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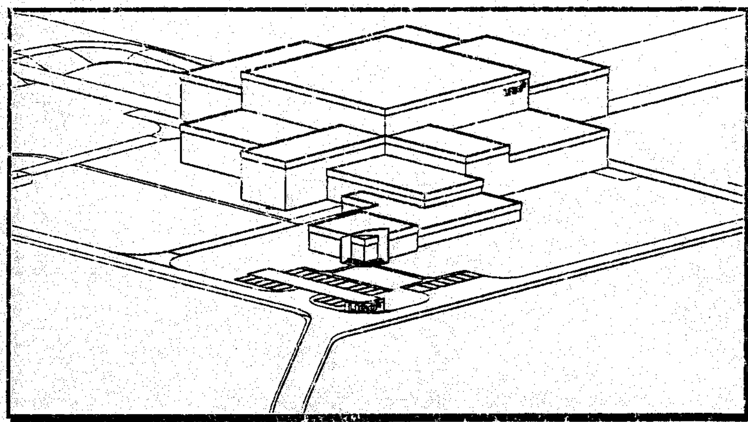

Final Design Configuration Control Document

July 10, 1995

LIGO
Laser Interferometer Gravity Wave Observatory
California Institute of Technology
The Ralph M. Parsons Company
Contract Number: PP150969

LIGO Document ______

CDRL Number 07

DRD Number 03

APPROVAL STATUS

YES NO NOT REQUIRED

Project Manager, Parsons

Technical Representative, Caltech

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1. Scope

The purpose of this document is to establish baseline design criteria for the Laser Interferometer Gravitational-Wave Observatory (LIGO) Facility Design. The baseline design criteria are developed from:

- Appendix A, B, and C of the LIGO Facility Request for Proposal No. YM 193
- Exhibit I of the LIGO Vacuum Equipment Request for Proposal No. MH 178
- Tiger Team Meetings
- Comments on previously submitted drafts of this document
- 90% Concept Design Report
- Facility and Beam Tube Enclosure Trade Studies
- Caltech and Parsons Technical Interchanges
- Our understanding of LIGO Project needs
- Industry standard design and construction practices that will meet or exceed these needs

This document serves as Facility design criteria from which the configuration of the Facility will evolve. As it evolves, this document will be updated. This document will continue to be the source for configuration control information for the direction of the design process. It is also the baseline for the design effort.

By reference, criteria provided in Appendix A, B, and C of the LIGO Facility Request for Proposal Number YM 193, and Exhibit I (LIGO Document 1100003) of the LIGO Vacuum Equipment Request for Proposal Number MH 178 constitute an element of this document and are therefore considered an element of the Facility's controlled design configuration. Concept strawman design approaches presented in these RFPs are not an element of the controlled design configuration; however, the layouts of the Vacuum Equipment in the LVEA and VEAs are considered a controlled design configuration.

This document will explain the concept design approach for the Hanford Site only. Occasional references are made to the Livingston Site, but only to establish some frame of reference, and to establish a general baseline for that Site also.

2. Facility Overview

The LIGO project is a pioneering effort to design and construct a novel scientific Facility -- a gravitational-wave observatory -- that will open a new observational window on the universe.

LIGO will consist of two observatory facilities. One will be located at Hanford, Washington, and the other at Livingston, Louisiana. These facilities will incorporate L-shaped vacuum systems with arms of 4 km length. The vacuum systems (by Others) will house laser interferometer detectors sensitive to gravitational waves generated by astrophysical sources. Initial detector sensitivity will detect strains as small as 10^{-22}. Correlation of data from interferometers at the two Sites will allow identification of gravitational waves, their sources and origin in space. LIGO will become the first part of a planned worldwide network of gravitational-wave detectors coordinated to operate as a single observatory complex. Current plans are to begin observatory operations by the year 2000.

Constructed facilities at each Site include the main Corner Station, with the large Laser and Vacuum Equipment Area (LVEA), End, and Mid Stations (Mid-Point Pumping Station at Livingston) on each Beam Tube arm, and a Site service area with chillers, pumps, water tank, and other ancillary maintenance components. Building work includes, but is not limited to, earth work, power distribution, lighting, security systems, fire protection, communications, control system, access platforms, cleanrooms, cranes, heating ventilating and air conditioning, and cable raceways. Each Site will have two Beam Tube Enclosure structures, each 4 km long. Sitework for the virgin Sites includes Site grading, drainage, roads, parking, landscaping, water supply developed from wells, sanitary facilities, waste water treatment and disposal and power distribution from area utilities.

Facility design will address special building requirements for the Laser and Vacuum Equipment Area located at the Corner Station, and Vacuum Equipment Area at the Mid, and End Stations.

- Vibration isolation and reduction is required in order that transmitted vibration energy is as low as possible given the size and budgetary constraints. Both Sites were selected based on their low ambient background noise and vibration levels. This requires seismic mass type foundations for critical scientific equipment and separate foundations and remote locations for vibration producing equipment and occupancy.
- Laser and vacuum equipment will be located in a large open space of high volume and provided with cleanroom type finishes but serviced by conventional air changes and quality.
- Smaller support areas for scientific equipment will require cleanroom conditions to Class 5000 or better.
- The laser interferometer detector is sensitive to EMI effects and will require special design for power, lighting, and control circuits to minimize disturbances.

3. Systems Provided by Others

These systems are designed, provided, and installed by Others and, in general, consist of the following items

3.1 Beam Tube System

- Beam Tube Segments
- Expansion Joints
- Pumping Ports
- Baffles (Internal to Beam Tube)
- Beam Tube Support and Leveling Subsystem
- Bakeout Subsystem
- GPS Positioning and Alignment Monitoring Subsystem

3.2 Vacuum Equipment System

- Vacuum Chamber Subsystem
- Pumping Subsystem
- Valve Subsystem
- Vent and Purge Subsystem
- Bakeout Subsystem
- Monitor and Control Subsystem

3.3 Detector System

- Interferometers
  - Lasers
  - Optics
  - Coarse Alignment
  - Seismic Isolation
- Control and Data System
- Physics Monitoring
- Support Equipment

4. Growth and Flexibility

4.1 Laser and Vacuum Equipment Area

The vacuum equipment is of a modular design to facilitate phased expansion. The initial installation at Hanford will serve two interferometers but may be expandable to a total capacity of five by adding an additional LVEA mat foundation, extension of building envelope, and interferometers at the Corner Station. For purposes of this design and construction package, only Site space is provided for this future expansion. No design, foundations, structure, mechanical capacities, or infrastructure is required at this time for possible expansion of the Facility.

At Livingston, one interferometer is planned initially with capacity for an additional one by adding chambers and vacuum components at the End and Corner Stations. This expansion will be accommodated by the Facility with only moderate modifications which involve placement of second interferometer and hook-up to existing utilities (i.e., power, laser cooling, etc.).

Also both Sites will have provisions for future length extension of the Mode Cleaners. This provision amounts to a "stay clear zone" in the direction of the possible extension. No foundations, structure, mechanical capacities, or infrastructure is required at this time for this possible expansion of the Facility.

4.2 Operations Support Building

Operations will require expansion of the office and shop facilities at some future time. Initial construction should facilitate this expansion with minimum impact to the existing Facility. Temporary population surge at time of interferometer installation may be accommodated by adding temporary trailers in a designated area near the Operations Support Building (OSB).

5. Design Criteria and Interface Requirements

5.1 General Facility Requirements

A. Units of measurement are in English units.

B. Various Federal specifications will be used as the Guideline Construction Specification.

5.1.1 Fabrication and Construction Tolerances

The A-E will provide, in the drawings and specifications, all tolerances for fabrication, construction, and installation.

5.1.1.1 Structural Steel

Minimum tolerances for structural steel construction will be per the AISC "Code of Standard Practice for Steel Buildings and Bridges".

5.1.1.2 Concrete

Minimum tolerances for concrete construction and materials will be per ACI 117, "Standard Specification for Tolerances for Concrete Structures and Materials".

5.1.1.3 Installed Equipment

Tolerances for equipment interfaces specified by the A-E will not exceed the manufacturer's tolerance requirements.

5.1.2 Service Life

5.1.2.1 Facility Design Life

Facility design will be for a 30 year service life.

5.1.2.2 Systems and Equipment Design Life

Operating systems and equipment design will be for a 20 year service life.

5.1.3 Construction Category

The LIGO project is categorized as permanent construction, in accordance with the UBC and SBC.

5.1.4 Occupancy

Each LIGO project Site will be designed for a maximum shift population of 40 people. The breakdown of anticipated personnel and their classification is as follows:

Staff	Quantity
Technician and/or Operators	10
Technician Specialists	3
Engineers	3
Site Administration	2
Scientific Staff	3
Visiting Scientists	6
Interns and/or Visitors	9
Maintenance Personnel	4

Table 5.1-1 -- Staff List

5.1.5 Design

Design of the Facility will comply with the Industry Standards and Specifications referenced herein and good design principles. The Facility will be designed for, low risk, and ease of maintenance and operability.

5.1.6 Safety

Construction of the facilities will comply with OSHA- 29 CFR, and applicable local codes (e.g., Washington Institute of Safety and Health Administration (WISHA) at the Hanford Site).

5.1.7 Security

Security of the facilities will comply with good industrial practice. The major security effort will be to design for minimum potential intrusion into the Station buildings and Beam Tube Enclosures.

5.1.8 Material Selection

5.1.8.1 Flame Spread

All materials will be noncombustible or have a flame spread rating of 25 or less in accordance with ASTM E84.

5.1.8.2 Cleanliness/Contamination

Also see Section 5.4.9 for additional cleanroom interior design requirements.

A. Design will use non-corrosive and/or corrosion resistant material as required.

B. Exclude use of fraying or other material that could contribute to contamination in the LVEA and all other Cleanrooms.

C. Preclude ledges that may trap dirt and minimize oil leakage from mechanisms and mechanical equipment.

D. Consideration will be given to out-gassing and particle generation of the materials.

E. All materials will be compatible with the cleanliness requirements of the room's classification.

5.1.8.3 Material Compatibility

As a design goal, all material selections should be made to minimize Non Volatile Residue (NVR) deposition in the LVEA.

5.2 Civil

5.2.1 General Civil Requirements

Civil requirements include Site preparation and earthwork, hydrology and drainage, roads and paving, parking, utilities, wastewater treatment and other Site improvements. Area contours shall be provided by Caltech's surveying Consultant for each Site.

Careful attention will be paid to development of the Site to the special needs of LIGO and of the individual Site characteristics. Establishing and maintaining alignment are important considerations at both Sites.

Caltech's Consultant shall provide soil conditions and allowable design parameters.

5.2.2 Coordinate Control

5.2.2.1 Global and Local Coordinate Systems

At each Site there will be both a "Global Coordinate System", and five "Local Coordinate Systems". A Local Coordinate System will be established for each of the five Station Locations (i.e., Corner Station, 2 Mid Stations, and 2 End Stations). The Global Coordinate System (i.e., X_G, Y_G, Z_G) is dependent on the X_G, Y_G, Z_G system defined by the Beam Tube arms with the Z_G axis up.

Local coordinates (i.e., X_L, Y_L, Z_L) are determined by Z_L being plumb at each Station, and the X_L and Z_L axes are in the same vertical plane as the longitudinal axis of the respective Beam Tube and Z_G.

Note that even though the global and local coordinate systems share a common origin, the plane defined by X_L and Y_L will not lie in the same plane as the X_G and Y_G axes unless the Z_G axis is also plumb (i.e., normal to the surface of the Earth) at that origin. This means that over a distance of 4000 meters, the plane defined by X_L and Y_L will rotate about the Y_L axes by as much as 0.6214×10^{-3} radians.

5.2.2.2 Hanford

The intersection of the two centerlines of the property arms is located at latitude 46° 27' 18.5"N and longitude 119° 24' 27.1"W. The northwest arm is at a bearing of N36.8°W and the southwest arm is at a bearing of S53.2°W from the origin of the global coordinate system. For further coordinate and Site boundary information see Figure 5.2-1.

5.2.2.3 Livingston

The intersection of the two centerlines of the property arms is located at latitude 30° 33' 46.0"N and longitude 90° 46' 27.3"W. The southeast arm is at a bearing of S18°E and the southwest arm is at a bearing of S72°W from the origin of the global coordinate system. For further coordinate and Site boundary information see Figure 5.2-2.

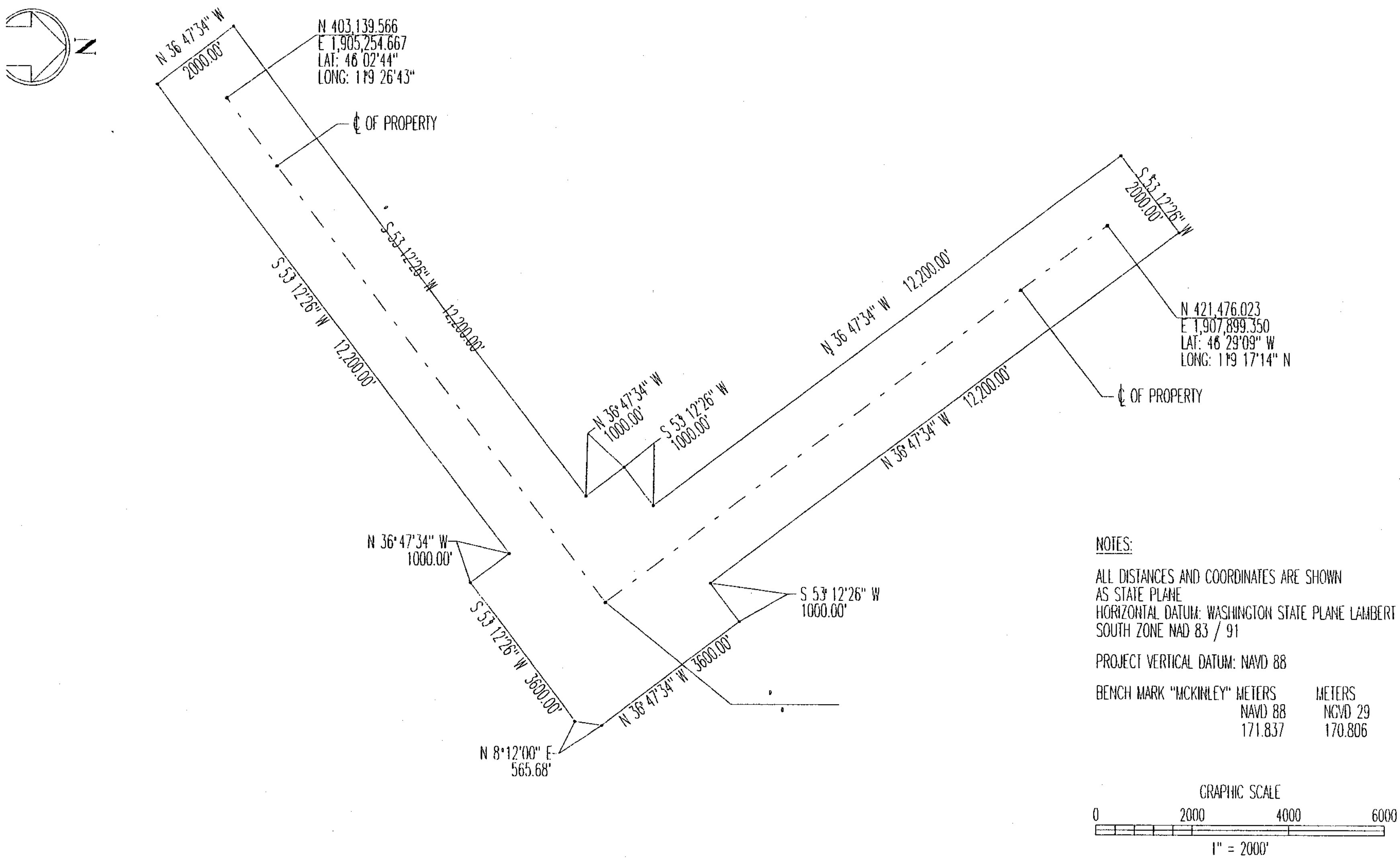

Figure 5.2-1 -- Hanford Property Boundaries (For Reference Only)

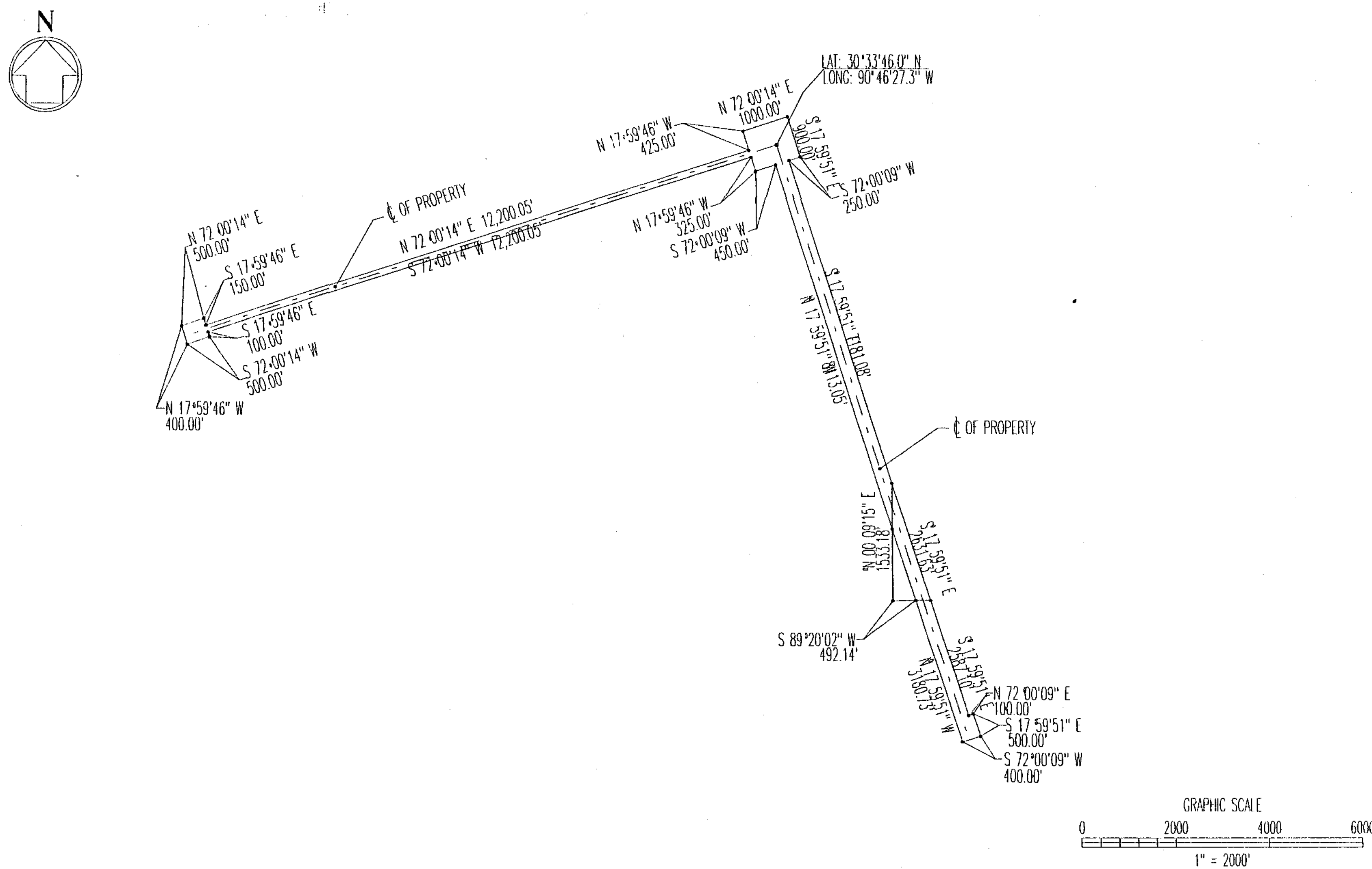

Figure 5.2-2 -- Livingston Property Boundaries (For Reference Only)

5.2.3 Site Preparation and Earthwork

Roads and graded areas shall be laid out to minimize environmental damage. Natural drainage patterns shall be maintained to the maximum extent possible. All Site areas will be graded away from buildings.

