LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type	**LIGO-T960024-A - CDR**	5/8/96

Vacuum Control and Monitoring System (VCMS) Design Requirements

R. Bork

Distribution of this draft:

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (818) 395-2129
Fax (818) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20E-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

WWW: http://www.ligo.caltech.edu/

Table 1: List of Revisions

Rev. No.	*Date*	*Author*	*Description*
00	3/19.96	R. Bork	Initial Draft Release
01	4/15/96	R. Bork	Incorporates initial comments
A	5/8/96	R. Bork	Incorporates comments from DRR held 5/1/96

1 INTRODUCTION

1.1. Purpose

This document defines the requirements for the LIGO Vacuum Control and Monitoring System (VCMS).

1.2. Scope

The end product, for which this document specifies the requirements, is an integrated Control and Data System (CDS) for the LIGO vacuum equipment at Hanford, WA and Livingston, LA. The primary function of the VCMS is to provide for remote operation and monitoring of LIGO vacuum equipment during LIGO operations. Included in this scope is:

- Hardware and software applications specific to Vacuum Equipment (VE) control and monitoring, including digital processing equipment, Input/Output (I/O) interfaces, interactive operator interfaces, data collection, conversion and logging, signal conditioning, closed loop control, automatic sequences, interlocks and all necessary equipment housings.
- Hardware and software, as necessary, to interface the VCMS to the VE provided by the VE vendor and to the infrastructure of the LIGO CDS.

The VCMS is to be developed as an integrated subsystem of the LIGO CDS. As such, the system infrastructure and operational support components will be provided by the LIGO CDS and are not included in the scope of the VCMS. This includes such items as the data communication networks, operator consoles, compute servers, mass storage systems, software development tools and software general services.

Also not in the scope of the VCMS are control functions associated with equipment, such as roughing, turbo pumps and bake out systems, used for initial pumpdown of LIGO vacuum spaces. This function is to be provided by stand-alone control and monitoring systems associated with portable “pumpdown carts”, which are to be provided by the Vacuum Equipment (VE) vendor, Process Systems International (PSI).

1.3. Definitions

Isolation Valves: Large (44” and 48” diameter) gate valves used to isolate vacuum sections.

1.4. Acronyms

- AI Analog Input
- AO Analog Output
- BSC Beam Splitter Chamber
- CDS Control and Data System
- CIM Computer Integrated Manufacturing
- DI Digital Input
- FCR Facility Control Room

- GUI Graphical User Interface
- HAM Horizontal Access Module
- IFO Interferometer
- I/O Input/Output
- LIGO Laser Interferometer Gravitational Wave Observatory
- LN2 Liquid Nitrogen
- L/S Liters/Second
- MTBF Mean Time Before Failure
- MTTR Mean Time To Repair
- P&ID Piping and Instrumentation Drawing
- PSI Process Systems International
- RH Relative Humidity
- TBD To Be Determined
- T/C Thermocouple
- VCMS Vacuum Control and Monitoring System
- VE Vacuum Equipment

1.5. Applicable Documents

1.5.1. LIGO Documents

T950054-C Global CDS Control and Monitoring Design Requirements Document

T950120-C Global CDS Control and Monitoring Conceptual Design

M950046-F LIGO Project System Safety Management Plan

L950003 LIGO Document Numbering System

T950111 LIGO Naming Conventions

E950091 Detector - Vacuum Equipment ICD

E950090 Detector - Civil Construction ICD

1.5.2. Non-LIGO Documents

- Process Systems International (PSI) Piping and Instrumentation Drawings (P&ID) , dated March 20, 1996, as listed in the following table:

Table 2: PSI P&ID Listing

PSI Number	*LIGO Number*	*Rev*	*Description*	*Sheets*
V049-0-001	D960107-00-V	0	Vac Equip Legend	3
V049-0-002	D960108-00-V	0	BSC Mid Stations	1
V049-0-003	D960109-00-V	0	BSC Corner Vertex Arms	1

Table 2: PSI P&ID Listing

PSI Number	*LIGO Number*	*Rev*	*Description*	*Sheets*
V049-0-004	D960110-00-V	0	Horizontal Access Module	1
V049-0-005	D960111-00-V	0	112cm and 122cm Gate Valves	1
V049-0-006	D960112-00-V	0	80K Cryopump	1
V049-0-010	D960113-00-V	0	Washington LT End Station	1
V049-0-011	D960131-00-V	0	Washington LT Mid Station	1
V049-0-012	D960114-00-V	0	Washington LT Beam Manifold	1
V049-0-013	D960115-00-V	0	Washington Vertex Section	1
V049-0-014	D960116-00-V	0	Washington Diagonal Section	1
V049-0-015	D960117-00-V	0	Washington RT Beam Manifold	1
V049-0-016	D960118-00-V	0	Washington RT Mid Station	1
V049-0-017	D960119-00-V	0	Washington RT End Station	1
V049-0-018	D960120-00-V	0	Washington Crnr St Mechanical Rm	1
V049-0-020	D960121-00-V	0	LA Left End Station	1
V049-0-021	D960122-00-V	0	LA Left & Right Mid Joints	1
V049-0-022	D960123-00-V	0	LA Left Beam Manifold	1
V049-0-023	D960124-00-V	0	LA Vertex Section	1
V049-0-024	D960125-00-V	0	LA Right Beam Manifold	1
V049-0-025	D960126-00-V	0	LA Right End Station	1
V049-0-026	D960127-00-V	0	LA Corner St Mechanical Rm	1

- PSI transmittal V049-1-013, Approximate Total I/O Count for WA site, dated December 1, 1995
- PSI transmittal V049-1-036, Rev. 1, Instrument List, dated March 11, 1996

2 GENERAL DESCRIPTION

2.1. Specification Tree

This document is part of an overall LIGO detector requirement specification tree. This particular document is highlighted in the following figure.

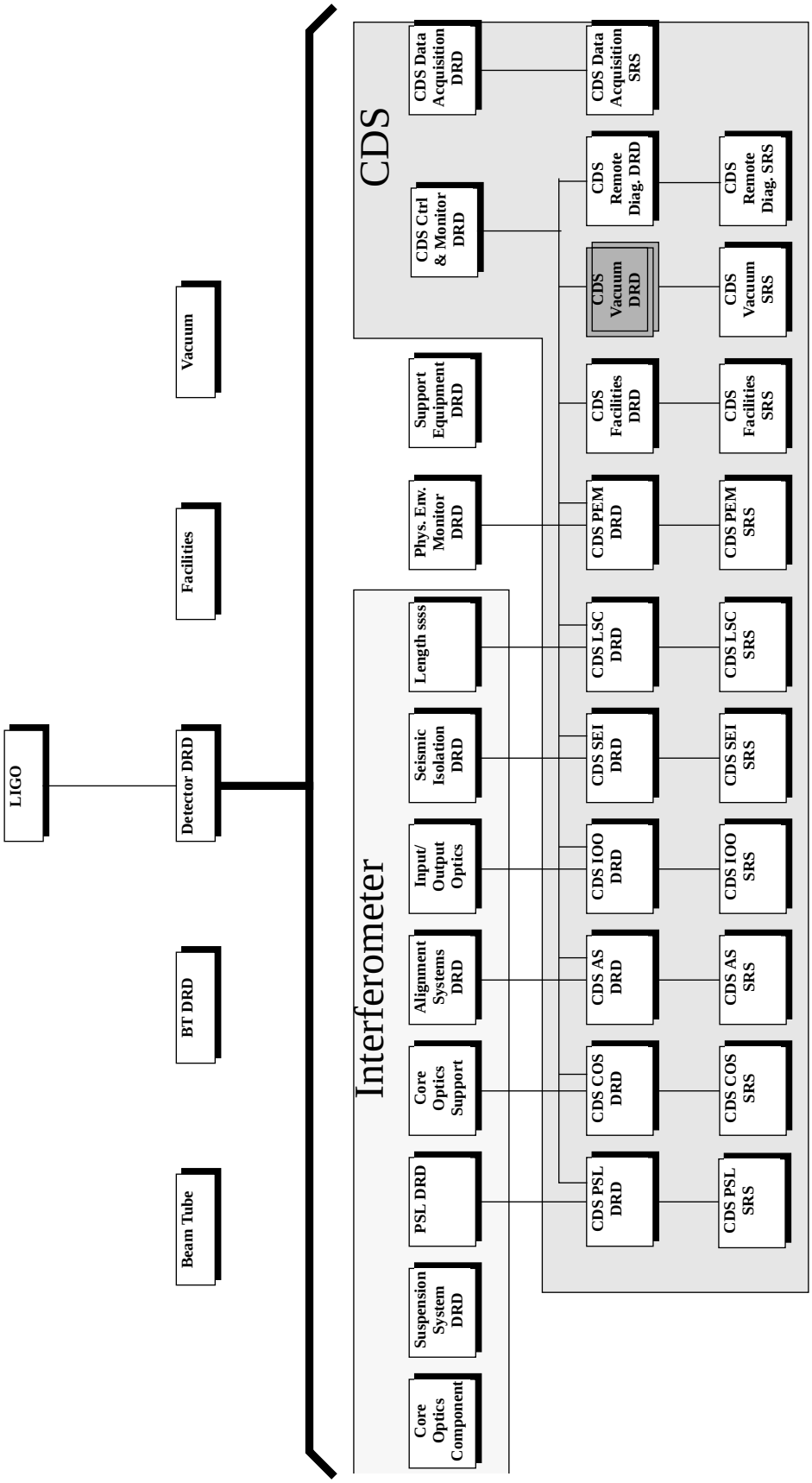

Figure 1: LIGO Specification Tree

2.2. Product Perspective

The VCMS is to be a subsystem of the larger LIGO CDS. Figure 2 depicts the relationship of the VMCS to the LIGO CDS and to the VE.

