - Implement Recycling (Fall 1996)
  - Comparison with Model
- Length Sensing System PDR Scheduled for 10/96

Vacuum Equipment Specification Science Review

AGENDA
August 31, 1994

I. INTRODUCTION & CHARGE TO COMMITTEE (REV, MEZ)

II. SCIENCE REQUIREMENTS (DHS)

III. ENGINEERING REQUIREMENTS & IMPLEMENTATION (JW)

IV. INTERFEROMETER OPTICS COMPATIBILITY

- A. Validation exercises; outline (DHS)
- B. Beam raytracing layout (AA)
- C. Auxiliary alignment layout (MEZ)
- D. Results (MEZ)
    1. Port locations
    2. Initial IFO compatibility
    3. Advanced & Phase C compatibility
    4. Summary of adopted changes

V. SEISMIC ISOLATION & SUSPENSION COMPATIBILITY (LS)

- A. Initial interferometers
- B. Advanced interferometers
- C. Chamber access

VI. GENERAL DISCUSSION & ACTION ITEMS

VACUUM EQUIPMENT SPECIFICATION
LIGO FACILITY

LIGO Document 1100003

PREPARED BY: John Worden

APPROVED BY:

EFFECTIVE DATE: July 18, 1994

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LIGO PROJECT

DOCUMENT CONTROL PAGE

DOCUMENT CUSTODIAN: worden

FILE: vecontr/vesnew

REVISION	DATE	BY	DESCRIPTION OR DCN	APPROVED

Contents

1. SCOPE

This specification defines the technical requirements for the design, procurement, delivery, qualification, installation, and acceptance testing of the LIGO (Laser Interferometer Gravitational-Wave Observatory) vacuum equipment.

The LIGO includes two installations at widely separated sites, near Hanford, WA and Livingston, LA. Each installation includes laser interferometers in an L shape with 4-km long arms, a vacuum system for the sensitive interferometer components and optical beams, and other support facilities. The vacuum equipment consists of interconnected vacuum vessels, pumping systems, valves and a monitoring and control system for each site. The vacuum equipment will be located in structures called stations, located at the corners, mid points, and ends of the L-shaped pattern. See Figure 1.

The vacuum tube joining the vacuum equipment in the stations is provided under separate contract, and is described by LIGO 1100004, Beam Tubes Specification.

Cleaning, alignment and leak checking are critical processes. Vacuum levels during operation may range from a nominal 10^{-6} torr at the chambers to 10^{-9} torr in the beamtube.

2. APPLICABLE DOCUMENTS

If more than one document applies to a technical requirement, the more stringent standard shall have precedence. Requirements set forth in this specification shall have final precedence.

2.1 Industry Documents

2.1.1 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code

- Pressure Vessels, Section VIII, Division I
- Welding and Brazing Qualifications, Section IX

2.1.2 American Society of Civil Engineers

- Minimum Design Loads for Buildings and Other Structures, ASCE 7–88

2.1.3 "Standards of Expansion Joint Manufacturer's Association", published by Expansion Joint Manufacturer's Association (EJMA)

2.1.4 National Fire Protection Association (NFPA) Standards

- No. 70—National Electrical Code

2.2 Government Standards

- Building and safety codes: local, state, and federal, including OSHA

2.3 LIGO Documents

2.3.1 LIGO Drawings

- LIGO Drawing 1101100, Vacuum Equipment, Corner Station, Washington Site, Phase A, attached
- LIGO Drawing 1101101, Vacuum Equipment, Corner Station, Louisiana Site, Phase A, attached
- LIGO Drawing 1101102, Vacuum Equipment, End Stations, Phase A, attached
- LIGO Drawing 1101103, Vacuum Equipment, Mid Stations, Washington Site, Phase A, attached
- LIGO Drawing 1101009, Beam Splitter Chamber (BSC)
- LIGO Drawing 1101010, Horizontal Axis Module (HAM)
- LIGO Drawing 1101011, 10" Isolation Bellows
- LIGO Drawing 1101012, 7" Isolation Bellows
- LIGO Drawing 1101013, Test Mass Chamber, Type 1 (TMC-1)
- LIGO Drawing 1101018, Support Beam Assembly, Large Chambers
- LIGO Drawing 1101041, Support Beam Assembly, HAM Chambers

2.3.2 LIGO Specifications

- LIGO 1100004, Beam Tubes Specification

2.4 Interface Control Documents

2.4.1 Provided by the Vacuum Equipment Contractor

- Vendor document XXXX, Vacuum Equipment to Beam Tube Interface
- Vendor document XXXX, Vacuum System to Station Enclosure and Utilities Interface
- Vendor document XXXX, Vacuum vent/purge air system to internal air showers.
- Vendor document XXXX, Vacuum Equipment to Process Control System

3. SYSTEM DESCRIPTION

The LIGO vacuum system is divided into two parts: the beam tube modules and the vacuum equipment. The beam tube modules are two kilometers long and are addressed in a separate contract. The vacuum equipment is housed in buildings located at the intersection (corner) and ends of the beam tube modules. These buildings are the corner station, mid stations, and end stations. The vacuum equipment consists of the following subsystems:

1. Vacuum enclosure subsystem
2. Pumping subsystem
3. Valve subsystem
4. Vent and purge subsystem
5. Bakeout subsystem
6. Monitor and control subsystem

Together these subsystems, along with the beam tube modules, make up the vacuum system. The Washington site schematic is shown in Figure 2 and the Louisiana site schematic is shown in Figure 3. A description of the system according to station is given below.

3.1 Corner Station Washington Site The vacuum enclosure for the corner station of the Washington Site is shown in Figure 4 (a reduced LIGO drawing #1101100). Three types of vacuum chambers enclose the optical components of the laser interferometers: test mass chambers (TMC), beam splitter chambers

(BSC), and horizontal access modules (HAM). One of the BSCs shall be located at the intersection of the two arms in the Washington site corner station. As shown in Figure 4, an array of nine HAMs shall connect with the diagonal chamber, as extensions of the arms. Interconnecting two sets of HAM groups are 76 cm diameter mode cleaner tubes. Along each arm, an additional BSC and TMC shall be located in that order. A section of 183 cm diameter tube shall provide for the addition of TMCs in future expansions. A second BSC (with HAM array) shall be located on a 45 degree diagonal between the arms, and two 122 cm tubes shall connect this to the TMCs, through 122 cm diameter isolation valves. The corner station building will be built with enough room for the future addition of up to four TMC/BSC/HAM groupings. Removal of access covers from the chambers will allow for servicing the optical components during normal operations; the seals on these covers shall be designed as double O-rings for economical reuse during the early period of operation when access is more frequent and permeation is more tolerable; later, the inboard O-ring may be replaced with a metal seal. A clean air vent and purge system shall be provided to break vacuum and maintain cleanliness of the optical components whenever a chamber is open.

The corner station pumping system shall include two LN_2 (liquid nitrogen) pumps near the beam tube interfaces, getter pumps, and main ion pumps as shown in Figure 2. Ion pumps shall also be used to pump the annulus of all double O-ring seals. Rough pumping from atmosphere shall be done with portable pump stations.

3.2 Corner Station Louisiana Site The vacuum equipment for the corner station at the Louisiana site is similar to that at the Washington site, except that initially there shall be no TMCs, and only one of the BSC/HAM groupings shall be installed. See Figure 5 (a reduced LIGO drawing #1101101) for details.

3.3 End Stations Both Sites The vacuum equipment for the end stations is shown in Figure 6 (a reduced LIGO drawing #1101102). Vacuum enclosures shall include one BSC initially.

The pumping system shall include one LN_2 pump with isolation valves, getter pumps, and ion pumps for both the enclosure and the annulus. Rough pumping from atmosphere shall be done with portable pump stations.

3.4 Mid Station Washington Site The vacuum equipment for the mid stations is shown in Figure 7 (a reduced LIGO drawing #1101103). Vacuum enclosures shall include one TMC initially.

The pumping system shall include two LN_2 pumps with isolation valves, getter pumps and ion pumps for both the enclosure and the annulus. Rough pumping from atmosphere shall be done with portable pump stations.

3.5 Midpoint Pumping Station Louisiana Site No chambers are to be housed here. A 122 cm diameter gate valve allows isolation of the adjoining beam tube modules. A valved and instrumented roughing port and an independent, separately valved getter pump set shall be located on each side of this gate valve. Refer to Figure 3.

4. SYSTEM REQUIREMENTS

4.1 Leak Rate All leaks greater than 1×10^{-8} torr•liters/sec of helium shall be repaired according to Caltech approved procedures.

4.2 Pump Down Time Each vacuum section (an isolatable volume), without interferometer components, shall pump down from atmosphere to 1×10^{-6} torr in less than 24 hours. In the case of the vertex and diagonal vacuum sections, two pump stations may be connected at once to accomplish this. Otherwise, only a single pump station shall be connected at one time.

4.3 Ultimate Pressures Each vacuum section (empty) shall attain 5×10^{-9} torr after 100 hours of pumping with the ion pumps and open to the LN_2 pumps. The prior conditioning permitted is a 48 hour bakeout followed by a vent and purge for 24 hours.

4.4 System Control and Protection Each vacuum section shall have sufficient instrumentation and hardware to allow safe and reliable operation of valves, pumps and gauges under all conditions. Control logic shall be specified to allow incorporation into a commercial process control system to be supplied by Caltech at a later date.

4.5 Bakeout/Degassing Capability A means shall be provided to heat all vacuum surfaces to any desired temperature, ranging from ambient to 150°C. All ion pumps and gauges shall be bakeable to 300°C. Ramping of temperatures shall be controlled to minimize the stresses on vacuum connections. There shall be no particulate generation or shedding caused by placement or removal of the insulation.

Alternate means using photo-induced and/or ion-induced desorption may be utilized if cost effective degassing is obtained.

4.6 Special Environmental Requirements The LIGO vacuum equipment and laser areas house instrumentation which is potentially highly sensitive to vibration and acoustic noise, shock-induced damage or misalignment, electromagnetic interference, and contamination. The following requirements on installed equipment have been developed without detailed consideration of cost impact. They are subject to future revision.

4.6.1 Shock Valve actuation or other intermittent device operation shall induce no more than 0.01 g peak-to-peak acceleration at any point within 1 meter of any chamber.

4.6.2 Acoustic Noise Acoustic noise from all simultaneously operating equipment (including turbopumps and their backing pumps, gauge and pump controllers and supplies, but EXEMPTING main mechanical roughing pumps on intermittent duty) shall not exceed PNC-40 (Preferred Noise Criterion 40) at any location within LIGO vacuum equipment and laser areas. Limited narrowband exemptions may be permitted subject to Caltech approval.

4.6.3 Vibration Vibration from all simultaneously operating equipment (EXEMPTING main mechanical roughing pumps on intermittent duty) shall not cause the vibration measured at any point within 1 meter of any chamber to exceed the LIGO Site Vibration Baseline (Figure {FIG. TO BE SUPPLIED BY LISA FAIRLY SOON}) by more than 6 dB (a factor of two in amplitude) at any frequency between 0.1 Hz and 10 kHz. Limited narrowband exemptions may be permitted subject to Caltech approval.

4.6.4 Electromagnetic Emissions All electrical equipment shall conform to {IEC? ISO? IEEE?} standard # {?????} limiting electromagnetic radiation, emission and powerline contamination. {VOLKER WILL BE PROVIDING SOME ACTUAL STANDARDS TO ADHERE TO FOR EMI; I WILL BUG HIM ABOUT IT SHORTLY}

4.6.5 Particulates and other contaminants No installed equipment shall emit or harbor particulates at a level inconsistent with maintenance of a clean environment conforming to Federal Standard 209D Class 50,000.

4.7 Interfaces The following interfaces shall be provided for and documented accordingly:

1. Vacuum equipment to beam tube.**
2. Vacuum system to station enclosure and utilities.
3. Vacuum vent/purge air system to internal air showers.
4. Vacuum equipment to process control system.

** For the purposes of this proposal the interface shall be taken as the "Tube Termination Interface" on Figure 4.

4.8 Design Life The contractor shall design the vacuum equipment for a minimum serviceable life of 20 years.

4.9 Environmental Under normal operations, the vacuum equipment will be operated in a temperature and humidity controlled environment. In case of power or control failure, and during the construction phase, conditions will be dictated by diurnal and seasonal ranges. Exposure to these conditions shall not damage the vacuum equipment.

5. SUBSYSTEMS

5.1 Vacuum Enclosure Subsystem The vacuum enclosure includes all components such as chambers, tubes, flanges, elbows, tees, blank-offs, and other fittings, which form the barrier between atmosphere and vacuum. These components are required to be compatible with use at 1×10^{-9} torr. Specific requirements are below.

5.1.1 Materials All fabricated components exposed to vacuum shall be made from type 304L or 316L stainless steel, using low carbon weld filler wire, where required. Standard catalogue items of 304 or 316 stainless steel are acceptable if not available in 304L or 316L. Copper and aluminum may be used for seals. All other materials are subject to Caltech approval. Copies of mill test reports of chamber, tube and flange materials shall be furnished.

Internal surface finish is subject to Caltech approval.

5.1.2 Cleaning All surfaces exposed to vacuum shall be cleaned in accordance with procedures approved by Caltech prior to fabrication and installation; surface recontamination shall be prevented during all subsequent processes.

All items shall be wrapped or sealed after cleaning to maintain cleanliness through handling, transportation, and storage. Care shall be taken to minimize exposure to corrosive environments, such as chloride compounds.

No visible contaminant (as viewed under both natural and "blacklight") of any form shall be left within the vacuum enclosures when installed (for example: water, dust, sand, hydrocarbon film, etc.).

5.1.3 Welding All welding exposed to vacuum shall be done by the tungsten-arc inert-gas (TIG) process. Welding techniques shall deviate from the ASME Code in accordance with the best ultra high vacuum practice to eliminate any "virtual leaks" in the welds; i.e., all vacuum welds shall be, wherever possible, internal and continuous; all external welds added to these for structural purposes shall be intermittent to eliminate trapped volumes. Defective welds shall be repaired by removal to sound metal and rewelding.

All vacuum weld procedures shall include steps to avoid contamination of the heat affected zone with air, hydrogen, or water. This requires that inert purge gas, such as argon, be used to remove unwanted gases over the vacuum side of heated portions.

5.1.4 Alignment and Dimensions All chambers shall be aligned to within 2mm of the design optical axis in both transverse directions and to within 25mm of the design position in the axial direction. Unless noted otherwise, dimensions of chambers (including interconnecting tubes) refer to nominal internal dimensions.

5.1.5 Mechanical Loads All vacuum components shall be anchored to the floor or to each other in such manner as to restrict all motion to bellows units. The design of the vacuum enclosure shall allow for strains and stresses due to the following:

1. normal cycling of the station HVAC (heating, ventilating, and air conditioning) system (expected to maintain temperature within a range of +/- 2°C);
2. variations in atmospheric pressure;
3. vacuum cycling of other sections of the vacuum enclosure;
4. bakeout of any vacuum section;
5. failure or non-operation of the HVAC.

5.1.6 Design Each vacuum element with a diameter greater than 12 inches shall be designed according to the latest edition of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 and its subsequent addenda (except as noted in 3.5.5.5), even though vacuum chambers lie outside of the scope of that document. Code certification and stamping are not required. All separable parts shall be fully interchangeable between assemblies. Adequate clearance shall be provided for assembly of mating flanges, and for handles. External access shall be provided to all vacuum seams for leak checking.

All vacuum elements heavier than 50 lbs shall have lift lugs installed and each chamber assembly shall have an electrical ground connection (removable for diagnostic purposes).

Calculations shall be made to determine design features, including the need for and the size of any reinforcements due to openings. Chambers shall be designed to withstand the loadings exerted by all applicable loads in accordance with the provisions of all applicable codes and standards. All chambers shall be designed to be free standing. To determine the probability of earthquakes and seismic coefficients in various areas of the United States, Standard ANSI A58.1 (ASCE Minimum Design Loads for Buildings and Other Structures) shall be applied.

5.1.7 Chambers All optics are housed in three types of chambers. These chambers contain the seismic isolators and alignment mechanisms which support the optical elements. The three chambers are BSC, HAM and TMC.

5.1.7.1 Beam Splitter Chamber (BSC) The Beam Splitter Chamber (BSC) configuration is shown in Figure 8. Note that the Support Beam Assembly(Figure 9) and four 10" Isolation Bellows(Figure 10) are to be provided by others.

5.1.7.2 Horizontal Axis Module (HAM) The Horizontal Axis Module (HAM) configuration is shown in Figure 11. Note that the Support Beam Assembly (Figure 12)and four 7" Isolation Bellows (Figure 13) are to be provided by others.

5.1.7.3 Test Mass Chamber (TMC) The Test Mass Chamber configuration is shown in Figure 14. It includes special features which permit isolation and removal of an interferometer's Test Mass Assemblies with minimal disturbance to the beam paths of other interferometers operating concurrently at the same site. Cited specifications have been developed without consideration of cost. Note that the Support Beam Assembly(Figure 9) and four 10" Isolation Bellows(Figure 10) are to be provided by others.

5.1.7.3.1 Integrated Airlock The airlock enables isolation of the TMC Dome from the lower chamber body (which is integral with the beam tube manifold and may not be vented while another interferometer is in operation). The Airlock shall provide a 152 cm dia. clear aperture when open. When closed it shall withstand atmospheric pressure (only from above), with maximum leak rate determined as for Gate Valves. It is required to stroke from fully open to sealed, or from sealed to fully open, in five minutes or less. The Dome must have provisions for evacuation, vent and purge, and seal annulus evacuation and vent which are fully independent of those for other volumes. The Airlock shall be interlocked to exclude operation with unacceptable pressure differentials or unretracted equipment.

5.1.8 Flanges Dual O-ring flanges shall be designed for convenient, quick and easy disassembly and assembly, consistent with reliable sealing. The design shall allow replacement of the inner O-ring with a metal seal at some time in the future. O-rings shall be vacuum quality Viton, free of lubricant, and baked to remove contaminants. O-ring grooves shall retain the O-ring during assembly/disassembly. Flange centering pins shall be tapered, rounded, and replaceable; centering pins for flange sets in the vertical plane shall support the weight of the mating cover. Except for the case of chamber to chamber connections, flange centering pins shall be included in the chamber flange of flange sets in the vertical plane, and the lower flange of flange sets in the horizontal plane. Flange neck (wall) thickness shall be the minimum practical (considering vacuum and other loads), to maximize available aperture area.

5.1.9 Access Connectors The 152 cm diameter short tube sections located at each BSC chamber on the diagonal are defined as access connectors, and shall be designed for convenient removal and installation. The minimum axial space required at these locations is 60 cm.

5.1.10 Optical Baffles All connecting tubes shall be designed to allow for installation of optical baffles at a later date. This requirement can be met by allowing access to all internal surfaces.

5.1.11 Annular Spaces All annuluses of each chamber shall be connected to a single flange. Pumping speed between this flange and any point of the pumped annulus is to be greater than 0.3 liters/sec for air, in molecular flow. Multiple annuluses may be connected together to minimize the number of ion pumps and valves. Interconnecting tubing shall be routed close to the chamber wall, with all connections to be welded or CF flanges.

5.1.12 Fasteners Flange fasteners shall be of high quality, appropriate for efficient assembly and disassembly. All fasteners shall be plated or made of alloys which allow use without lubricants. Where possible plate nuts shall be used.

5.1.13 Component Leak Rate The contractor shall ensure that all leaks greater than 1×10^{-9} torr•liter/second of helium on each chamber or tube section are repaired at the site of manufacture.

5.1.14 Workmanship, Finish, and Appearance The finished product shall have a workmanlike finish and be free of weld spatter, cutoff spatter, free iron, weld oxidation and injurious defects. There shall be no grinding or abrasion of completed welds or internal vacuum surfaces.

5.1.15 Marking Each separable part (except fasteners, seals, and interchangeable, standard blank flanges) shall be permanently marked with a unique identification number in a location readily viewed.

5.2 Pumping Subsystem Vacuum pumps include portable roughing pumps, annulus pumps, main ion pumps, getter pumps, and LN_2 pumps. The roughing pumps are used to pump the systems down from atmosphere to 10^{-6} torr. The ion pumps, getter pumps, and LN_2 pumps are used for vibration-free pumping during normal operation.

The main pumping phases include:

1. Initial Pumpdown: (from 760 torr to less than 1 torr) main roughing pump sets, noise and vibration expected, minimized, and tolerated for the short periods of time;
2. Intermediate Pumpdown: (from 1 torr to less than 10^{-6} torr) regeneration of LN_2 pumps and getter pumps: turbo molecular pump sets, low noise and vibration, extended time periods;
3. Final Pumpdown: (maintaining vacuum) roughing and turbo pumps are turned off; ion, getter and LN_2 pumps provide continuous operation.

5.2.1 Roughing Pumps The roughing pumps shall consist of two types of portable pump stations, the main roughing pump set and the turbo molecular pump sets. The main roughing pump set shall be used for pumping from atmosphere to less than 1 torr while the turbo molecular pump set shall be used for pumping from 1 torr to less than 10^{-6} torr. The main roughing pump sets are exempt from the vibration and acoustic noise limits. The turbo molecular pump sets, however, shall be designed to operate for extended periods of time without contributing to vibration and noise levels beyond those described in Section 3.2.6.

The design of the roughing pumps shall preclude contaminating the beam tubes and chambers during the life of the equipment, even with equipment failures and operator mistakes.

5.2.1.1 Main Roughing Pump Sets Each main roughing pump set shall consist of a roots blower backed by one or more mechanical pumps. If feasible there shall be no oil in the pumping path. The roots blower shall incorporate a "canned" motor. The pump set shall be self contained so that under power failure or pump failure, interlocks shall prevent the pumped chambers from being vented or exposed to pump oil. Provisions for connection to the control system shall be provided. Provision for sealed connection to a ducted facility exhaust system shall be provided.

There shall be vacuum gauges located at each pump inlet (both the roots pump and the backing pump) and there shall be auxiliary valved (manual) ports to allow connection of a leak detector at any location. All unused connections shall be fitted with blankoff flanges.

5.2.1.2 Turbo Molecular Pump Sets Each turbo molecular pump set shall consist of a "wide range" magnetically levitated turbo molecular pump backed by a dry pump (diaphragm, piston, or scroll pump). The minimum pumping speed at the roughing port shall be 1400 liters/sec for nitrogen at 10^{-3} torr. Throughput at a backing pressure of 10 torr shall be at least 15 torr liters/second. The pump set shall be self contained so that under power failure or pump failure, interlocks shall prevent the pumped chambers from being vented. Provisions for connection to the control system shall be provided.

There shall be vacuum gauges located at each pump inlet (both the turbo pump and the backing pump) and there shall be auxiliary valved (manual) ports to allow connection of a leak detector or auxiliary backing turbo at any location. All unused connections shall be fitted with blankoff flanges.

5.2.2 Main Ion Pumps The LIGO ion pumps shall have nominal pumping speeds of 3000 liter/sec minimum for nitrogen. Each of these pumps may physically consist of multiples of smaller units. Their expected life shall be

80,000 hours or more at an operating pressure of 10^{-6} torr. Noble gas diode pumps shall be used. There shall be a minimum of three and a maximum of six power supply/controllers for each ion pump. The maximum starting pressure shall be 10^{-5} torr. The ion pump controllers shall be mountable in standard 19 inch racks.

5.2.3 LN_2 Pumps There are two types of LN_2 pumps: long and short. The long LN_2 pumps shall have a cold surface 3.7 m long, and the short LN2 pumps shall have a cold surface 1.2 m long. All other features of the LN_2 pumps shall be identical. The LN_2 pumping surface shall be coaxial with the beam tube axis, and provide a clear aperture of ≥ 1.05 m, warm or cold. The insulated vacuum space shall be separated from the beam tube vacuum and shall have it's own pumping ports and instrumentation.

Certain parts of the LN_2 pumps may have large thermal gradients which may give rise to local, intermittent release of gas. The design shall preclude the sudden and direct release of this gas into the optical path.

Each LN_2 pump shall be capable of operating at full pumping speed with a minimum of 90 days between LN_2 transfers, even with a thick layer of condensed gas (emissivity = 1). There shall be provisions to minimize the LN_2 consumption, including multilayer insulation, polished surfaces away from the optical paths, and low loss supports.

5.2.4 Getter Pumps Getter pumps of 10000 to 20000 liters/sec pump speed (hydrogen) shall be mounted near the LN_2 pumps (on the beam tube side) to pump the non-condensible active gases. These shall be UHV compatible and isolatable to enable regeneration or replacement.

5.2.5 Annulus Pumps Turbo molecular pump sets shall be provided for roughing of the annulus spaces. The pump set shall be self contained so that under power failure or pump failure, interlocks shall prevent the pumped chambers from being vented. Provisions for connection to the control system shall be provided. These pump sets shall not allow contamination of the annuluses with oil.

Ion pumps shall be provided to maintain the annulus vacuum; they shall hold the maximum annulus pressure to less than 10^{-3} torr. Noble gas diode pumps shall be used. The same pump may be used for several adjacent annuluses provided the required pressures are achieved. The ion pump controllers shall be mountable in standard 19 inch racks.

5.3 Valve Subsystem

5.3.1 Gate Valves All gate valves shall be stainless steel with metal sealed flanges or weld fittings where appropriate, and metal bellows stem feedthroughs. Only non-contaminating and non-migratory lubrication shall be used on the internal mechanisms. Valve body and flange leakage shall be measured to be less than 10^{-10} torr•liter/sec of helium before installation. 48 inch and larger gate valves shall have double viton gate seals. Annular spaces between gate valve seals shall be isolated and independent of other annulus volumes for pumping and venting requirements. Smaller valves shall have a single viton seal. All gate seals shall be leak free to a level of 10^{-9} torr•liter/sec of helium.

Valves of the same size and type shall be identical to minimize the number of required spare parts.

All valves, regardless of operation (electric, pneumatic, or manual), shall be protected from accidental operation. Such protection may be provided by mechanical, electrical, or procedural means. In instances where accidental venting is possible, redundant means shall be employed.

5.3.2 Small Valves Small valves (less than 15cm aperture), such as right angle manual valves exposed to the beam chamber, shall be all metal and bakeable. Valves used on the o-ring annuluses and those which are mounted on the portable pump stations may be viton sealed.

5.4 Vent and Purge Subsystem Components inside each of the chambers shall be protected against particulate contamination at all times: when chambers are open, while venting to air, during opening and closing, and when closed, including pumpdown. This protection shall be equivalent to exposure within a Fed. Std. 209 Class 100 clean room. The vacuum enclosure area of each station will be designed as a Fed. Std. 209 Class 50,000 clean room. Vent and purge systems shall be provided with valved and pressure limited, non-condensing, Class 100 air with a water vapor dew point of less than —20 degrees Celsius. The purge system shall allow for the connection of air shower manifolds in the chambers, used to distribute purge gas over the optical components inside the chambers.

5.5 Bakeout Subsystem Insulation and heating equipment shall be modular so as to allow efficient removal and placement. There need only be enough equipment to bake the largest contiguous vacuum section at one time; however, the equipment shall be capable of baking any of the vacuum sections. Temperature sensors shall be installed at positions representing minimum and maximum temperatures. Bakeout controls shall be sufficient to insure that the performance requirements are met.

Alternate degassing methods such as photo-induced and/or ion-induced desorption may be employed provided they can be shown to be cost effective or cleaner (no insulation needed).

5.6 Monitor and Control Subsystem Vacuum monitoring equipment includes Pirani gauges, ion gauges (cold cathode), leak detectors, RGAs and auxiliary ports. Gauge tubes shall be mounted on 2 3/4 inch metal seal CF flanges at the locations shown in Figures 2 and 3. Ports(4 1/2 inch CF) shall be provided for RGA sensors. The RGA type and model will be selected by Caltech at a future date. There shall be two auxiliary ports (one 2 3/4 and one 4 1/2 inch CF) complete with all metal valves and blankoffs for each chamber.

Vacuum controls includes the control logic, interlocks, and instrumentation required to allow safe and reliable operation of valves, pumps and gauges under all conditions. There shall be sufficient logic to allow control of the entire system (one site) from a central location in the corner station. The control logic will be incorporated into a commercial process control system to be provided by Caltech. The interfaces to this system shall consist of discreet digital and analog signals. Signal types, cabling and connectors are subject to Caltech approval.

Electronics racks and cable trays will be provided by Caltech.

5.6.1 Monitoring Instruments Vacuum instrumentation shall be provided for pressures from atmospheric down to 10^{-10} torr. Each chamber and beam tube section which can be isolated shall have installed one Pirani gauge, and one cold cathode gauge. Controllers shall be provided for all instruments. All vacuum feedthroughs shall be alumina ceramic.

5.6.1.1 Pirani Gauges Pirani gauges shall operate from atmosphere to 10^{-4} torr. The gauge controller shall be mountable in a standard 19 inch rack. The controller shall have a digital display and at least one setable process control contact or setpoint. The gauges shall be installed on CF flanges and be bakeable to 300 degrees Celsius.

5.6.1.2 Cold Cathode Gauges Cold cathode gauges shall operate from 10^{-3} torr to 10^{-10} torr. The gauge controller shall be mountable in a standard

19 inch rack. The controller shall have a digital display and at least one setable process control contact or setpoint. The gauges shall be installed on CF flanges and be bakeable to 300 degrees Celsius.

5.6.2 Control Logic In order to prevent accidental venting all gate valves with pneumatic or electric operators shall have at least 2 independent levels of interlock protection provided. All high voltage (greater than 24 volts in vacuum) devices shall be interlocked to prevent or minimize filament burnout, high current flow, glow discharge, or arcing. The design of the interlocks and control logic shall not preclude incorporation into the process control system (to be provided by Caltech). The vacuum system shall be designed to allow local protection and control as well as centralized control, monitoring and logging.

5.6.3 Helium Leak Detectors The helium leak detectors shall be mobile and have a minimum detectable leak rate of less than $1x10^{-10}$ torr•liter/sec for helium. The leak detector shall be turbopumped and shall be designed for connection to the backing side of the pump stations. The leak detector shall not permit oil backstreaming to the test port. Calibrated helium leaks shall be provided with each detector.

6. QUALITY ASSURANCE

6.1 Test Plans Detailed plans including descriptions of the test equipment and procedures for the qualification, screening, and acceptance tests shall be approved by Caltech prior to use.

6.2 Control of Contamination Detailed plans to insure control of cleanliness shall be approved by Caltech.

6.3 Component Acceptance Tests

6.3.1 Chamber and Tube Leak Tests The contractor shall measure total helium leakage rates on each vacuum chamber or tube section as part of the fabrication process. No vacuum chamber or fabricated tube section shall be field installed without first demonstrating acceptable leakage.

6.3.2 Pumps Each electrically powered vacuum pump shall be tested (or certified) for speed, ultimate pressure, leakage, noise and vibration, and operation of protective features, before shipment from the manufacturer.

6.3.3 Valve Tests Each vacuum valve shall be tested for leakage prior to shipment from the manufacturer. For dual gate seals, each seal shall be individually tested. As well, each vacuum valve (including each individual gate seal) shall be tested for leakage after installation on the LIGO vacuum system. Operation of each valve shall also be demonstrated.

6.4 System Acceptance Tests

6.4.1 Leakage All vacuum leaks greater than the limit set by the system requirements section shall be measured, repaired and documented.

6.4.2 Pumpdown Pumpdown from atmosphere to ultimate pressure (100 hours pumping) shall be performed on all vacuum sections and documented.

6.4.3 Noise and Vibration Acoustic noise shall be measured and documented at the vacuum chamber walls with all the vacuum equipment operating simultaneously; background levels shall be measured and documented as well. Vibration levels at the floor near the chambers shall be measured and documented, both with and without simultaneous operation of all of the vacuum equipment.

6.4.4 Control and Monitoring Operation of each vacuum gauge shall be demonstrated after installation.

Operation of each vacuum pump and each valve shall be demonstrated after installation.

Operation, temperature uniformity, and temperature stability of the bakeout system shall be demonstrated.