Earthwork slopes and grading shall be in accordance with the recommendations of the geotechnical reports and the following:

A. Cut slopes shall be 2:1 for Hanford and 2:1 (maximum) for Livingston Sites.

B. Fill slopes shall be 2:1 for Hanford and 3:1 for Livingston Sites.

C. Graded area pads shall be sloped 2% minimum for drainage.

D. At Livingston a minimum freeboard of 2 feet shall be used above the 100 year storm level.

E. The Beam Tube arm embankments form an "L" shape that will accommodate the LIGO interferometer arms. The two arms lie along two intersecting lines oriented perpendicular to one another, and define the plane of the interferometer. The Beam Tube arm embankments shall be flat graded with respect to this plane (as opposed to the normal grading practice that is relative to the earth's curvature). In order to accommodate local topography and minimize earthwork, the orientation of this plane may be modified by as much as $\pm 0.31 \times 10^{-3}$ radians with respect a tangent to the Earth's surface (i.e., a theoretical sphere) at the center of the square plane of the Beam Tube arms. The direction of the component of the interferometer plane normal which lies in the local horizontal plane (at the center of the square) can point in any compass direction.

F. The Beam Tube embankments shall be designed to minimize settlement.

5.2.4 Roads, Paving and Parking

The Site roads consist of a main access road to the facilities and a perimeter road around the facilities that also tie into the Beam Tube Enclosure service roads. The paved Beam Tube Enclosure service roads along each arm provide access to the Beam Tube at 780 foot (237.74 meter) intervals as well as access to the End and Mid Stations. For fire department access as well as access to the "backside" of the facilities during construction a road bridging at least one Beam Tube near the Corner Station is required.

Parking for permanent staff and visitors will be provided. A frost penetration depth of 24 inches maximum and 12 inches average shall be considered for the Hanford Site.

5.2.4.1 Roads

The road geometrics and cross-sectional design shall be in accordance with the following:

A. Roads shall be designed to positively drain with a minimum cross slope of 2% whenever possible.

B. Roads shall have a shoulder width of 4 feet (3 feet for Beam Tube service roads) minimum with a cross slope of 4%.

C. Roads shall be two-lanes where possible

D. Road side slopes shall generally be 2:1 for Hanford and 3:1 for Livingston.

E. Corner radii shall be no less than 35 feet.

F. Road centerline radius shall be as required for Site vehicles and construction equipment and deliveries (i.e. Beam Tube segments)

G. Road profile grades shall not exceed 6% whenever possible.

5.2.4.2 Paving

Paving design for the Facility roads and parking areas shall be in accordance with the following:

A. The pavements shall be designed to provide all weather access.

B. All access and service roads shall be flexible pavement unless operational considerations dictate otherwise.

C. Axle loading for roads shall be AASHTO H-20.

D. California Bearing Ratio (CBR) value for pavement design shall be [per geotechnical reports]

E. Paving shall be as flat and smooth as possible. No speed bumps, manholes, lane divider bumps, grating, etc.

5.2.4.3 Parking

Parking spaces shall be provided and designed in accordance with the following:

A. Parking for the LVEA/OSB facilities (Corner Station) shall be for:

1. 40 employees (including maintenance vehicles)
2. 7 visitors
3. 2 handicapped
4. 1 bus

B. Parking for the End Station shall be for:

1. 5 employees (including maintenance vehicles)

C. Parking for the Mid Station shall be for:

1. 5 employees (including maintenance vehicles)

5.2.5 Site Drainage

All drainage systems shall be designed to properly drain all surface water that can cause damage to the facilities, property, and adjoining land. A storm frequency of 50 years will be used for the design of all drainage structures.

5.2.5.1 Ditches

Sheet drainage to open ditches will be used to the maximum extent possible. Ditch side slopes at Livingston shall be no steeper than 3:1 to facilitate mowing and minimize erosion where required. Primary ditch work at Hanford has already been accomplished with ditch slopes at 2:1.

5.2.5.2 Pipes

Pipes or closed conduits will be used for drainage when open ditches interfere with the intended use of the area.

5.2.5.3 Culverts

Culverts shall be provided under roads or the Beam Tube embankment and whenever the natural drainage pattern is interrupted. Culverts shall comply with the following requirements:

A. Minimum diameter = 12 inches

B. Minimum gradient = 1%

C. Alignment shall be in the direction of storm flow and as nearly perpendicular to roads, embankments or obstructions as possible

D. The preferred culvert material shall be reinforced concrete pipe or concrete box sections

5.2.6 Utilities

The domestic water supply and the sanitary sewer system for the Corner Station (LVEA/OSB) shall be designed for a total work force of 40 on day shift and 10 each on swing and graveyard shifts. Fifty gallons per person per day shall be used as a basis.

Water and sanitary sewer requirements for the Mid Stations and End Stations are 10 personnel (not concurrent with 40 at the Corner Station. The firewater system will be designed in accordance with Local requirements.

5.2.6.1 Potable Water

A. Water shall be provided from an existing well located near the End Station of the southern arm for Hanford.

B. Water shall be pumped to a pneumatic storage tank to accommodate Facility requirements and to minimize well pump start/stops.

C. Based on water quality data from well tests the water may require treatment for potable use

D. Potable water shall be distributed from the tank to all facilities at the Corner Station via an underground system.

E. The potable water distribution system shall be in accordance with the following:

   1. Design velocity shall be 5 fps, with a maximum of 10 fps

   2. Minimum earth cover of 3 feet

   3. Backflow preventers will be provided at connections with the possibility of contamination.

   4. Water supply shall be designed for the combined peak flow requirement

5.2.6.2 Firewater

A. Firewater shall be provided from an existing well located near the End Station of the southern arm for Hanford.

B. Firewater shall be pumped to a storage tank to accommodate Facility requirements and to minimize well pump start/stops and to provide the required fire water reserve per code requirements.

C. A portable propane engine driven firewater pump shall be provided to the servicing Fire Department in case a complete power outage occurs

D. Fire hydrants will be strategically placed only around the Corner Station as required. Hydrant spacing shall be 300 feet maximum. At branch lines to fire hydrants, gate valves shall be provided. Fire hydrants are not required along the Beam Tubes, or at the Mid and End Stations.

E. If the buildings are equipped with sprinklers, post indicator valves will be provided at each building sprinkler connection.

F. Valving for fractional isolation of the firewater system will be provided if necessary.

5.2.6.3 Sanitary Sewer

Sanitary sewer pipelines will be designed in accordance with the following:

A. The minimum line size will be 6 inches diameter

B. Design velocity will be a minimum of 2 fps flowing at half depth or 3 fps when cleaning is difficult

C. Sewers will have straight runs between manholes (if manholes are needed)

D. Clean-outs will be used for changes in direction of minor sewer laterals and building connections

E. To help eliminate vibration sources, man holes shall not be located in road or parking lot surfaces or other traffic areas

5.2.7 Wastewater Treatment Facilities

Federal, State, and local codes regarding collection, treatment and discharge of sanitary wastes will be met. Sewage collected from the LIGO facilities at Hanford will be treated by a septic tank system with disposal through a leach field system. Sewage collected from the LIGO facilities at Livingston will be processed through a package tertiary wastewater treatment plant with discharge to natural waterways. Sludge from both cases will be picked up by local contractors.

5.2.8 Miscellaneous Sitework

5.2.8.1 Solid Waste Disposal

Solid waste (trash) shall be collected by a locally contracted solid waste disposal firm from a Facility location near the main road outside the 200 foot non critical traffic exclusion zone.

5.2.8.2 Security Fencing

Security fencing shall be limited to the area around the Corner, Mid, and End Stations and will consist of a 6 foot chain link fence (with 3 strands of barbed wire at the top at the Mid and End Stations only). Gated access from the main access road shall be provided. No guard Station is required.

A standard "range" fence may be required around the perimeter of the Livingston Site to keep out cattle and to some extent people. This will be simple metal T-posts with 3 strands of barb wire.

5.2.8.3 Pipeline Crossings

There are two right-of-ways for oil company pipelines crossing the Livingston Site. These pipelines will be protected in a method in a manner acceptable to the oil companies and LIGO.

5.3 Structural

5.3.1 General Structural Requirements

5.3.1.1 Steel Design and Construction

Steel structures and components will be designed and constructed in accordance with the AISC Specification for Structural Steel Buildings, Allowable Stress Design and Plastic Design, and the AISC Code of Standard Practice for Steel Buildings and Bridges. All structural welding will be in accordance with AWS D1.1, A2.4 and A3.0.

5.3.1.2 Concrete Design and Construction

Concrete structures and components will be designed and constructed in accordance with ACI 318.

5.3.1.3 Concrete Reinforcing Steel

Steel reinforcement will conform to the requirements of ASTM A615, Grade 60. Detailing, fabrication and placement will be in accordance with CRSI-1.

5.3.1.4 Masonry Design and Construction

Masonry structures and components will be designed and constructed in accordance with ACI 530.

5.3.1.5 Inspection Requirements

Inspection requirements, along with acceptance criteria, for steel and concrete structures and components will be clearly specified by the A-E in the drawings and specifications.

5.3.2 Loading Conditions

Structural systems and components will meet or exceed the requirements the UBC code for Hanford, or Standard Building Code (SBC) for Livingston.

5.3.2.1 Minimum Floor Live Load

The minimum floor live load will be as follows:

A. 250 psf for storage and receiving areas

B. 100 psf for control room, shops and LVEA areas

C. 50 psf for office area

5.3.2.2 Seismic Load

A. Seismic loads will be applied and the structure analyzed using one of the methods described in the UBC for the Hanford Site. Seismic loads will be applied and the structure analyzed using the equivalent static method per SBCCI for the Livingston Site.

B. At the Hanford Site, the structure is located in seismic zone 2B per UBC. At the Livingston Site, the seismic classification is Hazard exposure group I, performance category A, per SBCCI.

5.3.2.3 Wind Loads

Wind loads, for the Hanford Site, will be determined in accordance with UBC using a design wind speed of 70 MPH, exposure C and importance factor I=1.0. Wind loads, for the Livingston Site will be determined in accordance with SBCCI using a design wind speed of 100 MPH, exposure C and importance factor I=1.0.

5.3.2.4 Forklift Loads

A 10,000 pound capacity forklift will operate anywhere within the following areas of the Corner, Mid, and End Stations. .

- Inspection/Shipping/Receiving
- Cleaning Area
- LVEA/VEA
- Active Storage Area
- Long Term Storage Area

5.3.2.5 Volcanic Ash Loads

The Hanford Site structures will be designed for a volcanic ash load of 2 psf.

5.3.2.6 Load Combinations

Load combinations will be in accordance with the UBC for the Hanford Site and SBC for the Livingston Site.

5.3.2.7 Serviceability Requirements

Deflections due to live load, wind or seismic will be limited as follows:

1. Maximum allowable live load deflection will be L/240, except for elements supporting plaster ceilings or wall in which case the maximum will be L/360.

2. Seismic or wind induced lateral drift will not exceed the requirements of 0.005 times the story height.

5.3.2.8 Beam Tube Foundation and Enclosure Requirements

A. Initial Beam Tube slab "straight line" variance of finish floor will be limited to ±1 inch for the entire length of all Beam Tube arms (Distance = 4 km).

B. Initial slab "straight line" variance of finish floor will be limited to ±1/8 inch in 10 feet.

C. The foundation at the Beam Tube support must be constructed to a tolerance of ±1/2 inch between the successive supports (about 65 ft).

D. The long term differential settlement is limited to ±2 inches with reference to the Beam Tube axis.

E. End flanges or valves where atmospheric pressure can exist on one side only, will require support from the foundation to react to the combination of all applied fixed support loads plus appropriate safety factors.

F. Beam Tube Enclosure and doors at entrances to the Beam Tube Enclosure will be capable of stopping penetration of a stray bullet. The parameters to be used are as follows.

Item	Property
Caliber:	308
Weight:	180 Grains
Velocity at Impact:	2900 Feet Per Second
Energy at Impact:	2800 Foot-Pounds
Material:	Lead Core, Fully Jacketed with Copper

Table 5.3-1 -- BTE Projectile Data

5.4 Architectural

The LIGOs are comprised of a Facility for the Corner Station containing a "Clean Environment" for the Laser Vacuum Equipment Area (LVEA). This clean environment is not required to meet Federal Standard 209 requirements. The Corner Station also contains an Operations Support Building (OSB) for maintenance and administrative functions. Other facilities are the Beam Tube Enclosures, Mid and End Stations, and utility components that provide conditioned air, power, and water/waste treatment. These structures are to be located at both Hanford, Washington and Livingston, Louisiana. The Mid Station at Livingston is a simple Mid-Point Pump Station that does not house any special vacuum equipment chambers.

5.4.1 Laser and Vacuum Equipment Area

The Laser and Vacuum Equipment Area (LVEA) is designed to house the high precision, sensitive interferometer components (provided by Others). The interferometers require a relatively clean and controlled environment with a minimum of disturbance from acoustic noise, ground vibrations, electromagnetic interference, and other localized disturbances. Each interferometer uses one or more high power lasers which will be located within this area. Many of the interferometer components are contained within a high vacuum envelope generally referred to as the "vacuum equipment".

The vacuum equipment (provided by Others) is comprised of a network of vacuum chambers, which house sensitive interferometer components, and interconnecting beam-tubes which facilitate transmission of laser beams between the chambers. High vacuum gate valves are provided between operation-critical sections of the interconnecting tubing to isolate different portions of the vacuum system for diagnostics, maintenance, or upgrades while other portions remain operable.

Re-locatable vacuum pumps (provided by Others) are deployed where needed by overhead cranes, air pallets, or carts, and coupled locally to valved ports for pump-down. Stationary high-vacuum ion pumps are attached to individual chambers. Liquid nitrogen (LN_2) pumps at the ends of the adjacent Beam Tube modules provide additional pumping capacity.

The vent/purge subsystem (provided by Others) generates and distributes filtered, dry air for backfilling chambers when they are to be opened. This subsystem also provides internal filtered air showers to maintain cleanliness while working inside the chambers.

A bakeout subsystem (provided by Others), comprised of relocatable heaters, insulation, and power connections, allows optional vacuum baking of individual valved-off sections of the vacuum equipment. This permits removal of contaminants and reduction of outgassing when required.

In addition to lasers and vacuum equipment, this area contains electronics racks, cable trays, and cabling for the interferometers, and is provided by Others.

A. The LVEA is not classified as a cleanroom, however the design intent is to achieve a "Clean Environment". This will be approached by using cleanroom design methods and techniques for selecting material, sealing doors and surrounding surfaces, selecting supply air filters (but not air flow), and using physical features as described in Section 5.4.9.

B. The LVEA is accessible by both Staff and equipment via the Cleaning Area.

C. The LVEA ceilings have heights to accommodate overhead crane systems to facilitate movement of equipment components for repair, maintenance, and replacement.

D. LVEA walls have a durable, cleanable surface of an inorganic, and non-gassing finish or coating to aid the maintenance of cleanliness.

5.4.2.3 Computer and Mass Storage Room

The Computer and Mass Storage house rack-mounted computing equipment, mass storage units, and peripherals (disk and tape drives, etc.) as well as storage cabinets for magnetic tapes. Portions of this area will have access flooring to allow easy cabling. The equipment for these areas consists mainly of desktop computing workstations for the Diagnostics portion of the operation. The room will be provided with a gaseous fire suppression system.

A. The Computer Room and Mass Storage Room is approximately 450 square feet, and is accessible to the Control Room.

B. Floors are 24 inch raised access floor system and has a floor finish as described in Section 5.4.7.1.

C. Walls are painted gypsum board. Ceiling height is 12 feet and suspended acoustical tile system.

5.4.2.4 Tape Room

This area will have access flooring to allow easy cabling. The room will be provided with a gaseous fire suppression system. The Tape Room will be the on-site repository for all data tapes. A duplicate, off-site storage space shall also exist.

