LIGO-C930063-00-B

DRD #8
PRELIMINARY DESIGN REVIEW DATA PACKAGE
NOVEMBER 15, 1993

LIGO BEAM TUBE MODULE DESIGN & QUALIFICATION TEST

CALTECH CONTRACT NUMBER C146

ORIGINAL RELEASE

BY

CBI TECHNICAL SERVICES COMPANY
CBI CONTRACT 930212

DOCUMENT CDRL #14

☐ SUBMITTED FOR APPROVAL

☐ APPROVED

☒ APPROVAL NOT REQUIRED

Martin L.
CBI Technical Services

Caltech Institute of Technology

TABLE OF CONTENTS
FOR
PRELIMINARY DESIGN REVIEW (PDR) DATA PACKAGE
LIGO BEAM TUBE MODULE DESIGN & QUALIFICATION TEST

TABLE OF CONTENTS
FOR
PRELIMINARY DESIGN REVIEW (PDR) DATA PACKAGE
LIGO BEAM TUBE MODULE DESIGN & QUALIFICATION TEST

SECTION 1

GENERAL REQUIREMENTS

Cleanliness

Vacuum Surfaces

- Contaminant materials of any form to be removed by procedures approved by Caltech
- Recontamination to be prevented in all subsequent operations
- Beam Tube Module components to be wrapped/sealed after cleaning until installation

External Surfaces

- Contaminant materials which may induce corrosion to be removed by procedures approved by Caltech
- Recontamination to be prevented in all subsequent operations
- Beam Tube Module components to be protected from external environment throughout operating life

GENERAL REQUIREMENTS

Leak Rate

- Furnish Beam Tube Modules with helium leak rate not exceeding 1×10^{-10} atm cc/s

GENERAL REQUIREMENTS

Outgassing Performance

- All material exposed to vacuum to be produced and fabricated in accordance with LIGO "Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products"
- Test coupons of material produced for the Beam Tube Modules and supply Caltech with data for determination of material acceptability

GENERAL REQUIREMENTS

Clear Aperture

- Furnish at installation a 1.07m minimum clear aperture between reference monuments spaced @ 250m intervals
- Provide convenient means of adjusting tubes to original installation alignment after subsequent foundation movement

GENERAL REQUIREMENTS

Structural / Mechanical / Thermal

- Full vacuum design per ASME Pressure Vessel Code
- Design loads and combinations per ASCE 7-88
- Design of expansion joints for cyclic loading in accordance with EJMA
- Thermal loads for daily and seasonal variations
- Thermal loads for 20 bakeouts at 140°C (284°C)

GENERAL REQUIREMENTS

Site Specific Requirements

Site 1 - Hanford, WA

- 70 mph basic wind speed (approx. 37#/ft)
- Zone 1 seismic (V = 0.0525W, approx. 5#/ft)
- 10 psf ground snow load (approx. 20#/ft)

Site 2 - Livingston, LA

- 100 mph basic wind speed (approx. 76#/ft)
- Zone 0 seismic (V = 0.0525W min., approx. 5#/ft)
- No applicable snow load

Both Sites

- Sustain potentially corrosive environment w/o jeopardizing structural integrity or operational requirements

BEAM TUBE SECTION LENGTH

Requirements

- Tube length must not be difficult to fabricate
- Beam Tube Sections must not be difficult to handle
- Beam Tube Sections must satisfy design code requirements for applicable loads and load combinations

BEAM TUBE SECTION LENGTH

Critical Parameters

- Beam Tube Section length must be compatible with design of support for transfer of loads at ends
- Beam Tube Section length must not impose dimensional tolerance requirements which are difficult to meet
- Beam Tube Section length must allow constructability

BEAM TUBE SECTION LENGTH

Design Options

- Investigated structural compliance with design code for Beam Tube Section lengths ranging from 12.2m (40') to 24.4m (80')
- Assuming a simple vertical support without moment resistance for longitudinal loads:
    - All lengths considered comply with ASME for effects of tube bending stresses
    - Midspan deflections range from ~1/32" to ~1/2"
    - Required expansion joint shear capacity ranges from ~4000# to ~7000#
    - All lengths considered would require stiffener rings at support location (somewhat larger than typical stiffener ring size)
    - Lowest acceptable spring rate is ~17,000#/in @ 80' span
    - Beginning at 80' span, required supported width of tube to control local stresses increases significantly

BEAM TUBE DIAMETER

Requirements

- Provide 1.07m clear aperture
- Establish tube center externally for operational alignment
- Identify and quantify all tolerances and displacements which influence determination of tube diameter
- Base tube diameter on economically achieved tolerances and accurately predicted displacements

BEAM TUBE DIAMETER

Critical Parameters

- Tube diameter tolerance
- Tube roundness tolerance
- Tube straightness tolerance
- Accuracy of establishing tube center
- Alignment accuracy: Surveying and adjustment
- Deflection of beam tube span
- Lateral offset and rotation of expansion joint
- Baffle radial projection as installed

BEAM TUBE DIAMETER VARIABLES

TOLERANCE / ACCURACY ITEM	LEVEL ACHIEVED			
	A	B	C	D
Surveying tolerance	0.125	0.125	0.188	0.313
Centering tolerance	0.063	0.063	0.094	0.125
Tube diameter tolerance	0.032	0.063	0.094	0.125
Tube roundness tolerance	0.032	0.063	0.094	0.125
Baffle projection tolerance	0.063	0.141	0.25	0.281
Tube staightness tolerance	0.032	0.125	0.25	0.375
Tube adjustment accuracy	0.032	0.032	0.032	0.032
Tube displacement	0.188	0.188	0.188	0.188
Direct summation of tolerances	0.567	0.8	1.19	1.564
Baffle radial projection	2.362	2.362	2.362	2.362
Aperture radius	21.079	21.079	21.079	21.079
Required Tube Diameter	48.02	48.48	49.26	50.01
Nominal Tube Diameter	48.00	48.50	49.25	50.00

Cost to increase the Dia ($2.00/#) =	$0	$70,101	$175,253	$280,404
Equivalent Manhours (@$40/HR) =	0	1753	4381	7010
Mhrs per tube section =	0.00	2.26	5.65	9.03
% increase in surface area =	0.00	1.04	2.60	4.17

BEAM TUBE DIAMETER

Range Considered

- 48" I.D. minimum
- 50" I.D. maximum

Follow Up / Further Investigation

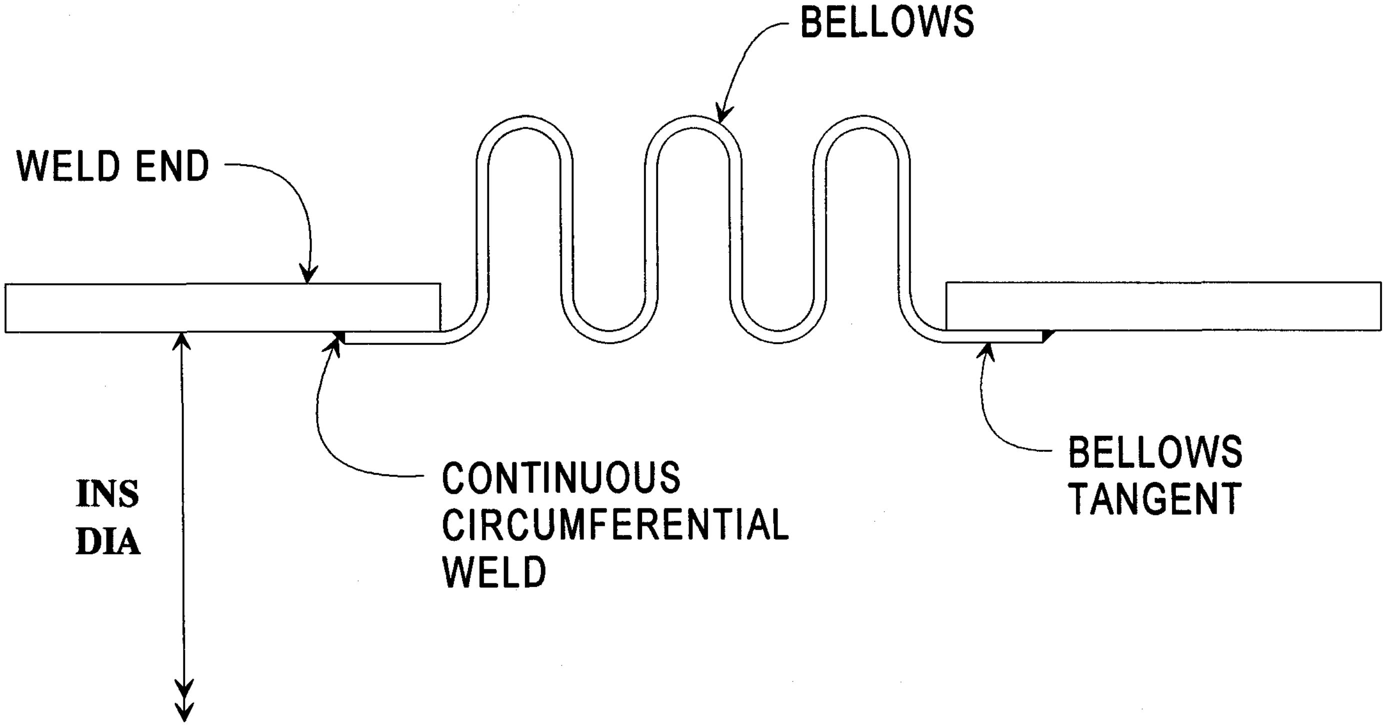
- Refine estimates on various tolerances
- Evaluate stiffened tube behavior for deflections
- Determine achievable tolerances on baffles
- Define expansion joint design properties and determine effect on displacements

EXPANSION JOINTS

Requirements

- Axial extension/compression for
  - 20 bakeouts @ 140°C (284°F)
  - Daily and seasonal temperature variations
- Facilitate installation alignment
- Facilitate alignment adjustments during operation
- Axial spring rate not to exceed allowable limit for compression on tube
- Shear capacity if support on one side only
- Bellows thickness to:
  - Ensure durability w/o damage
  - Ensure adequate torsional capacity
  - Eliminate Caltech's need to cool during bakeout
- Helium leak rate not to exceed 1×10^{-11} atm cc/s
- Material produced and fabricated in accordance with LIGO specification
- Attachment of bellows on inside of tube

TYPICAL EXPANSION JOINT CONFIGURATION



EXPANSION JOINTS

Critical Parameters

- Bellows thickness, convolution depth and pitch all determine structural performance of expansion joint
- Weld details to be TIG welded w/o filler wire from inside:
  - Longitudinal seam in weld ends
  - Longitudinal seam in bellows
  - Circumferential weld of bellows to weld ends
- Material supply to be for two thicknesses:
  - Weld ends to be same as tube wall (0.1250")
  - Bellows to be thinner material (possibly 0.0359" min.)

EXPANSION JOINT MANUFACTURERS' CAPABILITIES

	ALL WELDS w/o WIRE?	LEAK TEST SENS TO 1x10E-11?	ELIMINATE CS CONTAM?	SUPPORT 1 SIDE ONLY?	PROPOSED DESIGN
MICROFLEX	YES	NO (1x10E-9)	NO, PASSIVATE	NOT RECOMM w/o GUIDING	0.048", 3 CONS, 2.25" HT
AMERICAN BOA	YES	YES	YES	POSSIBLY	0.020", 3 CONS, 1.25" HT 0.125", 4 CONS, 2.5" HT
PATHWAY	YES	NO (1x10E-9)	NO, PASSIVATE	YES	0.125", 6 CONS, 2" HT
SENIOR FLEXONICS	NOT RECOMM @ BELLOWS ATT	YES	NO, PASSIVATE	POSSIBLY	0.0359", 3 CONS, 2" HT
HYSPAN	-	-	-	-	0.025", 5 CONS, 1.5" HT

EXPANSION JOINTS

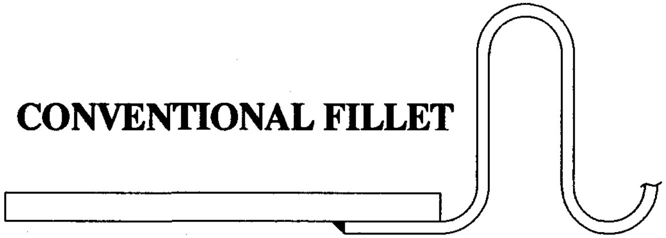
Design Options

- Weld ends can be short (~4") or long (up to 3 or 4')
- Weld ends can be equal or unequal lengths
- Bellows can be as thin as 0.020", as thick as 0.125"
- Bellows can be attached in several ways

POSSIBLE BELLOWS ATTACHMENT METHODS

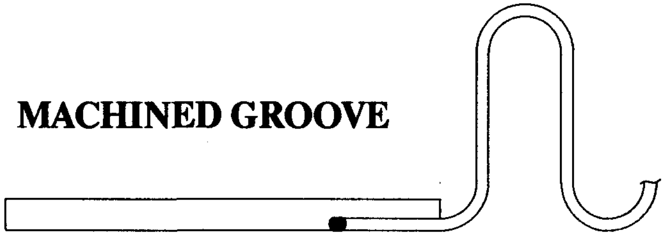
COMMENTS

CONVENTIONAL FILLET



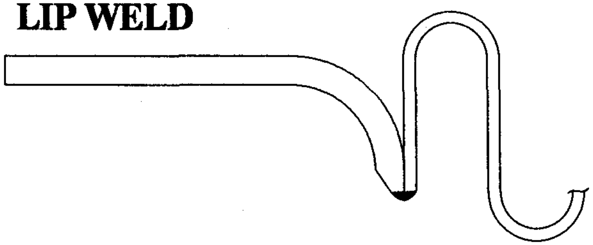
Difficult to weld without wire
Ability to achieve req'd leak rate is questionable

MACHINED GROOVE



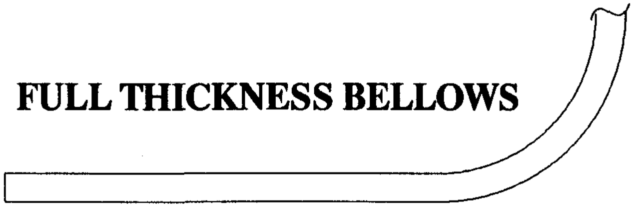
Could weld without wire
Expensive to machine groove,
limited thickness with which to work

LIP WELD



Weld wire not required
Weld end must be formed with lip
Internal projection must not restrict aperture

FULL THICKNESS BELLOWS



No welding except longitudunal seam
Fabrication is primarily forming
Much higher axial spring rate results in:
High end loads @ interface
High loads on supports due to variation in spring rates

EXPANSION JOINTS

Costs

- Present cost information based on precontract request from 9/92
- Requests for quotation to be made 12/6/93
- Cost will be dependent on particular requirements imposed

EXPANSION JOINTS

Follow Up Activities

- CBI investigating all necessary requirements
- Expansion joint design is normally left to the discretion of manufacturer
- CBI-to determine a range of acceptable designs based on EJMA
- CBI to update and issue original purchase specification to include these requirements
- Selection of expansion joint design will be made based on quotation and ability of manufacturer to meet requirements

BEAM TUBE SUPPORTS

Requirements

- Support all applicable loads and loading conditions
- Maintain tube center line elevation at 1.07m above foundation
- Adjustment capability:
  - ±7.5 cm vertical
  - ±7.5 cm transverse horizontal
- Thermal isolation to limit local tube wall temperature drop to 10°C (18°F)
- Allow thermal movement of tube w/o occurrence of stick-slip
- Maximize available clearance between top of tube and enclosure
- Minimize torque induced to bellows from differential settlement of slab
- Provide alignment targets at or near support

BEAM TUBE SUPPORTS

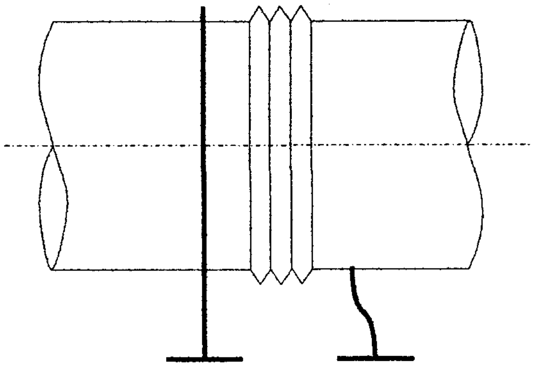
Critical Parameters

- Simple fabrication and means of attachment
- Ease of adjustments for alignment throughout operation
- Convenient interface to foundation
- Method of restraining tube thermal movement during construction before module is closed

SUPPORT DESIGN APPROACHES
TUBE END LOAD

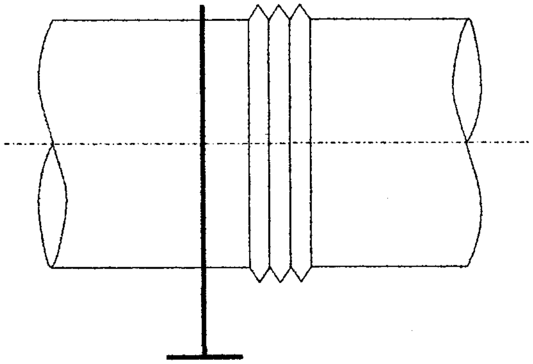
COMMENTS

BOTH SIDES:



Expansion joint does not carry shear load
Differential settlement would impose greater load due to
high lateral spring rate
Differential settlement would induce torsion directly to bellows
Alignment adjustments become complicated
Redundant support must be flexible; cannot be a guide

ONE SIDE ONLY:

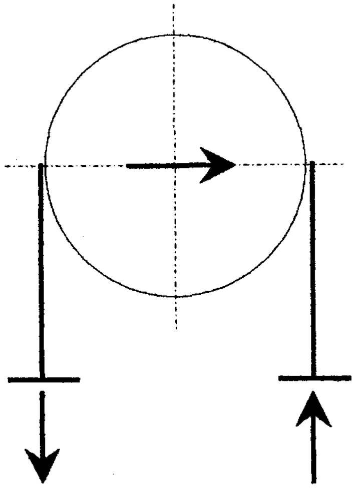


Expansion joint must carry shear load
Expansion joint must be designed for concurrent
axial and lateral displacements
Differential settlement distributes most of torsion to tube
instead of bellows

SUPPORT DESIGN APPROACHES
TRANSVERSE LOAD

COMMENTS

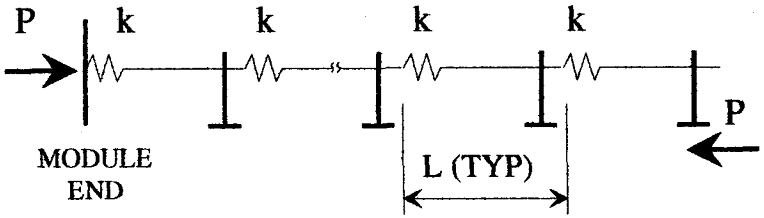
FOR ANY TYPE SUPPORT:



Lateral loads are due to wind or seismic
Vertical dead loads help reduce uplift
Minimum of 2 anchorage points required

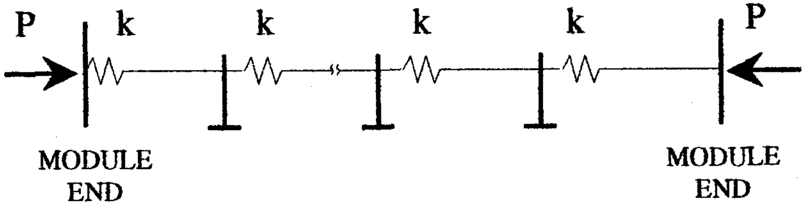
SUPPORT DESIGN APPROACHES
LONGITUDINAL LOAD

DURING CONSTRUCTION:



P must be resisted near last support placed
to maintain proper station

AFTER CONSTRUCTION:



P is transmitted directly through tubes

COMMENTS

Nominal longitudinal load due to seismic

Critical longitudinal load is due to thermal variation throughout construction until module is completed

Thermal load is dependent on:

- Axial spring rate
- Beam Tube Section length
- Temperature change from fabrication temp

After construction, thermal load is transmitted directly through Beam Tube Sections w/o appreciably load imposed on supports

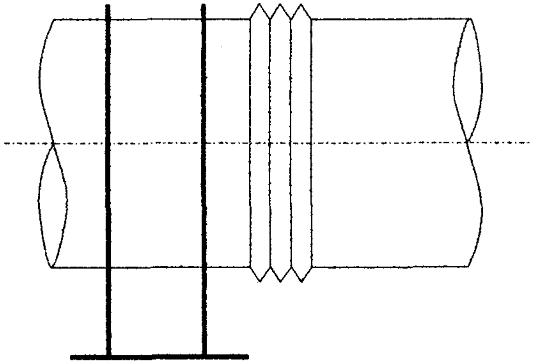
P = k a L dT

k = axial spring rate
a = coefficient of thermal expansion
L = Beam Tube Section fabrication length
dT = temperature change from fabrication

SUPPORT DESIGN APPROACHES
LONGITUDINAL LOAD

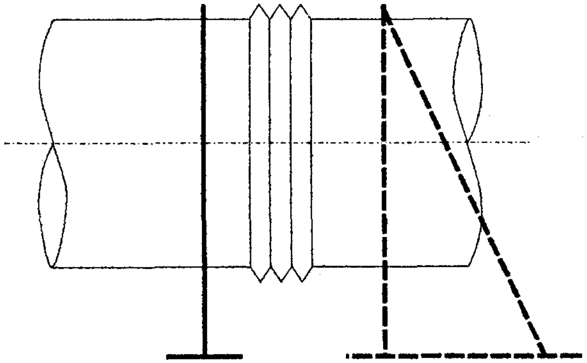
<u>COMMENTS</u>

MOMENT RESISTING:



Requires 2 additional anchorage points
Would secure end of tube as construction progresses

LONGITUDINALLY FLEXIBLE:

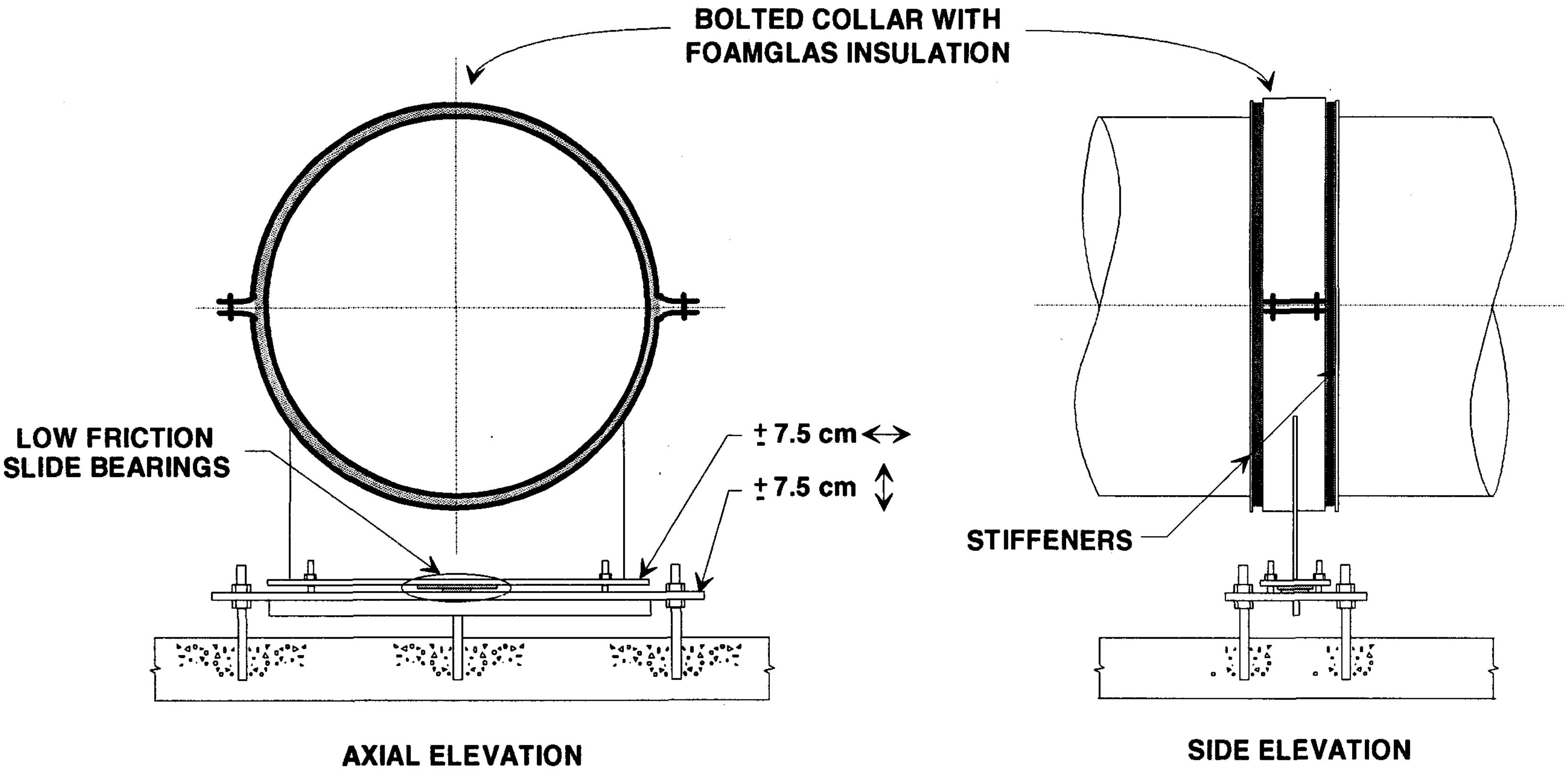


Does not require additional anchorage
Must restrain end of tube by temporary means
  until module is completed
After construction, support must be flexible to allow
  nominal movement (w/o slippage of attachment to tube)

BEAM TUBE SUPPORTS

Design Options

- Thermal isolation
  - Insulation must be load bearing
  - Insulation must sustain wet conditions
  - Insulation must possess satisfactory thermal conductivity
  - Insulation must be obtainable in required thickness and shape
- Insulation must be placed in appropriate location, ideally minimizing or eliminating direct contact of support metal to tube metal
- Foamglas
  - CBI uses foamglas in cryogenic applications with sustained load bearing and wet condition requirements
  - Could be produced in quantity to required thickness and shape
  - Other suitable materials have not been identified



SUPPORT CONCEPT

BEAM TUBE SUPPORTS

Selected Configuration

- Bolted collar
  - Easily installed
  - Does not require precise matching to element already attached to tube
  - Can be unbolted for entire module immediately after construction to eliminate any residual longitudinal load imposed on supports
- Foamglas wrapping tube directly eliminates metal to metal contact
- Transverse horizontal adjustment by studs in slotted holes
- Low friction bearing pads allow easy horizontal movement
- Vertical adjustment by nuts on anchor bolts
- Horizontal and vertical adjustment performed separately
- Pair of stiffeners is required at support to control local stresses in tube wall due to vertical loads alone
- Galvanized/painted carbon steel components

BEAM TUBE SUPPORTS

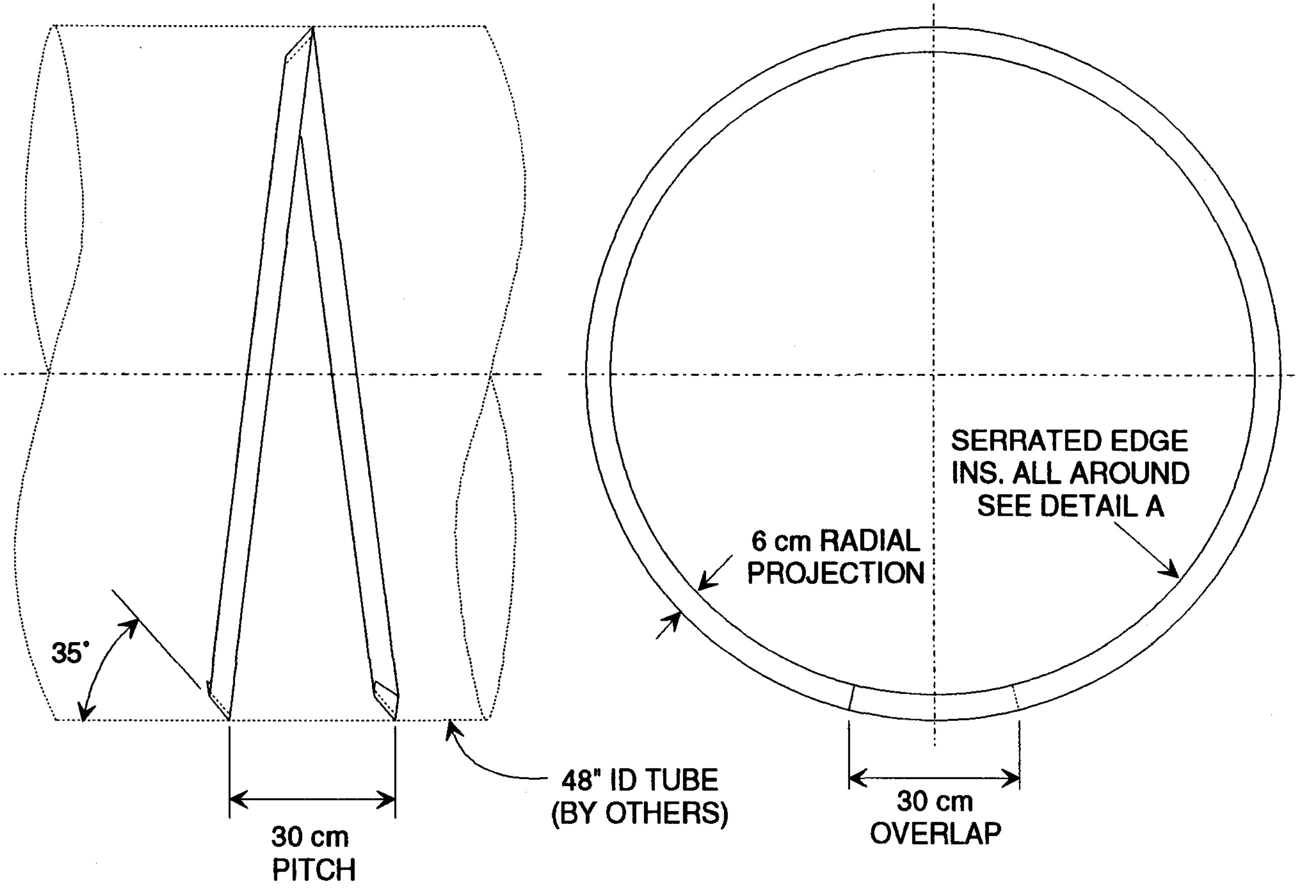
Follow Up Activities

- Perform finite element analysis to determine required insulation thickness
- Refine design of support concept

BAFFLES

Requirements

- Quantity as necessary to satisfy minimum spacing of LIGO Beam Tube Module Configuration
- Helical shape with 30cm pitch and depth
- 6.0cm radial projection
- 35° slope from inside of tube wall
- Projected edge to be serrated up to 0.35cm depth and pitch
- Projected edge to slope toward center of each module
- Material produced and fabricated in accordance with LIGO specification


35˚
30 cm
PITCH
48" ID TUBE
(BY OTHERS)
6 cm RADIAL
PROJECTION
SERRATED EDGE
INS. ALL AROUND
SEE DETAIL A
30 cm
OVERLAP

BAFFLES

Critical Parameters

- Installation to require no welding or fastening to tube wall
- Baffles to be sprung into place and held securely by friction
- Means of applying tool or device to constrain when installing
- Cleanliness requirements for vacuum surfaces apply also to baffles
- Can be any thickness up to 0.1300"
- For best control of materials, use same material as produced for either the tube wall (0.1250") or the thinner bellows
- Manufacturers have a preference to use the thicker material
- Economically achieved tolerances will be used to determine final tube diameter

BAFFLES

Design Options

- Unequal leg angle section with legs @ 35° and 55°
- Single ribbon screw flight
- Manufacturers determine and demonstrate their best fabrication method to satisfy requirements economically
- Caltech to select degree of serration based on manufacturer's relative costs

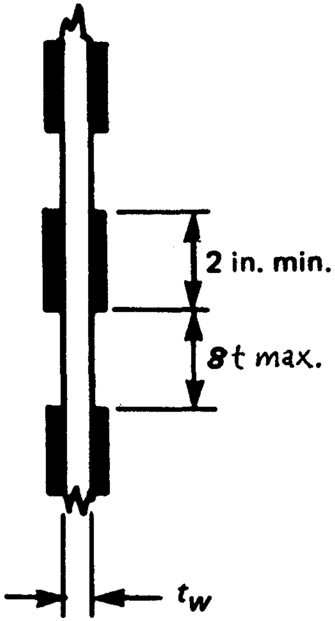
BEAM TUBE STIFFENERS

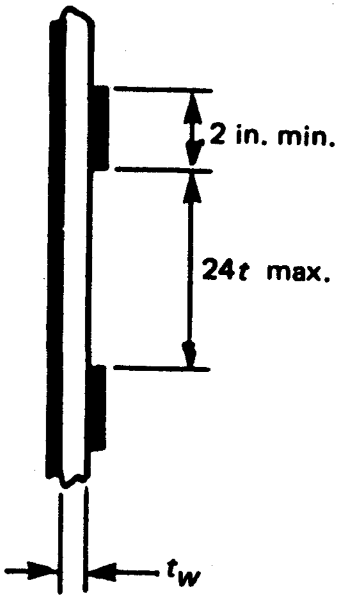
Requirements

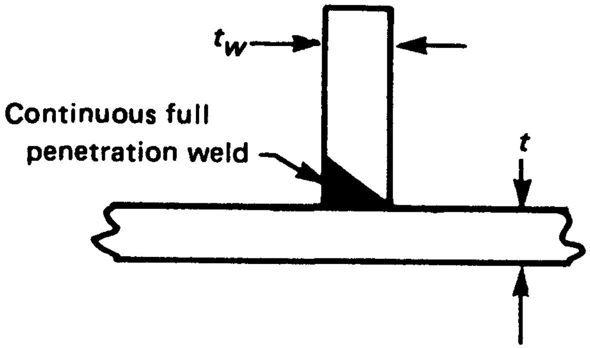
- Cross-sectional area and moment of inertia to satisfy ASME requirements
- Spacing not to exceed ASME requirements
- Stiffener design directly dependent on tube wall design thickness
- Tube wall material purchased as 0.1250" to half mill tolerance (±0.005") will:
    - Satisfy ASME for design on basis of 0.1250" thickness
    - Ensure compliance with LIGO specification for thickness not exceeding 0.1300"
- Corrosion protection as applicable
- 20,000 to 25,000 total quantity, depending on spacing
- Stiffener attachment per ASME

BEAM TUBE STIFFENERS

ASME ATTACHMENT REQUIREMENTS







BEAM TUBE STIFFENERS

Requirements (Cont'd)

- Splice of stiffener ends/segments to:
  - Maintain moment of inertia of section
  - Transfer compressive load carried by ring
- Stiffener material can be carbon steel or stainless steel
- Material selection affects stiffener size requirements to some degree

BEAM TUBE STIFFENERS

Critical Parameters

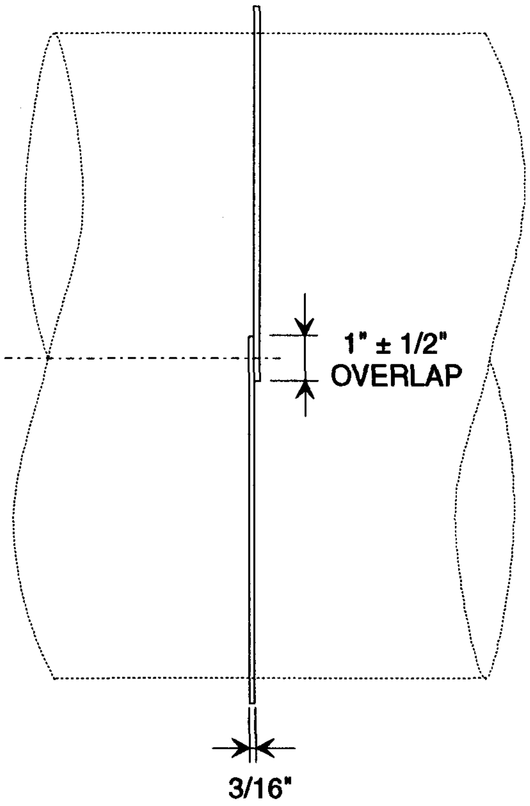
- Efficient use of material
  - Thickness and depth selection
  - Fabrication method
- Simplicity of fabrication and installation

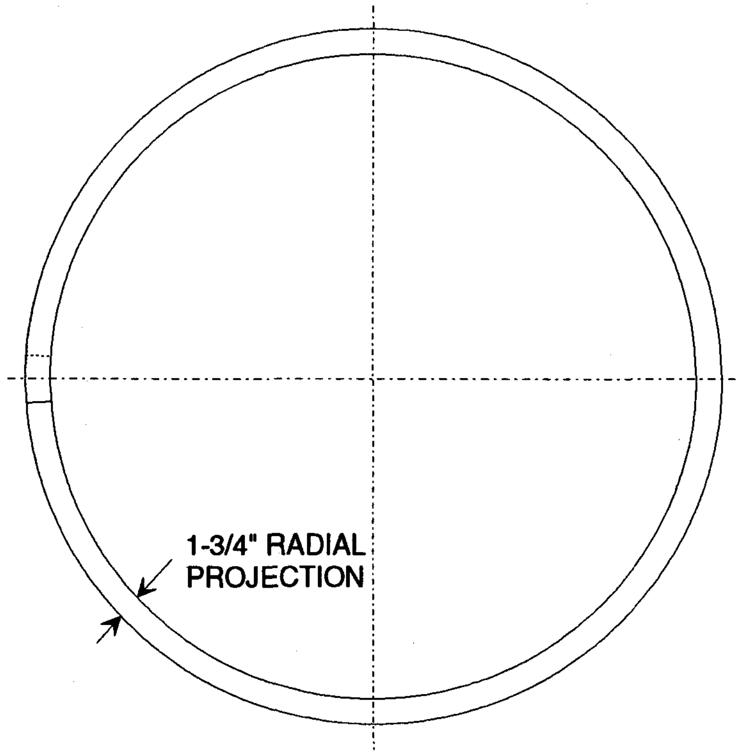
BEAM TUBE STIFFENERS

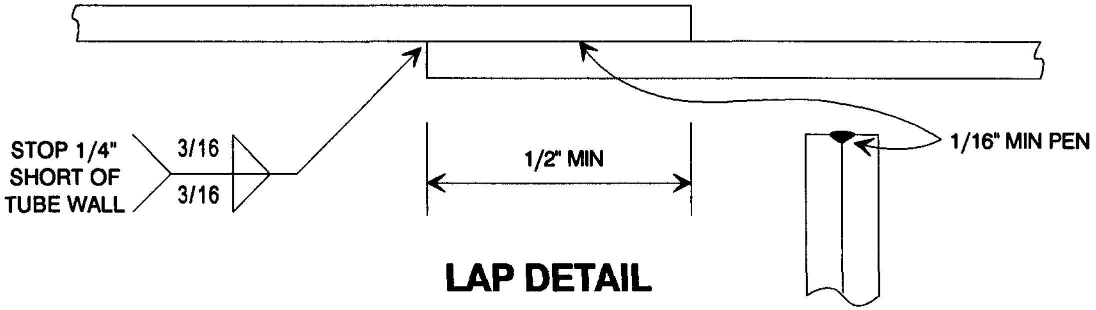
Design Options

- 304 stainless steel
- 304L stainless steel (same as tube wall)
- Other more expensive stainless materials which do not return benefit to degree of added cost
- A36 carbon steel

- External pressure design rules
  - ASME Pressure Vessel Code
  - Alternate rules of ASME Code Case N-284
  - Alternate Rules of API Bulletin 2U
- Stiffener attachment weld requirements
  - ASME Section VIII, Division 1
  - Alternate rules which satisfy strength requirements


1" ± 1/2"
OVERLAP
3/16"


1-3/4" RADIAL
PROJECTION


STOP 1/4"
SHORT OF
TUBE WALL
3/16
3/16
1/2" MIN
1/16" MIN PEN

LAP DETAIL

BEAM TUBE STIFFENERS

Preliminary Design

- Based on:
  - 48" I.D. tube
  - 0.1250" wall thickness
  - 304L stiffener material
  - Attachment weld satisfying ASME strength requirements
- Stiffener size: 3/16" x 1-3/4"
- Spacing: 27.7" maximum
- Attachment weld: 1/8" continuous fillet, nearly 360° around, one side only
- Basis of prequalification investigations
- Design is somewhat affected by increase in tube diameter