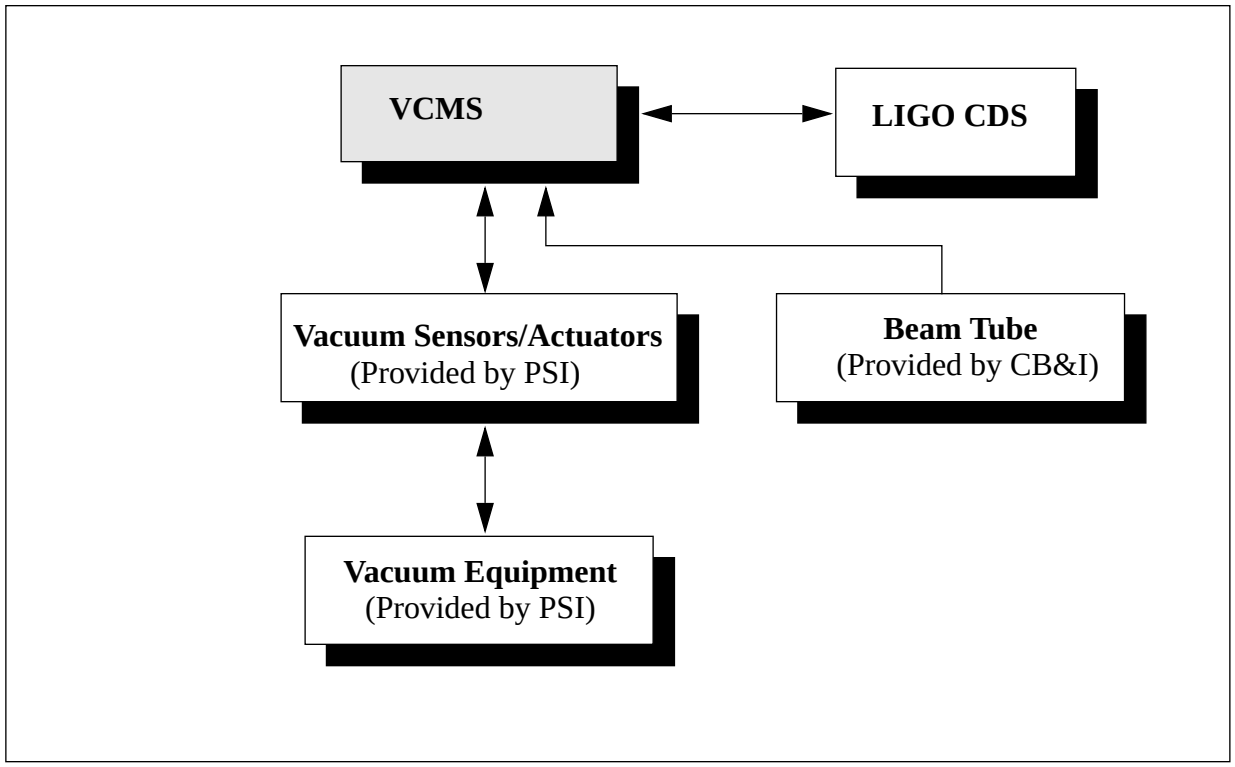

Figure 2: Product Perspective

2.3. Product Functions

The primary VCMS functions are:

- Monitoring of all sensors provided by the vacuum equipment manufacturer (except those associated with the bakeout system).
- Closed loop control of specified equipment.
- Appropriate interlocking systems, such that equipment is not operated in a hazardous manner (except those on the roughing pumps, turbo pumps and bakeout system).
- Local operation (adjacent to the equipment in the vacuum equipment areas) of all controlled and monitored vacuum equipment.
- Remote operation (from a central Facility Control Room (FCR)) of all controlled and monitored vacuum equipment.
- Operator interfaces, as necessary, to support both local and remote operation.
- Operational support services, such as data archiving and retrieval and alarm management.
- Integration with the remainder of the LIGO CDS systems.

2.4. General Constraints

The design and implementation of the VCMS shall be in compliance with the LIGO CDS control and monitoring requirements, LIGO T950054-C, and the global CDS design and design standards, as defined in LIGO T950120-C, to ensure proper integration with the remainder of the LIGO CDS.

2.5. Assumptions and Dependencies

2.5.1. LIGO Global CDS

The infrastructure, such as timing, networking, and operational support, will be provided by the LIGO CDS. As such, only requirements particular to the VCMS, such as particular display and alarm management layouts, are specified here and not the overall scheme for providing these functions.

2.5.2. Vacuum Equipment (VE) Design

The vacuum equipment and its sensors and actuators are being provided by PSI under contract to LIGO. The VCMS requirements are therefore highly dependent on the PSI designs and documentation. As details of the VE designs change, this document will be updated to reflect those changes.

2.5.3. VE Vendor Provided Equipment/Documentation for Control and Monitoring

The VE vendor is to provide all VE sensor and actuator equipment.

The VE vendor is to provide all P&IDs and signal lists which include types, levels, engineering unit conversions and calibration constants.

The VE vendor is to provide closed loop control specifications.

2.5.4. System Installation

It is assumed that LIGO CDS personnel will have access to VE areas prior to VE acceptance tests such that the VCMS required for those tests may be installed and checked out. Access is also required to install the LIGO CDS network infrastructure if data logging and archiving is desired during the acceptance test period.

3 REQUIREMENTS

3.1. Introduction

A Computer Integrated Manufacturing (CIM) model has been developed and is used to as a guide to specify the VCMS requirements. This CIM model is shown in figure 3. The remainder of this

section follows this model, from the system level down to the device level. At each level, requirements are listed which either:

- Are general requirements that pertain to that level and everything below that level.
- Pertain to the control and monitoring of multiple, lower level components. Example: System level would specify any requirements which would involve the control of multiple subsystems; Subsystem level would specify the control requirements for multiple assemblies; etc.