A. The Tape Room is approximately 350 square feet and accessible to the Control Room.

B. Floors are 24 inch raised access floor system and has a floor finish as described in Section 5.4.7.1.

C. Walls are painted gypsum board. Ceiling height is 12 feet minimum and suspended acoustical tile system.

D. A single door is provided to allow access for personnel and equipment.

5.4.2.5 Staff Offices, Lobby, and Visitor Accommodations

This area includes offices and common areas such as rest rooms, break room, conference room, suitable for 40 permanent and visiting staff/scientists. Permanent staff will consist of approximately 8 professionals and 13 technicians/operators. Approximately 15 visiting scientists and interns are anticipated at any time during the year, each with a stay of one week to six months. Other visitors will include tour groups of students, educators, scientists, and dignitaries. The Facility entrance for employees, users, and visitors is through a lobby and is controlled from an Administration Assistant area. The conference room, all workspaces, and all offices have provisions for computer networking.

5.4.2.6 Optics Lab

This lab is designated to provide support for inspections, cleaning, testing, and storing of optics required for operation of experiment. This will also be the location of an optics technician.

A. The Optics Lab is approximately 900 square feet and adjacent to the Vacuum Prep and Assembly Lab, and Cleaning Area.

B. Materials and finishes are durable and cleanable. Floors are resilient flooring. Walls and ceilings are painted gypsum board.

C. The Lab will be a Class 5000 (minimum) cleanroom with Class 100 vertical laminar flow area(s) for assembly of objects up to 1 meter cubed and weighing up to several hundred kilograms

5.4.2.7 Vacuum Prep and Asssembly Lab

This Lab provides for the assembly and disassembly of vacuum components and subsystems for cleaning with solvents and detergents, and bakeout and outgassing certification of new components. This will also be the location for mechanical engineer and technician functions at workstations and workbenches.

A. The lab will be a Class 5000 (minimum) cleanroom with Class 100 vertical laminar flow area(s) for assembly of objects up to 1 meter cubed and weighing up to several hundred kilograms.

B. This Area is approximately 700 square feet, adjacent to the Optics Lab, and accessible to the Inspection and Cleaning Areas.

C. Materials and finishes are durable and cleanable. Floors are resilient flooring. Walls and ceilings are painted gypsum board.

5.4.2.8 Electronics Test and Maintenance Shop

This Shop is designated to enable the repair and assembly of electronics and cabling, perform measuring, calibration and troubleshooting of the electronic components of the lasers and interferometers, both new and existing. Other activities will include the design of new electronics necessary to support the testing and experiments. This will also be the location of electronics engineer and technician functions.

5.4.2.9 Mechanical Shop

This Shop provides the space to check, maintain, and repair interferometer and Facility equipment. The mechanical shop contains small scale machining and welding equipment (provided by Others) such as drill presses and lathe/milling machines, for maintaining or modifying interferometer and vacuum equipment components.

5.4.2.10 Inspection/Receiving/Shipping

Equipment that arrives at the LIGO Facility loading area will be processed through this area in a manner which ensures the integrity of the clean environments. Packages that arrive at the loading area will be cleaned externally before being moved into the Inspection/Receiving and Shipping Area. There, they are unpacked from the outer shipping container and moved to the Cleaning Area.

A. Inspection/Receiving/Shipping is approximately 600 square feet in size and accessible to the Cleaning Area and the loading area.

B. The ceiling height is 20'-0" (minimum).

C. An overhead equipment door is provided from outside the LIGO facilities for access and deliveries via the loading area. See Section 5.4.8.2 for additional information.

D. Materials and finishes are durable and cleanable. Concrete floors are sealed. Walls and ceilings are painted gypsum board with a hard surface wainscot.

E. Movement of large objects from the loading dock or Cleaning Area, to the Inspection/Receiving/Shipping shall be by a ground based system.

5.4.2.11 Cleaning Area

Equipment destined for the LVEA is moved from the Inspection/Receiving/Shipping Area to the Cleaning Area. Here the inner packaging is removed and the contents are inspected and cleaned. Doors connecting through this area will be opened one at a time to prevent outside dust or particulate contamination riding on packaging from reaching the LVEA.

A. Cleaning Area is approximately 400 square feet in size and accessible to the LVEA and the Inspection/Receiving/Shipping area.

B. The ceiling height is 20'-0"(minimum)

C. An overhead equipment door is provided to allow direct access to the LVEA from the Cleaning Area. See Section 5.4.8.2 for additional information.

D. Materials and finishes are durable and cleanable. Concrete floors are sealed. Walls and ceilings are painted gypsum board with a hard surface wainscot.

E. Movement of large objects from the loading dock to the Cleaning Area shall be by a ground based system.

5.4.2.12 Active and Long Term Storage

These areas will be used to store parts and components integral to the common maintenance of Facility and equipment.

5.4.2.13 Change Room

All personnel will enter the LVEA via this space. This space will contain small lockers and benches to facilitate the gowning-up process prior to entering the LVEA.

A. The Change Room accommodates 5 personnel, shall be approximately 100 square feet, and is accessible to the LVEA via the Cleaning Area. The door exiting the Cleaning Area, towards the LVEA, is controlled by the Facility Operator located in the Facility Control Room.

B. The room is equipped with storage lockers and portable benches. Lockers shall be used for clean smocks, booties, gloves and other necessities for cleanroom entry and work. Disposal bins shall also be provided.

C. The flooring is sheet vinyl with a coved base.

D. The ceiling height is 8'-0" minimum and is painted gypsum board.

5.4.3 Mechanical/Utility Room

This building provides space for equipment such as heating, ventilation, and air conditioning (HVAC), and other mechanical and electrical equipment associated with the Facility operations.

The Mechanical/Utility Room is vibrationally isolated from the LVEA and is serviced by a remotely located chiller plant to minimize vibration transfer to the LVEA. Air handling units are designed for minimum induced vibration and acoustic noise. Cooling for the lasers is provided by individual closed-loop water cooling systems (provided by Others) with heat exchangers that is coupled to a Facility chilled-water line.

5.4.4 Chiller Plant at Corner Station

The Corner, Mid, and End Station chilled water plants provides chilled water to the HVAC systems, and, at the Corner Station, the closed loop cooling systems for the lasers. The chilled water plant is remotely located from the Corner Station to minimize transmitted vibration and is isolated acoustically to minimize acoustic energy transmission to the LVEA.

5.4.5 Mid and End Station Facilities

Facility areas shall follow height and material criteria for like spaces of the Corner Station except there are no cleanroom requirements.

The buildings for the End Stations at both Sites and the Mid Stations at the Washington Site are of similar design, but differ in their vacuum equipment layout. The functional requirements and designs are similar to those of the Corner Stations, except that the vacuum equipment in these Stations is much simpler and there is no need for personnel offices. These Stations include a Vacuum Equipment Area (VEA), a support services area, a

Mechanical Room, and a remote chilled water plant. Access to the buildings and the VEA is controlled and monitored from the Facility Control Room in the Corner Station by the Facility operator.

Finish floor elevation of the End Station is 2'-3 $^{9}/_{16}$" below the finish floor elevation of the adjacent Beam Tube Enclosure. Finish floor elevation of the Mid Station at Hanford is the same as the finish floor elevation of the adjacent Beam Tube Enclosures.

The design and construction approaches of VEA are similar to those used in the LVEA in the Corner Station. These areas contain vacuum chambers, pumps, and valves (provided by Others) which are serviced by an overhead bridge crane. It also encloses electronics racks (provided by Others) and associated cabling for control and data acquisition.

The Mid and End Stations also contain areas for unpacking, inspection, and cleaning of interferometer and vacuum equipment. It also includes a small work area for maintenance and servicing interferometer components and optics. If these items need a cleanroom working environment, then they will be bagged and moved to the Corner Station cleanroom.

An attached utility room, with separate foundation for vibration control, houses mechanical (i.e., HVAC air handler units, etc.), and electrical equipment (i.e., motor control centers, etc.).

Chillers are located at a separate and remote plant. This plant is separate from the Mid and End Stations and is of similar design to the Corner Station Plant. Chilled water will be required for the HVAC system only since there are no high-power lasers in these Stations.

5.4.6 Beam Tube Enclosures

The Beam Tube Enclosures at each Site are made up of four similar 2 kilometer long modules. The Beam Tube Enclosure protects the high-vacuum Beam Tube walls from vibration induced by wind. In addition, it protects the tube walls from mechanical impacts which could release bursts of gas into the interferometer beams, thereby contributing noise. The enclosure provides moderate amount of thermal stability for the Beam Tubes, reducing the variation in residual gas pressure. It also provides protection against damage to the Beam Tubes from stray bullets. A potential configuration is shown in the Figure 5.4-1.

The foundation at the Beam Tube support must be constructed to a vertical tolerance of ±1/2 inch between the successive supports (about 65 ft apart). Beam tube supports will be attached to the foundation with anchor bolts. The foundation must be designed to minimize settlement and to take static and vacuum related loading of the Beam Tubes and their various components. See Section 5.3.2.8 for additional criteria on this subject.

The Beam Tube Enclosures are not occupied spaces, however access is required for occasional maintenance and scientific activities. The enclosure configuration provides adequate room for access to repair leaks, adjust alignment of the Beam Tube and conduct occasional Beam Tube bakeouts. Entries to the Beam Tube Enclosure are required at 780 foot intervals for installing and servicing the future vacuum pumps. The enclosure provides space for internal distribution of signal and power cables. Minimal permanent lighting is required. Utility outlets are provided at the 780 foot entries. The foundation is transversely sloped to drain accumulated water from the floor of the Beam Tube Enclosure.

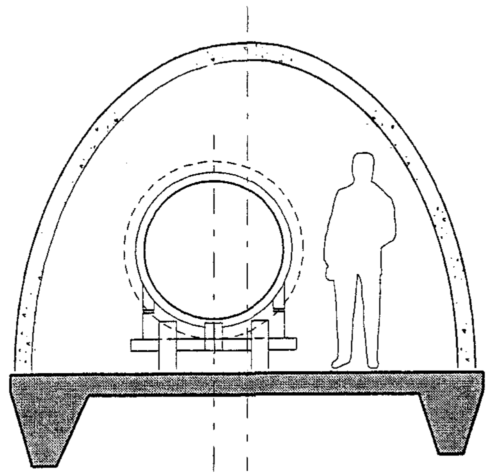

Figure 5.4-1 -- Beam Tube Enclosure Cross Section

The Beam Tube Enclosure will have *provisions for* a HVAC System that is not dependent on any air distribution from the Corner, Mid, or End Stations. These provisions consist of power distribution along the length of the Beam Tube Enclosure with sufficient capacity to add the additional load of the dehumidifying units; and loops in the fiber optic cable at every Service Entrance so it can be connected to a future fiber optic interface panel. This panel will have broad capabilities to hook-up possible future components such as HVAC temperature and humidity sensors, telephone, intrusion detectors, smoke detectors, etc.

A. Service access to the enclosure is located at every 780 feet.

B. Emergency egress from the enclosure is at a maximum of every 300 feet (90 m) as required by the UBC Section 1003.4, Travel Distance.

C. The enclosure is not equipped with permanent fans. LIGO Operations will have to provide proper temporary ventilation to meet health and safety requirements prior to human access.

D. Floors are sloped to a floor drain.

E. The enclosure structure is not water tight but all joints are to be sealed to prevent intrusion of vermin and insects. The enclosure is also resistant to penetration of bullets (see section 5.3.2.8).

5.4.7 Finishes

A. All architectural finishes shall be compatible with internal and external environments described in Sections 5.1.8, 5.5.2.1, and 5.5.2.2.

B. All paints and coatings shall conform to the States of Washington and Louisiana local Air Pollution Control District requirements respectively.

5.4.7.1 Floor Finishes

A. LVEA floors have a durable surface to withstand occasional forklift.

B. Other exposed interior concrete floor surfaces shall have a smooth, steel trowelled finish with a surface hardener.

C. Facility Control Room and other computer spaces shall have anti-static access flooring with carpet.

D. Offices, lobby, and receptionist areas shall have carpet.

E. All other interior spaces shall have resilient floor tile except the toilet facilities which shall have ceramic tile.

F. Exterior concrete floor surfaces shall have a broom finish.

G. Special finishes shall be designated for the main entry to the Operations Support Building (OSB).

H. Joint filler and sealer materials resistant to the effects of the induced environment as required shall be used.

5.4.7.2 Walls

A. Exterior walls will be proven architectural materials and will be insulated, weather resistant materials providing an air- and water-tight, maintenance free enclosure.

B. Exterior walls shall be durable, minimally maintenance materials with an expected minimum life expectancy of 30 years.

C. Interior walls for the "clean areas" shall be smooth, non-shedding, and compatible with the rooms intended use and classification (if any).

D. Interior walls for toilet areas shall be water resistant (WR) gypsum board with ceramic tile.

5.4.7.3 Ceiling Finishes

A. Ceilings shall be suspended acoustical tile in general areas such as offices, lobby and computer rooms.

B. Suspended ceilings shall be used in clean areas to be compatible their respective area classification (if any). Materials shall be selected as required to meet acoustic requirements as described in Section 0 Acoustics.

C. Other areas, such as toilet facilities, locker rooms, and janitors rooms, shall be suspended hard surfaced ceilings.

D. Exposed ceiling/roof structure shall be used in other areas such as shop areas, and utility spaces.

E. Water resistant (WR) gypsum board will not be used for ceiling applications.

5.4.7.4 Painting -- General

A. All exposed and untreated materials requiring protection shall be field painted.

B. Surfaces shall be finished, cleaned and dry prior to receiving painting.

C. Materials shall be primed with one coat 0.5 mils dry film thickness of paint primer.

D. Materials shall receive one intermediate coat and one finish coat of paint. The intermediate coat shall be a different color than the finish coat. Each coat shall be a minimum of 3 mils dry film thickness.

E. Surfaces not to be painted:

1. Concrete floors
2. Glass
3. Masonry, unless specified
4. Precast concrete, unless specified
5. Factory finished items
6. Items specified in construction documents as surfaces not to be painted

F. All colors shall be selected in accordance with the color palette as established by the architect and the Caltech Technical Representative. The finish coat of all painted interior cleanroom surfaces shall be white.

5.4.7.5 Shop and Field Painting (Metals)

A. All exposed ferrous and nonferrous metal to be installed and used for flashing, railings, louvers, doors and frames (including copper and galvanized surfaces) shall be shop or field painted. Ferrous metal surfaces preparation shall be in accordance with Steel Structures Painting Council (SSPC) specifications.

B. Blast cleaning shall be in accordance with SSPC-SP-10. In areas where sand blasting is not allowed, surfaces shall be prepared in accordance with SSPC-SP-2 and/or SSPC-SP-3.

C. Ferrous metals shall be painted with one coat, 3 mils dry film thickness

D. Nonferrous metals shall be prime coated with 0.5 mils dry film thickness of primer.

E. All ferrous and nonferrous metals shall receive one intermediate coat and one finish coat. The intermediate coat shall be a different color than the finish coat. Each coat shall be a minimum of 3 mils dry film thickness.

F. Surfaces not to be painted:

1. Air terminals (Lightning Protection System)
2. Ladder rungs
3. Chain rails and hoist points

4. Bridge crane wheel/wire rope/rail interfacing surfaces
5. Lightning connectors/down cable isolation blocks
6. Stainless steel, brass and bronze
7. Top surface of aluminum floor plates
8. Aluminum handrails
9. Handrail post sockets
10. Wear surfaces of hinges or mechanisms
11. Winch cable drums
12. Factory finished items

G. All colors shall be compatible with the color palette established as stated in the Section for Painting - General.

5.4.7.6 Caulk and Sealant

Caulk/tape/sealant used in each type of cleanroom shall be compatible with the classification of the cleanroom environment.

5.4.8 Doors -- General

A. The cleanroom door opening mechanisms design will minimize the amount of contaminants generated by their operation.

B. All doors in the cleanroom perimeter walls will be equipped with weather-strips and seals in order to minimize air leakage/loss from clean environments and contamination.

5.4.8.1 Equipment Doors

A. All equipment doors will be 6'-0" wide by 7'-0" high, 1-3/4" thick, insulated hollow metal doors

5.4.8.2 Large Access Doors

A. All large access doors are metal unless otherwise noted.

B. All large access doors will be power actuated (with provisions for manual override), insulated at exterior exposures, and will provide a finished clear opening of 12 feet wide by 16 feet high to the OSB shipping/receiving area, 8 feet wide by 12 feet high inside the OSB or between the OSB and LVEA; and 14 feet by 24 feet high from the LVEA to the outside. See Section 5.6.11 for door control requirements.

C. Large access door between to the Cleaning Area and LVEA shall be rapid close fabric type to reduce loss of "clean environment".

D. All large access doors will be installed per NFPA 80.

E. In closed position, all edges of large access doors shall be sealed to prevent infiltration of outside air, insects, animals, and dust; and prevent pressure loss from interior spaces.

5.4.8.3 Personnel Doors

A. Personnel doors will be 3'-0" wide x 7'-0" high insulated hollow metal doors.

B. All doors will be 1-3/4" thick.

C. UBC, SBC, and NFPA requirements will be applied when fire rated doors are required.

D. Door hardware will comply with Industry Codes and Standards.

E. Specialized door hardware will include automated entry control and intrusion detection devices, door mounted combination locks, dead-bolts and padlocks, lever type hardware, exit hardware, electric strikes/latches, electric power transfers, heavy duty door closers meeting vibration requirements, lock cylinders, sound or weather seals, automatic door bottoms, hinges with non- removable pins, and associated equipment.

5.4.8.4 Thresholds

Thresholds will be flush with the floor.

5.4.9 Cleanroom Interior Design

To assist in maintaining a clean environment, interior surfaces of these areas will be designed to the following criteria. This is required in the LVEA, however this area is <u>not</u> classified as a "Cleanroom" by Federal Standard 209. Only the Optics Lab, and Vacuum Preparation and Assembly Lab need to comply with Federal Standard 209, Class 5000 as a minimum.