- Use of carbon steel would:
  - Require expensive painting operations
  - Require compatible weld material, more difficult weld
  - Require sealing of unwelded crevices to inhibit corrosion
- Use of 304 stainless would:
  - Require next available bar width (2")
  - Increase material weight by 14%
  - Save only 4% in base material grade costs

PUMP PORTS

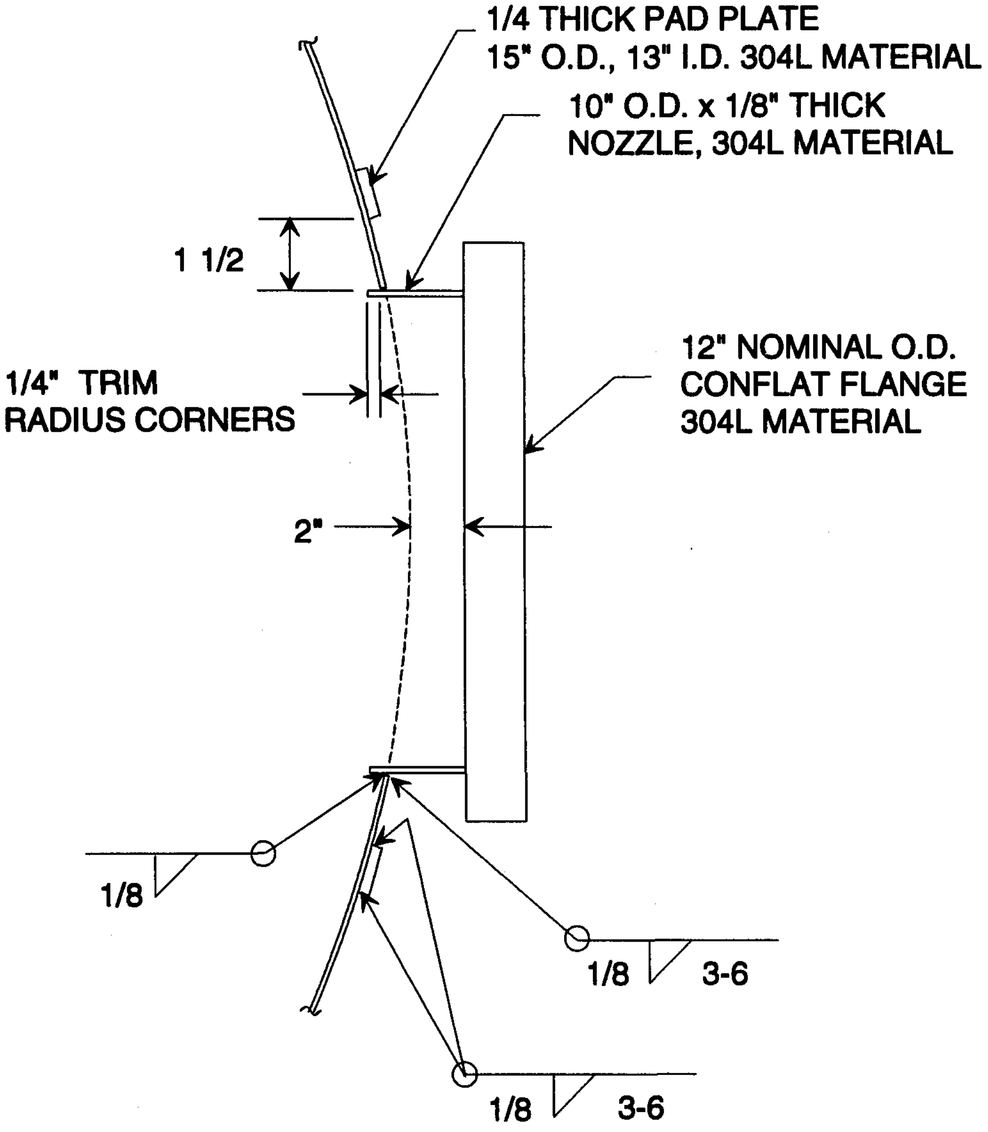
Requirements

- 25cm nominal diameter
- Conflat flanges
- 150# vertical dead load at face imposed by attached valve
- 7 per module @ ~250m spacing
- Tube wall reinforcement as required by ASME

PUMP PORTS

Critical Parameters

- Flange size and bolting compatible with mating flange
- Neck material produced and fabricated in accordance with LIGO specification
- Weld details which eliminate potential for creation of a virtual leak
- Fabrication and attachment of neck to flange



25 cm NOMINAL DIAMETER PUMP PORT

MODULE GENERAL PLAN

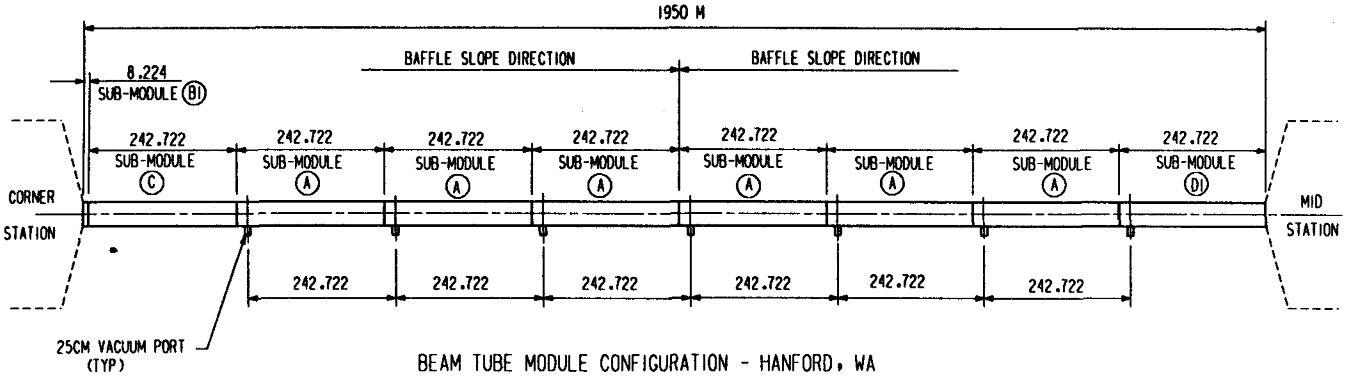
Proposed Layout

- All Beam Tube Sections at both sites of uniform length (20.23m)
- Single make up section to account for difference in module length of 2 sites
- Pump ports equally spaced @ ~243m (every 12th Beam Tube Section)

- Majority of baffles to be placed near end of Beam Tube Section:
  - Eliminates effect of tube deflection
  - Provides direct control of clear aperture by support adjustments
  - Assures roundness of if stiffener rings are specifically required at supports
  - Facilitates installation w/o requiring access far inside tube

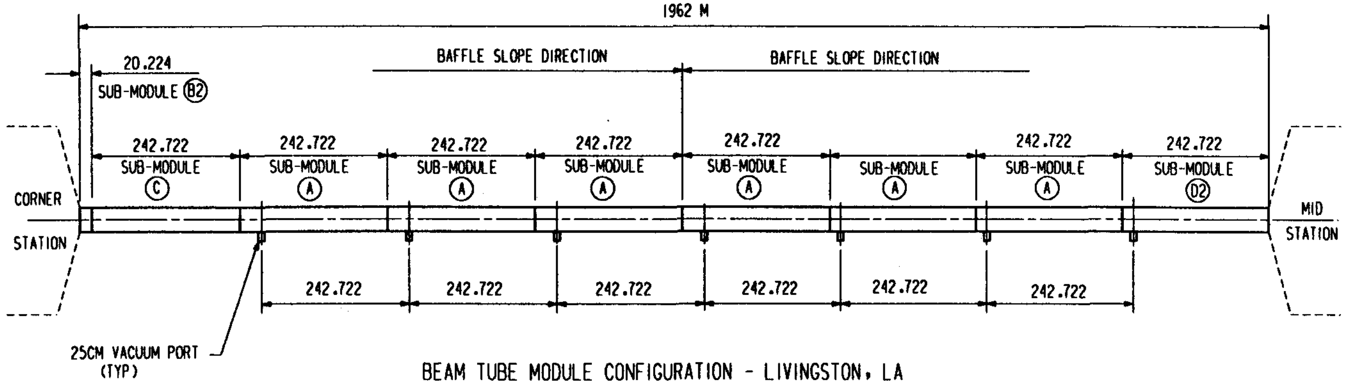
- Beam Tube Sections which require more baffles at closer spacing:
  - Represent small percentage of Beam Tube Sections
  - Define required tube diameter
  - Can incorporate most dimensionally correct tube produced

- Totals required for 8 modules at 2 sites:
  - 784 expansion joints
  - 776 supports
  - 928 baffles



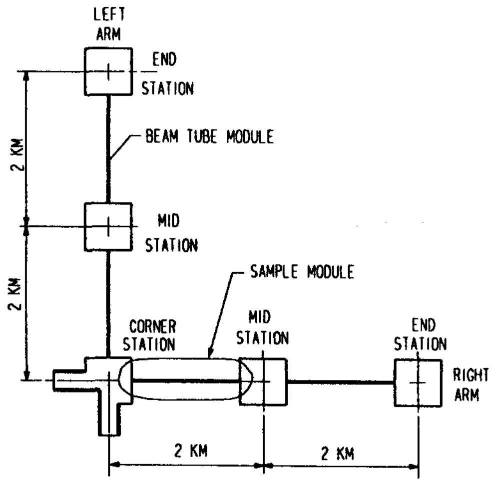
BEAM TUBE MODULE CONFIGURATION - HANFORD, WA

(4) - REQD
(DIMENSIONS IN METERS)
(96) - BEAM TUBE SECTIONS
(1) - END SECTION
(98) - EXPANSION JOINTS
(120) - BAFFLES
(7) - VACUUM PORTS
(97) - SUPPORTS



BEAM TUBE MODULE CONFIGURATION - LIVINGSTON, LA

(4) - REQD
(DIMENSIONS IN METERS)
(96) - BEAM TUBE SECTIONS
(1) - END SECTION
(98) - EXPANSION JOINTS
(112) - BAFFLES
(7) - VACUUM PORTS
(97) - SUPPORTS



NOTE:
WORK THIS DRAWING W/DWG A002.

CBI

SUPPLIER'S / PURCHASER'S NO

LIGO BEAM TUBE MODULES

GENERAL MODULE CONFIGURATION
AND VACUUM PORT LOCATION

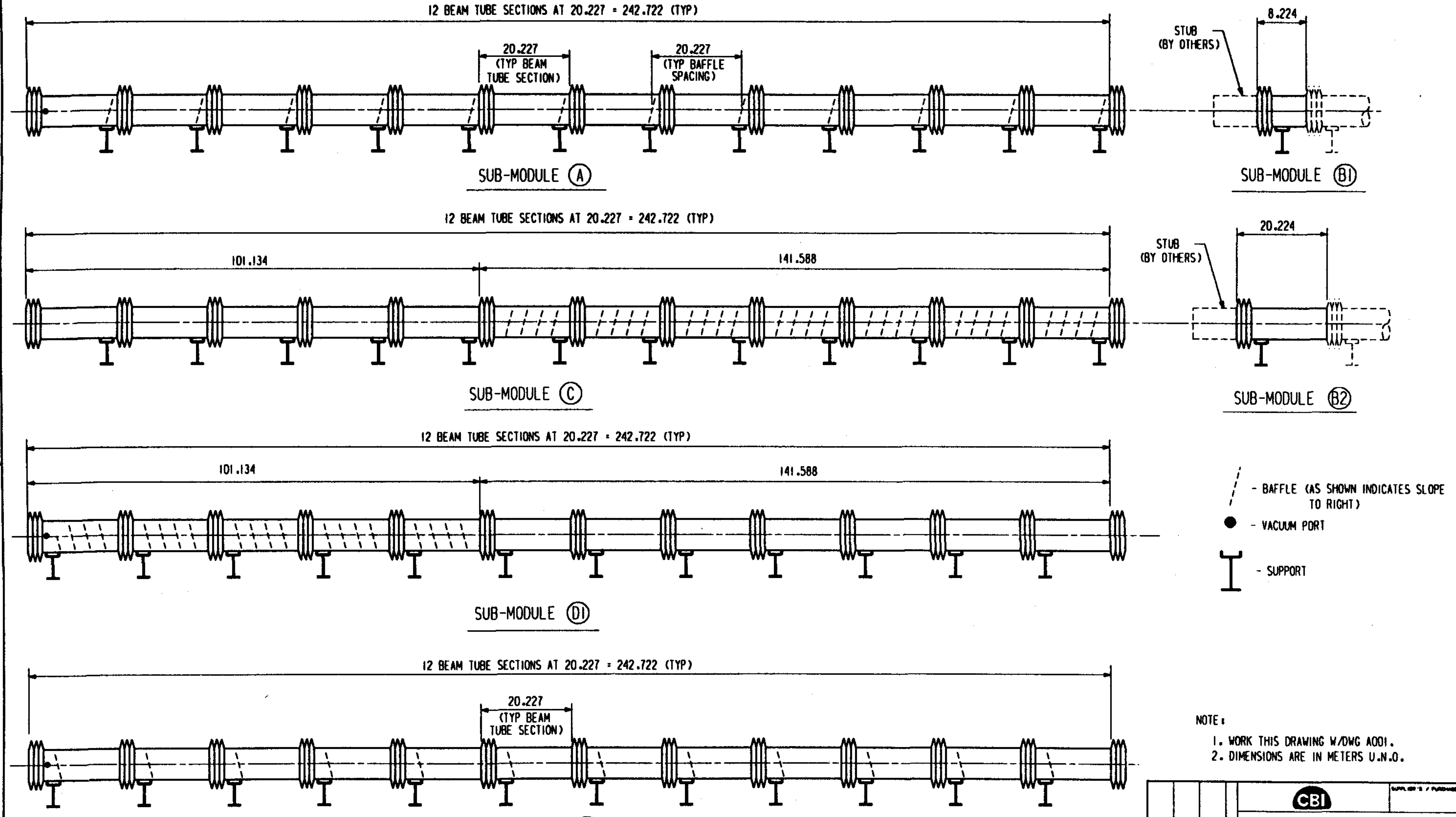
REMARKS

REVISIONS

SUBSCRIBER'S NO ______
BY DAP CHKD ______ DATE ______
J M BLANCHARD
ENGINEERING SUPERVISOR

CONTRACT NO
930212
DWG A001
SHT
REV
0

▶ INDICATES CHANGE FROM PREVIOUS ISSUE



NOTE:

1. WORK THIS DRAWING W/DWG A001.
2. DIMENSIONS ARE IN METERS U.N.O.

SUB-MODULE (A)	SUB-MODULE (B1)	SUB-MODULE (B2)	SUB-MODULE (C)	SUB-MODULE (D1)	SUB-MODULE (D2)
(12) - BEAM TUBE SECTIONS	(1) - TUBE SECTIONS	(1) - TUBE SECTIONS	(12) - BEAM TUBE SECTIONS	(12) - BEAM TUBE SECTIONS	(12) - BEAM TUBE SECTIONS
(12) - EXPANSION JOINTS	(2) - EXPANSION JOINTS	(2) - EXPANSION JOINTS	(12) - EXPANSION JOINTS	(12) - EXPANSION JOINTS	(12) - EXPANSION JOINTS
(12) - BAFFLES	(0) - BAFFLES	(0) - BAFFLES	(28) - BAFFLES	(20) - BAFFLES	(12) - BAFFLES
(1) - VACUUM PORTS	(0) - VACUUM PORTS	(0) - VACUUM PORTS	(1) - VACUUM PORTS	(1) - VACUUM PORTS	(1) - VACUUM PORTS
(12) - SUPPORTS	(1) - SUPPORTS	(1) - SUPPORTS	(12) - SUPPORTS	(12) - SUPPORTS	(12) - SUPPORTS

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

CBI

SUPPLIER'S / PURCHASER'S NO

LIGO BEAM TUBE MODULES

SUB- MODULE DETAILS

REMARKS

REVISIONS

BY CHKD DATE BY CHKD DATE BY CHKD DATE

SUBCONTRACTOR'S NO
BY DAP CHKD DATE
J M BLANCHARD
ENGINEERING SUPERVISOR

CONTRACT NO 930212
DWG A002
SHT
REV 0

COIL STEEL

REQUIREMENTS:

a. Material meets or exceeds Caltech's specification 1100007, Type 304L Stainless Steel Vacuum Products, dated April 5, 1993 and is approved by Caltech.
  - Thickness of 0.130" or less
  - Air Bake material at 440° C +/- 8° C for 36 hours
  - Material samples taken after air bake to confirm acceptable outgassing levels.
  - Materials shall not be used for fabrication until its acceptability is assured.

b. Material meets the requirements of ASME Section VIII, Div. I pressure vessel code.

c. The material surface finish shall be no smoother than 2.5 microns rms roughness. Hot Rolled, Annealed, and Pickled (HRAP) 304L stainless steel is acceptable. Any alternate finish is subject to Caltech's approval.

d. Maintain material traceabilty.

e. Produce, air bake, and test approximately 3,500,000# of 304L coil material to meet the project schedule.

COIL STEEL

CRITICAL PARAMETERS

a. Develop coil steel production and air bake processes that assures compliance with all the LIGO requirements:

- Produce the coil steel to a thickness and thickness tolerance that satisfies both vacuum and structural design requirements.
- Produce the coil material with a surface finish no smoother than 2.5 microns.
- Control the coil steel air bake process to produce acceptable hydrogen content.

b. Develop a coil steel material manufacturing and air bake process that will produce coil steel to meet the LIGO schedule requirements.

c. Develop a coil steel production and air bake process that is economical.

COIL STEEL

Current activities

a. Identifying and contacting potential domestic suppliers of 304L HRAP coil steel

b. Gathering technical and cost information for the coil steel production process to better define the process and establish the capabilities of the coil steel suppliers.

c. Defining the coil steel air bake process.

d. Preparing the preliminary coil steel technical specification and air bake procedure.

Future activities

a. Prepare the final coil steel technical specification and air bake procedure.

b. Obtain quotes from the steel suppliers for the qualification test material.

c. Obtain updated quotes for the 3,500,000# of coil steel for the beam tube modules.

d. Select and order the coil steel material for the qualification test by mid January.

SPIRAL WELDED TUBE MANUFACTURING

REQUIREMENTS

a. Process identification for industry requirements and special LIGO requirements
b. Production capacity and capability
    Schedule, cleanliness, weld expertise, dimensional capability.
c. Quality assurance and control, process inspection and control.
d. Tube section costs, accountability, and financial stability.

CRITICAL PARAMETERS

a. Forming process, weld fit-up, contamination, mill environment
b. Dimensional tolerances, end circumference, sizing and facing
c. Weld quality, weld speed, leak tightness, inspection, and repair
d. Tube inspection at the mill, visual inspection and in-line weld technique evaluation
e. Documentation, material and tube traceability, weld records
f. Limited and effective tube handling and transportation, manufacturer location
g. Quality assurance and process control

FABRICATION PROCESS DEVELOPMENT

a. Pipe industry characteristics, typical product lines, capabilities, and financial condition
b. Pipe mill characteristics and costs
c. Tube mill plant tours
    Naylor Tube, Chicago, Illinois
    Northwest Pipe, Portland, Oregon
    Roscoe Moss, Los Angeles, California
    Tubetec, Sanford, Florida
d. Potentially qualified suppliers: Northwest Pipe and Tubetec

SPIRAL WELDED TUBE MANUFACTURING

NORTHWEST PIPE AND TUBETEC COMPARISON

a. Geographical Location
    NWP is located in Portland Oregon near the Hanford site
    Tubetec is located in Sanford, Florida, the nearest supplier to the Livingston site.
b. Clear truck route: Both facilities are located amenable to interstate and state highway systems. No obstacles to over length shipments.
c. Competitive pricing: The two suppliers will bid on the tubes, with supply for one and/or both sites and the qualification test. The use of one supplier for the qualification test should not preclude use of the other for the option.
d. Initial set up
    NWP must convert existing large diameter carbon steel mill to stainless steel production
    Tubetec can produce thin wall, large diameter tubes with current equipment
e. Special equipment requirements
    None for tube manufacturing for either supplier
    Special on line weld evaluation equipment must be developed.
f. Production capacity
    NWP projects 2 tubes per shift, Tubetec projects 1 1/2 tubes per shift
g. Transportation: freight truck shipment, 4 tubes @ 65' to the trailer for both manufacturers
h. Experience in tube size range
    NWP's tubes in this diameter range are typically much thicker, pervious 3/16" minimum
    Tubetec typically manufactures stainless steel tube in this diameter and thickness

SPIRAL WELDED TUBE MANUFACTURING

i. Equipment capability
    NWP can utilize 36" to 60' coil, Tubetec is presently limited to 16", but evaluating 20" & 24"

j. Welding process
    Both NWP and Tubetec prefer 2-pass TIG, autogenous inside, with filler outside

k. Tolerances: Should not be a problem with either supplier, straightness and circumference control are within the equipment capability, both are very operator dependent.

l. Forming process
    NWP uses a traditional pinch roll forming process. The mill to be used for LIGO can accept 48" wide coil and has a large drive capacity for relatively thick plate.
    Tubetec uses 16" wide coil and relatively thin sheet which eliminates the need for large drives and allows the tube to be "free formed" off the coil.

m. Cleanliness
    NWP produces primarily carbon steel pipe and their 48" mill must be modified for stainless steel. Carbon steel contamination will be difficult to prevent.
    Tubetec is a stainless steel manufacturer and can readily limit contamination

n. Schedule
    Both manufactures can meet the production schedule requirements

o. Inspection: procedures will be developed for inspection in supplier's facility addressing dimensional control, visual weld inspection and potential in line weld inspection.

p. Financial stability
    D & B rates NWP as "fair" (One lien outstanding). NWP currently for sale
    D & B rates Tubetec as "strong"

SPIRAL WELDED TUBE MANUFACTURING

q. Documentation: Each tube to be uniquely identified including material traceabilily by both suppliers

PROCESS AND MANUFACTURER PRE QUALIFICATION

a. Unique requirements of LIGO project require pre qualification prior to qualification test.
b. 20' section of 48" diameter tube to be made by Tubetec and NWP
c. CBI to evaluate tube sections: Visual inspection, dimensional inspection, weld sectioning, portions leak tested.

CURRENT AND FUTURE ACTIVITIES

a. 20' section received form Tubetec and under evaluation at CBI's Houston weld laboratory.
b. NWP tube section should be delivered to CBI sometime in December.
c. Evaluations of pre qualification sections will be used to develop fabrication, welding, dimensional, and inspection requirements for the tube manufacturers.
d. Tube section specification will be prepared for the Final Design Report

Circumferential Butt Weld

Caltech Requirements

- All welds exposed to a vacuum must be done by the GTAW process
- All welds must be full penetration
- All vacuum welds shall be, wherever possible, internal and continuous
- Filler wire shall not be used on welds exposed to vacuum

Circumferential Butt Weld

Key Parameters

- Tube is in fixed (5G) position - welding apparatus must rotate around 360° circumference
- Limited access in and under tube (approx. 18" between tube and foundation, 48" diameter tube approx. 66' long)
- High quality welds required
- Repeatability - 784 total joints to weld (392 at each location)

Circumferential Butt Weld

Equipment Selection

Dimetrics Gold Track II

- Automatic - Reduces chances of operator variation and error
- Programmable to provide repeatability
- Easy to program and control - Reduces training time
- Produces high quality welds
- Capable of meeting all contract requirements

Circumferential Butt Weld

Autogenous Welding

Advantages

- Obtains good weld appearance on inside of tube

Disadvantages

- Will not provide a full thickness weld due to weld shrinkage and gaps
- Root gap must be held at zero with no tolerance permitted for wide gaps to attain a <u>near</u> full thickness weld

Circumferential Butt Weld

Welding Procedure Development

- Determine optimum procedure regarding the addition of filler metal
- Determine best shielding gas and purge gas
- Determine joint configuration and tolerances for gap variation and misalignment
- Optimize welding parameters including amperage, voltage and travel speed

Circumferential Butt Weld

Recommended Welding Procedure

- Dimetrics Gold Track II
- Autogenous root pass with filler metal on second pass - all passes welded from outside
- Shielding gas to be 60% Argon - 40% Helium
- Purge gas to be 100% Argon
- Vertical welds may be welded uphill or downhill

The above procedure meets the contract specifications by providing

- Full thickness weld joint
- GTAW welding process with no filler metal exposed to vacuum

Circumferential Butt Weld

Fit-Up Equipment

- Deerman Rim Clamp

- Very large and hard to attach
- One time fit-up sequence
- Conforms shape of one tube to the other which minimizes miss-match

- Deerman Chain Clamp

- Light weight and easy to attach
- Requires several fit-up sequences

- CBI Equipment

- Currently developing equipment to utilize both types of clamping operations

Stiffener Cost Analysis

Equipment Costs

Manufacturer	Description	Cost
CBI	Stitch Welding	245,296
CBI	Stitch Welding (without torch shifting)	230,193
Ransome	Stitch Welding (without torch shifting)	244,155
CBI	Continuous Welding	191,661

Repair Costs

	Continuous	Stitch
# Starts/Stops	46,000	1,734,200
(Assume 5% repair rate to starts/stops at 15 min/repair)		
Repair Costs	20,125	758,713

Stiffener Cost Analysis

	Continuous	Stitch
Cost of Equipment	$191,661	$245,296
Cost of Repairs	$20,125	$758,713
Cost of Filler Metal	$121,716	$60,858
Total Cost	$333,502	$1,064,867

By Cost Comparison, Welding One Side Continuous Would be more Economical

Vacuum Port Welding

Requirements

- All welds exposed to a vacuum must be done by the GTAW process
- All welds must be full penetration
- All vacuum welds shall be, wherever possible, internal and continuous
- All external welds added to these for structural purposes shall be intermittent to eliminate trapped volumes
- Filler wire shall not be used on welds exposed to vacuum

Vacuum Port Welding

Key Parameters

- Support tube to minimize distortion due to weld shrinkage
- High quality weld
- Limited access to inside of tube
- Limited access to outside of flange neck
- Limited number of vacuum ports per site (approx. 28)

Vacuum Port Welding

Welding procedures

- Continuous fillet weld on inside of tube with intermittent fillet welds on outside of tube
  - Must be welded from inside of tube, limited space
- Full penetration weld from outside of tube
  - Can be welded from the outside
  - Excessive heat input due to full penetration

These welding procedures are still under development

Spiral Weld Procedure

<u>Caltech Requirements</u>

- All welds exposed to a vacuum shall be done by the GTAW process
- All welds must be full penetration
- All vacuum welds shall be, wherever possible, internal and continuous
- All external welds added to these for structural purposes shall be intermittent to eliminate trapped volumes
- Filler wire shall not be used on welds exposed to a vacuum

Spiral Weld Procedure

Key Parameters

- Mill capabilities
- Ability of the mills to adapt to our needs
- Fast welding rate to be economical
- High quality welds
- Repeatable (approx. 16 km of tube)

Spiral Weld Procedure

Autogenous Welding

Advantages

- Obtains good weld appearance on inside of tube

Disadvantages

- Will not provide a full thickness weld due to weld shrinkage and gaps
- Root gap must be held at zero with no tolerance permitted for wide gaps to attain a near full thickness weld

Spiral Weld Procedure

Mill Recommended Procedure

- Two pass procedure
  - First pass autogenous on inside
  - Second pass hot/cold wire on the outside
  - Shielding gas 60% argon - 40% helium
- On-line inspection to assure full fusion

Spiral Weld Procedure

Follow-Up Activities

- Obtain samples from possible tube vendors
- Dimensional tolerances of sample tubes
- Leak testing of sample tubes
- Cross-sectional analysis of tube spiral welds
- Welding procedure verification for circumferential welds and stiffener attachment

Stiffener Attachment Welds

Caltech Requirements

- Inside of tube must be shielded with an inert purge gas
- All external welds added for structural purposes shall be intermittent to eliminate trapped volumes

Stiffener Attachment Welds

Key Parameters

- Should be welded downflat
- High deposition rate
- Repeatable (23000 total, 11500 per site)
- Low heat input to minimize oxidation, distortion and burn throughs
- Minimal clean-up time

Stiffener Attachment Welds

Process Selection - GMAW

- **Short circuit**
  - Low heat input to minimize oxidation
  - Weld spatter that requires post cleaning
  - Low tolerance for torch positioning
- **Fluxed Cored**
  - Higher heat input yet purge yielded little oxidation
  - Very clean as-welded appearance
  - Forgiving in torch position

Stiffener Attachment Welds

Joint and Weld Details

- **Full penetration groove weld**
    - Requires excessive heat input which causes distortion
    - Will not obtain a full penetration weld
- **Continuous fillet weld on one side**
    - More filler metal required resulting in higher cost
- **Intermittent fillet welds on both sides**
    - Requires less filler metal
    - More starts/stops which are potential weld repairs
    - Expensive operating equipment

Stiffener Attachment Welds

Recommended Welding Procedure

- Fluxed Cored welding process
- Shielding gas 75% Argon - 25% Carbon dioxide
- Purge gas 100% Nitrogen
- Travel speed 16 inches per minute
- Continuous fillet weld on one side only

The nitrogen purge provides inert gas shielding to reduce oxidation
A continuous fillet weld on one side will not trap any virtual leaks

SUBASSEMBLY CONSTRUCTION

REQUIREMENTS

a. Dimensional inspection and documentation.
b. Stiffener, expansion joint, and pump port attachment to weld procedure including purge.
c. Subassembly leak testing to specified leak rate sensitivity and repair if required.
d. Cleaning to final procedure to remove visible traces of contamination.
e. Sealing and transportation of subassemblies to field for installation.

CRITICAL PARAMETERS

a. Effective and economical attachment of the stiffeners with specified weld procedure.
b. Effective and efficient expansion joint attachment with specified weld procedure.
c. Effective and efficient detection and location of leaks at specified sensitivity.
d. Facility location to limit handling and transportation costs of tube subassemblies.
e. Automated execution of the cleaning procedure in a clean environment.
f. Sealing and effective prevention of contamination.
g. Production rate and process integration and control.

SUBASSEMBLY CONSTRUCTION

SUBASSEMBLY FABRICATION SEQUENCE

a. A general process flow diagram has been developed and work will be by specific procedure

b. The general sequence of work is as follows:

1. Receive & inspect materials
2. Fit stiffeners to tube
3. Weld stiffeners to tube
4. Inspect and measure stiffened tube
5. Fit and weld pump ports
6. Inspect and measure
7. Fit and weld expansion joint
8. Inspect and measure to center
8. Leak test subassembly & repair if req'd
10. Clean subassembly and seal

c. Special equipment is required for the following:

- Stiffener fit up and purge
- Expansion joint fit up & welding
- Leak testing and location
- Stiffener welding
- Pump port installation
- Cleaning automation

SUBASSEMBLY FABRICATION LOCATION OPTIONS

a. Tube mill fabricators location

Advantages: Enables leak detection just after tube fabrication.
Limits tube transpiration and handling.

Disadvantages: Tube manufacturers do not have capabilities beyond tube fabrication
Attachment of stiffeners may restrict shipping to one tube per truck

b. Fabrication facility in vicinity of the tube manufacturer.

c. Current CBI fabricating facility.

d. Fabrication facility in the vicinity of the LIGO sites

e. Fabrication at the LIGO sites.

SUBASSEMBLY CONSTRUCTION

ADVANTAGES AND DISADVANTAGES OF LOCATION OPTIONS

a. Tube fabricators do not have the abilities or facilities to meet LIGO requirements

b. Fabrication near the tube fabricator makes cleanliness maintenance difficult and may restrict shipping to one tube per truck but may be feasible.

c. Existing CBI shops are oriented toward thick carbon steel plate fabrication. Dedicated floor space for this special work and cleanliness would be problematic.

d. Leasing of fabrication facilities near the site will limit the contamination problems associated with off site fabrication and cleaning, would limit site activity, and may not be cost prohibitive.

e. Site fabrication is presently the preferred location due to:

- Project dedicated resources
- Better management control
- Use of highly skilled personnel
- Minimizes handling costs and risks
- Standard CBI approach
- Cost control
- Better process control
- Standard CBI approach
- Facilitates cleaning maintenance

CURRENT ACTIVITIES AND PROPOSED COURSE OF ACTION

a. Finalize process development and control requirements

b. Develop layout of optimum subassembly fabrication facility.

c. Assess feasibility and costs of site fabrication facility

d. Assess feasibility, availability, and costs of fabrication facility near each site.

BEAM TUBE MODULE CONSTRUCTION

REQUIREMENTS

a. Subassembly transportation to field placement location.
b. Cleanliness maintenance.
c. Subassembly placement
d. Initial alignment and fit up to module in progress
e. Attach permanent support and adjust leveling mechanism
f. Weld circumferential seam
g. Remove fit up and purge equipment
h. Clean weld and inspect tube for cleanliness during tube exit
i. Seal tube end and prepare for next section

CRITICAL PARAMETERS

a. Maintain cleanliness and integrity of tube subassemblies.
b. Efficient and effective of circumferential weld
c. Detect and locate any leaks in circumferential weld to required sensitivity and repair
d. Controlled and limited personnel access to prevent contamination ensure worker safety
e. Final inspection to ensure that tube access is no longer required
f. Maintain clean environment in module under construction to ensure cleanliness
g. Develop fabrication and installation procedures for two sites
h. Develop plans and procedures for testing & acceptance
i. Provide a clean site at completion

BEAM TUBE MODULE CONSTRUCTION

SPECIAL EQUIPMENT: Special erection equipment is required for:

Portable Clean Room
Portable Leak Test Room
Positive Air Flow System For In-Place Tubes
Portable Welding Room
Special Fit Up Device & Weld Equipment

ERECTION PLAN: The general process flow diagram reflects the activities. Detail procedures control the work. The general sequencing of the work is:

1. Transport Tubes
2. Fit Tubes Together
3. Purge
4. Weld
5. Vacuum Leak Test
6. Clean & Seal
7. Align Tube

Clean room and weld room and testing room are moved as required to accomplish work and protect the tube interior.

Detailed process flow has been made indicating each step of fabrication.

Processes are automated to produce predictable quality work and to minimize labor dependence.

At site simple hauling trailers will be used

Work flow: Detailed process flow has been made indicating each step of erection.

Work covers: Shelters must be provided for clean room access, welding, and leak testing

Buildings: All temporary buildings will be removed, consideration will be given to leaving structures useful to project. unusable slabs will be removed.

GENERAL CONTRUCTION PLANS

REQUIREMENTS

a. Project coordination and control
b. Subcontractor coordination and control
c. Personnel safety
d. Site and component security
e. Environmental preservation
f. Personnel management

CRITICAL PARAMETERS

a. Accident prevention
b. Productivity and cost control
c. Schedule maintenance
d. Defined responsibilities and accountability
e. Partnering

GENERAL CONTRUCTION PLANS

GENERAL CONSTRUCTION PLAN CONTENTS

- Mobilization
- Subcontracting Plan
- Contract Administration
- Transport
- Quality Plan
- Environmental Plan
- Demobilization
- Procurement
- Project Organization
- Fabrication Plan
- Erection Plan
- Safety Plan
- Schedule & Costing
- Commissioning/Acceptance

CONTRACT ADMINISTRATION

- Project Procedures
- Insurance
- Accounting
- EEO Program
- Labor Policy
- Changes
- Local Permitting
- Site Security
- Documentation
- Substance Abuse Program
- Minority Subcontracts Plan
- Patents/Inventions/Rights
- Certifications
- Termination/Liability

GENERAL CONTRUCTION PLANS

PROCUREMENT PLAN

- Contract/P.O. Provisions
- Authorization
- Expediting
- Value Engineering
- Traffic Of Goods
- Damaged Supplies
- Federal Regulations
- Release Of Lien
- Termination/Liability
- Notification, Approvals
- Special Equipment
- Pricing & Analysis
- Use Of Government Facilities
- Supplier Corrective Action
- Stop Work Orders
- Gov't. Furnished Equipment
- Certifications Of Materials

SUBCONTRACTING PLAN

- Subcontract Provisions
- Major Subcontract Areas
- Federal Notification Requirements
- Minority/Small Business Subcontracting
- Local Subcontracting

QUALITY PLAN

Plan Model: As Per ISO 9000 (Also Known As ANSI/ASQC Q91-1987), But Without Certification. This Incorporates ASME Code Requirements Needed By Contract .

GENERAL CONTRUCTION PLANS

MANUAL ADDRESSES FOLLOWING:

- Management Responsibility
- Contract Review
- Document Control
- Purchaser Supplied Products
- Process Control
- Inspection, Measuring, And Test Equipment
- Control Of Non conforming Product
- Handling, Storage, Packaging, And Delivery
- Quality Records
- Training
- Quality System
- Design Control
- Purchasing
- Product Identification & Traceability
- Inspection & Testing
- Inspection & Test Status
- Corrective Actions
- Statistical Techniques
- Internal Quality Audits
- Servicing

SAFETY PLAN

Program Developed Based On CBI Standard Accident Prevention Program And Associated General Contractors Safety Program. Covers All Trades

Confined Working Space Requirements Are In Safety Program

Draft Manual Completed, Final Manual Being Tailored For LIGO Application

GENERAL CONTRUCTION PLANS

ENVIRONMENTAL PLAN

General Conditions Written And Included In This Submittal

Plan Addresses:

- Site Documentation
- Hazardous Materials
- State/Local Requirements
- Sanitation
- Communication
- Chemical Hygiene
- Site Clean Up
- Storm Water Permits
- Regulatory Inspections
- Outfall Discharges
- Training
- Spill Prevention
- Fuel Handling

SCHEDULE & COST CONTROL

CPM Software: Using PC/Windows Driven Program, "Texim" Which Can Convert To Database "Open Plan" If Required

Reporting And Formats To Be Established:

- Update Timing
- Submittal Control
- Short Term Scheduling
- Dual Site Coordination
- Progress Reporting
- Schedule Meetings
- Payment Evaluation
- Detail Level Of WBS

GENERAL CONTRUCTION PLANS

ORGANIZATION

Team to be located in Houston with site assignments dictated by developing work scope. Organization chart shows relationships with CBI resources.

SITE LOCATION

It is anticipated that there will be adequate time for the team and equipment to move from Hanford, to Livingston, no overlap or duplication is anticipated.

DEMOBILIZATION

Equipment: Following Completion, All Equipment Will Be Removed Form The Sites

Buildings: All Temporary Buildings Will Be Removed, Consideration Will Be Given To Leaving Structures Useful To Project. Unusable Slabs Will Be Removed.

Personnel: Necessary Supervisory Personnel Will Remain On Site Until Demobilization Effort Is Acceptable To Caltech.

ALIGNMENT

REQUIREMENTS:

a. Align the beam tube to ensure that no part of the beam tube will intrude into the 1.07 meter minimum clear aperture.

b. During the construction process align each beam tube section to a level of accuracy that permits final alignment within the construction adjustment allowance for the supports.

c. Final align the beam tube module after construction to the final alignment that ensures the beam tube (including the baffles) will not intrude into the 1.07 meter clear aperture. This alignment uses only the adjustment allowance allotted for construction.

d. Prepare and install a system for operational alignment of the beam tube. This system will provide the means to periodically monitor and adjust the alignment of the beam tube. The system will provide a support adjustment range of +/- 7.5 cm in both the vertical and horizontal directions.

e. Provide the most accurate and reasonably priced alignment system that minimizes the beam tube diameter.

ALIGNMENT

CRITICAL PARAMETERS:

a. Establishment of the 1.07 meter clear aperture between the monuments spaced at 250 meters provided by Caltech.

b. Determination of the beam tube centerline at the baffle locations using an external alignment measuring system.

c. Confirm by calculation and/or measurement the critical dimensions of beam tube parts that cannot be checked during the final alignment of the beam tube.

d. Develop the most cost effective method to accomplish the initial and operational alignments that meet the specified requirements.

ALIGNMENT

CURRENT ACTIVITIES:

a. Developing two alignment systems applicable for use on LIGO
  - A system that uses optical tooling equipment and techniques.
  - A system that uses 3-D surveying equipment and techniques.

b. Comparing the accuracy, equipment costs and operating costs for the two alignment systems.

FUTURE COURSE OF ACTION:

a. Select the system that is best for the LIGO project.

b. Prepare the final procedures for alignment during construction, final alignment after construction, and periodic operational alignment.

c. Develop the special equipment needed for the alignment.

d. Prepare a plan to demonstrate the alignment procedures during the qualification test if required

d. Perform the alignment demonstration during the qualification test.