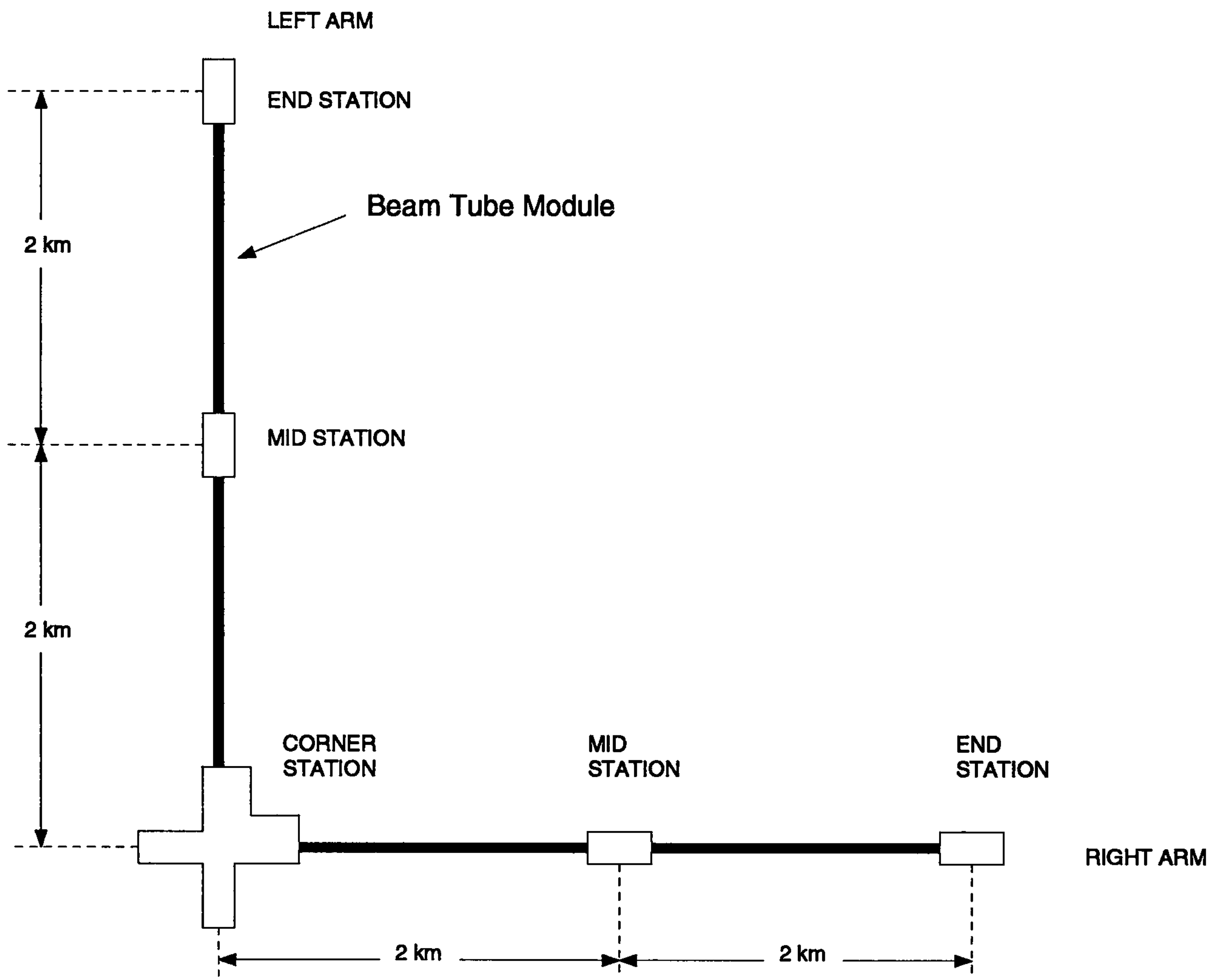


Figure 1. LIGO Geometry

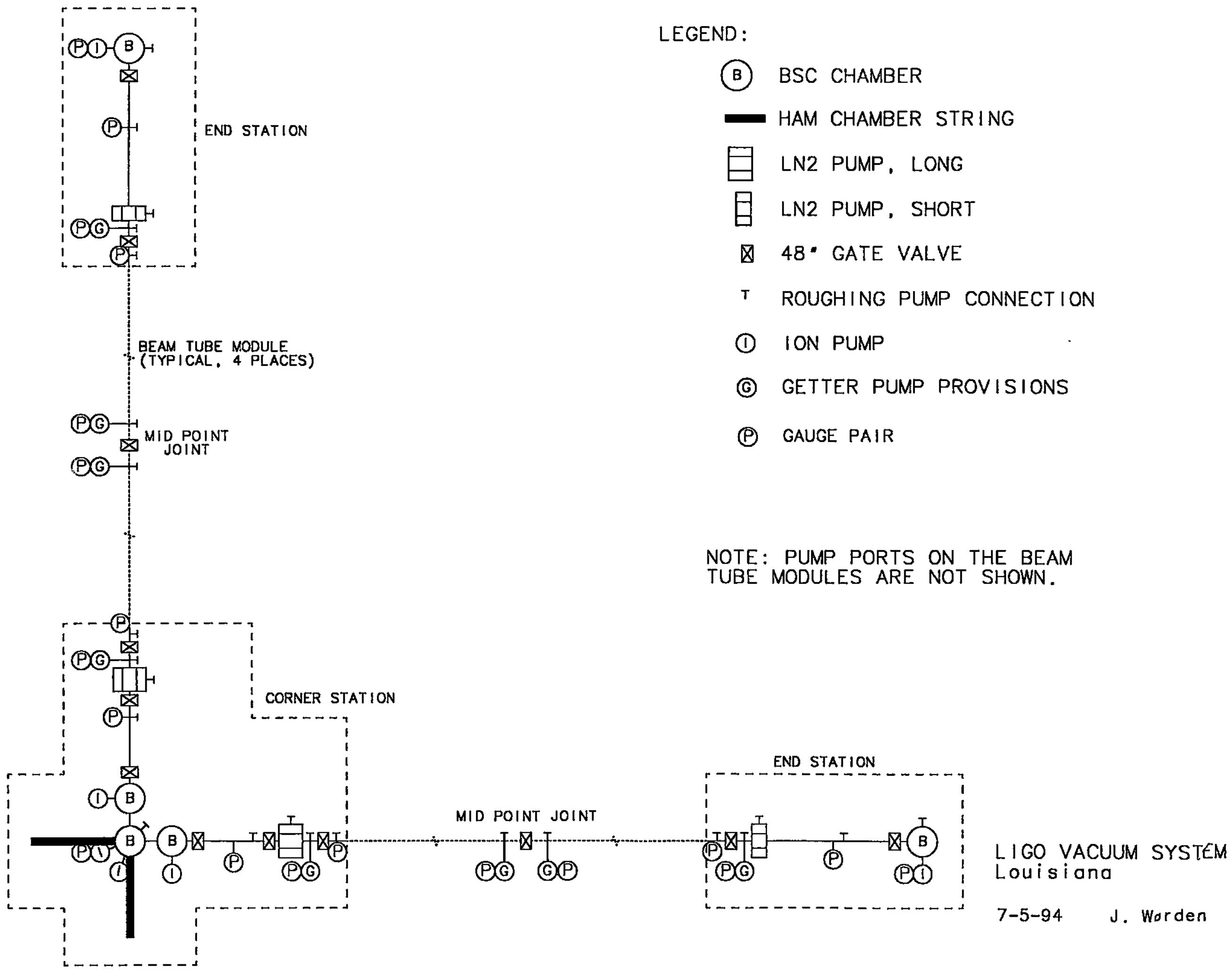
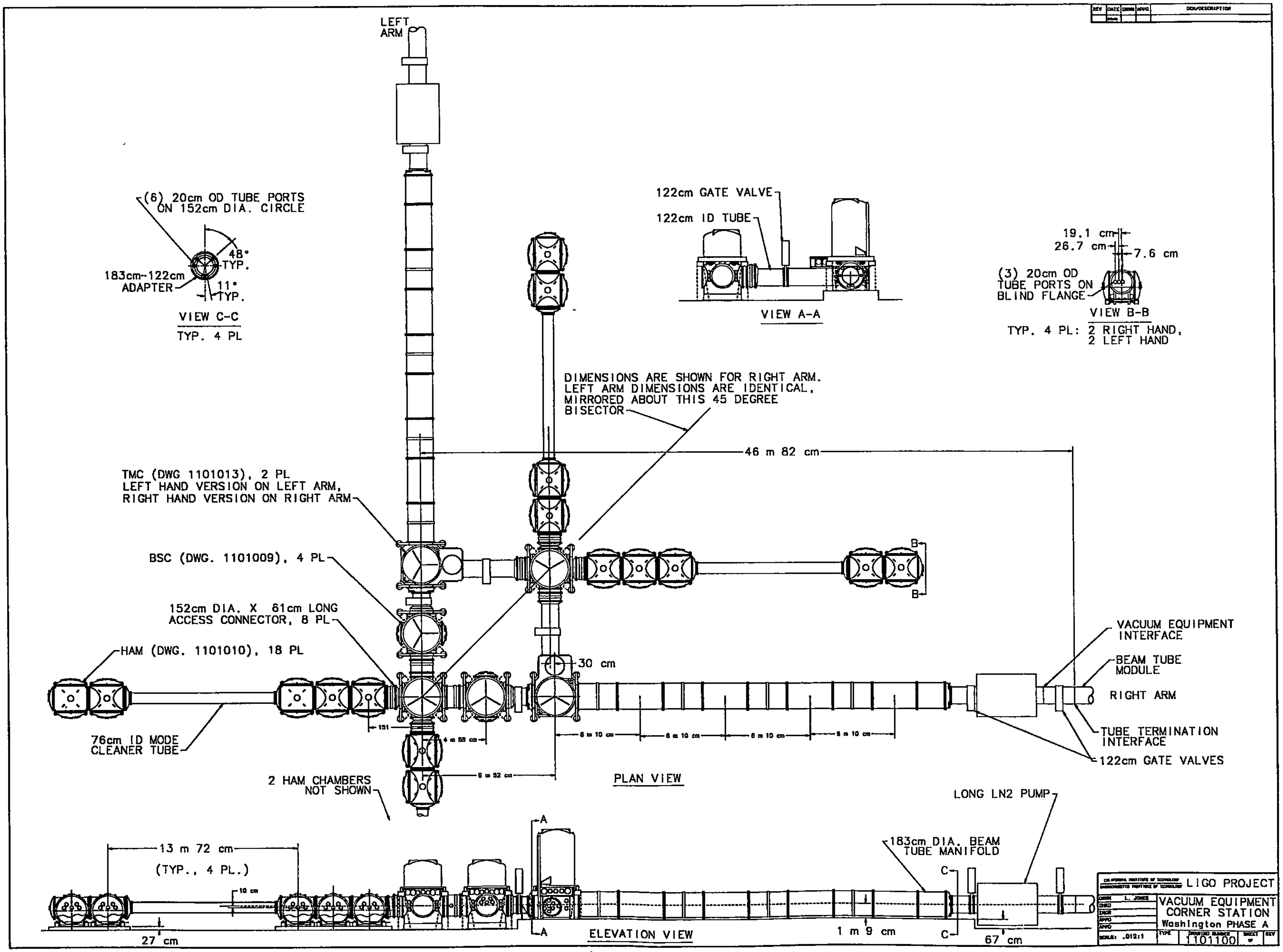
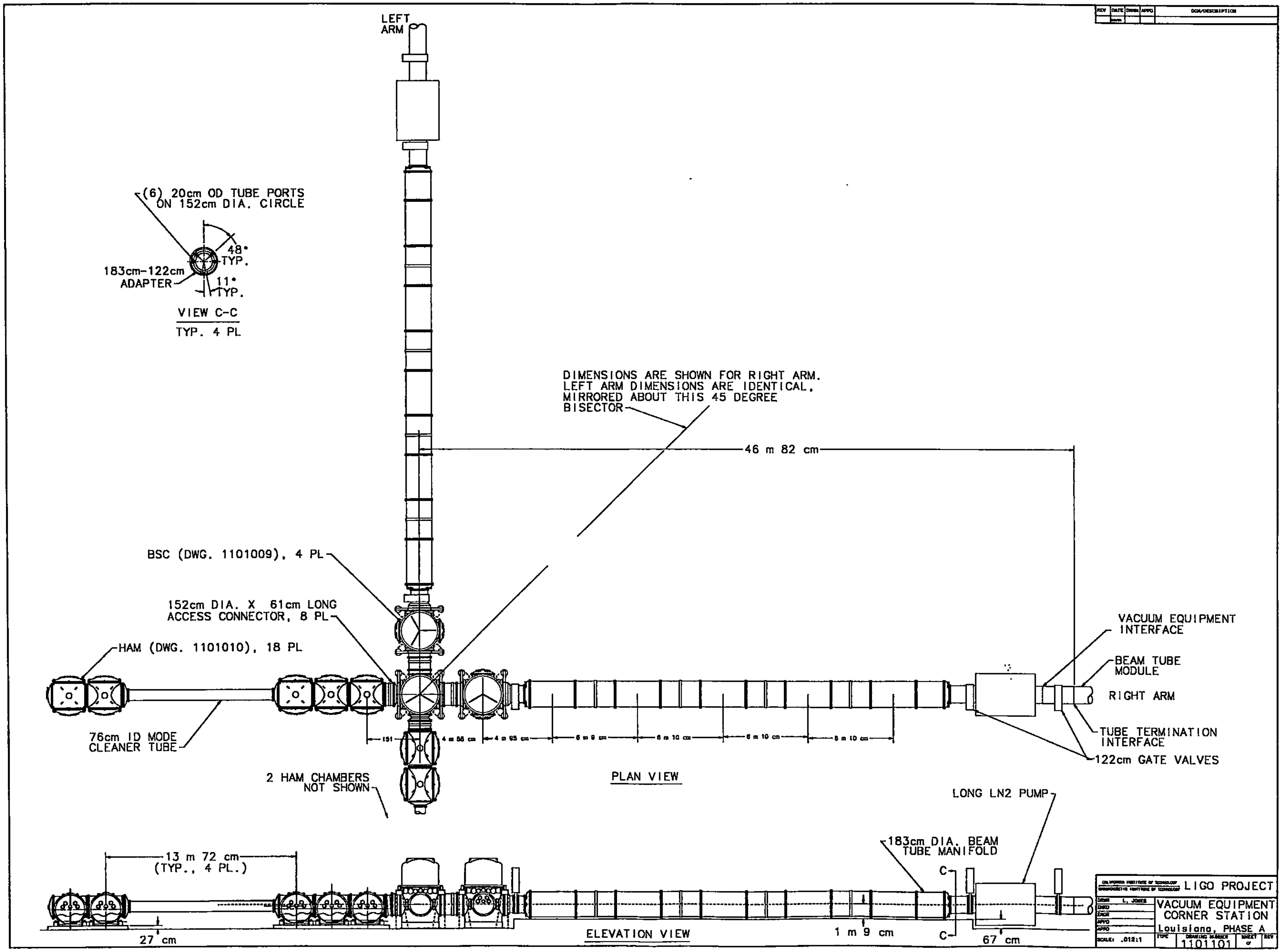

END STATION
BEAM TUBE MODULE (TYPICAL, 4 PLACES)
MID POINT JOINT
CORNER STATION
MID POINT JOINT
END STATION
LEGEND:
BSC CHAMBER
HAM CHAMBER STRING
LN2 PUMP, LONG
LN2 PUMP, SHORT
48" GATE VALVE
ROUGHING PUMP CONNECTION
ION PUMP
GETTER PUMP PROVISIONS
GAUGE PAIR
NOTE: PUMP PORTS ON THE BEAM TUBE MODULES ARE NOT SHOWN.
LIGO VACUUM SYSTEM
Louisiana
7-5-94 J. Worden

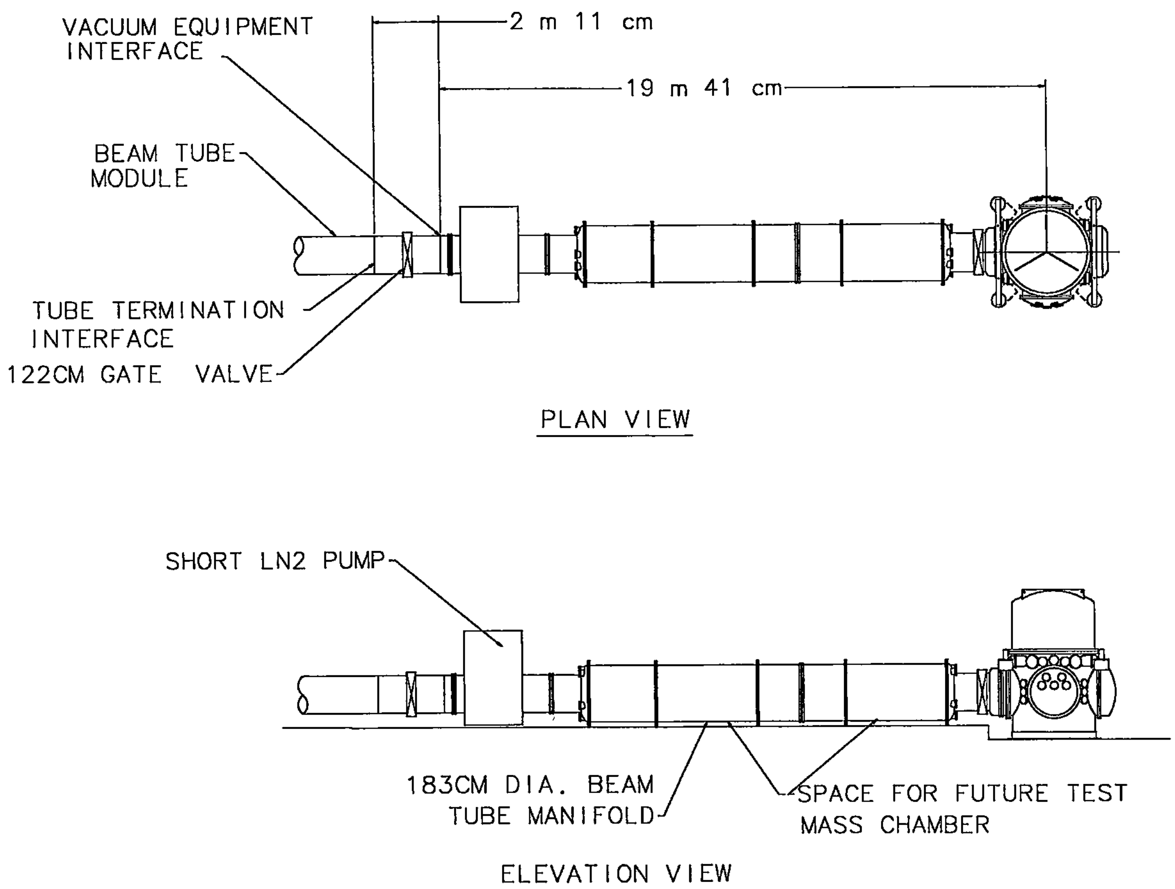
Figure 3.



LEFT ARM
(6) 20cm OD TUBE PORTS ON 152cm DIA. CIRCLE
48° TYP.
183cm-122cm ADAPTER
11° TYP.
VIEW C-C
TYP. 4 PL
122cm GATE VALVE
122cm ID TUBE
VIEW A-A
19.1 cm
26.7 cm
7.6 cm
(3) 20cm OD TUBE PORTS ON BLIND FLANGE
VIEW B-B
TYP. 4 PL: 2 RIGHT HAND, 2 LEFT HAND
DIMENSIONS ARE SHOWN FOR RIGHT ARM. LEFT ARM DIMENSIONS ARE IDENTICAL, MIRRORED ABOUT THIS 45 DEGREE BISECTOR
46 m 82 cm
TMC (DWG 1101013), 2 PL LEFT HAND VERSION ON LEFT ARM, RIGHT HAND VERSION ON RIGHT ARM
BSC (DWG. 1101009), 4 PL
152cm DIA. X 61cm LONG ACCESS CONNECTOR, 8 PL
HAM (DWG. 1101010), 18 PL
30 cm
VACUUM EQUIPMENT INTERFACE
BEAM TUBE MODULE
RIGHT ARM
TUBE TERMINATION INTERFACE
122cm GATE VALVES
76cm ID MODE CLEANER TUBE
2 HAM CHAMBERS NOT SHOWN
PLAN VIEW
LONG LN2 PUMP
13 m 72 cm
(TYP., 4 PL.)
183cm DIA. BEAM TUBE MANIFOLD
27 cm
ELEVATION VIEW
1 m 9 cm
67 cm
LIGO PROJECT
VACUUM EQUIPMENT CORNER STATION Washington PHASE A
1101100

Figure 4.


LEFT ARM
(6) 20cm OD TUBE PORTS ON 152cm DIA. CIRCLE
48° TYP.
183cm-122cm ADAPTER
11° TYP.
VIEW C-C
TYP. 4 PL
DIMENSIONS ARE SHOWN FOR RIGHT ARM. LEFT ARM DIMENSIONS ARE IDENTICAL, MIRRORED ABOUT THIS 45 DEGREE BISECTOR
46 m 82 cm
BSC (DWG. 1101009), 4 PL
152cm DIA. X 61cm LONG ACCESS CONNECTOR, 8 PL
HAM (DWG. 1101010), 18 PL
VACUUM EQUIPMENT INTERFACE
BEAM TUBE MODULE
RIGHT ARM
TUBE TERMINATION INTERFACE
122cm GATE VALVES
76cm ID MODE CLEANER TUBE
2 HAM CHAMBERS NOT SHOWN
PLAN VIEW
LONG LN2 PUMP
183cm DIA. BEAM TUBE MANIFOLD
13 m 72 cm (TYP., 4 PL.)
C
C
27 cm
ELEVATION VIEW
1 m 9 cm
67 cm
LIGO PROJECT
VACUUM EQUIPMENT CORNER STATION
Louisiana, PHASE A
1101101



END STATION

BOTH SITES

LIGO PROJECT

VACUUM EQUIPMENT END STATIONS

J. Worden

1101102

Figure 6.

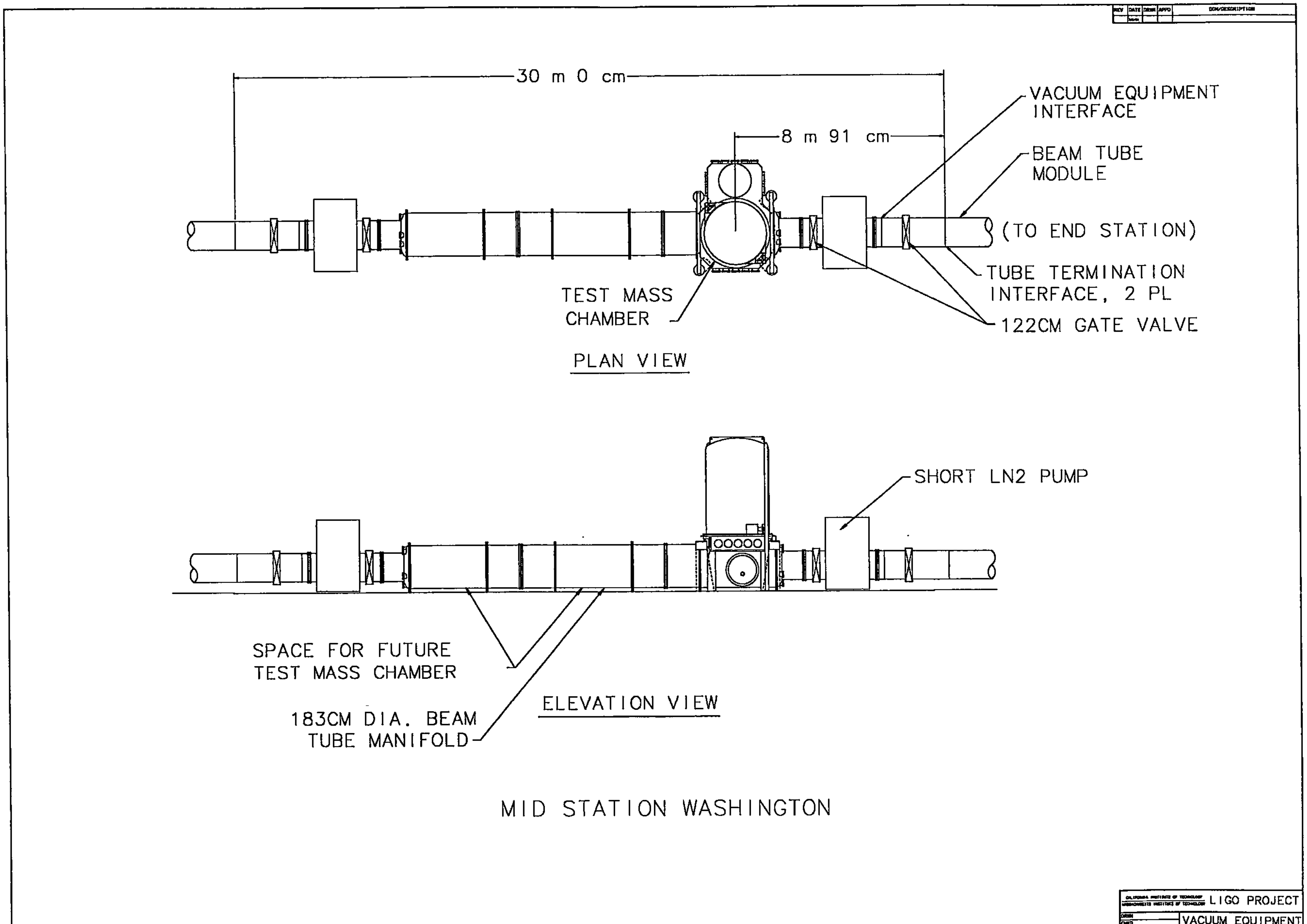
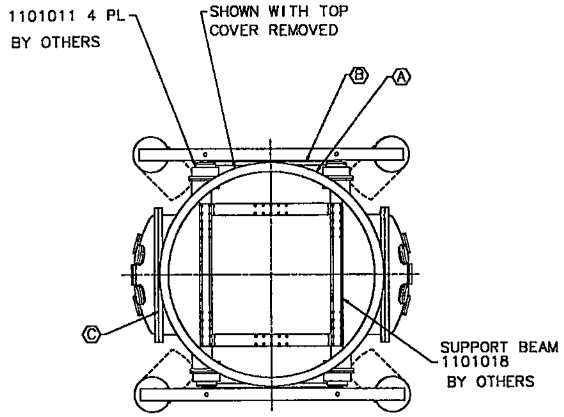

30 m 0 cm
8 m 91 cm
VACUUM EQUIPMENT INTERFACE
BEAM TUBE MODULE
(TO END STATION)
TUBE TERMINATION INTERFACE, 2 PL
122CM GATE VALVE
TEST MASS CHAMBER
PLAN VIEW
SHORT LN2 PUMP
SPACE FOR FUTURE TEST MASS CHAMBER
183CM DIA. BEAM TUBE MANIFOLD
ELEVATION VIEW
MID STATION WASHINGTON
LIGO PROJECT
VACUUM EQUIPMENT
MID STATION
Washington
1101103

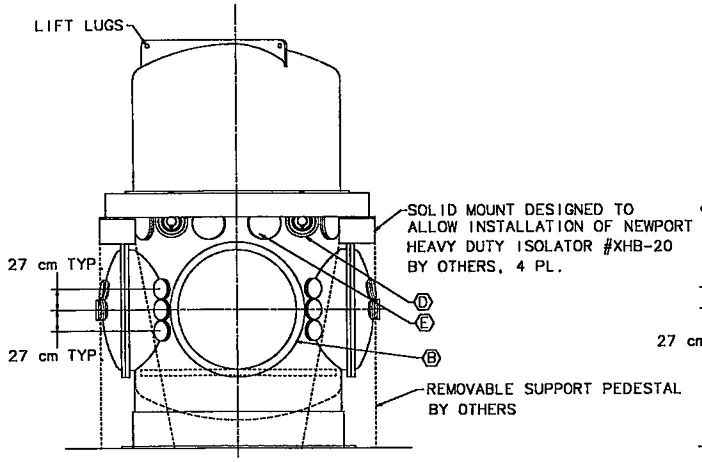
Figure 7.

NOTES:
1. HEADS ARE ASME F&D.
2. INCLUDE CENTERING PINS ON NOZZLE FLANGES WHERE APPROPRIATE.
3. VIEWPORT (ITEM Ⓖ) MEASUREMENTS REFER TO INTERSECTION OF VIEWPORT AXIS WITH OUTER SURFACE OF VACUUM WALL.
4. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.25 CM
ANGULAR, ± 1 DEGREE
5. NOZZLE SCHEDULE PER TABLE BELOW:

ITEM	SIZE	QUANTITY	FLANGE TYPE	PURPOSE
Ⓐ	264cm ID TUBE	1	O/O-O/METAL*	MAJOR ACCESS
Ⓑ	152cm ID TUBE	2	O/O-O/METAL*	LASER BEAM, ACCESS (MINIMIZE NECK LENGTH)
Ⓒ	152cm ID TUBE	2	O/O-O/METAL*, WITH BLIND FLANGE	ACCESS (MINIMIZE NECK LENGTH)
Ⓓ	35cm OD TUBE	4	CONFLAT**	SUPPORT BEAMS
Ⓔ	35cm OD TUBE***	8	CONFLAT**, WITH BLIND FLANGE	AIR SHWR, BACK-TO-AIR PURGE ROUGHING & ION PUMPS, UTILITY
Ⓕ	25cm OD TUBE***	6	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS
Ⓖ	20cm OD TUBE***	22	CONFLAT**, WITH BLIND FLANGE	OBSERVATION, BEAM PICK-OFFS
Ⓗ	3.8cm OD TUBE	1	CONFLAT**, WITH BLIND FLANGE	ANNULUS PUMPOUT (NOT SHOWN)

*DUAL O-RING DESIGN, WITH CAPABILITY OF REPLACING INBOARD O-RING WITH METAL SEAL. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLDED TO A SINGLE PUMPOUT PORT ON EACH CHAMBER, WITH CONFLAT** SEAL.
**REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS; COMPATIBLE ALTERNATES ARE ACCEPTABLE.
***THESE FLANGES ARE TANGENT TO LOCAL VACUUM WALL, WITH MINIMUM NECK LENGTH.





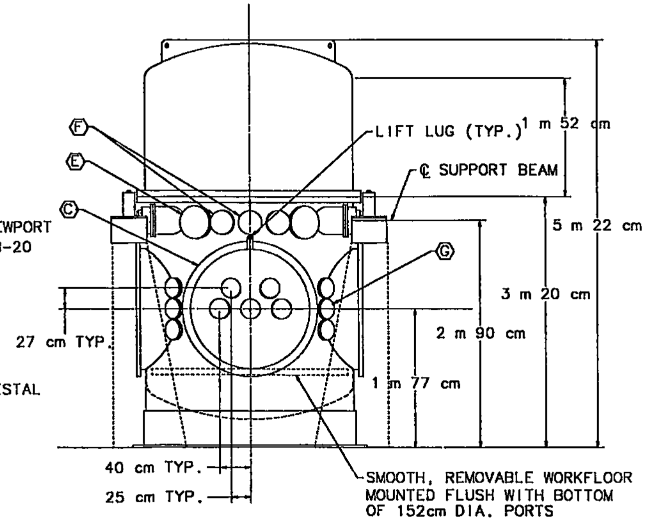


Figure 8.

LIGO PROJECT
BEAM SPLITTER CHAMBER (BSC)
1101009
1 of 1

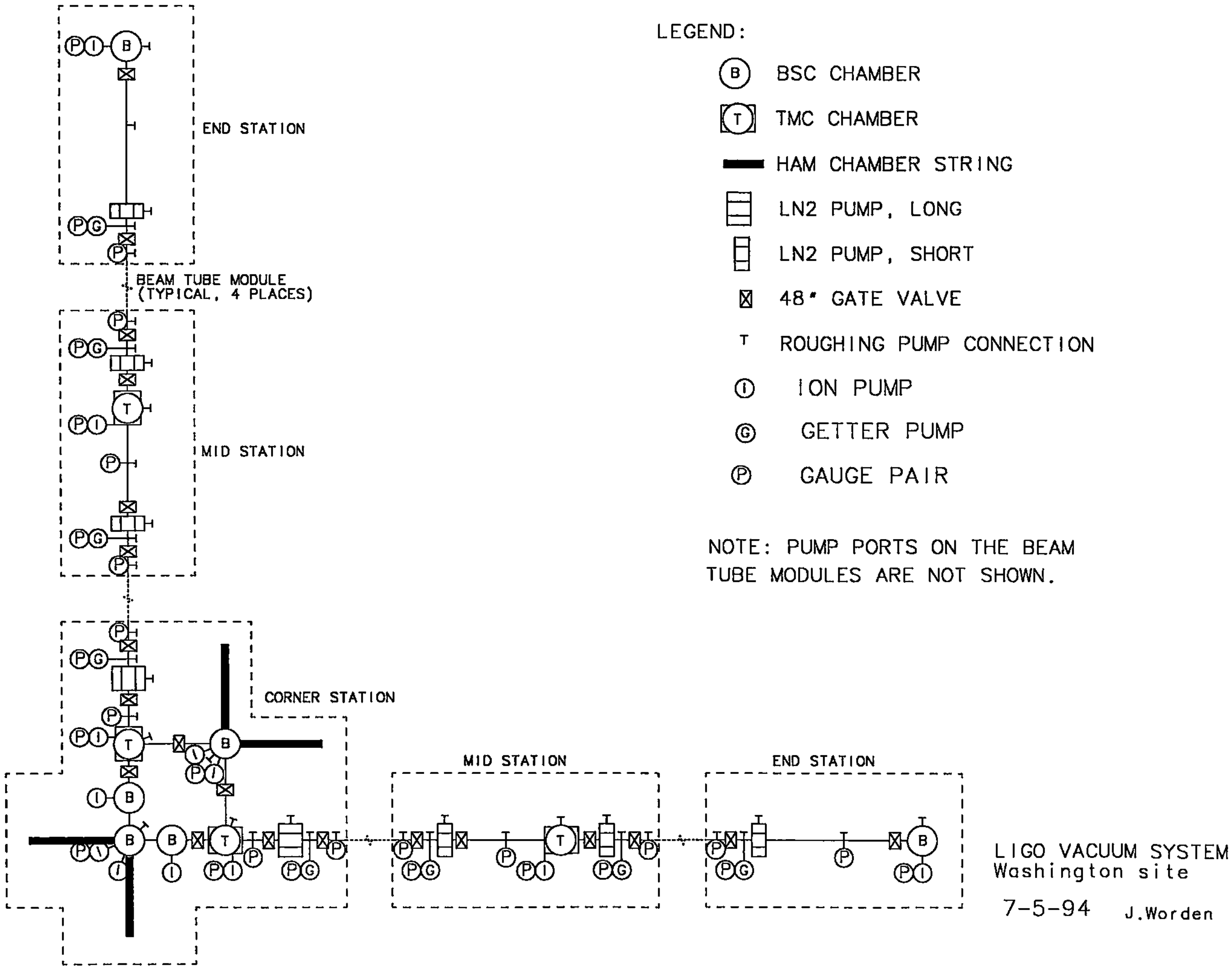

LEGEND:
B BSC CHAMBER
T TMC CHAMBER
HAM CHAMBER STRING
LN2 PUMP, LONG
LN2 PUMP, SHORT
48" GATE VALVE
ROUGHING PUMP CONNECTION
I ION PUMP
G GETTER PUMP
P GAUGE PAIR
NOTE: PUMP PORTS ON THE BEAM TUBE MODULES ARE NOT SHOWN.
END STATION
BEAM TUBE MODULE (TYPICAL, 4 PLACES)
MID STATION
CORNER STATION
MID STATION
END STATION
LIGO VACUUM SYSTEM
Washington site
7-5-94
J.Worden

Figure 2.

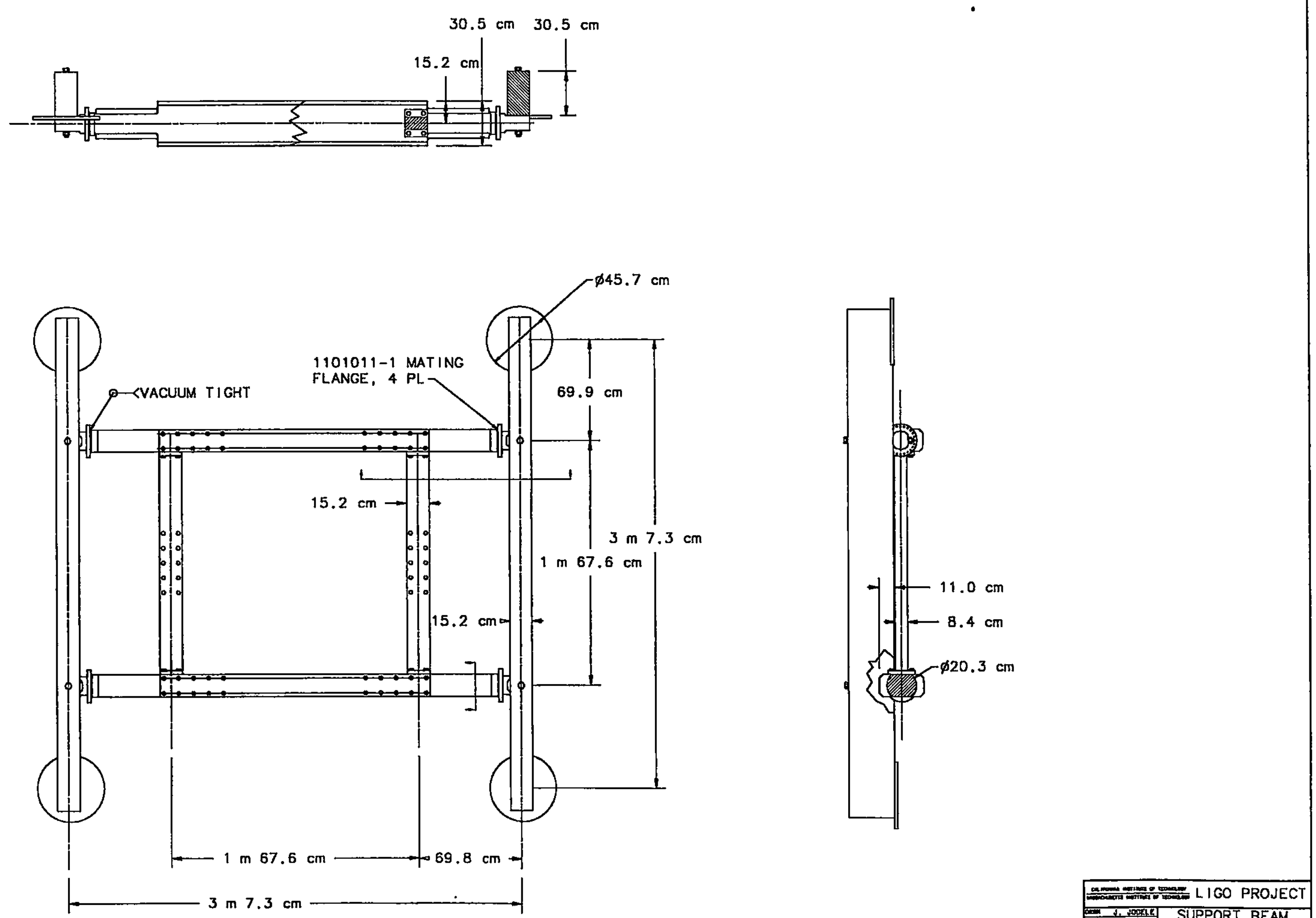

30.5 cm
30.5 cm
15.2 cm
ø45.7 cm
1101011-1 MATING
FLANGE, 4 PL
VACUUM TIGHT
69.9 cm
15.2 cm
3 m 7.3 cm
1 m 67.6 cm
15.2 cm
11.0 cm
8.4 cm
ø20.3 cm
1 m 67.6 cm
69.8 cm
3 m 7.3 cm
LIGO PROJECT
J. JOOELE
SUPPORT BEAM
ASSEMBLY,
LARGE CHAMBERS
1/10
1101018
1 of 1

Figure 9.