A. Minimize horizontal ledges and surfaces

B. Fully enclose all structural shapes

C. Line all necessary pockets and recesses with cleanable shapes

D. Cove all inside corners

E. Provide seams that will not retain soil or dust

F. Provide smooth, non-flaking and washable surfaces and finishes

G. Provide closed chases for pipes and conduits where possible

H. Provide access for cleaning all surfaces

I. Provide flush/surface mounted lighting fixtures

5.4.10 Roofs and Gutters

Roofing design for structures will meet the requirements of UBC and SBC. Roof penetrations will be eliminated if at all possible. Rain gutters and/or roof drains with overflow drains will capture all roof runoff and direct it to an appropriate storm drain system. Precautions shall be taken to guard against effects of wind and rain water runoff in gutters causing vibration transfer to the LVEA area.

5.4.11 Life Safety

The LIGO Project will be designed in accordance with the Uniform Building Code (UBC) for the Washington Facility, and the Standard Building Code (SBC) for the Louisiana Facility. These codes will be followed to provide emergency exits and exit access ways as applicable for all facilities including the Beam Tube Enclosures.

5.4.12 Energy Conservation

"U" values for roofs and exterior walls will be determined in accordance with the governing state codes for energy conservation, or with ASHRAE design guidelines.

5.5 Mechanical

5.5.1 General Mechanical Requirements

5.5.1.1 Mechanical System and Component Identification

Mechanical system and component identification comply with the requirements stated in ANSI A13.1 for lettering, colors, band widths, marker locations, and viewing angles.

5.5.1.2 Wind Loads

All exposed mechanical equipment and plumbing piping systems are to be designed to withstand wind loads as specified in ASCE 7-88.

A. For non-critical systems, the Importance Factor equals unity.

B. For critical systems, the Importance Factor equals 1.1.

5.5.1.3 Corrosion Control

Corrosion control measures include cathodic protection systems, copper-finned coils and tubes, as well as, the use of protective coatings.

A. The use of protective coatings will be in accordance with NACE-RP-02-75.

B. Protection will be provided against corrosion caused by galvanic action due to physical contact of dissimilar metals.

5.5.1.4 Factory Paint

A. Unless otherwise specified, all ferrous and nonferrous metal to be installed inside the Facility will have surfaces prepared in accordance with SSPC-SP-10 and shop primed with two-part, organic zinc rich epoxy for ferrous metals, or organic zinc rich chromate primer for non ferrous metals.

B. Field painting will be in accordance with Section 5.4.7.5.

5.5.1.5 Vibration Control

A. All major rotating equipment will be statically and dynamically balanced as a complete assembly.

B. Maximum displacement amplitude of any major piece of rotating equipment will be 2 mils peak-to-peak, at all steady state operating speeds.

5.5.1.6 Motors

All motors will be high-efficiency type, non-overloading in accordance with Section 5.6.3. The HVAC fan motors will be synchronous type motors with position/phase control between the motors located within a single mechanical room. The fans will have adjustable pitch blades to control air flow-rate. The HVAC fans and motors will be skid mounted to permit each fan and motor pair to be vibration isolated from the mechanical room foundation.

5.5.1.7 Safety Requirements

Provide the following safety requirements:

A. Belts, pulleys, chains, gears, protruding set screws, keys and other rotating parts will be fully enclosed or properly guarded in accordance with OSHA 29 CFR 1910.219.

B. High temperature equipment and piping so located as to endanger personnel or create a fire hazard will be properly guarded or covered with insulation.

C. Where required for safe operation and maintenance of equipment, provide such items as catwalks, platforms, ladders, and guard rails.

5.5.1.8 Redundancy

A. Provide redundancy by including a standby unit for all critical areas which are served by only one air handling system.

B. For air handler units (AHUs) supplying air to the LVEA and VEAs, there will be one standby unit. Redundant critical components are an acceptable alternative to providing complete redundant AHUs. This requirement can also be met with 3- 50% units.

C. For chillers, boilers, pumps and air compressors, there will be at least one standby unit. This requirement can also be met with 3- 50% units.

D. All redundant equipment will be provided with automatic start capability, and manual override.

5.5.2 Heating, Ventilating, and Air Conditioning Systems

The Heating, Ventilation and Air Conditioning (HVAC) systems will be designed for optimum energy conservation and operational cost. Centralized automatic control and system surveillance will be provided by the Facility Monitoring and Control System (FMCS). In response to the vibration and acoustic requirements imposed by the interferometers, the HVAC system will incorporate the following features:

A. The location of machinery, chiller plants, high-velocity exhausts, etc. will be chosen to limit transmission of vibration and noise.

B. Equipment will be provided with vibration isolators and flexible connectors for ducts, electrical conduits, and piping to avoid structural transmission of vibrations and acoustic noise.

C. Diffusers, grills, fans, heating and ventilating units, and other equipment will be carefully selected to meet or exceed noise criteria for the serviced area

D. Excessive velocity and turbulence in ducts and piping will be avoided everywhere.

E. To limit noise transmission through the ventilating ducts, intra-duct acoustic attenuators will be installed where necessary.

5.5.2.1 Climatic Design Criteria

Environment	Hanford	Livingston
Nearest Town	Richland, WA	Baton Rouge, LA
Latitude	47 N	30 N
Longitude	119 W	91 W
Elevation	532 ft above sea level	60 ft above sea level
Summer Outdoor Design Temp	96 $°F_{db}$, 68 $°F_{wb}$	93 $°F_{db}$, 80 $°F_{wb}$
Daily Temp Range	30 °F	19 °F
Winter Outdoor Design Temp	5 $°F_{db}$	25 $°F_{db}$
Clearness Number, Summer Clearness Number, Winter	1.05 0.95	0.9 0.9
Design Wind Velocity, Summer Design Wind Velocity, Winter	3.6 mph 15 mph	7.5 mph 15 mph

Table 5.5-1 -- Climatic Design Criteria

5.5.2.2 Inside Design Conditions

Space	Design temperature	Air flow rate
Vacuum equipment operating (HI- and Low-bay areas)	72 ± 3.5 °F 0.15" wg above ambient	2 CFM/sf
Laminar flow area(s)	72 ± 3.5 °F 0.05" wg above adjacent area	60 to 90 fpm (clean air class 100)
Optics Lab Vacuum Prep & Assmb. Lab	72 ± 3.5 °F 0.05" wg above adjacent area	25 fpm (clean air class 5,000)
Electronics Test/Maint Mech. Shop.	72 ± 3.5 °F 0.05" wg above ambient	2 CFM/sf
Cleaning Area Active Storage Long Term Storage Changing Room	72 ± 3.5 °F 0.05" wg above ambient	2 CFM/sf
Inspection/Shipping/ Receiving	72 ± 3.5 °F 0.05" wg above ambient	1.0 cfm / sf
Facility Control, Computer Users, Tape Room, Computer Mass Storage, and Diag. Support	72 ± 3.5 °F	1.5 cfm / sf
Cleaning Area	72 ± 3.5 °F	2 cfm / sf
Offices	72 ± 3.5 °F	As required
Main Lobby	72 ± 3.5 °F	As required
Conference Room	72 ± 3.5 °F	As required
Multi-use / Visitors Area	72 ± 3.5 °F	As required
Mechanical/Elec. Room	72 ± 3.5 °F	As required
Admin. Assistant	72 ± 3.5 °F	As required
Lounge/ Conf./Lab	72 ± 3.5 °F	As required
Toilets	75 ±3.5°F	2 cfm / sf exhaust
Beam Tube Enclosure	No temperature, humidity, or pressurization requirements	No ventilation requirements

Table 5.5-2 -- Inside Design Conditions

5.5.2.3 Space Humidity Requirements

A. All occupied spaces inside the facilities at Hanford and Livingston will have a relative humidity range from 20 to 70% RH.

5.5.2.4 Insulation Systems

All thermal insulation systems materials will be noncombustible as defined by ANSI/NFPA 220.

5.5.2.5 Penetrations

Effective sound stopping, vapor, dust, and vermin sealing, and adequate operating clearances will be provided to prevent structure contact where ducts and pipe penetrate walls, floors, or ceilings into occupied spaces.

5.5.2.6 HVAC Air Systems

HVAC air systems design will comply with the Uniform Mechanical Code (UMC) for Hanford and the Standard Mechanical Code (SMC) for Livingston; applicable SMACNA publications, including but not limited to, HVAC Duct Construction Standards - Metal and Flexible; Rectangular Industrial Duct Construction Standards; Round Industrial Duct Construction Standards; Accepted Industry Practice for Industrial Duct Construction; HVAC Systems Duct Design; and HVAC Air Duct Leakage Test Manual.

5.5.2.6.1 Air Handling Units

A. Air handling units will have automatic restart capability in the event of Site power failure.

B. Air handling units will not be mounted on the roof, and other roof penetrations will be avoided.

C. Refrigerant coils will not be used in cleanroom system, since CFC is a contaminant itself.

5.5.2.6.2 Ductwork

Ductwork (See Section 5.1.8) will conform to the following requirements:

A. Duct system will be capable of withstanding static pressure variation +10%, and without pulsating.

B. Fire dampers will be provided at duct penetrations through fire rated walls, ceilings, and partitions.

5.5.2.6.3 Air Filters

A. All filters will be fire retardent type, nonallergenic, and nontoxic, with no detectable odors.

B. Dry filter gaskets will be closed-cell foamed neoprene or urethane elastomer of sufficient hardness to compress not more than 40 percent of original thickness when the filter is in position.

C. High-Efficiency Particulate Air (HEPA) Filter:

    1. HEPA filters will be capable of withstanding minimum 90% relative humidity determined dynamically between 70 and 100 degrees.

2. HEPA filters will bear numbered Underwriter's Laboratories label certifying the filter is UL 586 classified.

3. HEPA filters will provide, as a minimum, a 99.97% overall efficiency on 0.3 micron particles.

4. Dioctylphalate (DOP) tested HEPA filters are not acceptable. DOP mist is a contaminant.

5.5.2.6.4 Humidifiers

A. Humidifiers may be electric, evaporative, or clean steam.

B. Electric and evaporative humidifiers will utilize reverse osmosis water as water source.

C. Electrode/jug type humidifiers are not acceptable.

5.5.2.7 HVAC Hydronic Systems

5.5.2.7.1 Chillers

A. In general, each chiller will be a complete, factory tested, water chilling package consisting of compressors, capacity control system, water cooler, refrigerant condenser, starters, disconnect switch, and steel base.

B. Chillers will be rated in accordance with ARI 540.

C. Chillers will comply with the ASME Code, Section VIII.

D. Control panels will be provided integral to the chiller unit.

E. Control panels will have the capability to interface with the HVAC and Control System (See Section 5.5.6.2).

F. The chillers will operate smoothly within the 15% to 100% capacity range without surge or vibration.

G. The chillers will have an automatic restart capability in the event of Site power failure.

5.5.2.7.1.1 Chlorofluorocarbon Limitation

A. The contractor will supply the most cost-effective chiller type using an acceptable alternate refrigerant (No CFCs) as allowed by the Clean Air Act.

B. Comply with the refrigeration equipment room requirements specified in ASHRAE Standard 15-1992, and safety classification of refrigerants based on ASHRAE Standard 34-1992.

C. No refrigerant will be present inside the clean air flow stream, by design, single point failure, or accident.

5.5.2.7.1.2 Condensers

A. Air- cooled condensers will be used.

5.5.2.7.2 Electric Heaters

A. Electric heaters shall be sheathed type.

B. Heaters shall be UL listed.

C. Heaters shall be provided with all necessary safety devices.

D. Heaters shall be Silicon Control Rectifier (SCR) controlled (i.e., modulating type control).

5.5.2.7.3 Water Treatment

A. A Reverse Osmosis (RO) water treatment system will be furnished to provide a source of water for humidification.

B. Chilled water will be treated for closed system application. Chilled water will utilize glycol mixture to avoid freezing in winter.

5.5.2.7.4 Pumps

A. Pump will be capable of accommodating static pressure variations of plus or minus 10%.

B. Pumps will have an automatic restart capability in the event of Site power failure.

5.5.2.7.5 Chilled Water

A. Piping 4" and smaller will be copper ASTM/ANSI B88, hard drawn, Type K (underground and exposed use) and Type L (aboveground and concealed use).

B. Copper fittings will comply with ANSI/ASME B16.29; joints, ANSI/ASTM B32, solder grade 95TA.

C. Route piping parallel with building lines with branch runs extended from the top of the mains and with pipe transitions in the eccentric to avoid cavitation and facilitate venting of air.

D. Provide vents at high points and drains at low points.

E. Provide unions or flanges at equipment connections to facilitate removal and maintenance.

5.5.2.7.6 Valves

A. Valves will be angle, ball, check, gate, globe, and automatic or manual balancing types.

1. Valves will have rising stems and open when turned counterclockwise.

2. Provide valves to permit isolation of branch piping and each equipment item to permit balancing of the system.

3. All valves 2" or smaller will be ball valves.

B. As a minimum, manual and control valves will conform to the following:

1. Bronze Gate, Check: MSS SP80

2. Cast Iron Gate: MSS SP70

3. Butterfly: MSS SP67, ASTM A126, and ANSI B16.1

4. Ball: FED-STD WW-V-35 or MSS SP72, Class 150, flanged

5. Cast Iron Check: MIL-V-18436, Class 125

6. Globe and Angle: MSS SP80

7. Standard Check: MSS SP80 or ASTM A126

8. Non-Slam Check: ASTM A278

C. Control valve actuators will conform to the following:

1. Will be electric, pneumatic (large actuators only) or electronic for Direct Digital Control.

2. Will have a feature that allows conversion to accept new controller output signal without having to replace the motor actuator.

3. Valve actuators will be industrial grade, spring return, or non-spring return type.

D. Balance valve will be a circuit setter or an automatic balancing device such as variable orifice, precisely calibrated, and able to preset, balance and meter the flow and will have the following:

1. Positive cutoff.

2. Flow memory.

3. Readout ports.

4. Vent connection.

5.5.2.7.7 Pipe Supporting Elements

With the exception that C-clamps will not be used, supporting elements will comply with the requirements of ANSI/ASME B31.1, ANSI/MSS SP-58, and MSS SP-69.

5.5.3 Industrial Grade Piping Systems

5.5.3.1 Clean Dry Air

A. Provide clean dry and oil free compressed air at a nominal pressure of 125 psig.

B. Air will be filtered and regulated to achieve the cleanliness requirements of the room supplied.

C. Clean dry air capacity will be 50 SCFM at 100 psig air pressure at point of delivery.

5.5.3.1.1 Air Compressor

A. Use a central compressed air system to serve multiple points of use.

B. Provide centrifugal or rotary helical screw type, air-cooled.

C. Air compressor will be an oil free type, 125 psig operating pressure, complete with air receiver, ASME code rated and stamped for 300 lb. test, air filter and after-cooler.

D. Comply with standards of Compressed Air and Gas Institute (CAGI).

E. Air compressors will have an automatic restart capability in the event of Site power failure.

F. The air receiver will be able to supply the air requirements for a minimum of 4 hours in the event of power failure (control/instrument air only).

5.5.3.1.2 Air Dryer

The air dryer will be a refrigeration type capable of maintaining air at 35°F to 39°F pressure dew point.

5.5.3.1.3 Compressed Air Piping for Facility Use

A. Compressed air piping will be copper ASTM B88, hard drawn fittings to comply with ANSI/ASME B16.29; joints, solder grade 95TA.

   1. Piping will be oxy-clean per CGA 4.1 or cleaned in accordance with ASTM B280 as required by application.

   2. Cleaned tubing will be capped and pressurized with nitrogen, in accordance with CGA 4.1.

B. For piping above grade use type "L" copper, and for below grade use type "K".

5.5.4 Plumbing Systems

5.5.4.1 Potable Water

5.5.4.1.1 Flushing Water

A. Within the LVEA provide a potable water connection (standard 3/4 inch hose bib) to supply 5 gpm (min.) at 50 psig (max.).

B. Provide a potable water connection (standard 3/4 inch hose bib) in a wash down area outside the LVEA adjacent to the exterior door to supply 5 gpm (min.) at 50 psig (max.).

5.5.4.1.2 Backflow Prevention Devices

A. Provide backflow prevention device to prevent contamination of potable water supply system.

B. Backflow preventer will be a reduced pressure principle backflow type in accordance with UPC, Section 1003 general requirements; ASSE 1013-1971.

C. Provide domestic cold and hot water to all rest rooms.

5.5.4.2 Drains and Vents

5.5.4.2.1 Floor Drains

A. Provide floor drains with traps.

B. Provide automatic trap priming device except for drains in the Beam Tube Enclosure. These traps will be manually primed and provided with screens to prevent intrusion of insect or animals.

C. All required water drains will be routed to an appropriate waste collection system, as required by Local directives.

D. Provide drainage for all rest rooms.

5.5.4.2.2 Plumbing Materials

Select materials based on water quality that conform the minimum requirement in UPC.

5.5.4.2.3 Eyewash and Showers Equipment

A. Eyewash/showers will be a combination type single head emergency shower and eyewash.

    1. Number of installations will be based upon the number of people and the size of the hazardous area.

    2. Use materials that will resist corrosion.

    3. Provide emergency sign, hand and foot control.

B. Design supply line using a minimum water pressure of 30 psi or an acceptable portable system.

C. Eyewash/showers will comply with ANSI Z358.1.

D. Eyewash/showers required will be placed outside of the cleanroom, adjacent to emergency exits.

5.5.5 Fire Suppression and Detection Systems

The design, installation and testing of the Wet Standpipes and Hose System will be in accordance with NFPA 14

All fire alarm, detection, and fire suppression systems will be interconnected, and monitored by central fire reporting systems in accordance with NFPA Standard. Fire suppression systems for Facility Control Room, Computer Users Room, Diagnostics Support Room, and Computer Mass Storage Room will be suitable for use with computers and other electronics.

Hand held fire extinguishers are placed in all buildings and rooms in accordance with NFPA 10.