CLEANING

1. REQUIREMENTS

a. No visible contaminant material of any form

b. Cleaned in accordance with the Caltech specified cleaning process
    Solvent wipe, 2% Oakite hot water wash and rinse, repeat

c. Maintain cleanliness during installation and construction

2. CRITICAL PARAMETERS

a. Effective execution and control of the cleaning process

b. Safe handling and disposal of cleaning solvents and liquids

c. Automated process execution with limited spot and hand cleaning to minimize cost
    (Strictly controlled and limited entry and controlled environment)

d. Limit contamination after "final" cleaning to limit rework and degrade cleanliness

e. Effective final inspection

3. CLEANING PROCEDURE OPTIONS

a. Caltech specified cleaning procedure:
    Effective procedure with known characteristics
    Potentially dangerous Oakite 33
    Disposal may be costly

b. CBI cleaning procedures
    Successfully used on high vacuum facilities
    Known effective in cleaning and iron freeing
    Unknown effects on hydrogen outgassing characteristics

CLEANING

4. CLEANING PROCEDURE DEVELOPMENT

a. Caltech specified cleaning process:
  - Develop procedure for execution of the specified cleaning process
  - Determine costs of handling and disposing or of neutralizing Oakite 33

b. Develop an alternate cleaning procedure based on CBI's past experience
  - Determine an alternate cleaning procedure based on CBI's experience
  - Determine the effectiveness and outgassing characteristics of alternate procedure
  - Elevated temperature to truly steam clean opposed to the 60 degree C specified
  - Determine the costs of executing the alternate process
  - See alternate cleaning procedure CLALT

5. OVERALL CLEANING PLAN:

a. Cleaning procedure "LIGOCP"Brief description of procedure and additional requirements

6. PURCHASED ITEMS:

a. Baffles final cleaned by fabricator in controlled environment, bagged and sealed for shipment

b. Preliminary cleaning and protection of tube and expansion joint by the manufacturer

CLEANING

7. TUBES PRECLEAN AT SITE:

a. Initial black light inspection per procedure VT1
b. Alcohol solvent wipe down to remove hydrocarbons per procedure CL1N
c. Stiffener attachment, bellows attachment, and leak test on precleaned sections

8. TUBE ASSEMBLY CLEANING:

a. Steam jet cleaning with Oakite 33
b. De ionized hot water rinse
c. Recycle cleaner with neutralizers for spent fluids. per procedure CL1N if contamination can be eliminated
d. Seal tubes after cleaning in a security controlled clean room area

9. CLEANING MAINTENANCE:

a. Positive filtered air flow & pressure in installed tubes per procedure BDF1
b. Filtered air to have humidity and cleanliness controls
c. Traveling clean room per procedure CR1TSM

LEAK TESTING

1. REQUIREMENTS

a. Helium leak rate of each module not to exceed 1 x 10^{-10} atm cc/s
b. Vacuum level during operation nominally 10^{-9} to 10^{-10}.
c. Each beam tube section leak tested and documented prior to field installation.
d. Beam tube module leak procedure required.

2. CRITICAL PARAMETERS

a. Component leak rate sensitivity to ensure total module leak rate
b. Effective and efficient methods of detecting and locating leaks
c. Locate leaks prior to module completion through component and local leak test methods
d. Leak detection integrated into the construction process to maintain production
e. Non contaminating leak test procedures

3. COMPONENT LEAK TEST PROCEDURES

- a. Expansion joint to be tested by manufacturer by CBI approved procedure
- b. Tube section with expansion joint leak tested per CBI procedure HMST1N
  - Hood chamber for leak detection.
  - Separate leak location if required per Time of Flight method
- c. Circumferential field seams leak tested locally per CBI procedure HMST2N
  - Inside helium purge with outside curved vacuum box and seal
- d. Equipment selected to test to 1 x 10^{-11} $^{\text{OR } -12}$
- e. Equipment perfrmance to be demonstrated by supplier

4. MODULE TESTING:

- a. All tubes must have successfully passed component test and closing seam test
- b. Caltech bake out complete. Utilizes Caltech furnished pumping system, per procedure HSTM3N if required

COUPON TEST SYSTEM

Requirements

- Provide coupon test facility to test hydrogen outgassing rates of all material to be supplied for the beam tube modules and for the Qualification Test beam tube.
- Test the material for the beam tube modules and for the Qualification Test beam tube.
- Supply Caltech with outgassing data for determination of material acceptability

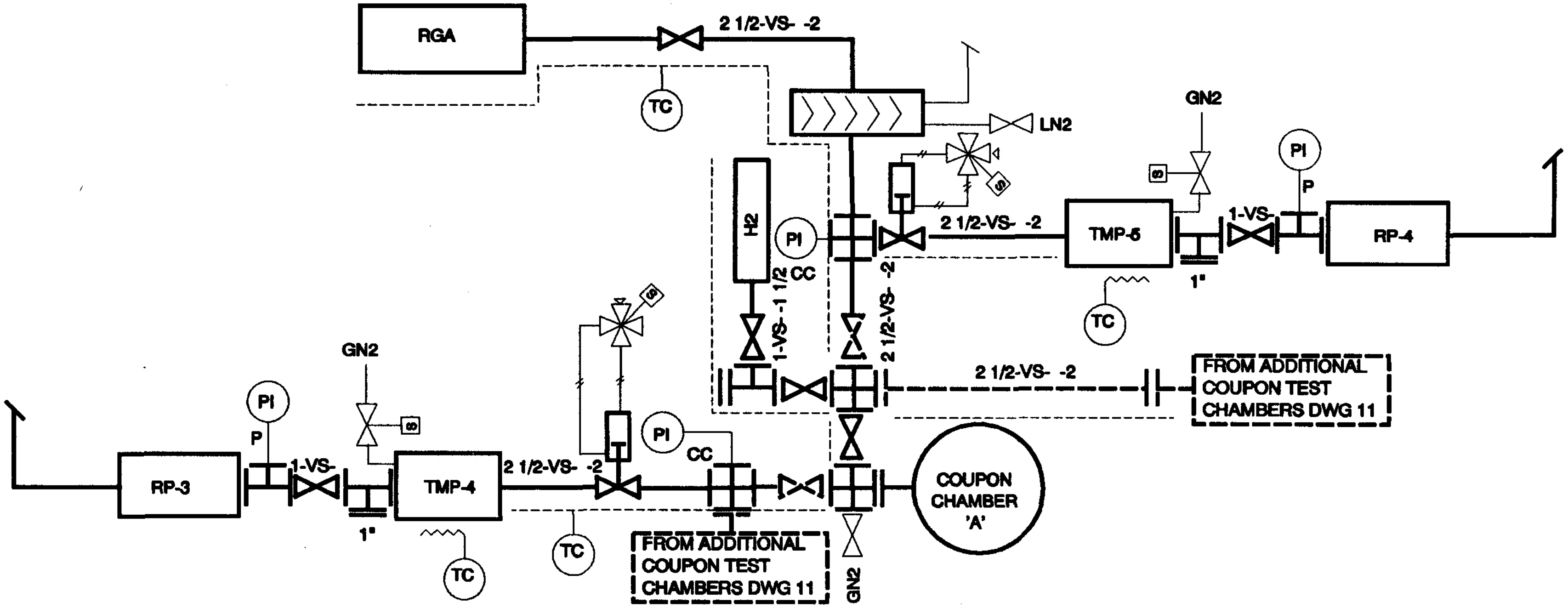
Critical issues

- Maximize the surface area ratio between the coupons and the test apparatus.
- Minimize the test apparatus hydrogen outgassing rate.
- Minimize false hydrogen outgassing rate from water vapor and hydrocarbons.

COUPON TEST SYSTEM

Selected Configuration

- Same size chamber and coupons as Caltech for data compatibility and error reduction.
- Chamber baked to reduce outgassing.
- Use wide range turbomolecular pumps for UHV pumping.
- Cold trapped RGA for elimination of false H2 outgassing data.
- Bake all piping and equipment to component temperature limitations.
- Use "no frills" chamber to minimize outgassing, and leakage possibilities.
- Provide pumping systems with automatic valving to minimize possibilities of contamination.
- Minimize system surface area by close-coupling equipment.



NOTE:

--------- INDICATES LINES OR FITTINGS REQUIRED FOR MULTIPLE COUPON TEST CHAMBERS WHICH WOULD BE SUPPLIED FOR THE FULL CONSTRUCTION PHASE. THESE FITTINGS WILL NOT BE SUPPLIED FOR THE QUALIFICATION PHASE OF THE PROJECT.

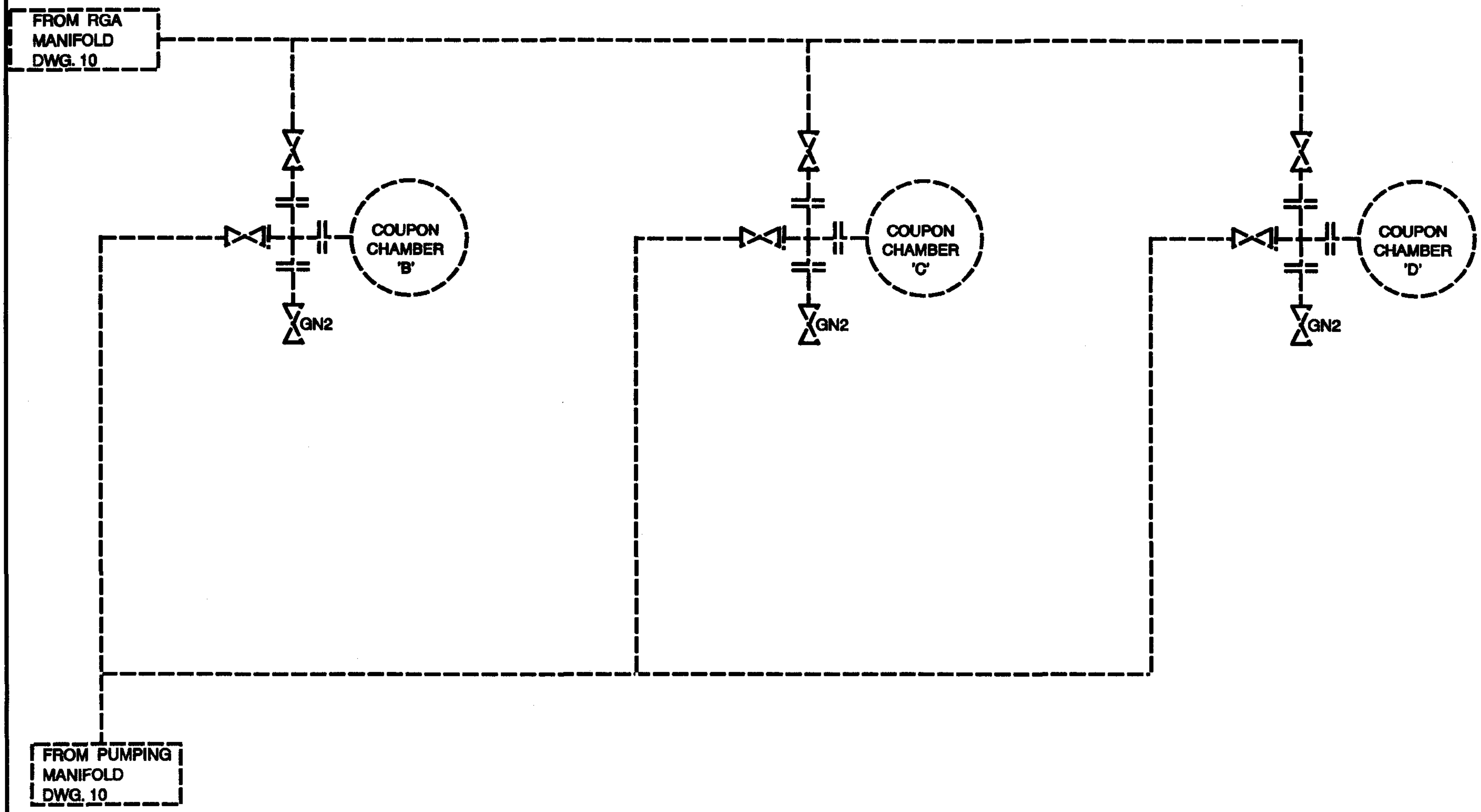
CBI

P & I DIAGRAM
VACUUM SYSTEMS
COUPON TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/8/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 10
SHT 1
REV 1



P & I DIAGRAM
VACUUM SYSTEMS
COUPON TEST
LIGO PROJECT
CALTECH

BY WAC CHKD _____ DATE 11/3/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 11
SHT 1
REV 0

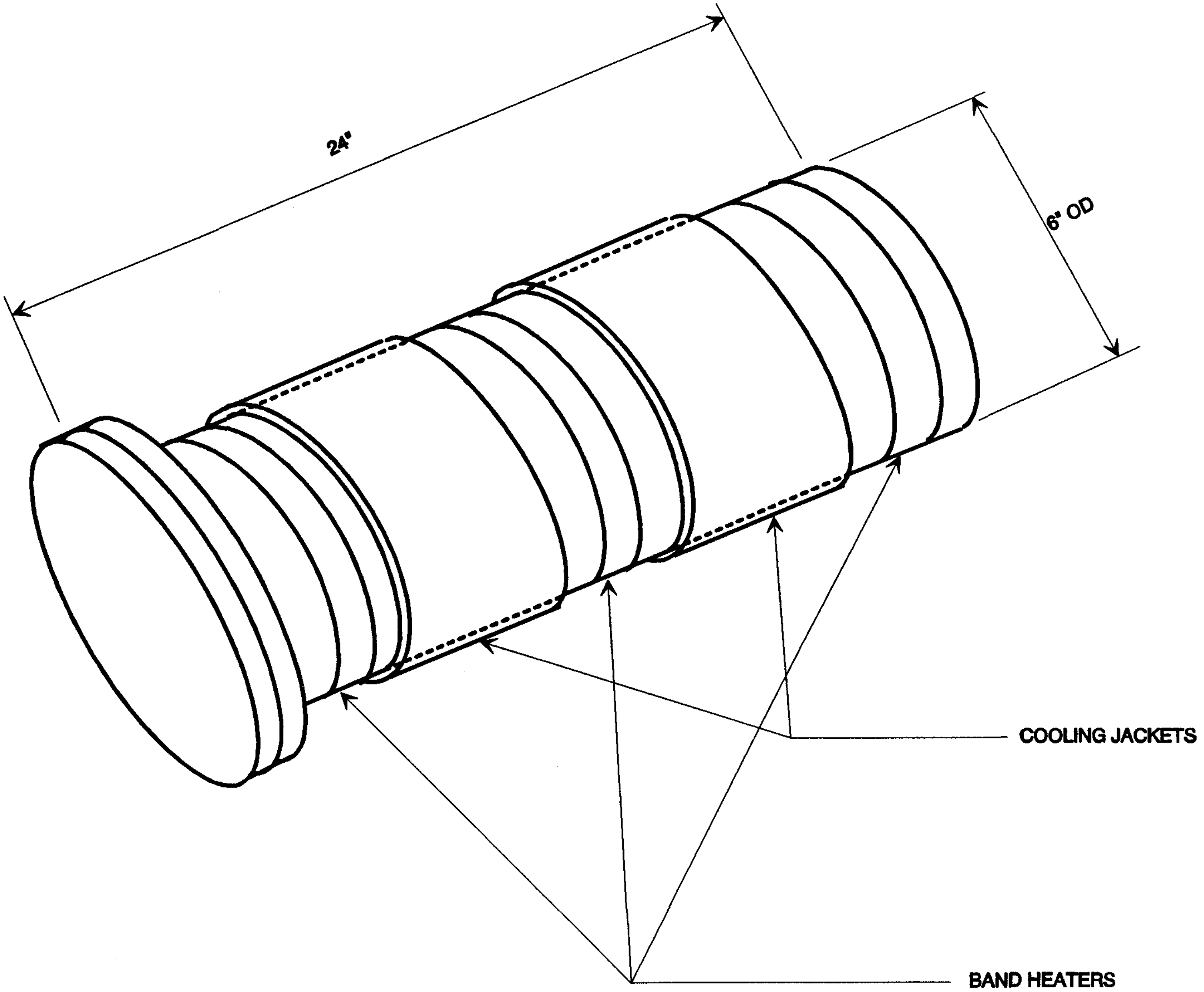


FIGURE 'A'

PRELIMINARY COUPON OUTGASSING TEST PROCEDURE

1. Clean and assemble all components.
2. Leak check the system.
3. Insulate the system.
4. Evacuate the vessel and all ancillary systems
5. Bake out the system for a minimum of one week at 300°C (the turbomolecular pumps will be baked at only 120°C due to equipment temperature limitations).
6. Cool to ambient temperature.
7. Leak check flanges to confirm leak tightness after bake-out.
8. Fill the RGA cold trap.
9. Activate the RGA and record the hydrogen outgassing rate.
10. Repeat steps 5 through 9 until the hydrogen outgassing rate stabilizes.

PRELIMINARY COUPON OUTGASSING TEST PROCEDURE

11. Calibrate the system using the calibrated leaks after each outgassing measurement.

12. Repressurize the chamber with nitrogen.

13. Clean the coupons with the approved cleaning procedure, stamp the coil identification into one of the coupons, record the I.D. and load into the vessel.

14. Bake the vessel at 250°C for 24 hours. The 24 hour timing starts after the coupons are all up to 250°C.

15. Cool to ambient temperature. Possible backfill with helium or nitrogen to enhance the cooling and reduce waiting perion for cooling.

16. Evacuate the chamber if backfilled. Record the outgassing rate.

17. Repressurize the vessel with nitrogen and remove the coupons. Package the coupons and store until after beam tube module acceptance.

18. Evacuate the vessel and bake for 24 hours at 250°C.

19. Cool to ambient temperature.

20. Fill the RGA cold trap

PRELIMINARY COUPON OUTGASSING TEST PROCEDURE

21. Record the hydrogen outgassing rate for the empty system.

22. Calibrate the RGA

23. Average the outgassing rates for the empty system taken prior to the coupon test and after the coupon test. Subtract the average empty system background outgassing rate from the coupon test outgassing rate.

QUALIFICATION TEST OUTGASSING TEST SYSTEMS

Requirements

- Test the Qualification Test beam tube for hydrogen and water vapor outgassing rates.
- Provide a system to Measure the above outgassing rates.
- The desired material outgassing rates are 1 X 10^{-13} T L/sec cm^2 for hydrogen and 1 X 10^{-16} T L/sec cm^2 for water vapor after a 30 day bake at 140°C.
- Net water vapor pumping speed must be less than 600 L/Sec in order to simulate the ratio of surface area to pump speed which will be available on the beam tube modules.

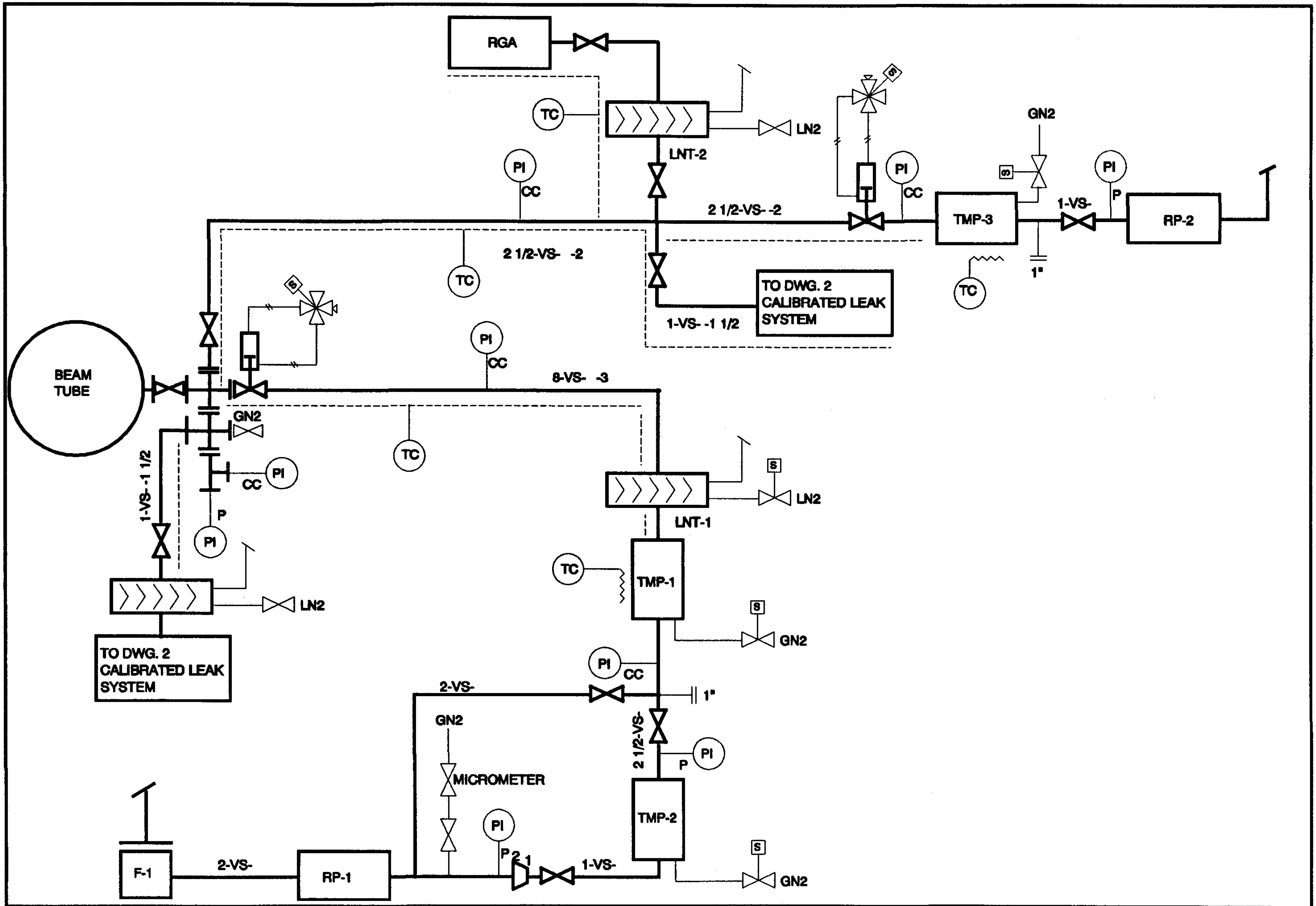
Critical Issues

- Background outgassing rate for water vapor are critical due to the extremely low outgassing rate.
- High quality RGA is required to provide maximum measurement sensitivity.
- Minimize contamination from hydrocarbons and water vapor

QUALIFICATION TEST OUTGASSING TEST SYSTEMS

Selected Configuration

- Pay specific attention to the system to reduce surface areas and minimize water and hydrocarbon contamination.
- Cold trap the RGA to eliminate false hydrogen rates due to ionization.
- cold trap the pumping system to prevent contamination. Ensure that the net water pumping speed is less than 600 L/Sec.
- Bake out the entire system to reduce water and hydrocarbons.
- Select dry calibrated leaks to prevent water contamination.
- Use an auxiliary pumping system for independent bake out of the RGA or calibrated leak system.
- Use wide range turbomolecular pumps to increase hydrogen compression ratio.
- Use two turbomolecular pumps in series for increased hydrogen pumping speed where wide range pumps are not provided.

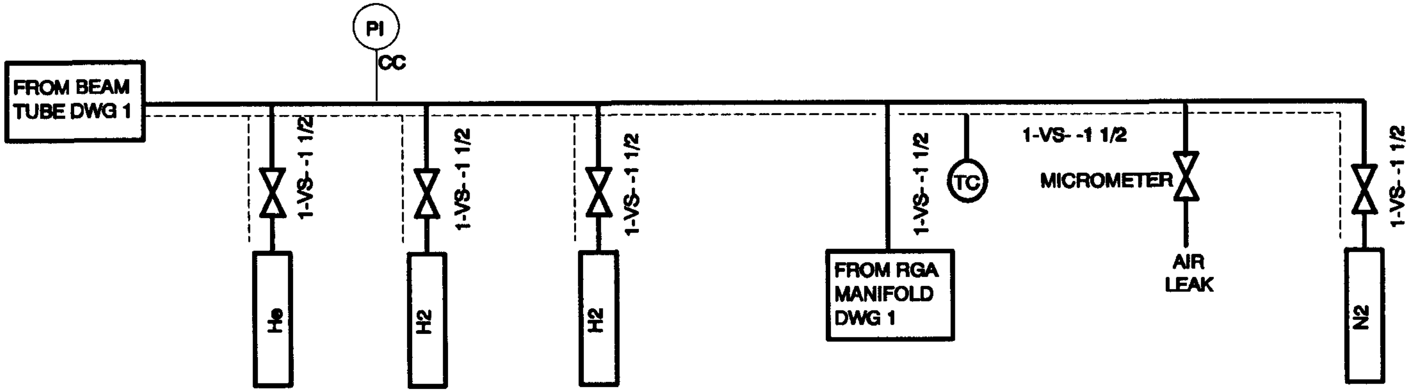


CBI

P & I DIAGRAM
VACUUM SYSTEMS
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/3/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO. 930212			
DWG	1	REV	3
SHT	1		



CBI

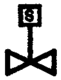
P & I DIAGRAM
CALIBRATED LEAK SYSTEM
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/3/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 2
SHT 1
REV 3

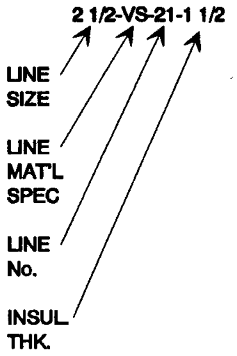
P & I SYMBOLS

	COLD CATHODE VACUUM GAGE
	PIRANI VACUUM GAGE
	MANUAL VALVE
	ELECTROPNEUMATEC VALVE
	TWO WAY SOLENOID VALVE
	FOUR WAY SOLENOID VALVE WITH PNEUMATIC SUPPLY
	TWO WAY SOLENOID VALVE WITH PNEUMATIC SUPPLY
	TEMPERATURE CONTROL
	HEAT TRACED PIPING

PRELIMINARY EQUIPMENT SIZING

TMP -1	1000 L/S
TMP-2	60 L/S
TMP-3	60 L/S
TMP-4	60 L/S
TMP-5	60 L/S
RP-1	50 CFM
RP-2	1 CFM
RP-3	1 CFM
RP-4	1 CFM
LNT-1	8" TRAP
LNT-2	2 1/2" TRAP
LNT-3	2 1/2" TRAP

LINE DESIGNATION



CBI

P & I DIAGRAM
P & I SYMBOLS
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD _____ DATE 11/10/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG S
SHT 1
REV 4

PRELIMINARY BEAM TUBE OUTGASSING TEST PROCEDURE

1. Clean and assemble all components.
2. Leak check the system.
3. Insulate the system.
4. Evacuate all ancillary systems
5. Bake out the analysis and pumping systems for a minimum of one week at 300°C (the turbomolecular pumps will be baked at only 120°C due to equipment temperature limitations).
6. Cool to ambient temperature and record the temperature.
7. Measure and record the water outgassing rate.
8. Fill the RGA cold trap.

PRELIMINARY BEAM TUBE OUTGASSING TEST PROCEDURE

9. Measure and record the hydrogen outgassing rate.

10. Repeat steps 5 through 8 until the hydrogen and water outgassing rates stabilizes. The hydrogen partial pressure should be less than 1x 10^{-11} torr and the water partial pressure should be less than 1 x 10^{-14} torr.

11. Calibrate the system using the calibrated leaks after each outgassing measurement.

12. Evacuate the beam tube.

13. Bake the beam tube for 30 days at 140°C. The analysis and pumping systems will also be baked during the 30 day period.

14. Cool to ambient temperature and record the temperature.

15. Record the hydrogen and water outgassing rates as discussed above.

16. Isolate the beam tube from the analysis and pumping systems and bake the systems for 24 hours at 250°C. The RGA will always be heated prior to heating the cold trap in order to prevent condensation of contaminants on the RGA.

PRELIMINARY BEAM TUBE OUTGASSING TEST PROCEDURE

17. Allow the RGA to return to ambient temperature and check the closed system outgassing rates for hydrogen and water vapor as discussed above.

18. Calibrate the RGA

19. Subtract the final recorded system background outgassing rates from the recorded beam tube outgassing rates.

VIII. DESIGN QUALIFICATION TEST

A. REQUIREMENTS

1. DEMONSTRATE FULL CONFORMANCE OF LIGO BEAM TUBE MODULE DETAILED DESIGN WITH REQUIRED PERFORMANCE PARAMETERS AND CONSTRAINTS.

2. IDENTIFY FEATURES THAT CAN BE DEMONSTRATED THROUGH ANALYSIS AND THOSE THAT MUST BE VERIFIED THROUGH TESTING.

3. UTILIZE A PHYSICAL CONFIGURATION WHICH PERMITS TESTINGOF FULL SCALE LIGO BEAM TUBE COMPONENTS AND VALIDATES THE PLANNED FABRICATION, FIELD INSTALLATION, AND TESTING TECHNIQUES.

4. ACCOMPLISH QUALIFICATION TEST IN ACCORDANCE WITH AN APPROVED/DOCUMENTED DESIGN QUALIFICATION TEST PLAN AND PROCEDURES.

VIII. DESIGN QUALIFICATION TEST

A. REQUIREMENTS

1. DEMONSTRATE FULL CONFORMANCE OF LIGO BEAM TUBE MODULE DETAILED DESIGN WITH REQUIRED PERFORMANCE PARAMETERS AND CONSTRAINTS.

2. IDENTIFY FEATURES THAT CAN BE DEMONSTRATED THROUGH ANALYSIS AND THOSE THAT MUST BE VERIFIED THROUGH TESTING.

3. UTILIZE A PHYSICAL CONFIGURATION WHICH PERMITS TESTING OF FULL SCALE LIGO BEAM TUBE COMPONENTS AND VALIDATES THE PLANNED FABRICATION, FIELD INSTALLATION, AND TESTING TECHNIQUES.

4. ACCOMPLISH QUALIFICATION TEST IN ACCORDANCE WITH AN APPROVED/DOCUMENTED DESIGN QUALIFICATION TEST PLAN AND PROCEDURES.

B. CRITICAL PARAMETERS

1. CONFIGURATION

- A. OVERALL BEAM TUBE MODULE CONFIGURATION - EXPANSION JOINT AND SUPPORT LOCATION
- B. BEAM TUBE SECTION LENGTH
- C. BEAM TUBE DIAMETER
- D. BEAM TUBE STIFFENING
- E. EXPANSION JOINT CONFIGURATION
- F. BEAM TUBE SUPPORTS INCLUDING ADJUSTABILITY
- G. BAFFLES
- H. PUMP PORTS

2. DIMENSIONAL VERIFICATION/ALIGNMENT

- A. BEAM TUBE DIMENSIONAL REQUIREMENTS
- B. STIFFENED BEAM TUBE DIMENSIONAL REQUIREMENTS
- C. EXPANSION JOINT WITH STUB ENDS DIMENSIONAL REQUIREMENTS
- D. BAFFLE DIMENSIONAL REQUIREMENTS
- E. SUPPORT DIMENSIONAL REQUIREMENTS
- F. BEAM TUBE SECTION ALIGNMENT
- G. BEAM TUBE MODULE ALIGNMENT BETWEEN 250 M MONUMENTS
- H. BEAM TUBE REALIGNMENT

3. WELD PROCEDURES AND APPARATUS

- A. STIFFENER FIT-UP AND LAP WELD
- B. STIFFENER TO TUBE WELD
  - (1) STRUCTURAL ADEQUACY
  - (2) TUBE SHAPE
- C. EXPANSION JOINT TO TUBE CIRCUMFERENTIAL WELD
- D. BEAM TUBE SECTION TO BEAM TUBE SECTION WELD CIRCUMFERENTIAL WELD
  - (1) LEAK TIGHT
  - (2) STRUCTURAL
  - (3) SHAPE
- E. PUMP PORT WELD
  - (1) LEAK TIGHT
  - (2) STRUCTURAL
- F. PUMP PORT FLANGE AND/OR COVER WELD
  - (1) LEAK TIGHT
  - (2) STRUCTURAL

4. CLEANING PROCEDURES AND EXECUTION

- A. HIGH VACUUM LAB AND EQUIPMENT CLEANING AND MAINTENANCE
- B. BEAM TUBE SECTION CLEANING PRIOR TO LEAK TEST
- C. BEAM TUBE SECTION CLEANING AFTER LEAK TEST
- D. CLEANING OF CIRCUMFERENTIAL BEAM TUBE SECTION TO BEAM TUBE SECTION WELD
- E. CLEANLINESS MAINTENANCE OF BEAM TUBE DURING INSTALLATION AND TESTING

5. STRUCTURAL DEMONSTRATION

- A. STRUCTURAL CAPACITY OF STIFFENED BEAM TUBE UNDER VACUUM CONDITIONS
- B. EXPANSION JOINT BEHAVIOR UNDER VACUUM CONDITIONS AND BAKEOUT CONDITIONS
- C. SUPPORT LOADS OF STIFFENED BEAM TUBE AND EXPANSION JOINT
- D. SUPPORT ADJUSTABILITY

6. LEAK RATE

HELIUM LEAK RATE ≤ $10X10^{-11}$ ATM CC/S INTO BEAM TUBE.
NECESSARY CRITERIA
- **BEAM TUBE SECTIONS AND QT MODULE = 0 LEAK RATE.**

7. OUTGAS RATE

A. COUPON OUTGASSING RATES (BOTH ENDS OF COIL)

HYDROGEN $< 1x10^{-13} \frac{\text{torr} \cdot \text{liter}}{\text{s} \cdot \text{cm}^2}$

WATER $< 1x10^{-16} \frac{\text{torr} \cdot \text{liter}}{\text{s} \cdot \text{cm}^2}$

B. INSTALLED BEAM TUBE OUTGASSING RATES

HYDROGEN $< 1x10^{-13} \frac{\text{torr} \cdot \text{liter}}{\text{s} \cdot \text{cm}^2}$

WATER $< 1x10^{-16} \frac{\text{torr} \cdot \text{liter}}{\text{s} \cdot \text{cm}^2}$

C. QT LOCATION OPTIONS

1. TUBE OUTSIDE WITH PIPING TO INDOOR VACUUM/OUTGASSING SYSTEM.
2. INDOOR TUBE END CONNECTION TO VACUUM/OUTGASSING SYSTEM WITH BALANCE OF BEAM TUBE OUTSIDE.

a. ADVANTAGES
   (1) TUBE IS EXPOSED TO CURRENT ENVIRONMENT
   (2) OUTSIDE TUBE SECTION CONSTRUCTION ALIGNMENT IS REPRODUCED

b. DISADVANTAGES
   (1) LONGER RUN FROM PUMPING/OUTGASSING SYSTEM TO BEAM TUBE
   (2) POSSIBILITY OF CONTAMINATION FROM OUTSIDE TO INSIDE
   (3) CONCRETE SLAB MIGHT HAVE TO BE REPRODUCED
   (4) POSSIBLE DAMAGE TO BEAM TUBE SECTIONS, IF FABRICATED INSIDE (AS IN OPTION), WHEN MOVED OUTSIDE
   (5) ROLLING RAIL WELDING, LEAK TESTING, AND CLEANING EQUIPMENT/OPERATION ROOMS FOR OPTION WILL NOT BE REPRODUCED FOR THE QT TEST. SO IF BEAM TUBE IS OUTSIDE, WELDING, LEAK TESTING AND CLEANING WOULD BE IN MORE ADVERSE CONDITIONS IN QT (NOT REPRESENTATIVE OF OPTION) AND RESULTS MAY NOT BE ACCEPTABLE.

(6) BEAM TUBE OUTGASSING, BAKE OUT, AND POST BAKEOUT OUTGASSING ARE BEING PERFORMED FOR THE QT. IF TUBE IS BUILT OUTSIDE IT WOULD EITHER HAVE TO BE MOVED INSIDE FOR INSULATION, BAKEOUT, AND OUTGASSING; OR A SPECIAL COVER BUILT. BOTH OF THESE OPTIONS INDUCE UNREPRESENTATIVE HAZARDS.

c. COSTS

PERFORMING THE QT OUTDOORS WOULD BE VERY COSTLY BOTH INITIALLY FOR SETUP, HANDLING, AND OPERATION AND, IF DETRIMENTAL CONDITIONS OCCURRED, COULD INVOLVE REWORK COSTS.

d. RISKS

THE RISKS IN PERFORMING THE QT TEST OUTDOORS ARE THAT MORE UNREPRESENTATIVE OPERATIONS OCCUR AND THE ABILITY TO MEET ACCEPTANCE REQUIREMENTS COULD BE SERIOUSLY JEOPARDIZED.

3. INDOOR (BASEMENT OF RESEARCH AND DEVELOPMENT CENTER) BEAM TUBE WITH VACUUM/OUTGASSING SYSTEM IN HIGH VACUUM LAB (INCLUDES A SEPARATE OUTDOOR ALIGNMENT QUALIFICATION FOR LONG DISTANCE - 250 M)

   a. ADVANTAGES

      (1) GOOD CONTROL OF VACUUM/OUTGASSING SYSTEM INTERFACE WITH BEAM TUBE
      (2) BETTER SIMULATION OF REALIGNMENT PROCEDURE AND TECHNIQUES
      (3) PROVIDES THE KIND OF ENVIRONMENT FOR WELDING, LEAK CHECKING, AND CLEANING THAT WILL BE PRODUCED BY ROLLING RAIL EQUIPMENT/OPERATION ROOMS IN THE OPTION. THEREFORE THE QUALITY OF THESE OPERATIONS WILL MOST CLOSELY REPRESENT THOSE OF THE LIGO BEAM TUBE MODULE.
      (4) ALLOWS BAKEOUT AND OUTGASSING TO BE PERFORMED WITH THE TUBE IN ITS INSTALLED LOCATION AND WITH A REPRESENTATIVE OPTION ENVIRONMENT
      (5) STILL PROVIDES A LONG DISTANCE ALIGNMENT QUALIFICATION
      (6) THE BASEMENT OF THE R&D CENTER PROVIDES SUPPORT FOR THE BEAM TUBE WHICH IS ESSENTIALLY EQUIVALENT TO OPTION CONCRETE SLAB.

b. DISADVANTAGES

(1) QT BEAM TUBE NOT AVAILABLE FOR OUTSIDE SHORT DISTANCE CONSTRUCTION ALIGNMENT CHECKS
(2) TUBE NOT SUBJECTED TO AN OUTDOOR ENVIRONMENT WHICH MAY (OR MAY NOT) BE REPRESENTATIVE OF AN OPTION OUTDOOR ENVIRONMENT.

c. COSTS

THE APPARENT INITIAL COSTS OF DOING THE QT INDOORS SEEM TO BE MUCH LOWER THAN THE OUTDOORS OPTIONS. THERE ARE ALSO VERY FEW POTENTIAL REWORK COSTS.

d. RISKS

THE RISKS OF DOING THE QT INDOORS IS REFLECTED IN THE SHORT LIST OF DISADVANTAGES. THE BENEFITS, ESPECIALLY ACCURATE AND QUALITY REPRESENTATION OF THE OPTION, FAR OUTWEIGH THE RISKS ESPECIALLY WHEN SUCH A HIGH LEVEL OF VACUUM IS REQUIRED FOR THE BEAM TUBE MODULE.