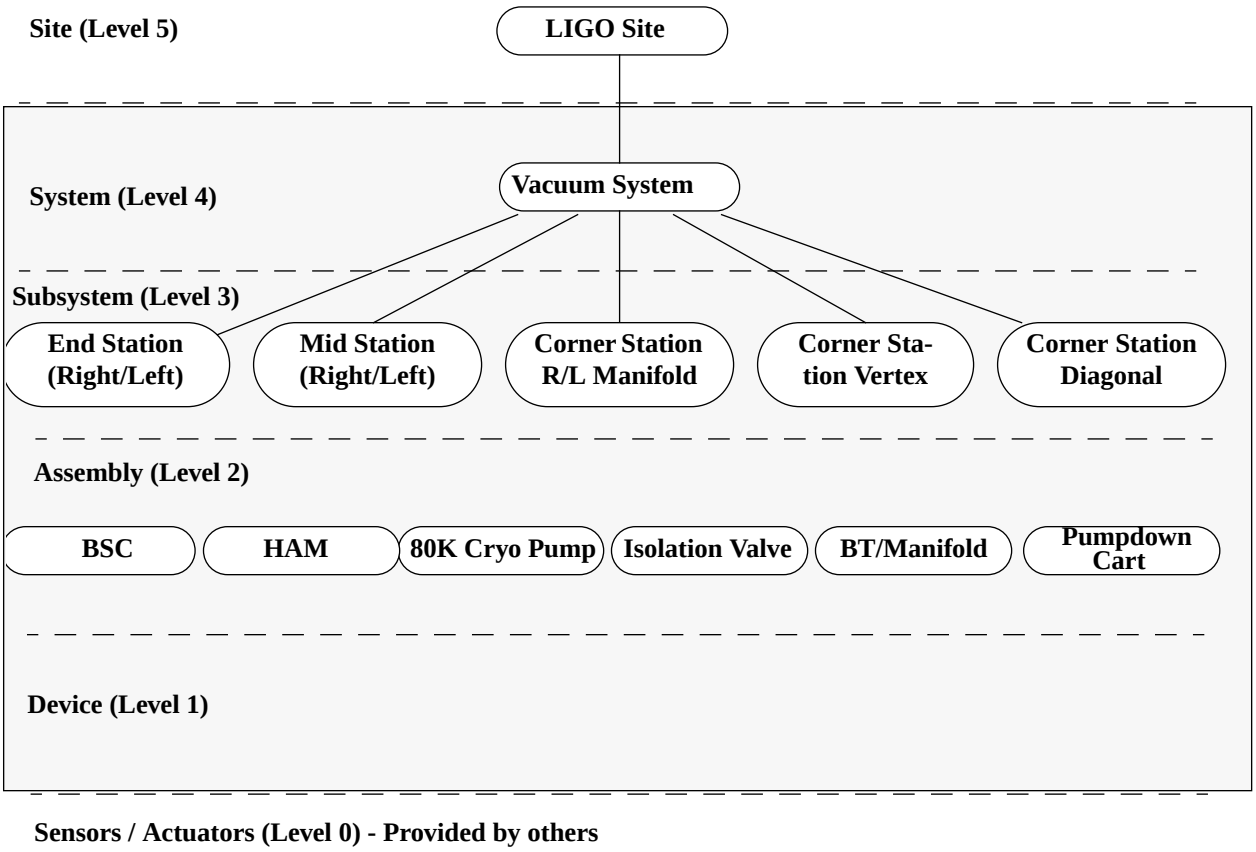

Figure 3: Vacuum System CIM Model

3.2. Characteristics

3.2.1. Performance Characteristics

3.2.1.1 System Level

3.2.1.1.1 General

The VCMS shall meet the applicable requirements as outlined in the LIGO CDS Control and Monitoring DRD, LIGO T950054-C, and be implemented using applicable standards as established in the LIGO CDS Control and Monitoring Conceptual Design, LIGO T950120-C. These documents provide the overall LIGO CDS requirements and design standards for the CDS infrastructure, including timing and networking systems, to which the VCMS must interface, and operational support hardware and software, such as operator stations and software for operator displays, alarm management, and archival tools, which will provide the infrastructure for specific implementations required for the VCMS.

3.2.1.1.2 Operator Stations

3.2.1.1.2.1 Remote

Remote operator consoles are to be provided by the LIGO Global CDS in the Facility Control Rooms (FCR) at both LIGO sites. The VCMS operator interface displays shall be designed and implemented such that they can be run from any of the operator consoles in the FCR.

3.2.1.1.2.2 Local

Local, i.e. in the vicinity of the VCMS equipment racks in the Vacuum Equipment (VE) areas, operation of VE will be required during acceptance testing and maintenance periods. To support this, the VCMS shall provide TBD portable computers, which provide the same control and monitoring features as the FCR operator consoles for the subset of equipment in a particular area.

3.2.1.1.3 Operator System Level Displays

In general, the VCMS shall provide a hierarchy of operator interface displays, from a system overview panel, down through subsystem and assembly panels. Movement through this hierarchy shall be accommodated by the use of icon selections.

3.2.1.1.3.1 System Overview Panel

The following system level displays shall be provided as a minimum:

- Navigator: This window shall depict the various defined VE subsystems. On operator select of a subsystem, that subsystem overview window shall be displayed.
- Vacuum Summary: A summary window shall be provided which depicts the vacuum readings and isolation valve status in all sections of the VE.
- Pump Summary: A summary window shall be provided which depicts the present status of all vacuum pumps and isolation valves.

3.2.1.1.3.2 System Trend Plots

Trend plots shall be provided to depict all vacuum readings in the system.

3.2.1.1.3.3 Use of color on displays

The use of certain colors shall be restricted and have specific meaning when applied to VCMS operator interface displays. These are:

- Green: Shall be used to indicate that a device is in its proper state to support LIGO laser operations.
- Blue: A device is a “don’t care” condition (i.e. is not critical to high vacuum operations)
- Yellow: Warning indication that a device is transiting to/from its proper state for high vacuum operations.
- Red: A device is in an alarm condition or is a critical item which is not in its proper state to support high vacuum operations.

3.2.1.1.3.4 Symbols

Standard symbols, as shown on PSI drawings, for vacuum components shall be depicted for VE on operator displays. Along with the use of the previous standard colors, the present state (i.e. opened/closed, on/off, etc.) of the components shall also be indicated.

3.2.1.1.4 VCMS Diagnostics

The VCMS shall provide self-diagnostics, in keeping with LIGO CDS standards. These diagnostics shall be performed on all hardware and software associated with the VCMS.

3.2.1.1.5 VCMS Start-up

On power up or reset of any portion of the VCMS itself, the VCMS shall not disturb the present state of the VE. The VCMS shall detect the present state of the VE and update its internal state vectors to correspond to this state.

3.2.1.1.6 Interlocks

3.2.1.1.6.1 Overview

The primary interlocks associated with the LIGO VE is the opening of the large 44” and 48” vacuum section isolation valves. The VCMS shall provide a hierarchy of interlocks, as shown in Figure 4: Isolation Valve Interlock Chain, all of which must be met prior to permitting the opening of these valves.

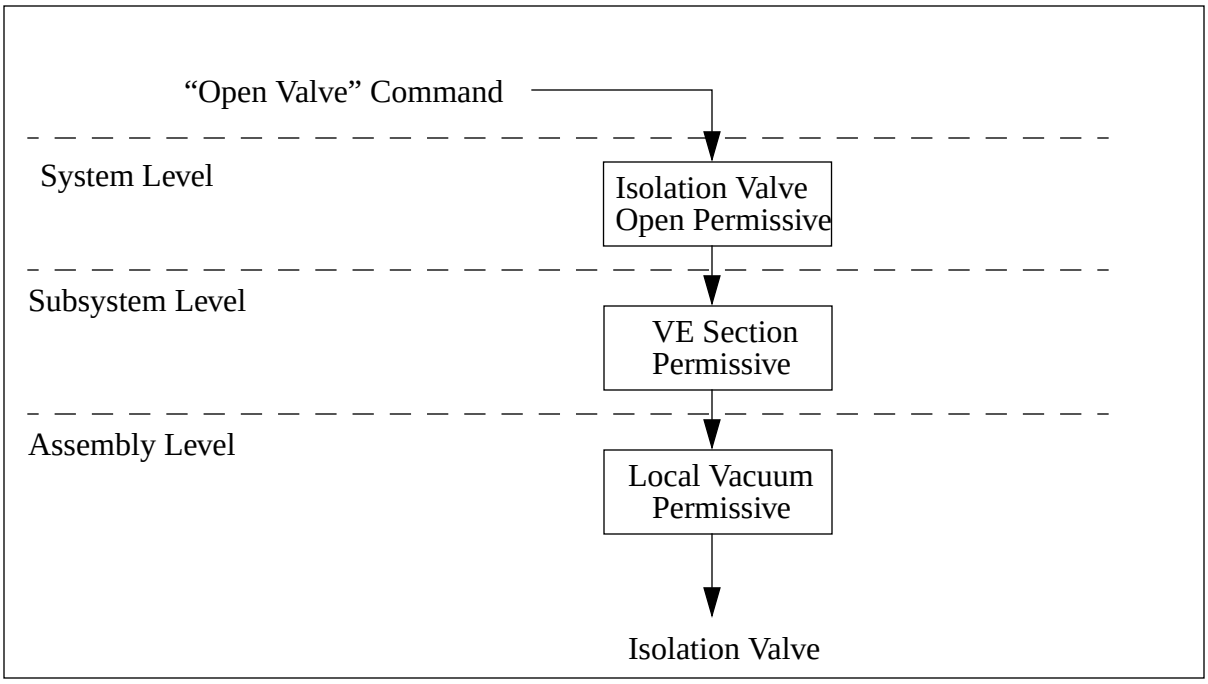

Figure 4: Isolation Valve Interlock Chain

3.2.1.1.6.2 Isolation Valve Open Permissives (Normal Operations)

The VCMS shall ensure that the two isolatable vacuum sections either side of an isolation valve have a "VE Section Permissive" (see section 3.2.1.2.2 Interlocks) prior to permitting opening of the associated isolation valve.

3.2.1.1.6.3 Maintenance/Test Mode

There will be certain times, such as during VE acceptance testing and at atmosphere maintenance periods, that it will be desired to operate the isolation valves without the VE system being under vacuum, and thereby not meeting the interlock requirements specified in 3.2.1.1.6.2 Isolation Valve Open Permissives (Normal Operations) above. Therefore, the VCMS shall provide a mechanism which allows bypassing these interlocks. This bypass mechanism:

- Shall not be implemented in software or otherwise be readily accessible such that it could be inadventently installed.
- Shall cause an alarm condition to be introduced into the VCMS alarm monitors, with visual and audible enunciation at operator stations whenever this bypass is invoked.
- Shall cause a visual (red light) panel indication to be illuminated at the associated VCMS subsystem equipment rack whenever this bypass is invoked.

3.2.1.1.7 System Status Reporting

The VCMS shall provide a "Ready for Normal Operations" signal to the LIGO CDS. This signal shall be set True when and only when:

- The VCMS is operational as indicated by no failure in its self-diagnostic tests.
- VE system is at high vacuum state as indicated by all isolation valves being open, all high vacuum pumping operational, and all vacuum readings are in the normal, high vacuum range.