NOTES:
1. BELLOWS SPRING RATE: AXIAL <500 LB/IN.
2. RATED PRESSURE DIFFERENTIAL (EXTERNAL) ≥ 40 PSI AT 300 DEGREES F
3. DESIGN LIFE OF BELLOWS, AT ±0.59" AXIAL STROKE, ±0.84" LATERAL STROKE, AND ±11 MINUTES ROTATIONAL STROKE: 2000 CYCLES
4. ALL LINEAR DIMENSIONS ARE IN INCHES
5. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.1 INCH
   ANGULAR, ±1 DEGREE

*REGISTERED TRADEMARK, VARIAN ASSOCIATES, INC.

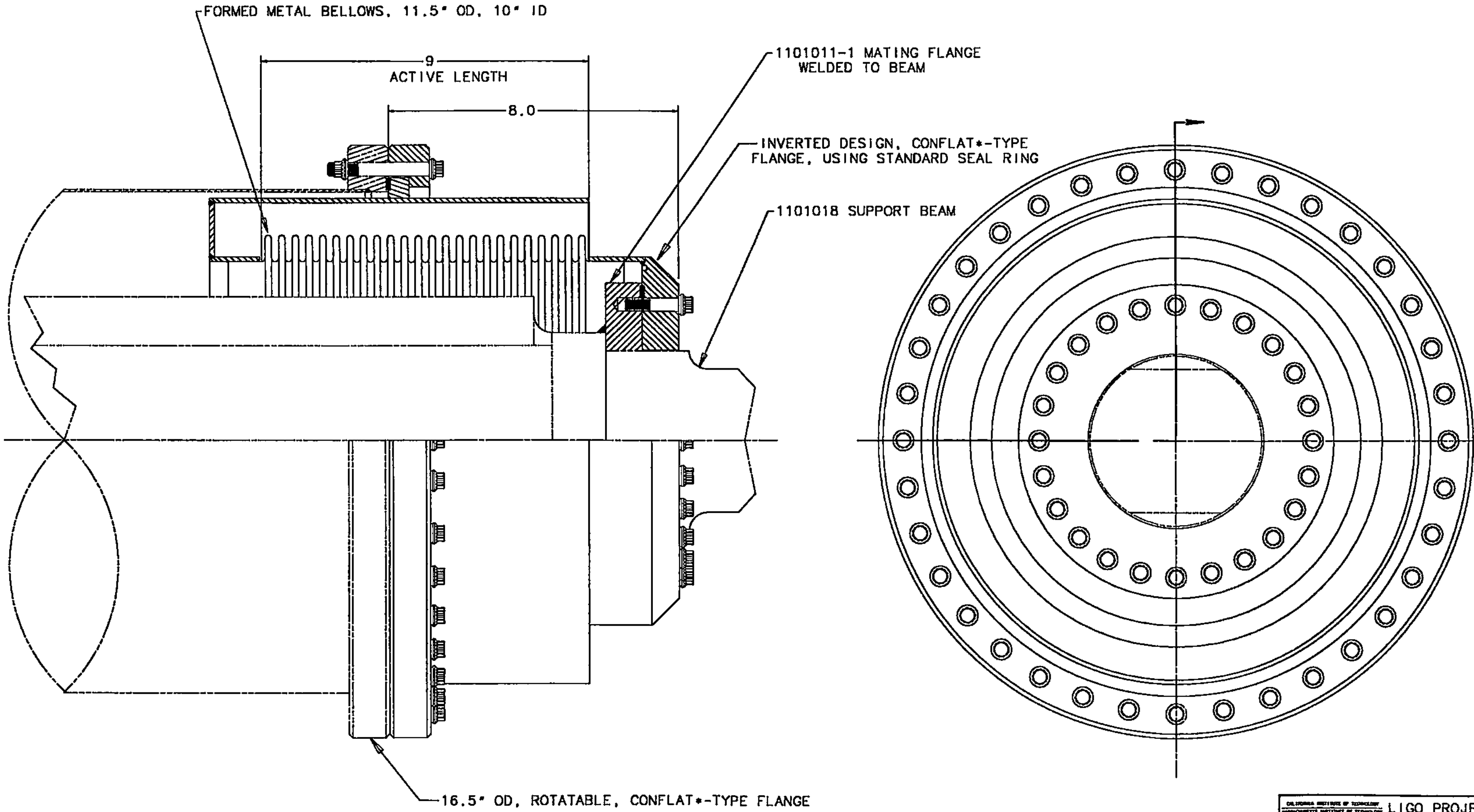


Figure 10.

LIGO PROJECT
10" ISOLATION BELLOWS
(CONFIGURATION)
1101011

NOTES:
1. HEADS ARE ASME F&D.
3. INCLUDE CENTERING PINS ON NOZZLE FLANGES WHERE APPROPRIATE.
3. VIEWPORT (ITEM (F)) MEASUREMENTS REFER TO INTERSECTION OF VIEWPORT AXIS WITH OUTER SURFACE OF VACUUM WALL.

4. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.25 CM
ANGULAR, ± 1 DEGREE

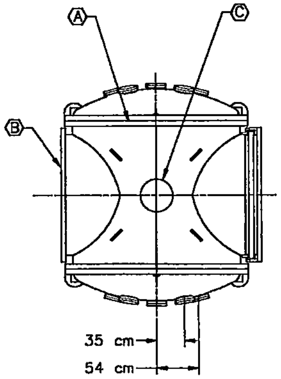
5. NOZZLE SCHEDULE PER TABLE BELOW:

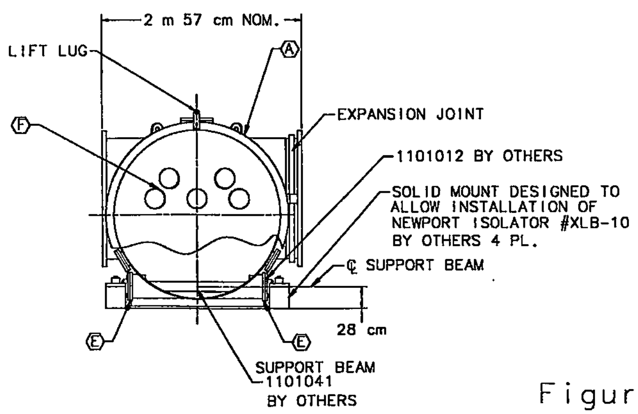
ITEM	SIZE	QUANTITY	FLANGE TYPE	PURPOSE
(A)	213cm ID TUBE	2	O/O-O/METAL*	MAJOR ACCESS
(B)	152cm ID TUBE	2	O/O-O/METAL*	LASER BEAM
(C)	35cm TUBE	1	CONFLAT**, WITH BLIND FLANGE	ION PUMP/AIR SHOWERS, BACK-TO-AIR PURGE
(D)	25cm OD TUBE	8	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS, UTILITY
(E)	30cm OD TUBE	4	CONFLAT**	SUPPORT BEAMS
(F)	20cm OD TUBE***	10	CONFLAT**, WITH BLIND FLANGE	OBSERVATION, PICKOFFS
(G)	3.8cm TUBE	1	CONFLAT**, WITH BLIND FLANGE	ANNULUS PUMPOUT (NOT SHOWN)

* DUAL O-RING DESIGN, WITH CAPABILITY OF REPLACING INBOARD O-RING WITH METAL SEAL. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLDED TO A SINGLE PUMPOUT PORT ON EACH CHAMBER, WITH CONFLAT** SEAL.

** REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS; COMPATIBLE ALTERNATIVES ARE ACCEPTIBLE

*** THESE FLANGES ARE TANGENT TO LOCAL VACUUM WALL, WITH MINIMUM NECK LENGTH





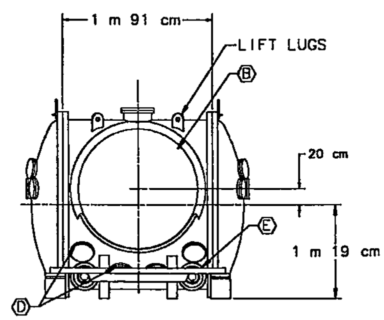


Figure 11.

LIGO PROJECT
DRWN J. JODELE
HORIZONTAL AXIS MODULE (HAM)
1101010

NOTES:
1. BELLOWS SPRING RATE: AXIAL <120LB/IN
2. RATED PRESSURE DIFFERENTIAL (EXTERNAL) ≥ 40 PSI AT 300 DEGREES F
3. DESIGN LIFE OF BELLOWS, AT ± 0.59" AXIAL STROKE, ± 0.84" LATERAL STROKE, AND AT ± 17 MINUTES ROTATIONAL STROKE: 2000 CYCLES
4. ALL LINEAR DIMENSIONS ARE IN INCHES
5. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ± 0.1 INCH
   ANGULAR, ± 1 DEGREE

*REGISTERED TRADEMARK, VARIAN ASSOCIATES, INC.

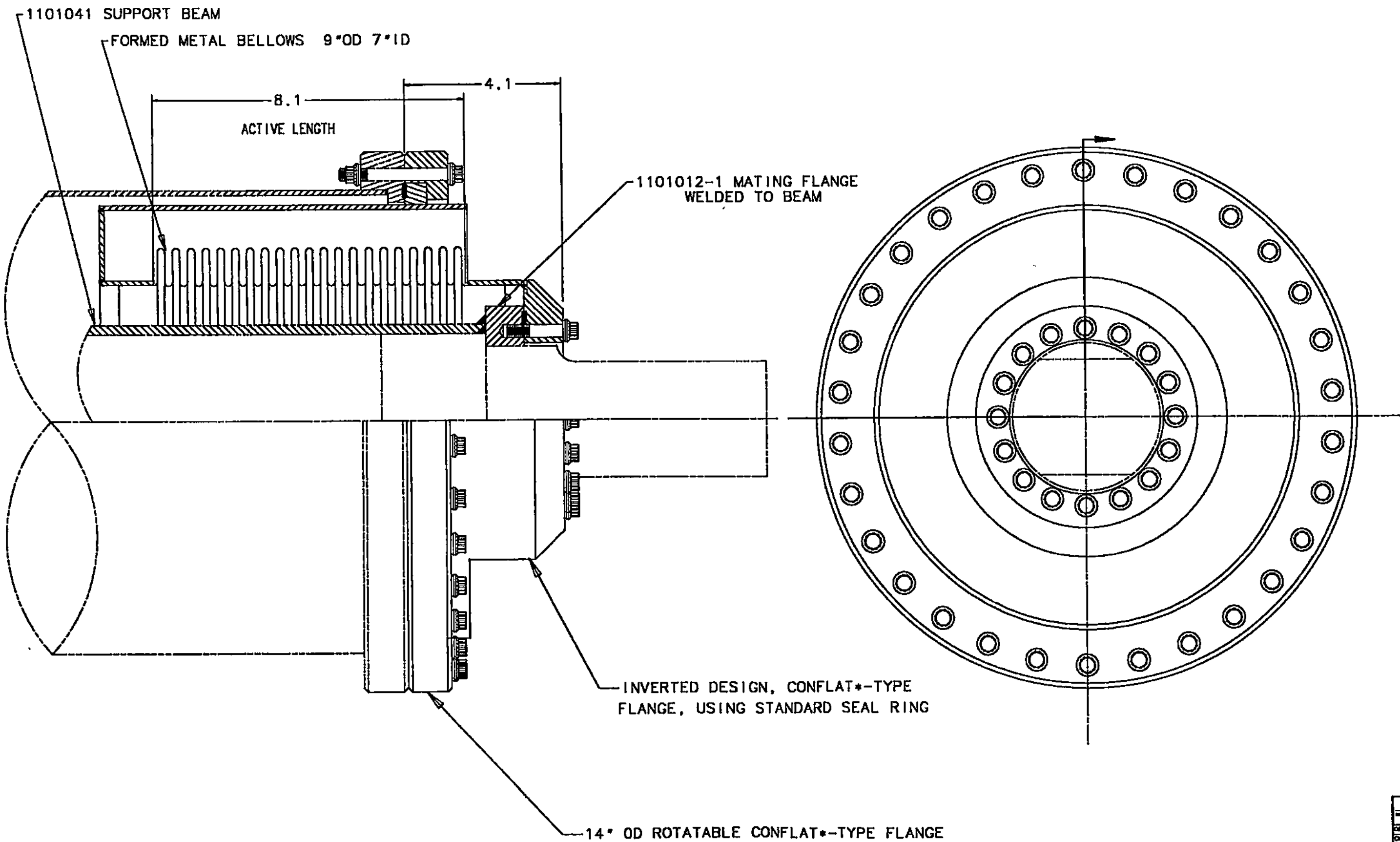


Figure 12.

LIGO PROJECT
7" ISOLATION BELLOWS (CONFIGURATION)
SCALE: FULL
1101012 1 of 1

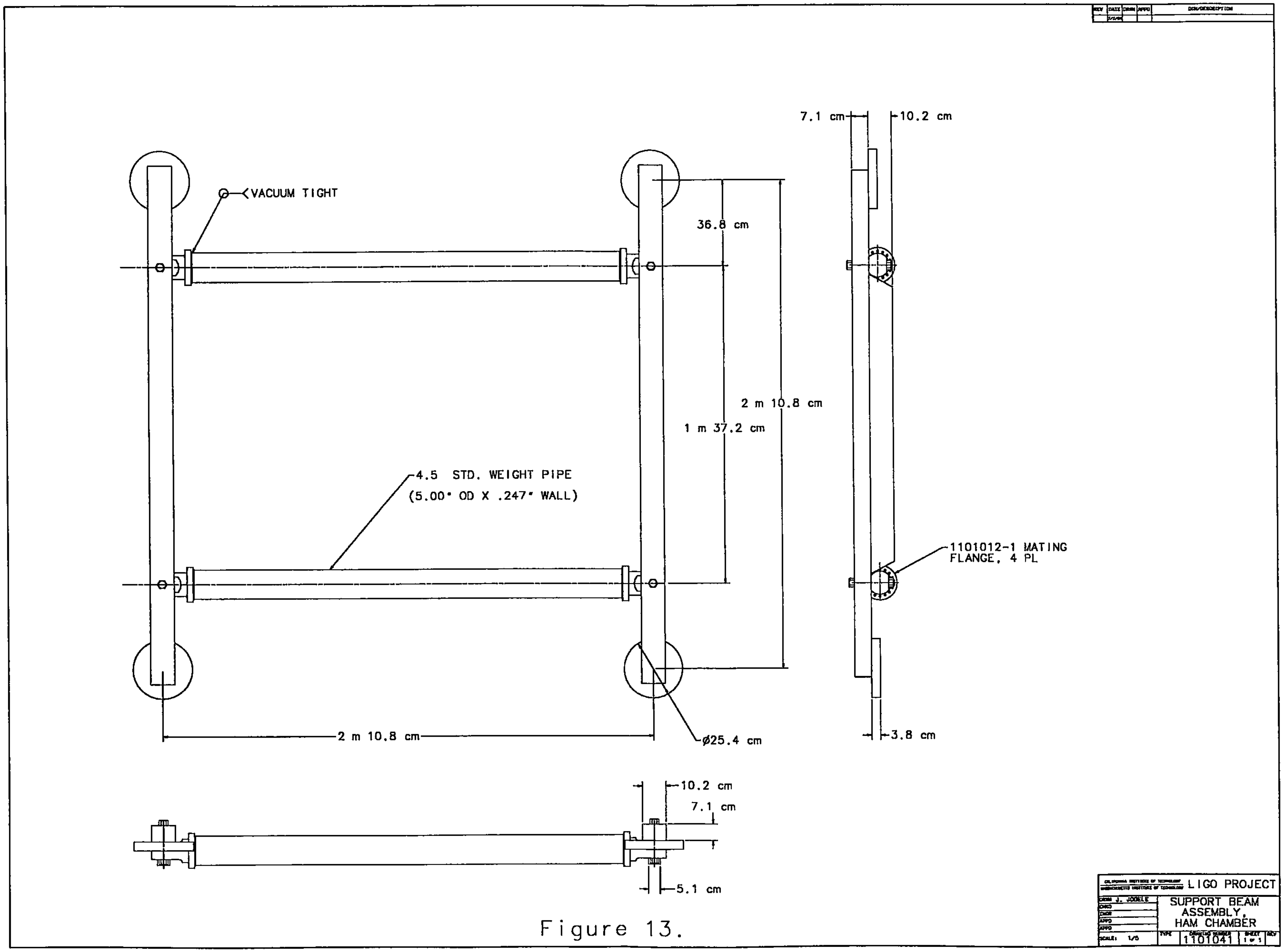

VACUUM TIGHT
36.8 cm
2 m 10.8 cm
1 m 37.2 cm
4.5 STD. WEIGHT PIPE
(5.00" OD X .247" WALL)
2 m 10.8 cm
ø25.4 cm
7.1 cm
10.2 cm
1101012-1 MATING FLANGE, 4 PL
3.8 cm
10.2 cm
7.1 cm
5.1 cm
LIGO PROJECT
SUPPORT BEAM ASSEMBLY, HAM CHAMBER
1101041

Figure 13.

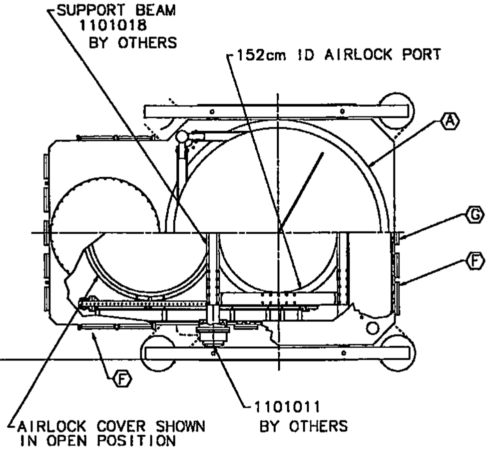
NOTES:
1. HEADS ARE ASME F&D.
2. INCLUDE CENTERING PINS ON NOZZLE FLANGES WHERE APPROPRIATE.
3. VIEWPORT (ITEM Ⓗ) MEASUREMENTS REFER TO INTERSECTION OF VIEWPORT AXIS WITH OUTER SURFACE OF VACUUM WALL.

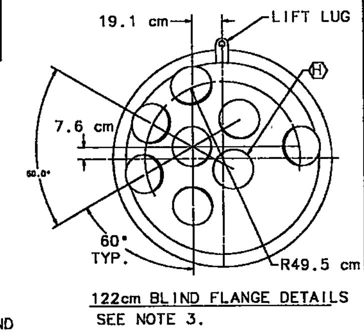
4. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.25 CM
ANGULAR, ± 1 DEGREE

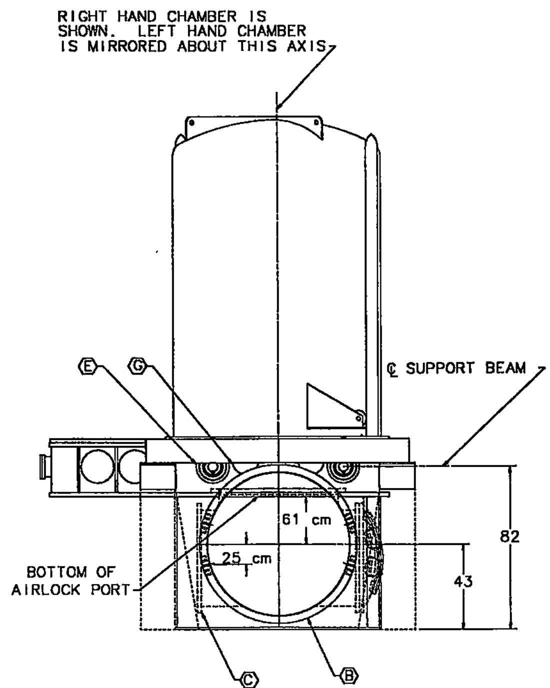
5. NOZZLE SCHEDULE PER TABLE BELOW:

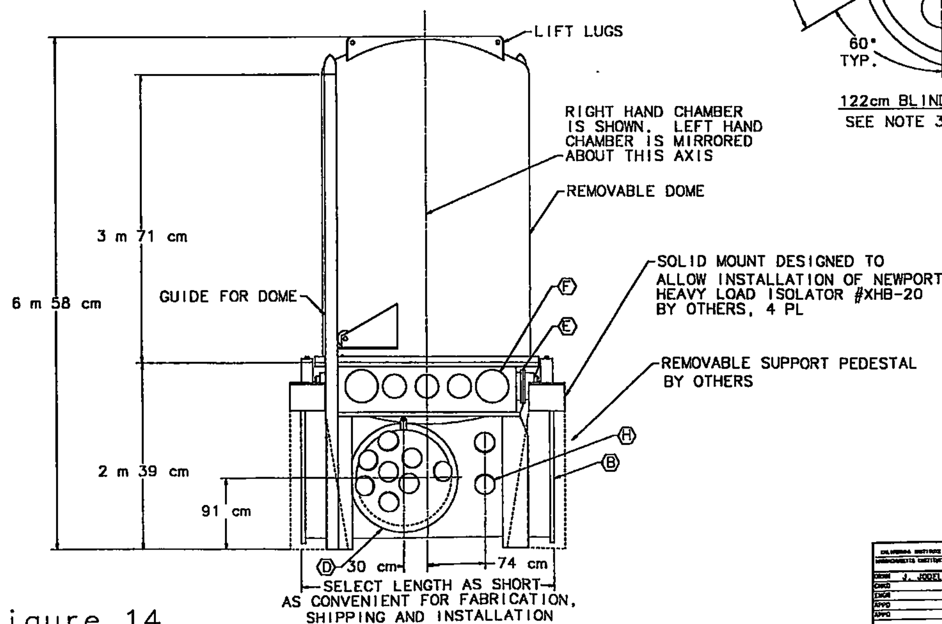
ITEM	SIZE	QUANTITY	FLANGE TYPE	PURPOSE
Ⓐ	264cm ID TUBE	1	O/O-O/METAL*	MAJOR ACCESS
Ⓑ	183cm ID TUBE	2	METAL SEAL	LASER BEAM
Ⓒ	122cm ID TUBE	1	O/O-O/METAL*	LASER BEAM
Ⓓ	122cm ID TUBE	1	O/O-O/METAL*, WITH BLIND FLANGE	EMERGENCY ACCESS (MINIMIZE NECK LENGTH)
Ⓔ	35cm OD TUBE	4	CONFLAT**	SUPPORT BEAMS
Ⓕ	35cm OD TUBE	6	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS ROUGHING & ION PUMPS, UTILITY
Ⓖ	25cm OD TUBE	12	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS, BACK-TO-AIR PURGE
Ⓗ	20cm OD TUBE***	12	CONFLAT**, WITH BLIND FLANGE	OBSERVATION, BEAM PICKOFFS
Ⓘ	3.8cm OD TUBE	1	CONFLAT**, WITH BLIND FLANGE	ANNULUS PUMPOUT (NOT SHOWN)

*DUAL O-RING DESIGN, WITH CAPABILITY OF REPLACING INBOARD O-RING WITH METAL SEAL. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLDED TO A SINGLE PUMPOUT PORT ON EACH CHAMBER, WITH CONFLAT** SEAL.
**REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS COMPATIBLE ALTERNATIVES ARE ACCEPTABLE
***THESE FLANGES ARE TANGENT TO LOCAL VACUUM WALL, WITH MINIMUM NECK LENGTH









LIGO PROJECT
TEST MASS CHAMBER (TMC)
DRAWN J. JOODLE
DRAWING NUMBER 1101013

Figure 14.

Science Requirements for the Vacuum Equipment

DHS

August 29, 1994

Science Requirements for the Vacuum Equipment

Pressure Requirements: Phase Noise

statistical fluctuation in optical path length

- **statistical fluctuation in optical path length**
- **can scale from beam tube requirements**
- **100 times shorter L, so 100 times higher P**
- **BUT: dominated by H2O for VacEq, by H2 for beam tubes**
- **higher polarizability so tighter pressure requirement**

Requirements

	beam tube (H2)	VacEq (H2O)
initial	10^{-6}	10^{-5}
enhanced	3×10^{-7}	3×10^{-6}
advanced	10^{-9}	10^{-8}

LIGO

Pressure Requirements: Pendulum Damping

viscous damping of pendulum by residual gas

- would increase pendulum thermal noise
- require that this be smaller than intrinsic damping
- phase noise requirement leads to $Q > 10^9$

no additional requirement beyond phase noise (previous page)

Pressure Requirements: Gas Bursts

pulse-like pressure fluctuations

- due to release of gas from microscopic pockets
- basically same problem as in beam tubes
- possibly more important in VacEq due to
  - frequent pumpout/backfill stresses
  - shocks due to valve opening/closing, lift mechanisms
- welds, bellows likely sources
- ion pumps also (best to turn on at low pressure: 10^{-6} or less

number of molecules in a just-visible burst, allowed 1/(20 sec) if no filter, veto:

initial	4×10^{11}
enhanced	1×10^{11}
advanced	3×10^{10}

no requirement has been determined for gas bursts at present

Science Requirements for the Vacuum Equipment

Contamination

degradation of optical surfaces by residual gas

- do not have data which allow a firm requirement to be set
- heavier hydrocarbons most likely culprit (with light power)
- have rule presently used in MarkII, no contradiction seen
- research underway to illuminate the problem

Present model:

The sum of partial pressures of AMU 41, 43, 53, 55, 57 should be less than 2×10^{-11}torr

Notes

- specify precautions (instead of partial pressure requirement):
    - only accepted materials in construction of VecEq
    - stainless, Viton, ceramic
    - oil-free pumping system with sure protection
- (more complicated materials used in detector proper)
- will have monitors (RGA, deposition) in chamber

Science Requirements for the Vacuum Equipment

Non-vacuum requirements

Vibration

- **Requirement: Vibration not to exceed LIGO Site Vibration Baseline by more than a factor of 2 in amplitude in normal operation**
- **Shocks not to drive suspended, controlled optics into earthquake stops**

Acoustics

- **Broad-band spectrum to be less than** $10^{-3}\mathrm{dyn/cm^2}\sqrt{\mathrm{Hz}}$ **at all frequencies between 0.3 Hz to 10 kHz with only few narrowband exceptions**

EMI

- **External EMI to be less than** $10^{-3}\mathrm{V/m}\sqrt{\mathrm{Hz}}$
- **Magnetic fields from mains to be less than 1 mgauss rms**

Cleanliness during purge and while open

- **Class 100 clean room conditions to be maintained during backfill and while at atmospheric pressure**

Failure modes, Consequences of failures

- **no foreseeable failure to admit hydrocarbons to VaqEq chambers**
- **beam tube vacuum protected as priority**

Science Requirements for the Vacuum Equipment

Requirements from the Operations Scenario

non-interference of independent interferometers for service/upgrade

- independent Ifos to be able to run independently
- possible to change optical layout in one Ifo,
    - without major disturbance of other Ifos; not on-line, but
    - no irreversible alignment changes in other Ifos (e.g., hit earthquake stops)
    - possible to run other Ifos during next 'shift' (e.g., at night)

pumpdown and purge

- assume rough pumping puts other Ifos off-line
- turbopumping not to interfere with other Ifos
- Requirement: 5 hours rough pumping time

alignment drift due to pumpout, thermal and barometric changes

- bellows arrangement to decouple VacEq from seismic isolation supports
- change in height of stack supports to be less than (say) 100 microns
    - (coupling of A&E with VaqEq requirements)

envelope compatibility, flexibility

- require that initial Ifo fit comfortably
- require that installation and adjustment be practical
- require that likely enhanced Ifo 'upgrades' fit comfortably
- require that all basic optical components of advanced Ifos fit comfortably
- require that layout be flexible (length, configuration)

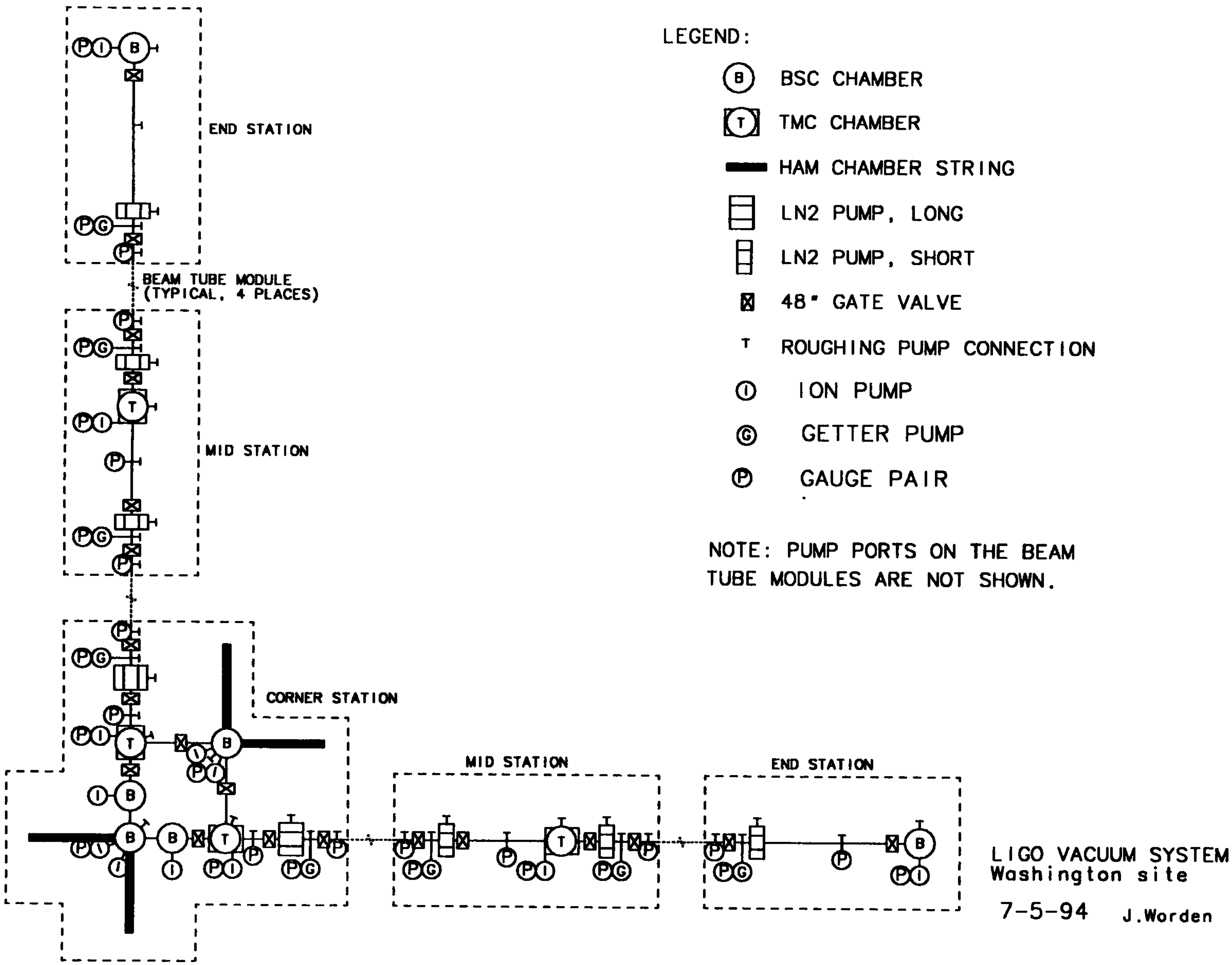
Vacuum Equipment Specification Review

J. Worden

Aug 31/94

Outline

- Performance
- Machine safety and controls
- Interfaces
- Failure modes



LEGEND:
BSC CHAMBER
TMC CHAMBER
HAM CHAMBER STRING
LN2 PUMP, LONG
LN2 PUMP, SHORT
48" GATE VALVE
ROUGHING PUMP CONNECTION
ION PUMP
GETTER PUMP
GAUGE PAIR
NOTE: PUMP PORTS ON THE BEAM TUBE MODULES ARE NOT SHOWN.
END STATION
BEAM TUBE MODULE (TYPICAL, 4 PLACES)
MID STATION
CORNER STATION
MID STATION
END STATION
LIGO VACUUM SYSTEM
Washington site
7-5-94
J.Worden

Figure 2.

Performance

The vacuum equipment must provide

- a "UHV" quality environment with respect to cleanliness
- a rigid, quiet structure
- minimum gas load due to air leaks
- reasonable pump down times
- sufficient pumping to handle the IF gas loads
- isolation of the beam tube from the IF gas loads
- robust, fail-safe controls

Cleanliness

Cleanliness will be obtained and maintained by:

- selection of materials — SS, Cu, Al, ceramics, viton, hard coating "lubricants"
- welding procedures to avoid virtual leaks and contaminant traps
- cleaning, handling and bakeout procedures
- selection of pumps-all "dry"
- operational procedures

Vent/Purge System

To aid in cleanliness and pump down

- dry clean air-class 100 with dew point of −70C
- 100 cfm provides < 8 feet per minute flows but vents largest section in 70 minutes.