D. ITEMS DEMONSTRATED BY TEST

1. STRUCTURAL AND MECHANICAL PERFORMANCE OF THE BEAM TUBE CONFIGURATION
2. COIL MANUFACTURE AND TRACEABILITY
3. COUPON OUTGAS TEST PROCEDURE AND EQUIPMENT
4. BEAM TUBE MANUFACTURING PROCESS AND WELDING PROCEDURE
5. EXPANSION JOINT DESIGN AND MANUFACTURING PROCESS.
6. DIMENSIONAL VERIFICATION AND INSPECTION PROCEDURES
7. STIFFENER MANUFACTURING PROCESS
8. BAFFLE CONFIGURATION AND MANUFACTURING PROCESS
9. STIFFENER ATTACHMENT PROCESS AND EQUIPMENT
10. CIRCUMFERENTIAL SEAM PREPARATION AND FIT UP PROCESS AND EQUIPMENT
11. CIRCUMFERENTIAL WELD PROCESS AND EQUIPMENT
12. BEAM TUBE SECTION LEAK TEST PROCEDURE
13. CIRCUMFERENTIAL SEAM LEAK TEST PROCEDURE AND EQUIPMENT
14. CLEANING PROCEDURE
15. QUALIFICATION TEST OUTGAS CHARACTERISTICS
16. ALIGNMENT VERIFICATION AND PROCEDURES

E. ITEMS DEMONSTRATED BY ANALYSIS

1. THERMAL PERFORMANCE OF BEAM TUBE SUPPORTS
2. STRUCTURAL AND MECHANICAL PERFORMANCE OF BEAM TUBE CONFIGURATION UNDER ENVIRONMENTAL LOADS
3. ALL BEAM TUBE HANDLING AND TRANSPORTATION
4. CLEAN ROOM ENCLOSURE ENVIRONMENT AND EFFECTIVENESS
5. AUTOMATED CLEANING EQUIPMENT PERFORMANCE
6. BEAM TUBE SECTION LEAK TEST CASK EQUIPMENT PERFORMANCE

F. PRELIMINARY QT PLAN

1. COUPON TESTING

a. PREPARE AND INSTALL COUPON OUTGAS SYSTEM INCLUDING LEAK CHECK, BAKEOUT AND CALIBRATION
b. CLEAN COUPONS PER PROCEDURE
c. BAKE COUPONS AND VESSEL TO 250°C, THEN COOL
d. RECORD OUTGAS RATE
e. REMOVE COUPONS, EVACUATE, BAKE, AND COOL VESSEL
f. RECORD OUTGASSING RATE
g. OUTGASSING RATE = COUPON OUTGASSING RATE - SYSTEM BACKGROUND OUTGASSING RATE

2. **FABRICATE BEAM TUBE SECTIONS**
   a. **FIT-UP AND WELD STIFFENERS ONE AT A TIME TO BEAM TUBE SECTIONS USING CBI PROCEDURE WPS 308LT-1 (STIFFENER FIT-UP WILL SIMULATE CONSTRUCTION PLAN STIFFENER FIT-UP)**
   b. **PERFORM DIMENSIONAL INSPECTION PER CBI PROCEDURE (SEE SECTION 3)**
   c. **WELD EXPANSION JOINT TO BEAM TUBE TO CREATE A BEAM TUBE SECTION PER CBI WELD PROCEDURE WPS AUTOG/ER 308L**
   d. **WELD QT END COVER TO BEAM TUBE SECTION PER CBI WELD PROCEDURE (TO BE DEVELOPED)**
   e. **WELD VACUUM PUMP PORT TO BEAM TUBE SECTION PER CBI WELD PROCEDURE (TO BE DEVELOPED)**
   f. **LEAK TEST BEAM TUBE SECTION PER CBI PROCEDURE HMST1N - MODIFIED TO USE A BAG FOR THE HOOD INSTEAD OF AN ENCLOSURE AS SHOWN IN HMST1N**
   g. **CLEAN BEAM TUBE SECTION PER CBI PROCEDURE QT CLN-BT**
   h. **PLACE TEMPORARY "CLEAN" COVER ON OPEN END OF FIRST BEAM TUBE SECTION**

   (BAFFLE INSTALLATION SEQUENCE HAS NOT YET BEEN DECIDED UPON)

3. DIMENSIONAL TESTING/INSPECTION

a. BEAM TUBES

- (1) SIZE
- (2) STRAIGHTNESS
- (3) THICKNESS
- (4) SPIRAL WELD PEAKING AND OFFSET
- (5) LENGTH
- (6) SQUARENESS OF ENDS
- (7) FLATNESS OF ENDS

b. STIFFENED BEAM TUBE

- (1) ROUNDNESS
- (2) STRAIGHTNESS
- (3) LENGTH
- (4) SQUARENESS OF ENDS
- (5) FLATNESS OF ENDS

c. EXPANSION JOINTS

- (1) ROUNDNESS
- (2) SIZE
- (3) LENGTH
- (4) SQUARENESS OF ENDS
- (5) FLATNESS OF ENDS

d. BEAM TUBE SECTIONS

- (1) STRAIGHTNESS
- (2) SQUARENESS OF ENDS
- (3) SAG

4. BEAM TUBE SECTION INSTALLATION
   a. INSTALL FIRST BEAM TUBE SECTION ON END RESTRAINT AND SUPPORT 1
   b. ALIGN THIS SECTION PER CBI PROCEDURE (SEE SECTION 5)
   c. BRING IN SECOND BEAM TUBE SECTION
   d. WELD CIRCUMFERENTIAL BEAM TUBE SECTION TO BEAM TUBE SECTION PER CBI WELD PROCEDURE WPS AUTOG/ER308l
   e. LEAK TEST CIRCUMFERENTIAL SEAM PER CBI PROCEDURE HMST2N
   f. CLEAN CIRCUMFERENTIAL SEAM PER CBI PROCEDURE QT CLN-BT
   g. WELD QT BEAM TUBE MODULE END EXPANSION JOINT. LEAK TEST AND CLEAN PER e. AND f.
   h. WELD IN CLOSURE END TO SEAL OFF QT BEAM TUBE MODULE IN ACCORDANCE WITH CBI WELD PROCEDURE (TO BE DEVELOPED) WHICH WILL INCLUDE A BACK PURGE.

5. ALIGNMENT DEMONSTRATION

A. OUTDOOR LONG DISTANCE +250 M DEMONSTRATION

(1) CONSTRUCTION ALIGNMENT

- ESTABLISH SEMI-PERMANENT MONUMENTS AT 250 M SPACING
- SET INTERMEDIATE LOCATION ON LINE OF SIGHT BETWEEN MONUMENTS
- TRANSFER LINE DEFINED BY 2 MONUMENTS TO A PARALLEL LINE DEFINED BY TARGETS PLACED AT APPROXIMATELY 66' SPACING (REPRESENTS BEAM TUBE SUPPORT SPACING)
- RECORD READINGS AND ACCURACIES

(2) FINAL ALIGNMENT AND REALIGNMENT

(a) SET TEMPORARY 250 M MONUMENTS UNDER COVER

- SET UP ON MONUMENT (M1) AND SIGHT TO SECOND MONUMENT (M2) 250 M AWAY. THEN SIGHT ON AND SET TEMPORARY LOCATION TO REPRESENT MONUMENT (TM1) INSIDE OF COVER.
- MOVE INSTRUMENT TO SIGHT ON BOTH TM1 AND M1. THIS WILL ESTABLISH Y DIMENSION.
- REPEAT ABOVE STEPS TO SET POSITION TM2.

(b) ESTABLISH TUBE LOCATION TO PROVIDE CLEAR APERTURE

- FOR 3-D COORDINATE SYSTEM - SIGHT TM1 AND TM2 FROM BETWEEN THEM AND INSIDE COVER. ADJUST TUBES TO BRING TARGETS INTO CALCULATED LINE TO ACHIEVE CLEAR APERTURE.

B. CONSTRUCTION ALIGNMENT

(1) ESTABLISH TEMPORARY MONUMENTS IN BASEMENT AT ~ 150FT.

(2) PERFORM CONSTRUCTION ALIGNMENT AS IN A(1) ABOVE

C. FINAL ALIGNMENT

PERFORM FINAL ALIGNMENT AS IN A(2) ABOVE

D. REALIGNMENT

PERFORM FINAL ALIGNMENT AS IN A(2) ABOVE

6. **QT BEAM TUBE MODULE OUTGAS TESTING**
   a. **PREPARE AND INSTALL THE BEAM TUBE VACUUM/OUTGAS SYSTEM**
   b. **LEAK TEST THE VACUUM SYSTEM**
   c. **INSULATE, EVACUATE, AND BAKE OUT THE VACUUM SYSTEM**
   d. **MEASURE AND RECORD WATER AND HYDROGEN OUTGASSING RATES**
      REQUIREMENTS: HYDROGEN PARTIAL PRESSURE $< 1X10^{-11}$ TORR
      WATER PARTIAL PRESSURE $< 1X10^{-14}$ TORR
   e. **EVACUATE AND BAKE OUT THE Q BEAM TUBE MODULE. BAKEOUT SHALL BE IN ACCORDANCE WITH PROCEDURE BO-QT.**
   f. **COOL AND RECORD HYDROGEN AND WATER OUTGAS RATES**
   g. **ISOLATE, BAKE, THEN COOL THE RGA**
   h. **MEASURE AND RECORD HYDROGEN AND WATER OUTGAS RATES**
   i. **OUTGASSING RATE (OR) = QT BEAM TUBE MODULE OR - SYSTEM BACKGROUND OR**

7. BAKEOUT - CBI PROCEDURE BO-QT

OCCURS AFTER QT BEAM TUBE MODULE IS ASSEMBLED, LEAK CHECKED, CLEANED, AND AN INITIAL PRE-BAKEOUT MEASUREMENT OF AMBIENT TEMPERATURE OUTGAS RATE

a. WRAP THE BEAM TUBE WITH RESISTANCE HEATING CABLE IN A HELICAL PATTERN. EACH BEAM TUBE SECTION WILL HAVE A SEPARATE CIRCUIT AND THE BELLOWS CONVOLUTIONS WILL HAVE NO HEATER CABLE DIRECTLY APPLIED.
b. INSTALL THERMOCOUPLES AT CRITICAL LOCATIONS
c. INSULATE THE BEAM TUBE WITH 4" OF KNAUF DUCT WRAP OR EQUAL
d. EVACUATE THE BEAM TUBE TO 10^{-5} TORR
e. OVER 24 HOURS, RAISE BEAM TUBE TEMPERATURE TO 140°C
f. HOLD THE BEAM TUBE AT 140°C FOR 30 DAYS WHILE UPHOLDING THE VACUUM AND RECORDING TEMPERATURES AND OUTGASSING RATES
g. AFTER THE 30 DAYS, TURN OFF HEATERS AND ALLOW TUBE TO RETURN TO AMBIENT TEMPERATURE.

8. ACCEPTANCE TESTING/FINAL LEAK TEST

AFTER QT BEAM TUBE MODULE HAS BEEN BUILT, LEAK TESTED, CLEANED, BAKED OUT AND OUTGAS RATES MEASURED, IT WILL BE LEAK TESTED.

a. EVACUATE THE QT BEAM TUBE MODULE
b. BAG THE QT BEAM TUBE MODULE
c. EVACUATE THE BAG AND BACKFILL WITH HELIUM
d. MONITOR THE LEAK TESTING EQUIPMENT FOR HELIUM LEAKS INTO THE QT BEAM TUBE MODULE
e. ACCEPTABLE HELIUM LEAK RATE = 0 (< $10X10^{-11}$ ATM CC/S)

9. REALIGNMENT

AFTER FINAL LEAK CHECKING OF QT BEAM TUBE MODULE, ALIGNMENT WILL BE CHECKED. THE TUBE WILL BE REALIGNED TO THE POSITION PROVIDING THE INITIAL CLEAR APERTURE. THIS WILL BE ACCOMPLISHED BY REESTABLISHING TUBE TARGET POSITIONS RELATIVE TO TEMPORARY BENCHMARKS PROVED ON SLAB. THESE BENCHMARKS REPRESENT A LINE PARALLEL TO THE CLEAR APERTURE AXIS. TUBE SUPPORTS WILL BE ADJUSTED TO BRING FIXED TARGETS INTO POSITION.

G. REPORT FORMAT

1. COVER
2. EXECUTIVE SUMMARY
3. TABLE OF CONTENTS
4. NOMENCLATURE
5. GLOSSARY
6. INTRODUCTION
7. TEST CONFIGURATION
8. EQUIPMENT AND PROCEDURES
9. DATA/RESULTS
10. DISCUSSION OF RESULTS
11. SUMMARY AND CONCLUSIONS
12. RECOMMENDATIONS
13. ACKNOWLEDGMENTS
14. REFERENCES
15. APPENDICES

SECTION 2

WBS #121 Preliminary Design of the Beam Tube Stiffeners

Several stiffener size possibilities have been identified. The current intent is to use a 3/16" thick bar or plate, projected at a depth of approximately 1-3/4" from the tube wall. The spacing would be at approximately 27", but will depend on the final beam tube section length selected. This stiffener size and spacing are in accordance with ASME for a 0.125" thick tube with a 48" inside diameter. This is based on an inside tube diameter of 48". Selection of a somewhat different final tube diameter may influence the stiffener design. A determination of whether or not specific advantages can be taken by application of alternate external pressure design rules will be made after all other aspects of the beam tube section design have been established.

The attachment of the stiffeners to the tube wall will be a 1/8" continuous fillet one side, either with or without a nominal amount of intermittent fillet on the opposing side. This would satisfy ASME for strength considerations, but not for the minimum attachment weld requirements of paragraph UG-30. Since the LIGO modules are not to be code stamped and there is adequate justification (both structurally and economically) to take exception, CBI is to proceeding with this approach.

The stiffeners themselves will be 304L stainless steel. Corrosion of the tubes in what might be considered to be a marine environment (Livingston, LA) will be in the form of scattered superficial rust patches which would have no effect on the mechanical properties of the stainless steel and they could be easily removed. Therefore, since there will be no need to paint the exterior of the tube walls, the expense of only painting carbon steel stiffeners would not be justified in order to reduce material costs. Also, any unsealed crevices at a carbon steel stiffener to tube wall attachment would be subject to certain corrosion, regardless of painting or other precautions taken to inhibit it. Furthermore, the elevated temperature during bakeout could be detrimental to a painted surface.

CBI has reviewed the proposed insulation material for the bakeout. CBI has determined that the Knauf Duct Wrap can be purchased to the ASTM C795 Standard (or comparable military specifications) to ensure that an acceptable level of water-leachable chloride is not exceeded. CBI recommends that this requirement be specified by Caltech for the purchase of the insulation material.

WBS #122 Preliminary Design of the Beam Tube Section Length

The overall cost of the beam tube modules is naturally reduced by increasing the length of the beam tube sections. The savings are realized through a reduction in the number of times each activity must be executed as well as a reduction in the total number of supports and expansion joints.

There are structural, mechanical and practical limits to the beam tube section length. The beam tube section length is limited by the increasing difficulty and costs of handling increasingly long sections. Four 65' tube sections can be shipped on a 60' trailer with a 5' over hang without escorts. Loads over 65' are prohibitively costly due to escort requirements. Site handling of long sections is also difficult but 65' is judged to be feasible. Sections placed in the field are limited to 65' plus the length of the expansion joint attached to the tube section at site. Expansion joint manufacturers are generally limited by equipment requirements to expansion joint lengths of 6' to 8'. Thus, tube sections with expansion joints are limited to approximately 72'.

A number of expansion joint and support configurations were considered. The desire to limit the number of supports and the restrictions on sliding supports favors the use of one support per tube section. The primary function of the expansion joints is to accommodate thermal elongation of the tube sections. Relatively short expansion joints are capable of carrying significant shear loads without the need for longitudinal guides to ensure axial movement. Expansion joint manufacturers have been consulted to confirm the ability of the expansion joints to carry shear and perform successfully with a 70 ' unsupported tube length. Longer unsupported lengths require increasingly thicker and longer bellows which are increasingly difficult and costly to fabricate. Circumferential seams without expansion joints were considered but the combined sections became unacceptably long based on the limits imposed by the expansion joints.

Although the tube dimensional tolerances increase with tube length, the placement of one baffle per section at or near the tube support prevents the tube tolerance and deflection from infringing on the clear aperture. Placement of the baffles at the end of the section s near the supports eliminates the increase in diameter due to tube tolerances and deflections. A module layout has been developed which is based on 20.23 meter beam tube sections including the expansion joint. Compliance with the applicable design codes has been verified for the prescribed loads and loading conditions based on this length.

WBS #123 Preliminary Design of the Baffle Configuration

A single ribbon flighting is being pursued as the most suitable and economical baffle configuration. CBI's intent is that the majority of the baffles be placed at a spacing which coincides with the beam tube section length (£20m). The baffles would be placed in the immediate vicinity of a support and in a section of the tube where the diameter is well controlled. This approach would essentially eliminate concerns of the effects of tube roundness, straightness, and deflection on the clear aperture for those baffles positioned in this manner. The placement of the majority of the baffles might be in a long weld end of the expansion joints. This would be required especially if the ends of the spiral tube will be belled to achieve uniformity.

CBI intends to use the same material purchased for either the tubes or the bellows also for the baffles. This will limit and better control the materials incorporated into the beam tube modules. The bellows material will be approximately 20 gauge which is 0.0359" and the tube wall is a nominal 0.125". Baffles fabricated from the thinner bellows material will be easier to form and install and may allow serrations to be stamped. However, thinner baffles would be more susceptible to damage and may not fit as tightly against the tube wall. Thicker baffles will less likely be damaged and are more likely have a more uniform shape and fit, but may be more difficult to fabricate, serrate and install.

Potential baffle fabricators have been contacted to determine what fabrication methods are best and what baffle thickness is expected. A working purchase specification has been developed for this purpose. A single ribbon flighting is being pursued as the most suitable configuration. Fabrication of baffles without the serrations as well as varying degrees of serration are being investigated. A final tube diameter determination will be based on economically achievable tolerances on the baffle aperture.

Baffles placed at those locations which require a closer spacing (6m) will receive more careful attention. Although the tube diameter will already be selected based on these more critical locations, attaining the required clear aperture can be assured by selective placement of the spiral tube produced (i.e., the best tube produced in terms of roundness and straightness can be used in these regions).

WBS #124 Preliminary Design of the Expansion Joints

CBI has been in contact with a number of potential expansion joint suppliers to determine what their capabilities and limitations are, as well as convey what the LIGO needs are. In general, the two welding ends of the expansion joints can be made to any specified lengths, equal or unequal. The overall length of the expansion joint could therefore accommodate any reasonable difference in the actual shipped length of a spiral tube and the final desired beam tube section length. Also, the weld ends of the expansion joints can typically be produced to tighter tolerances than the spiral tube.

The longitudinal butt seam in the thinner bellows and the longitudinal butt seams in the two welding ends can be made in a single pass, without filler metal. However, most expansion joint fabricators would have difficulty making the circumferential weld of the bellows to the welding ends without using filler wire. Some have said that it can be done, but it would be more costly and thinning is likely to be a problem. A number of questions regarding the requirements for the expansion joints are included in the following as concerns requiring input from the Institute.

The required design loadings for the expansion joints have been determined. Indications are that the necessary capacity can be attained. Actual deflections will depend on the final expansion joint design and spring constants, but the flexibility of the expansion joints will allow only a minimal relative offset across the bellows as they carry the required shear load.

A possible expansion joint configuration which was initially entertained but has since been discarded is one which would eliminate the need for welding ends by field attaching the bellows directly to the ends of the spiral tube sections. Even though this has potential to eliminate a large number of circumferential butt joints, the attachment of the thinner bellows material is best performed by an expansion joint manufacturer in a shop environment. The option contractor would not be expected to have capabilities in this area, and the type of fit up to the tube end required for a successful weld would not realistically be attained.

A possible solution to the problem of welding the bellows to the expansion joint weld ends would be the bakeout of the filler wire, or even a bakeout of the entire expansion joint after assembly. CBI would like Caltech to respond to this idea.

CBI has recognized that some expansion joint manufacturers regularly use a thin back-up strip electric resistance welded to the end of the bellows in order to facilitate the welding of the bellows to the expansion joint weld ends. CBI would like Caltech to consider whether or not this practice is objectionable to them so that any specific requirements in this regard can be written into the purchase specification.

In conjunction with the proposed acceptance of alternate weld procedures for the spiral and circumferential butt joints in the beam tube itself, CBI would like the same matter to be addressed for the longitudinal seams in the expansion joint welding ends. (Even though the diameter and relatively short length afford ready access to the inside surface, welding from the outside would be preferred by the expansion joint manufacturers. In addition, use of filler wire would make the production easier.)

CBI would like to specify a minimum thickness in the expansion joint purchase specification such that the bellows would not require cooling during the bakeouts. For a given number of convolutions, a greater torsional capacity exists as the bellows thickness is increased. For this reason also CBI would like to specify a minimum thickness. CBI proposes an even gauge thickness of 0.0359" (20 gauge sheet) and would like Caltech to confirm that this is suitable for the bakeout without requiring cooling.

Completely eliminating the possibility of iron contamination throughout fabrication may not be achievable by all manufacturers. CBI would like to know if a passivation (not a pickling) process using nitric acid or a suitable organic acid to free iron particles from the stainless steel surfaces of the expansion joints would be acceptable to Caltech. Detection of iron contamination could be done either by visual inspection 24 hours after a clean water washdown, or by means of a more sensitive ferroxyl test. Specific requirements addressing inspection for and removal of iron contamination can be written into the purchase specification. CBI intends to issue the updated purchase specification for quotation around 12/6/93.

WBS #125 Preliminary Design of the Beam Tube Supports

CBI will design beam tube supports for one side of the expansion joint only. This will require that the dead load, snow load, wind loads and seismic loads be transmitted in shear across the expansion joint bellows. Support of the beam tube sections from both ends is not a valid option, since differential settlement of the slab could impose across the bellows a load much greater in magnitude than would otherwise be expected.

All applicable loads which must be transferred into the slab by the supports have been identified and their magnitudes determined. The magnitude of the axial thrust upon the supports due to temperature variations during construction of the beam tube modules has been approximated. The magnitude of this axial thrust cannot be precisely determined since it is dependent upon both the actual expansion joint spring constant (which has not yet been determined) and the temperature differential during construction (which cannot be accurately predicted). The beam tube supports will not be loaded with the end pressure thrust load.

Initially, the conceptual designs of the beam tube supports were based upon the assumption that both the beam tube and its supports would resist a moment caused by a longitudinal load (due either to seismic load or thermal effects) acting along the axis of the beam tube. Subsequent investigations of these conceptual designs revealed that the wall of the beam tube, when subjected to the expected moment, would be stressed well above the allowable stress permitted by ASME. The concept of a moment resisting support system has thus been abandoned. In its place, the axially flexible support concept shown in Figure 1 has been developed and found to be superior to the moment resisting support concept in both function and cost. This support system consists of the following components:

- o Bolted Collar
- o Saddle Assembly
- o Low Friction Slide Bearings
- o Leveling Plate
- o Leveling Bolts

A circumferential two piece bolted collar is used in conjunction with a load bearing insulating material (such as FOAMGLAS cellular glass insulation manufactured by Pittsburgh Corning Corporation) between the collar and the beam tube which eliminates heat transfer resulting from direct steel-to-steel contact during bakeout. The collar bolts are tightened sufficiently so as to develop adequate friction between the tube, insulation and collar to eliminate slippage and the associated vibrations. The primary advantage to the use of a two piece bolted collar support is that after the construction of each module is completed, all the collars could be loosened and retightened under a uniform temperature to permit an equalization of the effect of varying expansion joint spring rate. This operation would ensure that longitudinal loads on the supports throughout the operation of the LIGO would be effectively eliminated.

Welded to the bolted collar is a support saddle assembly consisting of a saddle web plate and a saddle base plate. The saddle web plate is flexible enough in the longitudinal direction to permit nominal axial translation of the beam tube and bolted collar without inducing a detrimental resisting moment in the beam tube. The saddle base plate, welded to the web plate, is fabricated with a total of four slotted holes in the transverse direction, which allow for the required +/-7.5 centimeter transverse alignment of the beam tube assembly.

One low friction slide bearing assembly (such as the Fabreeka Slide Bearing manufactured by Fabreeka Products Company) is provided between the saddle base plate and the leveling plate. This slide bearing assembly consists of an upper unit and a lower unit. The upper bearing unit consists of a 20 gage stainless steel sliding surface, highly polished, mechanically bonded to a carbon steel plate which is welded to the bottom of the saddle base plate. The lower bearing unit consists of a polytetrafluorethylene (PTFE) self-lubricating element bonded to a carbon steel plate which is welded to the top of the leveling plate. The resulting coefficient of static friction between the stainless steel sheet and the PTFE element is approximately 0.05 at 7000 kPa compressive stress, and decreases with higher stresses. The low friction slide bearing assembly would provide a means by which the transverse alignment of the saddle assembly and the beam tube could be accomplished smoothly with relatively little effort.

A leveling plate is used to support the saddle assembly. Supported at three locations above the top of the slab by the leveling bolts, the elevation of this plate could be adjusted in order to provide the required +/- 7.5 centimeter vertical alignment of the beam tube assembly. The leveling plate would be restrained from horizontal movement by the leveling bolts. A stiffener welded to the underside of the leveling plate may be necessary depending upon the final thickness of the leveling plate. Four threaded rods welded to the top of the leveling plate and passing through the slotted holes in the saddle base plate would act to guide the saddle during transverse alignment. Once transverse alignment of the saddle is accomplished, hex nuts on these threaded rods would be tightened to prevent further transverse movement of the saddle. Additionally, the four threaded rods would provide the means by which transverse wind and seismic loads are transferred into the leveling plate and subsequently to the concrete slab.

Three leveling bolts would be installed by drilling into the concrete slab. The necessary bond between the bolts and the slab would be provided either through epoxy grouting or mechanical anchorage of the bolts. Heavy hex nuts threaded onto the bolts would provide support of the leveling plate and the means by which vertical alignment of the beam tube assembly is accomplished. The leveling rods would be sized to accommodate the expected vertical operating loads, as well as the additional vertical loads, shear loads and bending moments that the bolts would be subjected to due to transverse wind and seismic loads.

WBS 170 Components Procurement

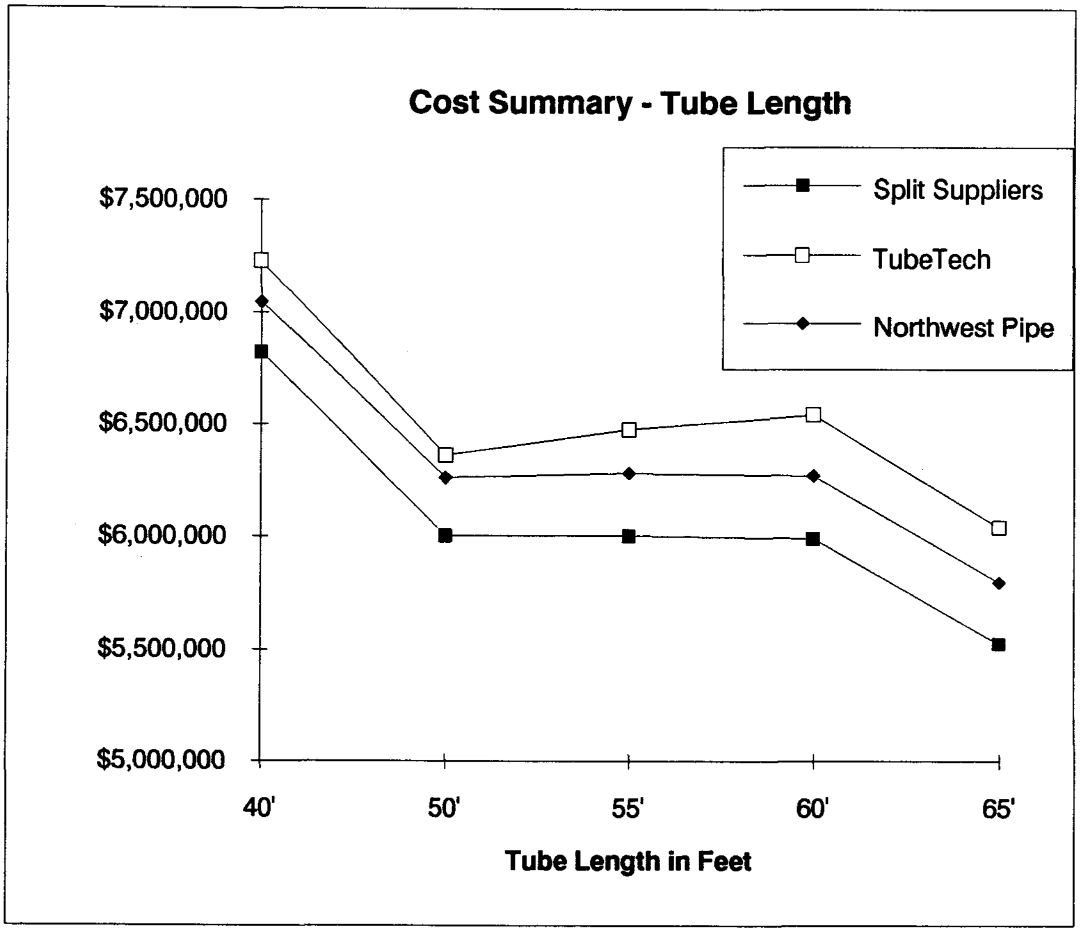
CBI will procure the coil steel, spiral welded tube sections, expansion joints, baffles and stiffeners for the beam tube module qualification test. Supports will likely be fabricated by CBI although some adjustment mechanism may also be procured. CBI is preparing technical procurement specifications for all beam tube modules not fabricated by CBI. All beam tube module component requests for quotation will include CBI's technical and commercial requirements which incorporate CBI, Caltech, and code requirements. A draft of CBI's commercial requirement package is contained at the end of this section.

WBS 180 Detailed Drawings

A General Module Configuration drawing has been prepared which shows the proposed beam tube section lengths and layout at the Hanford and Livingston sites. The configurations are based on the use of 20.23 meter sections at both sites. Baffles in the interior of the tube lengths are located at the supports to eliminate the dimensional variations due to tube tolerances and deflections. Tube sections placed in the areas of 6 meter baffle spacing will be screened to ensure the use tight tolerance tube sections. Module construction will tentatively begin at the mid station for all modules. A make up section will accommodate the varying module length at the two sites. Based on the present configuration, the eight modules will be composed of 784 expansion joints, 776 tube section and supports, and 928 baffles. Expansion joints will be located at the beam tube interface to minimize the forces imposed the chambers through the beam tubes.

TUBE LENGTH COST SUMMARY

	40'	50'	55'	60'	65'
Split Suppliers	$6,820,769	$6,003,920	$6,003,998	$5,990,572	$5,525,606
TubeTech	$7,228,221	$6,362,478	$6,476,984	$6,542,119	$6,041,161
Northwest Pipe	$7,048,989	$6,263,295	$6,281,895	$6,272,729	$5,798,393



NOTES:

1) Loads in excess of 65' require an escort which significantly increases the cost of shipping.

2) The costs shown do not include the cost of the coil steel or the cost of the fabricated tube sections.

LIGO COST SUMMARY - TUBE LENGTH IMPACT

KHF 11/10/93									PER EXP. BELLOW	
	COST PER TRUCKLOAD								INSTL'D. COST	$1,687.43
	SANFORD FL. TO LIVINGSTON, LA.			MILEAGE=	657	# TUBES	# LOADS	AVG. COST	# REQ'D PER	EXT.COST
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE					
40	$915.30	$886.95		$901.13	$1.37	485	121	$109,261	486	$1,640,186
50	$915.30	$886.95		$901.13	$1.37	427	107	$96,150	428	$1,443,769
55	$1,290.00	$1,152.65		$1,221.33	$1.86	423	106	$129,238	424	$1,431,865
60	$1,520.00	$1,349.75	$1,365.00	$1,411.58	$2.15	420	105	$148,334	421	$1,421,945
65	$1,175.00	$1,349.75	$1,569.00	$1,364.58	$2.08	388	97	$132,365	389	$1,312,824
	SANFORD FL. TO HANFORD WA.			MILEAGE=	2895				PER SUPPORT	
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE				INSTL'D. COST	$1,538.10
40	$3,735.00	$3,908.25		$3,821.63	$1.32	485	121	$463,372	486	$1,495,034
50	$3,735.00	$3,908.25		$3,821.63	$1.32	427	107	$407,767	428	$1,315,999
55	$5,711.00	$4,447.75		$5,079.38	$1.75	423	106	$537,490	424	$1,305,148
60	$6,295.00	$5,466.25	$6,047.00	$5,936.08	$2.05	420	105	$623,783	421	$1,296,106
65	$5,571.00	$5,466.25	$6,950.00	$5,995.75	$2.07	388	97	$581,588	389	$1,196,642
	PORTLAND OR. TO HANFORD WA.			MILEAGE=	227				PER TUBE INST.	
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE				INSTL'D. COST	$1,434.15
40	$650.00	$272.40		$461.20	$2.03	485	121	$55,921	486	$1,393,997
50	$650.00	$272.40		$461.20	$2.03	427	107	$49,210	428	$1,227,061
55	$790.00	$429.15		$609.58	$2.69	423	106	$64,504	424	$1,216,944
60	$790.00	$497.25	$775.00	$687.42	$3.03	420	105	$72,236	421	$1,208,513
65	$650.00	$497.25	$895.00	$680.75	$3.00	388	97	$66,033	389	$1,115,771
	PORTLAND OR. TO LIVINGSTON LA.			MILEAGE=	2420				PER LEAK TEST	
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE				INSTL'D. COST	$2,187.62
40	$2,662.70	$2,904.00		$2,783.35	$1.15	485	121	$337,481	486	$2,126,371
50	$3,760.00	$2,904.00		$3,332.00	$1.38	427	107	$355,524	428	$1,871,732
55	$4,078.00	$3,617.00		$3,847.50	$1.59	423	106	$407,135	424	$1,856,299
60	$4,205.00	$3,980.00	$4,105.00	$4,096.67	$1.69	420	105	$430,491	421	$1,843,438
65	$3,829.44	$3,980.00	$4,721.00	$4,176.81	$1.73	388	97	$405,151	389	$1,701,972
TOTAL COST-SPLIT SUPPLIEF		40'	50'	55'	60'	65'				
SANFORD/LIVINGSTON		$109,261	$96,150	$129,238	$148,334	$132,365				
PORTLAND/HANFORD		$55,921	$49,210	$64,504	$72,236	$66,033				
	FREIGHT	$165,182	$145,360	$193,743	$220,570	$198,397				
	BELLOWS	$1,640,186	$1,443,769	$1,431,865	$1,421,945	$1,312,824				
	SUPPORTS	$1,495,034	$1,315,999	$1,305,148	$1,296,106	$1,196,642				
	TUBE INSTAL	$1,393,997	$1,227,061	$1,216,944	$1,208,513	$1,115,771				
	LEAK TEST	$2,126,371	$1,871,732	$1,856,299	$1,843,438	$1,701,972				
COST SUMMARIES		**$6,820,769**	**$6,003,920**	**$6,003,998**	**$5,990,572**	**$5,525,606**				
TOTAL COST- TUBETECH										
SANFORD/LIVINGSTON		$109,261	$96,150	$129,238	$148,334	$132,365				
SANFORD/HANFORD		$463,372	$407,767	$537,490	$623,783	$581,588				
	FREIGHT	$572,633	$503,917	$666,729	$772,117	$713,952				
	BELLOWS	$1,640,186	$1,443,769	$1,431,865	$1,421,945	$1,312,824				
	SUPPORTS	$1,495,034	$1,315,999	$1,305,148	$1,296,106	$1,196,642				
	TUBE INSTAL	$1,393,997	$1,227,061	$1,216,944	$1,208,513	$1,115,771				
	LEAK TEST	$2,126,371	$1,871,732	$1,856,299	$1,843,438	$1,701,972				
COST SUMMARIES		**$7,228,221**	**$6,362,478**	**$6,476,984**	**$6,542,119**	**$6,041,161**				
TOTAL COST - NORTWEST PIPE								note: tubing material & mfg cost not included		
PORTLAND/HANFORD		$55,921	$49,210	$64,504	$72,236	$66,033				
PORTLAND/ LIVINSTON		$337,481	$355,524	$407,135	$430,491	$405,151				
	FREIGHT	$393,402	$404,734	$471,640	$502,727	$471,184				
	BELLOWS	$1,640,186	$1,443,769	$1,431,865	$1,421,945	$1,312,824				
	SUPPORTS	$1,495,034	$1,315,999	$1,305,148	$1,296,106	$1,196,642				
	TUBE INSTAL	$1,393,997	$1,227,061	$1,216,944	$1,208,513	$1,115,771				
	LEAK TEST	$2,126,371	$1,871,732	$1,856,299	$1,843,438	$1,701,972				
COST SUMMARIES		**$7,048,989**	**$6,263,295**	**$6,281,895**	**$6,272,729**	**$5,798,393**				

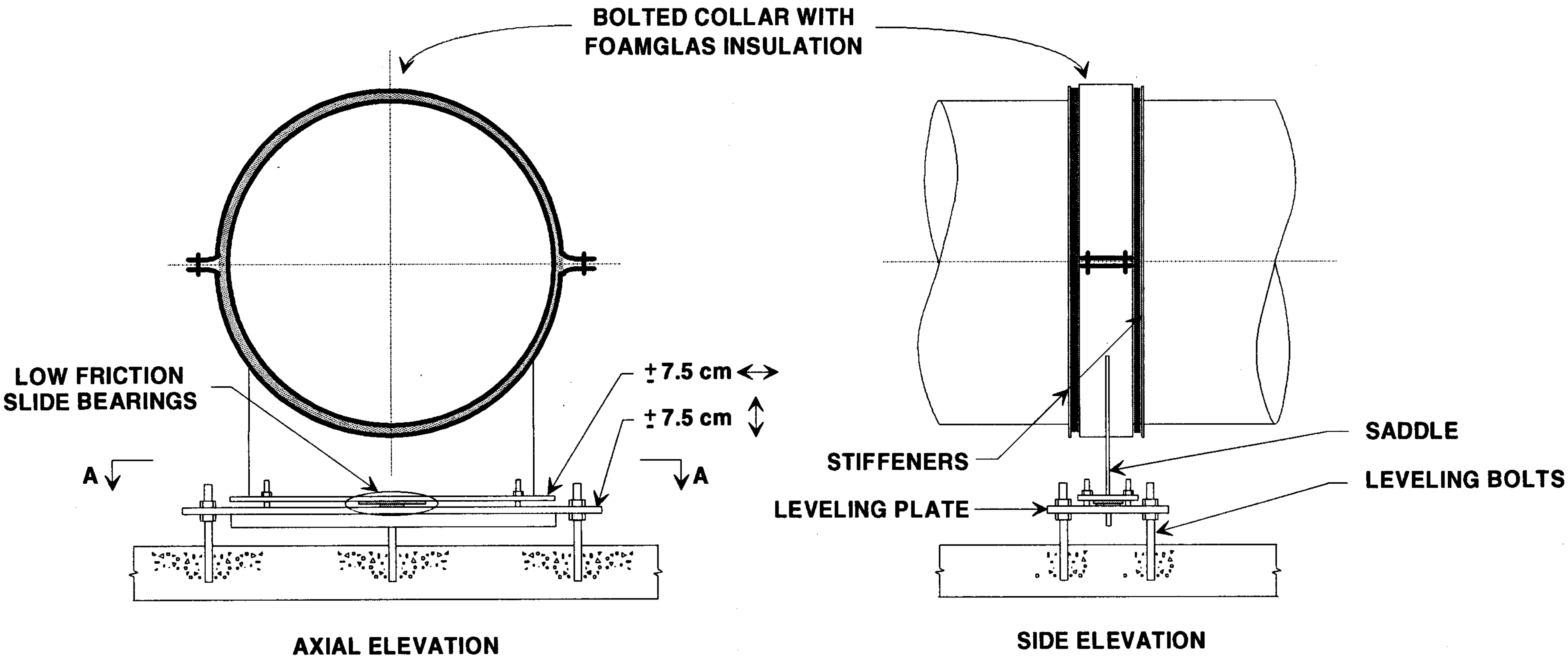


FIGURE 1

SUPPORT CONCEPT

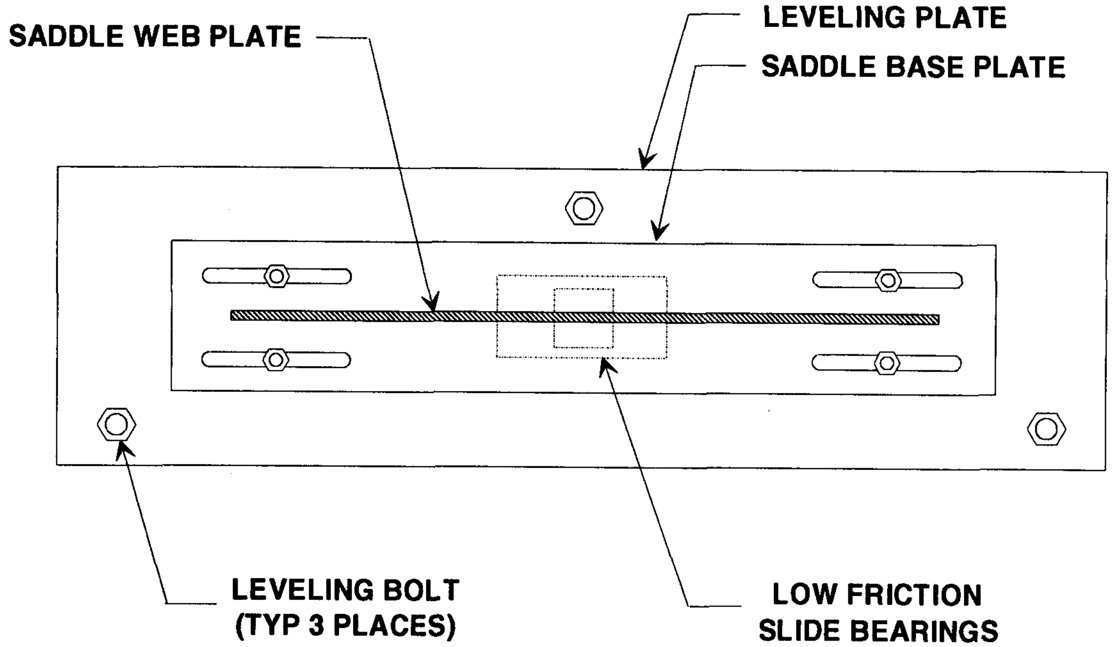
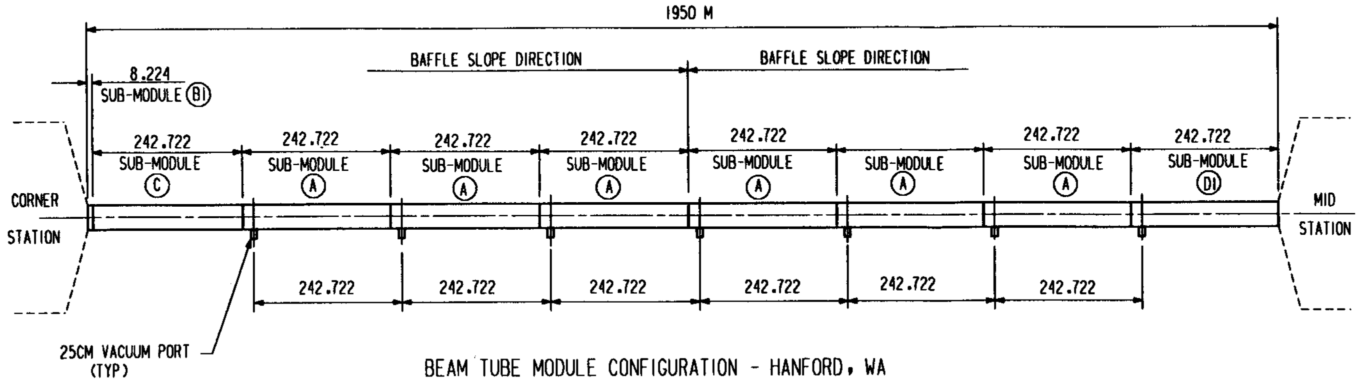