3.2.1.1.8 Closed Loop Control

None.

3.2.1.1.9 Automatic Sequences

3.2.1.1.9.1 Rate of Rise Calculations

The VCMS shall provide automatic rate of rise calculations for each isolatable vacuum section. Provisions shall be made to allow turning this function on/off and setting both the frequency and period of the calculations.

3.2.1.1.9.2 Fault Condition Monitoring and Corrective Action

While the “Ready for Normal Operations”, defined above, is set to True, the VCMS shall automatically monitor the rate of rise and absolute pressure on all isolatable vacuum sections. If any of the rate of rise calculations or pressure readings are above a settable limit, a warning is to be issued through the VCMS alarm management system. If this condition continues beyond a set time limit after the warning, the VCMS shall automatically close all isolation valves. To support this feature, the VCMS shall provide:

- An adjustable rate of rise and pressure fault limit
- A time setting, indicating the time to wait between the warning condition and the automatic shutting of the isolation valve.
- An on/off mechanism, which would allow operators to turn on/off the automatic valve closing feature.

3.2.1.1.10 Alarm Management

3.2.1.1.10.1 General

The VCMS shall provide an alarm tree structure, which shall be viewable with the standard LIGO CDS alarm management software. This alarm tree shall be structured in the same manner as the VCMS CIM model. The VCMS shall monitor, record and enunciate all alarm conditions associated with the VE, as defined in following sections of this document.

One branch of the alarm tree shall be the internal VCMS self-diagnostics.

3.2.1.1.10.2 VCMS Status

The VCMS shall provide a TBD status word to the CDS, updated at a rate of TBD, indicating that the VCMS has/has not passed its self-diagnostic tests.

3.2.1.1.11 Data Archival

3.2.1.1.11.1 General

VCMS data archiving shall be developed and compatible with the standard LIGO CDS data archiving system. Specifically, the VCMS shall archive:

- All operator actions.
- All digital (binary) VE signals on change of state.
- The status of specific VE analog signals on change beyond a deadband, as detailed in following sections of this document.

The VCMS shall also provide a method for operators to start and stop the data archival processes.

3.2.1.1.11.2 System Level Analog Signals

Table 3: System Level Data Archival lists the signals at this level which are to be archived by the VCMS and under what conditions.

Table 3: System Level Data Archival

Signal	*Archive Condition*
Rate of Rise	Deadband TBD

3.2.1.1.11.3 Pump Hours

For all pumps monitored by the VCMS, a pump operating hours log shall be maintained to augment, not replace, a separate pump use and maintenance log. The VCMS shall facilitate operator input of pump serial numbers for pump tracking.

3.2.1.1.11.4 State Vector

A state vector (TBD format) indicating the state of the VE monitored by the VCMS (and the time) shall be archived whenever the state changes. The state vector shall be the concatenation of subsystem status words.

3.2.1.1.11.5 State Vector

3.2.1.1.12 On-Line Documentation

All VCMS documentation shall be available on-line, i.e. displayed on request at any FCR console or local operator station.

3.2.1.2 Subsystems

The VCMS CIM has defined subsystems to agree with the PSI P&IDs to maintain the same terminology. These subsystems and the assemblies which they contain are listed below. (Note: The

Beam Tube (BT)/Manifold assembly is intended to cover and is defined as devices which are not a part of other assemblies but rather directly connect to the beam tube/manifold, such as various gauges and pumps.)

1. Right and Left End Stations
   - 80K Cryopump (1)
   - 44” Isolation Valve, Electric Actuator (2)
   - BSC (1)
   - BT/Manifold (1)
2. Right and Left Mid Stations

Since only the Hanford site contains a 2Km IFO, the mid stations at the two sites differ in the assemblies which they contain. The Hanford site contains:

- 80K Cryopump (2)
- 44” Isolation Valve, Electric Actuator (4)
- BSC (1)
- BT/Manifold (1)

The Livingston site mid stations only contain the following assemblies:

- 48” Isolation Valve, Electric Actuator (1)
- BT/Manifold (1)

3. Corner Station - Right and Left Beam Manifolds
   - 80K Cryopump (1)
   - 44” Isolation Valve, Pneumatic Actuator (2)
   - BSC (1) (Hanford site only)
   - BT/Manifold (1)
4. Corner Station - Vertex
   - 48” Isolation Valve, Electric Actuator (2)
   - BSC (3)
   - HAM (6)
   - BT/Manifold (1)
5. Corner Station - Diagonal

The corner station diagonal at the Hanford site contains the following assemblies. Since Livingston only has one interferometer, this subsystem and its associated assemblies will not exist at that site.

- 48” Isolation Valve, Electric Actuator (2)
- BSC (1)
- HAM (6)
- BT/Manifold (1)

3.2.1.2.1 General Subsystem Requirements

3.2.1.2.1.1 Operator Interfaces

An interactive GUI shall be provided for each defined subsystem. This GUI shall provide a background replicating the appropriate PSI P&ID.

A parameter page shall be provided which lists all devices and signal channels associated with a subsystem.

3.2.1.2.1.2 Subsystem Operations

Various subsystem and assembllies and devices shall be operable via interactive icons on appropriate operator display pages. However, the operation of these units shall require two independent icons to be selected by the operator:

1. State to go to: Open/Close, On/Off, cooldown, vent, etc.
2. Verification, in the form of a Cancel/Confirm icon, that the Open/Close, On/Off, cooldown, vent, etc. request was not in error. The VCMS default shall be “Cancel” and automatically timeout in 30 seconds if there is no operator response.

The purpose of this is to prevent the devices from changing states due to an inadvertent operator selection on a VCMS display.

3.2.1.2.1.3 Stand alone operation

To accommodate VE acceptance testing and certain maintenance periods, each VCMS subsystem shall be capable of stand alone operation i.e. without the LIGO CDS network backbone installed and/or operational. In stand alone operation, data archival and alarm logging shall still be provided locally.

3.2.1.2.2 Interlocks

3.2.1.2.2.1 VE Section Permissive

Each VCMS subsystem shall provide a “VE Section Permissive”, to be used by the VCMS system level interlock chain for the isolation valves, for each isolatable vacuum volume in its domain. This VE Section Permissive shall be set True when, and only when:

1. Isolation valve interlocks are satisfied. (See 3.2.1.3.4.2 Interlocks)
2. All ion pumps are on and operational within the isolatable section.
3. All pumpout port valves in that section are closed.

3.2.1.2.3 Subsystem Status

Each subsystem shall issue a “Subsystem Ready”, i.e. ready for normal operations, for use by the system level to determine readiness of the VCMS as a whole for normal operations, when:

1. The conditions of 3.2.1.2.2.1 VE Section Permissive are met.
2. All isolation valves associated with a subsystem are open.

3.2.1.2.4 Subsystem State

A subsystem state vector (word) shall be maintained for each subsystem. Changes in the subsystem state vector shall be flagged to the system level.

3.2.1.2.5 Closed loop controls

None.

3.2.1.2.6 Automatic Sequences

None

3.2.1.2.7 Alarms

The VCMS equipment associated with subsystems shall provide self-diagnostics to verify the status of the VCMS hardware and software. An alarm and/or warning, as appropriate, will be generated for any VCMS components which do not pass these self-diagnostic tests.

3.2.1.2.8 Data Archival

None, except as noted in section 3.2.1.2.1.3 Stand alone operation.

3.2.1.3 Assemblies

3.2.1.3.1 80 K Cryo Pump

80K cryopumps will exist in the mid and end stations, and at the corner station in the right and left beam manifold areas. In total, there are 8 cryopumps at the Hanford site and 4 at the Livingston site. Each 80K cryopump consists of the following devices as shown in Figure 5: Vacuum System CIM Model - 80K Cryopump Devices