5.5.6 Facility Monitoring and Control Systems

The status of all fans, pumps, hoists, vents, dampers and other Facility equipment which can produce vibration, acoustic noise, or electrical interference is sensed, reported to the Facility Monitoring and Control Systems (FMCS) and updated periodically. This allows operators to track possible instrumentation interference problems to specific pieces of Facility equipment, even if that equipment is activated autonomously or intermittently.

Data reported to the FMCS will be stored for subsequent reporting. Reports will include a log of all duty cycles of all connected equipment. As a minimum, the duty cycle data will include when equipment starts or stops time (minimum of 1 second accuracy), and any out of tolerance performance (e.g., excess vibration, voltage fluctuations, low flow rate, etc.). See Section 5.10 for a matrix showing Facility Monitoring and Control Nodes.

5.5.6.1 Control System Design

A. The sequence of operation will be presented clearly and concisely.

B. Each mode of operation will specify operating ranges, valve and damper positions (fail open or closed) for the following functions:

1. Heating
2. Humidification
3. Dehumidification

4. Cooling
5. Economizer

5.5.6.2 HVAC Control and Monitoring System

5.5.6.2.1 Control Devices

A. Provide all sensor/transmitter control devices as a completely assembled unit, manufactured and assembled by one supplier, with calibration traceable to National Institute of Standards and Technology (NIST, formally NBS) standards.

B. Sensor/transmitter assemblies will be factory assembled, calibrated, and shipped as a single entity.

C. Assembly will be compatible with the HVAC control and monitoring system.

   1. All control devices will be selected for minimum accuracy of 1% except temperature and dew point sensors will have a minimum accuracy of 0.5% over the control range.
   2. Components will be specified with regards to functional attributes and not solely on manufacturer model numbers.
   3. Controls will be housed in enclosures that are ventilated and will be mounted indoors in an air conditioned environment.

5.5.6.2.2 Operator Interfaces

Operator interface will be provided for status monitoring from the Facility Control Room which provide on line operator interaction, supervision, coordination and control.

5.5.6.2.3 Control Points

A. The system will control all significant points of the central chiller and boiler plant and the air handling systems.

B. The system will interface with the environmental control and monitoring system.

C. The monitor and control points for the HVAC system will include, but not be limited to the following.

   1. Temperature (local and remote)
   2. Humidity (local and remote)
   3. Flow-rate (Air and Hydronic Systems)
   4. Pressure
   5. Remote start/stop status, and run time
   6. Filter differential pressure indication

7. Dew-point monitoring
8. System on-off operation (local and remote)
9. Changeover control
10. Vapor detection status
11. All necessary boiler, chiller, pump, condenser and damper controls (status, run time, and operation selection)

5.5.6.3 Particulate Monitoring System

A. Provide a particulate monitoring system for the Class 5,000 Cleanroom, using optical counter technology of either a manifold, multiplexing type or an individual sample point type. Use a particulate monitoring system that is in accordance with IES recommended practices and procedures, FED-STD-209 and ASTM F50 and F328.

1. Maximum time for collection of the 20 sample point particles shall be less than 5 minutes.
2. Acceptable sample flow rates shall be within the range of 0.1 cfm to 1 cfm with statistical analysis and standard deviation features based on FED-STD-209.

B. Provide output for communication with a remote monitoring workstation in the Control Room.

1. Workstation shall have color monitor and graphics capability for real-time monitoring and trend analysis capabilities.
2. Provide long term data storage in 15 minute time intervals for a 24 hour time period, full reporting features including alarms and conditions, and statistical analysis features based on FED-STD-209.
3. Provide multilevel password protection for system access.

5.5.7 Cranes

5.5.7.1 General Crane Requirements

A. Electric bridge cranes are required in LVEA of the Corner Station, the VEA of the End Stations at both Sites, and the Mid Station at the Hanford Site.

B. Cranes will comply with the applicable requirements of CMAA, ASME HST M4, ANSI B30.2, B30.10, NEC Article 610, and AWS D14.1.

C. Cranes will operate in a non-hazardous environment.

D. Cranes will have a 20 year design life based on CMAA class "C" service.

E. The cranes hoist will be electric wire rope type and will conform to the requirements of ASME HST M4.

F. Operation of the cranes will be monitored by the Facility Monitoring and Control System (see Section 5.5.6).

5.5.7.2 Crane Capacity

The LVEA cranes will have a rated capacity of 2 tons for all low-bay cranes (Areas 2 through 5) and 10 ton for the high-bay crane (Area 1). The Mid and End Stations at both Sites, each will also include a 10 ton capacity crane. The Mid-Point Pumping Station at the Livingston Site does not require a crane.

5.5.7.3 Lift Height at the Corner Station

The hook height for the low-bay cranes is 23 feet, and for the high-bay crane is 41 feet and 8 inches.

5.5.7.4 Lift Height at the Mid and End Stations

The hook height for Mid and End Stations is 41 feet and 8 inches.

5.5.7.5 Crane Electrification

Crane electrification will be by the means of festooning. For EMI requirements refer to Section 5.6.15.

5.5.7.6 Hoist Reeving and Wire Rope System

A. The hoists will have a double reeving and will have a true vertical lift capability.

B. The ropes for the hoists will consist of one right and left regular lay and will be sized for a minimum of 5:1 safety factor.

5.5.7.7 Hoist Brakes

The hoists will be equipped with double braking system. Emergency holding brake will be applied automatically when power to the brakes are removed.

5.5.7.8 Crane Drives

A. Hoist:

1. Drives will have a variable speed to maximum 25 fpm with creep mode capability.

2. Hoist drive will include "soft" start and stop feature.

B. Trolley and Bridge:

1. Drives will have a double speed, with traveling speed of 20 and 80 feet per minute and with inching capability.

5.5.7.9 Crane Control

The cranes will be operated by a pendant control station suspended from the bridge. An emergency stop button will be incorporated in the pendant which will set all brakes and stop all crane motion when depressed.

5.5.7.10 Drip Pans

All cranes will be provided with stainless steel drip pans installed under motors, gear boxes, hoist drums, and other components where leakage of grease, oil, or other contaminants could occur. Drip pans will be designed to permit easy removal of collected lubricant.

5.5.7.11 Manual Load Lowering Capability

The crane hoist will have an emergency load lowering capability such that in the event of a power failure or any other equipment failure, the crane operator has the capability of manually lowering any load up to the rated capacity from any hook height.

5.5.7.12 Special Requirements

A. A visual warning device will be provided on the crane to caution the personnel when either the trolley or the bridge is in motion

B. An overload sensor and alarm light will be provided to halt the hoisting operation and alarm the operator when the load exceeds the preset maximum.

5.6 Electrical

5.6.1 Area Classification

There are no areas in this Facility that are defined by the NFPA as "Hazardous Locations". The contents and processes used in this Facility do not necessitate using equipment or installation practices suitable for hazardous locations.

5.6.2 Electrical System Description

The electrical system receives power from the local servicing utility, or a Rural Electrification Administration (REA) affiliate, depending on the Site location. The power will be brought onto the Site, and will be continued to the electrical primary switchgear by underground cable. The power is distributed through a 13.8kV outdoor metal-enclosed switchgear to the various loads. The power for the Corner Station is transformed by a single transformer from the utility voltage (13.8kV) to 480Y/277V for distribution to the major power using centers of the building. The power system on the LIGO Sites will be laid-out in a simple non-redundant radial topology, with the main substation at the vertex of the radials. The Mid and End Stations of each leg will be on the same radial, each having a pad-mounted transformer. At this time, there is only one source of electrical supply at the LIGO Sites, however, the primary switchgear will be equipped to handle a redundant utility feed circuit.

The power is transformed from 13.8kV to 480Y/277 V, 3- phase and 208Y/120 V, 3- phase near the points of use. The nominal frequency of the power shall be 60 Hz. Grounding and circuit neutrals will be in accordance with accepted industry practice and NEC. The Mid and End Stations will be fed from single 3- phase transformers, that constitute a single point of failure. A spare transformer could be available to rapidly restore power should one of these transformers fail in service. This spare transformer could be warehoused on-site or could be available from the serving electrical utility, depending on the service agreements made between the User and the Utility.

The Facility Monitoring and Control Systems (FMCS), will be fed from highly reliable UPS units located near the points-of-use.

5.6.3 Electrical Equipment

A. Electrical equipment shall be designed in accordance with ANSI C2 and NFPA 70 (NEC).

B. Motors: Fractional and integral horsepower motors shall conform to NEC code letter G or better, NEMA MG1, UL, and NEC, continuous duty induction type. Motors shall meet or exceed nominal full-load efficiency of 91%.

C. Electrical equipment that contains electronic devices or sub-assemblies shall be able to meet the electro-magnetic interference (EMI) emission limits expressed in FCC Rule 15 subpart J, Class A.

D. Transient voltage suppression devices or equipment that provides transient suppression shall comply with UL 1449 requirements.

E. Electrical equipment and circuits shall be located in the Facility so as to minimize influences upon the LIGO experiment and data handling equipment.

5.6.4 Receptacles

Receptacles fed from appropriate voltage and current circuits will be installed throughout the Facility. The locations, voltage, current and plug type will be coordinated with the users. Receptacles in office areas shall be distributed with a minimum of one duplex receptacle on each wall, with spacing not to exceed 12 feet on center, unless otherwise indicated. Receptacles for portable lighting and small electrically powered tools will be provided around the perimeter of the LVEA and other work areas.

5.6.5 Lighting

5.6.5.1 Illumination

Illumination levels shall be as specified in this paragraph for each occupancy type. Lighting instruments and fixtures shall be distributed and arranged to reduce glare and spectral reflection.

Occupancy	Illumination Level [fc]
General Offices	50
Workrooms	50
Corridors	25
Storage Areas	10
Laser and Vacuum Equipment Area	5[1]
Cleanroom and Inspection Areas	100
Mechanical Equipment Rooms	25

Table 5.6-1 -- Illumination Levels

A. Illumination levels shall be measured at 30 inches above finish floor (AFF) unless otherwise specified.

B. Interior lighting color shall have a Color Rendering Index (CRI) of 75 or greater as rated per the Illuminating Engineers Society of North America (IESNA) Handbook.

C. Lamp selection shall be based on current industry standards for power efficiency ratings.

D. Lighting fixtures will be selected with a criteria that factors lumen efficiency, beam control, cleanliness, acoustic noise, and EMI shielding performance.

E. Low Pressure Sodium (LPS) lighting shall not be used. High Pressure Sodium (HPS) lamps with a CRI greater that 60 will be used outdoors.

[1] Normal Operations at a minimum of 5 foot-candles. Portable work lights will be provided for operations that require more illumination.

F. Areas that are furnished with lamps exhibiting non-instant-on operating characteristics shall include auxiliary lamps that provide reduced illumination levels during the period that the main lamp achieves full brightness.

G. Lamps may be energized with direct current when EMI and experimental equipment considerations dictate.

5.6.5.2 Controls

A. Lighting controls for office and corridor type spaces shall be local, unless otherwise specified, and adjustable to provide approximately 1/3, 2/3, and full illumination levels.

B. Lighting circuits in the LVEA, Mid and End Stations will be remotely controllable via the Facilities Monitoring and Control and System (FMCS). The remote controlled circuits will use contactor panels or Square-D PowerLink (or similar) remote actuating circuit breakers as appropriate.

C. Lighting controls for closets and for spaces under 100 square feet shall provide one level of lighting only.

5.6.5.3 Emergency Lighting

Self-contained (battery pack) emergency lighting in accordance with OSHA Standards and NEC Article 700 shall be used in all occupied areas. There are no plans to have on-site power generation due to the vibrations emanating from a reciprocating internal combustion engine.

5.6.6 Crane

The LVEA crane electrical power, controls, and readout systems shall meet the requirements of the clean environment. The LVEA is classified as non-hazardous. The power electronics in the crane drives shall not introduce EMI into the LVEA.

5.6.7 Electrical Power Characteristics

The estimated power requirements for the scientific equipment is outlined in the following preliminary load summary:

Equipment	Peak[2] (kW)	Average[3] (kW)
Beam tube rough vacuum pumping	200[4]	-
Chamber rough vacuum pumping	33[4]	1
Ion vacuum pumps (during first year of operation)	6	-
Ion vacuum pump (Site fully operational)	-	1
Electronic equipment	200	100
Shop and service equipment	60	28
Chamber bakeout heaters	80[4]	-
Lasers (including cooling)	120[4]	120

Table 5.6-2 -- Electrical Power Demands

Electrical power shall be provided by two distinct systems (i.e., Facility, and Technical Power Supply). Large motor loads such as air-handling equipment and vacuum roughing pumps and lighting will be fed from the facilities power network. Sensitive electronic equipment will be fed from a technical power network. The two networks differ by the amount of electrical isolation and transient voltage suppression that is provided.

5.6.7.1 Facility Power

Facility electrical power characteristics shall be in accordance with ANSI C84.1-1982 and ANSI/IEEE Std. 141-1986, and shall meet the following minimum requirements:

Parameter	Range
120 volts nominal	108 to 132V (±10%)
480 volts nominal	432 to 528V (±10%)
Voltage Harmonic Content	5% Total Harmonic Distortion (THD)
Frequency	60 Hz ±1 Hz

Table 5.6-3 -- Facility Power Characteristics

Transients shall not exceed +10% of the specified voltage for a duration not exceeding 200 microseconds.

2 Short term peak (e.g., motor starting) transients excluded.
3 Average power consumption after startup of operations.
4 Will not operate simultaneously.

5.6.7.2 Technical Power

A. Technical electrical power will be derived from the Facility Power network.

B. Technical power shall be available to furnish sensitive electronic equipment directly related to the LIGO experiment.

C. Technical power feeders shall be isolated from Facility power feeders by using ultra-isolator transformers and transient voltage surge suppressors at the power distribution panels.

D. Technical power shall not be common with any other Facility loads that are 480V or lower.

E. The power quality of the technical power system shall meet the performance levels indicated in FIBS PUB 94 and shall meet the following minimum requirements.

Parameter	Range
120 volts nominal	110 to 125V (+4%, -8%)
480 volts nominal	440 to 500V (+4%, -8%)
Voltage Harmonic Content	5% THD for nonlinear loads
Frequency	60 Hz ±1 Hz

Table 5.6-4 -- Technical Power Characteristics

5.6.7.3 Uninterruptible Power Supply Power

The Uninterruptible Power Supply (UPS) power equipment shall meet the following requirements.

Parameter	Range
RF Emissions	In accordance with FCC Part 15, Subpart J, Class A
Common Mode NRR	-120 db up to 100kHz
Voltage Harmonic Content	5% THD
Transverse Mode NRR	-60 dB up to 100khz
Surge Protection	IEEE 587/ANSI C62,41 Category B
Acoustical Noise	Less than 50 dBA at one meter distance
Total Harmonic Distortion	5% for nonlinear loads
Voltage Regulation	±2%
Frequency	60 Hz ±1 Hz

Table 5.6-5 -- UPS Power Characteristics

5.6.7.4 Backup Power

There is no requirement to provide backup power for this Facility. Safe shutdown power for the Facility Monitoring and Control System (FMCS) shall be provided by a UPS located at the Corner Station. UPSs for the Detector System's Control and Data System (CDS), and the Vacuum Equipment System's Monitor and Control System (MCS) are specified and provided by Others.

5.6.7.5 Power Distribution System

A. 25% spare capacity shall be provided throughout the Facility and Technical Power distribution systems.

B. Power distribution panels and equipment will be clearly identified.

C. Power distribution diagrams and circuit schedules of the distribution panels will be provided.

D. Lighting and receptacle circuits will be switched by local wall-mounted toggle switches and remotely-actuated contactors or circuit breakers, as appropriate.

5.6.7.5.1 Electric Outlet Reference Designator

A unique identification designator shall be printed and affixed near each electrical outlet to identify the circuit breaker panel, circuit breaker designator and voltage.

5.6.7.5.2 Circuit Breaker Reference Designator

A unique identification designator shall be printed and affixed near each circuit breaker correlating with the outlet reference designator.

5.6.8 Materials

A. Copper conductors, buses and transformer winding shall be used throughout the electrical system, except the 13.8kV circuits and switchgear will use aluminum conductors

B. All air plenum and cable chase cables shall be shielded, and rated as air plenum type.

C. Plastic insulated and jacketed cables shall be in conformance with NFPA and IEEE smoke evolution and flame spread requirements.

D. Polymeric materials shall not introduce Volatile Organic Compounds (VOC)or out-gassing products in the enclosed spaces.

E. Conduits and raceways carrying 480Y/277 V and 208Y/120 V power shall be made of galvanized steel.

5.6.9 Grounding

The LIGO shall have a power equipment grounding system in accordance with NFPA-70 (NEC)

The LIGO grounding system shall consisting of the following subsystems described and detailed in NFPA-70 (NEC) and FIPS-94 and IEEE Std-1100 (Emerald Book). Philosophically, the grounding network can be represented by a "tree" diagram. The bottom of the tree consists of the lightning protection grounds, the major branches of the tree serve the major power consuming loads, and the smaller branches serve the instrumentation systems. Smaller branches in this grounding network are interconnected to their next larger branch at only one point. This philosophy is known as "single-point grounding". The intent of the single point ground is to avoid ground loops and the resulting electrical common-mode noise. Following is a listing of the probable grounding subsystems.

5.6.9.1 Facility Ground Subsystem

The Facility grounding subsystem will provide a "green wire" safety ground in compliance with the National Electrical Code - NFPA 70.

5.6.9.2 Technical Ground Subsystem

The technical ground subsystem will provide a "quiet" ground that is connected to the Facility ground subsystem at one point. Each ground in this subsystem will be connected together with a single connection only to the Facility ground subsystem.

5.6.9.3 Signal Reference Ground Subsystem (Single-Point Ground)

The signal reference ground subsystem is isolated from all other ground circuits and is to provide a "quiet" equi-potential plane for instrument signal reference. This subsystem is connected to the Facility ground at one point.

5.6.9.4 Lightning Protection Subsystem

The lightning protection subsystem forms a girdle around each of the buildings and physically circumscribes all other grounding subsystems. This ground network is to dissipate the charge and current that results from a lightning strike to any of the buildings. This subsystem is represented by the trunk of the "grounding tree".