FIGURE 2

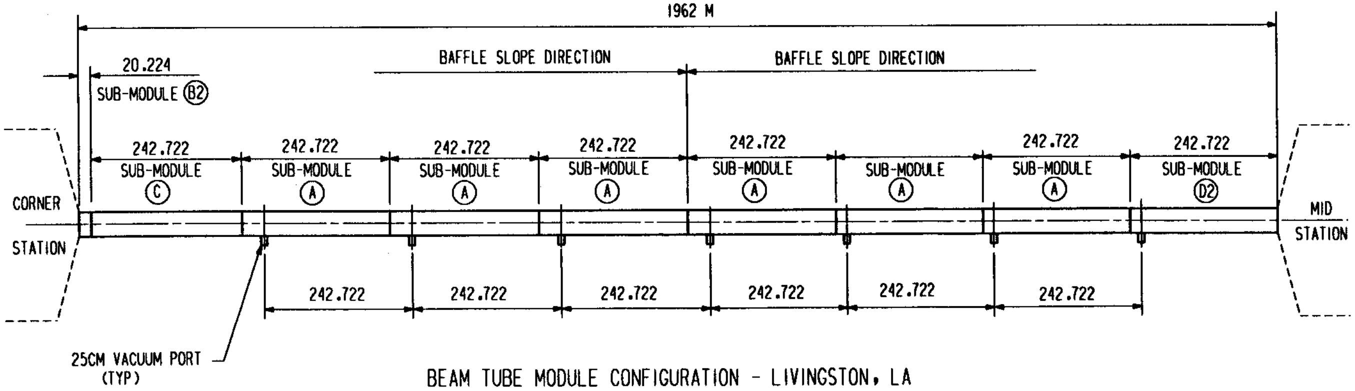
<u>SECTION A-A</u>



BEAM TUBE MODULE CONFIGURATION - HANFORD, WA

(4) - REQD
(DIMENSIONS IN METERS)

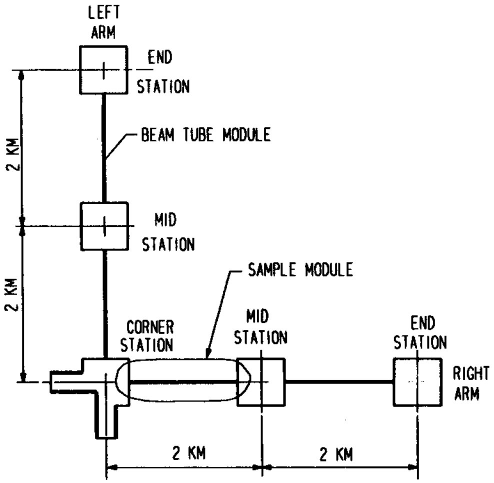
- (96) - BEAM TUBE SECTIONS
- (1) - END SECTION
- (98) - EXPANSION JOINTS
- (120) - BAFFLES
- (7) - VACUUM PORTS
- (97) - SUPPORTS



BEAM TUBE MODULE CONFIGURATION - LIVINGSTON, LA

(4) - REQD
(DIMENSIONS IN METERS)

- (96) - BEAM TUBE SECTIONS
- (1) - END SECTION
- (98) - EXPANSION JOINTS
- (112) - BAFFLES
- (7) - VACUUM PORTS
- (97) - SUPPORTS

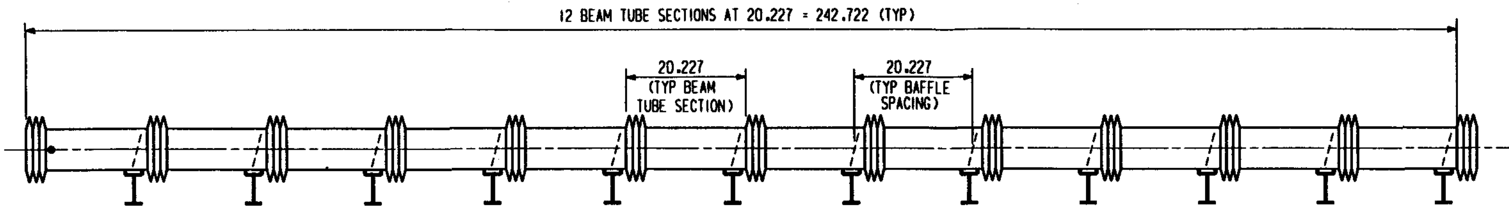


NOTE:
WORK THIS DRAWING W/DWG A002.

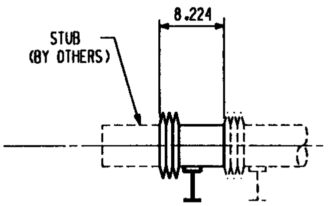
▶ INDICATES CHANGE FROM PREVIOUS ISSUE

CBI	SUPPLIER'S / PURCHASER'S NO
LIGO BEAM TUBE MODULES	
GENERAL MODULE CONFIGURATION AND VACUUM PORT LOCATION	
SUBENGRS NO BY DAP CHKD DATE J M BLANCHARD ENGINEERING SUPERVISOR	CONTRACT NO 930212 DWG A001 REV 0 SHT

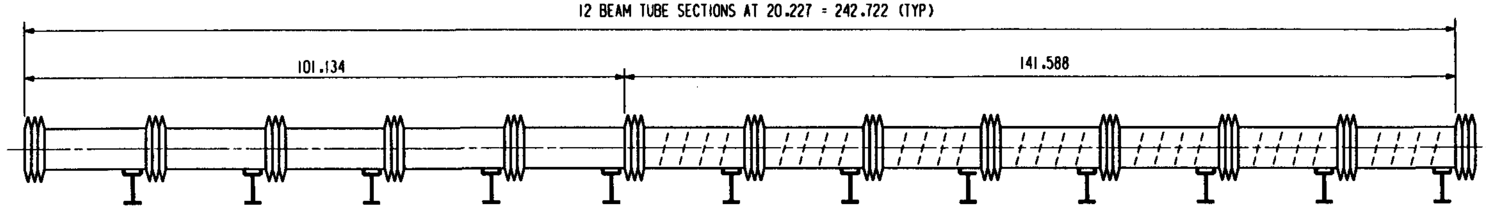
REMARKS			
REVISIONS	BY CHKD DATE	BY CHKD DATE	BY CHKD DATE



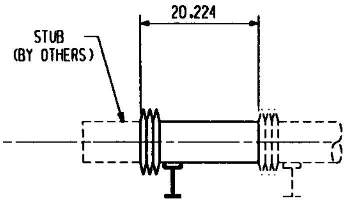
SUB-MODULE Ⓐ



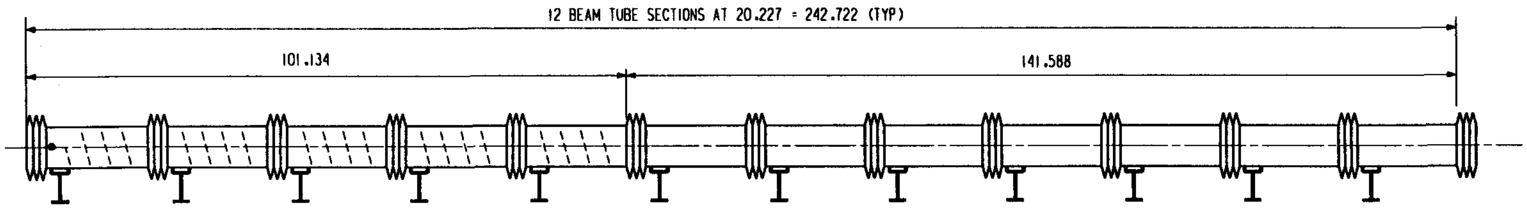
SUB-MODULE (B1)



SUB-MODULE Ⓒ



SUB-MODULE (B2)

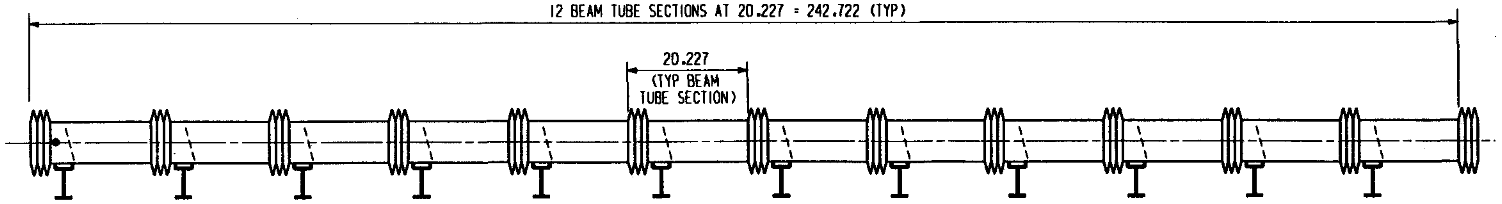


SUB-MODULE (D1)

/ - BAFFLE (AS SHOWN INDICATES SLOPE TO RIGHT)

● - VACUUM PORT

⊥ - SUPPORT



SUB-MODULE (D2)

NOTE:

1. WORK THIS DRAWING W/DWG A001.
2. DIMENSIONS ARE IN METERS U.N.O.

SUB-MODULE Ⓐ

(12) - BEAM TUBE SECTIONS
(12) - EXPANSION JOINTS
(12) - BAFFLES
(1) - VACUUM PORTS
(12) - SUPPORTS

SUB-MODULE (B1)

(1) - TUBE SECTIONS
(2) - EXPANSION JOINTS
(0) - BAFFLES
(0) - VACUUM PORTS
(1) - SUPPORTS

SUB-MODULE (B2)

(1) - TUBE SECTIONS
(2) - EXPANSION JOINTS
(0) - BAFFLES
(0) - VACUUM PORTS
(1) - SUPPORTS

SUB-MODULE Ⓒ

(12) - BEAM TUBE SECTIONS
(12) - EXPANSION JOINTS
(28) - BAFFLES
(1) - VACUUM PORTS
(12) - SUPPORTS

SUB-MODULE (D1)

(12) - BEAM TUBE SECTIONS
(12) - EXPANSION JOINTS
(20) - BAFFLES
(1) - VACUUM PORTS
(12) - SUPPORTS

SUB-MODULE (D2)

(12) - BEAM TUBE SECTIONS
(12) - EXPANSION JOINTS
(12) - BAFFLES
(1) - VACUUM PORTS
(12) - SUPPORTS

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

BY CHKD DATE BY CHKD DATE BY CHKD DATE REVISIONS REMARKS

CBI

SUPPLIER'S / PURCHASER'S NO

LIGO BEAM TUBE MODULES

SUB- MODULE DETAILS

SUBCONTRACTOR'S NO

BY DAP CHKD ____ DATE ____

J M BLANCHARD
ENGINEERING SUPERVISOR

CONTRACT NO 930212

DWG A002 REV 0

SHT

3212A002

TITLE

PURCHASE ORDER & SUBCONTRACT PROVISIONS
FOR THE SUPPLY OF GOODS AND/OR SERVICES
LIGO BEAM TUBE MODULE

CBI

CBI TECHNICAL SERVICES Company

PURCHASE ORDER & SUBCONTRACT PROVISIONS

Table of Contents

INTRODUCTION

I GENERAL

This booklet contains the purchase order and subcontract provisions applicable to all CBI purchases of goods and/or services for this project. In addition to these provisions, each purchase order or subcontract will include a specific set of specifications and requirements as needed to fully define the goods and/or services being purchased.

II BUY AMERICA

All goods supplied for this contract must be of domestic origin as defined by FAR 52.225-5.

III DOCUMENT ORDER OF PRECEDENCE

In the event there are any conflicting provisions or requirements in the component parts of the purchase order or subcontract, the attached documents shall take precedence in the following priority order:

1. Revisions to purchase order or subcontract
2. Purchase order or subcontract
3. Purchase Order Conditions (on back of order form)
4. Section E - General Conditions
5. Specifications and Drawings attached to individual purchase order or subcontract

IV INTERPRETATION/APPLICABILITY OF THE PROVISIONS IN THIS BOOKLET:

1. When interpreting the General Conditions, and General Provisions you should assume that you are the lowest tier supplier or subcontractor mentioned regardless of the language used to define the specific parties. Similarly, CBI Technical Services Company, is the next tier subcontractor above you.

2. Many of the clauses included in this booklet are applicable <u>only</u> if your order and/or subcontract includes execution of work on the job sites at Hanford, Washington and Livingston, Louisiana. As a supplier of goods and/or services to CBI for this project, it is your responsibility to understand which clauses do or do not apply to your scope of work.

3. Many of the articles in the General Provisions contains substance which is applicable regardless of the next tier. Those articles are so stated and special attention should be given to their contents.

V SELLER'S CERTIFICATION

Prior to the issuance of any purchase order or subcontract, CBI MUST have on file the following form, completed and signed by an authorized representative of the proposed seller:

1. Form GE 670 (3 pages) entitled "Equal Employment Certificate of Compliance"

VI SUBMITTALS

Each purchase order or subcontract will include a Submittal Register which will list all documents required from the supplier or subcontractor. Invoice payment will be delayed until all requirements or the submittal register have been met.

CBI EQUAL EMPLOYMENT CERTIFICATE OF COMPLIANCE

During the performance of any purchase order to which this agreement is applicable, the supplier agrees as follows:

A EQUAL EMPLOYMENT OPPORTUNITY – EXECUTIVE ORDER 11246, AS AMENDED

1 The supplier will not discriminate against any employee or applicant for employment because of race, color, religion, sex, age, or national origin. The supplier will take affirmative action to ensure that applicants are employed, and that employees are treated during employment, without regard to their race, color, religion, sex, age, or national origin. Such action shall include, but not be limited to the following: employment, upgrading, demotion, or transfer; recruitment or recruitment advertising; layoff or termination; rates of pay or other forms of compensation; and selection for training, including apprenticeship. The supplier agrees to post in conspicuous places, available to employees and applicants for employment, notices setting forth the provisions of this nondiscrimination clause.

2 The supplier will, in all solicitations or advertisments for employees placed by or on behalf of the supplier, state that all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, age, or national origin.

3 The supplier will send to each labor union or representative of workers with which he has a collective bargaining agreement or other contract or understanding, a notice, to be provided by the agency contracting officer, advising the labor union or workers' representative of the supplier's commitments under Section 202 of Executive Order 11246 of September 24, 1965, and shall post copies of the notice in conspicuous places available to employees and applicants for employment.

4 The supplier will comply with all provisions of Executive Order 11246 of September 24, 1965, and of the rules, regulations, and relevant orders of the Secretary of Labor.

5 The supplier will furnish all information and reports required by Executive Order 11246 of September 24, 1965, and by the rules, regulations, and orders of the Secretary of Labor, or pursuant thereto, and will permit access to his books, records, and accounts by the contracting agency and the Secretary of Labor for purposes of investigation to ascertain compliance with such rules, regulations, and orders.

6 In the event of the supplier's noncompliance with the nondiscrimination clauses of this contract or with any such rules, regulations, or orders, any purchase order to which this agreement is applicable, may be canceled, terminated or suspended in whole or in part and the supplier may be declared ineligible for further Government contracts in accordance with procedures authorized in Executive Order 11246 of September 24, 1965, and such other sanctions may be imposed and remedies invoked as provided in Executive Order 11246 of September 24, 1965, or by rule, regulation, or order of the Secretary of Labor, or as otherwise provided by law.

7 The supplier will include the provisions of paragraph (1) through (7) in every subcontract or purchase order unless exempted by rules, regulations, or orders of the Secretary of Labor issued pursuant to section 204 of Executive Order 11246 of September 24, 1965, so that such provisions will be binding upon each subcontractor or vendor. The supplier will take such action with respect to any subcontract or purchase order as the contracting agency may direct as a means of enforcing such provisions including sanctions for noncompliance. Provided, however, that in the event the supplier becomes involved in, or is threatened with, litigation with a subcontractor or vendor as a result of such direction by the contracting agency, the supplier may request the United States to enter into such litigation to protect the interests of the United States.

B STANDARD FORM 100 - (EEO-1)

Supplier certifies to the filing of annual compliance reports on standard Form 100 (EEO-1) in compliance with Section 60-1.7 of Rules and Regulations, Office of Federal Contract Compliance (EEO) Department of Labor, unless exempt under Section 60-1.5, and to the requirement of a similar certification from each of its nonexempt suppliers.

C AFFIRMATIVE ACTION PROGRAM

Supplier certifies to the maintenance of written and signed affirmative action plan as specified in Sub-part C-Ancillary Matters; Section 60-1.40 of Rules and Regulations, Office of Federal Contract Compliance (EEO) Department of Labor, for each of its establishments, and certifies further the requirement of a similar certification from each of its nonexempt suppliers.

D NONSEGREGATED FACILITIES

Supplier certifies that he does not maintain or provide for his employees any segregated facilities at any of his establishments, and that he does not permit his employees to perform their services at any location, under his control, where segregated facilities are maintained. Supplier certifies further that he will not maintain or provide for his employees any segregated facilities at any of his establishments, and that he will not permit his employees to perform their services at any location, under his control, where segregated facilities are maintained. Supplier agrees that a breach of this certification is a violation of the Equal Opportunity clause in this agreement. As used in this certification, the term "segregated facilities," means any waiting rooms, work areas, rest rooms and wash rooms, restaurants and other eating areas, time clocks, locker rooms and other storage or dressing areas, parking lots, drinking fountains, recreation or entertainment areas, transportation, and housing facilities provided for employees which are segregated by explicit directive or are in fact segregated on the basis of race, color, religion or national origin, because of habit, local custom, or otherwise. Supplier further agrees that (except where he has obtained identical certifications from proposed subcontractors for specific time periods) he will obtain identical certifications from proposed subcontractors prior to the award of a subcontracts exceeding $10,000 which are not exempt from the provisions of the Equal Opportunity clause; that he will retain such certifications in his files; and that he will forward the following notice to such proposed subcontractors (except where the proposed subcontractors have submitted identical certifications for specific time periods):

NOTICE TO PROSPECTIVE SUBCONTRACTORS OF REQUIREMENT FOR CERTIFICATIONS OF NONSEGREGATED FACILITIES

A certificate of Nonsegregated Facilities must be submitted prior to the award of a subcontract exceeding $10,000 which is not exempt from the provisions of the Equal Opportunity clause. The certification may be submitted either for each subcontract or for all subcontracts during a period (i.e., quarterly, semiannually, or annually).

E MINORITY BUSINESS ENTERPRISE – EXECUTIVE ORDER 11625

It is the policy of the Government that minority business enterprises shall have the maximum practicable opportunity to participate in the performance of Government contracts.

The supplier agrees to use his best efforts to carry out this policy in the award of his subcontracts to the fullest extent consistent with the efficient performance of the contract. As used in the contract, the term "Minority Business Enterprise" means a business, at least 50 percent of which is owned by minority group members or, in the case of publicly owned businesses, at least 51 percent of the stock is owned by minority group members. For the purposes of this definition, minority group members are Negroes, Spanish-speaking American persons, American-Orientals, American-Indians, American Eskimos, and American Aleuts. The supplier may rely on written representations by subcontractors regarding their status as minority business enterprises in lieu of an independent investigation.

F MINORITY BUSINESS ENTERPRISES SUBCONTRACTING PROGRAM

The supplier agrees to comply with the Minority Business Enterprises Subcontracting Program clause as set forth in 41 CFR 1-1310-2(b) which is incorporated in this certificate by reference.

G EXECUTIVE ORDER 11701-EMPLOYMENT OF VETERANS

As provided by 41 CFR 50-250, the supplier agrees that all suitable employment openings which exist at the time of the execution of this contract and those which occur during the performance of this contract, including those not generated by this contract and including those occuring at an establishment of the contractor other than the one wherein the contract is being performed but excluding those of independently operated corporate affiliates, shall, to the maximum extent feasible, be offered for listing at an appropriate local office of the state employment service system wherein the opening occurs and to provide such periodic reports to such local office regarding employment openings and hires as may be required; provided, that this provision shall not apply to openings which the supplier proposes to fill from within the organization or are filled pursuant to a customary and traditional employer-union hiring arrangement and that the listing of employment openings shall involve only the normal obligations which attach to the placing of job orders.

H EXCUTIVE ORDER 11758-EMPLOYMENT OF HANDICAPPED PERSONS

The supplier certifies that, in employing persons to carry out contracts entered into with the company, it will take affirmitive action to employ and advance in employment qualified handicapped individuals, defined as "any individual who has a physical or mental disability which for such individual constitutes or results in a substantial handicap to employment".

I WOMEN OWNED BUSINESS CONCERNS – EXECUTIVE ORDER 12138

(a) It is the policy of the United States Government that women-owned businesses shall have the maximum practicable opportunity to participate in the performance of contracts awarded by any Federal agency.

(b) The Contractor agrees to use his best efforts to carry out this policy in the award of subcontracts to the fullest extent consistent with the efficient performance of this contract. As used in this contract, a "woman-owned business" concern means a business that is at least 51% owned by a woman or women who also control and operate it. "Control" in this context means exercising the power to make policy decisions. "Operate" in this context means being actively involved in the day-to-day management. "Women" mean all women business owners.

J WOMEN OWNED BUSINESS CONCERNS SUBCONTRACTING PROGRAM

The supplier agrees to comply with the Women Owned Business Concerns Subcontracting Program clause as set forth in Executive Order 12138 (FR VOL 45, NO. 92, Friday May 9, 1980) which is incorporated in this certificate by reference.

K SMALL BUSINESS AND SMALL DISADVANTAGED BUSINESS CONCERNS

UTILIZATION OF SMALL BUSINESS CONCERNS AND SMALL BUSINESS CONCERNS OWNED AND CONTROLLED BY SOCIALLY AND ECONOMICALLY DISADVANTAGED INDIVIDUALS.

(a) It is the policy of the United States that small business concerns and small business concerns owned and controlled by socially economically disadvantaged individuals shall have the maximum practicable opportunity to participate in the performance of contracts let by any Federal agency.

(b) The contractor hereby agrees to carry out this policy in the awarding of subcontracts to the fullest extent consistent with the efficient performance of this contract. The contractor further agrees to cooperate in any studies or surveys as may be conducted by the Small Business Administration or the contracting agency which may be necessary to determine the extent of the contractor's compliance with this clause.

(c) (1) As used in this contract, the term "small business concern" shall mean a small business as defined pursuant to section 3 of the Small Business Act and relevant regulations promulgated pursuant thereto.

(2) The term "small business concern owned and controlled by socially economically disadvantaged individuals" shall mean a small business concern -

(i) which is at least 51 per centum owned by one or more socially and economically disadvantaged individuals; or in the case of any publicly owned business, at least 51 per centum of the stock of which is owned by one or more socially and economically disadvantaged individuals; and

(ii) whose management and daily business operations are controlled by one or more of such individuals

The contractor shall presume that socially and economically disadvantaged individuals include Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, and other minorities, or any other individual found to be disadvantaged by the Small Business Administration pursuant to section 8 (a) of the Small Business Act.

(d) Contractors acting in good faith may rely on written representations by their subcontractors regarding their status, as a small business concern or a small business concern owned and controlled by socially and economically disadvantaged individuals.

L SMALL BUSINESS AND SMALL DISADVANTAGED BUSINESS SUBCONTRACTING PLAN

The supplier agrees to comply with the Small Business and Small Disadvantaged Business Subcontracting Plan Clause as set forth in Public Law 95-507, Section 211 which is incorporated in this certificate by reference.

M LABOR SURPLUS AREA CONCERNS – 41 CFR 1-1.805-3(a)

(The following clause is applicable if this contract exceeds $10,000.)

(a) It is the policy of the Government to award contracts to labor surplus area concerns that agree to perform substantially in labor surplus area, where this can be done consistent with the efficient performance of the contract and at prices no higher than are obtainable elsewhere. The Contractor agrees to use his best efforts to place his subcontracts in accordance with this policy.

(b) In complying with paragraph (a) of this clause and with paragraph (b) of the clause of this contract entitled "Utilization of Small Business Concerns," the Contractor in placing his subcontracts shall observe the following order of preference: (1) Small business concerns that are labor surplus area concerns, (2) other small business concerns, and (3) other labor surplus area concerns.

(c) (1) The term "labor surplus area" means a geographical area identified by the Department of Labor as an area of concentrated unemployment or underemployment or an area of labor surplus.

(2) The term "labor surplus area concern" means a concern that together with its first-tier subcontractors will perform substantially in labor surplus areas.

(3) The term "perform substantially in a labor surplus area" means that the costs incurred on account of manufacturing, production, or appropriate services in labor surplus areas exceed 50 percent of the contract price.

N LABOR SURPLUS AREA SUBCONTRACTING PROGRAM

The supplier agrees to comply with the Labor Surplus Area Subcontracting Program Clause as set forth in 41 CFR 1-1.805-3 (b). which is incorporated in this certificate by reference.

O CLEAN AIR AND WATER

Applicable only if the contract exceeds $100,000 in any one year.

The supplier agrees to comply with the requirements of section 114 of the Clean Air Act and section 308 of the Federal Water Pollution Control Act and the Clean Air and Water contract clause published in 41 CFR 1-1.2302-2, which is incorporated in this certificate by reference.

SUPPLIER/CONTRACTOR CLASSIFICATION – Check appropriate block(s)

☐ Small Business Concern

☐ Minority Business Enterprise

☐ Women-Owned Business Concern

☐ Small Business Concern Owned and Controlled By Socially and Economically Disadvantaged Individuals.

☐ Labor Surplus Area Concern

This certificate shall be effective for one (1) year from the date stated below.

(Please type Company name)

Date

Signature of Authorized Representative

Title of Authorized Representative

PLEASE RETURN COMPLETED FORM TO:

SHIG KOGA
PURCHASING DEPARTMENT
CBI TECHNICAL SERVICES
1501 N. DIVISION STREET
PLAINFIELD, ILLINOIS 60544-8929

Printed in USA

PROCUREMENT PLAN
FOR
LIGO BEAM TUBE MODULES
DESIGN & QUALIFICATION TEST

1.0 PURPOSE

This plan describes the procurement procedures and documentation to be used by CBI in the execution of the LIGO Beam Tube Module Design and Qualification Test.

2.0 SCOPE

This plan covers the procurement of all materials and equipment required to develop the beam tube module detailed design and required to execute the qualification test.

3.0 CLASSIFICATION OF PROCUREMENT ITEMS

The material and equipment procured for the LIGO Beam Tube Module Design and Qualification Test will be classified according to its use.

3.1 Beam Tube Module Components

All items which physically represent components is the beam tube modules are classified as "Module Components". Module components are considered to be contract material even though CBI retains ownership of all module components in the design and qualification test. Module components are subject to all ASME code and CBI procurement and material controls and procedures for contract material. The following items are module components:

- Spiral welded beam tube sections
- Beam tube stiffeners
- Beam tube expansion joints
- Beam tube supports and adjustment mechanisms
- Beam tube baffles
- 10" diameter pumping port
- Welding material

3.2 Demonstration Components

All items used in the development of the procedures for the design and qualification test and for the option which may be representative of option activities are classified as demonstration components. Items should be considered to be demonstration components as long as they potentially represent option activities or configurations. The demonstration components include, but are not necessarily limited to the following items:

- Alignment equipment
- Welding equipment and prototype
- Cleaning equipment
- Leak testing equipment
- Outgas testing equipment

3.3 Qualification Test Construction Equipment

All items used in the execution of the design and qualification which are not representative of the option are considered to be QT Construction Equipment. The QT construction components include the following items:

- Bake out equipment
- Temporary supports
- Thrust blocks or end supports
- Qualification test pumping equipment

4.0 PROCUREMENT DOCUMENTATION

4.1 Module Components

Module components will be procured and identified in accordance with CBI's practice for ASME Section VIII Division 1 structures. CBI's practice for these structures is described in CBI's ASME QCS Manual.

4.1.1 Module component items and services shall be purchased in accordance with written requisitions.

4.1.2 To assure item and service conformance's, the following steps shall be implemented:

A. Purchase orders shall contain all technical and QA information needed to satisfy the LIGO Beam Tube Module Design and Qualification Test contract. The Project Services Department shall prepare a LIGO Project Procurement Specification which contains all LIGO pass through requirements. The responsible design groups shall prepare Technical Specifications for all purchased module components which completely describe the physical, material, inspection and documentation requirements. The Procurement Specification and the Technical Specification shall accompany all requests for quotation and purchase orders.

B. Purchased items shall be inspected at the source or upon receipt for identity, compliance with the P.O. and shipping damages.

C. The result of the receiving inspection shall be documented on a Receiving Inspection Report, RIR.

D. Accompanying documentation shall be reviewed by the Purchasing Manager or the Qualification Test Manager for completeness, correctness and compliance with the requirements of the P.O.

E. The user of the service is responsible for verifying its compliance with the P.O.

4.2 Demonstration Components and Construction Equipment

Demonstration components and construction equipment will be procured by Houston Corporate Welding and Plainfield Research & Development in accordance with the attached "Procurement Procedure" for the respective departments.

5.0 PRODUCT IDENTIFICATION AND TRACEABILITY

Product identification and traceability shall be maintained for all Module Components fabricated by CBI or supplied by others.

5.1 CBI Fabricated Module Components

CBI fabricated module components are those components manufactured in CBI shops.

5.1.1 Engineering-Assigned shall prepare contract drawings, procurement specifications and bill sheets which identify the material and items required. The bill sheets shall indicate the material identification (ID) required for each item. This ID will indicate the traceability required for the item.

5.1.2 The Superintendent shall identify all material and items with a contract number and piece mark and, when required, with a serial number which can be related to a mill marking so that traceability can be maintained throughout the fabrication and installation processes. Identification shall be made in the form of a mark, label or hardstamp. The marking or labeling shall be legible, durable and in accordance with any application procedures or instructions. CBI Standards shall be followed for material identification coding systems.

5.1.3 The Superintendent shall prepare a "Daily Fabrication or Stores Release Report" (DFR). The DFR identifies the material and provides a tie between the CBI piece mark and serial number and supplier heat and lot number. The completed DFR is used for material verification.

5.2 Vendor Supplied Module Components

5.2.1 Material supplied by vendors shall be inspected upon receipt for proper identification, shipping damage and any special contract requirements.

5.2.2 Any products that are lost, damaged, rendered unusable, received without proper documentation or inadequate identification shall be documented and immediately reported to the vendor for disposition.

5.2.3 When the vendor supplies material, the vendor identification system may be used. Alternately, the CBI identification system may be used.

6.0 PROCUREMENT PROCEDURES

6.1 Module Components

6.1.1 Only module components for the qualification test are within the scope of this plan. Purchasing documents prepared by Engineering and Project Services shall be assembled and issued to potential suppliers by the Project Services department. Project Services shall receive all quotations and proposals. Proposals shall be reviewed by all relevant departments and by the Engineering Project Manager.

6.1.2 After review and approval of the Engineering Project Manager, the Project Services department shall issue written requisitions or purchase orders to the selected supplier. To assure item and service conformance, purchase orders, including any referenced attached procurement specification, shall contain all the technical and QA information needed to satisfy the requirements of the contract.

6.1.3 The Engineering Project Manager shall obtain Caltech's review and comments prior to issuing any module component purchase order.

6.2 Demonstration Equipment and Construction Equipment

6.2.1 Purchasing documents shall be prepared and issued by the responsible department in accordance with the attached procurement procedures. Proposals shall be received by the issuing department and reviewed by all relevant departments and by the Engineering Project Manager.

6.2.2 After review and approval of the Engineering Project Manager, the issuing department shall issue a written requisition or purchase order to the selected supplier. To assure item and service conformance, purchase orders, including any referenced attached procurement specification, shall contain all the technical and QA information needed to satisfy the requirements of the contract.

6.2.3 The Engineering Project Manager shall obtain Caltech's review and comments prior to issuing major equipment purchase orders.

6.3 Verification of Items and Services

6.3.1 Purchased items shall be inspected at the source or upon receipt for identity, compliance with the P.O. and shipping damage.

6.3.1.1 The result of receiving inspection shall be documented on a Receiving Inspection Report (RIR) for all module components.

6.3.1.2 Accompanying documentation (CMTR, COC, etc.) shall be reviewed by the Purchasing Manager or Welding and QC Manager for completeness, correctness and compliance with the requirements in the P.O.

6.3.2 The user of the service is responsible for verifying its conformance with the P.O.

6.3.3 Beam tube module sections shall be inspected at the point of fabrication prior to releasing sections for shipment.

7.0 CALTECH NOTIFICATION

7.1 Module Components

7.1.1 Copies of all RFP's for module components shall be sent to Caltech when issued to potential vendors.

7.1.2 Caltech shall be notified of all visits to vendors or potential vendors of LIGO module components.

7.1.3 In addition to those requirements contained in Contract No. C146, CBI shall notify Caltech of any module component vendor selection prior to issuing the P.O. to enable Caltech to review and comment.

7.1.4 Caltech or their representatives shall have non-escort privileges to all areas of CBI's or CBI's subcontractor's facilities where work in being performed under the Beam Tube Module contract. All purchase orders shall include notification to vendors and subcontractors to this effect.

7.2 Demonstration Components

7.2.1 In addition to those requirements contained in Contract No. C146, CBI shall notify Caltech of the purchase of any potential demonstration component when the component is purchased.

7.3 Construction Equipment

7.3.1 No special notification is required for construction equipment. Notification shall be in accordance with Contract No. C146.

GENERAL CONDITIONS

ARTICLE 1

DRAWINGS AND SPECIFICATIONS

All Work shall be performed in accordance with the Drawings and Specifications and all other requirements of this Subcontract. Contractor may reject any work which is determined by Contractor to be not in accordance with the Drawings and Specifications.

The various parts of this Subcontract are intended to be complementary to each other, but should any discrepancy appear, or any misunderstanding arise as to the import of anything contained therein, the resolution shall be per mutual agreement of Contractor and Subcontractor. The correction of any errors or omissions of the Drawings and Specifications may be made by Contractor when such correction is necessary to bring out clearly the intention which is indicated by a reasonable interpretation of the Drawings and Specifications as a whole.

Additional drawings and explanations to exhibit or illustrate details may be provided by Contractor, and if consistent with the Drawings and Specifications, they shall be binding upon Subcontractor.

Omissions from the Drawings or Specifications or other Subcontract Documents of details of Work which are manifestly necessary to carry out the intent of the Drawings and Specifications, or which are customarily performed, shall not relieve the Subcontractor from performing such omitted details or work, but they shall be performed as if fully correctly set forth and described in the Drawings and Specifications.

Matters shown either on the Drawings or in the Specifications shall be performed and furnished as if shown in both except when expressly excepted either on the Drawings or in the Specifications. In all cases, figured dimensions shall be taken in preference to scale measurement, and detailed drawings consistent with general drawings shall be taken in preference to general drawings of the same part of the Work.

In case of a discrepancy or difference between any figures, Drawings or Specifications, the matter shall be immediately submitted in writing to Contractor, whose decision shall be final and conclusive, and without whose decision said discrepancy or difference shall not be adjusted by Subcontractor, save only at Subcontractor's own risk and expense. The foregoing remedies shall not preclude Subcontractor's right for additional compensation and a change in the schedule, if appropriate.

Neither Contractor nor Engineer assume responsibility for bidding errors or omissions caused by failure of Subcontractor or any Sub-subcontractors to inspect and familiarize themselves with the complete set of Drawings, Specifications and other documents relating to this Subcontract which are available for inspection.

Subcontractor shall keep one (1) record copy of all Specifications, Drawings and other drawings at the Jobsite in good order and annotated (as-built drawings) to show all changes made during construction. These shall be available to Contractor and shall be delivered to Contractor upon completion of the Work.

All Drawings, Specifications, technical data and other information furnished to Subcontractor by Contractor in connection with this Subcontract are and shall remain the property of Contractor, and may not be copied or otherwise reproduced by Subcontractor or used in any way, except in connection with the Work performed under this Subcontract, or disclosed by Subcontractor to third parties or used in any manner detrimental to the interests of Owner or Contractor. They shall not be used by Subcontractor on another project, and shall be returned to Contractor on request upon completion of the Work.

Subcontractor agrees to insert in any Sub-subcontract a restriction on the use of such information, data, Drawings and Specification similar to that set forth in the above paragraph.

ARTICLE 3
INSPECTIONS AND TESTS

Subcontractor shall, upon demand, furnish Contractor with a list of all Subcontractor's vendors and Sub-subcontractors.

Subcontractor shall furnish to Contractor status of materials data to ensure the availability of the necessary equipment required by Contractor or other contractors for their erection/installation at the time and location required.

Subcontractor shall provide, to Contractor, inspection reports, drawing submittals and status schedules, and production schedules, as required by this Subcontract, which accurately depicts the progress and status of the Work and the key equipment delivery dates.

Subcontractor shall, in a timely manner, furnish samples of materials, mockups, certificates, prints of the Subcontractor's shop drawings, erection drawings, schedules, reports, affidavits and any other written or physical data that may be necessary, in the opinion of Contractor, for proper prosecution of the Work.

Subcontractor shall perform all applicable quality control activities, except those to be provided by Contractor, away from and at the Jobsite, including radiography. Subcontractor shall also provide all equipment as required to perform such quality control activities. Where required in the Special Conditions, Subcontractor shall provide, for Contractor's review and approval, a Quality Control Plan pertaining to Work under the Subcontract.

Unless otherwise specified, all materials and equipment permanently incorporated in the Work shall be new, and both workmanship and materials shall be of highest quality. Subcontractor shall, if required by Contractor, furnish satisfactory evidence as to source of supply and quality of material and equipment.