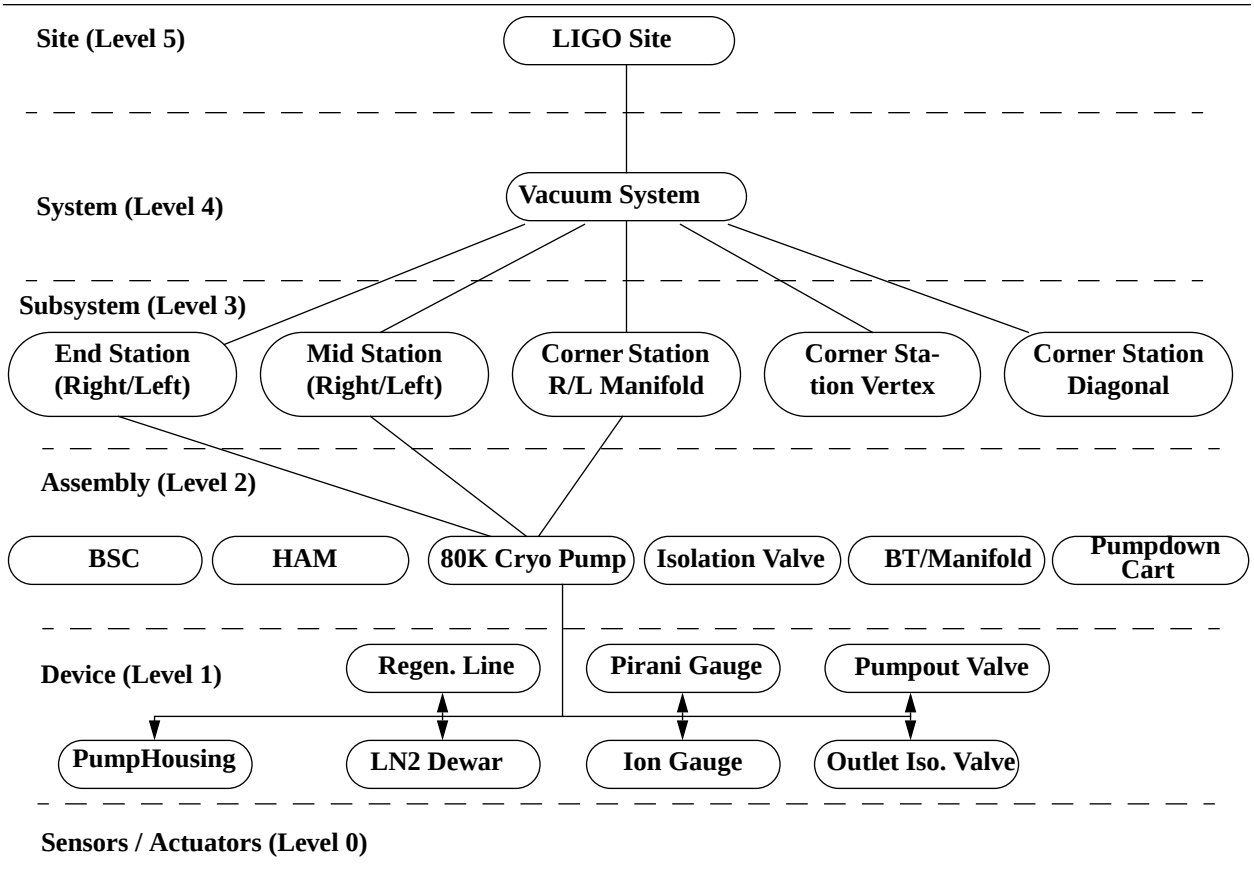

Figure 5: Vacuum System CIM Model - 80K Cryopump Devices

3.2.1.3.1.1 Control/Monitoring Signals

A list of signals associated with these devices is shown in Table 4: 80K Cryo Pump Device Signals.

Table 4: 80K Cryo Pump Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Pump Housing	Level Control Loop Output	AO		
Pump Housing	Level Transmitter (LT)	AI		
Pump Housing	Level Control Valve Solenoid	DO		
Pump Housing	Level Control Valve Closed	DI		
Pump Housing	Discharge Pressure Transmitter (DPT)	AI		
Pump Housing	Discharge Temperature Thermocouple (DTT)	T/C		
Regen Line	Temperature Control Output	AO		
Regen Line	Loop Temperature Thermocouple (3 ea)	T/C		
Dewar	LN2 Level Transmitter	AI		
Pirani Gauge	Vacuum Reading	AI		
Ion Gauge	Vacuum Reading	AI		
Pumpout Port Valve	Closed Indication	DI		
Pumpout Port Valve	Open Indication	DI		
Outlet Iso. Valve	Closed Indication	DI		
Outlet Iso. Valve	Open Indication	DI		

3.2.1.3.1.2 Operator Displays

The VCMS shall provide an interactive operator display which emulates the 80K cryopump P&ID V049-0-006. Such a display shall be provided for each cryopump.

3.2.1.3.1.3 Interlocks

The flow of liquid nitrogen (LN) from the LN Dewar to the cryopumps shall not be permitted when the pressure in the cryopump section is > TBD.

3.2.1.3.1.4 Closed Loop Control

The VCMS shall provide for closed loop control of the LN2 level within the pump housing and the regeneration temperature in accordance with specifications to be provided by PSI.

3.2.1.3.1.5 Automatic Sequences

3.2.1.3.1.5.1 Calculations

The VCMS shall provide automatic calculations for the following parameters for operator information:

- Dewar LN2 consumption rate
- Estimated time to Dewar empty
- Dewar integrated absorption rate

3.2.1.3.1.5.2 Mode Sequences

The VCMS shall provide automated sequences for transitioning between 80K cryopump operational, regeneration and cooldown modes.

3.2.1.3.1.6 Alarms

The VCMS shall produce alarms and warnings for the 80K cryopump in accordance with the conditions shown in Table 5: 80K Cryopump Alarm and Warning Conditions.

Table 5: 80K Cryopump Alarm and Warning Conditions

Device	*Type*	*Alarm/Warning Condition*
Pump Level Transmitter	Hi Alarm	TBD
Pump Level Transmitter	Low Alarm	TBD
Pump Discharge Temp.	Hi Alarm	TBD
Regen Loop Temperature	Hi Alarm	TBD
Dewar Level	Low Warning	TBD
Dewar Level	Low Alarm	TBD
Pirani Guage	Hi Alarm	TBD
Ion Gauge	Hi Alarm	TBD

Table 5: 80K Cryopump Alarm and Warning Conditions

Device	*Type*	*Alarm/Warning Condition*
Pumpout Port Valve	Hi Alarm	Valve not closed

3.2.1.3.1.7 Data Archival

The VCMS shall archive 80K cryopump signals in accordance with Table 6: 80K Cryopump Data Archival.

Table 6: 80K Cryopump Data Archival

Signal	*Archive Condition*
Pump LN2 Level	TBD
Regen Loop Temperature	TBD
Pump Discharge Temp.	TBD
Pump Discharge Pressure	TBD
Regen Line Temperature	TBD
Dewar LN2 Level	TBD
Dewar LN2 consumption rate	TBD
Dewar integrated absorption	TBD
Pirani Gauge Vacuum Reading	TBD
Ion Gauge Vacuum Reading	TBD

3.2.1.3.2 HAM Chamber

There are to be a total of 12 HAM chambers at the Hanford site and 6 at the Livingston site. All HAM chambers are located within the vertex and diagonal sections at the corner stations.

3.2.1.3.2.1 Control/Monitoring Signals

The only VCMS monitored devices associated with a HAM chamber are to be 75 l/s annulus ion pumps. Table 7: HAM Chamber Devices shows the signals to be monitored by the VCMS.

Table 7: HAM Chamber Devices

Description	*Type*	*Signal Range*	*Engineering Unit Range*
75 l/s Ion Pump Current Indication	AI		

3.2.1.3.2.2 Operator Displays

None.

3.2.1.3.2.3 Interlocks

None.

3.2.1.3.2.4 Closed Loop Control

None.

3.2.1.3.2.5 Automatic Sequences

None.

3.2.1.3.2.6 Alarms

The VCMS shall enunciate alarm conditions for a HAM chamber as described in Table 8: Ham Chamber Alarm Conditions.

Table 8: Ham Chamber Alarm Conditions

Device	*Type*	*Alarm/Warning Condition*
75 l/s IP Current Indication	High Alarm	TBD
75 l/s IP Current Indication	Low Alarm	TBD

3.2.1.3.2.7 Data Archival

The VCMS shall log the 75 l/s ion pump current whenever it changes by TBD.

3.2.1.3.3 Beam Splitter Chamber

There are to be a total of 10 BSC at the Hanford site and 5 at the Livingston site. The devices associated with a BSC are shown in Figure 6: Vacuum System CIM Model - BSC Devices.

Note: BSC 1 and 3 at Hanford and Livingston do not have purge air control valves or vacuum gauges.