Note that the Beam Tube Enclosures will not be provided with lightning protection.

5.6.9.5 Equipment Fault Protection Subsystem

This grounding subsystem is part of the Facility ground and is provided in compliance with NFPA 70. This ground system is also referred to as the "green wire" ground.

5.6.9.6 Resistance to Earth

A. The dc resistance to earth from any point of the Grounding System shall be 10 ohms or less.

B. Where 10 ohms cannot be obtained with basic electrode configuration due to high soil resistivity, rock formations, or other terrain features, alternate methods for reducing the resistance to earth shall be considered.

5.6.9.6.1 Facility Ground

The primary power shall be grounded only at the neutral of the transformer in accordance with the NEC.

5.6.9.6.2 Technical Ground

A. The dc resistance between the primary and technical power shall be at least 1 megohm.

B. The various technical power subsystems shall have dc isolation resistance of 1 megohm.

C. All single phase and three phase transformers shall have grounded secondary points in accordance with the NEC.

5.6.9.6.3 Signal Reference Ground

The signal reference shall be designed as a single-point grounding connection point for instruments that are sensitive to ground loops.

5.6.9.6.4 Lightning Protection Grounding

The LIGO lightning protection subsystem shall be designed in accordance with appropriate provisions of NFPA 78, UL 96 and UL 467.

5.6.9.6.5 Grounding Plates

Technical ground plates shall be provided at the Experiment Power and Utility Outlets located in the LVEA. The connections between the ground plates and the grounding cabling shall be bolted, to allow for isolation and testing. These ground plates shall be isolated from the Facility ground with appropriate hardware. The dc resistance between these grounding plates and other grounds shall be 1 megohm or more.

5.6.9.6.5.1 Physical Description

The grounding plates shall be 3/8" (thick) x 2" (wide) x 6" (long) minimum copper bar with six nontapped 3/8" holes.

5.6.9.6.5.2 General Installation

The grounding plates shall be located appropriately to allow movement of equipment in the LVEA. Otherwise they will be mounted 12 inch (min.) above the floor and 4 inch from mounting surfaces on insulating supports or other appropriate devices.

5.6.9.6.5.3 Installation Locations

OSB Cleanroom Area technical and Facility grounding plates shall be provided at workbench locations and spaced at 12 foot intervals (minimum) around the perimeter of the Cleanroom.

5.6.9.6.6 Bonding

All metal-to-metal bonds within the LIGO shall be in accordance with NEC requirements for electrical equipment and devices and ASHRAE recommendations for ductwork and air handling equipment.

5.6.10 Fire Detection System

A Fire Detection System in accordance with NEC Article 760 and NFPA 72E in concert with the Fire Suppression System defined in Section 5.5.5 shall be provided.

5.6.11 Doors and Controls

A. Power shall be provided as required for motorized doors.

B. Door Control Stations shall be adjacent to the door opening and provided on both sides of the wall. Provisions for manual override shall be provided.

C. The ability to lockout the operation of either door control shall be provided.

D. The ability to switch control from either door control station to the other shall be provided.

5.6.12 Optics and Vacuum Preparation and Assembly Labs

These Labs will be provided with power and grounding in accordance with the Utilities Matrix shown as Table 5.9-1.

5.6.12.1 Facility Power

Spacing between receptacles shall not exceed 12 feet on center throughout the OSB Cleanroom perimeter, see Section 5.6.4.

5.6.12.2 Technical Power

Technical power characteristics and isolation shall be per Section 5.6.7.2.

5.6.12.3 Lighting

5.6.12.3.1 Illumination

Average illumination levels shall be per Section 5.6.5.1.

5.6.12.3.2 Lighting Controls

Lighting controls shall be local, unless otherwise specified, and adjustable to provide approximately 1/3, 2/3 and full illumination levels.

5.6.12.4 Particulate Monitoring System

A. Required power and wiring for the Particulate Monitoring System as defined in Section 5.5.6.3 shall be provided.

B. Readout displays shall be located in the 5,000 Class Cleanroom Area with remote display in the Facility Control Room.

5.6.13 Facility Control Room

A. Power in the Facility Control Room shall be technical power.

B. Lighting shall be filtered, and electro-magnetically shielded.

C. Technical ground plates shall be provided.

5.6.14 Beam Tube Enclosures

A. The Beam Tube Enclosures shall be provided with minimal lighting, exit signs, and 120 Vac convenience power receptacles at Service Entrances.

B. Provisions shall be made to feed a nominal 5 kW of electrical power to each Service Entrance which are located at Beam Tube vacuum ports at 780 foot intervals along the Beam Tube length. This 5 kW power is for future vacuum pumps, a CDS rack, and bakeout for the vacuum pump. In addition, a provision for a future additional demand of 10 kW at every other Service Entrance (total of 16 per Site) will be made for possible future additions of dehumidifiers.

C. Beam Tube bake-out power requirements shall be satisfied with portable generators brought in for the occasion. This is done by Others.

D. There are no provisions for general illumination lighting inside the Beam Tube Enclosures. This will be accomplished with portable work lights as required, and provided by LIGO Operations.

5.6.15 Electromagnetic Compatibility (EMC)

LIGO interferometer equipment is sensitive to stray electric magnetic field interference, particularly at radio frequencies. Attention will be paid to stray magnetic loops from power distribution circuits, grounding networks, and EMI from lighting and power supplies and equipment power controllers.

The LIGO shall be designed to achieve EMC within the Facility in accordance with MIL-STD-461D Section 6.3.

Overhead cranes will be designed to reduce RFI emissions from the power feeding circuits and the crane motor drive equipment mounted on the crane bridge structures. Sliding contacts (third-rails) will be not be used to deliver power to the cranes.

5.6.15.1 Perimeter Penetrations

Vents, ducts, louvered openings, pipes, conduit, etc., that penetrate the Facility's perimeter (i.e. exterior walls and roof) will receive the following special treatment to reduce conducted RF signals that may enter the building. Open penetrations will have a length to diameter ratio greater than 7 so that the penetration functions as a waveguide beyond cutoff. Screened or honeycomb vents may be required.

A. Air handling ducts that penetrate the perimeter (roof or exterior walls) will contain non-conductive sections positioned within 6 inches of the inner (secure) side of the wall or roof.

B. Wireways, raceways, and conduit will contain non-conductive sections within 6 inches of the inner (secure) side of a wall and roof. Electrical ground continuity will be maintained.

C. Metal pipe penetrations will be treated with lead wrap foil, 1/8 inch thick for a distance of 12 inches, on the inner (secure) side of a wall or roof.

5.6.16 Communication Systems

The Facility will be served by an internal communications system which may involve a combination of telephones and intercoms. The system will provide sufficient capability to serve the needs of widely dispersed teams working on coordinated installation and integration tasks.

The equipment will consist of:

- Administrative telephones with on- and off-site access
- Public address and area warning system
- Tie-ins to a Local Area Network that serves the entire Facility
- The telephone and data systems will be separated from each other

5.6.16.1 Conduits

A. All communication conduits shall be routed separately from other conduits.

B. Materials shall be galvanized steel, of Intermediate Metallic Conduit Grade or heavier.

C. Conduit and raceway networks shall be bonded and electrically continuous in accordance with NEC.

5.6.16.2 Distribution Boxes

All distribution boxes shall be supplied with a non-conductive, fire-resistant back mounting panel.

5.6.16.3 Fiber Optic Network

A broad-band fiber optic network shall be provided to carry signals of the Facility Monitoring and Control System (FMCS). This fiber optic network shall be isolated from the experiment fiber optic backbone. The fiber optic cable shall connect all Station buildings, Chiller Plants, and provide interfacing with possible future needs along the Beam Tube Enclosures (e.g., every Service Entrance).

5.7 Vibration Isolation

The Facility vibration criteria for the Hanford, Washington Site and the Livingston, Louisiana Site are defined in Appendix C, Special Building Needs, of the LIGO Facility Strawman Design. The LIGO goal is to design and build a completed, operating Facility which does not increase the Power Spectral Density (PSD) plots by more than a factor of two above the natural background. This is to be accomplished over the frequency range from one Hertz to one hundred Hertz, measured at the foundation for the Laser Vacuum Equipment Areas (LVEA). Exceptions may be allowed over narrow frequency bands, to permit specific operating equipment to exceed these levels caused by a spike in the foundation PSD at the operating frequency of specific equipment.

As a result of the cost of the initial conceptual design shown in the Facility 90% Concept Design Report, the Facility has been redefined on the basis of limiting the initial cost of the Facility. Therefore, during the next design phase of the project scheduled to start in late July, 1995, detailed vibration evaluations will be made using the modified conceptual design to confirm foundation performance. Due to the reduction in foundation size and thickness, as well as the relocation of the chiller equipment closer to the LVEA foundations it may not be possible to satisfy "two times ambient" PSD criteria. Furthermore, additional limits on the spike frequency requirements have been proposed that appear to be very restrictive and exceed spike amplitudes measured at another laser site at the 60 Hz frequency. The analytical estimates of the vibration levels of the current Facility concept will be used to determine if the cost-based Facility design performance is close enough to the proposed criteria to be acceptable. This implies that the current vibration criteria is no longer a requirement but rather a goal that will be used to evaluate various cost effective design options.

The preliminary estimate of the ambient PSD spectra for the Hanford, Washington Site and for the Livingston, Louisiana Site is shown below. The following graph shows estimates of the displacement power spectral density in $m/\sqrt{Hz}$ of the ground at the Livingston and Hanford Sites before construction.

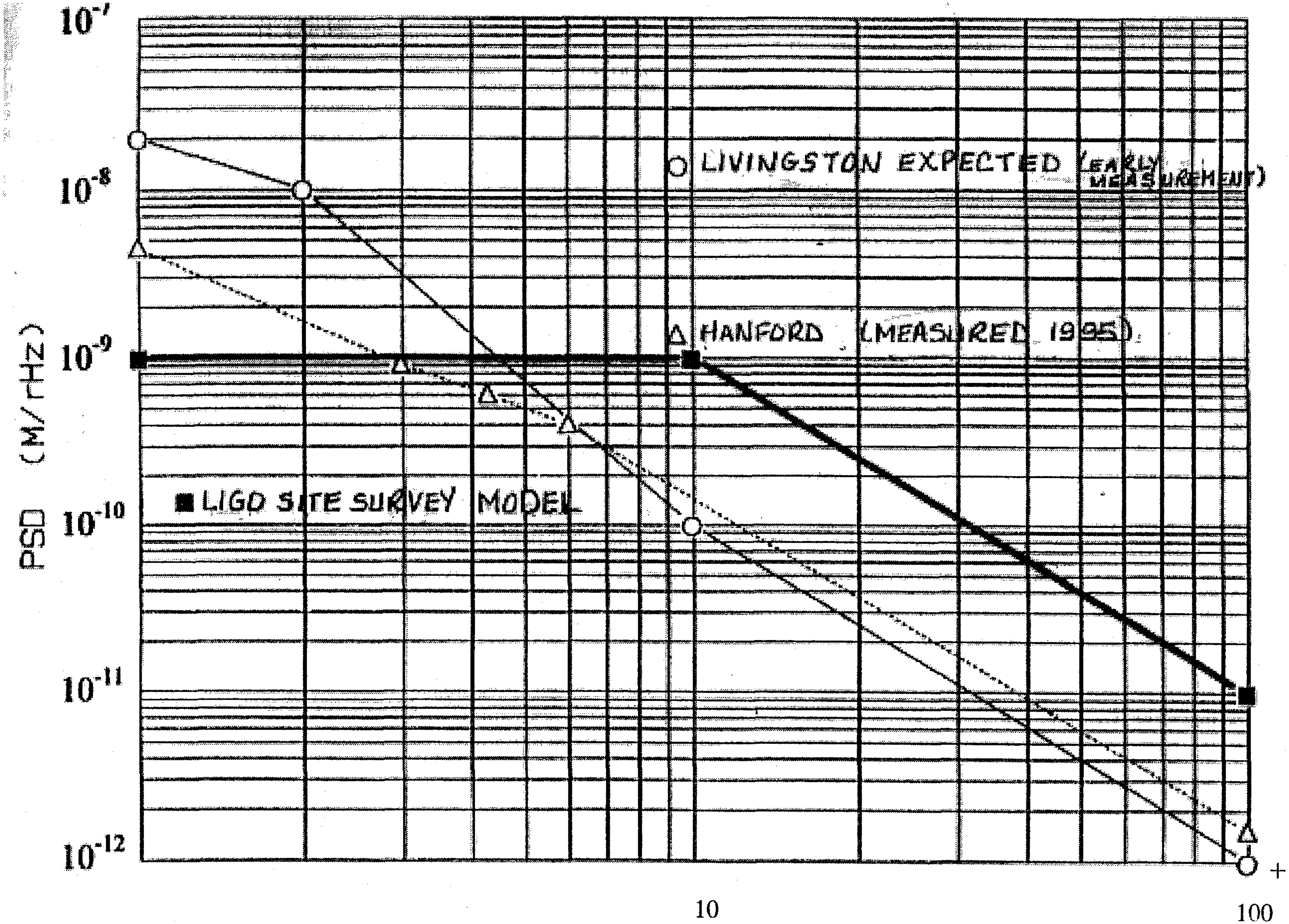

Figure 5.7-1 -- Ambient PSD Predictions

5.8 Acoustics

5.8.1 Laser Facility and End Stations Background Noise

The acoustic background level due to mechanical equipment associated with the building Facility will be limited to a PNC 40 (Preferred Noise Criterion) between 8 Hz to 10 Khz. The main concern is minimizing acoustic noise in the frequency band below 100 Hz.

5.8.2 Offices Space Background Noise

Office space background noise environment will be designed to a PNC 35.

5.8.3 Reverberation Times

In order to control reverberant noise the LVEA and Vacuum Equipment Areas at the Mid and End Stations will be designed to a reverberation time of no more than 2.5 ±0.2 seconds at the mid-frequencies (500 and 1,000 Hz.).

5.8.4 Exterior to Interior Noise Control

Exterior to interior noise reduction will be approximately 50 dB at the mid-frequencies. This will be designed for a source located on the ground outside the Facility such as a heavy truck as measured in the LVEA and Vacuum Equipment Areas at the Mid and End Stations.

The design will not include control of rain-generated noise.

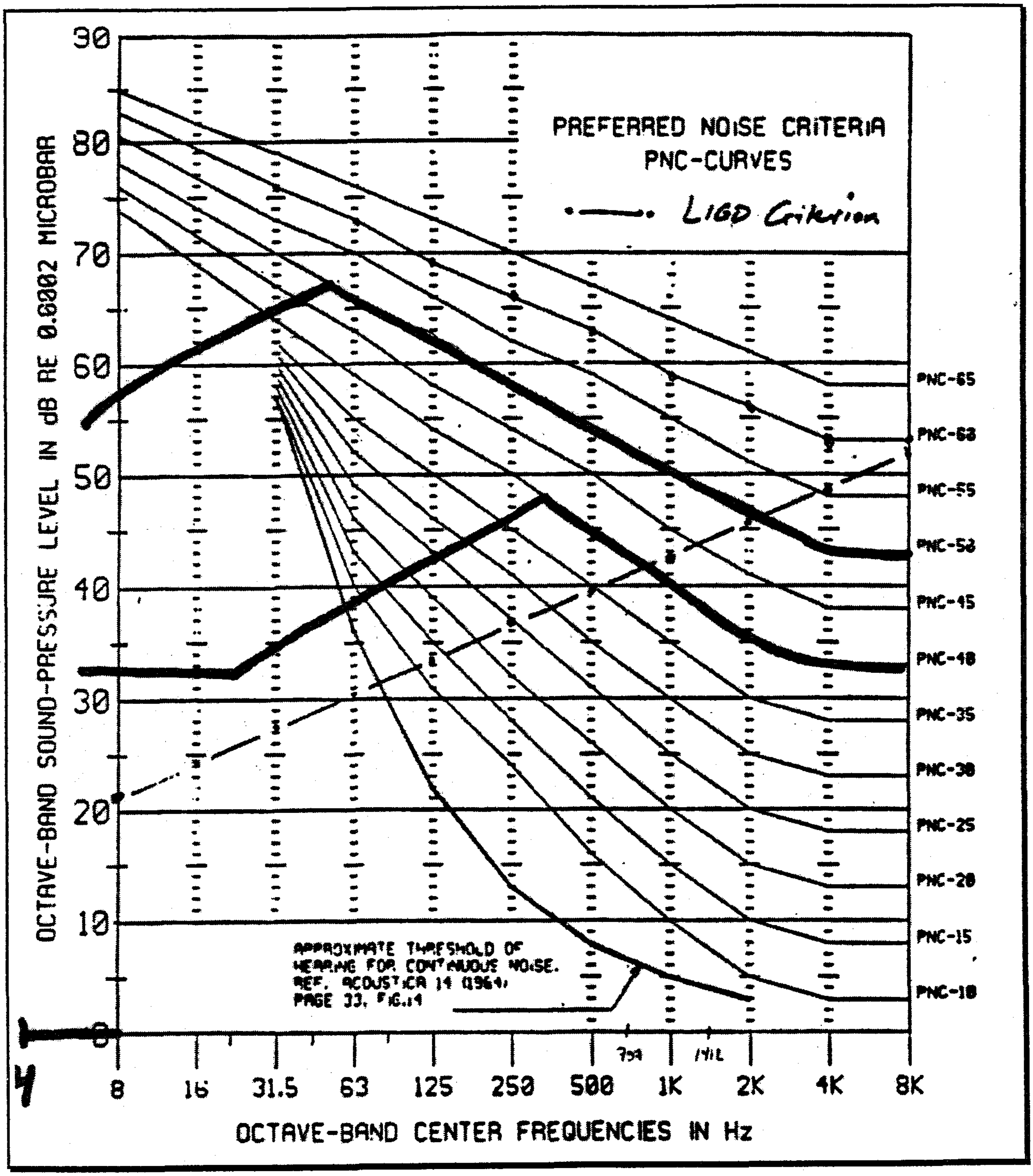

Figure 5.8-1 -- PNC Curves -- LIGO Criteria

5.9 Utility Matrix

The following matrix (Table 5.9-1) illustrates the types of Facility supplied utilities that are to be provided for each area listed in the left hand column. An indication of "*F*" means this utility may be added in the *future*.