All materials and equipment furnished for permanent incorporation in the Work shall be subject to shop and field inspection and testing in accordance with standards specified by the Drawings and Specifications. In addition to inspection and testing which may be specified as part of the Work, Contractor reserves the right to arrange for such testing and inspection of materials and equipment as it may deem necessary. Any inspection and testing shall not relieve Subcontractor of his responsibility for furnishing materials and equipment complying with the Specifications. The cost of inspection and testing not specified will be borne by Contractor in the event that the materials or equipment tested prove satisfactory. If, however, the inspection and testing prove that materials or equipment are not in accordance with the Specifications, the cost of the inspection and testing shall be borne by Subcontractor.

Contractor's inspector(s) shall be advised per submittal requirements as to the schedule for inspections and testing at Subcontractor's shops, and every effort shall be made to provide Contractor or its representative the opportunity to witness this Work during regular working hours.

Contractor's and/or Owner's inspection of the Work or their failure to inspect shall in no way relieve Subcontractor of its obligation to fulfill the requirements of this Subcontract and shall not be construed as acceptance by Contractor of the Work or any part thereof.

Subcontractor shall provide, for the use of Contractor's and/or Owner's inspector(s), all protective clothing and apparatus to witness inspections and testing at Subcontractor's shops.

Prior to any inspection and testing, Subcontractor shall furnish Contractor a fabrication, inspection and testing schedule for all items to be fabricated. Further, Subcontractor shall, within forty-five (45) days after completion of all tests or as otherwise specified in this Subcontract, provide Contractor a complete set of all required inspection and test records. Subcontractor shall have and implement surveillance and inspection programs for all major equipment, which shall also include its subcontractor supplied major equipment. Subcontractor shall, prior to start of fabrication, provide Contractor with a copy of such program and Contractor shall have the right to audit such programs.

Contractor and/or Owner, or their designees, shall at all reasonable times have access to the Work. Without relieving Subcontractor of any responsibility hereunder, Contractor reserves the right to perform such examinations, inspections and tests of equipment, material and workmanship as it may desire to assure itself that the Work meets all specified requirements.

Subcontractor and all of its Sub-subcontractors shall permit unrestricted access to Contractor, and/or Owner or their designees for the purpose of conducting such examinations, inspections and tests at all reasonable times and places where the Work is in process, shall provide sufficient, safe and proper facilities such as ladders, scaffolds, openings, and drop lights required for such access, and shall make available any and all data which is relevant to the performance of the Work.

Subcontractor shall also give the Secretary of Labor, or his/her authorized representative, a right to entry to any site of Subcontractor's operations for the purpose of inspecting, investigating, or carrying out any of the Secretary's duties, including those duties under the Occupational Safety and Health Act of 1970, as amended (OSHA).

If this Subcontract, laws, ordinances, rules, regulations or orders of any public authority having jurisdiction require any Work to specifically be inspected, tested or approved by someone other than Subcontractor, Subcontractor shall give Contractor timely notice of readiness therefor. Subcontractor shall furnish Contractor the required certificates of inspection, testing or approval. All tests, inspections and/or approvals shall be arranged and/or performed by Subcontractor, unless otherwise specified in this Subcontract, in accordance with the methods prescribed or such other applicable methods as may be required by this Subcontract, laws, ordinances, rules, regulations or orders of any public authority having jurisdiction. If any Work by Subcontractor to be inspected, tested or approved is covered up prior to being inspected by Subcontractor and without written approvals or consent of Contractor, Subcontractor must, if directed by Contractor, uncover for observation at Subcontractor's expense. The cost of all inspections, tests and approval required under this Article, other than those arranged for or performed by Contractor shall be borne by Subcontractor unless otherwise provided in this Subcontract.

Observations, inspections, tests or approvals by persons other than Contractor shall not relieve Subcontractor from its obligations to perform the Work in accordance with the requirements of this Subcontract.

If any Work has been covered which Contractor has not specifically requested to observe prior to its being covered, or if Contractor considers it necessary or advisable that covered Work be inspected or tested by others, Subcontractor, at Contractor's request, shall uncover, expose or otherwise make available such Work for observation, inspection or testing. If it is found that such Work is defective or does not meet the requirements of this Subcontract, Subcontractor shall bear all expenses of uncovering, exposure, observation, inspection, testing and recovering of such Work. If, however, such Work is found not to be defective and meets the requirements of this Subcontract, Subcontractor shall be allowed an increase in the Subcontract Price or extension of the Subcontract Time directly attributable to such uncovering, exposure, observation, inspection, testing and recovering.

Nothing contained in the above paragraphs shall in any way void, restrict or limit the right of Contractor to later conduct such performance tests as it may desire, or void, restrict or limit Contractor's rights under this Subcontract.

ARTICLE 4

REVIEW OF SUBCONTRACTOR'S DRAWINGS, DATA AND WORK

Subcontractor shall furnish to Contractor such preliminary and final design drawings (if applicable), detail drawings and technical data including all reference drawings and related technical information and documents required for layout, installation, start-up, operation, and maintenance of equipment as are called for in this Subcontract. Subcontractor shall, as mutually agreed, also furnish reproducible drawings of equipment as delivered which contain equipment manufacturing tolerance, inspection and test requirements and submit general arrangement and equipment component drawings containing sufficient information and details to permit field construction to be carried out and to be monitored by Contractor.

Review by Contractor of any drawings, data and Work provided by Subcontractor shall be only for the purpose of ascertaining general conformity with the Drawings and Specifications and for confirmation of physical interface of the items shown with related work or systems. The review by Contractor of any drawings, data and Work does not include review of the efficiency, adequacy or safety of Subcontractor's methods of construction or the means adopted by Subcontractor to perform his Work, nor does it include a review of any detailed design or specifications prepared by Subcontractor for use in the Work.

Contractor's review or comment upon drawings, data and Work of Subcontractor shall not relieve Subcontractor from the entire responsibility for the correctness and suitability of Subcontractor's Work or for any other obligation of Subcontractor hereunder. While Subcontractor agrees to follow any and all comments made by Contractor on Subcontractor's drawings, data and Work insofar as such comments are acceptable to Subcontractor, this shall not relieve or release Subcontractor from such entire responsibility unless otherwise agreed to in writing.

Any drawings or other data required by the Specifications or otherwise to be furnished by Subcontractor for review by Contractor shall be submitted in the quantity and format specified.

Unless otherwise agreed to in writing, all drawings prepared by Subcontractor and submitted by him to Contractor in connection with Subcontractor's installation or erection activities pursuant to this Subcontract shall become the property of Contractor. Subcontractor shall not place his proprietary stamp on any such drawings.

ARTICLE 19

SUBCONTRACTOR'S BREACH, DEFAULT OR BANKRUPTCY

In the event of failure of Subcontractor to perform the Work required of it or to comply with the notices provided for in this Subcontract, or in the event that a petition under any of the provisions of the bankruptcy laws of the United States of America or any State or other jurisdiction, is filed by or against Subcontractor or in the event that provisions of any said bankruptcy laws are invoked by or against Subcontractor, or in the event Subcontractor admits in writing its inability to pay its debts or makes an assignment for the benefit of creditors, or in the event Subcontractor is adjudicated as bankrupt or insolvent, or a receiver, trustee or liquidator is appointed for any of its properties, or its properties pass into the hands of any legal representative, then Contractor, upon seven (7) days written notice to Subcontractor, shall have the right to any one or any combination of the following remedies:

1. Supply such number of men and quantity of material, equipment, etc., as Contractor deems advisable in and about the completion of such Work, and charge the cost thereof, together with all other reasonable expenses, to Subcontractor;

2. Terminate this Subcontract and after such termination to relet such Work and supply the same through its own forces or through other subcontractors or any other means. In case of such termination of the employment of Subcontractor, Subcontractor shall not be entitled to receive any further payment under this Subcontract until the said Work shall be wholly finished, at which time, if the unpaid balance of the amount to be paid under this Subcontract shall exceed the expense incurred by Contractor in finishing the said Work, such excess shall be paid by Contractor to Subcontractor; but if such expense shall exceed such unpaid balance, then Subcontractor shall pay the difference to Contractor. The expense incurred by Contractor shall include the cost of furnishing materials and of finishing the Work, also any damage incurred through the default of Subcontractor;

3. If Contractor is of the opinion that Subcontractor is not performing any part of the Subcontract Work properly, Contractor may terminate the right of Subcontractor to proceed with any separate parts of the Work without terminating the entire Subcontract. Contractor may exercise such right upon giving seven (7) days written notice to Subcontractor, whereupon Contractor may, after the said seven (7) days, take whatever steps it may deem necessary to perform those parts of the Work so terminated, and Contractor shall charge the cost thereof, together with all reasonable expenses, to Subcontractor; and

4. If this Subcontract is terminated by Contractor pursuant to the provisions hereof, all materials at the site shall belong to Contractor and all plant, tools, and equipment of Subcontractor shall remain upon the premises, and Contractor shall have the right to use the same without expense to Contractor, but after the Project Work has been fully completed and accepted by Owner, Subcontractor may remove such of the plant, tools and equipment as still remain.

If any of the events listed in this Article occurs and a legal representative of Subcontractor is appointed by any court, whether such representative be a trustee, receiver, assignee for the benefit of creditors, debtor in possession, or whatever the designation may be, the said legal representative shall have no rights whatsoever to assume the performance of this Subcontract unless Contractor agrees to the same in writing, and in the absence of such writing, the legal representative shall have no rights with respect to this Subcontract whatsoever.

ARTICLE 20
SUBCONTRACTOR'S RECORDS

Subcontractor shall maintain appropriate books and records with respect to wages, salaries, reimbursable costs, charges, fees and expenses related to the Work compensated for on a reimbursable cost basis, and such records shall be supported by payrolls, invoices, vouchers, correspondence and other documents evidencing in proper detail the nature and propriety of charges. All checks, payrolls, invoices and other documents pertaining in whole or in part to Work compensated for a reimbursable cost basis shall be clearly identified, readily accessible and, to the extent feasible, kept separate and apart from all other documents related to the Work. Subcontractor shall provide to Contractor free access to such books and records during reasonable business hours and the right to examine and audit the same and to make or have made copies of transcripts therefrom as necessary to allow inspection of all data, documents, proceedings and activities relating to the Work performed under this Subcontract on a cost reimbursable basis. Subcontractor agrees to maintain such books and records for a period of two (2) years from the date of completion of the Work and to make such records available to Contractor or its designated agent, during normal business hours within the two (2) year period. Subcontractor shall likewise specifically require all Sub-subcontractors to conform to the requirements of this Article.

ARTICLE 47

ANTI-DISCRIMINATION

Subcontractor, in performing the Work required by this Subcontract, shall not discriminate against any employee or applicant for employment because of race, creed, color, age or national origin. Subcontractor shall actively pursue a policy of nondiscrimination in accordance with any directives of Owner. Subcontractor shall also execute the Equal Employment Opportunity Obligations and Certifications attached hereto and made a part hereof.

Subcontractor shall insert the provisions of the above paragraph in all of its Sub-subcontracts and purchase orders.

Subcontractor shall conform with, and shall require all Sub-subcontractors to conform with, the applicable requirements of all Federal, State and local laws, ordinances, rules and regulations relating to Equal Employment Opportunity, including but not limited to the requirements of the Equal Employment Opportunity clause in Section 202, Paragraphs 1 through 7 of Executive Order 11246, as amended, Section 503 of the Rehabilitation Act, 38 USC 2012, and applicable portions of Executive Orders 11701 and 11758. The implementing Rules and Regulations of the Office of Federal Contracts Compliance are incorporated herein by this reference.

ARTICLE 6

QUALITY PROGRAM, INSPECTION, AND TESTING

Subcontractor shall establish and maintain a quality program, in accordance with the Subcontract Documents, throughout the life of this Subcontract. Subcontractor's quality program, as well as those of its Sub-subcontractors, shall be planned, executed, and documented with written policies, procedures, and instructions, and shall be submitted to Contractor for review and approval by Contractor and Owner in accordance with the Subcontract Document requirements. Any necessary modifications in the quality program shall be made by Subcontractor as may be required to conform to all requirements of the Subcontract Documents. The interpretation of such requirements shall be the responsibility of the Contractor. Subcontractors shall submit to Contractor in writing, for review by Contractor, any intended change in Subcontractor's quality program prior to its implementation. Subcontractor will not be permitted to start Work until the Subcontractor's quality program has been approved by Contractor and Owner.

Subcontractor shall assign an individual or individuals whose sole responsibility shall be for the field quality program under the terms of this Subcontract. This assignment shall begin with the start of Work and duties shall include supplying Contractor with applicable specification compliance submittals prior to starting any particular phase of the Work requiring such. This individual shall meet with project personnel on a bi-weekly basis (minimum) to discuss quality related issues.

Subcontractor's quality program will be subject to evaluation and audit by Owner or Contractor at any time during the life of this Subcontract.

Throughout execution of the Work, Subcontractor shall conduct in-process inspection of its Work to assure compliance with its quality program and the terms and conditions of this Subcontract.

Subcontractor, as a minimum, shall audit the implementation of the following quality program elements on a six month cycle. Reports documenting these audits shall be submitted to Contractor upon completion of the inspections.

- Drawing and specification control
- Examination and inspection
- Nonconformance
- Welding control
- Nondestructive examination
- Calibration of Subcontractor's test equipment
- Record retention and control
- Material control including formal storage program
- Maintenance procedures
- Safety training

Subcontractor shall provide to the Contractor for approval an inspection schedule that identifies those inspections planned for the following week as well as a proposed inspection plan for the following two weeks. The Subcontractor shall also provide to the Contractor an inspection summary report for the preceding week, identifying:

- Inspections performed
- Nonconformances identified and resolution status
- Nonconformance trends

Subcontractor shall provide personnel to perform inspection activities to include both supervision and inspection in the appropriate disciplines (Electrical, Civil, Mechanical, Piping, etc.) as required.

Subcontractor shall perform all shop and field tests required by the Subcontract Documents for equipment furnished by the Subcontractor.

Subcontractor shall perform all necessary inspection and testing, in accordance with the Subcontract Documents. Should it become evident to the Contractor that the quality of the Work performed is not in accordance with the Subcontract Documents, Subcontractor shall provide any documentation or perform any inspection and testing to assure Contractor and Owner that the quality of the installation is in accordance with the Subcontract Documents.

Subcontractor shall also verify that such final inspections and testing as may be necessary to demonstrate and verify freedom from damage, cleanliness, completeness, identification and proper freedom to operate have been made on material, structures and equipment installed hereunder, in accordance with applicable codes, and Subcontract Documents. Incomplete or improper items shall be rejected, pending correction, completion and reinspection to make ready for final acceptance by Owner.

Subcontractor's Work shall be in accordance with the Subcontract Documents and Subcontractor shall be liable for correction of all nonconformances at no cost to Owner or Contractor. However, at the option of the Contractor and when there is no construction schedule delay, Subcontractor may request, in writing, that Contractor and Owner evaluate possible acceptance of Subcontractor's nonconformance condition, if it appears to be an acceptable alternative. Any cost incurred by Contractor for performing such evaluation and testing, if required, whether or not the final evaluation results in acceptance of the change, will be for the Subcontractor's account.

Subcontractor shall maintain records, as mentioned hereinbefore, that provide objective evidence of quality control of items and services supplied. These records shall be subject to audit at any time during normal working hours by Contractor and Owner and shall be turned over to the Contractor at the completion of the Work, or as otherwise mutually agreed between Subcontractor and Contractor.

Subcontractor's Quality Program, to be furnished hereunder, shall address, as a minimum, the following areas:

- Authority and responsibility
- Organization and policy
- Drawings and specification control
- Material and equipment control
- Examination and inspection
- Nonconformances
- Welding control
- Nondestructive examination
- Equipment, receiving, storage and protection
- Equipment maintenance including documentation for Owner's warranty
- As-builts
- Calibration of Subcontractor's testing equipment
- Purchasing, expediting, and Subcontractor's quality program and shop tests
- Training of Owner personnel

Subcontractor agrees to keep and maintain separate information files for each individual piece of equipment to be installed hereunder.

A check list shall be developed by Subcontractor to cover its operations during the unloading, handling, storage, and installation for each piece of major equipment and shall include a sequential listing of critical requirements, inspections and checks as required by this Subcontract. The check list shall be derived from specific drawings, instruction books, and other information for and applicable to the individual piece of equipment. Subcontractor's personnel authorized to perform inspections and checks shall sign and date each check list item as it is completed.

Subcontractor shall be responsible for performing specification tests required by the Subcontract. All procedures and test data shall be submitted to Contractor for review.

Subcontractor's quality program personnel shall visit manufacturing facilities to establish confidence that the requirements of the Subcontract for Subcontract-furnished equipment are met. Subcontractor shall develop a quality program, inspection plan, available for Contractor's review, which, as a minimum, shall include the following data:

- A minimum list of equipment items to be inspected
- Tests and inspections to be witnessed
- Expected frequency of manufacturing facility visits

Subcontract compliance shall be verified by implementing the following methods:

- Reviewing all Subcontract requirements
- Determining that necessary drawings and procedures are available at the manufacturing facility
- Observing the equipment during fabrication to generally determine that the item is being fabricated in accordance with the requirements of the Subcontract

Subcontractor shall report each surveillance visit to a manufacturing facility in a report which shall include a description of activities including nonconformances noted as well as any other discrepant areas to be checked during future surveillance visits.

Subcontractor's quality program shall be audited by Subcontractor's personnel not actively involved in the Work on a semi-annual basis. Audit reports shall be submitted to Contractor upon completion of the audit. Subcontractor's inspection staffing will be subject to approval by Contractor.

General Provisions

ARTICLE 1 — Definitions

As used throughout this Contract, the following terms shall have the meanings set forth below:

(a) The terms "Caltech," "Institute," "Government Prime Awardee," and "Grantee" mean the California Institute of Technology.

(b) The term "NSF" means the National Science Foundation, also the Federal sponsoring agency, and the Government.

(c) The term "Grants and Contracts Officer," means the authorized representative of NSF cognizant for the LIGO Program.

(d) The term "DOE", means Department of Energy, also the Government.

(e) The term "Contract," means the subject agreement between Caltech and Chicago Bridge & Iron Technical Services Company for LIGO Beam Tube Modules.

(f) The term "Contractor," means Chicago Bridge & Iron Technical Services Company.

(g) The terms "awardee and subawardee," mean Contractor and lower tiered subcontractors.

(h) The term "contract amount" means the Contract price..

(i) The term "person" means any individual, partnership, corporation, association, institution or other entity.

(j) The term "Cooperative Agreement" means the contract between Caltech and NSF.

(k) The terms "subcontract" and "subaward" include, but are not limited to subcontracts, purchase orders and changes and modifications to subcontracts and purchase orders issued under this Contract.

(l) The term " Schedule," as used in this Contract, includes Statement of Work, and Delivery or Performance Schedule.

ARTICLE 2 — Order of Precedence

The rights and obligations of the parties to this Contract shall be subject to and governed by the Schedule, these General Provisions, and any proposals, specifications or other documents or provisions which are made a part of this Contract by reference or otherwise. To the extent of any inconsistency between

(i) the Schedule and General Provisions and (ii) any proposals, specifications, or other documents or provisions which are made a part of this Contract by reference or otherwise, the Schedule and General Provisions shall control. To the extent of any inconsistency between (i) the Schedule and (ii) General Provisions, the Schedule shall control. For the purpose of this Article, General Provisions include Additional General Provisions.

ARTICLE 3 – Authority of Caltech's Representatives

No request, notice, authorization, direction or order received by the Contractor and issued either pursuant to a provision of this Contract, or to a provision of any document incorporated in this Contract by reference, or otherwise, shall be binding upon either the Contractor or Caltech unless issued or ratified in writing by the Manager of Caltech Purchasing Department or her authorized representative. The Contractor shall provide immediate notification to Caltech of any unauthorized direction which would: (i) effect a change within the meaning of "Changes" Article; (ii) increase or decrease the Contract amount or amount allotted to this Contract; or (iii) otherwise be the basis for assertion of a claim by the Contractor under any provision of the Contract. The document designating Caltech authorized representatives and defining the scope and limitations of their respective authorizations is attached to these General Provisions.

ARTICLE 4 — Changes

(a) Caltech may by written Contract Unilateral Modification, at any time and without notice to the sureties, if any, make changes or issue directions within the general scope of this Contract requiring additional work or directing the omission of or variation in work covered by this Contract.

(b) If any such change causes an increase or decrease in the cost of, or the time required for, performing this Contract, Caltech shall make an equitable adjustment in (i) the Contract price, the time of performance, or both; and (ii) other affected terms of the Contract, and shall modify the Contract accordingly.

(c) The Contractor must assert its right to an adjustment under this Article within 30 days from the date of receipt of the Modification. However, Caltech may, at its discretion, receive and act upon a change proposal submitted anytime before the final payment under this Contract.

(d) The Contractor shall, for each change or series of related changes, maintain separate accounts, by job order or other suitable accounting procedure, of all incurred segregable, direct costs of work, both changed and not changed, allocable to the change. The Contractor shall maintain such accounts until the parties agree to an equitable adjustment for the changes ordered by Caltech.

(e) Nothing in this Article shall excuse the Contractor from proceeding with the Contract as modified.

ARTICLE 5 — Required Notices

Unless otherwise specified in this Contract, any notice which the Contractor is required to provide to Caltech under any provision of this Contract shall be directed to the Manager of Caltech Purchasing Department, or her authorized representative.

ARTICLE 6 — Subcontracts / Prior Review and Comment

Excluding contractual arrangements identified below, all subcontracts issued under this Contract involving substantive effort shall be subject to prior review and comment by Caltech. For purposes of this Contract, a subcontract valued in excess of $100,000 shall be considered substantive effort.

(a) Subcontracts for commercially available supplies, materials, equipment, or support services.

(b) Subcontracts based upon established catalog or market prices as defined by FAR 15.804-3(c).

(c) Subcontracts based upon prices set by law or regulation as defined by FAR 15.804-3(d).

ARTICLE 7 — Competition

All procurement transactions under this Contract shall be conducted in a manner providing to the maximum extent practical, open and free competition.

The substance of this Article shall be included in all subcontracts issued under this Contract regardless of tier.

ARTICLE 8 — Utilization of Small Business Concerns

It is the policy of the United States that small business concerns and small business concerns owned and controlled by socially and economically disadvantaged individuals including women-owned small businesses shall have the maximum practicable opportunity to participate in performing in contracts sponsored by any Federal agency. It is further the policy of the United States, that contractors establish procedures to ensure the timely payment of amounts pursuant to the terms of their subcontracts with small businesses and small business concerns owned and controlled by socially and economically disadvantaged individuals. The Contractor agrees that in the performance of this Contract it shall implement and support this policy to the maximum practicable extent.

The substance of this Article shall be included in all subcontracts issued under this Contract exceeding $10,000 regardless of tier.

ARTICLE 9 — Acknowledgment of Support

The Contractor shall acknowledge NSF support in any publication of any material based on or developed under this Contract, in the following terms:

> "This material is based upon work supported by the National Science Foundation under the Cooperative Agreement with the California Institute of Technology, No. PHY-9210038. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the view of the National Science Foundation."

The substance of this Article shall be included in all subcontracts issued under this Contract regardless of tier.

ARTICLE 10 — Metric System

All reports and publications resulting from this Contract shall use metric system of weights and measures, unless its use is impractical or is likely to cause significant inefficiencies.

The substance of this Article shall be included in all subcontracts issued under this Contract regardless of tier.

ARTICLE 11 — Assignment of Rights and Delegation of Duties

(a) The Contractor may assign monies due or to become due under this Contract, subject to the following conditions:

1. Any assignment, or subsequent reassignment, shall cover all amounts payable under this Contract and not paid as of (i) the effective date of assignment, or (ii) the date Caltech receives written notice of assignment, whichever is later.

2. No assignment may be made to more than one party.

3. Two copies of the notice of assignment, signed by the assignor, shall be furnished to Caltech.

4. No assignment may be made which includes, either specifically or by implication, any delegation of Contractor's duty to perform the work or provide the items required by this Contract without the prior written consent of Caltech in accordance with paragraph b, below.

(b) The Contractor agrees that he will delegate no part of the duties required of him by this Contract without the prior written consent of Caltech, provided however, that nothing contained herein shall be deemed to prohibit the Contractor from placing subcontracts subject to any requirement herein for approval of subcontracts.

ARTICLE 12 — Composition of Contractor

If the Contractor hereunder is composed of more than one legal entity, each such entity shall be jointly and severally liable hereunder.

ARTICLE 13 — Audit Rights

The Comptroller General of the United States, NSF and Caltech, and any of their duly authorized representatives, shall have access to any books, documents, papers and records of the Contractor which are directly pertinent to the subject Contract for the purpose of making audits, examinations, excerpts and transcripts. The subject access to books, documents, papers and records shall be available until three (3) years after the final payment under this Contract.

The substance of this Article shall be included in all negotiated subcontracts issued under this Contract exceeding $10,000 regardless of tier.

ARTICLE 14 — Audit / Negotiations

If, pursuant to law, the Contractor has been required to submit cost or pricing data in connection with pricing this Contract or any modifications of this Contract, the authorized representatives of the Government shall have the right to examine and audit all books, records, documents and other data of the Contractor (including computations and projections) related to negotiating, pricing, or performing the Contract or Contract modification, in order to evaluate the accuracy, completeness and currency of the submitted cost or pricing data.

The substance of this Article shall be included in all negotiated subcontracts issued under this Contract exceeding $100,000 regardless of tier.

ARTICLE 15 — Authorization and Consent / Government Patents

The Government authorizes and consents to all use and manufacture of any Government owned inventions and licensing rights in the performance of the Contract or any subcontract issued under this Contract regardless of tier.

The substance of this Article shall be included in all subcontracts issued under this Contract exceeding $25,000, regardless of tier.

ARTICLE 16 — Rights to Inventions and Materials

Matters regarding rights to inventions and materials generated under this Contract are subject to the NSF Grant policy, contained in the NSF Grant Policy Manual, Section 750, Intangible Property, a copy of which section is attached to these General Provisions.

The substance of this Article shall be included in all subcontracts issued under this Contract for experimental, developmental, or research work, regardless of tier.

ARTICLE 17 — Rights in Data

(a) Definitions

1. "Data," means recorded information, regardless of form or the media on which it may be recorded. The term does not include information incidental to Contract administration, such as financial, administrative, cost or pricing, or management information.

2. "Form, fit, and function data," means data related to items, components, or processes that are sufficient to enable physical and functional interchangeability, as well as data identifying source, size, configuration, mating, and attachment characteristics, functional characteristics, and performance requirements.

3. "Limited rights," means the rights of the Government (or in support or furtherance of its Government contract obligations, Caltech), in limited rights data.

4. "Limited rights data," means data that embody trade secrets or are commercial or financial and confidential or privileged, to the extend that such data pertains to items, components, or processes developed at private expense, including minor modifications thereof.

5. "Technical data," means data which is of a scientific or technical nature.

6. "Unlimited rights," means the right of the Government, or in support and furtherance of its Government obligations, Caltech, to use, disclose, reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly in a manner and for any purpose, and to have or permit others to do so.

(b) Allocation of Rights

1. Except as provided in paragraph (c) of this Article regarding copyright, the Government and in support and furtherance of its Government contract obligations, Caltech, shall have unlimited rights in:

   A. Data first produced in the performance of this Contract;

   B. Form, fit, and function data delivered under this Contract;

   C. Data delivered under this Contract that constitute manuals or instructional and training material for installation, operation, or routine maintenance and repair of items, components, or processes delivered or furnished for use under this Contract; and

   D. All other data delivered under this Contract unless provided otherwise in this Contract.

2. The Contractor shall have the right to:

   A. Use, release to others, reproduce, distribute, or publish any data first produced or specifically used by the Contractor in the performance of this Contract, unless provided otherwise in paragraph (d) of this Article;

   B. Protect from unauthorized disclosure and use those data which are limited rights data to the extent provided in this Contract;

   C. Substantiate use of, add or correct limited rights, restricted rights, or copyright notices and to take other appropriate action, in accordance with paragraphs (e) and (f) of this Article; and

   D. Establish claim to copyright subsisting in data first produced in the performance of this Contract to the extent provided in Article 16, Rights to Inventions and Materials and subparagraph (c)(1) below.

(c) Copyright

1. Data first produced in the performance of this Contract. When claim to copyright is made, the Contractor shall affix an acknowledgment of Government sponsorship as indicated in Article 9, Acknowledgment of Support. The Contractor grants to the Government, and in support and furtherance of its Government contract obligations, Caltech, and others acting on their behalf, a paid-up, nonexclusive, irrevocable worldwide license in such copyrighted data to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly by or on behalf of the Government.

2. Data not first produced in the performance of this Contract. The Contractor shall not, without prior written permission of Caltech, incorporate in data delivered under this Contract any data not first produced in the performance of this Contract, unless the Contractor identifies such data and grants to the Government, and in support and furtherance of its Government contract obligations, Caltech, or acquires on their behalf, a license of the same scope as set forth in subparagraph (c)(1) above.

(d) Release, Publication and Use of Data

1. The Contractor shall have the right to use, release to others, reproduce, distribute, or publish any data first produced or specifically used by the Contractor in the performance of this Contract, except to the extent such data may be subject to the Federal export control or national security laws or regulations, or unless otherwise provided in this Contract.

2. The Contractor agrees that to the extent it receives or is given access to data necessary for the performance of this Contract which contain restrictive markings, the Contractor shall treat the data in accordance with such markings unless otherwise specifically authorized in writing by Caltech.

(e) Subcontracting. The Contractor has the responsibility to obtain from its subcontractors all data and rights therein necessary to fulfill the Contractor's obligation to the Government and Caltech under this Contract. If a subcontractor refuses to accept terms affording the Government or Caltech such rights, the Contractor shall promptly bring such refusal to the attention of Caltech and not proceed with subcontract award without further authorization.

(f) Relationship to Patents. Nothing contained in this Article shall imply a license to the Government or Caltech under any patent or be construed as affecting the scope of any license or other right otherwise granted to the Government or the Institute.

ARTICLE 18 — Notice and Assistance Regarding Patent and Copyright Infringement

(a) The Contractor shall report to Caltech promptly, and in reasonable written detail, each notice or claim of patent or copyright infringement based on the performance of this Contract of which the Contractor has knowledge.

(b) In the event of any claim or suit against the Government and/or Caltech on account of any alleged patent or copyright infringement arising out of the performance of this Contract or out of the use of any supplies furnished or work or services performed under this Contract, the Contractor shall furnish to Caltech, when so requested, all evidence and information in possession of the Contractor pertaining to such suit or claim. Such evidence and information shall be furnished at the expense of Caltech except where the Contractor has agreed to indemnify Caltech.

(c) The substance of this Article shall be included in all subcontracts issued under this Contract for supplies or services (including construction and architect-engineer subcontracts and those for material, supplies, models, samples, or design or testing services) exceeding $25,000 regardless of tier.

ARTICLE 19 — Equal Employment Opportunity

By acceptance of this Contract, the Contractor assures Caltech that it will comply with and implement the following Acts:

(a) Title VI of the Civil Rights Act of 1964 (PL 88–352), the regulations issued pursuant to this Act by the NSF (45 CFR 611), and the Assurance of Compliance the Contractor has filed with Caltech.

(b) Section 504 of the Rehabilitation Act of 1973 (29 U.S.C. 794) and NSF's implementing regulations (45 CFR 605, as amended at 55 Federal Register 52142).

(c) Age Discrimination Act of 1975 as implemented by the Department of Health and Human Service regulations at 45 CFR 90 and the regulations of NSF at 45 CFR 617.

(d) Vietnam Era Veterans Readjustment Assistance Act of 1972, as amended, and

(e) Americans with Disabilities Act 42 U.S.C. Section 12101 et. seq. and all implementing regulations.

The substance of this Article shall be included in all subcontracts issued under this Contract exceeding $10,000 regardless of tier.

ARTICLE 20 — Notice of Labor Disputes

The Contractor shall give prompt notice to Caltech of any actual or potential labor disputes which delay or may delay timely performance of this Contract.

ARTICLE 21 — Labor Regulations

It is anticipated that from time to time this Contract will involve the employment of mechanics and laborers and/or require construction, alteration or repair effort as defined within the scope of the below Acts.

> Davis Bacon Act, Contract Work Hours and Safety Standards Act—Overtime Compensation, Apprentices and Trainees, Payrolls and Basic Records, Compliance with Copeland Regulations, Withholding of Funds, Subcontracts, Contract Termination—Debarment, Buy American Act—Construction, and Disputes Concerning Labor Standards.

All Contracts in excess of $2,500 involving employment of mechanics and laborers shall include a provision for compliance with Sections 103 and 107 of the Contract Work Hours and Safety Standards Act (40 U.S.C. 327–330) as supplemented by the Department of Labor regulations (29 CFR, Part 5) and as indicated in the Additional General Provisions, Article 2, Contract Work Hours and Safety Standards Act — Overtime Compensation.

In all construction efforts the Contractor shall comply with the requirements of these Acts and as indicated in the Additional General Provisions with the exception of the requirement for submission of weekly payroll records which is hereby waived. However, the Contractor shall be obligated to provide such records when and if requested by Caltech.

The substance of this Article shall be included in all subcontracts issued under this Contract in excess of $2,500 involving employment of mechanics and laborers and in excess of $2,000 for construction, alteration or repair that are within the scope of the above Acts, regardless of tier.

ARTICLE 22 — Safety and Health

The Contractor shall take all reasonable safety and health measures in performing under this Contract, and shall comply with all applicable Federal, state and local laws relating to safety and health in effect on the date of this Contract.

ARTICLE 23 — Hazardous Materials

The Contractor shall comply with all applicable Federal, State, and local laws, codes, ordinances, and regulations (including the obtaining of licenses and permits) in connection with hazardous material. Neither the requirements of this Article nor any act or failure to act by the Government or Caltech shall relieve the Contractor of any responsibility or liability for the safety of Government, Caltech, Contractor, or subcontractor personnel or property.

The Contractor agrees to submit to Caltech material safety information and a plan for handling of any and all hazardous materials delivered under this Contract which will involve exposure to hazardous materials or items containing these materials. The handling including disposition of hazardous materials shall be in accordance with the plan and as approved by Caltech.

"Hazardous material," as used in this Article, is as defined in Federal Standard No. 3138, in effect on the date of this Contract.

The Government's and Caltech's rights in data furnished under this Contract with respect to hazardous material are to use, duplicate, and disclose any data to which this Article is applicable for the purpose of (i) apprising personnel of the hazards to which they may be exposed in using, handling, packaging, transporting, or disposing of hazardous material; (ii) obtain medical treatment for those affected by the material; and (ii) have others use, duplicate, and disclose the data to the Government or Caltech for these purposes.

The substance of this Article shall be included all in subcontracts issued under this Contract involving hazardous material regardless of tier.

ARTICLE 24 — Drug Free Workplace

The Contractor agrees to inform all Contractor and subcontractors personnel, prior to their first entrance upon Caltech-controlled premises, of Caltech's policies to fully comply with the requirements of the Drug-Free Workplace Act and that Contractor and subcontractor personnel are required to comply with Caltech's policy of maintaining a drug-free workplace in all Caltech-controlled premises.

ARTICLE 25 — Convict Labor

The Contractor agrees not to employ any person undergoing sentence of imprisonment in performing this Contract except as provided by 18 U.S.C. 4082(c)(2) and Executive Order 11755, December 29, 1973.

The substance of this Article shall be included in all subcontracts issued under this Contract regardless of tier.

ARTICLE 26 — Buy American Act

The Buy American Act (41 U.S.C. 10) provides that the Government give preference to domestic supplies and construction materials. Accordingly, the

Contractor agrees to deliver only domestic end products and make use of only domestic construction material, as defined by the Buy American Act including exceptions therein and in the event of construction, as indicated in Additional General Provisions, Article 10, Buy American Act — Construction Materials, in the performance of this Contract.

The substance of this Article shall be included in all subcontracts issued under this Contract for procurement of significant supplies and construction materials subject to the Buy American Act regardless of tier.

ARTICLE 27 — Preference for Privately owned U.S.-Flag Air Carriers and Commercial Vessels

The Contractor shall use privately owned U.S. Air Carriers and U.S.-flag commercial vessels and no others, in the air and/or ocean and river transportation of any personnel, supplies and materials, to be furnished under this Contract.

The substance of this Article shall be included in all subcontracts issued under this Contract involving substantive air and/or ocean transportation effort regardless of tier.

ARTICLE 28 — Anti-Kickback

The Contractor shall comply with the Anti-Kickback Act of 1986 (41 U.S.C. 51–58) (the Act).

The substance of this Article shall be included in all subcontracts issued under this Contract regardless of tier.

ARTICLE 29 — Restrictions on Subcontractor Sales

Except as provided below, the Contractor shall not enter into any agreement with an actual or prospective subcontractor, nor otherwise act in any manner, which has or may have the effect of restricting sales by such subcontractors directly to Caltech or the Government of any item or process made or furnished by the subcontractor under this Contract including the option.

The prohibition above does not preclude the Contractor from asserting rights that are otherwise authorized by law or regulation.

The substance of the Article shall be included in all subcontracts issued under this Contract regardless of tier.

ARTICLE 30 — Clean Air and Water

The Contractor shall comply with all applicable standards, orders or regulations issued pursuant to the Clean Air Act of 1970 (42 U.S.C. 1857 et seq.) and the Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.) as amended. Violations shall be reported to NSF and the Regional Office of the Environmental Protection Agency.

The substance of this Article shall be included in any nonexempt subcontract exceeding $100,000 regardless of tier,

ARTICLE 31 — Prohibition of Contractor Use of Privately Owned Aircraft

The Contractor, its employees, agents and subcontractors shall not use privately owned (non commercial) aircraft in the performance of this Contract without having in effect Aircraft Liability Insurance coverage of not less than $5,000,000 for all deaths, injuries and property damage arising from one accident or occurrence.

The substance of this Article shall be included in any subcontract issued under this Contract involving air transportation travel regardless of tier.

ARTICLE 32 — Insurance and Indemnification

The Contractor shall take such steps as may be deemed necessary to insure or protect itself, its employees and its property. Accordingly, the Contractor shall provide appropriate insurance coverage for all supplies, equipment and personnel involved with the Contract effort. Caltech shall not assume any liability for accidents, illnesses, or claims arising out of any work supported by this Contract, or for unauthorized use of copyrighted materials and/or patents.

(a) Insurance. The Contractor shall, at its own expense, provide and maintain during the entire performance period of this Contract at least the following kinds and minimum amounts of insurance:

1. Workers' Compensation and Employer's Liability Insurance, as required by applicable Federal and state workers' compensation and occupational disease statutes. If occupational diseases are not compensable under those statutes, they shall be covered under the Employer's Liability section of the insurance policy, except when Contract operations are so commingled with the Contractor's commercial operations that this would not be practical. The employer's Liability coverage shall be no less than $1,000,000 per accident, except in states with exclusive or monopolistic funds that do not permit worker's compensation to be written by private carriers. However, the Contractor in fulfillment of its obligation to provide Workers' Compensation Insurance may maintain a self-insurance program if the Contractor is qualified pursuant to statutory authority to do so.

2. Comprehensive Liability Insurance, including automobiles (owned, non-owned, or leased), completed operations, products, and contractual liability, for a combined single limit of not less than $1,000,000 for all deaths, injuries, and property damage arising from one accident or occurrence.

3. Contractor's Risk or Course of Construction "All Risks" coverage, excluding earthquake and flood, covering damage to the work itself, including materials and supplies at the work site, protecting the interests of the Government, Caltech, the Contractor, and subcontractors in a sufficient amount to pay in full each loss exclusive of a deductible not to exceed $100,000. Deductible is the financial responsibility of the Contractor.

(b) Insurance Certificates. Before commencing work under this Contract, the Contractor shall furnish certificates of insurance for the coverages required hereunder. Such certificates shall provide that any cancellation or material change in the insurance policies shall not be effective (i) for such period as the laws of the State in which this Contract is to be performed prescribe, or (ii) until 30 days after the insurer or the Contractor gives written notice to Caltech, whichever period is longer. Also, such certificates shall (i) cover adjustment shall be made in the Contract price or the time of completion, and the Contract shall be modified in writing.

(c) If this Contract is terminated for default, Caltech may require the Contractor to transfer and deliver to Caltech, as directed by it, any (i) completed or partially completed work not previously delivered to, and accepted by Caltech, and (ii) other property, including contract rights, specifically produced or acquired for the terminated portion of this Contract. Upon direction of Caltech, the Contractor shall also protect and preserve property in its possession in which Caltech has an interest.