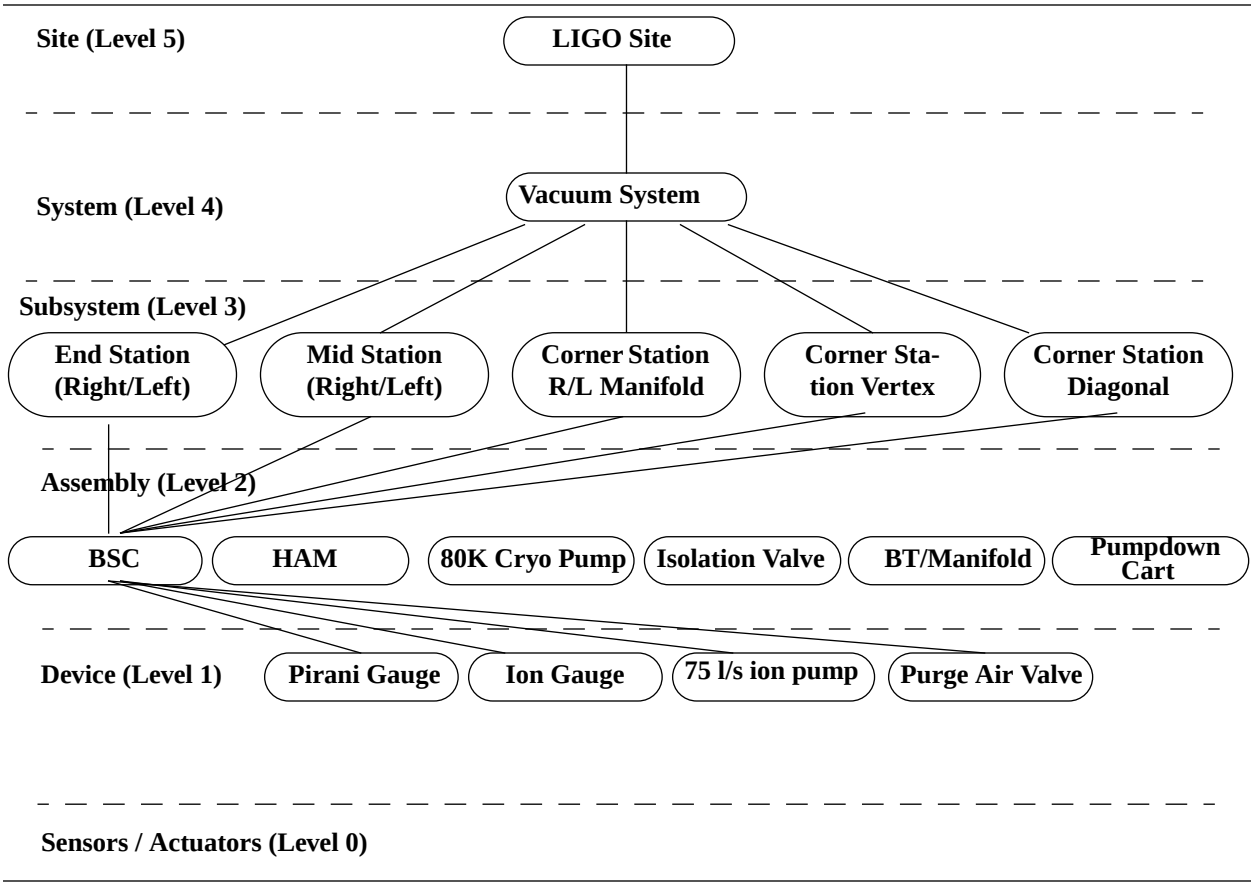

Figure 6: Vacuum System CIM Model - BSC Devices

3.2.1.3.3.1 Control/Monitoring Signals

The control and monitoring signals for these devices are shown in Table 9: BSC Device Signals.

Table 9: BSC Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Pressure Control Valve	Control Loop Output	AO		
Pirani Gauge	Vacuum Reading	AI		
Ion Gauge	Vacuum Reading	AI		
75 l/s Ion Pump	Current	AI		

3.2.1.3.3.2 Operator Displays

The VCMS shall provide an interactive operator display which emulates the BSC P&ID V049-0-002 and -003. Such a display shall be provided for each BSC.

3.2.1.3.3.3 Interlocks

The VCMS shall provide a TBD interlock for the purge air connection.

3.2.1.3.3.4 Closed Loop Control

The VCMS shall provide closed loop control on the purge air lines to all BSC which contain them. This control is to be in accordance with a TBD procedure to be specified by PSI.

3.2.1.3.3.5 Automatic Sequences

None.

3.2.1.3.3.6 Alarms

The VCMS shall provide alarm enunciation for each BSC in accordance with Table 10: BSC Alarm Conditions.

Table 10: BSC Alarm Conditions

Device	*Type*	*Alarm/Warning Condition*
Pirani Gauge	High Alarm	TBD
Ion Gauge	High Alarm	TBD
75 l/s Pump Current	High Alarm	TBD
75 l/s Pump Current	Low Alarm	TBD

3.2.1.3.3.7 Data Archival

The VCMS shall log BSC signals in accordance with Table 11: BSC Data Archival.

Table 11: BSC Data Archival

Signal	*Archive Condition*
Pirani Guage	TBD
Ion Gauge	TBD
75 l/s Pump Current	TBD
Purge air control loop out-put	TBD

3.2.1.3.4 Isolation Valves

There will be a total of 20 vacuum section isolation valves at the Hanford site and 12 at the Livingston site. These valves are of two types and sizes:

- 44 inch pneumatic (4 at each site)
- 44 inch and 48 inch electric (16 Hanford, 8 Livingston)

From the VCMS point of view, the operation and monitoring of the various valve types is identical.

The isolation valve assembly consists of two devices:

- Valve
- 25 l/s annulus ion pump

Note: LGV7 and LGV8 at Livingston do not have associated ion pumps.

3.2.1.3.4.1 Control/Monitor Signals

Table 12: Isolation Valve Device Signals lists the control and monitor points for the isolation valves.

Table 12: Isolation Valve Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Valve	Closed Indicator Switch	DI		
Valve	Open Indicator Switch	DI		
Valve	Open Solenoid	DO		
Valve	Common Alarm	DI		
25 l/s ion pump	Current Reading	AI		

3.2.1.3.4.2 Interlocks

This section describes the requirements for the “Local Vacuum Permissive” portion of the Isolation Valve Open interlock chain (refer to Figure 4: Isolation Valve Interlock Chain and section 3.2.1.1.6 Interlocks).

3.2.1.3.4.2.1 Normal Operation

The VCMS shall provide interlocks to prevent the inadvertent opening of these isolation valves. At the Assembly Level of this interlock chain, the VCMS shall not issue a “Local Vacuum Permissive” unless:

- The nearest up and down stream Parani gauges both provide a reading of $< 1\times10^{-3}$ Torr
- The nearest up and down stream Ion gauges both provide a reading of $< 1\times10^{-4}$ Torr

When and only when these conditions are met, a “Local Vacuum Permissive” shall be set to True for use by the subsystem level interlock checks (section 3.2.1.2.2.1 VE Section Permissive).

3.2.1.3.4.3 Closed Loop Control

None.

3.2.1.3.4.4 Automatic Sequences

The isolation valves shall be automatically closed on a fault condition as defined in section 3.2.1.1.9.2 Fault Condition Monitoring and Corrective Action.

3.2.1.3.4.5 Alarms

The VCMS shall provide alarm enunciation for isolation valves as defined in Table 13: Isolation Valve Alarm Conditions.

Table 13: Isolation Valve Alarm Conditions

Device	*Type*	*Alarm/Warning Condition*
Valve Common Alarm	High Alarm	Valve signal is set to True
Valve	High Alarm	Valve moves from its Open or Closed seat without being commanded to do so.

3.2.1.3.4.6 Data Archival

The VCMS shall log data for isolation valves in accordance with Table 14: Isolation Valve Data Archival.

Table 14: Isolation Valve Data Archival

Signal	*Archive Condition*
25 l/s pump current	TBD

3.2.1.3.5 Beam Tube/Manifold Assembly

This assembly is defined for the purposes of this specification to cover those devices which are not a direct part of other assemblies previously specified and which directly attach to the beam tube or beam manifold. Table 15: BT/Manifold Devices lists these devices and their quantity per VCMS subsystem. Predominantly, these devices are to be provided by PSI, with the exception of 10” pumpout port valves at the end of beam tube sections, which are to be provided by CB&I.

Table 15: BT/Manifold Devices

Subsystem	*Ion Gauge*	*Pirani Gauge*	*10” Pumpout Valve*	*6” Pumpout Valve*	*2500 l/s ion pump*
WA Left End Sta.	1	1	2	0	1
WA Left Mid Sta.	2	2	3	0	1
WA Left Manifold	1	1	2	1	1
WA Vertex	0	0	1	1	4
WA Diagonal	0	0	1	1	2
WA Rht Manifold	1	1	2	1	1
WA Rht Mid Sta.	2	2	3	0	1
WA Rht End Sta.	1	1	2	0	1
LA Left End Sta.	1	1	2	0	1
LA Left Mid Jnt.	2	2	2	0	0
LA Left Manifold	2	2	2	1	0
LA Vertex	0	0	1	1	4
LA Rht Manifold	2	2	2	1	0
LA Rht Mid Jnt.	2	2	2	0	0
LA Rht End Sta.	1	1	2	0	1

3.2.1.3.5.1 Control and Monitor Signals

The signals associated with the BT/Manifold devices are as shown in Table 16: BT/Manifold Device Signals. (Note: The Open/Closed indicators for the 2500 l/s ion pump gate valves are not in the present PSI instrumentation list)

Table 16: BT/Manifold Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Ion Gauge	Pressure Reading	AI		
Pirani Gauge	Pressure Reading	AI		
10” Pumpout Valve	Open Indication	DI		
10” Pumpout Valve	Closed Indication	DI		
6” Pumpout Valve	Open Indication	DI		
6” Pumpout Valve	Closed Indication	DI		
2500 l/s ion pump	High Volt Start Switch	DO		
2500 l/s ion pump	High Volt Stop Switch	DO		
2500 l/s ion pump	Voltage Indication	AI		
2500 l/s ion pump	Current Indication	AI		
2500 l/s ion pump	Fault Alarm	DI		
2500 l/s ion pump	Gate Valve Open Ind.	DI		
2500 l/s ion pump	Gate Valve Closed Ind.	DI		

3.2.1.3.5.2 Interlocks

None.