Notes:
208 = 3 Phase, 208/120 V
480 = 3 Phase, 480/277 V
120 = 1 Phase, 120 V

		Electrical							Comm.					Mechanical																	Handling	
Space/Area #	**Space/Area Name**	*Facility Power*	*Technical Power*	*UPS*	*Lightning Grnd*	*Instrumentation Grnd*	*Technical Grnd*	*Facility Grnd.*	*Ethernet/LAN*	*Telephone*	*Wireless Transceiver*	*Public Address System*	*Closed Circuit Video*	*Potable Water*	*Sewage*	*Drainage*	*Clean/Dry Instrument Air*	*Shop Air*	*Nitrogen Gas*	*Dionized Water*	*Propane*	*Exhaust Vents/Hoods*	*Clean Air Supply*	*Positive Pressure (inches w.g.)*	*Hose Bibs -- Washdown*	*Cleaning Vacuum Ports*	*Fire Extinguishers*	*Gaseous Fire Suppression*	*Fire Detection & Alarm*	*Particulate Monitoring*	*Bridge Cranes*	*Mono Rails*
Corner Station	***Provided Throughout UON*** ▶	*120*			*X*			*X*		*X*	*X*	*X*	*X*		*X*												*X*		*X*			
L-101	Laser and Vacuum Equipment Area	208	X			X	X		X					X		X	X							0.15		X					X	
L-102	Mechanical/Utilities Equipment Room	208 & 480							X					X		X	X	X				X			X							
O-101	Lobby/Reception Area								X					X		X																
O-102	Site Manager's Office								X																							
O-103	Site Director's Office								X																							
O-104	Administrative Assistant's Office								X																							
O-105	Conference Room								X																							
O-106	Copy/Fax/Storage																															
O-107	Lounge/Kitchen/First-Aid																															
O-108	Staff Offices								X																							
O-109	Resident Scientists								X																							
O-110	Facility Control Room		X	X			X		X								X							0.05				X				
O-111	Diagnostics Area		X				X		X								X							0.05				X				
O-112	Computer Users Area		X				X		X								X							0.05				X				
O-113	Computer & Mass Storage Room		X				X		X								X							0.05				X				
O-114	Inspection Area / Receiving & Shipping	208	X			X			X					X		X	X	X														
O-115	Tape Room																							0.05								
O-116	Cleaning Area													X		X	X							0.10								
O-117	Vacuum Prep & Assembly Area	208 & 480	X			X	X		X					X		X	X		X	X		X	X	0.15		X				X		
O-118	Optics Lab	208 & 480	X			X								X		X	X					X	X	0.15		X				X		
O-119	Electronics Test & Maintenance Shop	208 & 480	X			X	X		X					X		X	X		X			X		0.05						X		
O-120	Mechanical Shop	208 & 480												X		X	X	X				X										
O-121	Change Room													X		X								0.05								
O-122	Active Storage																															
O-123	Long Term Storage																															

Table 5.9-1 -- Utility Matrix

Notes:
208 = 3 Phase, 208/120 V
480 = 3 Phase, 480/277 V
120 = 1 Phase, 120 V

		Electrical							Comm.					Mechanical																Han
Space/Area #	Space/Area Name	Facility Power	Technical Power	UPS	Lightning Grnd	Instrumentation Grnd	Technical Grnd	Facility Grnd.	Ethernet/LAN	Telephone	Wireless Transceiver	Public Address System	Closed Circuit Video	Potable Water	Sewage	Drainage	Clean/Dry Instrument Air	Shop Air	Nitrogen Gas	Dionized Water	Propane	Exhaust Vents/Hoods	Clean Air Supply	Positive Pressure (inches w.g.)	Hose Bibs -- Washdown	Cleaning Vacuum Ports	Fire Extinguishers	Gaseous Fire Suppression	Fire Detection & Alarm	Particulate Monitoring	Bridge Cranes
Mid Station (End Station Similar)	***Provided Throughout UON*** →	***120***			*X*			*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*											*X*		*X*		
M-100	Vacuum Equipment Area	208	X			X	X										X							0.15		X					X
M-101	Mechanical/Utilities Equipment Room	208															X					X			X						
M-102	Inspection Area / Receiving & Shipping	208	X			X											X	X													
M-103	Cleaning Area																X							0.10							
M-104	Experiment Equipment Area	208 & 480	X			X	X										X		X			X		0.10							
M-105	Change Room																							0.05							
Beam Tube Enclosure		208						X	X	F							X					F		F			X		F		
Chiller Plants (5 Locations)		208 & 480			X			X	X	X	X			X		X						X			X		X		X		

Table 5.9-1 (Cont'd) -- Utility Matrix

5.10 Facility Monitoring and Control Nodes

The table which Facility supplied utilities are to be monitored and/or controlled by the Facility Monitoring and Control System. An indication of "*F*" means this utility may be added in the *future*.

		Electrical							Comm.					Mechanical												Handling	
Space/Area #	**Space/Area Name**	*Facility Power*	*Technical Power*	*UPS*	*Lightning Grnd*	*Instrumentation Grnd*	*Technical Grnd*	*Facility Grnd.*	*Ethernet/LAN*	*Telephone*	*Wireless Transceiver*	*Public Address System*	*Closed Circuit Video*	*Chillers*	*Air Handling Units*	*Personnel Doors*	*Large Access Doors*	*Clean/Dry Instrument Air*	*Exhaust Vents*	*Clean Air Supply*	*Positive Pressure*	*Cleaning Vacuum Ports*	*Gaseous Fire Suppression*	*Fire Detection & Alarm*	*Particulate Monitoring*	*Bridge Cranes*	*Mono Rails*
Corner Station	***Provided Throughout UON*** ▶	*X*							*X*				*X*					*X*						*X*			
L-101	Laser and Vacuum Equipment Area		X													X	X			X	X					X	
L-102	Mechanical/Utilities Equipment Room														X				X								
O-101	Lobby/Reception Area																										
O-102	Site Manager's Office																										
O-103	Site Director's Office																										
O-104	Administrative Assistant's Office																										
O-105	Conference Room																										
O-106	Copy/Fax/Storage																										
O-107	Lounge/Kitchen/First-Aid																										
O-108	Staff Offices																										
O-109	Resident Scientists																										
O-110	Control Room		X	X												X							X	X			
O-111	Diagnostics Area		X																				X	X			
O-112	Computer Users Area		X																				X	X			
O-113	Computer and Mass Storage Room		X																				X	X			
O-114	Inspection Area / Receiving & Shipping		X													X	X			X	X						
O-115	Computer Achives																							X			
O-116	Cleaning Area																X			X	X						
O-117	Vacuum Prep & Assembly Area		X													X	X		X	X	X				X		
O-118	Optics Lab		X													X			X	X	X				X		
O-119	Electronics Test & Maintenance Shop		X													X			X	X							
O-120	Mechanical Shop																			X							
O-121	Change Room															X					X						
O-122	Active Storage																										
O-123	Long Term Storage																										

Table 5.10-1 -- Facility Monitoring and Control Nodes

		Electrical							Comm.					Mechanical												Handling	
Space/Area #	**Space/Area Name**	*Facility Power*	*Technical Power*	*UPS*	*Lightning Grnd*	*Instrumentation Grnd*	*Technical Grnd*	*Facility Grnd.*	*Ethernet/LAN*	*Telephone*	*Wireless Transceiver*	*Public Address System*	*Closed Circuit Video*	*Chillers*	*Air Handling Units*	*Personnel Doors*	*Large Access Doors*	*Clean/Dry Instrument Air*	*Exhaust Vents*	*Clean Air Supply*	*Positive Pressure*	*Cleaning Vacuum Ports*	*Gaseous Fire Suppression*	*Fire Detection & Alarm*	*Particulate Monitoring*	*Bridge Cranes*	*Mono Rails*
Mid Station (End Station Similar)	***Provided Throughout UON***	*X*							*X*				*X*					*X*						*X*			
M-100	Vacuum Equipment Area		X													X	X			X	X					X	
M-101	Mechanical/Utilities Equipment Room														X	X			X								
M-102	Inspection Area / Receiving & Shipping															X	X										
M-103	Cleaning Area																X				X						
M-104	Experiment Equipment Area		X																		X						
M-105	Change Room															X					X						
Beam Tube Enclosure		X							F	F					F	F			F		F			F			
Chiller Plants (5 locations)		X							X					X													

Table 5.10-1 (Cont'd) -- Facility Monitoring and Control Nodes

5.11 Facility Interface with Interferometer, Vacuum Equipment, and Beam Tube Systems

This Table illustrates the interfaces that occur between the Facility supplied utilities and the components of the other Systems.

	Electrical						**Mechanical**			**Handling**	
System, Subsystem, or Component	*Facility Power*	*Technical Power*	*Instrumentation Grnd*	*Technical Grnd*	*Facility Grnd*	*Ethernet/LAN*	*Exhaust Vents*	*Fire Suppression*	*Fire Detection & Alarm*	*Bridge Cranes*	*Mono Rails*
Detector System											
Control & Data Acquisition System	X	X	X	X						X	
Physics Monitoring	X		X	X							
Interferometer Subsystem	X	X	X	X							
Support Equipment		X		X							
Vacuum Equipment System											
Test Mass Chambers					X					X	
Beam Splitter Chambers					X					X	
Horizontal Access Modules					X					X	
Monitor and Control Subsystem	X				X						
Roughing Pumps	X				X		TBD			X	
Cryo Pumps	X				X		X			X	
Ion/Getter Pumps	X				X						
Annulus Pumps	X				X						
Valves	X				X					X	
Vent and Purge Subsystem	X				X						
Bakeout Subsystem	X				X						
Beam Tube System											
Beam Tube Supports & Leveling					X						
Vacuum Pumps Subsystem	X				X						
Bake-Out Subsystem											

Table 5.11-1 -- Interface Matrix

6. Verification and Testing

This section describes the verification process of the design performance requirements contained in Section 5, and identifies additional testing beyond that required in Section 5.

6.1 Verification Methods

6.1.1 Analysis

The design effort will be subject to analysis by computation, by application of experience and engineering judgment, or by adoption or correlation of test and/or performance data documented on other similar projects. It is mandatory that such analyses be documented for the LIGO Project in a manner readily understood. Such documentation will indicate the source(s) if basic data was used, the method of computation or the formulas used, the step-by-step analytical process used, and the conclusion.

6.1.2 Inspection

Inspection is the visual determination of an item's qualitative or quantitative properties such as tolerances, finishes and identification.

6.1.3 Demonstration

Demonstration is the determination of qualitative and quantitative properties and performance of an item, and involves proof-by-doing without use of external resources. It is normally accomplished in conjunction with a test activity.

6.1.4 Standard Test

The standard test determines the qualitative and quantitative properties and performance according to standard test specifications and procedures specified in applicable accepted standards, manuals, regulations and/or codes.

6.1.5 Specific Test

The specific test determines the qualitative and quantitative properties and performance according to nonstandard test specifications and procedures. Specifications will include requirements, procedures, and plans for specific tests.

Where test results, experience, or judgment indicates that an item's malfunction could significantly impact performance of real property facilities and equipment, or results in unsafe conditions for users, operators or maintainers, that item will be subject to corrective action.

6.2 Requirements and Procedures

Special test requirements and procedures as well as standard inspection and test procedures necessary to meet the verification requirements in 6.3 through 6.7 will be developed. Necessary special instructions relative to tests and inspections will be identified. Materials and certain equipment, as well as pavement and concrete mix designs, will also be identified within the construction specification as items to be submitted for review by the Construction Manager and approved by the A-E's Engineer. Test procedures and test results will also be generated by the Construction contractor and submitted to the Construction Manager for review. All labor, equipment, and material involved in performing and documenting the tests will be the responsibility of the Construction Contractor. The Construction Manager will witness the test to ensure compliance with approved procedures and review documentation of test results.

6.3 Mechanical

6.3.1 Testing, Adjusting and Balancing of Building Systems

Testing and balancing of building HVAC and Hydronic systems will be conducted by firms certified by Associated Air Balancing Council (AABC) in those testing and balancing disciplines similar to those required for this project. Cleanrooms shall be tested in accordance to NEBB "Procedure Standards for Certified Testing Of Cleanrooms"

6.3.2 Cleanroom Systems

Testing and balancing of cleanroom air systems will be conducted by firms certified by AABC and will have a minimum of five previous test completion on similar cleanrooms.

6.3.3 HEPA Filters

Field certification tests on installed HEPA filters will be performed in accordance with IES-RP-CC-006-84-T, "Ambient Particle Aerosol Challenge and Air Particle Counter - Downstream Filter Scan Test Method."

6.3.4 Fire Protection

The fire suppression and detection systems will be tested in accordance with NFPA 13A.

6.4 Electrical Tests

All test results will be recorded and submitted in formal documentation by the Contractor for review by the Construction Manager.

6.4.1 Grounding

Facility grounding tests will be conducted in accordance with the recommendations in IEEE Std 81-1983 and IEEE Std 81.2-1991.

6.4.2 Electromagnetic Interference

The Facility will be "sniffed" for sources of EMI. RFI and EMI that is within the LIGO experiment pass-band will be remedied on a case-by-case and cost-effective manner. Methods of remediation include but are not limited to filtering, shielding, relocation, or bonding.

6.4.3 New Equipment

New equipment will be tested for operation as recommended by the manufacturer and UL 674.

6.4.4 Short Circuits

Equipment and conductors rated at 600V and less will be tested to ensure that the wiring system and equipment is free from short circuits and from grounds other than required grounds.

6.4.5 Continuity

All wiring will be tested for conductor continuity.

6.4.6 Insulation Resistance

All new conductors will be tested for an insulation resistance value of 1 megohm or greater, with respect to the nearest grounded metal.

6.4.7 Power Cables

Conduct tests of 5 kV and higher voltage power cables as follows:

A. Cable manufacturer will furnish certified test reports per AEIC CS 5, CS 6 and UL 1072, for all tests performed.

B. The completed cable will be tested for Corona Discharge and will comply with the AEIC requirements.

C. High voltage DC field testing before and after installation using test voltage(s) as recommended by AEIC S-68-516, CS 5 and CS 6.

6.4.8 Isolation Resistance

The grounding subsystems isolation resistance will be tested for 1 megohm isolation between each other.

6.4.9 Electric Power Characteristics

To ensure compliance with 7.6.7, the A-E will take required measurements of Site-available power and submit a formal report for review and approval.

6.4.10 Phase Rotation

Phase rotation will be per NEMA. All panels, 3-phase outlets, 3-phase equipment, motors, etc. will be tested for correct rotation.

6.4.11 Alarm Systems

All alarm systems will be tested for each alarm condition.

6.4.12 Controls and Interlocks

All controls and interlock circuits will be tested for proper and safe performance.

6.4.13 Motor Insulation

Motor insulation resistance will be measured before energizing per IEEE Standard 43.

6.4.14 Illumination

Lighting and illumination compliance with Section 5.6.5.1, will be determined by field measurement.

6.5 Architectural

6.5.1 Painting

All shop and field painting will be inspected and approved by a National Association of Corrosion Engineers (NACE) certified inspector.

6.6 Vibration Testing

All rotating equipment meeting a specified vibration criteria shall be shop tested and the tests shall be witnessed by the Owners representative. The vibration tests will include steady-state and transient (i.e., start-up) operating speeds. The vibration limits shall be met at all specified frequencies. Skid mounted rotating equipment shall be tested to demonstrate that the specified vibration limits on the skid and the specified vibration transmissibility of the skid isolation system has been met at all specified frequencies. The shop tests will include the affects of all equipment attachments such as electrical conduit, fluid piping, etc. that may "short circuit" the skid isolation system.

6.7 Acoustics

6.7.1 HVAC Background Noise

With all HVAC systems on in their normal operating condition, the sound pressure level measurements shall be made at the center of the critical areas to determine the octave band sound pressure levels. Measurements shall be made with a type 1 sound level meter and associated octave band filter. Octave band levels shall be taken at center frequencies ranging from 4 Hz to 8 Khz.

6.7.2 Reverberation Times

Reverberation time measurements shall be made in the 500 and 1,000 Hz octave frequencies. They shall be made near the center of the critical spaces.