(d) Caltech shall pay the Contract price for completed work it has accepted. In addition, Caltech and the Contractor may agree upon amounts for (i) partially completed work, (ii) other property described above that Caltech accepts, and (iii) the protection and preservation of the property. Caltech may withhold from these amounts any sum Caltech determines to be necessary to protect Caltech against loss from outstanding liens or claims of former lien holders.

(e) If, after termination, it is determined that the Contractor was not in default, or that the default was excusable, the rights and obligations of the parties shall be the same as if the termination had been issued pursuant to the Article 53, Termination for Convenience.

(f) The rights and remedies of Caltech in this Article are in addition to any other rights and remedies provided by law or under this Contract.

ARTICLE 49 — Reserved

ARTICLE 50 — Warranty

(a) In addition to any other warranties in this Contract, the Contractor warrants, except as provided in paragraph (j) of this Article, that work performed under this Contract conforms to the Contract requirements and is free of any defect in equipment, material, or design furnished, or workmanship performed by the Contractor or any subcontractor or supplier at any tier. The work as related to the Design and Design Qualification Test is limited to the deliverables provided and the warranty responsibilities under the contract would be limited to the correction of defects in those deliverables and not in any finished product which may be produced from the deliverables.

(b) The warranty shall continue for a period of one year from the date of final acceptance of the work. If Caltech takes possession of any part of the work before final acceptance, this warranty shall continue for a period of one year from the date Caltech takes possession.

(c) The Contractor shall remedy at the Contractor's expense any failure to conform, or any defect, which damage is the result of:

1. The Contractor's failure to conform to Contract requirements; or
2. Any defect of equipment, material, workmanship, or design furnished.

(d) The Contractor shall restore any work damaged in fulfilling the terms and conditions of this Article. The Contractor's warranty with respect to work repaired or replaced will run for one year from the date of repair or replacement.

(e) Caltech shall notify the Contractor, in writing, within a reasonable time after the discovery of any failure, defect, or damage.

(f) If the Contractor fails to remedy any failure, defect, or damage within a reasonable time after receipt of notice, Caltech shall have the right to replace, repair, or otherwise remedy the failure, defect, or damage at the Contractor's expense.

(g) With respect to all warranties, express or implied, from subcontractors, manufacturers, or suppliers for work performed and materials furnished under this Contract, the Contractor shall:

1. Obtain all warranties that would be given in normal commercial practice;

2. Require all warranties to be executed, in writing, for the benefit of Caltech; and

3. Enforce all warranties for the benefit of Caltech, if directed by Caltech.

(h) In the event the Contractor's warranty under paragraph (b) of this Article has expired, Caltech may bring suit at its expense to enforce a subcontractor's, manufacturer's, or supplier's warranty.

(i) Unless a defect is caused by the negligence of the Contractor or subcontractor or supplier at any tier, the Contractor shall not be liable for the repair of any defects of material or design furnished by Caltech nor for the repair of any damage that results from any defect in Caltech-furnished material, design, or specification.

(j) This warranty shall not limit Caltech's rights under Article 46, Inspection of Construction, with respect to latent defects, gross mistakes, or fraud.

(k) Defects in design, material, or manufacture of equipment, specified by Caltech shall not be included in this warranty. In this event, the Contractor shall require any subcontractors, manufacturers, or suppliers thereof to execute their warranties in writing directly to Caltech.

(l) ***All implied warranties of merchantability and "fitness for a particular purpose" are excluded from any obligation contained in this Contract.***

ARTICLE 51 — Responsibility for Products

(a) Title to products furnished under this Contract shall pass to Caltech upon formal acceptance by Caltech, regardless of when or where Caltech takes physical possession, unless the Contract specifically provides for earlier passage of title.

(b) Unless the Contract specifically provides otherwise, risk of loss or damage to products shall remain with the Contractor until Contract completion.

(c) Paragraph (b) above shall not apply to products that so fail to conform to Contract requirements as to give a right of rejection. The risk of loss of or damage to such nonconforming products remains with the Contractor until cure or acceptance. After cure or acceptance, paragraph (a) above shall apply.

(d) Under paragraph (b) above, the Contractor shall not be liable for loss of or damage to products caused by the negligence of officers, agents, or employees of Caltech acting within the scope of their employment.

ARTICLE 52 — Suspension of Work

(a) Caltech may, at any time, by written order to the Contractor, require the Contractor to stop all, or any part, of the work called for by this Contract for a period of 90 days after the order is delivered to the Contractor, and for any further period to which the parties may agree. The order shall be specifically identified as a stop work order issued under this Article. Upon receipt of the order, the Contractor shall immediately comply with its terms and take all reasonable steps to minimize the incurrence of costs allocable to the work covered by the order during the period of work stoppage. Within a period of 90 days after a stop work order is delivered to the Contractor, or within any extension of that period to which the parties shall have agreed, Caltech shall either:

1. Cancel the stop work order; or

2. Terminate the work covered by such order either for convenience of Caltech or the Government or, if appropriate, for default.

(b) If a stop work order issued under this Article is cancelled or the period of the order or any extension thereof expires, the Contractor shall resume work. Caltech shall make an equitable adjustment in the delivery schedule, the contract amount, and in any other provisions of the Contract that may be affected, and the Contract shall be modified, in writing, accordingly, if:

1. The stop work order results in an increase in the time required for, or in the Contractor's cost properly allocable to, the performance of any part of this Contract; and

2. The Contractor asserts a claim for the adjustment within 30 days after the end of the period of work stoppage; provided, that, if Caltech decides the facts justify the action, it may receive and act upon the claim asserted at any time before final payment under this Contract.

(c) If a stop work order is not cancelled and the work covered by the order is terminated for the convenience of Caltech or the Government, Caltech shall allow reasonable costs resulting from the stop work order in arriving at the termination settlement.

(d) If a stop work order is not cancelled and the work covered by the order is terminated for default, Caltech shall allow, by equitable adjustment or otherwise, reasonable costs resulting from the stop work order.

ARTICLE 53 — Termination for Convenience

(a) Caltech may terminate performance of work under this Contract in whole or in part, from time to time, if Caltech determines that a termination is in the interest of Caltech or the Government. Caltech shall terminate by delivering to the Contractor a Notice of Termination specifying the extent of termination and the effective date.

(b) After receipt of a Notice of Termination, and except as directed by Caltech, the Contractor shall immediately proceed with the following obligations, regardless of any delay in determining or adjusting any amounts due under this Article:

1. Stop work as specified in the notice.

2. Place no further subcontracts for materials, services, or facilities, except as necessary to complete the continued portion of the Contract.

3. Terminate all subcontracts to the extent they relate to the work terminated.

4. Assign to Caltech all right, title, and interest of the Contractor under the subcontracts terminated, in which case Caltech shall have the right to settle or to pay any termination settlement proposal arising out of those terminations.

5. With approval or ratification to the extent required by Caltech, settle all outstanding liabilities and termination settlement proposals arising from the termination of subcontracts.

6. Submit in a form acceptable to Caltech inventory schedules covering all items of property not consumed in the performance of this Contract or not previously delivered to Caltech.

7. As directed by Caltech, transfer title to Caltech and deliver to Caltech (i) the fabricated or unfabricated parts, work in process, completed work, supplies, and other material produced or acquired for the work terminated, and (ii) the completed or partially completed plans, drawings, information, and other property that, if the Contract had been completed, would be required to be furnished to Caltech.

8. Complete performance of the work not terminated.

9. Take any action that may be necessary, or that Caltech may direct, for the protection and preservation of the property related to this Contract that is in the possession of the Contractor and which Caltech has or may acquire an interest.

10. Use its best efforts to sell, as directed or authorized by Caltech, any property of the types referred to in subparagraph (7) above. The Contractor may acquire the property under the conditions prescribed by, and at prices approved by Caltech. The proceeds of any transfer or disposition will be

applied to reduce any payments to be made by Caltech under this Contract, credited to the price or cost of the work, or paid as directed by Caltech.

(c) After termination, the Contractor shall submit a final termination settlement proposal to Caltech in the form and with the cost or pricing certification prescribed by Caltech. The Contractor shall submit the proposal promptly, but not later than six months from the effective date of termination, unless extended in writing by Caltech, upon written request of the Contractor within this six month period. However, if Caltech determines that the facts justify it, a termination settlement proposal may be received and acted on after six months or any extension. If the Contractor fails to submit the proposal within the time period allowed, Caltech may determine unilaterally, on the basis of information available, the amount, if any, due the Contractor because of the termination and shall pay the amount determined.

(d) Subject to paragraph (c) above, the Contractor and Caltech may agree upon the whole or any part of the amount to be paid because of the termination. The amount may include a reasonable allowance for profit on work done. However, the agreed amount, whether under this paragraph (d) or paragraph (e) below, exclusive of costs shown in subparagraph (e)(3) below, may not exceed the total Contract price as reduced by (i) the amount of payments previously made and (ii) the Contract price of work not terminated. The Contract shall be amended, and the Contractor paid the agreed amount. Paragraph (e) below shall not limit, restrict, or affect the amount that may be agreed upon to be paid under this paragraph.

(e) If the Contractor and Caltech fail to agree on the whole amount to be paid because of the termination of work, Caltech shall pay the Contractor the amounts determined by Caltech as follows, but without duplication of any amounts agreed on under paragraph (d) above:

1. The Contract price for completed products or services accepted by Caltech not previously paid for.

2. The total of:

A. The costs incurred in the performance of the work terminated, including initial costs and preparatory expense allocable thereto, but excluding any costs attributable to products or services paid or to be paid under subparagraph (e)(1) above;

B. The cost of settling and paying termination settlement proposals under terminated subcontracts that are properly chargeable to the terminated portion of the Contract if not included in subdivision (A) above; and

C. A sum, as profit on subdivision (A) above, determined by Caltech to be fair and reasonable; however, if it appears that the Contractor would have sustained a loss on the entire Contract had it been completed, Caltech shall allow no profit under this subdivision (C) and shall reduce the settlement to reflect the indicated rate of loss.

3. The reasonable costs of settlement of the work terminated, including:

A. Accounting, legal, clerical, and other expenses reasonably necessary for the preparation of termination settlement proposals and supporting data;

B. The termination and settlement of subcontracts (excluding the amounts of such settlements); and

C. Storage, transportation, and other costs incurred, reasonably necessary for the preservation, protection, or disposition of the termination inventory.

(f) Except for normal spoilage, and except to the extent that Caltech expressly assumed the risk of loss, Caltech shall exclude from the amounts payable to the Contractor under paragraph (e) above, the fair value, as determined by Caltech, of property that is destroyed, lost, stolen, or damaged so as to become undeliverable to Caltech.

(g) The cost principles and procedures of Part 31 of FAR in effect on the date of this Contract, shall govern all costs claimed, agreed to, or determined under this Article.

(h) In arriving at the amount due the Contractor under this Article, there shall be deducted:

1. All unliquidated payments to the Contractor under the terminated portion of this Contract;

2. Any claim which Caltech has against the Contractor under this Contract; and

3. The agreed price for, or the proceeds of sale of, materials, supplies, or other things acquired by the Contractor or sold under the provisions of this Article and not recovered by or credited to Caltech.

(i) If the termination is partial, the Contractor may file a proposal with Caltech for an equitable adjustment of the price(s) of the continued portion of the Contract. Caltech shall make any equitable adjustment agreed upon. Any proposal by the Contractor for an equitable adjustment under this Article shall be requested within 90 days from the effective date of termination unless extended in writing by Caltech.

(j) 1. Caltech may, under the terms and conditions it prescribes, make payments against costs incurred by the Contractor for the terminated portion of the Contract, if Caltech believes the total of these payments will not exceed the amount to which the Contractor will be entitled.

2. If the total payments exceed the amount finally determined to be due, the Contractor shall repay the excess to Caltech upon demand, together with interest computed at the rate established by the Secretary of the Treasury under 50 U.S.C. App. 1215(b)(2). Interest shall be computed for the period from the date the excess payment is received by the Contractor to the date the excess is repaid. Interest shall not be charged on any excess payment due to a reduction in the Contractor's termination settlement

proposal because of retention or other disposition of termination inventory until 10 days after the date of the retention or disposition, or a later date determined by Caltech because of the circumstance.

(k) Unless otherwise provided in this Contract or by statute, the Contractor shall maintain all records and documents relating to the terminated portion of this Contract for three years after final settlement. This includes all books and other evidence bearing on the Contractor's costs and expenses under this Contract. The Contractor shall make these records and documents available to Caltech and the Government, at the Contractor's office, at all reasonable times, without any charge.

ARTICLE 54 — Default

(a) 1. Caltech may, subject to paragraphs (c) and (d) below, by delivery to the Contractor of a Notice of Default, terminate this Contract, in whole or in part, if the Contractor:

A. Fails to perform the work under the Contract within the time specified in this Contract or any extension;

B. Prosecutes the work, so as to endanger performance of this Contract [but see subparagraph (a)(2) below]; or

C. Fails to perform any of the other provisions of this Contract [but see subparagraph (a)(2) below]

2. Caltech's right to terminate this Contract under subdivisions 1(B) and 1(C) of this paragraph may be exercised if the Contractor does not effect the cure within the period specified in the Notice of Default.

(b) If Caltech terminates this Contract in whole or in part, it may acquire, under the terms and in the manner Caltech considers appropriate, work similar to the work terminated, and the Contractor will be liable to Caltech for any excess costs for the similar work. However, the Contractor shall continue the work not terminated.

(c) Except for defaults of subcontractors at any tier, the Contractor shall not be liable for any excess costs if the failure to perform the Contract arises from causes beyond the control and without the fault or negligence of the Contractor. Examples of such causes include (i) acts of God or of the public enemy, (ii) acts of the Government in either its sovereign or contractual capacity, (iii) fires, (iv) floods, (v) epidemics, (vi) quarantine restrictions, (vii) strikes, (viii) freight embargoes, and (ix) unusually severe weather. In each instance the failure to perform must be beyond the control and without the fault or negligence of the Contractor.

(d) If the failure to perform is caused by the default of a subcontractors at any tier, and if the cause of the default is beyond the control of both the Contractor and subcontractor, and without the fault or negligence of either, the Contractor shall not be liable for any excess costs for failure to perform, unless the subcontracted supplies or services were obtainable from other sources in sufficient time for the Contractor to meet the required delivery schedule or other performance requirements.

ARTICLE 55 — Allowable Costs
The allowability of costs and cost allocation method for work performed under this Contract shall be determined in accordance with the Federal Acquisition Regulations 31.2 (48 CRF 31.2).

ARTICLE 56 — Limitation of Funds
The parties contemplate that Caltech will incrementally fund the Contract effort. The Contractor agrees to perform, or have performed, the work specified in the Contract up to the point at which the total amount paid and payable by Caltech under this Contract approximates, but does not exceed the total amount actually allotted by Caltech to this Contract.

(a) Caltech shall not be obligated to reimburse the Contractor for costs incurred in excess of the total amount allotted to this Contract, and the Contractor shall not be obligated to continue performance under this Contract (including actions under the Termination clause of this Contract) or to otherwise incur costs in excess of the amount then allotted to the Contract.

(b) When and to the extent that the amount allotted to this Contract is increased, any costs the Contractor incurs before the increase that are in excess of the amount previously allotted shall be allowable to the same extent as if incurred afterward, unless Caltech issues a termination or other notice directing the increase solely to cover termination or other specified expenses.

ARTICLE 57 — Payments and Discounts

(a) Invoices shall be submitted in triplicate to the attention of Caltech and as specified in the Contract. Any applicable state sales or use taxes or Federal excise taxes shall be shown as a separate item.

(b) Caltech shall pay the Contractor, upon the submission of proper invoices or vouchers, the payments stipulated in this Contract for completed work less any deductions provided in this Contract.

(c) Payments will be made within the net period of 30 days, measured from the date of receipt of the invoice. Payment shall be deemed to have been made on the date the check is mailed.

(d) Payment for completed work in accordance with this paragraph will not waive or otherwise affect the right of Caltech to inspect such work or to reject, or revoke acceptance of, nonconforming work.

(e) Unless otherwise specified in this Contract, unliquidated payment shall be made upon acceptance for the sole purpose of partial payment of the work delivered or rendered in accordance with the payment schedule stated in the Contract. All partial payments shall be considered liquidated with Caltech's acceptance of the Final Detail Design, and acceptance of the LIGO beam tube modules in the event Contract Option is exercised.

ARTICLE 58 — Federal, State, and Local Taxes

(a) Definitions

1. "Contract date," as used in this Article, means the effective date of this Contract or Modification.

2. "All applicable Federal, State, and local taxes," as used in this Article, means all taxes in effect on the Contract date, that the taxing authority is imposing and collecting on the transactions or property covered by this Contract.

3. "After-imposed Federal tax," as used in this Article, means any new or increased Federal tax, or tax that was exempted or excluded on the Contract date, but whose exemption was later revoked or reduced during the Contract period. It does not include social security tax or. other employment taxes.

4. "After-relieved Federal tax," as used in this Article, means any amount of Federal tax, except social security or other employment taxes, that would otherwise have been payable on the transactions or property covered by this Contract, but which the Contractor is not required to pay or bear, or for which the Contractor obtains a refund or drawback.

(b) Unless otherwise provided in the Schedule, the Contract price includes all applicable Federal, State, and local taxes.

(c) The Contract price shall be increased by the amount of any after-imposed Federal tax, provided the Contractor warrants in writing that no amount for such newly imposed Federal tax increase was included in the Contract price, as a contingency reserve or otherwise.

(d) The Contract price shall be decreased by the amount of any after-relieved Federal tax.

(e) The Contract price shall be decreased by the amount of any Federal tax, except social security or other employment taxes, that the Contractor is required to pay or bear, or does not obtain a refund of, through the Contractor's fault, negligence, or failure to follow instructions of Caltech.

(f) No adjustment shall be made in the Contract price under this Article unless the amount of the adjustment exceeds $100.

(g) The Contractor shall promptly notify Caltech on all matters relating to any Federal excise tax that reasonably may be expected to result in either an increase or decrease in the Contract price and shall take appropriate action as Caltech directs.

(h) Caltech shall, without liability, furnish evidence appropriate to establish exemption from any Federal, State, or local tax when the Contractor requests such evidence and a reasonable basis exists to sustain the exemption.

ARTICLE 59 — Special Tooling

(a) Definition. "Special tooling," as used in this Article, means jigs, dies, fixtures, molds, patterns, taps, gauges, other equipment and manufacturing aids, all components of these items, and replacement of these items, that are of such a specialized nature that without substantial modification or alteration their use is limited to the development or production of particular supplies or parts thereof of performing particular services. It does not include material, special test equipment, facilities (except foundations and similar improvements necessary for installing special tooling), general or special machine tools, or similar capital items. Special tooling, for the purpose of this Article, does not include any item acquired by the Contractor before the effective date of this Contract, or replacement of such items, whether or not altered or adapted for use in performing this Contract, or items specifically excluded by the Schedule of this Contract.

(b) Use of Special Tooling. The Contractor agrees to use the special tooling only in performing this Contract or as otherwise approved by Caltech.

(c) Initial List of Special Tooling. The Contractor shall furnish Caltech an initial list of all special tooling acquired or manufactured by the Contractor for performing this Contract. The list shall specify the nomenclature, tool number, related product part number (or service performed), and unit or group cost of the special tooling.

(d) Changes in Design. Changes in the design or specifications of the end items being produced under this Contract may affect the interchangeability of end item parts. In such an event, unless otherwise agreed to by Caltech, the Contractor shall notify Caltech of any part not interchangeable with a new or superseding part.

(e) Contractor's Offer to Retain Special Tooling. The Contractor may indicate a desire to retain certain items of special tooling at the time it furnishes a list or notification pursuant to paragraphs (c), (d), or (h) of this Article. The Contractor shall furnish a written offer designating those items that it wishes to retain by specifically listing the items or by listing the particular products, parts, or services for which the items were used or designed. The offer shall be made on one of the following bases:

1. An amount shall be offered for retention of the items free of any Caltech interest. This amount should ordinarily not be less than the current fair value of the items, considering, among other things, the value of the items to the Contractor for use in future work.

2. Retention may be requested for a limited period of time and under terms as may be agreed to by Caltech and the Contractor. This temporary retention is subject to final disposition pursuant to paragraph (i) of this Article.

(f) Property Control Records. The Contractor shall maintain adequate property control records of all special tooling in accordance with its normal industrial practice. The records shall be made available for Caltech inspection at all reasonable times. To the extent practicable, the Contractor shall identify all special tooling subject to this Article with an appropriate stamp, tag, or other mark.

(g) Maintenance. The Contractor shall take all reasonable steps necessary to maintain the identity and existing condition of usable items of special tooling from the date such items are no longer needed by the Contractor until final disposition under paragraph (i) of this Article. These maintenance requirements do not apply to those items designated by Caltech for disposal as scrap or identified as of no further interest to Caltech under subparagraph (i)(4) of this Article. The Contractor is not required to keep unneeded items of special tooling in place.

(h) Final List of Special Tooling. When all or a substantial part of the work under this Contract is completed or terminated, the Contractor shall furnish Caltech a final list of special tooling with the same information as required for the initial list under paragraph (c) of this Article. The final list shall include all items not previously reported under paragraph (c). Special tooling that has become obsolete as a result of changes in design or specification need not be reported except as provided for in paragraph (d).

(i) Disposition Instructions. Caltech shall provide the Contractor with disposition instructions for special tooling identified in a list or notice submitted under paragraphs (c), (d), or (h) of this Article. The instructions shall be provided within 90 days of receipt of the list or notice, unless the period is extended by mutual agreement. Caltech may direct disposition by any of the methods listed in subparagraphs (1) through (4) of this paragraph, or a combination of such methods. Any failure of Caltech to provide specific instructions within the 90-day period shall be construed as direction under subparagraph (i)(3).

1. Caltech shall give the Contractor a list specifying the products, parts, or services for which Caltech may require special tooling and request the Contractor to transfer title to Caltech (to the extent not previously transferred under any other Article of this Contract) and deliver as directed by Caltech all usable items of special tooling that were designed for or used in the production or performance of such products, parts, or services and that were on hand when such production or performance ceased.

2. Caltech may accept or reject any offer made by the Contractor under paragraph (e) of this Article to retain items of special tooling or may request further negotiation of the offer. The Contractor agrees to enter into the negotiations in good faith. The net proceeds from Caltech's

acceptance of the Contractor's retention offer shall either be deducted from amounts due the Contractor under this Contract or shall be otherwise paid as directed by Caltech.

3. Caltech may direct the Contractor to sell or dispose of as scrap, for the account of Caltech, any special tooling reported by the Contractor under this Article. The net proceeds of all sales shall either be deducted from amounts due the Contractor under this Contract or shall be otherwise paid as directed by Caltech. To the extent that the Contractor incurs any costs occasioned by compliance with such directions, for which it is not otherwise compensated, the Contract price shall be equitably adjusted in accordance with the Article 4, Changes.

4. Caltech may furnish the Contractor with a statement disclaiming further Caltech interest or rights in any of the special tooling listed.

(j) Storage or Shipment. The Contractor shall promptly transfer to Caltech title to the special tooling specified by Caltech and arrange for either the shipment or the storage of such tooling in accordance with the final disposition instructions in subparagraph (i)(1) of this Article. Tooling to be shipped shall be properly packaged, packed, and marked in accordance with the directions of Caltech. Tooling shipped or stored shall be accompanied by operation sheets or other appropriate data necessary to show the manufacturing operations or processes for which the items were used or designed. To the extent that the Contractor incurs costs for authorized storage or shipment under this paragraph and not otherwise compensated for, the Contract price shall be equitably adjusted in accordance with Article 4, Changes.

(k) Subcontract Provision. In order to perform this Contract, the Contractor may place subcontracts (including purchase orders) involving the use of special tooling. If the full cost of tooling is charged to those subcontracts, the Contractor agrees to include in the subcontracts appropriate provisions to obtain Caltech rights comparable to the rights of Caltech under this Article. The Contractor agrees to exercise such rights for the benefit of Caltech and as directed by Caltech.

ARTICLE 60 — Special Test Equipment

(a) "Special test equipment," as used in this Article, means either single or multipurpose integrated test units engineered, designed, fabricated, or modified to accomplish special purpose testing in performing a contract. It consists of items or assemblies of equipment, including standard or general purpose items or components, that are interconnected and interdependent so as to become a new functional entity for special testing purposes. It does not include material, special tooling, facilities (except foundations and similar improvements necessary for installing special equipment), and plant equipment items used for general plant testing purposes.

(b) The Contractor may either acquire or fabricate special test equipment at Caltech's expense when the equipment is not otherwise itemized in this Contact and the prior approval of Caltech has been obtained. The Contractor shall provide Caltech with a written notice, at least 30 days in advance, of the Contractor's intention to acquire or fabricate the special test equipment. As a minimum, the notice shall also include an estimated aggregate cost of all items and components of the equipment the individual cost of which is less than $1,000, and the following information on each item or component of equipment costing $1,000 or more:

1. The end use application and function of each proposed special test unit, identifying special characteristics and the reasons for the classification of the test unit as special test equipment.

2. A complete description identifying the items to be acquired and the items to be fabricated by the Contractor.

3. The estimated cost of the item of special test equipment or component.

4. A statement that intra-plant screening of Contractor and Government-owned special test equipment and components has been accomplished and that none are available for use in performing this Contract.

(c) Caltech may furnish any special test equipment or components rather than approve their acquisition or fabrication by the Contractor. Such Caltech-furnished items shall be subject to Article 47, Caltech-Furnished Property, except that Caltech shall not be obligated to deliver such items any sooner than the Contractor could have acquired or fabricated them after expiration of the 30–day notice period in paragraph (b) of this Article. However, unless Caltech notifies the Contractor of its decision to furnish the items within the 30–day notice period, the Contractor may proceed to acquire or fabricate the equipment or components subject to any other applicable provisions of this Contract.

(d) If any engineering change requires either the acquisition or fabrication of new special test equipment or substantial modification of existing special test equipment, the Contractor shall comply with paragraph (b) above. In so complying, the Contractor shall identify the change order which requires the proposed acquisition, fabrication, or modification.

(e) The substance of this Article shall be included in all subcontracts issued under this Contract that require special test equipment or components to be acquired or fabricated for Caltech, regardless of tier. The names of such subcontractors shall be identified to Caltech.

```
PROGRAM E2013A [ IBM RS/6000 ]                    REVISION 4 - DECEMBER 17, 1991
DESIGN OF CYLINDRICAL SHELL SECTION FOR EXTERNAL PRESSURE

                              ************************
                              ***    INPUT DATA    ***
                              ************************

    48" LIGO BEAM TUBE  0.125" THK 304L, STIFF 3/16"X1 3/4" @ 27.7" SPCG

          DESIGN CRITERIA
          ---------------
              DESIGN PRESSURE (FOR INFO)    P =     14.70    PSI

              DESIGN TEMPERATURE         TEMP =      284.    DEG F

              CORROSION ALLOWANCE          CA =     .0000    IN.

          CYLINDRICAL SHELL
          -----------------
              SHELL MATERIAL           SHMATL =  3 / 304L

              INSIDE DIAMETER              ID =    4.0000    FT.

              TOTAL LENGTH                 TL =1000.0000    FT. (ARBITRARILY
                                                                 LARGE ENOUGH
                                                                 TO FIND MAX. SPCG.)
              SHELL THICKNESS (INCL CA)   THK =    .12500    IN.

              SPECIFIED MIN. YIELD         FY =    19500.    PSI

              ALL. STRESS AT DESIGN TEMP   ST =    15400.    PSI

          SHELL STIFFENER
          ---------------
              STIFFENER MATERIAL       STMATL =  3 / 304L

              NO. OF STIFFENER              N =       432  (SEE NOTE B)

              STIFFENER SIZE: WEB DEPTH    H1 =    1.7500    IN.

                                 WEB THK   W1 =     .1875    IN.

                               FLG WIDTH   W2 =     .0000    IN.

                                 FLG THK   H2 =     .0000    IN.


    NOTE A : FOR SHMATL AND STMATL
               1 - INDICATES MATERIAL PER FIG. 5-UCS-28.2
               2 - INDICATES MATERIAL PER FIG. 5-UHA-28.1
               3 - INDICATES MATERIAL PER FIG. 5-UHA-28.3

         B : NOT INCLUDING END STIFFENERS OF THE CYLINDRICAL SHELL SECTION

---------------------------------------------------------------------------------
    CBI            MADE BY: JEH   CHKD BY: RJW      CONTRACT NO: 930212
                      DATE: 10/25/93  DATE: 29 OCT 93  SHEET 1   OF 35
```

```
PROGRAM E2013A [ IBM RS/6000 ]                REVISION 4 - DECEMBER 17, 1991
DESIGN OF CYLINDRICAL SHELL SECTION FOR EXTERNAL PRESSURE

                          *************************
                          ***    OUTPUT DATA    ***
                          *************************
    THE FOLLOWING CALCULATION IS BASED ON CORRODED SHELL THICKNESS


    CORRODED SHELL THICKNESS                    T =       .1250   IN.
    VESSEL OUTSIDE DIAMETER                    OD =       48.25   IN.
    OD DIVIDED BY CORR. SHELL THK.           OD/T =      386.00
    NO. OF SHELL SECTIONS                      NS =       433
    LENGTH OF SHELL SECTION BTW STIFF           L =       27.71   IN.
    L DIVIDED BY OD                          L/OD =         .57
    MODULUS OF ELASTICITY                       E = 26712000.   PSI
    CYLINDER HAVING OD/T VALUE LARGER THAN OR EQ. TO 10
            A = .0003094       PER FIG. 5-UGO-28.0
            B =   4255.0       PER FIG. 5-UHA-28.3

ALLOWABLE EXTERNAL PRESSURE FOR CYLINDRICAL SHELL PER UG-28
           PA = (4.*B)/(3.*DOT)
              = (4.*  4255.0)/(3.* 386.00)
              =   14.70     PSI

    AVAILABLE STIFF. RING AND RING-SHELL SECTION PROPERTIES
            STIFFENER SIZE :
                WEB :  1.7500" X    .1875"
                FLG :    .0000" X    .0000"
                AREA:    .3281     IN.**2

            EFFECTIVE SHELL SECTION :
                WIDTH     =  2.7014     IN.
                THICKNESS =   .1250     IN.

            AVAILABLE I (STIFF. RING) =         .1     IN.**4
            AVAILABLE I (RING-SHELL)  =         .2     IN.**4

    REQUIRED STIFF. RING AND RING-SHELL SECTION PROPE RTIES PER UG-29
          B = .75*((P*OD)/((THK-CA)+(AS/L)))
            = .75*(( 14.7* 48.250)/((   .1250- .0000)+(   .3281/   27.71)))
            =   3887.4     PSI

          A = .0002830     PER FIG. 5-UHA-28.3

        REQUIRED MOMENT OF INERTIA OF THE STIFFENING RING SECTION
        RIS = ((OD**2)*L*((THK-CA)+(AS/L))*A)/14.
            = (( 48.2**2)*   27.7*((   .1- .00)+(   .3/   27.7))*.0002830)/14.
            =          .2    IN.**4

        REQUIRED MOMENT OF INERTIA OF THE COMBINED RING-SHELL SECTION
        RIC = ((OD**2)*L*((THK-CA)+(AS/L))*A)/10.9
            = (( 48.2**2)*   27.7*((   .1- .00)+(   .3/   27.7))*.0002830)/10.9
            =          .2    IN.**4

        NOTE: ONLY THE RIC REQUIREMENT MUST BE SATISFIED
-----------------------------------------------------------------------------
        CBI          MADE BY: JEH    CHKD BY: RJW    CONTRACT NO:  930212
                        DATE: 10/25/93   DATE: 29 oct 93  SHEET 2   OF
TOP [SYSIN]
```

SINCE CBI PROGRAM E2013A PRINTS REQUIRED AND AVAILABLE COMBINED RING-SHELL MOMENTS OF INERTIA TO ONLY A SINGLE DECIMAL PLACE, THE FOLLOWING CALCULATION IS ADDED TO SHOW GREATER ACCURACY:

3/16" x 1-3/4" BAR

Do = 48.25
L = 27.71
shell t = 0.125
stiff b = 0.1875
stiff d = 1.75
stiff As = 0.3281
A = 0.0002830

Ireqd = 0.229 in.^4

	A	y	Ay	Io	I
shell	0.3375	0.0625	0.0211	0.0004	0.0721
stiff	0.3281	1.0000	0.3281	0.0837	0.0741
	0.6656		0.3492		

ybar = 0.5246 Itot = 0.230 in.^4 **OK**

SUBJECT	CBI OFFICE		REVISION		REFERENCE NO.
LIGO BEAM TUBES STIFFENER RINGS	NoE				930212
	MADE BY JEH	CHKD BY RJW	MADE BY	CHKD BY	SHT 3 OF ___
	DATE 10/25/93	DATE 29 OCT 93	DATE	DATE	

IN LIGHT OF CAUTIONARY NOTE OF ASME VIII DIV.1 UG-29 FOR LATERAL BUCKLING OF STIFFENER RINGS, APPLY AISC TYPE CRITERIA FOR A DEPTH TO THICKNESS LIMIT:

FROM AISC 9TH EDITION OF MANUAL OF STEEL CONSTRUCTION, TABLE B5.1, LIMIT TO $95/\sqrt{F_y}$.

$$\frac{b}{t} = \frac{1.75}{.1875} = 9.3 < \frac{95}{\sqrt{F_y}} = \frac{95}{\sqrt{19.5}} = 21.5 \quad OK$$

SUBJECT	CBI OFFICE		REVISION		REFERENCE NO.
LIGO BEAM TUBES STIFFENER RINGS	NOE				930212
	MADE BY JEH	CHKD BY RJW	MADE BY	CHKD BY	SHT 4 OF ___
	DATE 11/3/93	DATE 4 NOV 93	DATE	DATE	

ATTACHMENT OF STIFFENER RINGS TO TUBE PER UG-30.

USE 1/8" FILLET WELD LEGS (MINIMUM PER UG-30(f))

ALLOWABLE FOR FILLET WELD PER UW-18(d):

0.55 x AREA x S

FOR A 1" LONG, 1/8" FILLET, AREA = 1/8 in^2

$$\text{ALLOWABLE} = 0.55 \times \frac{1}{8}\frac{in^2}{in} \times 15{,}400\ psi = 1059\ \#/in.$$

ATTACHMENT WELDS ARE SIZED PER UG-30(e) TO RESIST:

- FULL RADIAL PRESSURE LOAD FROM SHELL BETWEEN STIFFENERS, PL_s
- RADIAL SHEAR COMPUTED AS 2% OF RING COMPRESSIVE LOAD, $0.02 PL_s R_o$
- SHEAR LOADS ACTING RADIALLY ACROSS STIFFENER (NOT APPLICABLE)

ASSUME A MAXIMUM VALUE OF $L_s = 28"$

$$PL_s = 14.7\,psi\,(28\,in) = 412\ \#/in\ \text{RADIAL}$$

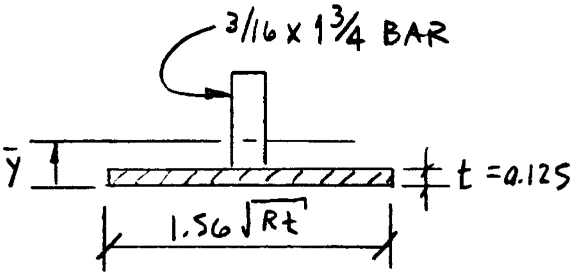
$$0.02 PL_s R_o = 0.02\,(14.7\,psi)(28\,in)(24.125\,in) = 199\ \#\ \text{RADIAL}$$

SUBJECT	OFFICE		REVISION		REFERENCE NO.
LIGO BEAM TUBES STIFFENER RINGS	CBI NoE				930212
	MADE BY JEH	CHKD BY RJW	MADE BY	CHKD BY	SHT 5 OF ___
	DATE 11/3/93	DATE 4 Nov 93	DATE	DATE	

PARTICIPATING WIDTH OF TUBE:

$$1.56\sqrt{Rt} = 1.56\sqrt{24(.125)} = 2.702 \text{ in}$$

DETERMINE Q, FIRST MOMENT OF AREA:



$$Q = A_{TUBE}\left(\bar{y} - \frac{t}{2}\right)$$

$$\bar{y} = 0.5246 \text{ in (COMBINED SECTION)}$$

$$Q = 2.702 \times 0.125 \left(0.5246 - \frac{0.125}{2}\right) = 0.156 \text{ in}^3$$

$$\frac{VQ}{I} = \frac{199\#(0.156 \text{ in}^3)}{0.230 \text{ in}^4} = 135 \#/\text{in. TANGENTIAL}$$

COMBINED LOAD ON WELD:

$$\sqrt{412^2 + 135^2} = 434 \ \#/\text{in}$$

% OF CIRCUMFERENCE WELDED REQ'D FOR ONE-SIDED:

$$\frac{434}{1059} \times 100 = 41\%$$

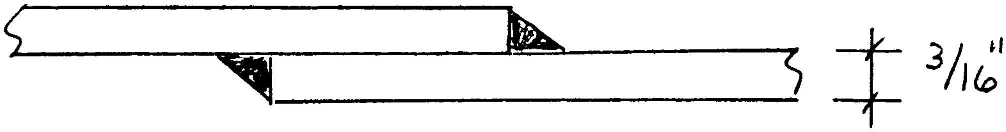
∴ CONTINUOUS 1/8" FILLET ON ONE SIDE ONLY IS ACCEPTABLE (SOME SMALL LENGTH WILL REMAIN UNWELDED WHERE JOINT IN STIFFENER CROSSES TUBE SEAM)

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
LIGO BEAM TUBES STIFFENER RINGS	MADE BY JEH	CHKD BY RJW	MADE BY	CHKD BY	SHT 6 OF
	DATE 11/3/93	DATE 4 NOV 93	DATE	DATE	

Printed In USA

GO 64 REV SEP 84

EVALUATE LAPPED ATTACHMENT OF STIFFENER ENDS:



ASSUME LOAD TO BE TRANSMITTED ACROSS JOINT IS 15,400 psi MULTIPLIED BY THE FULL STIFFENER AREA

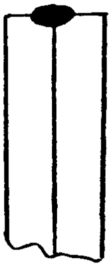
$$\text{LOAD} = 15{,}400 \text{ psi} \times 3/16 \times 1.75 = 5053\,\#$$

ASSUME FULL THICKNESS FILLETS, 1 1/2" LONG ARE USED:

$$\text{ALLOWABLE LOAD} = 0.55 \times 15{,}400 \text{ psi} \times 2(1.5) \times .1875 = 4764\,\#$$

$$4764 < 5053\,\# \text{ REQ'D} \quad \therefore \text{ ADD'L WELD IS REQ'D.}$$

DETERMINE LENGTH OF GROOVE WELD ACROSS TOP WHICH WILL SUPPLY THE NECESSARY ADD'L STRENGTH



USE BUTT GROOVE W/O EDGE PREPARATION. ASSUME 1/16" PENETRATION. USE A 60% GROOVE WELD EFFICIENCY FOR SHEAR IN ACCORDANCE WITH UW-15(c). IF LAP OF STIFFENERS IS SPECIFIED AS A NOMINAL 1", ± 1/2", THE SHORTEST LENGTH IS 1/2":

$$.60 \times 15{,}400 \text{psi} \times \frac{1}{16} \times \frac{1}{2} = 289\,\#$$

$$4764 + 289 = 5053\,\# \leq 5053\,\# \text{ REQ'D} \quad \text{OK}$$

SUBJECT LIGO BEAM TUBES STIFFENER RINGS	CBI OFFICE NOE		REVISION	REFERENCE NO. 930212
	MADE BY JEH	CHKD BY RJW	MADE BY	CHKD BY	SHT 7 OF
	DATE 11/3/93	DATE 8 NOV93	DATE	DATE	

Printed In USA

GO 64 REV SEP 84

LOAD CONDITIONS

1. DEAD LOAD OF TUBE INCLUDING BAFFLES & STIFFENERS
2. INSULATION (WET)
3. SNOW LOAD
4. WIND LOAD
5. SEISMIC LOAD
6. THERMAL LOADS (AMBIENT)
7. THERMAL LOADS (BAKE OUT)
8. VACUUM

SUBJECT	CBI OFFICE		REVISION		REFERENCE NO.
LIGO BEAM TUBE LOAD CONDITIONS	NO6-C				930212
	MADE BY RJN	CHKD BY BTS	MADE BY	CHKD BY	SHT B OF
	DATE 3 OCT 93	DATE 12 NOV 93	DATE	DATE	

LOAD COMBINATIONS

A	1	* B IS WORSE
B	1 + 2	* C IS WORSE
C	1 + 3	
D	1 + 2 + 4	* H IS WORSE
E	1 + 2 + 5	* D IS WORSE
F	1 + 2 + 6	* K IS WORSE
G	1 + 3 + 6	* C IS WORSE IF COLD 6 CAUSES TENSION
H	1 + 4 + 6	(HIGHER ALLOWABLE) (WARM)
I	1 + 2 + 5 + 6	* H IS WORSE
J	1 + 2 + 6 + 8	* K IS WORSE
K	1 + 2 + 7 + 8	
L	1 + 2 + 5 + 7 + 8	(HIGHER ALLOWABLE)

NOTES

* WILL NOT BE CONSIDERED BECAUSE OF THE STATED COMMENT

- SNOW LOAD & WIND LOAD WILL NOT OCCUR SIMULTANEOUSLY
- SNOW LOAD & WIND LOAD WILL NOT OCCUR DURING VACUUM

COMBINATIONS CONSIDERED

C = DEAD + SNOW
H = " + WIND + THERMAL AMBIENT
K = " + INSULATION + BAKE OUT + VACUUM
L = " + " + SEISMIC + BAKEOUT + VACUUM

SUBJECT
LIGO BEAM TUBE
LOAD COMBINATIONS

CBI OFFICE NDE-C
REVISION
REFERENCE NO. 930212
MADE BY RJW
CHKD BY BTS
MADE BY
CHKD BY
SHT 9 OF ___
DATE 30 Oct 93
DATE 12 NOV 93
DATE
DATE

- INPUT VARIABLES

Tube outside diameter, Do = 48.250 in
Beam Tube section length, L = 20.227 m = 66.362 ft
Tube thickness, t = 0.125 in
Insulation Density, Deni = 24 kg/m = 16.127 lbs/ft
Stiffener thickness, ts = 0.1875 in
Stiffener width, ws = 1.75 in
Stiffener spacing, Ls = 27.7 in
Mod. of Elast. @ ambient, Ea = 28,300 ksi Table TM-1 @ 70
Mod. of Elast. @ 284 degrees, Eb = 27,100 ksi Table TM-1
Anchor bolt spacing, Abs = 48 in
C. line height of tube, H = 42.115 in
Support Collar / Saddle width, b = 8.000 in
Coefficient of expansion, e= 9E-06 in/in/F Average from 70 to 300 degrees F

- ALLOWABLE STRESS PER ASME SECTION VIII DIV 1 UG 23(b)

- Allowable Stresses @ 284 Degrees F.