3.2.1.3.5.3 Closed Loop Control

None.

3.2.1.3.5.4 Automatic Sequences

For all 2500 l/s ion pumps, the VCMS shall provide an automatic function which turns off an ion pump if its current reading is not in its normal operating range. This function will become active 30 seconds after an ion pump has been turned on and deactivated when a pump is turned off.

3.2.1.3.5.5 Alarms

The VCMS shall monitor and post alarms in accordance with Table 17: Beam Tube/Manifold Device Alarm Conditions.

Table 17: Beam Tube/Manifold Device Alarm Conditions

Device	*Type*	*Alarm/Warning Condition*
Ion Gauge	High Alarm	
Pirani Gauge	High Alarm	
10” Pumpout Valve	High Alarm	Valve not closed
6” Pumpout Valve	High Alarm	Valve not closed
2500 l/s ion pump current	High Alarm	
2500 l/s ion pump current	Low Alarm	
2500 l/s ion pump fault	High Alarm	
2500 l/s ion pump gate valve	High Warn-ing	Ion pump on and gate valve not open.

3.2.1.3.6 Pumpdown Carts

3.2.1.3.6.1 Signal Monitoring

The VCMS shall provide for the monitoring of PSI provided signals from the roughing pump carts and turbomolecular pump carts used for initial pumpdown of LIGO vacuum sections. This includes both the main carts in the LVEA and VEA areas and the backing carts in the Mechanical Room and VE support rooms. The latter, backing carts, are to be wired by PSI to the main carts, at which point the signals are interfaced to the VCMS.

The portable pumpdown carts can be placed at a number of pump port locations, as shown in Table 18: Pumpdown Cart Locations +.The VCMS operator display shall indicate the current configuration in a graphical display. No more than one turbopump and one roughing pump will ever be used in a single subsystem (vacuum section). In addition, no more than 2 roughing pumps will be used simultaneously in the corner station. The VCMS shall request operator input of the pumpdown cart serial number (or other unique identifier) for tagging archival data.

** Hanford site only*
+ Not including pumpdown cart ports on the beam tube.

The devices and signals associated with these assemblies are shown in Table 19: Turbo Pump Cart Device Signals and Table 20: Roughing Pump Cart Device Signals. (Note: Pump speed indications are not on PSI’s present list of available signals)

Table 18: Pumpdown Cart Locations +

Subsystem	*Main Turbo*	*Main Roughing*
Right and Left End Stations	1	1
Right and Left Beam Tube Modules	2	2
Right and Left Mid Stations	2	1
Right and Left Beam Manifolds	2	1
Corner Vertex	1	1
Corner Diagonal	1	1

Table 19: Turbo Pump Cart Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Backing Pump	On/Off Indication	DI		
Backing Pump	Vacuum Reading	AI		
Backing Pump	Speed Indication	AI		
Turbo Pump	On/Off Indication	DI		
Turbo Pump	Inlet Vacuum Reading (2)	AI		
Turbo Pump	Speed Indication	AI		
Auto Valve	Closed Indication	DI		
Auto Valve	Open Indication	DI		
Purge Gas Valve	Open/Closed Indication	DI		

Table 20: Roughing Pump Cart Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Backing Pump	On/Off Indication	DI		
Backing Pump	Vacuum Reading	AI		
Backing Pump	Speed Indication	AI		
Roots Pump	On/Off Indication	DI		

Table 20: Roughing Pump Cart Device Signals

Device	*Signal Description*	*Type*	*Signal Range*	*Engineering Unit Range*
Roots Pump	Inlet Vacuum Reading (2)	AI		
Roots Pump	Speed Indication	AI		
Auto Valve	Open/Closed Indication	DI		
Purge Gas Valve	Open/Closed Indication	DI		

3.2.1.3.6.2 Data Archival

The VCMS shall log pump cart data in accordance with Table 21: Pump Cart Data Archival.

Table 21: Pump Cart Data Archival

Signal	*Archive Condition*
Pump Speeds (All)	TBD
Pump Vacuum (All)	TBD

3.2.2. Physical Characteristics

3.2.2.1 Electronic equipment housings

To the extent possible and reasonable, all VCMS electronic equipment shall be housed in standard 19” racks.

3.2.2.2 Weight Limits

VCMS equipment to be housed within the OSB shall not exceed weight limits imposed by the building raised floor loading capacities.

3.2.3. Interface Definitions

3.2.3.1 Interfaces to other LIGO detector subsystems

3.2.3.1.1 Mechanical Interfaces

The VCMS shall provide a VCMS standard hardware connection to the LIGO CDS communication networks.

3.2.3.1.2 Electrical Interfaces

The VCMS shall be electrically and software compatible with the LIGO CDS communication networks such that data can be transferred to/from the CDS infrastructure and the VCMS.

3.2.3.1.3 Optical Interfaces

None.

3.2.3.1.4 Stay Clear Zones

None.

3.2.3.2 Interfaces external to LIGO detector subsystems

The VCMS will have interfaces to the facilities and the VE provided by PSI.

3.2.3.2.1 Mechanical Interfaces

3.2.3.2.1.1 Facility

All VCMS equipment shall be housed in rack enclosures, mounted to the LIGO facilities floor at those points designated in the Detector - Civil Construction Interface Control Document.

3.2.3.2.1.2 PSI

The VCMS shall provide a standard 19” rack enclosure and terminal strips for the termination of PSI provided signal cables. This shall be the principle interface point between VE supplied by PSI and the VCMS provided by the LIGO CDS group.

The VCMS shall provide mounting space (4U, 7”) within the VCMS racks for the mounting of PSI provided 24VDC power supplies.

For the turbomolecular and roughing pump carts, the VCMS shall interface at the PSI provided terminal blocks on these units.

3.2.3.2.2 Electrical Interfaces

3.2.3.2.2.1 Facility

Facility power shall be provided at a circuit breaker panel within each of the building areas where VCMS is to be installed. Facilities shall provide 20A, 110VAC breakers at each panel, with a conduit and/or raceway from the panel to each VCMS rack enclosure. VCMS shall provide the necessary cable to connect the breaker panels to the VCMS racks and further distribute AC power.

3.2.3.2.2.2 PSI

The electrical connection between PSI provided equipment and the VCMS shall be at the terminal strips defined in section 3.2.3.2.1.2 above.

3.2.3.2.3 Stay Clear Zones

As per the Detector - Civil Construction and Detector - Vacuum Equipment Interface Control Documents.

3.2.4. Reliability

The Mean Time Before Failure (MTBF) for the VCMS shall be greater than TBD.

3.2.5. Maintainability

The Mean Time To Repair (MTTR) for any VCMS component shall be less than TBD.

3.2.6. Environmental Conditions

The VCMS shall meet all performance requirements when exposed to all specified natural and induced environments.

3.2.6.1 Natural Environment

3.2.6.1.1 Temperature and Humidity

All VCMS equipment shall meet the following temperature and humidity requirements.

Table 22: Environmental Performance Characteristics

Operating	*Non-operating (storage)*	*Transport*
+0 C to +50 C, 0-90%RH	-40 C to +70 C, 0-90% RH	-40 C to +70 C, 0-90% RH

3.2.6.1.2 Atmospheric Pressure

The VCMS equipment design must accommodate atmospheric pressure change from a maximum of 15.2 psia to a minimum of 14.2 psia.

3.2.6.2 Induced Environment

3.2.6.2.1 Vibrations

VCMS equipment shall not produce mechanical vibrations greater than those specified in TBD.

3.2.6.2.2 Acoustic Noise

VCMS equipment shall be designed to produce the lowest levels of acoustic noise as possible and practical. In any event, VCMS equipment shall not produce acoustic noise levels greater than TBD.

3.2.6.2.3 Electromagnetic Radiation

The VCMS shall not degrade due to electromagnetic emissions as specified by IEEE C95.1-1991.

The VCMS shall not produce electromagnetic emissions beyond those specified in TBD and shall complywith the LIGO EMC Plan.

3.2.7. Transportability

All items shall be transportable by commercial carrier without degradation in performance. As necessary, provisions shall be made for measuring and controlling environmental conditions (tem-

perature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation shall be utilized to prevent damage. All containers shall be movable for forklift. All items over 100 lbs. which must be moved into place within LIGO buildings shall have appropriate lifting eyes and mechanical strength to be lifted by cranes.

3.3. Design and Construction

3.3.1. Materials and Processes

3.3.1.1 Finishes

- Ambient Environment: Surface-to-surface contact between dissimilar metals shall be controlled in accordance with the best available practices for corrosion prevention and control.
- External surfaces: External surfaces requiring protection shall be painted or otherwise protected in a manner to be approved.

3.3.2. Component Naming

All tagging and naming of VCMS equipment shall be in accordance with LIGO naming standards TBD.