Low vibration

The Vacuum Equipment must include

- a rigid mechanical structure with well placed and designed expansion joints and supports
- "quiet" valve mechanisms
- "quiet" pumps

Gas load due to air leaks

Air leaks will be controlled by:

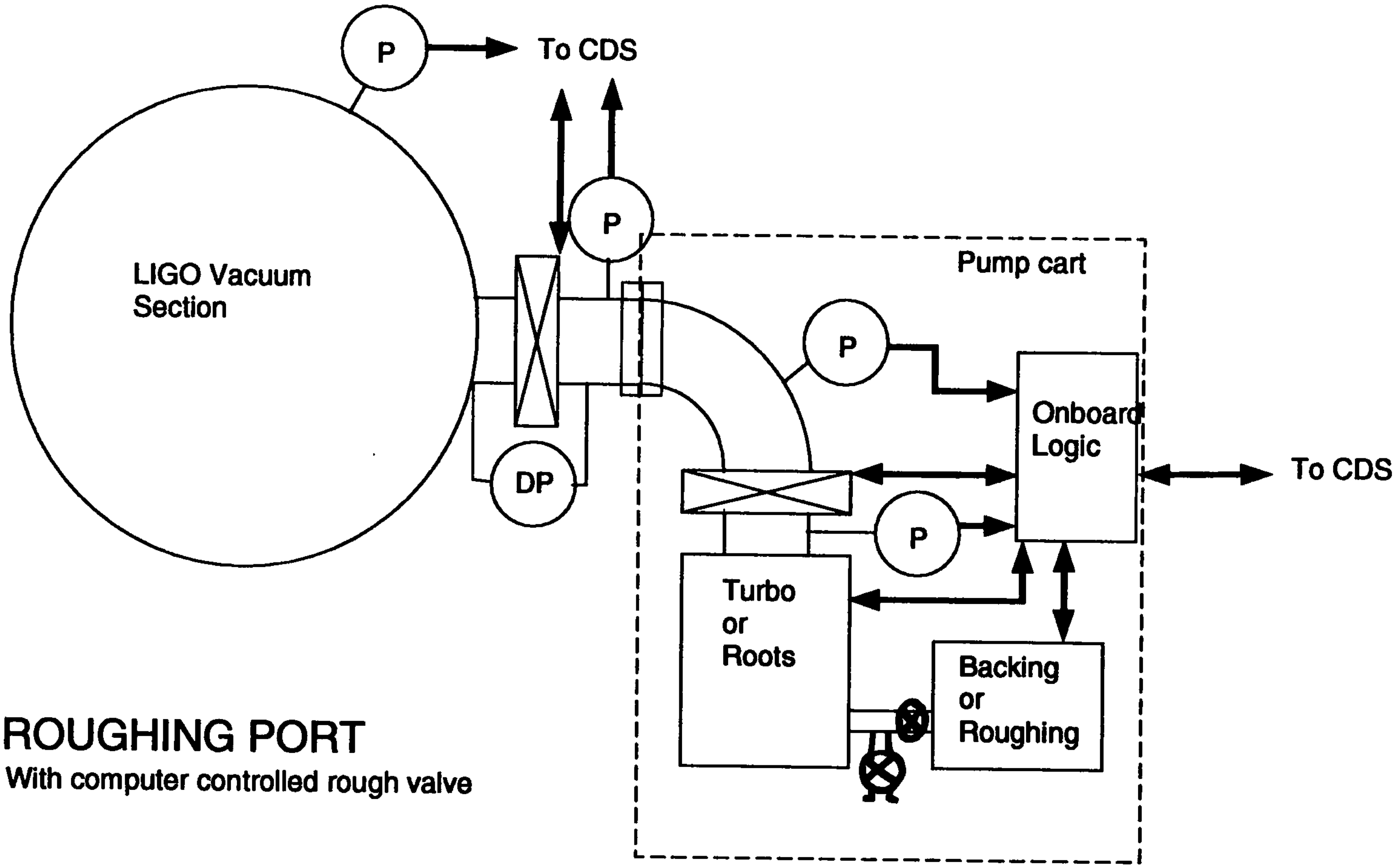
- leak testing of components to 10^{-9} tl/s
- leak testing of vacuum sections to 10^{-8} tl/s

A single 10^{-8}tl/s leak would contribute $< 10^{-11}$ torr to the total pressure of a vacuum section

Roughing Strategy

Portable roughing system

- 2 types of pump cart-Roots pump, Turbo pump-both backed by "dry pumps"
- each cart is self contained/protected
- Roughing valves may be manual or electro-pneumatic-if computer controlled requires extra sensors for redundant interlocks-if manual requires procedural controls, lockout devices.



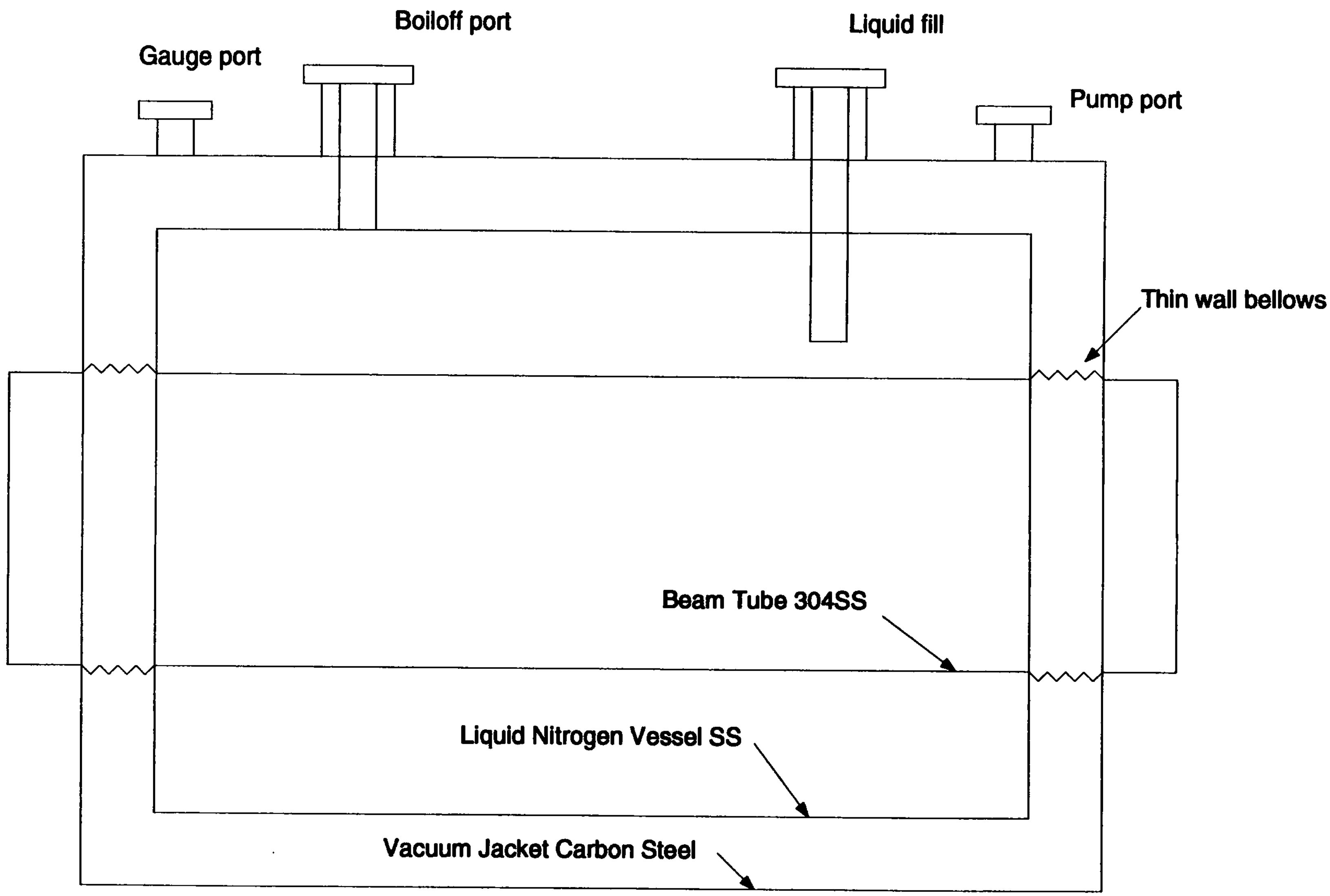
ROUGHING PORT

With computer controlled rough valve

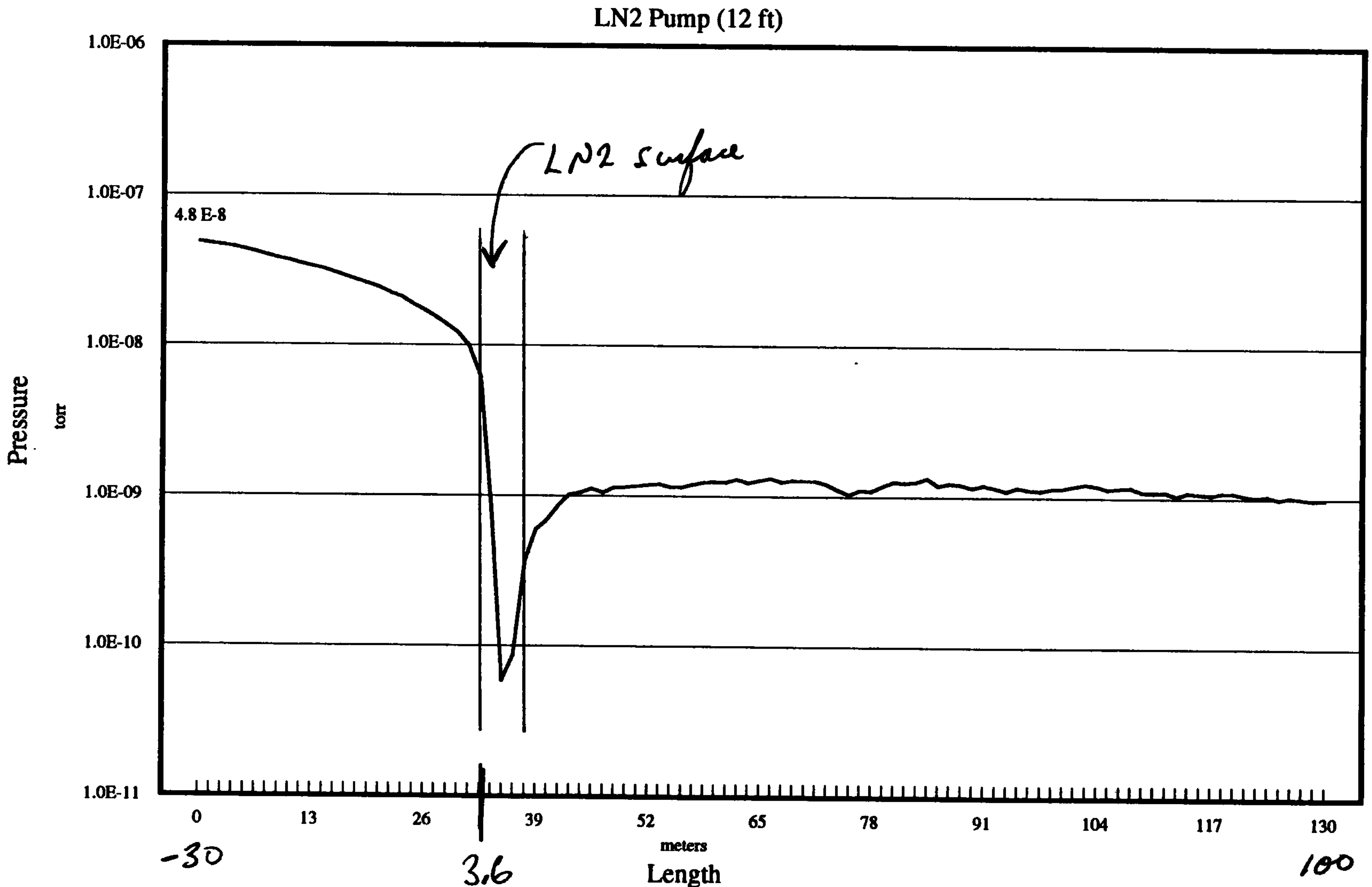
"Quiet" Pumps

- 3 types of pumps-Ion pumps, LN2 Pumps, and getter pumps
- Ion pumps are near the chambers and pump hydrogen as well as other gases. Need "noble gas" pumps as these will be the only pumps for inert gases. Ion pumps also provide additional pressure information.
- LN2 Pumps provide water vapour pumping and help isolate beam tube vacuum from chamber vacuum.
- Getter pumps-provide Hydrogen pumping in the beam tube.

LIQUID NITROGEN PUMPS (LN2 TRAP)

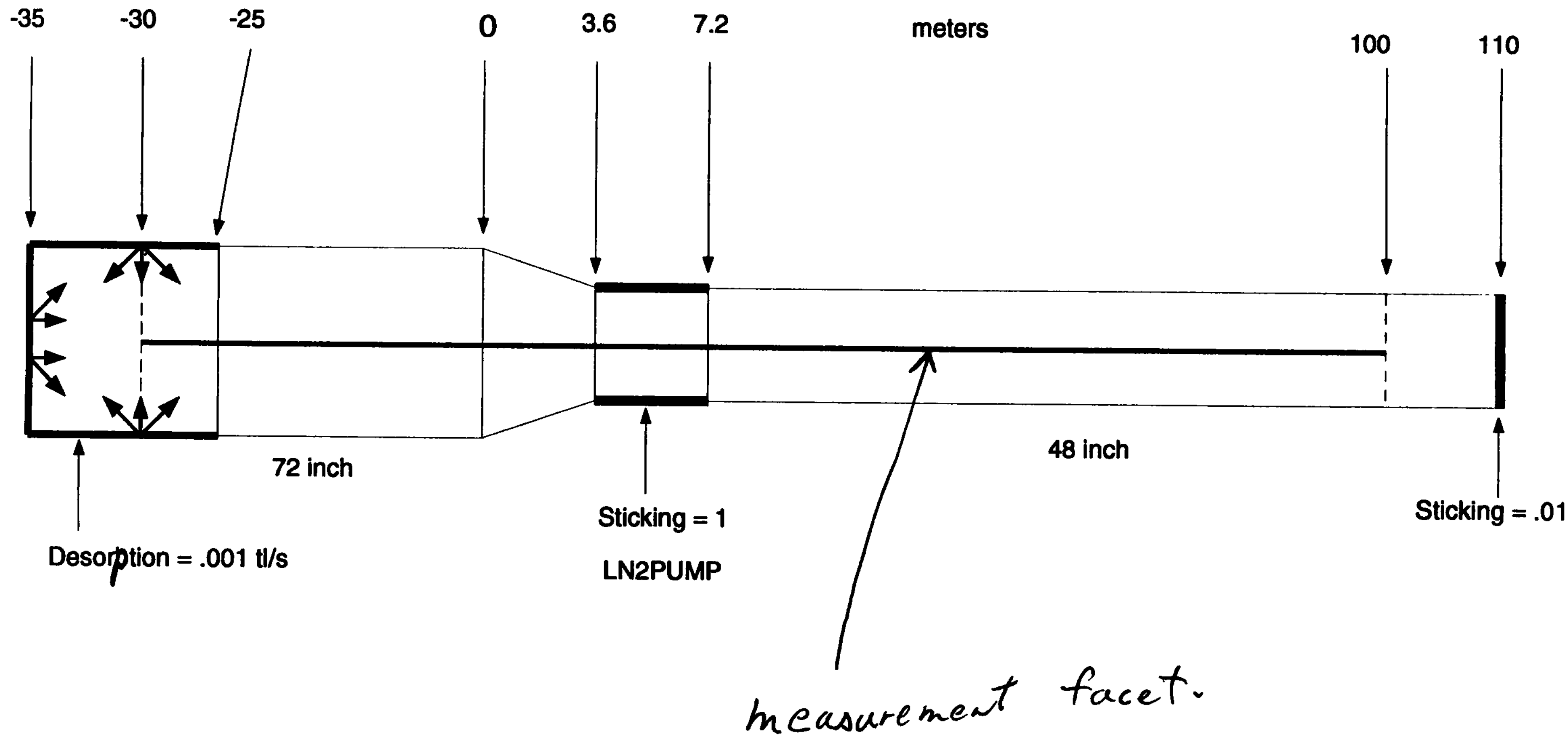


Pressure Distribution



Pump is from 33.6 to 37.2 m
Q(gas load) is .001 tl/s

Corner Station LN2 PUMP and beam manifold



Pre-conditions to Pumping Performance Tests

Both the pump down time and ultimate pressure will be improved by making use of the bake system and the dry air system. The prior conditioning outlined below will simulate actual maintenance operations:

- Bakeout at 150C for 24–48 hours or longer.
- Vent to dry clean air with −70C dewpoint.
- Purge with −70C dewpoint air at 100 CFM for 24 hours.
- Begin pumping tests.

Pump Down Times

The goal is to:

- limit time with roots system to <4 hours with IF components installed
- switch to turbo system after 4 hours
- be able to switch to ion pumps in <24 hours

Pump Down Times

Continued:

assume that the worst case is section 1 (3 BSCs, 9 HAMs-4.2E6 cm^2 and 195 m^3) Using a Leybold blower system WSU2001 with a DK200 backing pump we get to 0.1 torr in approx. 4 hours.

From this point the outgassing dominates: Assume outgas rates of 1E-11 Hydrogen and 4E-9/hours H20 (both tl/s cm^2)

At some pressure < 0.1 torr switch to Turbo pump system. At 10 hours outgas load = 4.1E-10 x 4.2E6 = .002 tl/s. With 1000 l/s net pump speed we get 2E-6 torr at which point the ion pumps should start. If the outgassing is 10 times worse then 24 hours gets us to 7E-6. We can double up on the turbos to get 3.5E-6. Therefore, without using the LN2 Pumps we can switch to ion pumps by 24 hours.

Ultimate Pressure (100 hours)

This test will demonstrate:

- the ion pump and LN2 pump performance
- the excess pumping capacity available for the IF gas loads
- overall system cleanliness and leak-tightness

Ultimate Pressure

Continued:

assume that the worst case is section 1 (3 BSCs, 9 HAMs-4.2E6 cm^2 and 195 m^3)

Present are 4 ion pumps for a net pumping speed of 7200l/s for hydrogen. The LN2 pumps provide > 40,000 l/s for H20

With outgas rates of 1E-11 Hydrogen and 4E-9/hours H20 (both tl/s cm^2):P_{H2} = 5.8 E-9 torr and P_{H20} = 3.6E-9 torr . Therefore the total pressure after 100 hours should be ~1E-8 torr.

SECTION 1.

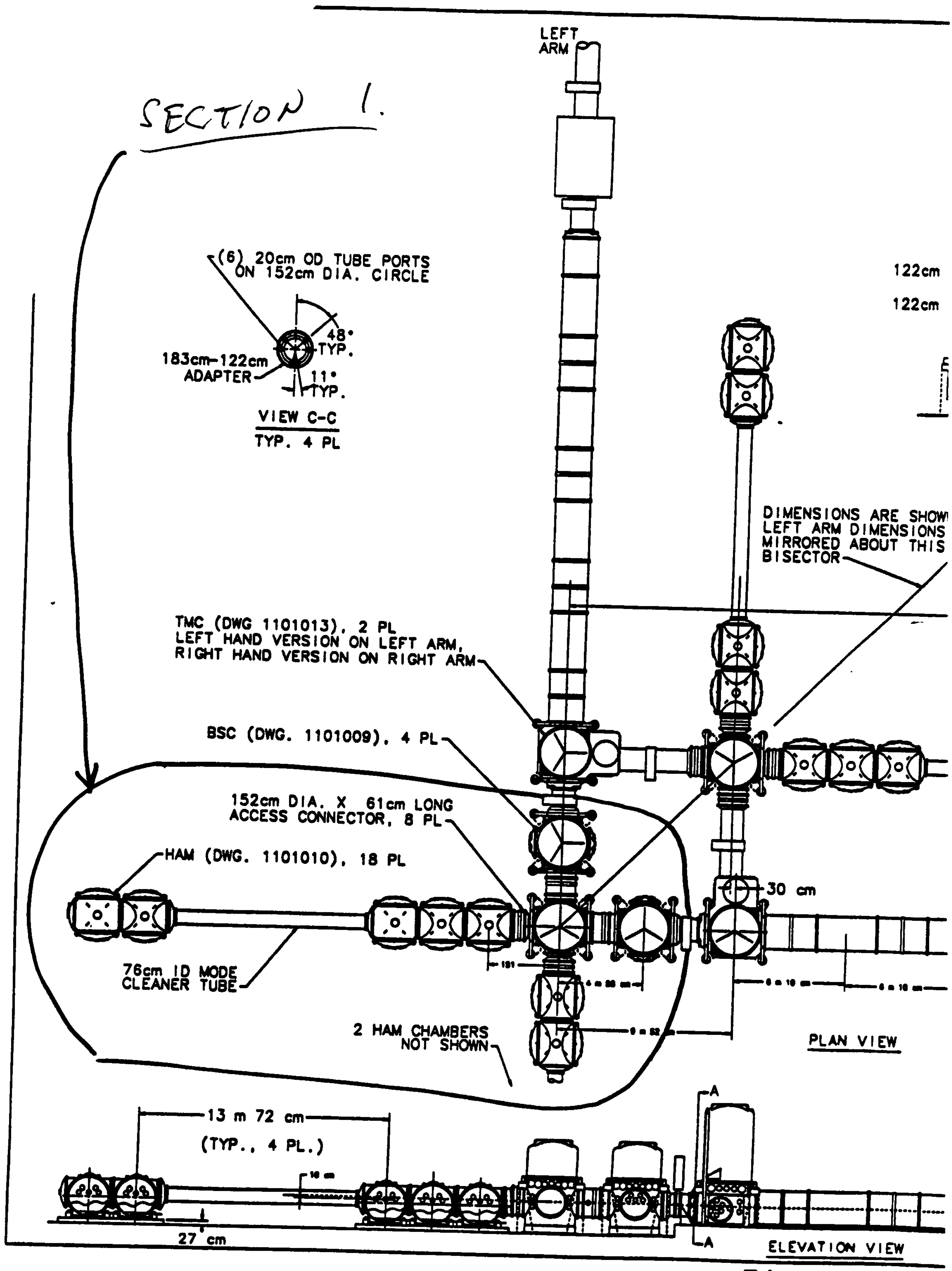
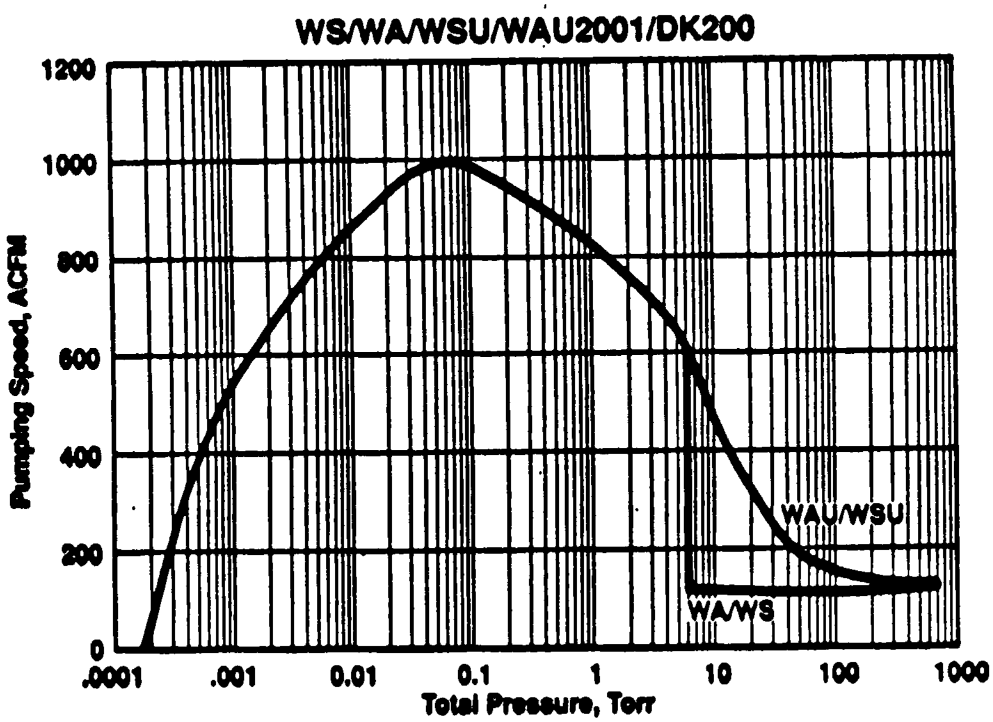
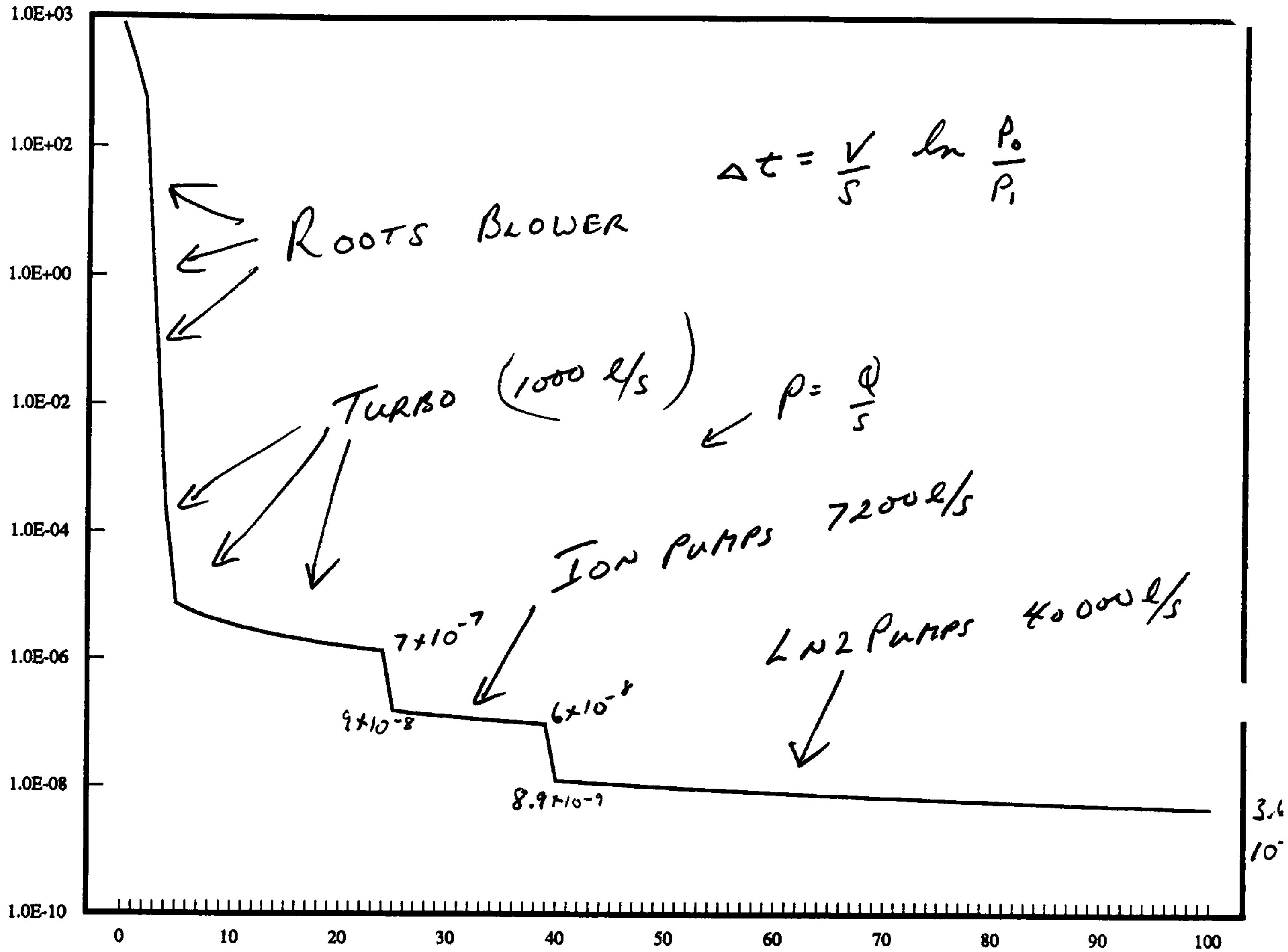


Figure 4.

ROOTS PUMP CART



SECTION 1 EMPTY



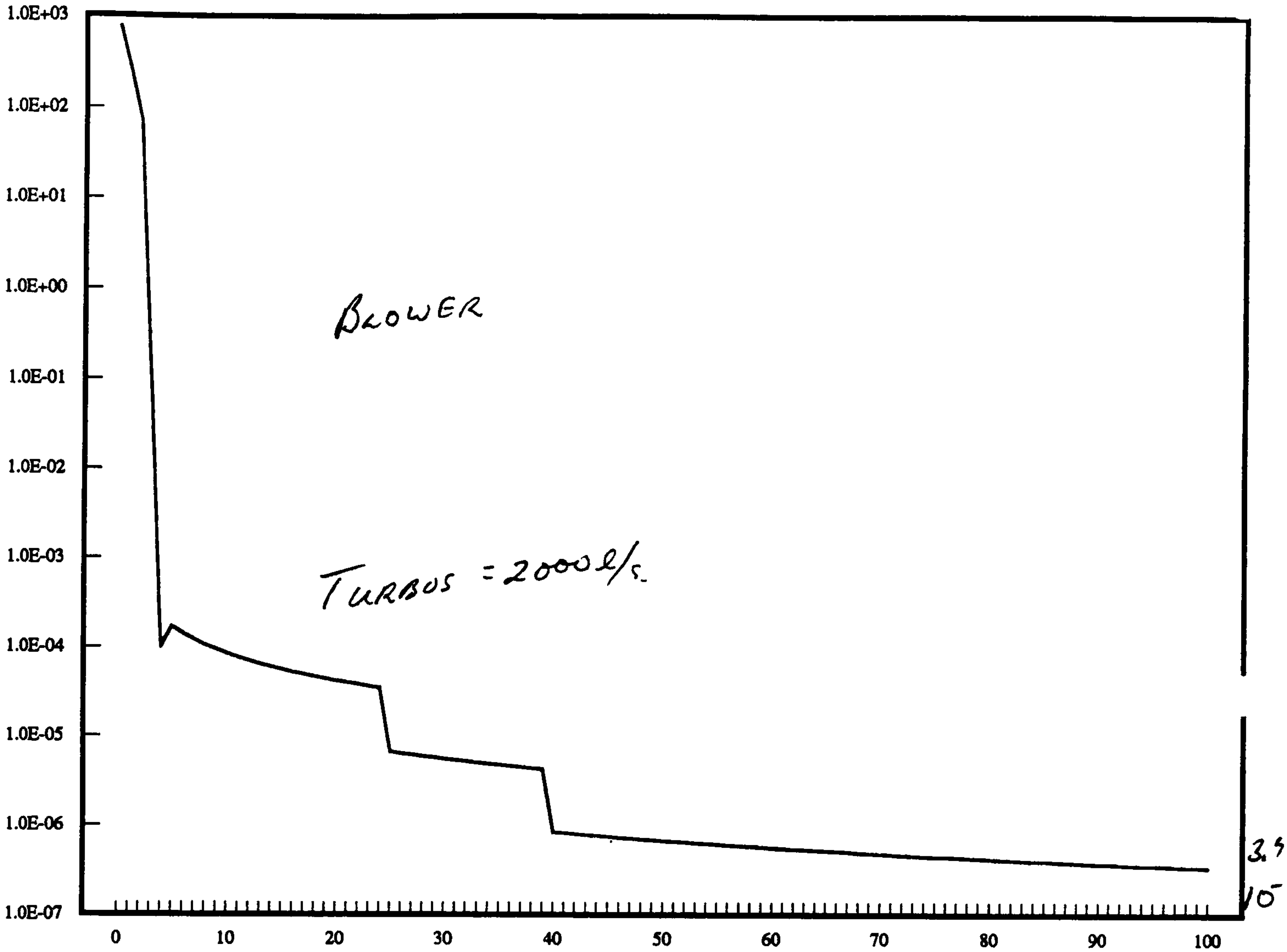
$J_{H_2O} = \frac{4\times10^{-9}}{t_{hr}}$ tl/scm² $\quad Q_{H_2O} = 1.7\times10^{-4}$ tl/s

$J_{H_2} = 1\times10^{-11}$

$P_{H_2O} = 3.6\times10^{-9}$

$P_{H_2} = 5\times10^{-9}$ t.

SECTION 1 with IF



$$J_{H_2O} = \frac{4\times10^{-7}}{t_{hr}} \ \ t\ell/s\,cm^2 \qquad \phi_{H_2O} = 1.7\times10^{-2}\ t\ell/s$$

$$P_{H_2O} = 3.4\times10^{-7}\ t.$$

"Large valves"

48 inch and 60 inch

- 48 inch valves allow isolation of beam tube and regeneration of LN2 Pumps.
- 48 inch valves and 60 inch "air lock" allow maintenance and access to chambers without venting all optics.
- Require independant interlocks and mechanical lock-out to ensure safe operation.

Controls

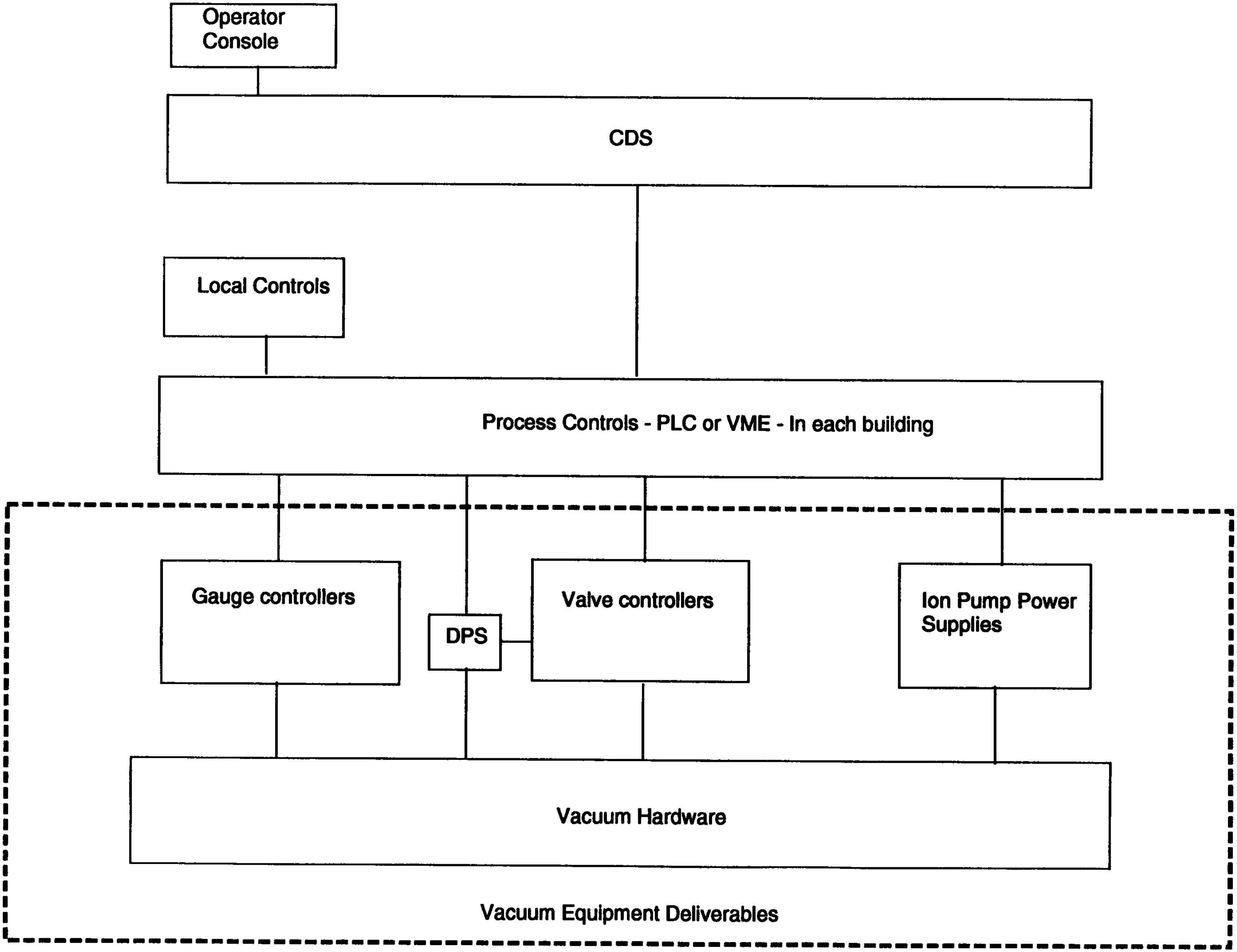
Monitoring and interlocking

- "Absolute" gauges for venting and rough down.
- Pirani type gauges to enable ion pumps, cold cathode ion gauges.
- Cold cathode gauges to monitor trends, provide interlocks for large gate valves.
- Differential pressure switches for independant interlocks for large valves.
- Ion pump current/pressure used to monitor trends, provide interlocks for large gate valves.
- LN2 Pump temperature sensors and liquid level sensors. May need a device to monitor "ice" thickness.