7. Referenced Documents

7.1 Federal Standards

Number	Title
FEDERAL STANDARDS	
FED-STD-209	Cleanroom and Work Station Requirements, Controlled Environment
FED-STD-595	Color and Number Identification
Title 29 CFR	**Federal Occupational and Health**
OSHA 2207	Construction Industry -- OSHA Safety and Health Standards

7.2 Military Standards

Number	Title
MILITARY STANDARDS	
MIL-STD-461D	**Grounding, Bonding, and Shielding for Electronics Equipment and Facilities Applications**
MIL-STD-1246	**Product Cleanliness Levels and Contamination Control Program**
MIL-V-18436	**Valves, Check: Bronze, Cast-Iron and Steel Body**

7.3 Industry Standard Codes

Number	Title
Industry Standard Codes	
ASME Codes	**Pressure Vessel Codes, Section VIII & IX**
-B16.29	Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings
-B31.1	Power Piping
-Section VIII	Rules for Construction of Pressure Vessels
-Section IX	ASME Boiler and Pressure Vessel Code
BOCA	**Building Officials and Code Administrators -- Standard for the Design and Installation of the Fire Suppression System for Life Safety**
SBC	**Standard Building Code**
UBC	**Uniform Building Code**
UFC	**Uniform Fire Code**
UMC	**Uniform Mechanical Code**
UPC	**Uniform Plumbing Code**

7.4 Industry Standard Specifications, and Guidelines

Number	Title
	Industry Standard Specifications, and Guidelines
AASHTO	**American Association of State Highway and Transportation Officials**
Manual	Guide for Design of Pavement Structures
Specification	Standard Specifications for Highway Bridges
Specification	Standard Specifications for Transportation Materials
Specification	Standard Specifications for Methods of Sampling and Testing
ACCA	**Air Conditioning Contractor's of America**
Manual D	Equipment Selection and System Design Procedures
Manual Q	Equipment Selection and System Design Procedures for Commercial Summer and Winter Air Conditioning
ACGIH	**American Conference of Governmental Industrial Hygienists**
-Chapter 2	General Ventilation
ACI	**American Concrete Institute**
-117	Standard Specification for Tolerances for Concrete Structures and Materials
-318	Building Code Requirements for Reinforced Concrete and Commentary 60
-530	Building Code Requirements for Concrete Masonry Structures and Commentary
AEIC	**Association of Edison Illuminating Companies**
-CS 5	Specification for Thermo Plastic and Cross-linked Polyethylene Insulated Shielded Power Cable Rated 5 through 69 kV
-CS 6	Specification for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 through 69 kV
-S-68-516	Ethylene Propylene Rubber Insulated Wire and Cable for Transmission and Distribution of Electrical Energy
AFBMA	**Anti-Friction Bearing Manufacturers Association**
-9	Load Rating and Fatigue Life for Ball Bearings
-11	Load Rating and Fatigue Life for Roller Bearings
AISC	**American Institute of Steel Construction -- Specification for Structural Steel Buildings, Allowable Stress Design and Plastic Design Code of Standard Practice -- Standard Practice for Steel Buildings and Bridges**
AISI	**American Iron and Steel Institute**
AMCA	**Air Movement Control Association**
-99	Standard Handbook
-211	Certified Ratings Program, Error Performance
-311	Certified Sound Ratings Program for Air Moving Devices
-500	Test Methods of Louvers, Dampers and Shutters

Number	Title
	Industry Standard Specifications, and Guidelines
ANSI	**American National Standards Institute**
-A13.1	Scheme for the Identification of Piping Systems
-A53	Specification for Pipe Steel, Black and Hot Dipped, Zinc Coated, Welded and Seamless
-B16.3	Malleable Iron Fittings
-B16.5	Pipe Flanges and Flanged Fittings
-B16.9	Factory Made Wrought Steel Butt Welding Fittings
-B16.29	Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings
-B30.2	Safety Code for Overhead and Gantry Cranes
-B30.10	Hooks
-B31.1	Power Piping
-B32	Standard Specification for Solder Metal
-B88	Specification for Seamless Copper Water Tube
-C2	National Electrical Safety Code (NESC)
-Z358.1	Eyewashes and Showers Equipment, Emergency
-900	Test Performance of Air Filter Units
ARI	**Air Conditioning and Refrigeration Institute**
-410	Force Circulation Air Cooling and Air Heating, Coils
-430	Central Station Air Handling Units
-530	Method of Measuring Sound And Vibration of Refrigerant Compressors
-540	Method for Presentation of Compressor Performance Data
ASCE	**American Society of Civil Engineers**
-7-88	Minimum Design Loads for Buildings and Other Structures
ASHRAE	**American Society of Heating, Refrigerating and Air Conditioning Engineers**
-15	Mechanical Code for Refrigeration
-52	Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter
-34	Number Designation and Safety Classification of Refrigerants
-1989 HDBK	Fundamentals
ASME Codes	**Pressure Vessel Codes, Section VIII & IX**
-B16.29	Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings
-B31.1	Power Piping
-Section VIII	Rules for Construction of Pressure Vessels
-Section IX	ASME Boiler and Pressure Vessel Code
ASSE	**American Society of Sanitary Engineers**
-1013	Reduced Pressure Principle and Pressure
ASTM	**American Society for Testing and Materials**

Number	Title
	Industry Standard Specifications, and Guidelines
-A36	Standard Specification for Structural Steel
-A53	Specification for Pipe, Steel, Black & Hot Dipped, Zinc Coated Welded and Seamless
-A123	Standard Specification for Zinc (Hot Dipped Galvanized) Coatings in Iron and Steel
-A126	Specification for Gray Iron Coatings for Valves, Flanges
-A278	Standard Specification for Gray Iron Castings and Pressure, Containing Parts for Temperature
-B32	Standard Specification for Solder Metal
-B88	Standard Specification for Seamless Copper Water Tube
-B280	Specification for Seamless Copper Tube and Air Conditioning and Refrigeration Field Service
-C553	Standard Specification for Mineral Fiber Blanket and Felt Insulation
-D2737	Specification for Polyethylene Plastic Tubing
-E84	Surface Burning characteristics of Building Materials
-F50	Standard Practice for Continuous Sizing and Counting of Airborne Particles in Dust-Controlled Areas Using Instruments Based Upon Light Scattering Principles
-F328	Standard Practice for Determining Counting and Sizing Accuracy of an Airborne Particle Counter Using Near-Monodisperse Spherical Particulate Materials
-F649	Standard Practice for Secondary Calibration of Airborne Particle Counter Using Comparison Procedures
AWS	**American Welding Society**
-A2.4	Symbols for Welding, Brazing and Nondestructive Examination
-A3.0	Standard Welding Terms and Definitions
-B2.1	Standard for Welding Procedure and Performance Qualification
-D1.1	Structural Welding Code -- Steel
-D14.1	Specification for Welding Industrial and Mill Cranes
BOCA	**Building Officials and Code Administrators -- Standard for the Design and Installation of the Fire Suppression System for Life Safety**
CGA	**Compressed Gas Association**
-4.1	Cleaning Equipment for Oxygen Service
CMAA	**Crane Manufacturers Association of America**
-70	Specification for Electric Overhead Traveling Cranes
CTI (TBS)	**Cooling Tower Institute Standards**
DHI	**Door Hardware Institute**
FIPS Pub 94	**Guideline on Electrical Power for ADP Installations**
IEEE	**Institute of Electrical and Electronic Engineers**
-43	Recommended Practice for Testing Insulation Resistance of Rotating Machinery

Number	Title
	Industry Standard Specifications, and Guidelines
IESNA HDBK	**Illuminating Engineering Society North America Handbook**
IES	**Institute of Environmental Sciences, Recommended Practices**
-RP-CC-001	HEPA Filters
-RP-CC-006	Testing Cleanrooms
-RP-CC-013	Recommended Practice for Equipment Calibration or Validation Procedures
MSS	**Manufacturers Standardization Society**
-SP58	Pipe Hangers and Supports
-SP67	Butterfly Valves
-SP69	Pipe Hanger and Supports, Selection and Application
-SP70	Cast Iron Gate Valves, Flanged, and Threaded Ends
-SP72	Ball Valves with Flanged Butt Welded Ends for General Service
-SP80	Bronze Gate, Globe, Angle and Check Valves
NACE-STD	**National Association of Corrosion Engineers Cathodic Protection**
-RP-02-75	Application of Organic Coating to External Surface of Steel Pipe for Underground Service
NASA	**National Aeronautics and Space Administration**
-NSS/GO-1740.9	NASA Safety Standard for Lifting Devices and Equipment
NEMA	**National Electrical Manufacturers Association**
-MG1	Motors and Generators
NFPA	**National Fire Protection Association**
-13	Installation of Sprinkler Systems
-13A	Inspection, Testing and Maintenance of Sprinkler Systems
-54	National Fuel Gas Code
-70	National Electrical Code
-72E	Automatic Fire Detectors
-78	Lightning Protection Code
-80	Fire Doors and Windows
-85B	Standard for Prevention of Furnace Explosions in Natural Gas-Fired Multiple Burner Boiler
-90A	Installation of Air Conditioning and Ventilating Systems
-99	Standards for Health Care Facilities
NIOSH	**Technical Report: Guide to Industrial Respiratory Protection**
NIST	**National Institute of Standards and Technology**
NSS	**National Safety Standards**
SBC	**Standard Building Code**
SMACNA	**Sheet Metal and Air-Conditioning Contractors National Association**
-	High Pressure Duct Construction Standards
-	Low Pressure Duct Construction Standards

Number	Title
	Industry Standard Specifications, and Guidelines
-	Guidelines for Seismic Restraints of Mechanical Systems
-	Round and Oval Duct Construction Standards
-	Architectural Sheet Metal
SSPC	**Steel Structures Painting Council**
-SP-2	Surface Preparation, Hand Tool Cleaning
-SP-3	Surface Preparation, Power Tool Cleaning
-SP-10	Surface Preparation, Near-White Blast Cleaning
UBC	**Uniform Building Code**
UFAS	**Uniform Federal Accessibility Standards**
UFC	**Uniform Fire Code**
UL	**Underwriter's Laboratories**
-96	Lightning Protection Systems
-181	Factory Made Air Ducts and Connectors
-467	Grounding and Bonding of Equipment
-555	Leakage Rated Dampers for Use In Smoke Control Systems
-586	High Efficiency Particulate, Air Filter Units
-900	Test Performance of Air Filter Units
-1072	Medium Voltage Power Cables
UMC	**Uniform Mechanical Code**
UPC	**Uniform Plumbing Code**
USGSA	**United States General Services Administration**
-	Certification Test for Air Flow Measuring Stations

7.5 Site Specific Reference Documents -- General

Number	Title
SITE SPECIFIC REFERENCE DOCUMENTS	
RFP-YM 193	Appendices A, B, and C of the Request for Proposal No. YM 193 for LIGO Facility Design and Construction Management Support
Washington DOT	Standard Specifications for Road and Bridge Construction
Washington DOT	Standard Plans for Road and Bridge Construction
941208-01	Exhibit I, Vacuum Equipment Specification, LIGO Facility, LIGO Document 1100003 of the LIGO Vacuum Equipment Request for Proposal No. MH 178
941220-02	Beam Tube Module Specification
941228-11	Beam Tube Enclosure Statement of Work and Beam Tube Support Details
950104-01	Utility Conduit Design Calculations and Drawing

7.6 Site Specific Reference Documents -- Hanford

Number	Title
SITE SPECIFIC REFERENCE DOCUMENTS	
OSHA/WISHA	Washington Institute of Safety and Health Administration
Washington DOT	Standard Specifications for Road and Bridge Construction
Washington DOT	Standard Plans for Road and Bridge Construction
941219-01	Hanford -- Land Use Permit
941219-02	Hanford -- Memorandum of Understanding
941219-03	Hanford -- Environmental Assessment
941219-04	Hanford -- Finding of No Significant Impact
941219-05	Hanford -- Report of Geotechnical Survey/Letters of Clarification
941219-06	Hanford -- Staking Survey
941219-07	Hanford -- Topographical Survey/Including Back-up Data and Seven Diskettes
941219-08	Hanford -- Specification and Contract Documents for Rough-Grading
941219-09	Hanford -- Drawings for the Rough-Grading
941219-10	Hanford -- Ground Water-Temporary Permit
950104-01	Utility Conduit Design Calculations and Drawing
950113-01	Hanford -- LIGO Rough Grading (with 12 diskettes)
950201-01	Hanford -- Water Well Drilling Log

7.7 Site Specific Reference Documents -- Livingston

Number	Title
SITE SPECIFIC REFERENCE DOCUMENTS	
Louisiana DOTC	Standard Specifications for Road and Bridge Construction
Louisiana DOTC	Standard Plans for Road and Bridge Construction
941228-01	Livingston -- Act of Cash Sale (Draft)
941228-02	Livingston -- Lease Agreement (Draft)
941228-03	Livingston -- Environmental Assessment (Draft Final, One Copy) Finding of No Significant Impact (Appendix B)
941228-04	Livingston -- Section 404 Permit
941228-07	Livingston -- Staking Survey
941228-08	Livingston -- Drainage Plan with Hydrologic and Hydraulic Report
941228-10	Livingston -- Conceptual Designs for Pipeline Crossings of the LIGO Embankment
950112-04	Livingston -- Lease Agreement
950112-05	Livingston -- Geotechnical Investigation, Final Report

Appendix A
Abbreviations

A	Ampere
AABC	Associated Air Balancing Council
AASHTO	American Association of State Highway and Transportation Officials
ABS	Acrylonitrite - Butadiene - Styrene
A/C	Air Conditioning
ACCA	Air Conditioning Contractors of America
Ach/hr	Air Changes per hour
ACI	American Concrete Institute
A-E	Architect/Engineer
AEIC	Association of Edison Illuminating Companies
ADA	Americans with Disabilities Act
ADC	Air Diffuser Council
A-E	Architect - Engineer
AECS	Automated Entry Control System
AEIC	Association of Edison Illuminating Companies
AFBMA	ANSI/Fan Bearing Manufacturers Association
AFF	Above Finished Floors
AISC	American Institute of Steel Construction
AMCA	Air Moving and Conditioning Association
AMP	Ampere
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASPE	American Society of Plumbing Engineers
ASSE	American Society of Structural Engineers
ASTM	American Society of Testing Materials
AWG	American Wire Gauge
AWS	American Weld Society
AWWA	American Water Works Association
BHMA	Builders Hardware Manufacturers Association
^{o}C	Degrees Centigrade
CAGI	Compressed Air and Gas Institute
CBR	California Bearing Ratio
CCR	Clothing Change Room
CDS	Control and Data System (Detector Group)
CECER-EM	Corps of Engineers Civil Engineering Regulation - Engineering Maintenance
CFC	Chlorofluorocarbon
cfm	Cubic feet per minute
CFR	Code of Federal Regulations

CGA	Compressed Gas Association
Ch	Chapter
CISCA	Ceilings and Interior Systems Construction Association
cm	Centimeters
CMAA	Crane Manufacturers Association of America
CRI	Color Rendering Index
CS	Communication System
CTI	Cooling Tower Institute
dB	Decibel
DC/dc	Direct Current
DDC	Direct Digital Control
DDCP	Direct Digital Control Panel
DL	Dead Load
DOP	Dioctylphalate
E	Seismic Load
EA	Environmental Assessment
EER	Electrical Equipment Room
EES	Earth Electrode Subsystem
EMC	Electromagnetic Compatibility
EMCS	Energy Management Control System
EMI	Electromagnetic Interference
EMT	Electric Metallic Tubing
EPR	Ethylene Propylene Rubber
ESR	Equipment Storage Room
ESS	Electronic Security System
ETL	Engineering Technical Letter
EX	Exceptions
°F	Degrees Fahrenheit
FACP	Fire Alarm and Control Panel
fc	Foot-candles
FCC	Federal Communications Commission
FDC	Facility Design Criteria
FED-STD	Federal Standard
FEMA	Federal Emergency Management Agency
FIP	Field Interface Panels
FMCS	Fire Monitoring and Control System
FMEC	Factory Mutual Engineering Corporation
$°F_{db}$	Degrees Fahrenheit-dry bulb
fpm	Feet per Minute
fps	Feet Per Second
ft	Foot
FTM	Federal Test Manual
$°F_{wb}$	Degrees Fahrenheit-wet bulb
g	Gravity Constant (Earth)

GFE	Government Furnished Equipment
GHe	Gaseous Helium
GHz	Gigahertz
GN_2	Gaseous Nitrogen
gpm	Gallons per Minute
gr/lbda	Grams per Pound Dry Air
HEPA	High Efficiency Particulate Air
Hg	Mercury
hr	Hours
HVAC	Heating, Ventilation and Air Conditioning
Hz	Hertz
ICEA	Insulated Cable Engineering Association
ICBO	International Conference of Building Officials
IEEE	Institute of Electrical and Electronics Engineers
IES	Institute of Environmental Science
IESNA	Illuminating Engineering Society of North America
in	Inches
ISA	Instrument Society of America
KHz	Kilo-hertz
km	Kilometers
kV	Kilo-volt
kVA	Kilo-volt-Ampere
LIGO	Laser Interferometer Gravitational-Wave Observatory
LL	Live Load
LN_2	Liquid Nitrogen
LPS	Low Pressure Sodium
LVEA	Laser and Vacuum Equipment Area
MCS	Monitoring and Control System (Vacuum Equipment)
mg/ft3	Milligram per cubic foot
mm	Millimeter
MPH	Miles per Hour
NACE	National Association of Corrosion Engineers
NACSEM	National COMSEC/EMSEC Information Memorandum
NACSIM	National COMSEC Information Memorandum
NAPHCC	National Association of Plumbing, Heating and Cooling Contractors
NBS	National Bureau of Standards
NEBB	National Environmental Balance Bureau
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NFC	National Fire Code
NFPA	National Fire Protection Association
NIBS	National Institute of Building Sciences
NIC	Not in Contract
NIOSH	National Institute for Occupational Safety and Health

NIST	National Institute of Standards and Technology
NLSC	National Life Safety Code
NPC	National Plumbing Code
NVR	Non-Volatile Residue
O&M	Operations and Maintenance
OSB	Operations Support Building
OSHA	Occupational Safety and Health Act
OSR	Operations Support Room
PNC	Preferred Noise Criterion
ppm	Parts per million
ppmv	Parts per million by volume
PSD	Power Spectral Density
psf	Pounds per Square Foot
psi	Pounds per Square Inch
psig	Pounds per Square Inch Gage
PVC	Polyvinyl Chloride
REA	Rural Electrification Administration
RF	Radio Frequency
RFI	Radio Frequency Interference
RPIE	Real Property Installed Equipment
SBC	Standard Building Code
SBCCI	Southern Building Code Congress International
SCFM	Standard Cubic Feet per Minute
sf	Square Feet
SJI	Steel Joist Institute
SMACNA	Sheet Metal Air Conditioning National Association
SSC	Systems Security Contractor
SSPC	Steel Structures Painting Council
STC	Sound Transmission Class
TAB	Testing and Balance
TBD	To Be Determined
TBR	To Be Revised
THD	Total Harmonic Distortion
UBC	Uniform Building Code
UFC	Uniform Fire Code
UL	Underwriters Laboratory
UMC	Uniform Mechanical Code
UON	Unless Otherwise Noted
UPC	Uniform Plumbing Code
UPS	Uninterruptible Power Supply
V	Volts
VAC	Volts Alternating Current
VEA	Vacuum Equipment Area
VOC	Volatile Organic Compounds
Vol	Volume

WISHA	Washington Institute of Safety and Health Administration
WL	Wind Load
w.c.	Water Column
w.g.	Water Gauge
WR	Water Resistant