3.3.3. Workmanship

All details of workmanship shall be of the highest grade appropriate to the methods and level of fabrication and consistent with the requirements specified herein. There shall be no evidence of poor workmanship that would make the components unsuitable for the purpose intended. All electronic circuits, modules and wiring shall be consistent with good engineering practice and fabricated to best commercial standards.

3.3.4. Interchangeability

The VCMS shall be designed to maximize interchangeability and replaceability of mating components. Using the Line Replaceable Unit (LRU) concept, the designs shall be such that mating assemblies may be exchanged without selection for fit or performance and without modification to the section, the unit being replaced or adjacent equipment. Mature, performance proven, standard, commercially available equipment shall not be modified unless it impacts safety.

3.3.5. Safety

This item shall meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements. A hazard/risk analysis shall be conducted in accordance with guidelines set forth in the LIGO Project System Safety Management Plan LIGO-M950046-F, section 3.3.2.

3.3.6. Human Engineering

The VCMS shall be designed and laid out in a manner consistent with good human engineering practices. Particular attention shall be paid to layouts of operator consoles/stations, work space and environmental conditions.

3.4. Documentation

3.4.1. Specifications

The following specifications shall be provided as part of the design process:

- Software Requirements Specification (SRS) for all software to be developed as part of the system.
- Interface Control Document (ICD)

3.4.2. Design Documents

The following design documents shall be provided:

- System overall design.
- System software design.

3.4.3. Engineering Drawings and Associated Lists

Engineering drawings, schematics, wire lists and cable routing lists shall be produced for the VCMS. To the greatest extent possible and practical, electronic copies shall be maintained and available on-line. All drawings shall be formatted according to LIGO standards.

3.4.4. Technical Manuals and Procedures

3.4.4.1 Procedures

Procedures shall be provided for, at minimum,

- Initial installation and setup of equipment
- Normal operation of equipment
- Normal and/or preventative maintenance
- Troubleshooting guide for any anticipated potential malfunctions
- Bypassing the isolation valve interlocks.

3.4.4.2 Manuals

The following manuals shall be provided:

- All manuals provided by commercial vendors for VCMS components.
- Manuals for all VCMS custom designed electronics and software.
- VCMS Operating Manual.

3.4.5. Documentation Numbering

All documents shall be numbered and identified in accordance with the LIGO documentation control numbering system LIGO document TBD

3.4.6. Test Plans and Procedures

All test plans and procedures shall be developed in accordance with the LIGO Test Plan Guidelines, LIGO document TBD.

3.5. Logistics

The design shall include a list of all recommended spare parts and special test equipment required.

3.6. Precedence

In the event of conflicts between this requirement document and other LIGO documents, the order of precedence shall be in accordance with the LIGO Requirement Specification Tree.

3.7. Qualification

The VCMS design shall be qualified through a series of reviews as prescribed in the LIGO Detector Implementation Plan.

Qualification of various VCMS components and subsystems shall be in accordance with Section 4 of this document.

4 QUALITY ASSURANCE (QA) PROVISIONS

4.1. General

This system shall be tested in accordance with applicable LIGO QA standards.

4.1.1. Responsibility for Tests

The LIGO CDS group shall be responsible for performing and documenting all tests associated with the VCMS.

4.1.2. Special Tests

Due to their critical nature, the isolation valve interlocks shall undergo extensive testing to ensure proper operation.

4.1.3. Configuration Management

Configuration control of specifications and designs shall be in accordance with the LIGO Detector Implementation Plan.

4.2. Quality Conformance Inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by inspection, analysis, demonstration, similarity, test or a combination thereof per the Verification Matrix, Appendix 1. Verification method selection shall be specified by individual specifications, and documented by appropriate test and evaluation plans and procedures. Verification of compliance to the requirements of this and subsequent specifications may be accomplished by the following methods or combination of methods:

4.2.1. Inspections

Inspection shall be used to determine conformity with requirements that are neither functional nor qualitative; for example, identification marks.

4.2.2. Analysis

Analysis may be used for determination of qualitative and quantitative properties and performance of an item by study, calculation and modeling.

4.2.3. Demonstration

Demonstration may be used for determination of qualitative properties and performance of an item and is accomplished by observation. Verification of an item by this method would be accomplished by using the item for the designated design purpose and would require no special test for final proof of performance.

4.2.4. Similarity

Similarity analysis may be used in lieu of tests when a determination can be made that an item is similar or identical in design to another item that has been previously certified to equivalent or more stringent criteria. Qualification by similarity is subject to Detector management approval.

4.2.5. Test

Test may be used for the determination of quantitative properties and performance of an item by technical means, such as, the use of external resources, such as voltmeters, recorders, and any test equipment necessary for measuring performance. Test equipment used shall be calibrated to the manufacture’s specifications and shall have a calibration sticker showing the current calibration status.

5 PREPARATION FOR DELIVERY

Packaging and marking of equipment for delivery shall be in accordance with the Packaging and Marking procedures specified herein.

5.1. Preparation

Equipment shall be appropriately prepared. For example, vacuum components shall be prepared to prevent contamination.

5.2. Packaging

Procedures for packaging shall ensure cleaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection shall be provided for shipping loads and environmental stress during transportation, hauling and storage.

5.3. Marking

Appropriate identification of the product, both on packages and shipping containers; all markings necessary for delivery and for storage, if applicable; all markings required by regulations, statutes, and common carriers; and all markings necessary for safety and safe delivery shall be provided.

6 NOTES

APPENDIX 1 VCMS QA MATRIX

Table 23: VCMS QA Matrix

DRD Section	*Inspect*	*Analysis*	*Demo*	*Similar*	*Test*
3.2.1.1.1 General	X				
3.2.1.1.2.1 Remote	X		X		
3.2.1.1.2.2 Local	X		X		
3.2.1.1.3.1 System Overview Panel			X		
3.2.1.1.3.2 System Trend Plots			X		
3.2.1.1.3.3 Use of color on displays	X				
3.2.1.1.3.4 Symbols	X				
3.2.1.1.4 VCMS Diagnostics			X		X
3.2.1.1.5 VCMS Start-up			X		X
3.2.1.1.6 Interlocks			X		X
3.2.1.1.9 Automatic Sequences			X		X
3.2.1.1.10 Alarm Management			X		X
3.2.1.1.11 Data Archival			X		X
3.2.1.1.12 On-Line Documentation			X		
3.2.1.2.1 General Subsystem Requirements			X		X
3.2.1.2.2 Interlocks			X		X
3.2.1.2.3 Subsystem Status			X		X
3.2.1.2.4 Subsystem State			X		X
3.2.1.2.7 Alarms			X		X
3.2.1.3.1.1 Control/Monitoring Signals			X		
3.2.1.3.1.2 Operator Displays			X		
3.2.1.3.1.3 Interlocks			X		X

Table 23: VCMS QA Matrix

DRD Section	*Inspect*	*Analysis*	*Demo*	*Similar*	*Test*
3.2.1.3.1.4 Closed Loop Control			X		X
3.2.1.3.1.5 Automatic Sequences			X		X
3.2.1.3.1.6 Alarms			X		X
3.2.1.3.1.7 Data Archival			X		X
3.2.1.3.2.1 Control/Monitoring Signals			X		X
3.2.1.3.2.6 Alarms			X		X
3.2.1.3.2.7 Data Archival			X		X
3.2.1.3.3.1 Control/Monitoring Signals			X		X
3.2.1.3.3.2 Operator Displays			X		X
3.2.1.3.3.3 Interlocks			X		X
3.2.1.3.3.4 Closed Loop Control			X		X
3.2.1.3.3.6 Alarms			X		X
3.2.1.3.3.7 Data Archival			X		X
3.2.1.3.4.1 Control/Monitor Signals			X		X
3.2.1.3.4.2 Interlocks			X		X
3.2.1.3.4.4 Automatic Sequences			X		X
3.2.1.3.4.6 Data Archival			X		X
3.2.1.3.4.5 Alarms			X		X
3.2.1.3.5.1 Control and Monitor Signals			X		X
3.2.1.3.5.4 Automatic Sequences			X		X
3.2.1.3.5.5 Alarms			X		X
3.2.1.3.6.1 Signal Monitoring			X		X
3.2.1.3.6.2 Data Archival			X		X
3.2.2. Physical Characteristics	X				

Table 23: VCMS QA Matrix

DRD Section	*Inspect*	*Analysis*	*Demo*	*Similar*	*Test*
3.2.3.1 Interfaces to other LIGO detector subsystems	X				
3.2.3.2 Interfaces external to LIGO detector subsystems	X				
3.2.4. Reliability		X			
3.2.5. Maintainability		X			
3.2.6. Environmental Conditions		X			
3.2.7. Transportability	X				
3.3.1. Materials and Processes	X				
3.3.2. Component Naming	X				
3.3.3. Workmanship	X				
3.3.4. Interchangeability	X				
3.3.5. Safety	X	X			
3.3.6. Human Engineering	X				
3.4. Documentation	X				
3.5. Logistics	X				
3.6. Precedence	X				
3.7. Qualification	X				