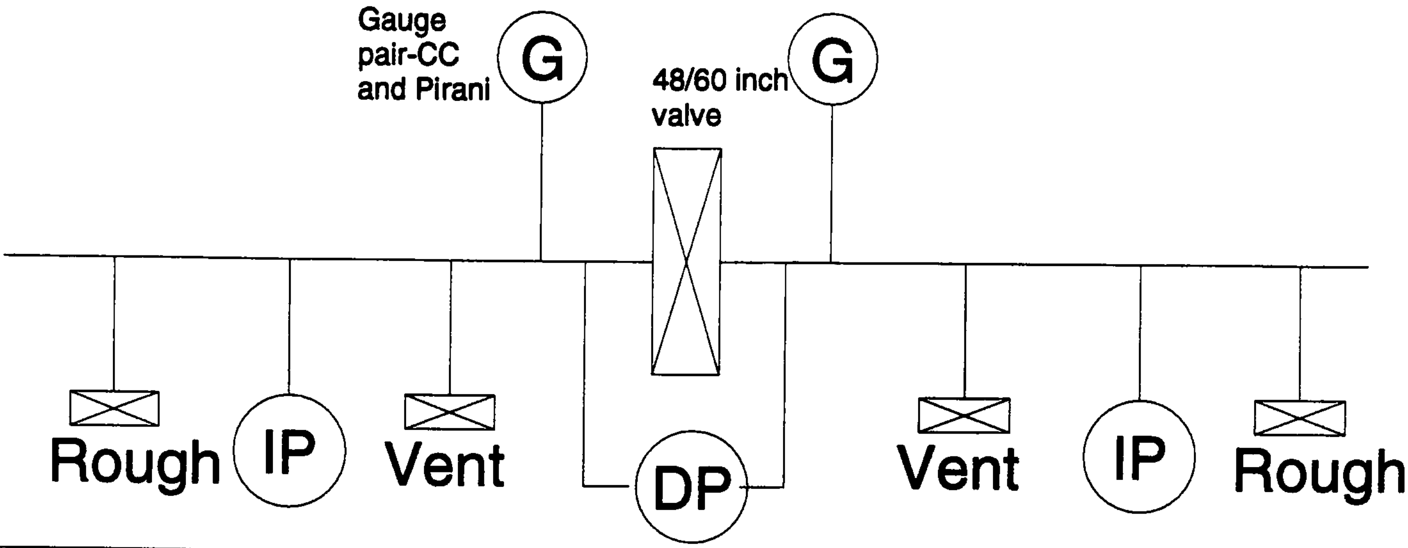
Controls

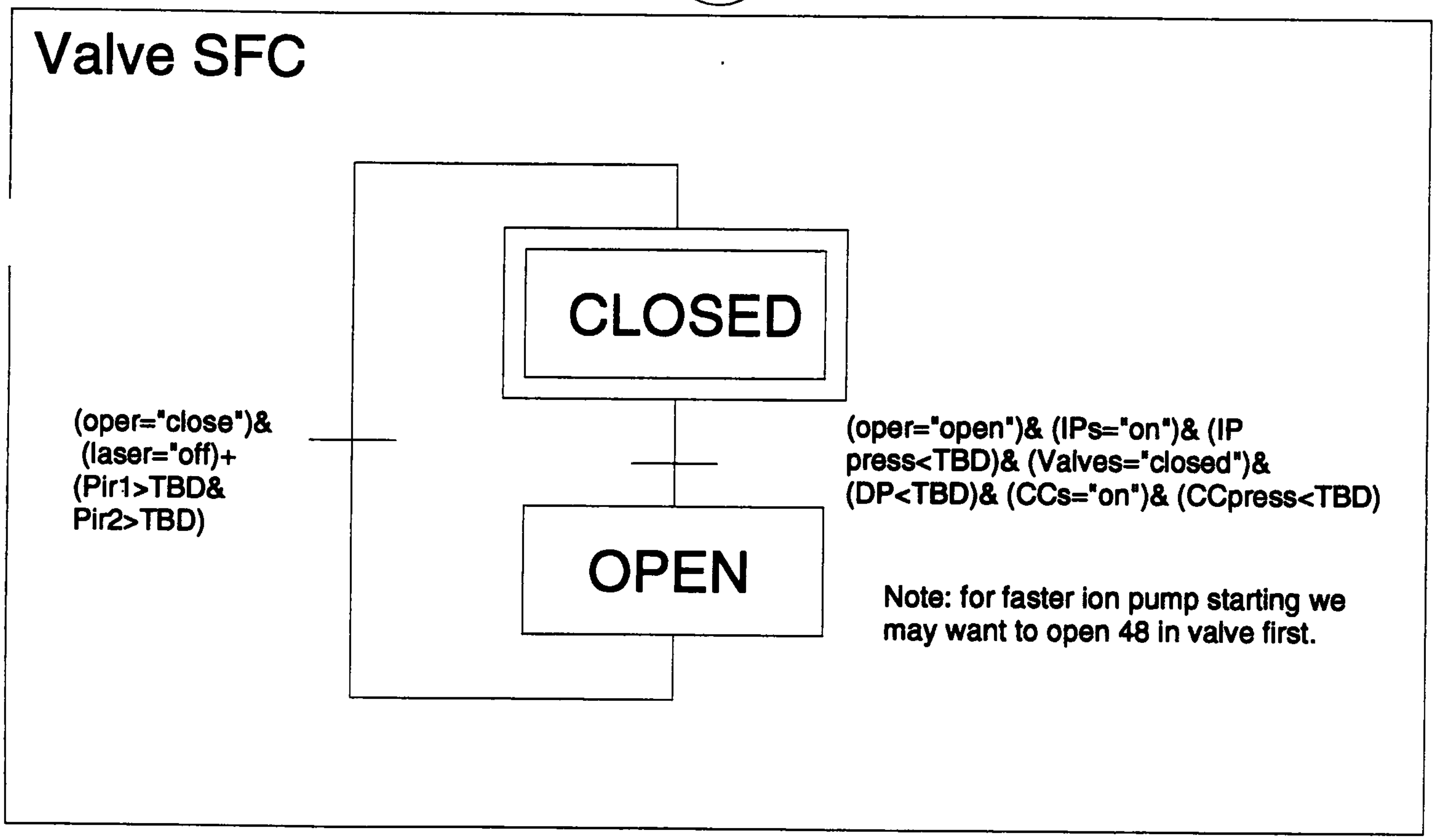
Process controls and user interface

- Dedicated process controls for year round, 24 hours per day operation and protection.
- "Local" control for operation and maintenance from any location.
- Central control for control room operation, data logging, interface to networks.

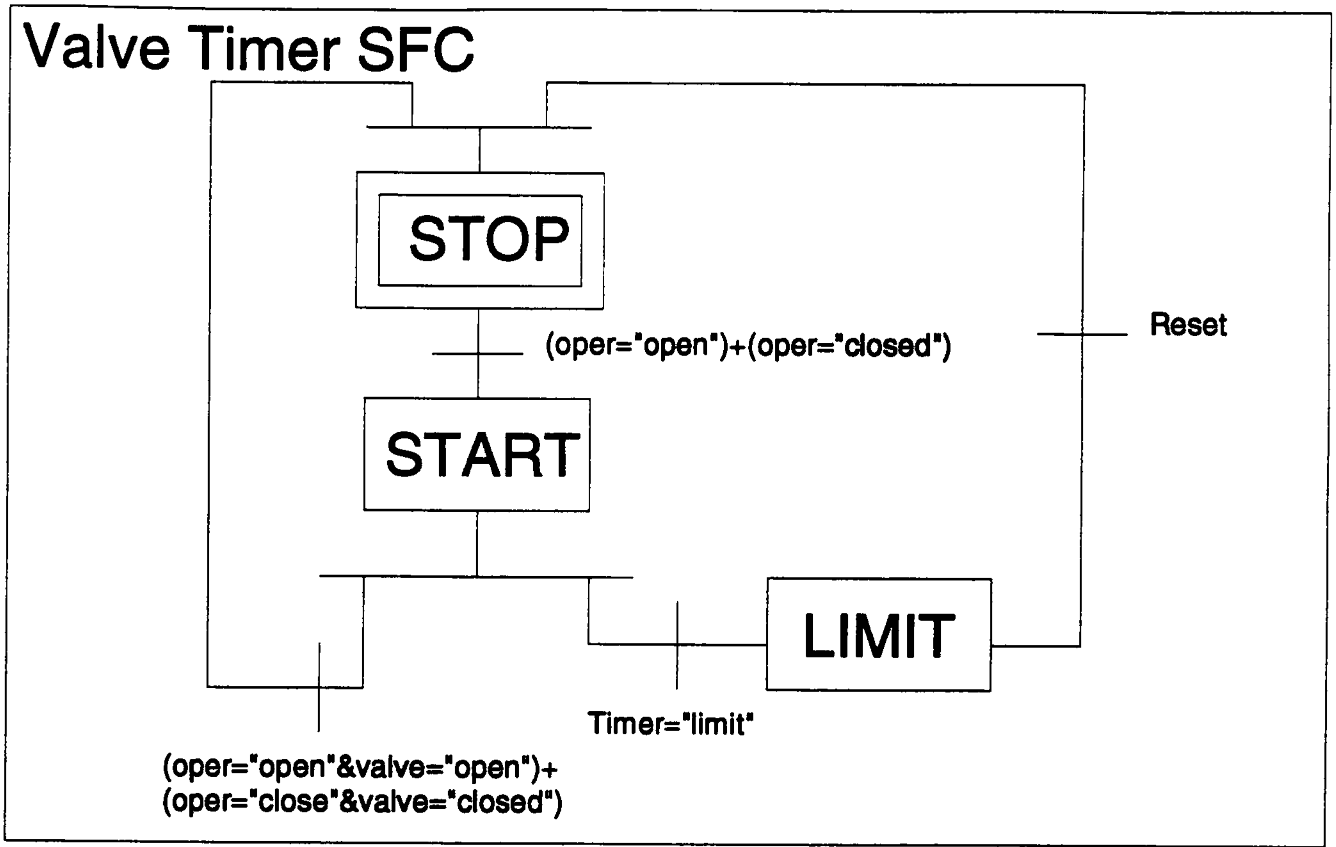

Operator Console
CDS
Local Controls
Process Controls - PLC or VME - In each building
Gauge controllers
DPS
Valve controllers
Ion Pump Power Supplies
Vacuum Hardware
Vacuum Equipment Deliverables

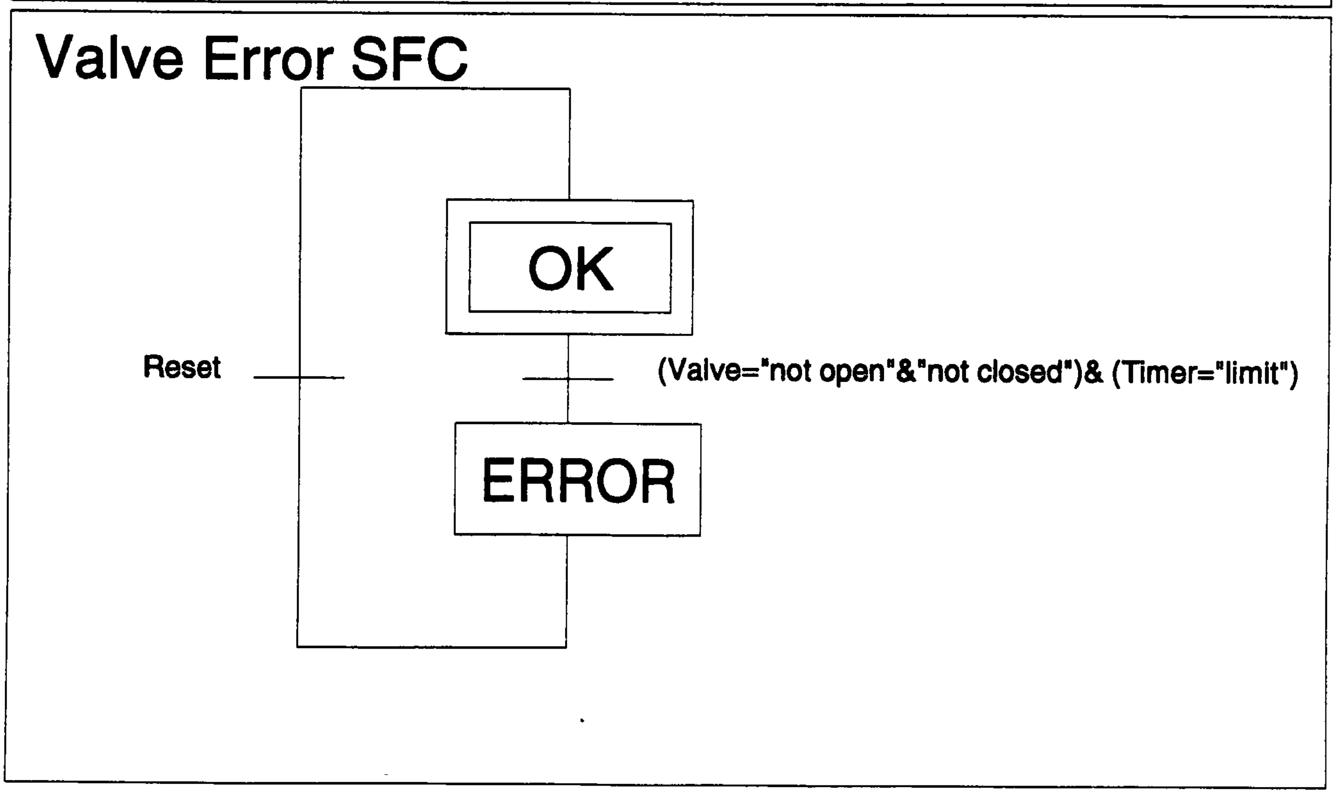
SAMPLE GATE VALVE LOGIC





SAMPLE GATE VALVE LOGIC cont'd





Interface Control

- Vacuum Equipment to Support Beam assembly-Supplied by Caltech/MIT
- Vacuum Equipment to Beam Tube-Supplied by Caltech/MIT
- Vacuum Equipment to building and utilities-supplied by VE contractor?
- Vacuum Equipment to process controls-Supplied by VE contractor.

Failure modes

Minor faults

- Pressure sensor failure-may cause 10inch valve closure, ion pump shutdown, ion gauge or RGA shutdown, rough pump shutdown. May require temporary modification of control logic to continue ops.
- Small valve failure-use alternate port, temporary modification to control logic to continue ops.
- Ion pump failure-substitute power supply, remove shorted pump from circuit, temporary modification to control logic to continue ops.
- mechanical pump failure-may cause 10inch valve closure. Use alternate pump.

Failure modes

Serious faults

- Contamination of vacuum system-may require extensive disassembly and cleaning. Use oil-free mechanical pumps, robust control system, monitor and control vent/purge gas quality, limit power input to any bake circuit, screen all materials and components before installation, no lubricants allowed even outside vacuum.
- 48/60 inch valve failure-use proven design, ensure proper mounting, use redundant seals, use robust controls to minimize unnecessary cycles, provide backup for bellows feedthrough.
- Structural failure of vacuum envelope or supports-perform redundant analysis of stresses at design. Design to ASME pressure vessel code. Procedures required to control, monitor and test support system. Load measurement devices on cranes. Skilled personnel to operate lifting equipment. Minimize size of optical ports.

Interface Control (more)

There are 4 major system to system interfaces which need to be clearly defined and controlled.

The first is the interface between the Vacuum chambers and the IF components. This interface is mainly defined by specifying the position, size, tolerances, etc. of the four flanges which the optics supports beams connect to via the isolation bellows. "Stay clear" regions also need to be defined. All three chamber designs must have this interface defined. These details should be supplied by the Caltech/MIT Interferometer group.

The second major interface is between the VE and the Beam Tube. Since it is likely that the beam tube will be installed first then the VE vendor must obtain the details of this connection from Caltech/MIT Facilities group.

The third interface is between the VE and the Civil construction. The VE will require certain utilities, mounting arrangements, overhead access, etc. The ideal case would have the VE contractor provide these requirements to the Civil construction A&E firm (via Caltech/MIT). However, due to schedule constraints, Caltech/MIT may have to make some educated guesses and supply details to both firms.

The fourth interface is that between the VE electronics and the LIGO Control and Data Systems. The VE vendor must supply signal, cable, and connector details to Caltech/MIT. However, we will supply the VE vendor with a list of acceptable signals and connector types.

Optics Compatibility Validation

DHS

August 29, 1994

Optics Compatibility Validation
Outline

- description of the generic initial interferometer
- beam raytracing layout
- auxiliary alignment layout
- conclusions from the layout exercise

Optics Compatibility Validation
Generic Ifo: configuration

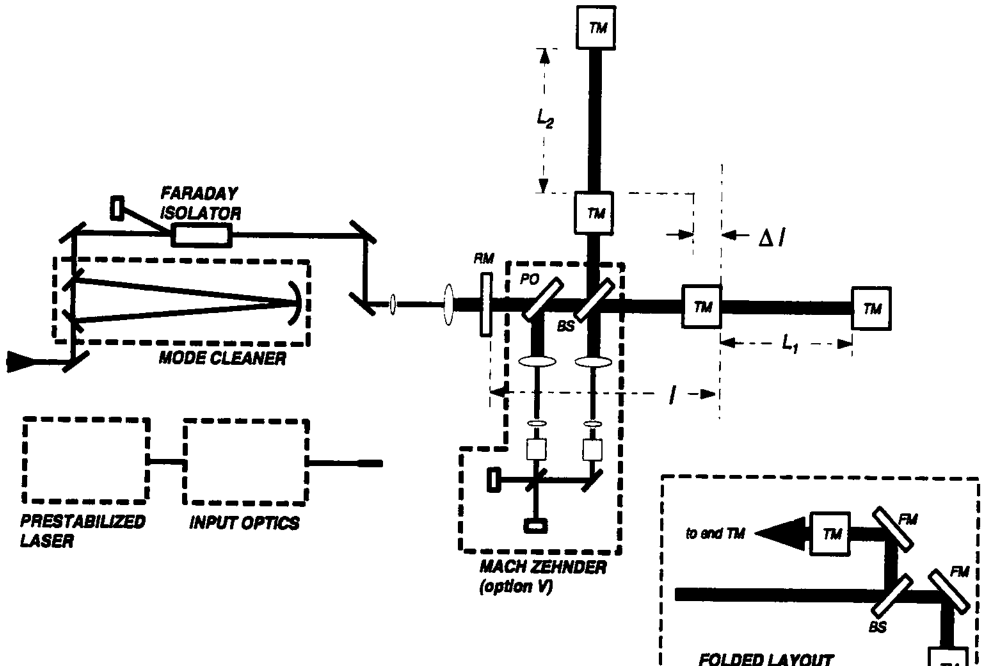


FIGURE 1:
GENERIC INITIAL INTERFEROMETER

mez 7/28/92
rev. 8/11/92

- wish to exercise flexibility, available space
- select superset of initial Ifo configurations
    - power recycled Michelson with Fabry-Perot arm cavities
    - triangular mode cleaner
    - configured for full– and half-length positions
- redundant GW readout systems
    - Mach-Zehnder post-modulation
    - Schnupp asymmetry pre-modulation
- redundant readout of other degrees of freedom
    - sums/differences of carrier modulation
    - two frequency (carrier/subcarrier) system

Optics Compatibility Validation
Generic Ifo: Length constraints

- 2:1 mode cleaner to recycling cavity length chosen
- RF phase modulation wavelengths must be resonant
  - in mode cleaner (12m length means 12.7 MHz FSR)
  - in recycling cavity (6m length gives 'FSRs' at 12.7, 37.5, ...)
- 15 cm near mirror asymmetry chosen
  - optimal value function of mirror imperfections
  - conservative (i.e., large) asymmetry
  -

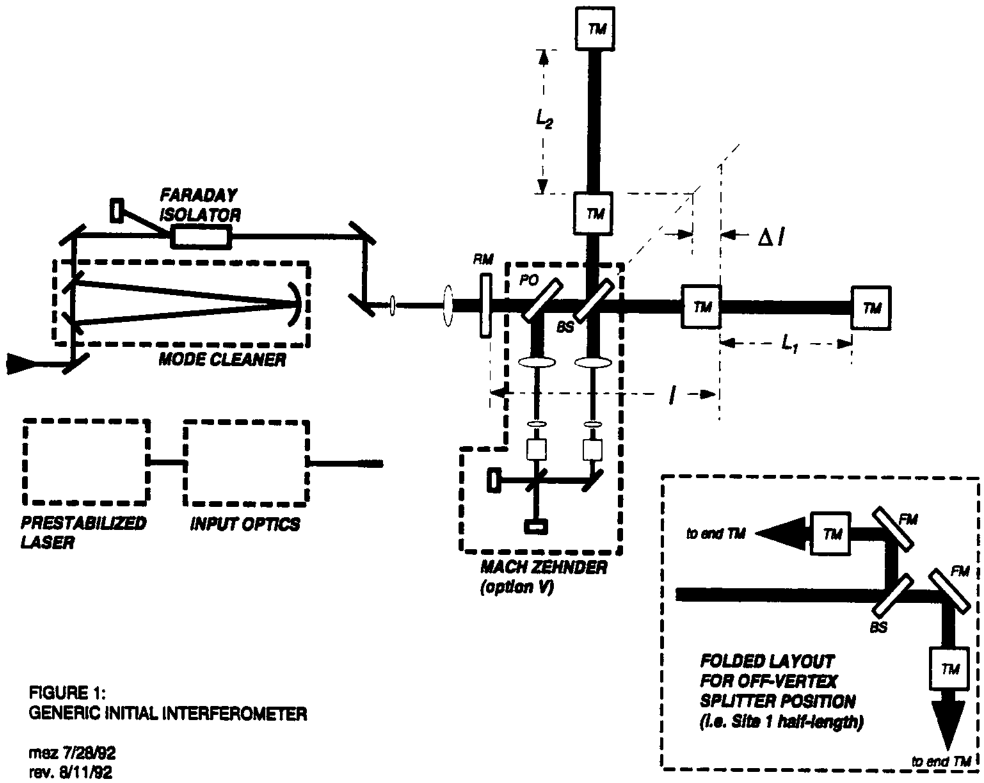
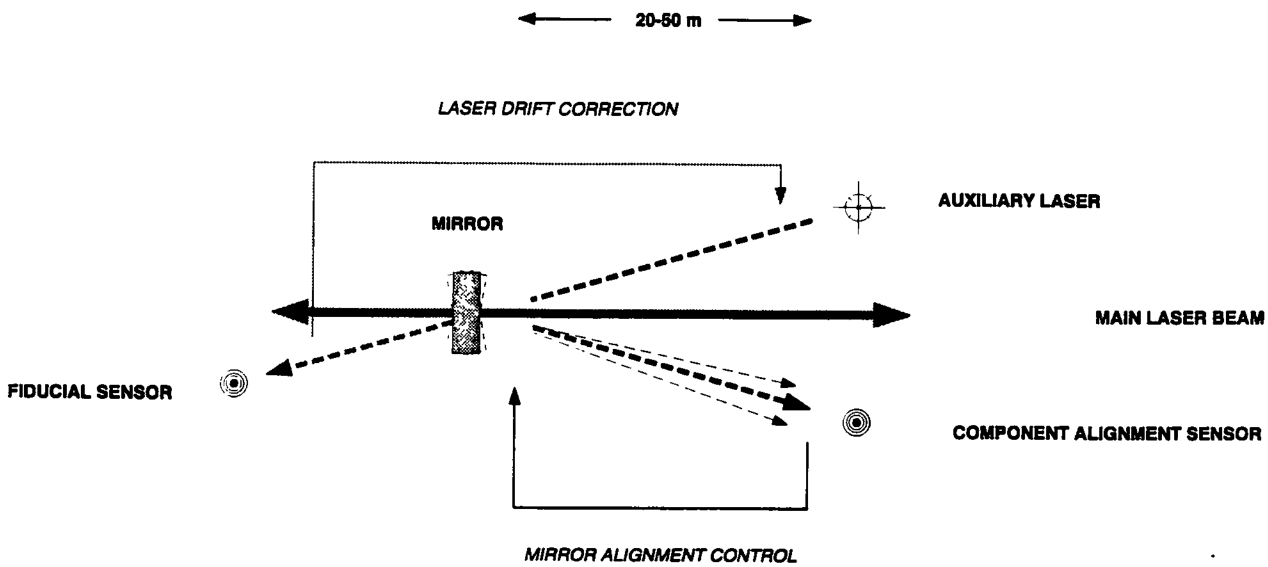


FIGURE 1:
GENERIC INITIAL INTERFEROMETER

mez 7/28/92
rev. 8/11/92

Optics Compatibility Validation
Generic Ifo: Auxiliary pointing



adoption of auxiliary pointing scenario

- **system must be short-term (minutes) operable with 40m-like pointing system**
- **conservative (expect operation with automated alignment system)**
- **creates significant requirement for clearance of ports, paths**

Optics Compatibility Validation

Generic Ifo: Stray Beam and Scattered Light control

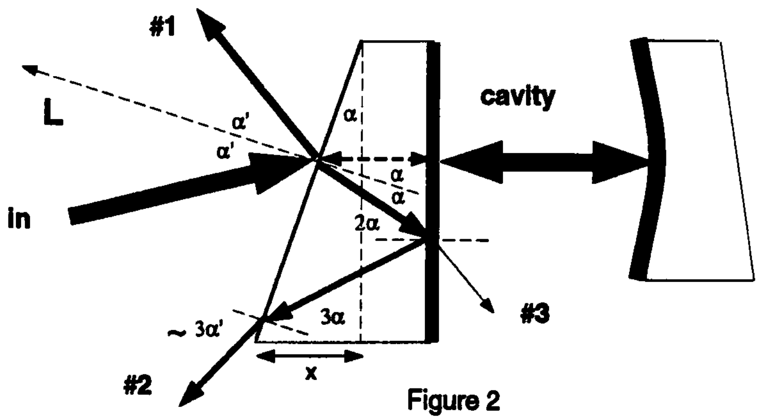


Figure 2

optical components wedged to avoid accidental interference

- **explicit calculation of beams**
- **adopt requirement for minimum intensity, clearance**
- **assume present-day Anti-Reflection coatings (10^{-3} – 10^{-4} reflection)**
- **some beams 'useful' (information led out through ports)**
- **others not (fed into beamstops)**

substrates and surfaces scatter light

- **substrates scatter 5–10 ppm/cm or 50–100 ppm per optic**
- **surface scatter 10–100 ppm/surface**
- **have assumed availability of a black baffling, vacuum compatible**

IV.B. BEAM RAYTRACING LAYOUT

AA

Assumptions

1.
   - Power of beam impinging onto recycling mirror: 3W.
   - Test mass coating transmission: 3.3%.
   - Recycling mirror transmission: 3.3%
   - Mach-Zender reflectivity (power): 1%.
   - Power reflectivity of AR coatings: 0.1%.
2. Beams carrying less than 0.1μW have been disregarded
3. Beams carrying between 0.1μW and about 10μW now end up on flat, black surfaces[1], which are not seismically isolated.
4. Beams carrying more than about 10μW are either photodetected or dumped.
5. The nominal diameter of the beams is, usually, 6".
6. Wherever it was necessary, the nominal diameter for low power beams was trimmed, such as to satisfy the criterion of Point 2.
7. Nominal beam dump sizes are 8" diameter, 16" long. The beam dumps are not seismically isolated.
8. Wherever it was necessary, the size of the beam dump was trimmed down, in tune with Point 6.
9. The nominal diameter of the photodiodes is 7". It has yet to be determined what degree of seismic isolation needs to be provided for the photodiodes.

---

1 The residual scattered light should not exceed 0.3%-1% of the incident light

Features of the Layouts

1. Either horizontal or vertical stray beam spread-out could be accommodated by the vacuum system.

2. Some stray beams had to be deflected downwards with a mirror, then caught with a vertical beam dump.

3. Some beams, deflected at large angles, were dumped either by placing a baffle at the appropriate location, or by placing a conical beam dump inside a spool. In the latter case, one will have to provide a 8" ID port at the spool.

4. The initial green directional monitoring beam for the diagonal interferometer was extracted by using a retroreflector, rather than a forward reflecting periscope.

5. Optics wedges had to be customized to the various locations, with tolerances TBD.

6. Baffled shrouds around the test masses are provided for catching $\sim$ 30% of the scattered light, which emerges at large angles. The cross section of the shroud fits inside the test mass cage outline as seen along the light beam.

Required Vacuum System Features

1. The beam splitter chambers were placed at fixed heights. This is important for beam clearances in the right arm, and makes it possible to remove the 48" necks between the vertex chamber and the TMC2 chambers, leaving 60" apertures.

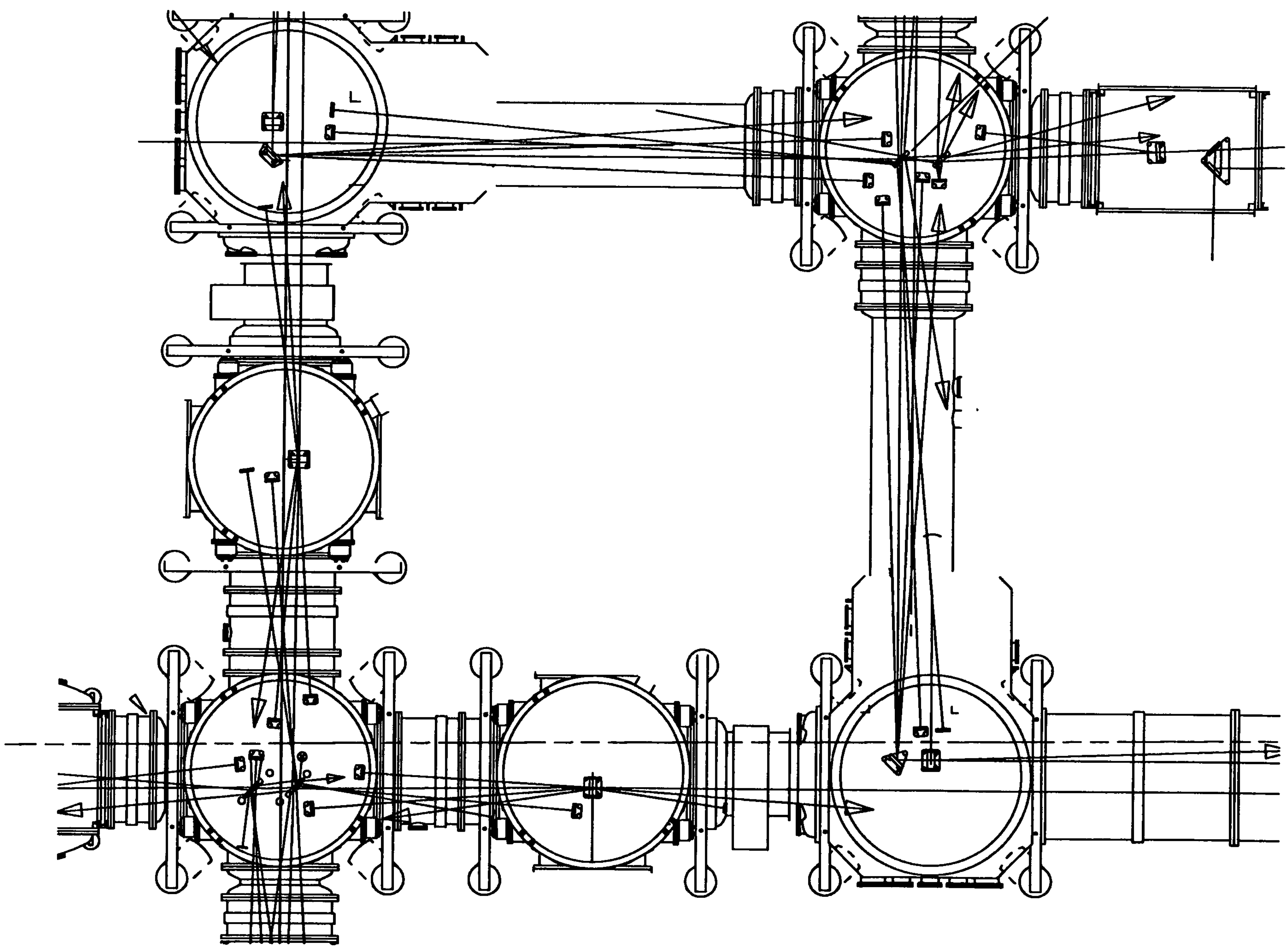
2. The 60" apertures between the vertex chamber and the HAMs have been necked down to 48", in order to allow for height adjustment.

3. The offset of the 60" ports of the beam splitter chambers was removed, as it has no apparent advantage. This change makes it possible to use a single design for both the beam splitter chambers and the TMC-2s.

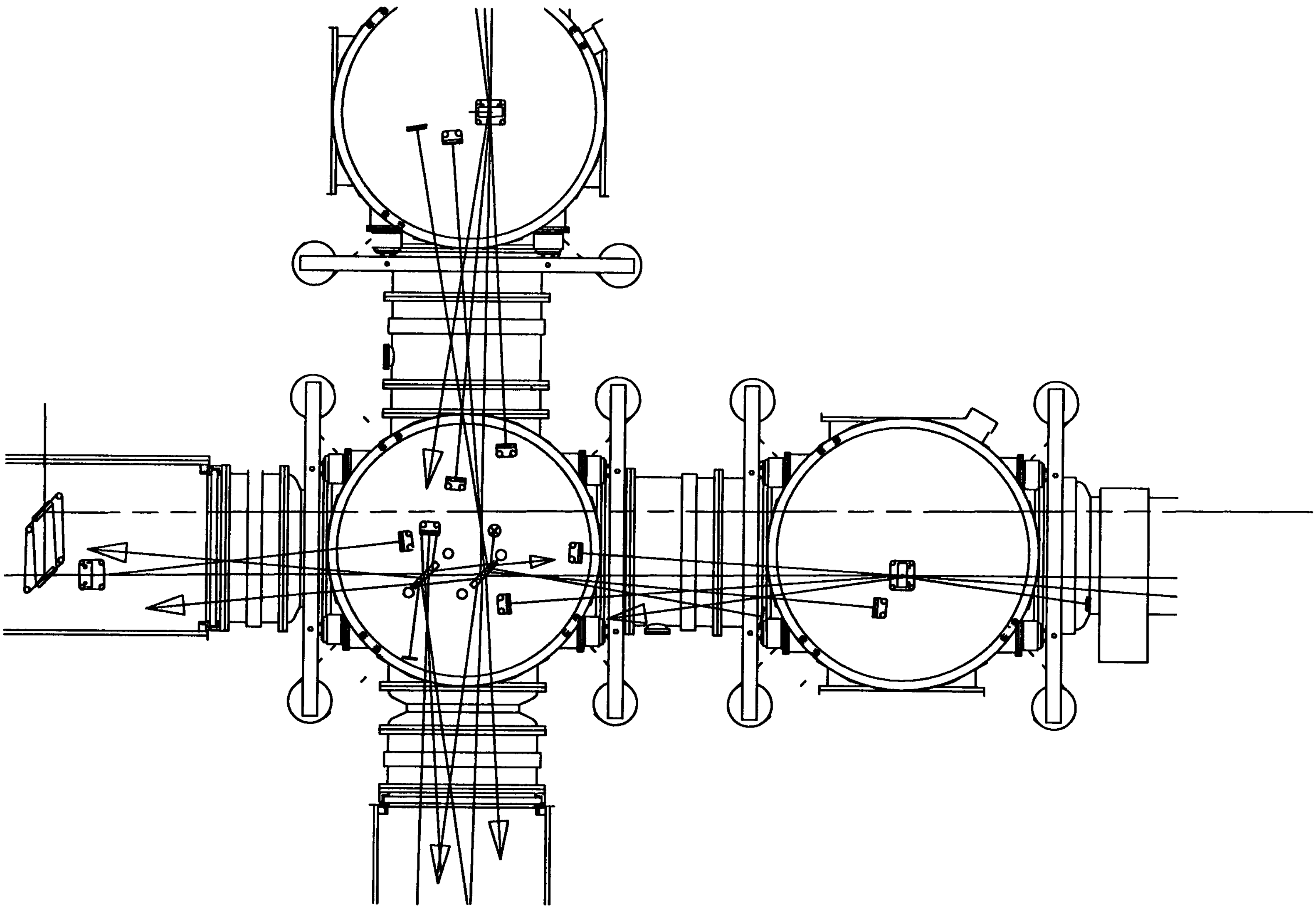
4. Baffles were placed at several locations, inside of connecting spools.

5. 8" ID ports were provided at several locations, on the connecting spools, in order to allow placement of some beam dumps.

WASHINGTON SITE

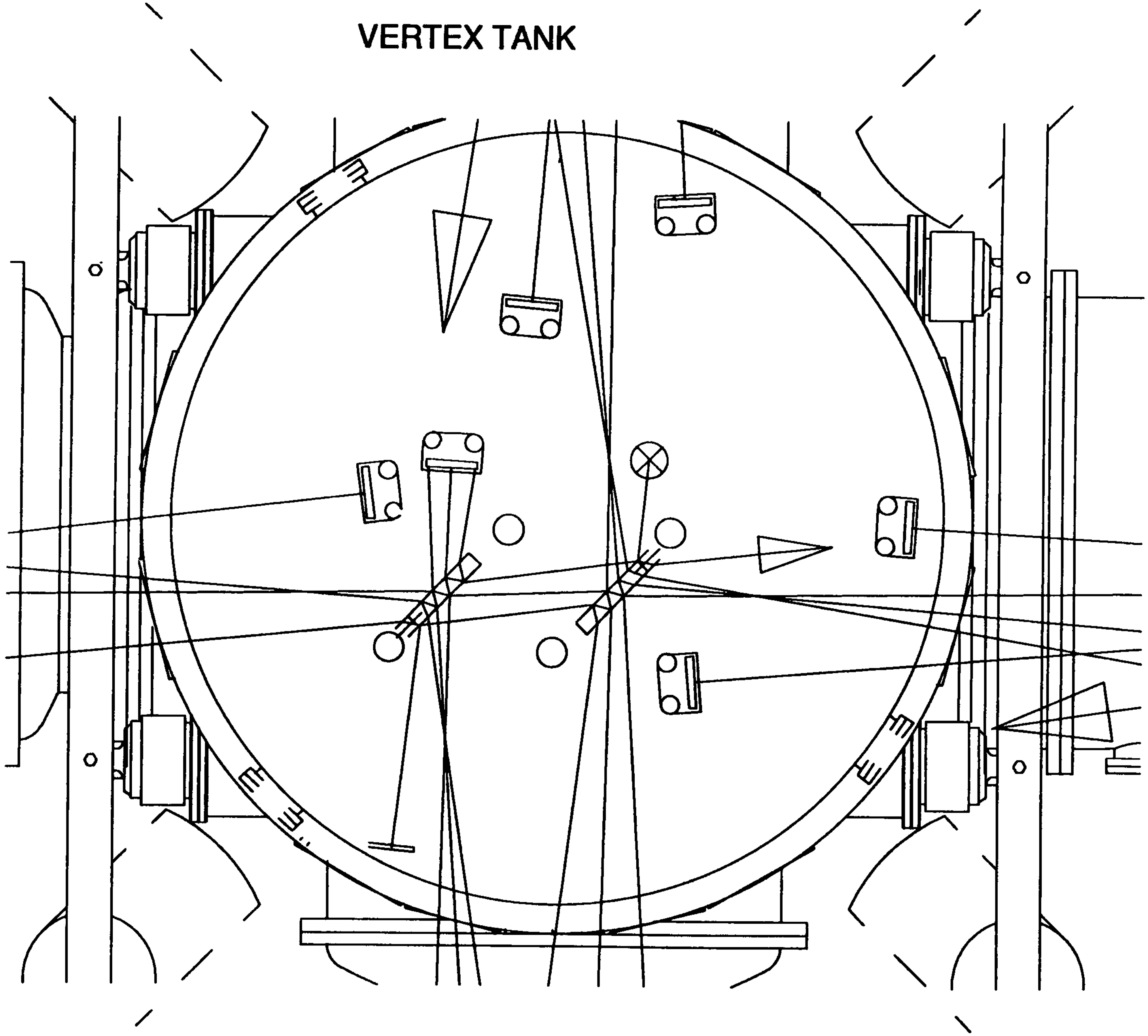


WASHINGTON SITE: VERTEX AREA

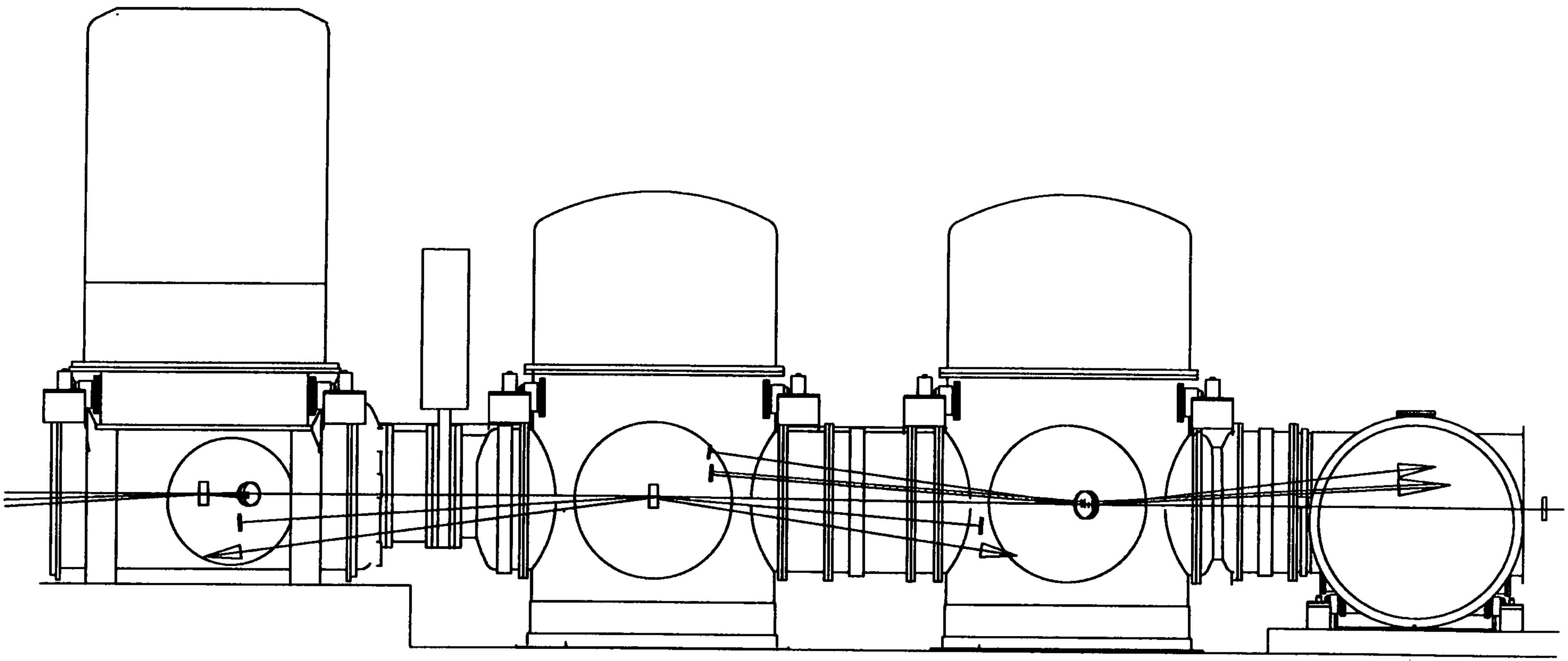


HORIZONTAL BEAM SPREAD:

VERTEX TANK

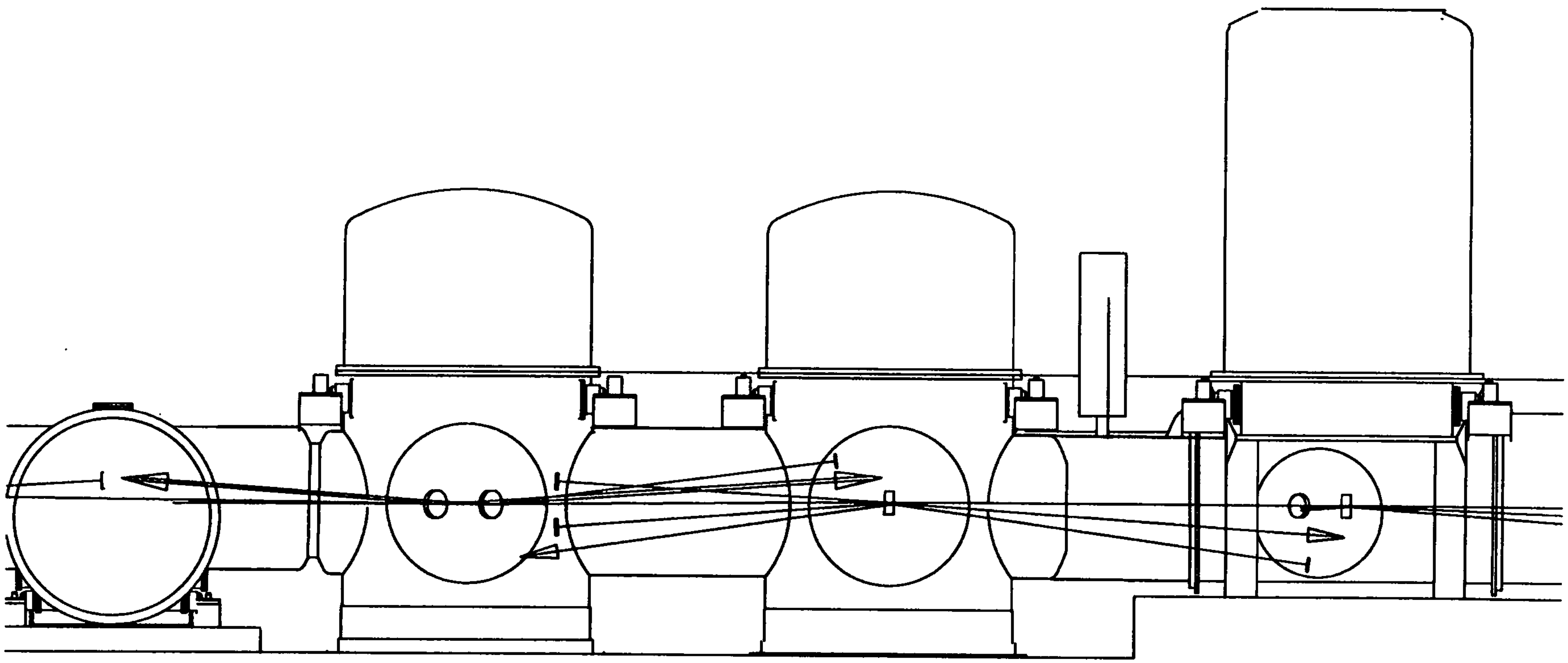


EXAMPLE OF LAY-OUT WITH VERTICAL BEAM SPREAD



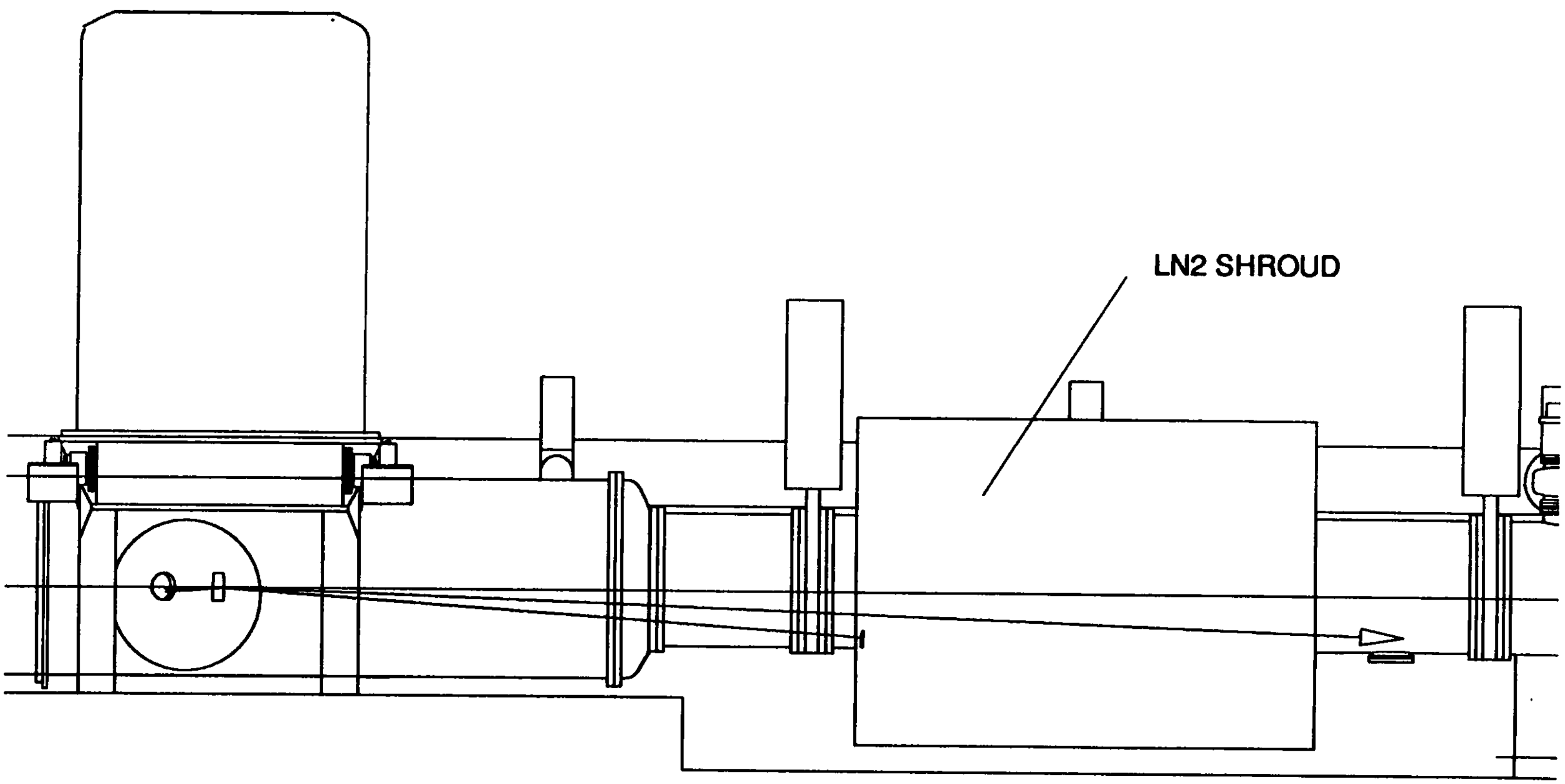
ELEVATION VIEW, LEFT ARM

EXAMPLE OF LAY-OUT WITH VERTICAL BEAM SPREAD



ELEVATION VIEW, RIGHT ARM

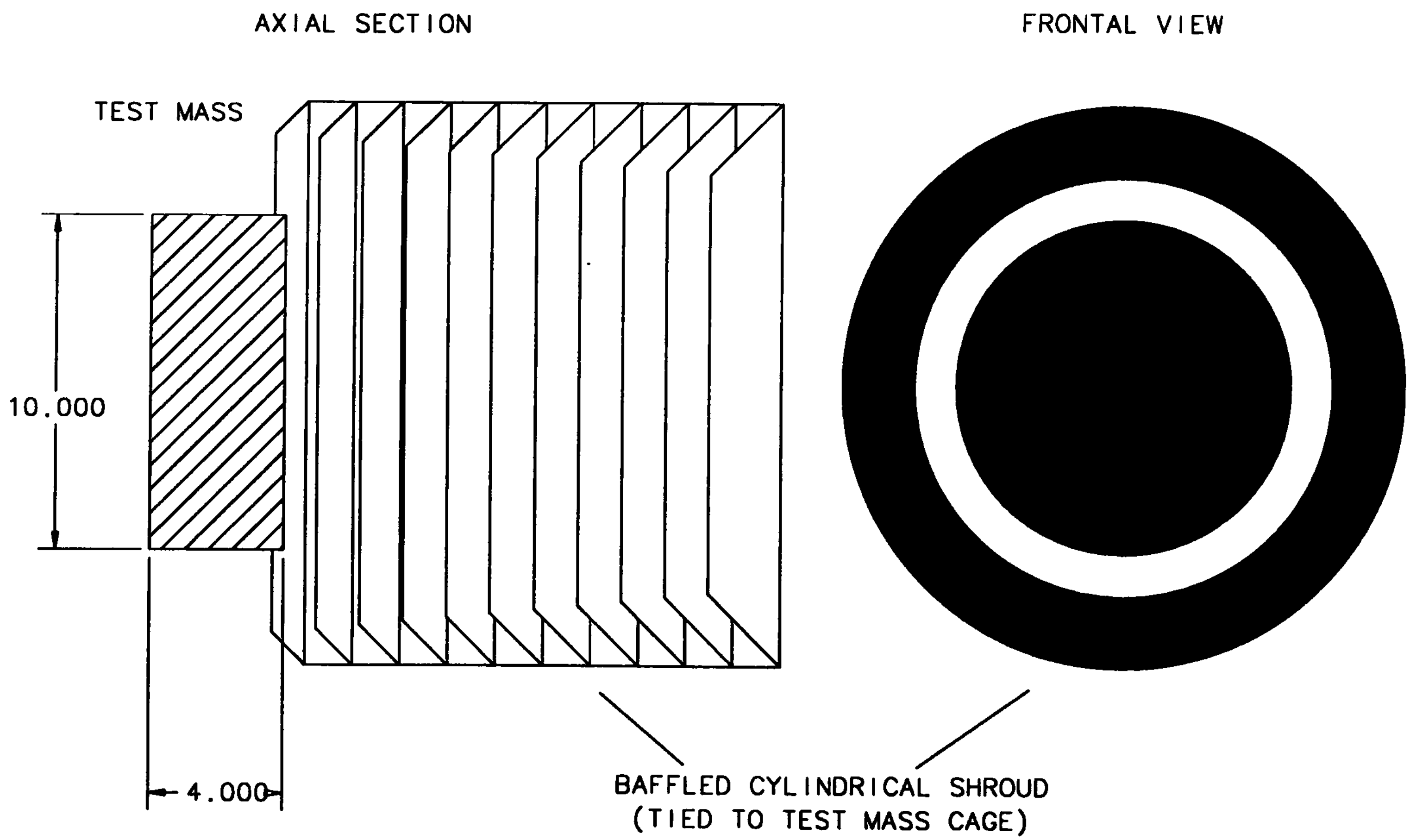
VERTICAL BEAM SPREAD FOR THE 6TH INTERFEROMETER



ELEVATION, RIGHT ARM

ARRANGEMENT FOR LARGE ANGLE SCATTERING CONTROL,
FROM TEST MASS REFLECTIVE COATING

AA, 9 February 1993



AUXILIARY LASER ALIGNMENT SYSTEM: LAYOUT EXERCISE

MEZ

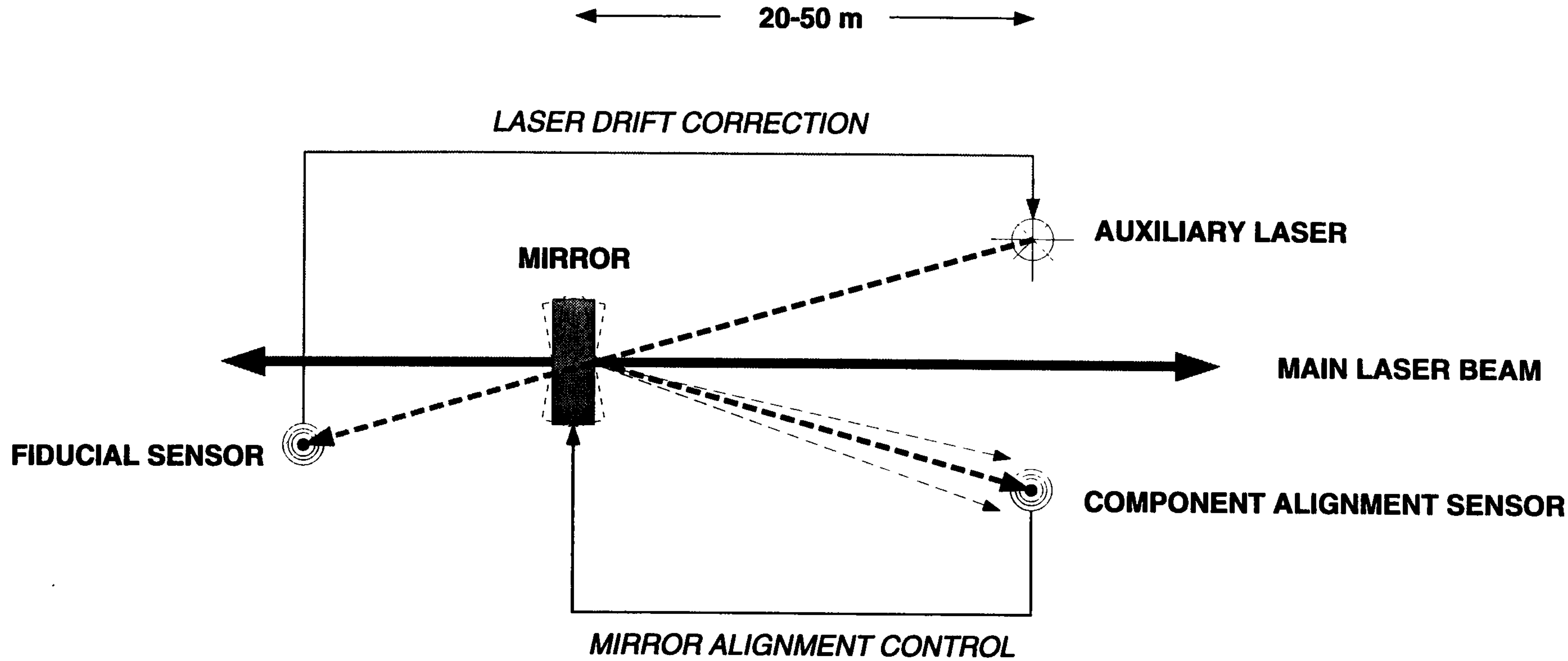
August 31, 1994

AUXILIARY LASER ALIGNMENT SYSTEM: LAYOUT EXERCISE

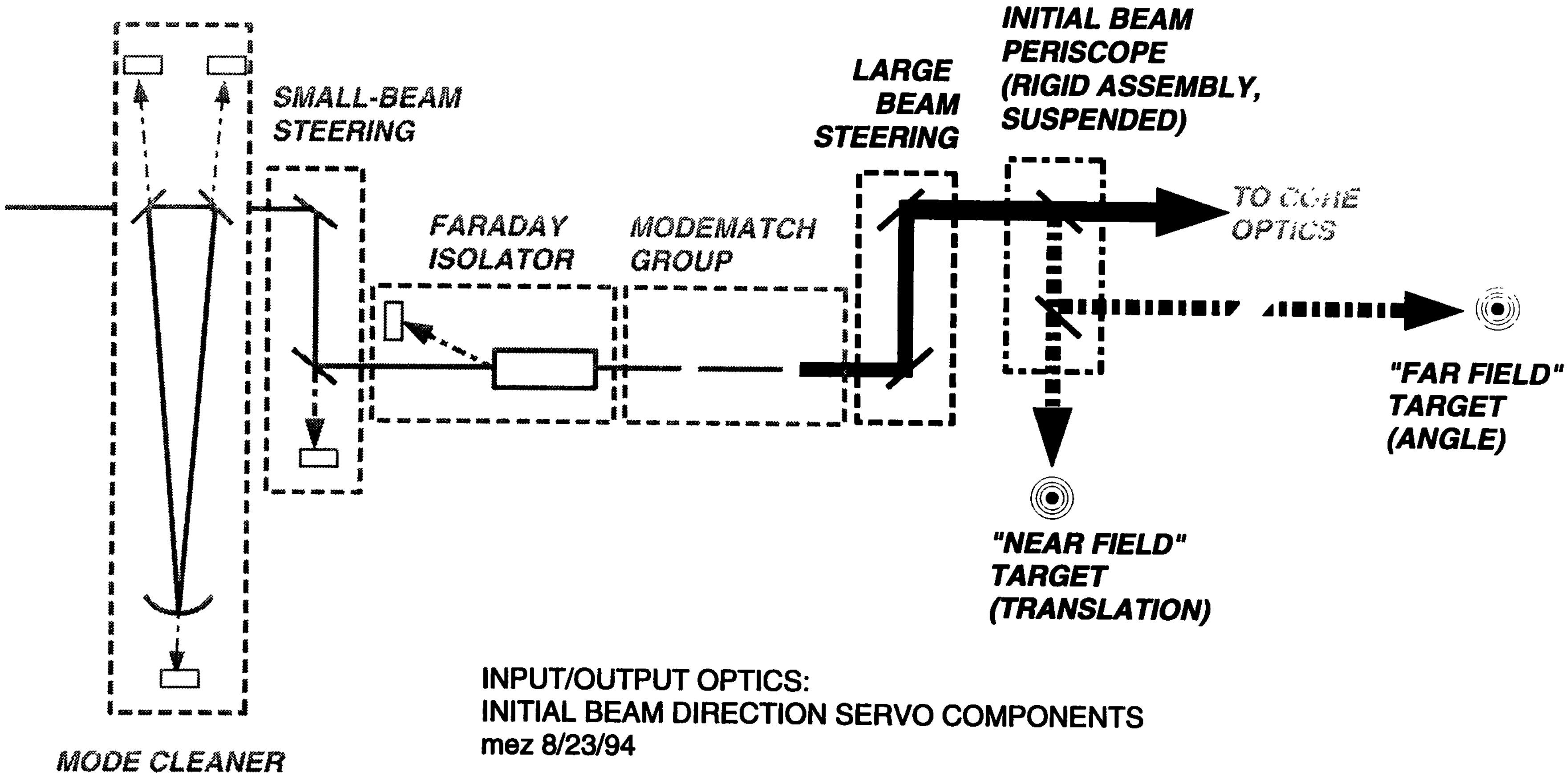
Strategy

- Divide suspended components into classes according to motion sensitivity
  - I/O optics (mostly)
  - Core optics
- Net beam motion after input chain sensed and stabilized using "Initial Beam Direction Servo"
  - Introduce new large-bore optic (sampling periscope)
  - Requires large suspended mirror pair to actuate corrections
- Core optics individually sensed and controlled with "standard" optical levers mounted to external monuments
  - Need "fiducial" (transmitted beam) control to eliminate laser direction drift (adds complexity; three monuments, two sensors per component)
  - Keep baselines $\gtrsim$ 10 m to suppress monument translation

AUXILIARY LASER ALIGNMENT SYSTEM: LAYOUT EXERCISE



AUXILIARY LASER ALIGNMENT SYSTEM: LAYOUT EXERCISE



INPUT/OUTPUT OPTICS:
INITIAL BEAM DIRECTION SERVO COMPONENTS
mez 8/23/94

AUXILIARY LASER ALIGNMENT SYSTEM: LAYOUT EXERCISE

Sample Layouts

Due to extreme aspect ratio, layouts are unreadable in this format. E-size drawings will be shown at review. For preview, load ~mike/vacequip/auxbeams/horwedge/zfig2laux and ~mike/vacequip/auxbeams/verwedge/zfig2m.a into the IDEAS drafting application.

RESULTS OF TRIAL LAYOUTS

MEZ

August 31, 1994

RESULTS OF TRIAL LAYOUTS

Port Locations

Port Functions

- Pump, vent/purge and gauge ports
- Electrical/fiberoptic feedthrough
  - Large reserve capacity
  - In fixed body (no disconnects req'd for access)
- Interferometer support structure feedthrough
  - Bellows isolate IFO supports from vacuum chamber walls
  - In fixed body (HAM), base (BSC), trunk between airlock and dome flange (TMC)
- Inspection & TV beam imaging
  - High and/or low view angle
  - Can image cavity mirrors at < 60 degrees off normal
  - HAM: on removable covers
  - BSC, TMC: on chamber body

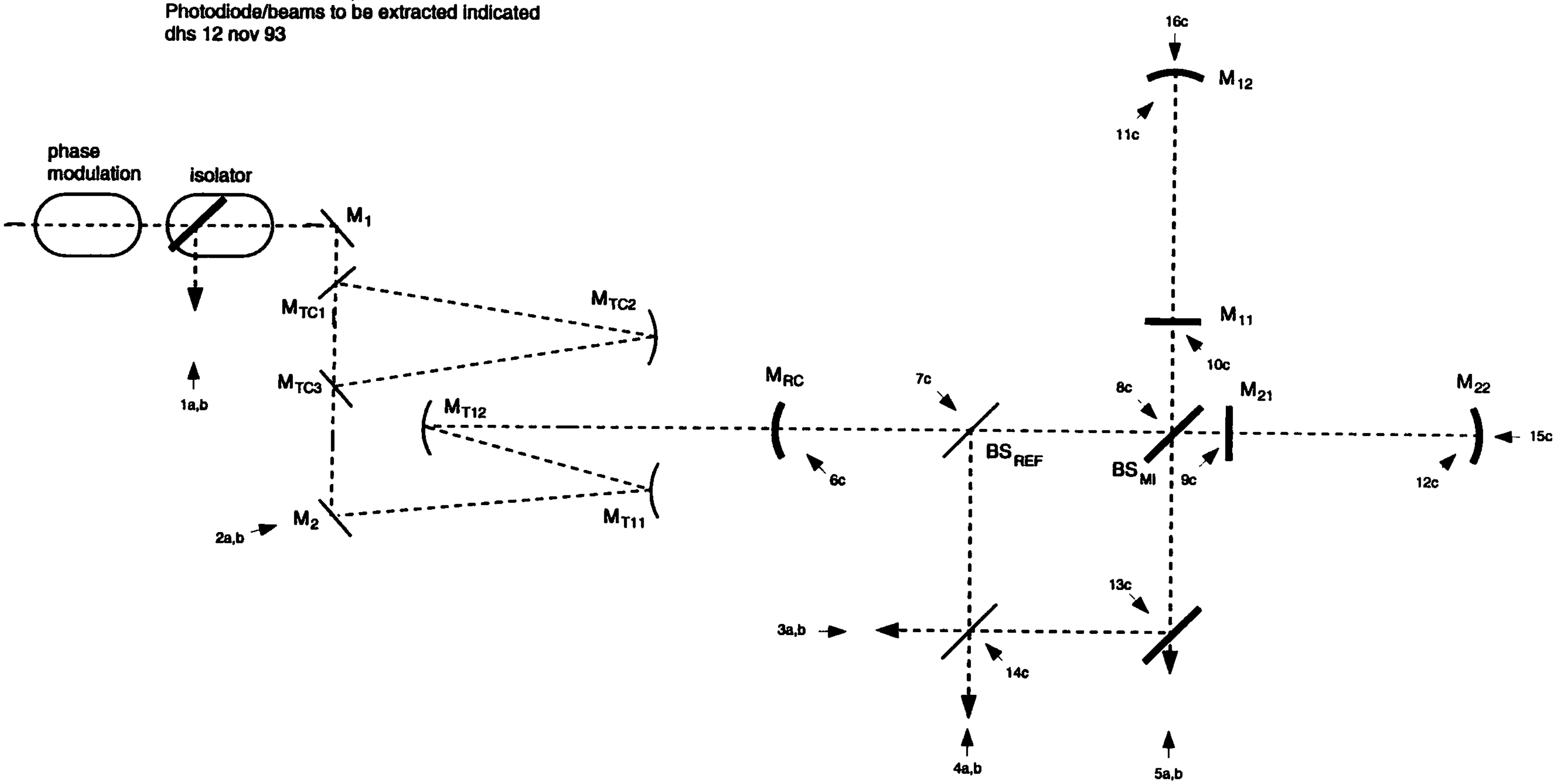
RESULTS OF TRIAL LAYOUTS

- Interferometer laser beam I/O
  - Require full size beam I/O at +/- 12 degree incidence (to clear specular reflection at 1m)
  - 10” nom. O.D. ConFlat type on minimum neck is adequate
  - Implemented on removable covers for reconfigurability
- Auxiliary alignment laser beam I/O
  - Implemented on removable covers
  - Generally in pairs, symmetric about beam axis/component normal
  - Port arrangement in manifold endcaps specific to TM placement in tube aperture

RESULTS OF TRIAL LAYOUTS

Interferometer laser beam I/O

Initial interferometer optical schematic
Photodiode/beams to be extracted indicated
dhs 12 nov 93



LIGO

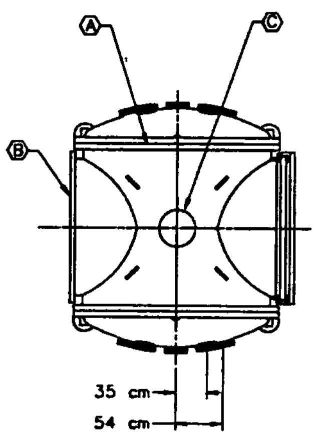
NOTES:
1. HEADS ARE ASME F&D.
3. INCLUDE CENTERING PINS ON NOZZLE FLANGES WHERE APPROPRIATE.
3. VIEWPORT (ITEM Ⓕ) MEASUREMENTS REFER TO INTERSECTION OF VIEWPORT AXIS WITH OUTER SURFACE OF VACUUM WALL.

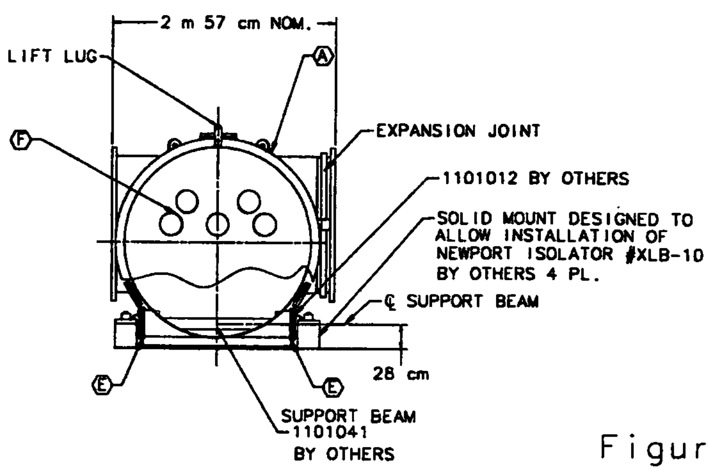
4. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.25 CM
ANGULAR, ± 1 DEGREE

5. NOZZLE SCHEDULE PER TABLE BELOW:

ITEM	SIZE	QUANTITY	FLANGE TYPE	PURPOSE
Ⓐ	213cm ID TUBE	2	O/O-O/METAL*	MAJOR ACCESS
Ⓑ	152cm ID TUBE	2	O/O-O/METAL*	LASER BEAM
Ⓒ	35cm TUBE	1	CONFLAT**, WITH BLIND FLANGE	ION PUMP/AIR SHOWERS, BACK-TO-AIR PURGE
Ⓓ	25cm OD TUBE	8	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS, UTILITY
Ⓔ	30cm OD TUBE	4	CONFLAT**	SUPPORT BEAMS
Ⓕ	20cm OD TUBE***	10	CONFLAT**, WITH BLIND FLANGE	OBSERVATION, PICKOFFS
Ⓖ	3.8cm TUBE	1	CONFLAT**, WITH BLIND FLANGE	ANNULUS PUMPOUT (NOT SHOWN)

* DUAL O-RING DESIGN, WITH CAPABILITY OF REPLACING INBOARD O-RING WITH METAL SEAL. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLDED TO A SINGLE PUMPOUT PORT ON EACH CHAMBER, WITH CONFLAT** SEAL.
** REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS; COMPATIBLE ALTERNATIVES ARE ACCEPTIBLE
*** THESE FLANGES ARE TANGENT TO LOCAL VACUUM WALL, WITH MINIMUM NECK LENGTH





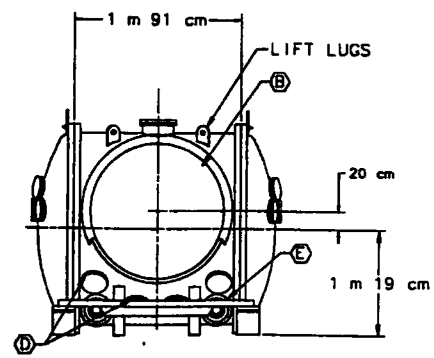


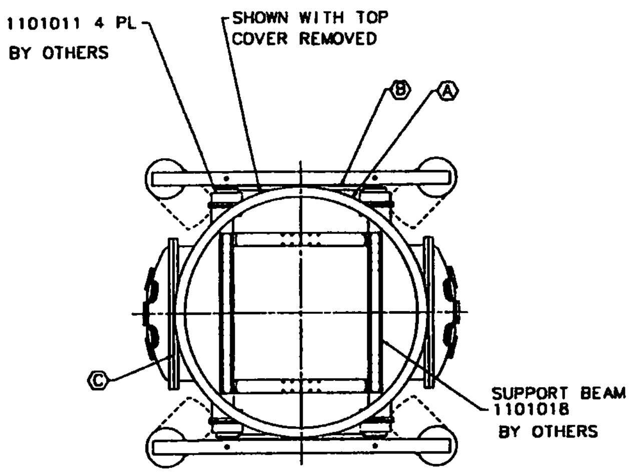
Figure 11.

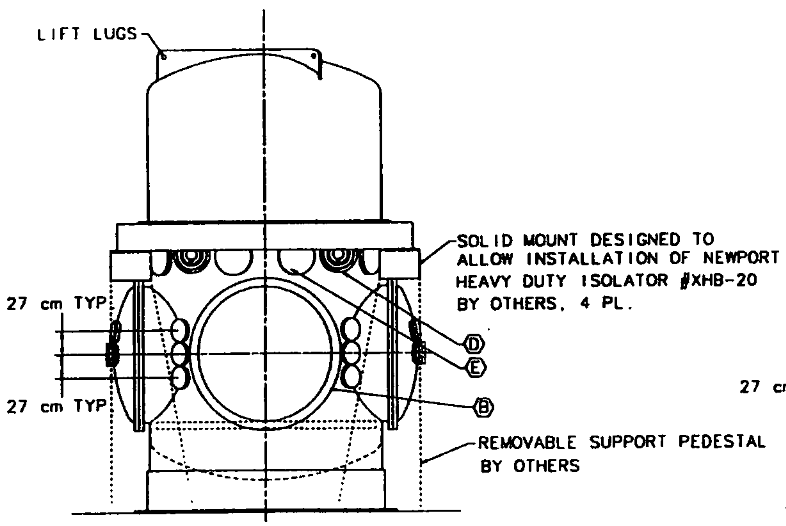
LIGO PROJECT
J. WORLEY
HORIZONTAL AXIS MODULE (HAM)
1101010

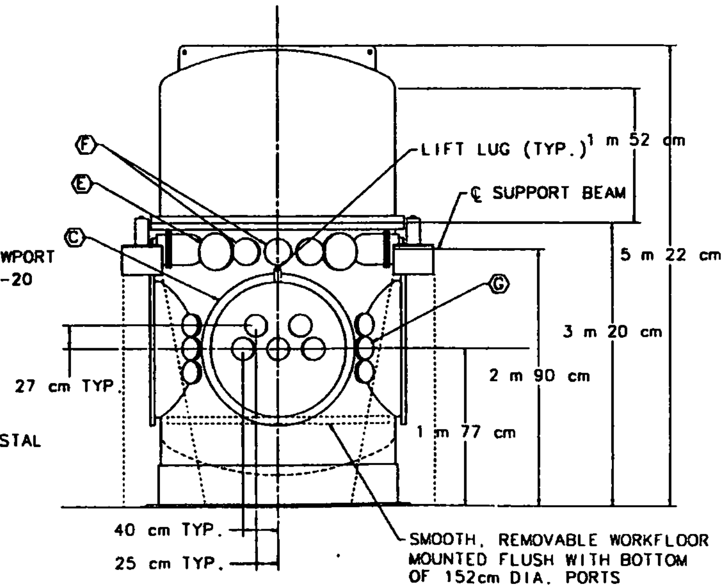
NOTES:
1. HEADS ARE ASME F&D.
2. INCLUDE CENTERING PINS ON NOZZLE FLANGES WHERE APPROPRIATE.
3. VIEWPORT (ITEM Ⓖ) MEASUREMENTS REFER TO INTERSECTION OF VIEWPORT AXIS WITH OUTER SURFACE OF VACUUM WALL.
4. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.25 CM
ANGULAR, ± 1 DEGREE
5. NOZZLE SCHEDULE PER TABLE BELOW:

ITEM	SIZE	QUANTITY	FLANGE TYPE	PURPOSE
Ⓐ	264cm ID TUBE	1	O/O-O/METAL•	MAJOR ACCESS
Ⓑ	152cm ID TUBE	2	O/O-O/METAL•	LASER BEAM, ACCESS (MINIMIZE NECK LENGTH)
Ⓒ	152cm ID TUBE	2	O/O-O/METAL•, WITH BLIND FLANGE	ACCESS (MINIMIZE NECK LENGTH)
Ⓓ	35cm OD TUBE	4	CONFLAT••	SUPPORT BEAMS
Ⓔ	35cm OD TUBE•••	8	CONFLAT••, WITH BLIND FLANGE	AIR SHWR, BACK-TO-AIR PURGE ROUGHING & ION PUMPS, UTILITY
Ⓕ	25cm OD TUBE•••	6	CONFLAT••, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS
Ⓖ	20cm OD TUBE•••	22	CONFLAT••, WITH BLIND FLANGE	OBSERVATION, BEAM PICK-OFFS
Ⓗ	3.8cm OD TUBE	1	CONFLAT••, WITH BLIND FLANGE	ANNULUS PUMPOUT (NOT SHOWN)

•DUAL O-RING DESIGN, WITH CAPABILITY OF REPLACING INBOARD O-RING WITH METAL SEAL. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLDED TO A SINGLE PUMPOUT PORT ON EACH CHAMBER, WITH CONFLAT•• SEAL.
••REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS; COMPATIBLE ALTERNATES ARE ACCEPTABLE.
•••THESE FLANGES ARE TANGENT TO LOCAL VACUUM WALL, WITH MINIMUM NECK LENGTH.







LIGO PROJECT

BEAM SPLITTER CHAMBER (BSC)

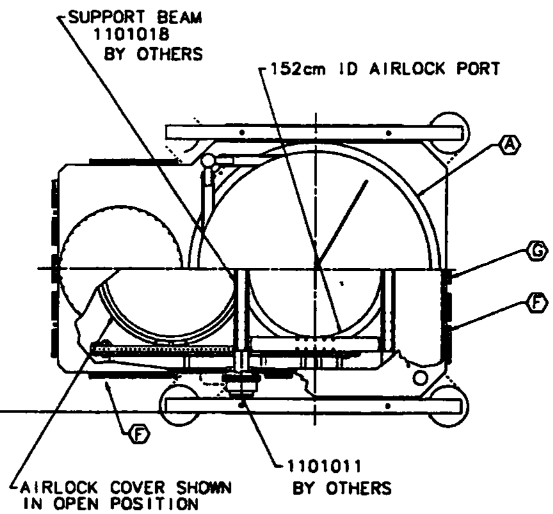
1101009

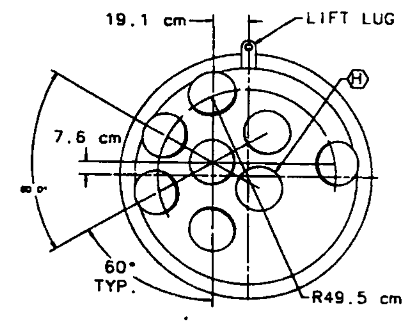
Figure 8.

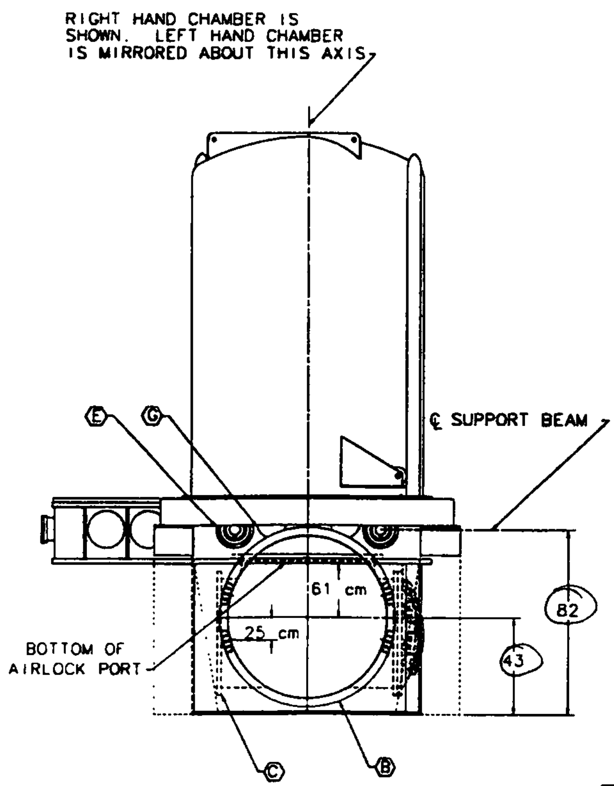
NOTES:
1. HEADS ARE ASME F&D.
2. INCLUDE CENTERING PINS ON NOZZLE FLANGES WHERE APPROPRIATE.
3. VIEWPORT (ITEM (H)) MEASUREMENTS REFER TO INTERSECTION OF VIEWPORT AXIS WITH OUTER SURFACE OF VACUUM WALL.
4. TOLERANCES, UNLESS OTHERWISE SPECIFIED: LINEAR, ±0.25 CM; ANGULAR, ± 1 DEGREE
5. NOZZLE SCHEDULE PER TABLE BELOW:

ITEM	SIZE	QUANTITY	FLANGE TYPE	PURPOSE
(A)	264cm ID TUBE	1	O/O-O/METAL*	MAJOR ACCESS
(B)	183cm ID TUBE	2	METAL SEAL	LASER BEAM
(C)	122cm ID TUBE	1	O/O-O/METAL*	LASER BEAM
(D)	122cm ID TUBE	1	O/O-O/METAL*, WITH BLIND FLANGE	EMERGENCY ACCESS (MINIMIZE NECK LENGTH)
(E)	35cm OD TUBE	4	CONFLAT**	SUPPORT BEAMS
(F)	35cm OD TUBE	6	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS ROUGHING & ION PUMPS, UTILITY
(G)	25cm OD TUBE	12	CONFLAT**, WITH BLIND FLANGE	ELECTRICAL FEEDTHROUGHS, BACK-TO-AIR PURGE
(H)	20cm OD TUBE***	12	CONFLAT**, WITH BLIND FLANGE	OBSERVATION, BEAM PICKOFFS
(I)	3.8cm OD TUBE	1	CONFLAT**, WITH BLIND FLANGE	ANNULUS PUMPOUT (NOT SHOWN)

*DUAL O-RING DESIGN, WITH CAPABILITY OF REPLACING INBOARD O-RING WITH METAL SEAL. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLDED TO A SINGLE PUMPOUT PORT ON EACH CHAMBER, WITH CONFLAT** SEAL.
**REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS COMPATIBLE ALTERNATIVES ARE ACCEPTABLE
***THESE FLANGES ARE TANGENT TO LOCAL VACUUM WALL, WITH MINIMUM NECK LENGTH







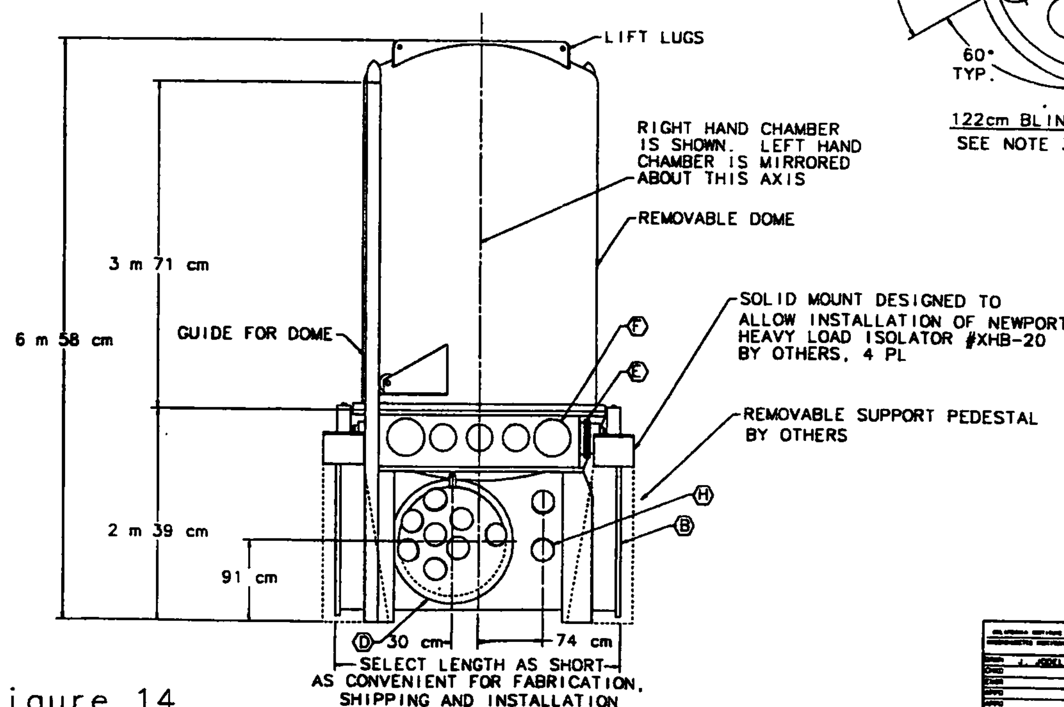
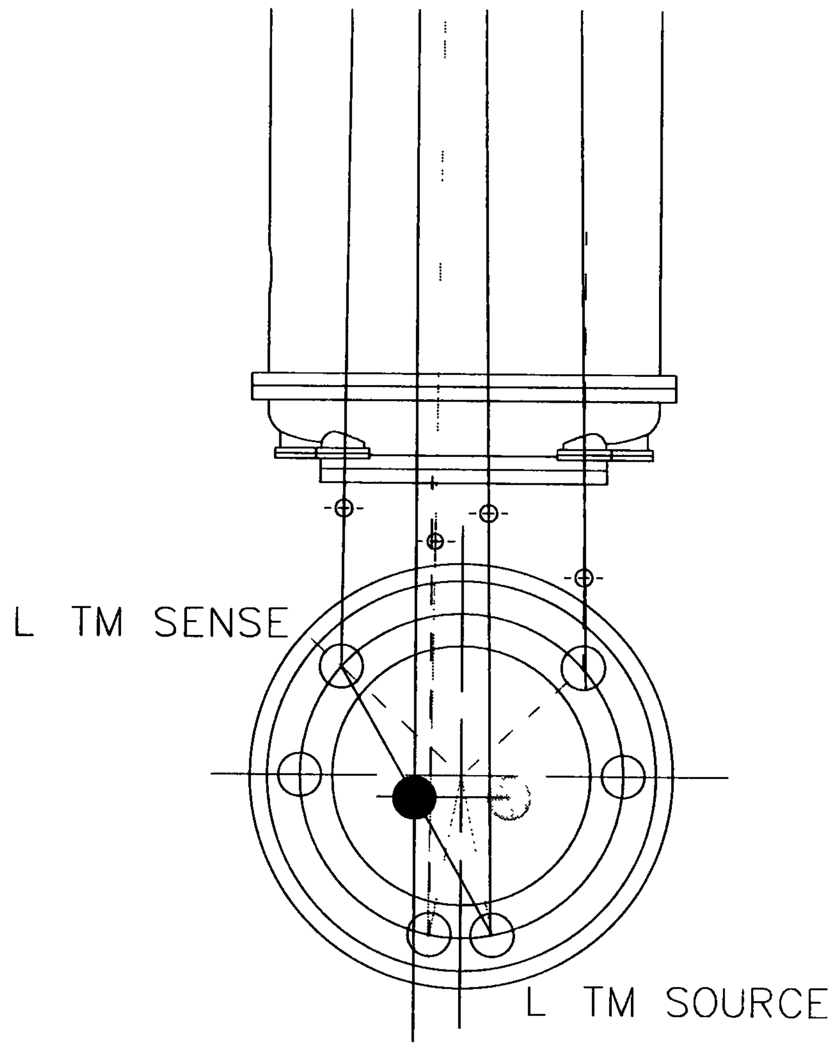


Figure 14.

LIGO PROJECT
TEST MASS CHAMBER (TMC)
1101013

RESULTS OF TRIAL LAYOUTS

Manifold Ports



RESULTS OF TRIAL LAYOUTS

Initial Interferometer Compatibility

- "Generic Interferometer" trial layouts successful and relatively straightforward
- Stray beam handling, auxiliary alignment systems took up much of space vacated by "excess" components found in '89 IFO design
- Unique wedge angles seem necessary for particular locations (some loss of optic interchangeability)
- Fine tuning of auxiliary laser paths much less stringent with "vertical" component wedges
- Compact alignment system, better AR coatings than assumed in baseline will increase margins still further

RESULTS OF TRIAL LAYOUTS

Advanced Interferometer/Phase C Compatibility

SATISFACTORY:

- 200 kg quartz TM's
- advanced (e.g. Perth design) stacks in BSC and TMC
- double suspensions (all chamber types)
- dual recycling
- output mode cleaners
- suspension-point interferometers

RESULTS OF TRIAL LAYOUTS

PROBLEMS:

- beam crossings for Phase C
  - proposal design (fancy crossing adapters) marginal, probable conflict with stray beam req's.
  - allowing periscopes to shift alternate HAM chains to higher tier solves problem
  - CRANE HOOK HEIGHT OVER HAM's SHOULD BE ADEQUATE TO CLEAR TWO-TIER ARRANGEMENT
- stray beam dumping for Phase C
  - better understanding of internal scattering needed to evaluate solutions
  - use of different wavelengths should mitigate interference between IFO's
- auxiliary laser alignment for Phase C
  - need compact alignment system
  - wavefront sensing a promising solution
- advanced (low frequency) isolation stacks in HAM chambers
  - intrinsic height restriction probably rules out sub-10 Hz isolation for mode cleaner, recycling mirror; resulting frequency noise too large to reject
  - may be able to replace with tall chambers
  - may add external satellite chambers at support feedthroughs for new isolators (original design feature)
- 100 meter mode cleaners
  - require facility reconfiguration & building modification
  - BUILDING LAYOUT SHOULD PERMIT EXTENSIONS OF MC VACUUM SYSTEM ALONG ARM

RESULTS OF TRIAL LAYOUTS

Summary: Adopted Changes from '89 Proposal Design

- Pump strategy revised
- BSC 60" side ports symmetrized
- BSC switched to "high stack" design like TMC–2 (no trench in facility floor req'd.)
- (TMC–2 identical to BSC now; designation dropped)
- Height adaptation (offset adaptor) now between BSC and first HAM
- HAM chamber body lowered w.r.t. beam height to add more room for stacks
- Port locations finalized

SEISMIC ISOLATION AND SUSPENSION COMPATIBILITY

Lisa Sievers, 8/31/94

1. Initial IFOs
   - Conceptual design and dimensions of TMC/BSC stacks
   - Fit into TMC/BSC chambers
   - Conceptual design and dimensions of HAM stacks
   - Fit into HAM chambers

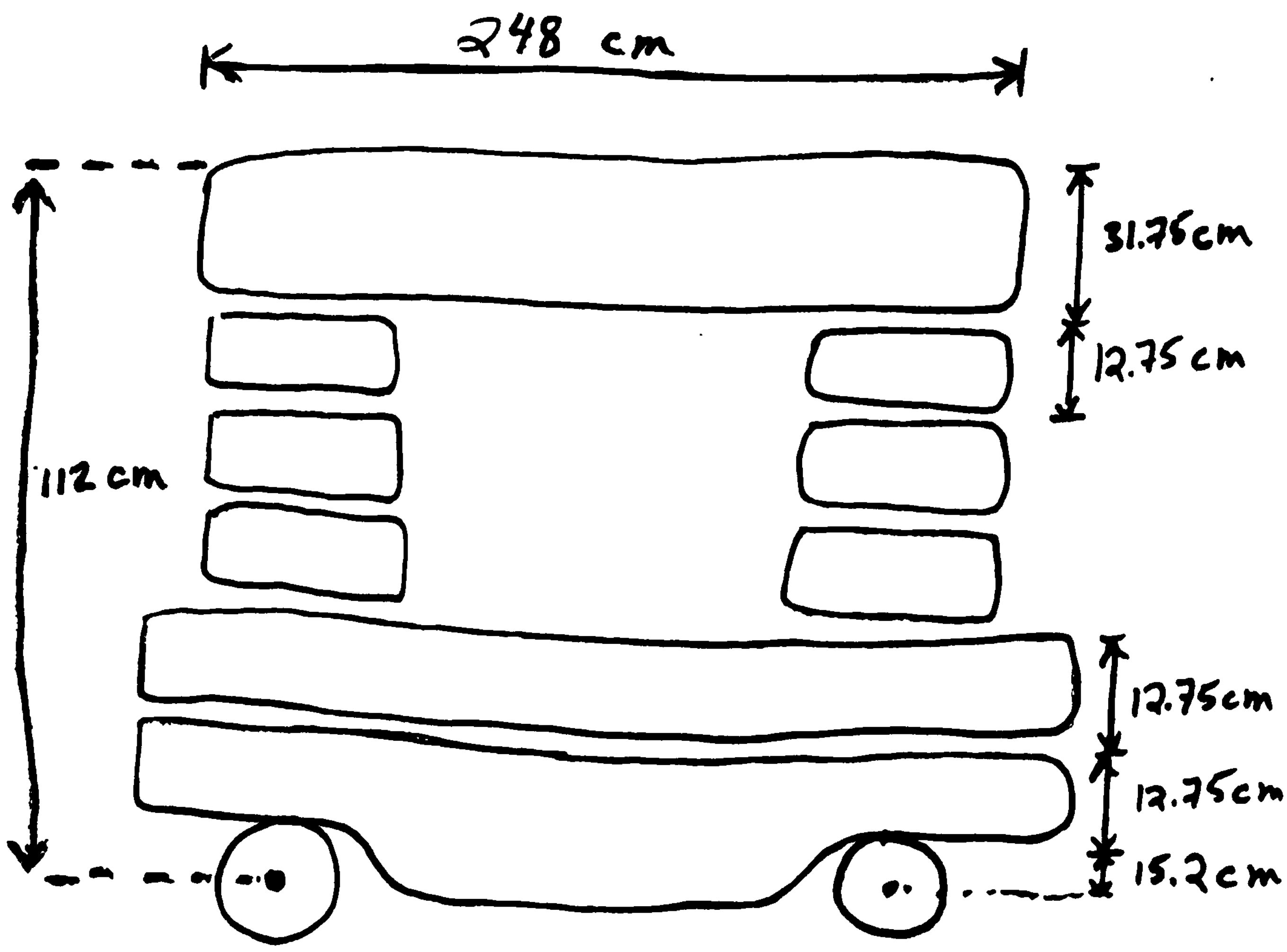
2. Advanced IFOs
   - Conceptual design and dimensions of TMC/BSC stacks
   - Fit into TMC/BSC chambers
   - Discussion of HAM chamber compatibility with advanced IFOs

3. Access and assembly for initial stacks

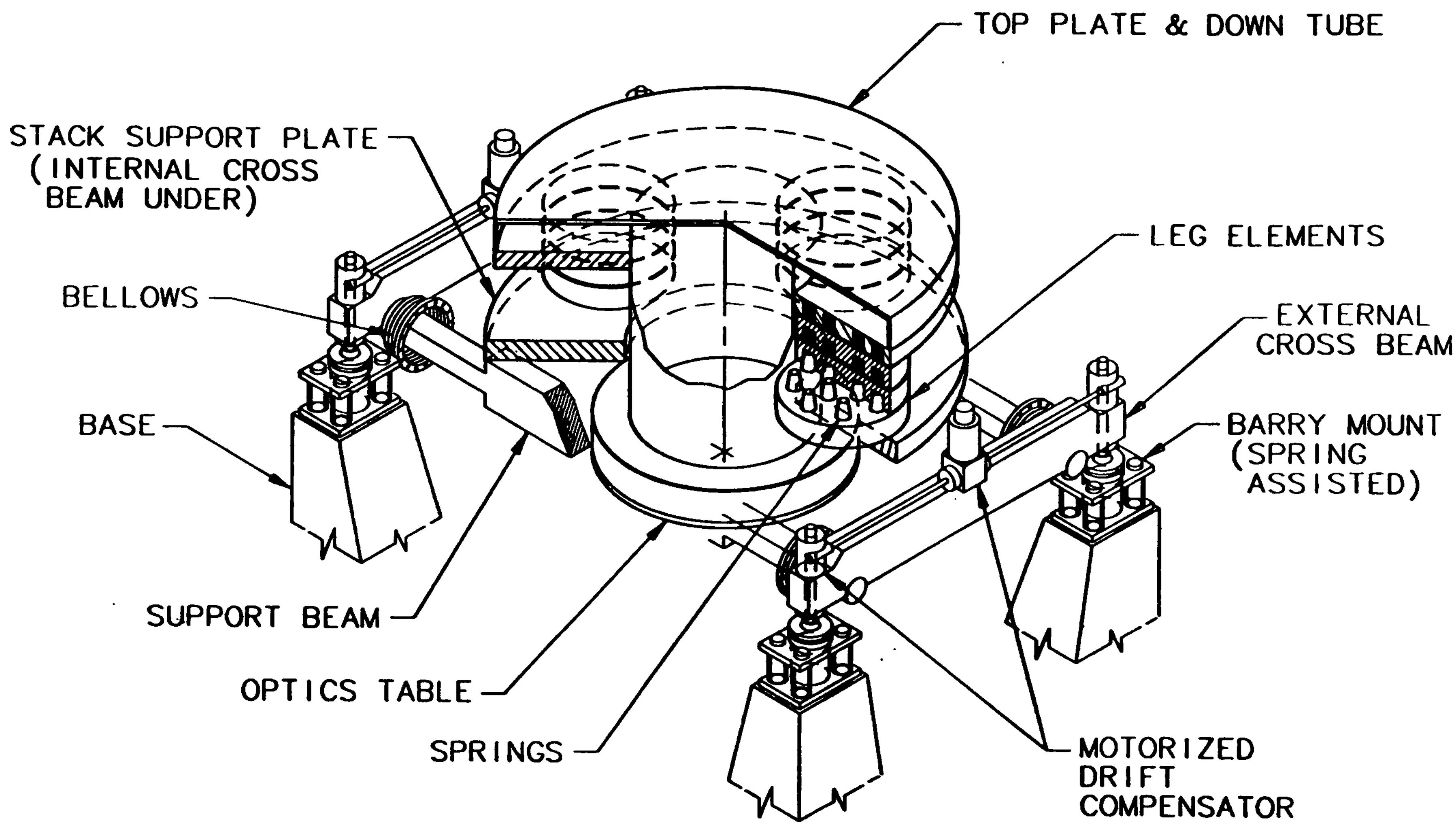
INITIAL IFOS:
Conceptual Design for TMC/BSC Stacks

Displacement sensitivity requirement at 100 Hz is $x = 5 \times 10^{-20} \frac{\mathrm{m}}{\sqrt{\mathrm{Hz}}}$

- 4 layers
- Springs must be as soft or softer than viton
- Each metal component has $f_o \geq 300$ Hz

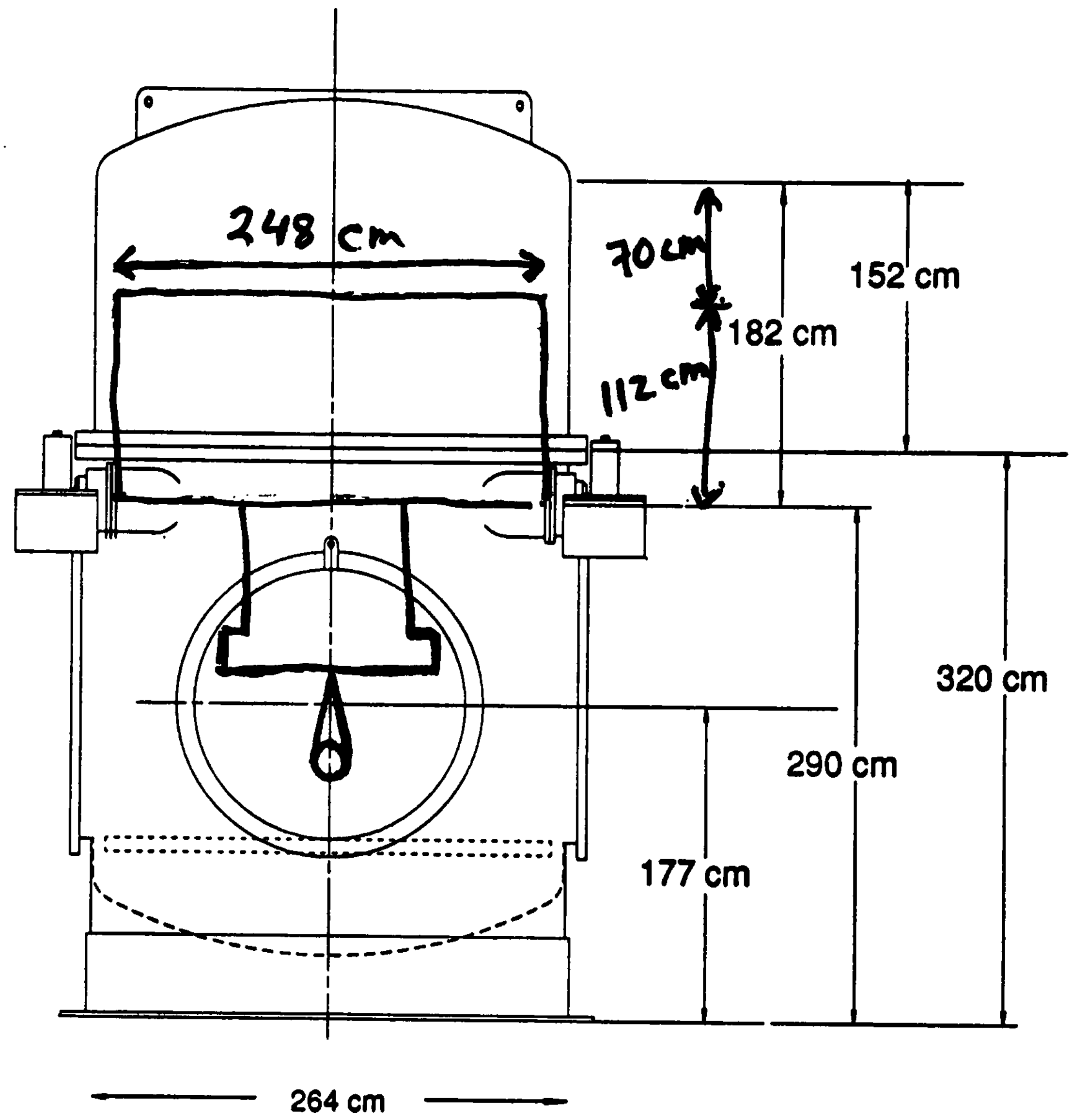


LIGO

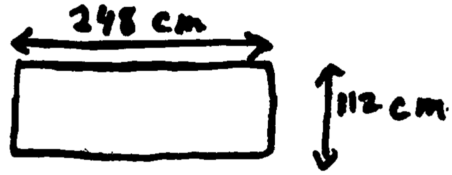


BSC SEISMIC ISOLATION

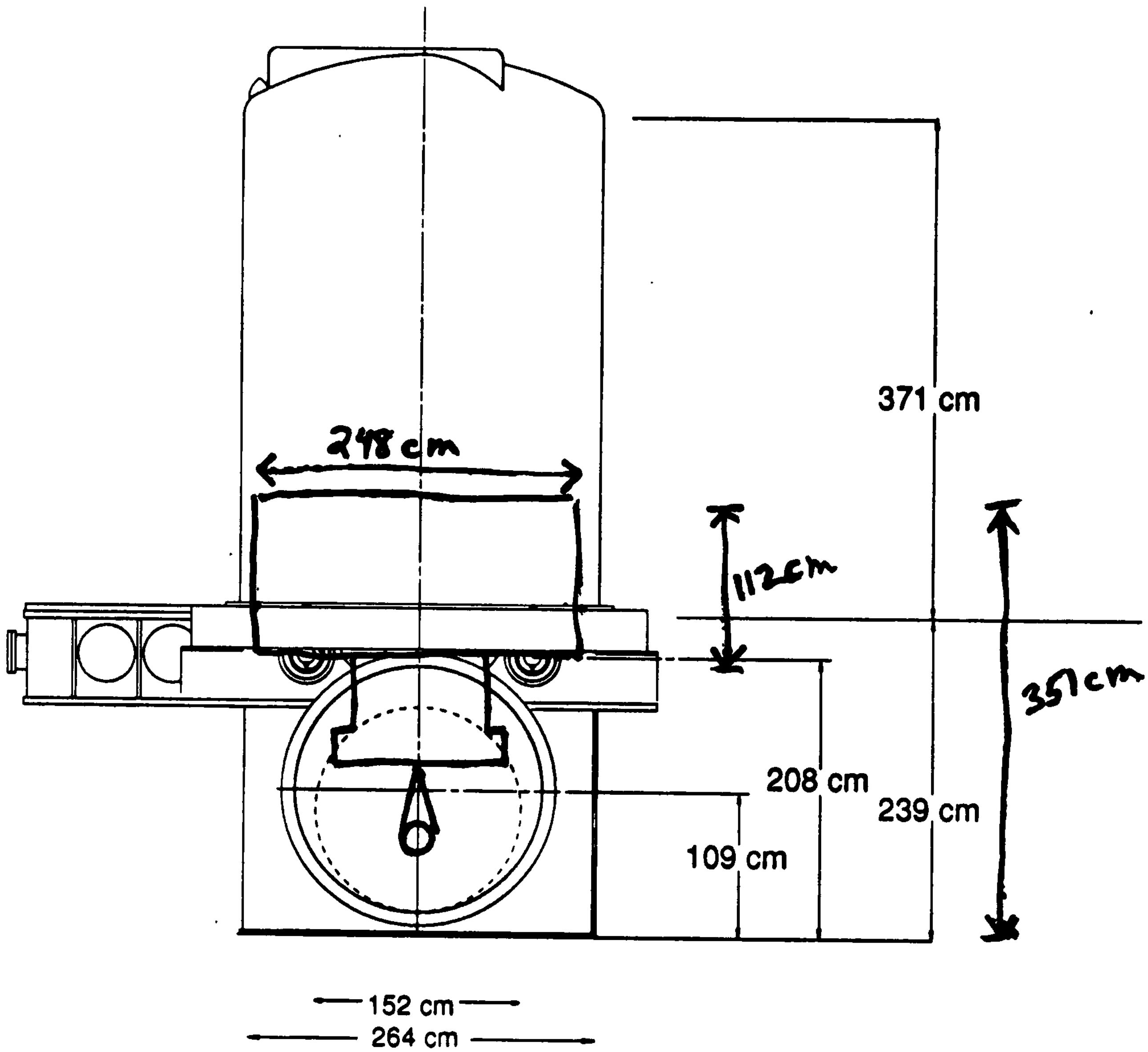
Initial IFO: BSC Chamber



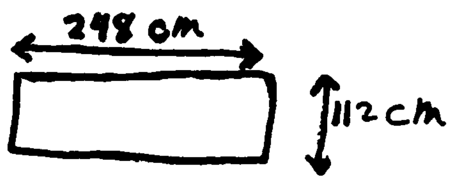
Stack dims:



Initial IFO: TMC Chamber



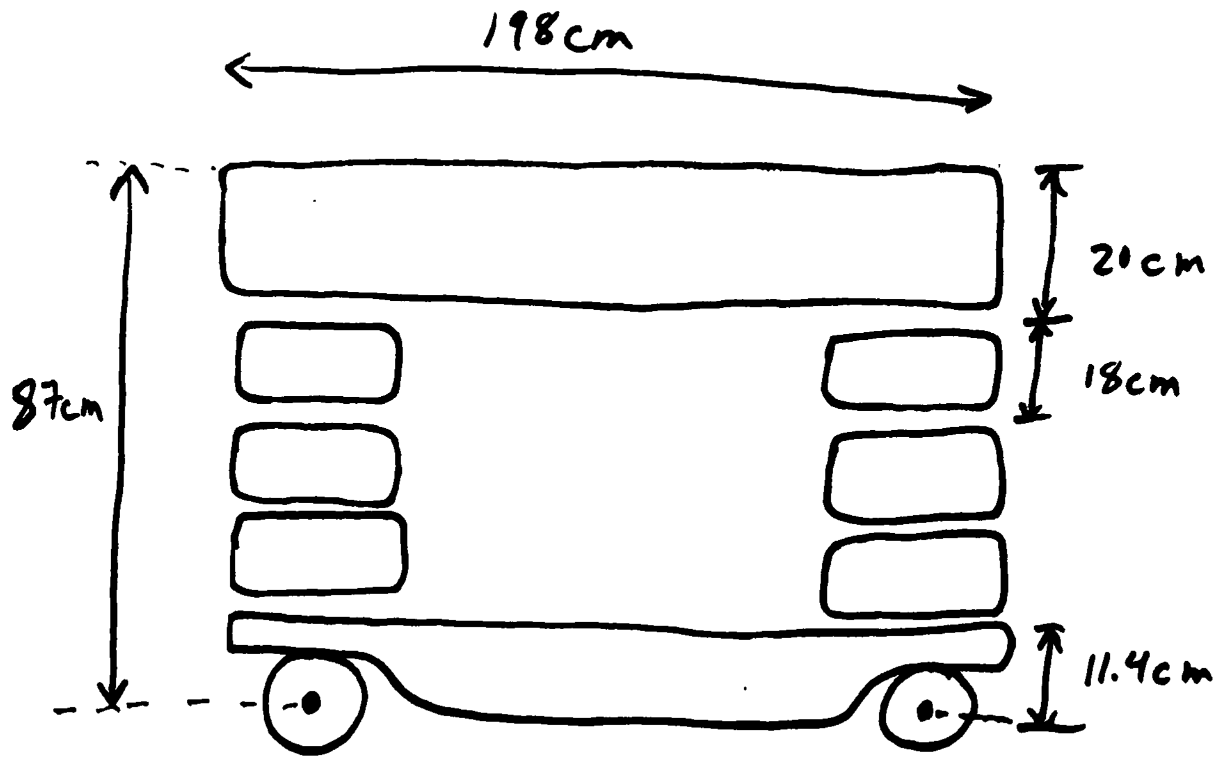
Stack dims:

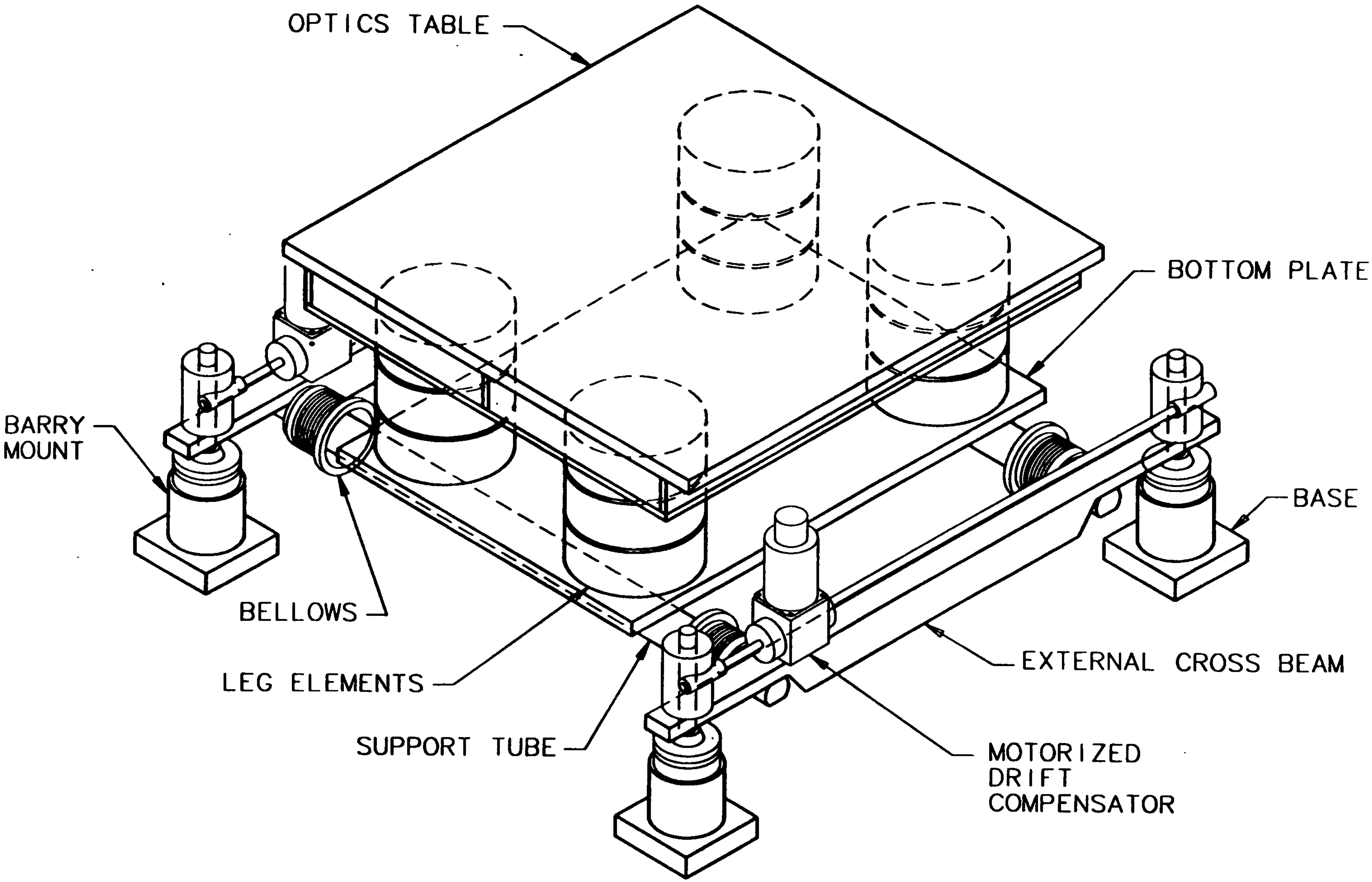


INITIAL IFOS:
Conceptual Design for HAM Stacks

Displacement sensitivity requirement at 100 Hz is $x = 5 \times 10^{-20} \frac{\mathrm{m}}{\sqrt{\mathrm{Hz}}}$

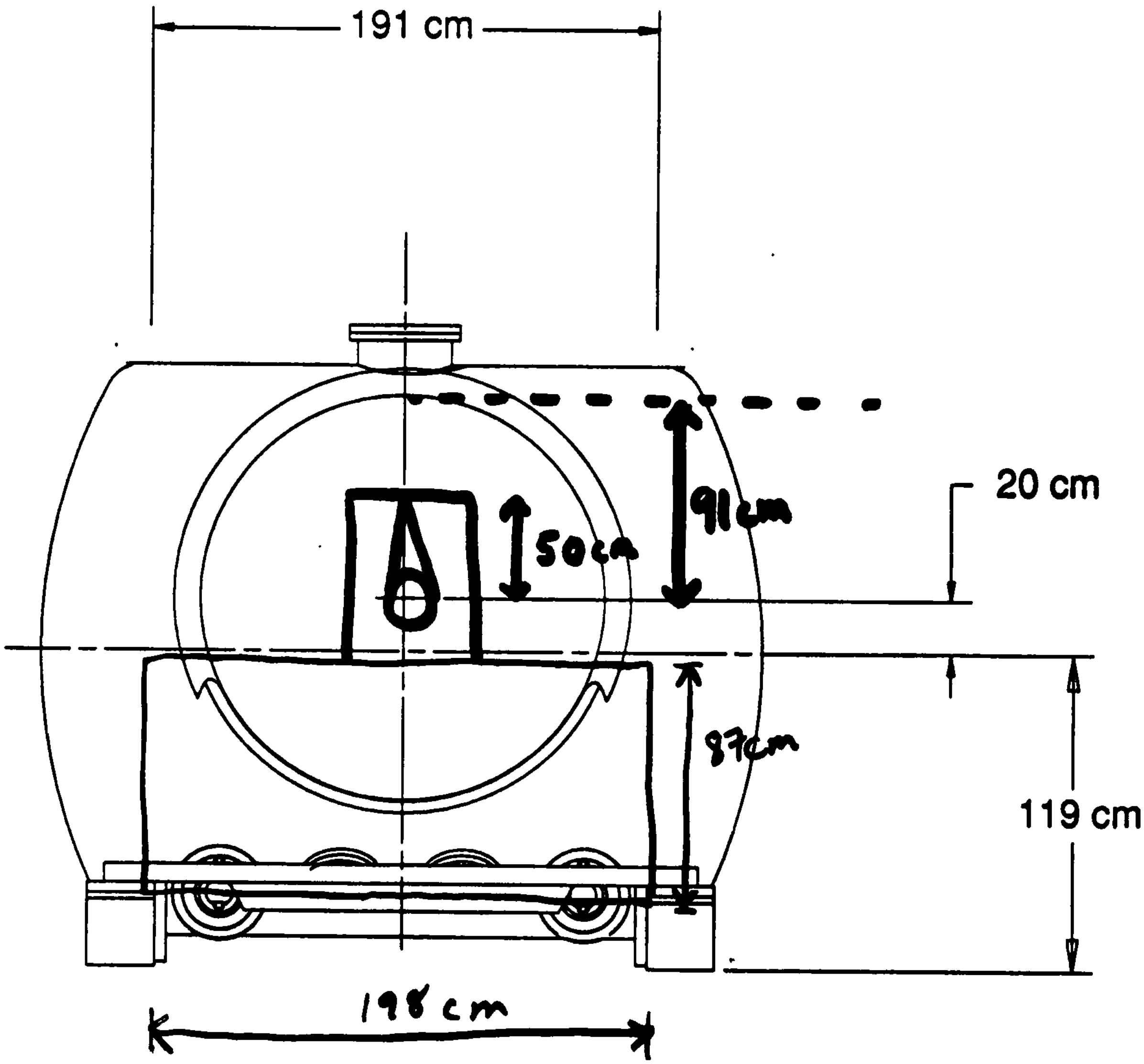
- 4 layers
- Springs must be as soft or softer than viton
- Each metal component has $f_o \geq 300$ Hz (HAM stacks are much smaller than TMC/BSC stacks since top plate is much smaller)



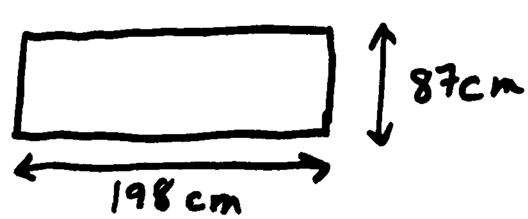


HAM SEISMIC ISOLATION

Initial IFO: HAM Chamber



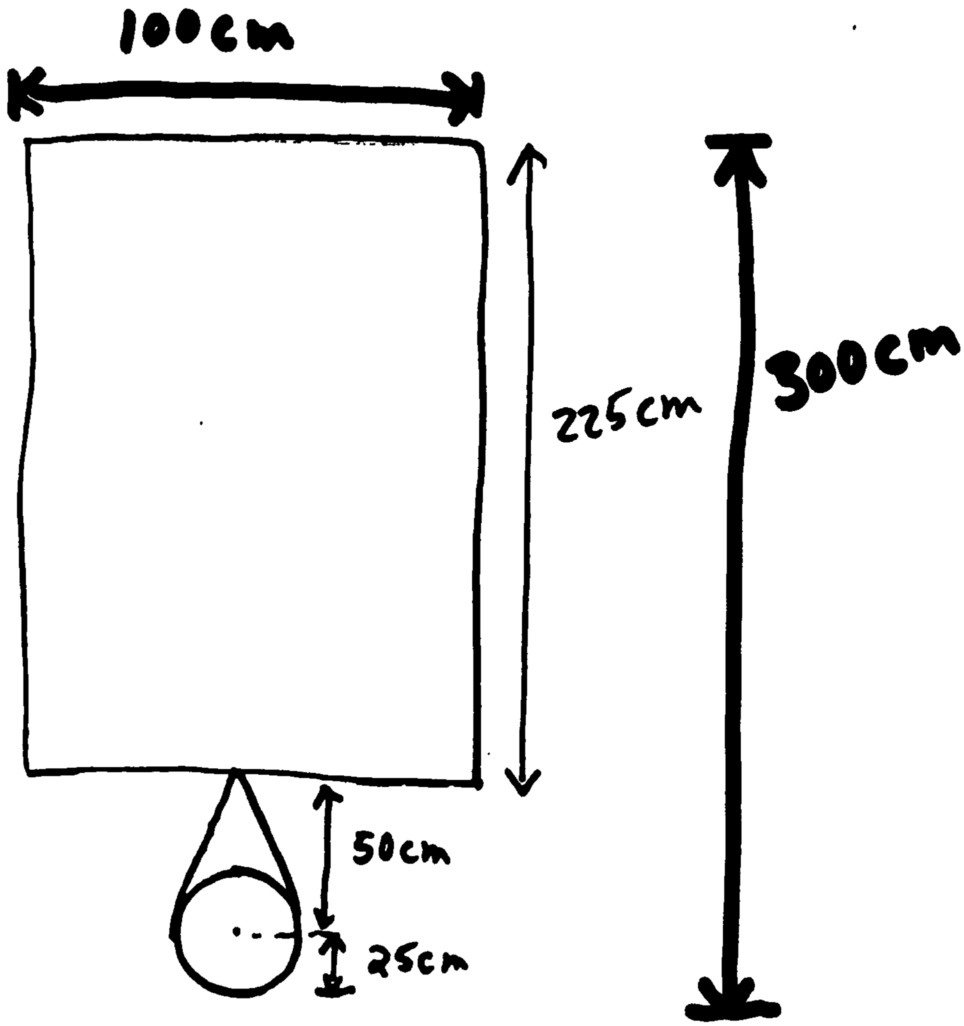
Stack dims:



ADVANCED IFOS: Conceptual Design for TMC/BSC Stacks

1. Advanced IFO requirement has displacement sensitivity of $x = 2 \times 10^{-19}\ \frac{\mathrm{m}}{\sqrt{\mathrm{Hz}}}$ at 10 Hz.
2. To estimate size of advanced stacks used Australian/Italian conceptual design
   - Horizontal: 6 stages of 1 Hz pendula
   - Vertical: 6 stages of 2 Hz cantilever springs

3. Size:



LIGO

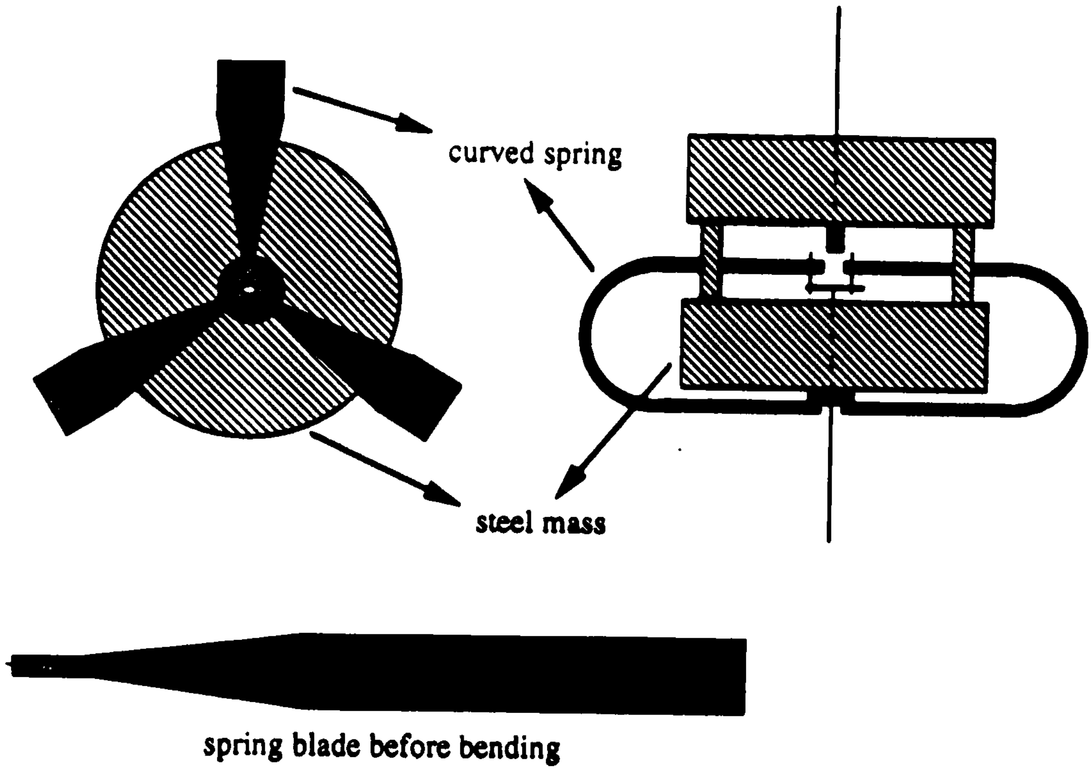


Figure 2. Configuration of 1 isolator element.

LIGO

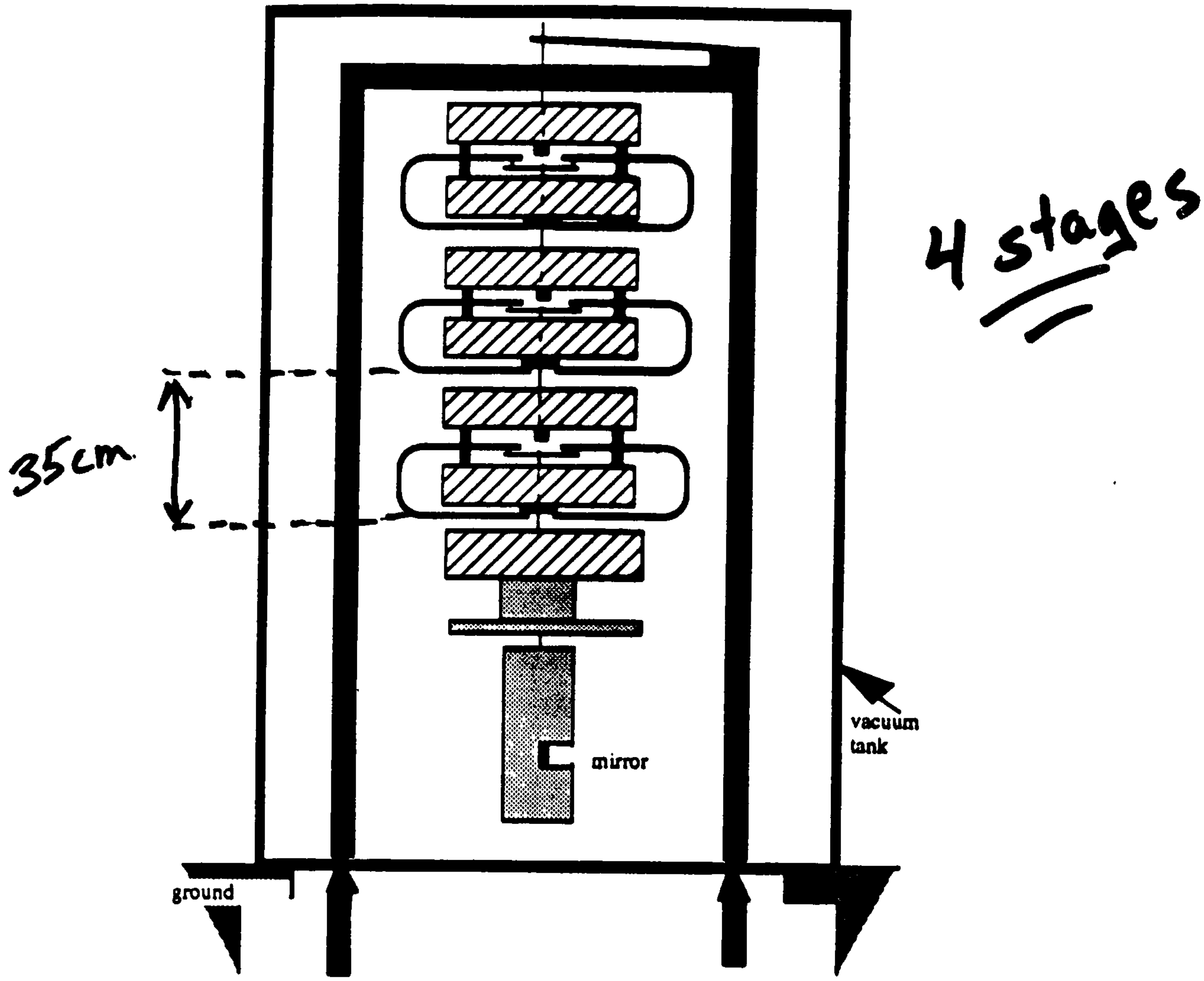
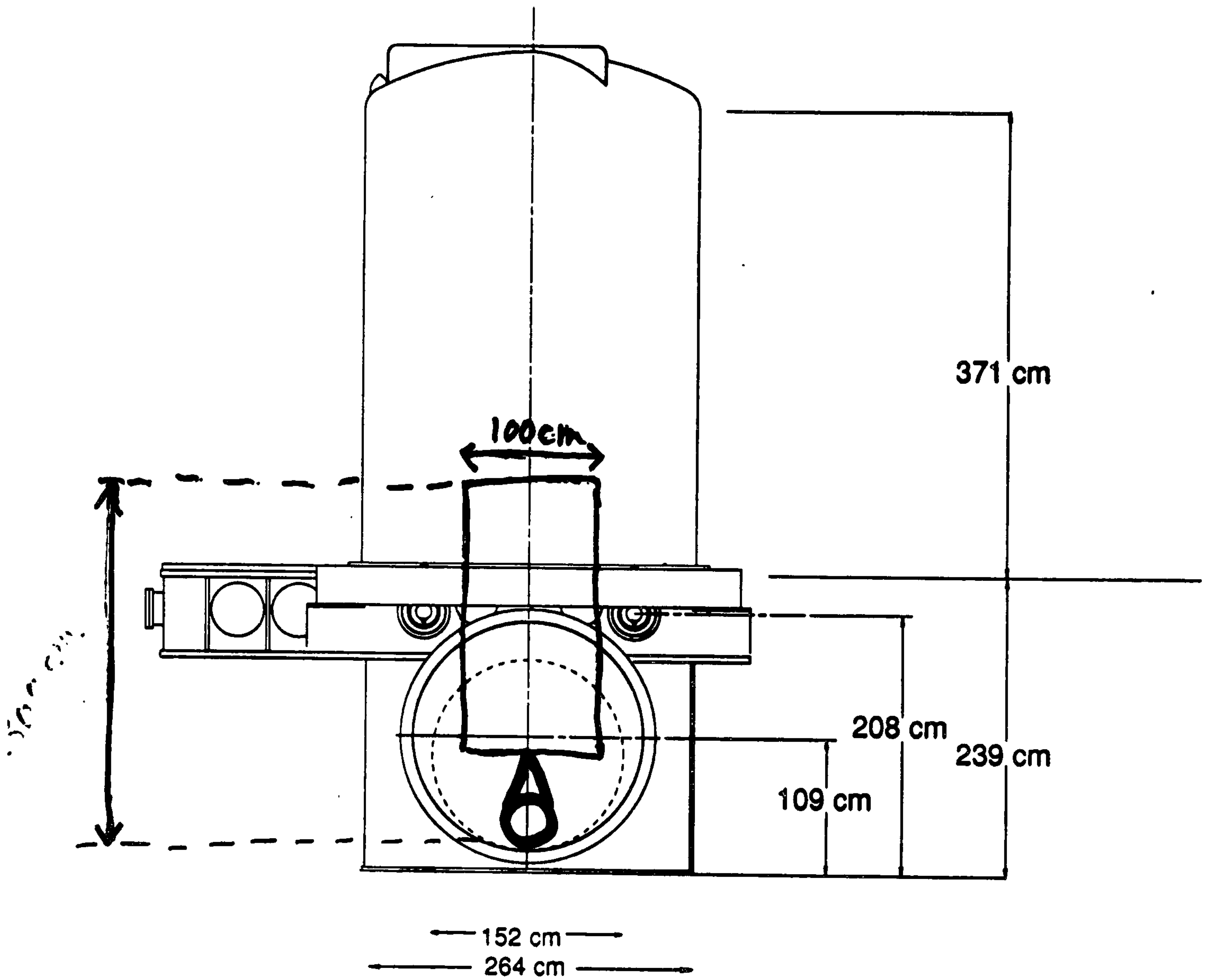


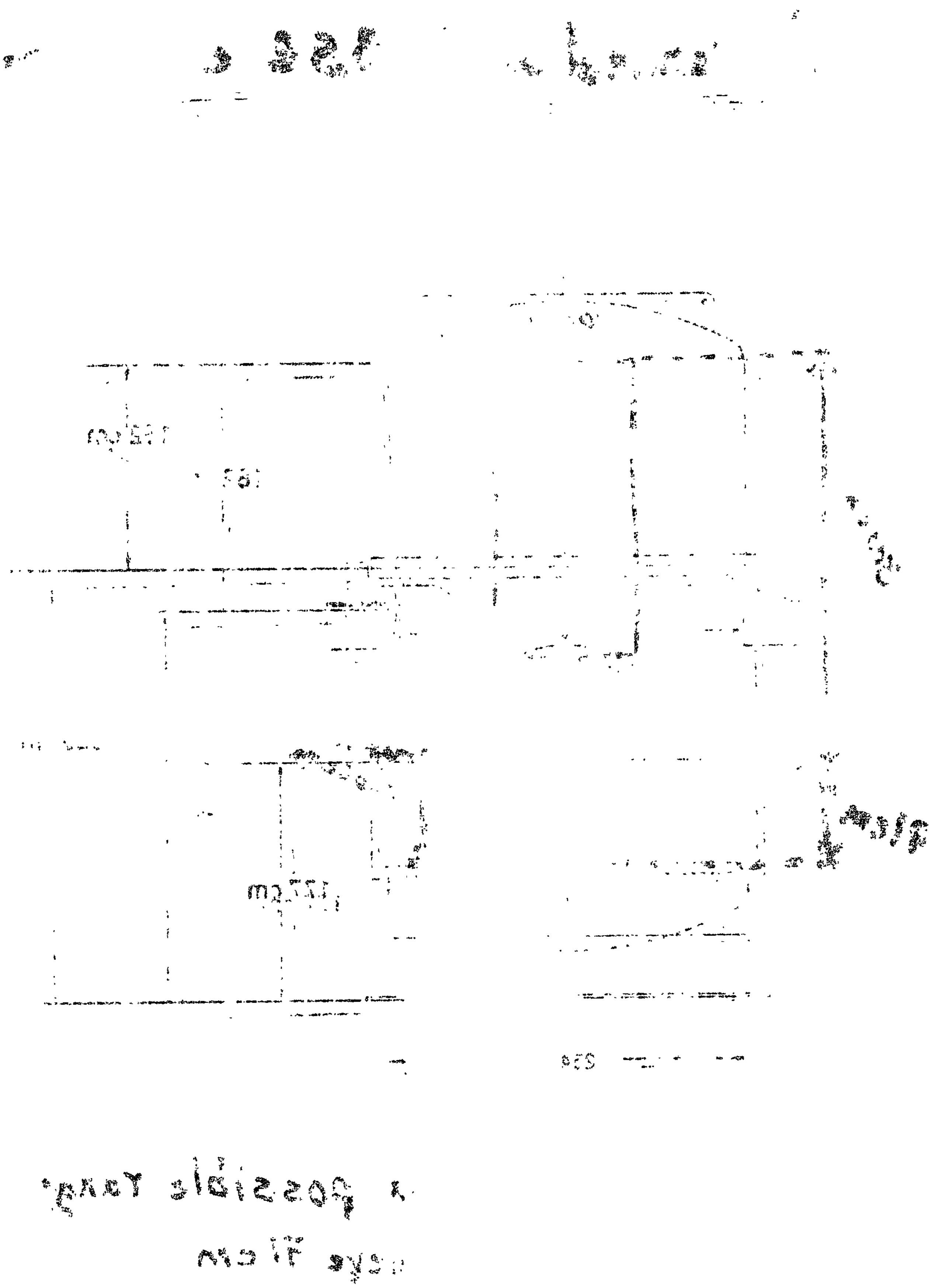
Figure 1. Current University of Western Australia Vibration Isolation Design

LIGO

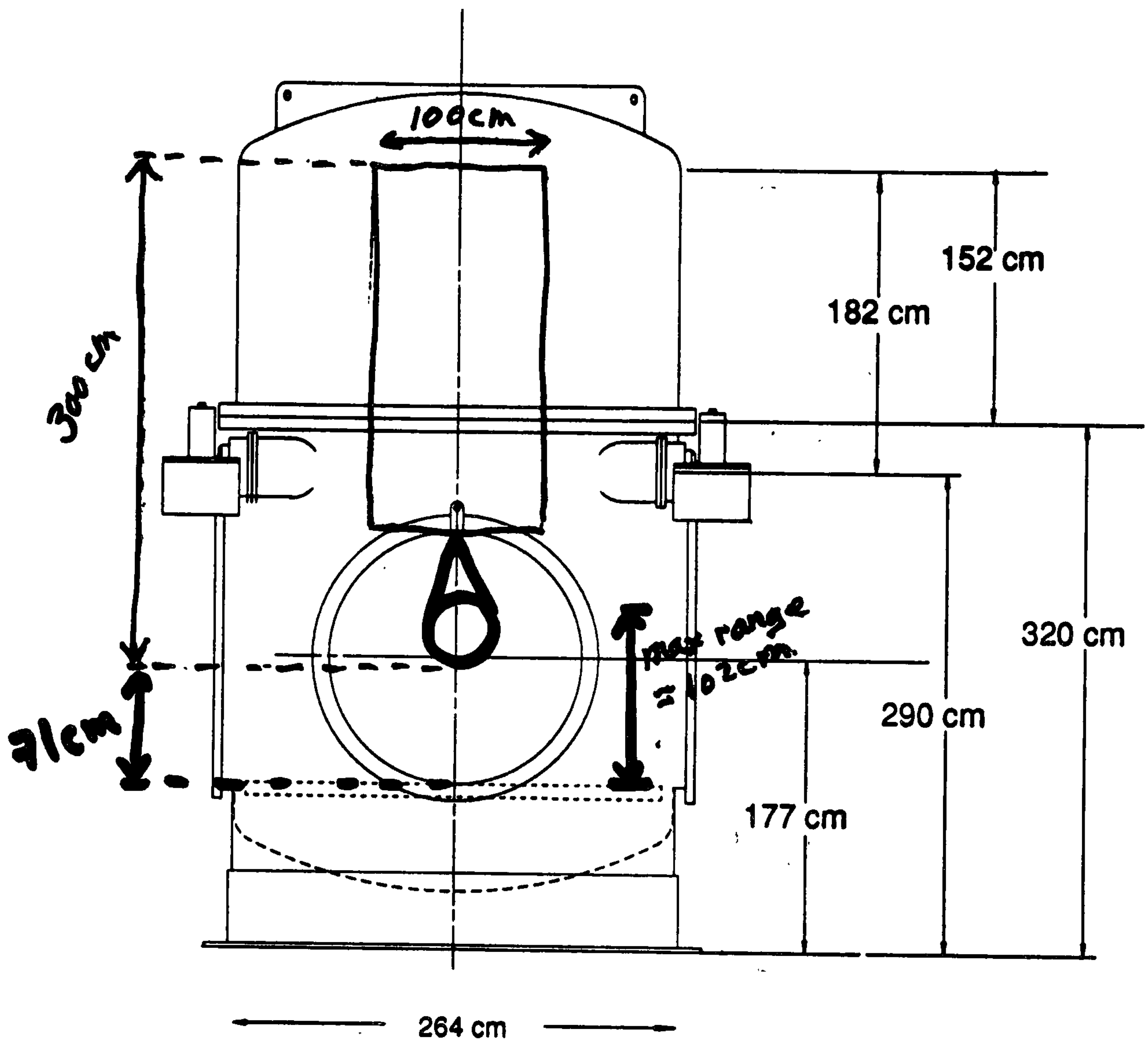
Advanced IFO: TMC chamber



-can achieve max possible range = 102 cm



Advanced IFO: BSC chamber



- max possible range = 102 cm
- achieve 71 cm