Yield Stress = 19,200 psi Table Y1
Tensile Allowable, Sh = 13000 psi Table 1A
Joint Efficiency, Et = 0.56
Compression Allowable UG 23(b)
A = 0.000648 = 0.125 / (Ro/t)
B = 5800 psi per Figure HA 3, interpolate to 300 degrees F.
Where B = Fa = Fbx = Fby = Fbxy

- Allowable Stresses @ Ambient (100 degrees F)

Yield Stress = 25,000 psi Table Y1
Tensile Allowable, Sa = 16,300 psi Table 1A
Compression Allowable UG 23(b)
A = 0.000648 = 0.125 / (Ro/t)
B = 7800 psi per Figure HA 3, 100 degrees F.
Where B = Fa = Fbx = Fby = Fbxy

- Allowable Stress Increase for Wind and Seismic

Allowable increase for wind or seismic is 1.20

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY RTS	MADE BY	CHKD BY	SHT 10 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- TUBE WEIGHT & PROPERTIES

Inside Diameter, Di = 48.00 in
Area, A = 18.899 in^2 = PI() * (Do^2 - Di^2) / 4
Section Modulus, S = 226.8 in^3 = PI() * (Do^4 - Di^4) / 32 / Do
Moment of inertia, I= 5471 in^4 = PI() * (Do^4 - Di^4) / 64
Radius of gyration, rg = 17.015 in = (I / A)^0.5

Number of stiffeners, Ns = 29 = Round(L/Ls*12)
True spacing = 27.460 in = L/(Ns)*12

Shell weight per section = 4311 lbs = 495 * A/144 * L

Weight per stiffener = 14.765 lbs = PI() * ((Do+2*ws)^2-Do^2)/4 * Ts * 495 / 12^3
Stiffener weight per section = 428.17 lbs = Weight ea * Ns
Estimated Baffle wt / section = 100 lbs

Total metal weight, DL = 4839 lbs, or 72.92 lbs/ft

Insulation weight per section = 1070 lbs = Deni * L

DL + Insulation = 5910 lbs, or 89.05 lbs/ft

SUBJECT LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 11 OF
	DATE 11/12/93	DATE 12NOV93	DATE	DATE	

- CALCULATE WIND LOAD PER ASCE 7-88 (Livingston, LA)

F = Qz * Gh * Cf * Af	Table 4
Qz = 20.48 = 0.00256*Kz * (I*V)^2	Eq 3
Kz = 0.80 , Assume exposure C	Table 6
I = 1.00	Table 5
V = 100 mph	Figure 1
Gh = 1.32	Table 8
Cf = 0.741 h / D = 0.0832	Table 12
h = (Do / 2 +H)/12	
D = L	
D' / Do = ws / Do = 0.03627	
Af = 4.021 Sqft / ft = Do / 12	
F = 80.51 lbs / ft	
F = 5343 lbs / section	

- CALCULATE WIND LOAD PER ASCE 7-88 (Hanford, WA)

F = Qz * Gh * Cf * Af	Table 4
Qz = 10.0352 = 0.00256*Kz * (I*V)^2	Eq 3
Kz = 0.80 , Assume exposure C	Table 6
I = 1.00	Table 5
V = 70 mph	Figure 1
Gh = 1.32	Table 8
Cf = 0.741 h / D = 0.0832	Table 12
h = (Do / 2 +H)/12	
D = L	
D' / Do = ws / Do = 0.03627	
Af = 4.020833 Sqft / ft = Do / 12	
F = 39.45 lbs / ft	
F = 2618 lbs / section	

SUBJECT LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 12 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- CALCULATE SEISMIC LOAD PER ASCE 7-88 (Livingston, LA)

V = Z * I * K * C * S * W Eq 7
Z = 0.125 Table 21
I = 1.0 Table 22
K = 2.00 Structures other than buildings Table 23
C*S = 0.14 Maximum Assumed Section 9.4.2
W = 89.05 lbs/ft = DL + Insulation

V = 0.0500W = 0.05W mimimum per 9.11.2
V = 4.45 Lbs/ft
V = 295.5 Lbs per section

- CALCULATE SEISMIC LOAD PER ASCE 7-88 (Hanford, WA)

V = Z * I * K * C * S * W Eq 7
Z = 0.1875 Table 21
I = 1.0 Table 22
K = 2.00 Structures other than buildings Table 23
C*S = 0.14 Maximum assumed Section 9.4.2
W = 89.05 lbs/ft = DL + Insulation

V = 0.0525W
V = 4.68 Lbs/ft
V = 310.2 Lbs per section

- CALCULATE SNOW LOAD PER ASCE 7-88 (Hanford, WA only)

Pf = 7.56 = 0.7 * Ce * Ct * I * Pg Eq 5a
Ce = 0.9 Little shelter assumed Table 18
Ct = 1.2 Unheated Table 19
I = 1 Category 1 Table 20
Pg = 10 psf Figure 6

Ps = 4.914 = Cs * Pf
Cs = 0.65 Angle is 35 degrees, 90-(180-70)/2, Figure 8b

Width = 45.340 in = Do * Sin 70 Per 7.4.3, slope > 70 no load
Snow Load per foot = 18.57 lbs/ft = Ps * Width
Snow load per section = 1232 lbs

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 13 OF
	DATE 11/12/93	DATE 12NOV93	DATE	DATE	

- DETERMINE REACTIONS, STRESSES AND DEFLECTIONS FOR INDIVIDUAL LOAD CASES

Mx = Moment about the horizontal axis due to vertical loads.
My = Moment about the vertical axis due to horizontal loads.

- CASE 1: Dead Load Reaction, Stresses and Deflections

Ry = 4839 lb = (w lb/ft) * (L ft)
Mx = 40143 lb-ft = (w lb/ft) * (L ft)^2 / 8 , Assumes simple span
fbx = 2124 psi = Mx * 12 / S
Delta y (amb)= 0.206 in = 5 * w * L^4 / 384 / Ea / I * 12^3 / 1000 (midspan)

- CASE 2: Dead Load plus Insulation Reaction, Stresses and Deflections

Ry = 5910 lb = (w lb/ft) * (L ft)
Mx = 49021 lb-ft = (w lb/ft) * (L ft)^2 / 8
fbx = 2594 psi = Mx * 12 / S
Delta y (284)= 0.262 in = 5 * w * L^4 / 384 / Eb / I * 12^3 / 1000

- CASE 3: Snow Load Reaction, Stresses and Deflections (Hanford, WA)

Ry = 1232 lb = (w lb/ft) * (L ft)
Mx = 10221 lb-ft = (w lb/ft) * (L ft)^2 / 8
fbx = 541 psi = Mx * 12 / S
Delta y (amb)= 0.052 in = 5 * w * L^4 / 384 / Ea / I * 12^3 / 1000

- CASE 4: Wind Load Reaction, Stresses and Deflections (Livingston, LA)

Rx = 5343 lb = (w lb/ft) * (L ft)
My = 44319 lb-ft = (w lb/ft) * (L ft)^2 / 8
fby = 2345 psi = Mx * 12 / S
Delta x (amb)= 0.227 in = 5 * w * L^4 / 384 / Ea / I * 12^3 / 1000

- CASE 5: Seismic Reaction, Stresses and Deflections (Hanford, WA)

Rx = 310 lb = (w lb/ft) * (L ft)
My = 2574 lb-ft = (w lb/ft) * (L ft)^2 / 8
fby = 136 psi = Mx * 12 / S
Delta x (284)= 0.014 in = 5 * w * L^4 / 384 / Eb / I * 12^3 / 1000

- CASE 6: Vacuum

Bellows pressure area = 57.28 sq. in, positive if Bellows dia > Do
Axial force, Pzp = 842 lbs = 14.7*Bellows pressure area, pos.=tension
Axial Stress due to vacuum, fav = 44.6 psi = Pzp / A, pos. = tension

SUBJECT	OFFICE: NOE-C		REVISION:	REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 14 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- LOAD COMBINATIONS FOR MAXIMUM REACTIONS, STRESS AND DEFLECTIONS
  - Load Combinations @ 284 Degrees F.

COMBINATION 1 - DL + Insulation + Vacuum (Case 2 + 6)

Ry = 5910 lbs, total support reaction
Rx = 0 lbs, total support shear
Rmax per bolt = 2955 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2955 lbs = Ry/2 - Rx * H / Abs
fav = 45 psi, pos = tension
fbx = 2594 psi
fby = 0 psi
Delta x (284) = 0.000 in = 5 * w * L^4 / (384 * E * I) (midspan)
Delta y (284) = 0.262 in = 5 * w * L^4 / (384 * E * I) (midspan)
Max Delta = 0.262 in = (Delta x ^2 + Delta y ^2)^0.5

Assumed Bellows spring rate K = 3500 lbs/in
Estimated temperature range, Tch = 250 degrees Fahrenheit
Thermal growth, x = 1.792 in = e * L * 12 * Tch
Longitudinal force, Pz = 6271 lbs = K * x
fa = -332 psi = Pz / A, Neg. = compression
Total axial stress, fat = -287 psi = fa + fav, Neg. = compression
fat, tension = 376 psi = abs(fa) +fav, (tension)

Pz * Max Delta = Md = 1644 in-lbs
fd = 7.2 psi = Md / S
Combined stress; fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy <= 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5800 psi for compression from page 1
Tension Allowable = 7280 psi = Sh * Et, for tension from page 1

	COMPRESSION		TENSION		
fat / Fa =	0.050		0.052		
fbx / Fbx =	0.447		0.356		
fby / Fby =	0.000		0.000		
fd / Fbxy =	0.001		0.001		
SUM =	0.498	< 1.00	0.409	< 1.00	Tube is adequate

Maximum fa (comp.) = 3181 psi = (B + fav - fbx - fby) / (1 + A*Max Delta/S) *
* from B >= fa - fav + fbx + fby + (fa * A * Max Delta / S)
Maximum Pz = 60,121 lbs, maximum longitudinal compressive force = fa * A
Maximum spring rate = 33,554 lbs/in = Pz/x

SUBJECT LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 15 OF
	DATE 11/12/93	DATE 12NOV93	DATE	DATE	

COMBINATION 2 - DL + Insulation + Seismic + Vacuum (Case 2+5+6)

Ry = 5910 lbs, total support reaction
Rx = 310 lbs, total support shear
Rmax per bolt = 3227 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2683 lbs = Ry/2 - Rx * H / Abs
Rxy = 5918 lbs = (Rx ^2 + Ry ^2)^0.5
fav = 45 psi, pos = tension
fbx = 2594 psi
fby = 136 psi

Delta x (284) = 0.262 in = 5 * w * L^4 / (384 * E * I) (midspan)
Delta y (284) = 0.014 in = 5 * w * L^4 / (384 * E * I) (midspan)
Max Delta = 0.262 in = (Delta x ^2 + Delta y ^2)^0.5

Assumed Bellows spring rate K = 3500 lbs/in
Estimated temperature range, Tch = 250 degrees Fahrenheit
Thermal growth, x = 1.792 in = e * L * 12 * Tch
Longitudinal force, Pz = 6271 lbs = K * x
fa = -332 psi = Pz / A, Neg. = compression
Total axial stress, fat = -287 psi = fa + fav, Neg. = compression
fat, tension = 376 psi = abs(fa) +fav, (tension)

Pz * Max Delta = Md = 1646 in-lbs
fd = 7.3 psi = Md / S
Combined stress; fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy <= 1.00
Where B=Fa=Fbx=Fby=Fbxy= 6960 psi = 1.2 * B, for comp. from page 1
Tension Allowable = 8736 psi = 1.2 * Sh * Et for tension from page 1

	COMPRESSION		TENSION	
fat / Fa =	0.041		0.043	
fbx / Fbx =	0.373		0.297	
fby / Fby =	0.020		0.016	
fd / Fbxy =	0.001		0.001	
SUM =	0.435	< 1.00	0.356	< 1.00 Tube is adequate

Maximum fa = 4183 psi = (B + fav - fbx - fby) / (1 + A*Max Delta/S)
Maximum Pz = 79,054 lbs, maximum longitudinal compressive force = fa * A
Maximum spring rate = 44,121 lbs/in = Pz/x

SUBJECT LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 16 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- Load Combinations Ambient

COMBINATION 3 - DL w/o insulation + Wind (Case 1+4)

Ry = 4839 lbs, total support reaction
Rx = 5343 lbs, total support shear
Rmax per bolt = 7107 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = -2268 lbs = Ry/2 - Rx * H / Abs
Rxy = 7209 lbs = (Rx ^2 + Ry ^2)^0.5
fav = 0 psi, (no vacuum)
fbx = 2124 psi
fby = 2345 psi

Delta x (amb.) = 0.206 in = 5 * w * L^4 / (384 * E * I) (midspan)
Delta y (amb.) = 0.227 in = 5 * w * L^4 / (384 * E * I) (midspan)
Max Delta = 0.306 in = (Delta x ^2 + Delta y ^2)^0.5

Assumed Bellows spring rate K = 3500 lbs/in
Estimated temperature range, Tch = 75 degrees Fahrenheit
Thermal growth, x = 0.538 in = e * L * 12 * Tch
Longitudinal force, Pz = 1881 lbs = K * x
fa = 100 psi = Pz / A

Pz * Max Delta = Md = 576 in-lbs
fd = 2.5 psi = Md / S

Combined stress; fa/Fa + fbx/Fbx + fby/Fby +fd/Fbxy = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 9360 psi = 1.2 * B from page 1
Tension Allowable = 10954 psi = 1.2 * Sa * Et for tension from page 1
fa / Fa = 0.011
fbx / Fbx = 0.227
fby / Fby = 0.251
fd / Fbxy = 0.000
SUM = 0.488 < 1.00, Tube is adequate
By inspection tension unity is less than compression unity.

Maximum fa = 4769 psi = (B - fbx - fby) / (1 + A*Max Delta/S)
Maximum Pz = 90,131 lbs, maximum longitudinal compressive force = fa * A
Maximum spring rate = 167,677 lbs/in = Pz/x

COMBINATION 4 - DL w/o insulation + Snow (Case 1+3)

Ry = 6071 lbs, total support reaction
Rx = 0 lbs, total support shear
Rmax per bolt = 3036 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3036 lbs = Ry/2 - Rx * H / Abs
Rxy = 6071 lbs = (Rx ^2 + Ry ^2)^0.5
fav = 0 psi, (no vacuum)
fbx = 2665 psi
fby = 0 psi

Delta x (amb.) = 0 in = 5 * w * L^4 / (384 * E * I) (midspan)
Delta y (amb.) = 0.258 in = 5 * w * L^4 / (384 * E * I) (midspan)
Max Delta = 0.258 in = (Delta x ^2 + Delta y ^2)^0.5

Assumed Bellows spring rate K = 3500 lbs/in
Estimated temperature range, Tch = 75 degrees Fahrenheit
Thermal growth, x = 0.538 in = e * L * 12 * Tch
Longitudinal force, Pz = 1881 lbs = K * x
fa = 100 psi = Pz / A

Pz * Max Delta = Md = 485 in-lbs
fd = 2.1 psi = Md / S

Combined stress; fa/Fa + fbx/Fbx + fby/Fby +fd/Fbxy = 1.00
Where B=Fa=Fbx=Fby=Fbxy = 7800 psi = B from page 1
Tension Allowable = 9128 psi = Sa * Et for tension from page 1
fa / Fa = 0.013
fbx / Fbx = 0.342
fby / Fby = 0.000
fd / Fbxy = 0.000
SUM = 0.355 < 1.00, Tube is adequate
By inspection tension unity is less than compression unity.

Maximum fa = 5027 psi = (B - fbx - fby) / (1 + A*Max Delta/S)
Maximum Pz = 95,005 lbs, maximum longitudinal compressive force = fa * A
Maximum spring rate = 176,745 lbs/in = Pz/x

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 18 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- CHECK TUBE AT SUPPORT SADDLES
  - Load Combinations @ 284 Degrees F.
    - Maximum reactions

Combination 1, Q1 = 5910 lbs = Ry, DL + Insulation
Combination 2, Q2 = 5918 lbs = Rxy, DL + Insulation + Seismic
Increase in allowable for W or S = 1.2
Is Q1 > Q2 / 1.2 ? YES, Use Q1 Q2/1.2 = 4931 lbs
Q used = 5910 lbs

- Variables for Stress Equations per "Design of Plate Structures" Part VI

K2 = 1.171 Table I, 120 saddle angle w/ No ring stiffeners
K3 = 0.0528 Table I, 120 saddle angle w/ No ring stiffeners
K5 = 0.76 Table I, 120 saddle angle w/ No ring stiffeners
r = 24.125 in = Do / 2
R = 2.010 ft = Do / 2 / 12
t = 0.125 in
L in these EQ's = 132.723 Ft = 2 * L
b = 8 in, (input on page 1)
A = 0 ft
H = 0 ft
Joint Efficiency @ saddle, Es = 0.56

- Tangential Shear Stress

S2 = 2295 psi = K2 * Q / r / t * (L-2*A) / (L + 4 * H / 3)

Allowable shear stress = 5824 psi = 0.8 * Allowable tension Stress (Sh) * Es
S2 < Allowable shear stress, OK

- Ring Compression on Shell over Saddle

Stress due to vacuum, Sv = 2837 psi = 14.7*r / t
S5 = 6192 psi = K5 * Q / (t * (b + 1.56*(r * t)^0.5)) + Sv

Allowable compression stress = 9600 psi = 1/2 * Compression Yield Point
S5 < Allowable Ring Compression, OK

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 19 OF
	DATE 11/12/93	DATE 12NOV93	DATE	DATE	

- Circumferential Stress at Horn of Saddle

L in these EQ's = 2*L = 132.723 ft > 8*R = 16.08 ft

S3 = -33895 psi = - Q / (4*t*(b+1.56*(r*t)^0.5) - 3*K3*Q/(2*t^2) - Sv

Allowable Stress = 10920 psi = 1.5 * Allowable Tensile stress (Sh) * Es
S3 > Allowable Horn Stress, NO GOOD, Ring Stiffeners Required

- Ring Stiffeners at Saddle RING STIFFENERS REQUIRED

Ring Height, Hr = 3.250 in
Ring Thickness, tr = 0.1875 in

Participating shell width = 2.709 in = 1.56 * (r*t)^.5

Ring Properties:

b	d	a	h	AREA	Y	AY	AY^2	Io
2.709	0.125	0.000	0.125	0.339	0.063	0.02	0.0	0.00
0.1875	3.250	0.125	3.375	0.609	1.750	1.07	1.9	0.54
			TOTAL AREA=	0.948 in^2		1.09		2.4

TOTAL DEPTH = 3.375 in
CENTROID (Y) = SUM(AY)/SUM(AREA) = 1.147 in
C2 = DEPTH - Y = 2.228 in.

I(total)= [SUM(AY^2)+SUM(Io)]-(AREA)(Y)^2 = 1.157 in^4
Sx1 = I/C1 = 1.01 in.^3
Sx2 = I/C2 = 0.52 in.^3
Radius of gyration (r) = (I/A)^1/2= 1.105 in.

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 20 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- Variables for Stress Equations per "Design of Plate Structures" Part VI

K3 = 0.0132
K6 = 0.0577
K7 = 0.263
a = 5 in
n = 2 Number of stiffeners at each saddle

- Stress on Ring Due to Internal Pressure

Svr = 1013 psi = 14.7 * r * Participating shell width / Total stiffeners area
r = 24.125 in
Shell width = 2.709 in
stiffener area = 0.948 sq in

- Circumferential Stress at Horn of Saddle

S3 = -9606 psi = - Q / (4*t*(b + 1.56*(r*t)^0.5) - 3 * K3 * Q / (2 *t ^2) - Svr

Allowable Stress = 10920 psi = 1.5 * Allowable Tensile stress (Sh) * Es
S3 < Allowable Horn Stress, OK

- Combined Stress at each Stiffener

S6 = -9091 psi = - K7 * Q / n / a - K6 * Q * r / (n * I / C2) - Svr

Allowable Stress = 9600 psi = 0.5 Compression Yield
S6 < Allowable Stress, OK

SUBJECT	OFFICE:	NOE-C	REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 21 OF
	DATE 11/12/93	DATE 12 NOV 93	DATE	DATE	

- Load Combinations @ Ambient
  - Maximum reactions

Combination 3, Q3 = 7209 lbs = Rxy, DL w/o Insulation + Wind
Combination 4, Q4 = 6071 lbs = Rxy, DL w/o Insulation + Snow
Increase in allowable for W or S = 1.2
Is Q4 > Q3 / 1.2 ? YES, Use Q4 Q3/1.2 = 6007 lbs
Q used = 6071 lbs

- Tangential Shear Stress

S2 = 2358 psi = K2 * Q / r / t * (L-2*A) / (L + 4 * H / 3)

Allowable shear stress = 7302.4 psi = 0.8 * Allowable tension Stress (Sa) * Es
S2 < Allowable shear stress, OK

- Ring Compression on Shell over Saddle

S5 = 3447 psi = K5 * Q / (t * (b + 1.56*(r * t)^0.5))

Allowable comp. stress = 12500 psi = 1/2 * Compression Yield Point
S5 < Allowable Ring Compression, OK

- Circumferential Stress at Horn of Saddle

L in these EQ's = 2*L = 132.723 ft > 8*R = 16.0833 Thus:

S3 = -31909 psi = - Q / (4*t*(b + 1.56*(r*t)^0.5) - 3 * K3 * Q / (2 *t ^2)

Allowable Stress = 13692 psi = 1.5 * Allowable Tensile stress (Sa) * Es
S3 > Allowable Horn Stress, NO GOOD, Ring Stiffeners Required

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN PRELIMINARY DESIGN - TRIAL 1	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 22 OF
	DATE 11/12/93	DATE 12NOV93	DATE	DATE	

- Ring Stiffeners at Saddle RING STIFFENERS REQUIRED

  - Variables for Stress Equations (input from 284 degrees F. Combinations)

    Ring Height, Hr = 3.250 in
    Ring Thickness, tr = 0.1875 in
    S = 0.52 in^3
    K3 = 0.0132
    K6 = 0.0577
    K7 = 0.263
    a = 5 in
    n = 2 Number of stiffeners at each saddle

  - Circumferential Stress at Horn of Saddle

    S3 = -8828 psi = - Q / (4*t*(b + 1.56*(r*t)^0.5) - 3 * K3 * Q / (2 *t ^2)

    Allowable Stress = 13692 psi = 1.5 * Allowable Tensile stress (Sa) * Es
    S3 < Allowable Horn Stress, OK

  - Combined Stress at each Stiffener

    S6 = -8299 psi = - K7 * Q / n / a - K6 * Q * r / (n * I / C2)

    Allowable Stress = 12500 psi = 0.5 Compression Yield
    S6 < Allowable Stress, OK

REINFORCEMENT OF OPENINGS

(Ref. ASME Section VIII, Division 1,Par. UG-36 thru UG-42, FIG. UG-37.1, & 1-7)

d	diameter of opening after corrosion, UG-37(b)	=	10	in.	
E1	1.0 for nozzle not located in weld joint. UG-40	=	1.0		
E2	joint efficiency of nozzle neck = 1.0	=	1.0		
H	product head	=	0	ft.	
h	internal projection at nozzle	=	0.25	in.	
R	inside shell radius after corrosion	=	24	in.	
Rn	inside nozzle radius after corrosion	=	5	in.	
Sv	allowable stress of vessel	=	13000	psi	SA-240-304L @ 284
Sn	allowable stress of nozzle neck	=	13000	psi	"
Sp	allowable stress of reinforcing pad	=	13000	psi	"
te	thickness of reinforcing pad	=	0.25	in.	
tn	nozzle neck thickness after corrosion	=	0.125	in.	
t	shell thickness furnished minus corrosion allowance	=	0.1250	in.	
P	design pressure	=	14.7	psig	
w	product weight	=	0	lbs/cu.ft.	
P'	design pressure + product head	=	14.7	psig	
CA	shell corrosion allowance	=	0	in.	
cn	neck corrosion allowance	=	0	in.	
F	stress correction factor	=	1.00		
fr1	Sn/Sv nozzle thru wall, 1.0 nozzle abutting wall [UG-41(	=	1.0		
fr2	strength reduction factor = Sn/Sv [UG-41(a)]	=	1.0		

Nozzle Mark	
Vessel thickness required after corrosion at centerline of fitting, UG-37(b) Cylindrical shell under external pressure FROM CODE CALCULATIONS	tr = 0.1250 in.
Area of reinforcement required, UG-37(c) A = 0.5[d(tr)F + 2(tn)(tr)F(1-fr1)]	A = 0.625 sq.in.
Limit of reinforcement parallel to shell, UG-40(b) L1 = greater of d or Rn + tn + t	L1 = Rn+tn+t2 = 5.25 in. L1 = d = 10 in.
Area available in shell, UG-40(d) larger of: A1 = d(E1 t - F tr) - 2 tn(E1 t - F tr)(1 - fr1) A1 = 2(t + tn)(E1 t - F tr) - 2 tn(E1 t - F tr)(1 - fr1)	A1 = 0.000 sq.in. A1 used = 0.000 A1 = 0.000 sq.in.
Neck thickness required outside, UG-27(c) Cylindrical shell under external pressure	trn = 0.0250 in. See next sheet
Radial limit outside, UG40(c) smaller of: K1 = 2.5 t or 2.5 tn + te	K1 = 0.313 in. K1 used = 0.3125 K1 = 0.563 in.
Area available in neck outside, UG-40(d) A2 = 2(K1)(fr2)(tn-trn)	A2 = 0.063 sq.in.
Radial limit inside, UG-40(c) K2 = smaller of 2.5(t), 2.5(tn) + te, or h	K2 = 2.5(t) = 0.313 in. h = 0.25 K2 = 2.5(tn)+te = 0.5625 in. K2 used = 0.25
Area available in neck inside, UG-40(d) A3 = 2 K2(tn-cn)(fr2)	A3 = 0.063 sq.in.
Area available in welds, UG-40(d) A4 = sum[(leg size)^2 (Si/Sv)] Si = smaller of Sn or Sp	A4 = 0.000 sq.in.
Area required in pad Arp= [A-(A1+A2+A3+A4)](Sv/Sp)	Arp = 0.500 sq.in.
O.D. Req'd = Arp/te+d+(2 tn) O.D. =< 2(L1)	O.D. Req'd = 12.250 in.
Pad used 0.25" Thick, 1" wide, OD = 15"	OUTER DIAMETER = 15 in. THICKNESS = 0.25 in

SUBJECT 10" Diameter opening Pump Port	OFFICE: NOE - C		REVISION 0		REFERENCE NO. 930212
	MADE BY RJW	CHKD BTS	MADE BY	CHKD BY	SHT 24 OF
	DATE 9/28/93	DATE 10NOV93	DATE	DATE	

PUMP PORT NECK THICKNESS

ASME VIII DIV 1
UG-28

ASSUME:

$t = 0.025$
$l = 3"$ (MAXIMUM NECK LENGTH)
$\phi = 10"$

$$D/t = 10"/0.025 = 400$$

$$L/D = \frac{3}{10} = 0.3$$

$A = 0.0006$ FIG G PART D SUBPART 3

$B = 5000$ FIG HA-3

$$P = \frac{4B}{3(D/t)} = \frac{4(5000)}{3(400)} = 16.7 \text{ psi} > 14.7$$

MAXIMUM OD

FOR EFFECTIVE LIMITS (UG-40) d FROM ℄ OF NOZZLE ∴ OD = 20"

SPACING FROM STIFFENERS 6" OR 8t STD 9301-2

STIFFENER SPACING = 27.7" SAY 27.5"

MAX OD = 27.5 - 3/16 THICK - 2(1/8 FILLETS) - 2(6" SPACING) = 15.0625"

THICKNESS REQUIRED

$$t_{REQ'D} = \frac{0.500 \text{ in}^2 \text{ (AREA REQ'D)}}{15" - (10 + 2 \times 1.5)} = 0.25"$$

SUBJECT 10" φ PUMP PORT LIGO BEAM TUBE	CBI OFFICE NOB-C		REVISION		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY BTS	MADE BY	CHKD BY	SHT 25 OF ___
	DATE 1 NOV 93	DATE 10NOV93	DATE	DATE	

Printed In USA GO 64 REV SEP 84

CHECK WELD SIZE BETWEEN NECK & SHELL

- LOAD ON NOZZLE

DUE TO EXTERNAL PRESSURE $= 14.7 \times \pi(5)^2 = 1154\ \#$

$$f = \frac{1154^{\#}}{\pi(10)} = 367\ \#/_{in}$$

DUE TO NOZZLE END LOADS 150# SAY 4" FROM SHELL

$$f = \frac{M}{S} = \frac{4(150^{\#})}{\frac{\pi(10)^2}{4}} = 7.64\ \#/_{in} \qquad S = \frac{\pi d^2}{4}$$

Pg 56 DESIGN OF ℞ STRUCTURES

DUE TO SHEAR

$$f = \frac{150^{\#}}{\pi 10} = 4.77$$

TOTAL STRESS

$$f = \sqrt{(4.77)^2 + (36.7+7.64)^2} = 44.6\ \#/_{in}$$

- CAPACITY OF WELD

FILLET $= (1/8)(0.49)(13000)(1\frac{1}{2}$, FULL 1 SIDE STITCH OTHER SIDE)
$= 1194\ \#/_{in}$

WELD IS ADEQUATE

SUBJECT	CBI OFFICE NOE C		REVISION		REFERENCE NO. 930212
10" ϕ PUMP PORT LIGO BEAM TUBE	MADE BY RW	CHKD BY BTS	MADE BY	CHKD BY	SHT 26 OF ___
	DATE 2NOV93	DATE 10NOV93	DATE	DATE	

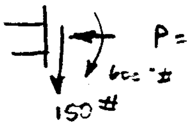
Printed In USA

GO 64 REV SEP 84

CHECK SHELL FOR NOZZLE LOADS

SEE STD 9107-3-6

LOAD ON NOZZLE



P = 1154# (VACUUM)

$P = 1154$

$V_L = 0$

$V_c = 150$

$M_c = -600"\#$

INITIAL STRESS

$$\sigma_\phi = \frac{PR_m}{T} = \frac{14.7(24)}{.125} = 2822 \text{ psi}$$

$$\sigma_x = \frac{PR}{2T} = \frac{\sigma_\theta}{2} = 1411.2$$

$$\sigma_x (A_m \rightarrow D_m) = 1411 \text{ psi}$$

$$\sigma_\phi (A_m \rightarrow D_m) = 2822$$

ASSUME SURFACE STRESSES = 1 1/2 × MEMBRANE

$$\sigma_x (A_u \rightarrow D_u) = 1.5(1411.2) = 2117$$

$$\sigma_\phi (A_u \rightarrow D_u) = 1.5(2822) = 4234$$

PUNCHING SHEAR

$$\tau_{xr} = \frac{1.5P}{2\pi r_o T} = \frac{1.5(1154)}{2\pi(5)(.125)} = 441 \text{ psi}$$

@ $.5\sqrt{Rt}$

$$\tau_{xr} = \frac{1.5(1154)}{2\pi(5 + \underbrace{.5\sqrt{24(.125)}}_{.866"}).125} = 376 \text{ psi}$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93212
10" φ PUMP PORT LIGO BEAM TUBE	MADE BY RW	CHKD BY BTS	MADE BY	CHKD BY	SHT 27 OF
	DATE 2NOV93	DATE 10NOV93	DATE	DATE	

Printed In USA

GO 64 REV SEP 84

```
GRAM E1027A STD 9107- 3- 6 [ IBM RS/6000 ]
VISION 14 - 04/22/93 (WRC-107 REV MAR 79)
ESS INTENSITIES AT LOADED ATTACHMENTS IN CYLINDERS AND SPHERES
 CBI STANDARD 9107-3-6 FOR INSTRUCTIONS ON USING THIS PROGRAM.

   INPUT
        ATTCHMTS     VESSEL      LOADING       ANALYSIS
           1          1=CYL     -1=FIXED          3D

           KN           KB           RM            T           LOC            C
          1.00         1.00       24.000         .125        .5000          .00

           RO           TI           TP            W
         5.000         .000         .000         .000

            P           VL           VC           MC            ML           MT
       1154.00          .00      -150.00      -600.00           .00          .00


   INITIAL STRESSES NEXT TO ATTCHMNT
      SX(AU)    SO(AU)    SX(CU)    SO(CU)    SX(AM)    SO(AM)    SX(CM)    SO(CM)
       2117.     4234.     2117.     4234.     1411.     2822.     1411.     2822.

   INITIAL STRESSES AT LOC*SQRT(R*T)
      SX(AU)    SO(AU)    SX(CU)    SO(CU)    SX(AM)    SO(AM)    SX(CM)    SO(CM)
       2117.     4234.     2117.     4234.     1411.     2822.     1411.     2822.

   INITIAL STRESSES AT EDGE OF REINF
      SX(AU)    SO(AU)    SX(CU)    SO(CU)    SX(AM)    SO(AM)    SX(CM)    SO(CM)
          0.        0.        0.        0.        0.        0.        0.        0.

    INT                    RADIAL PUNNCHING SHEAR STRESSES
   PRESS          NEXT TO ATTCHMNT        AT LOC*SQRT(R*T)           AT EDGE OF REINF
                   AT A,B,C, AND D         AT A,B,C, AND D            AT A,B,C, AND D
    -15.                      441.                    376.                         0.










   10" DIAMETER PUMP PORT
   930212
   ROUND  ATTCHMT 10" DIA NOZZLE                        ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY BTS	CHKD BY RJW	REV 0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10NOV93		CHKD		SHT 28 OF
				DATE		

```
OUTPUT
BIJLAARD COEFICIENTS
          NEXT TO ATTCHMNT          AT LOC*SQRT(R*T)
           A & B      C & D        A & B       C & D
NX/P       6.727     18.388        5.151      16.181
MX/P        .032       .013*        .025        .009*
NX/MC          16.360                   16.360
MX/MC            .022                     .020
NX/ML           5.532                    4.626
MX/ML            .014                     .012
NO/P      18.388      6.727       16.181       5.151
MO/P        .013       .032*        .009        .025*
NO/MC           5.573                    4.670
MO/MC            .054                     .051
NO/ML          11.680                    9.832
MO/ML            .010                     .008

*  MX/P FROM FIG 2C-1 INSTEAD OF 2C &/OR MO/P FROM 1C-1 INSTEAD OF 1C
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                       ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY BTS	CHKD BY	REV 0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10NOV93		CHKD		SHT 29 OF
				DATE		

```
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
       (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -16840.  11665.  -16840.  11665.  -10841.   -1810.  -14626.   -1017.
SO   -12733.  -1414.  -12733.  -1414.  -13731.    9066.  -19949.   14265.
TAU     -76.    -76.      76.     76.      0.       0.       0.       0.
SI    16827.  13080.   16827.  13080.   13716.   10876.   19934.   15282.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
       (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -13278.   9315.  -13278.   9315.   -8830.   -2343.  -11879.   -1844.
SO   -10355.  -2094.  -10355.  -2094.  -10786.    7187.  -15770.   11444.
TAU     -65.    -65.      65.     65.      0.       0.       0.       0.
SI    13265.  11410.   13265.  11410.   10771.    9531.   15755.   13287.

OUTPUT INCLUDING INITIAL STRESSES
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
       (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -14723.  12370.  -14723.  12370.   -8724.   -1105.  -12509.    -312.
SO    -8499.     -4.   -8499.     -4.   -9497.   10476.  -15715.   15675.
TAU     -76.    -76.      76.     76.      0.       0.       0.       0.
SI    14709.  12375.   14709.  12375.    9482.   11581.   15700.   15987.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
       (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -11161.  10020.  -11161.  10020.   -6713.   -1638.   -9762.   -1139.
SO    -6121.   -684.   -6121.   -684.   -6552.    8597.  -11536.   12854.
TAU     -65.    -65.      65.     65.      0.       0.       0.       0.
SI    11147.  10705.   11147.  10705.    6698.   10236.   11521.   13992.
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                          ON A CYLINDRICAL  VESSEL
```

SUBJECT

MADE BY BTS
DATE 10NOV93

CHKD BY RJW
DATE 10NOV93

REV 0
BY
CHKD
DATE

CHARGE NO. 930212
SHT 30 OF

```
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
                  (AM)            (BM)            (CM)            (DM)
SX              -2588.          -2588.          -6326.          -7821.
SO              -7073.          -7073.          -2333.          -2842.
TAU               -76.             76.              0.              0.
SI               7155.           7155.           6413.           7896.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
                  (AM)            (BM)            (CM)            (DM)
SX              -1981.          -1981.          -5587.          -6862.
SO              -6224.          -6224.          -1799.          -2163.
TAU               -65.             65.              0.              0.
SI               6301.           6301.           5669.           6932.

OUTPUT INCLUDING INITIAL STRESSES
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
                  (AM)            (BM)            (CM)            (DM)
SX              -1177.          -1177.          -4915.          -6410.
SO              -4251.          -4251.            489.            -20.
TAU               -76.             76.              0.              0.
SI               4407.           4407.           5665.           6845.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
                  (AM)            (BM)            (CM)            (DM)
SX               -570.           -570.          -4176.          -5451.
SO              -3402.          -3402.           1023.            659.
TAU               -65.             65.              0.              0.
SI               3597.           3597.           5322.           6281.








10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                         ON A CYLINDRICAL  VESSEL
[SYSIN]
```

SUBJECT	BTS	RJW	REV 0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10NOV93		CHKD		SHT 31 OF
				DATE		

```
OGRAM E1027A STD 9107- 3- 6 [ IBM RS/6000 ]
VISION 14 - 04/22/93 (WRC-107 REV MAR 79)
RESS INTENSITIES AT LOADED ATTACHMENTS IN CYLINDERS AND SPHERES
E CBI STANDARD 9107-3-6 FOR INSTRUCTIONS ON USING THIS PROGRAM.

     INPUT
            ATTCHMTS    VESSEL     LOADING       ANALYSIS
               1        1=CYL     -1=FIXED          3D

              KN          KB          RM           T          LOC          C
             1.00        1.00       24.000        .125       .5000        .00

             RO          TI          TF           W
            5.000        .000        .000         .000

              P          VL          VC          MC          ML          MT
            1154.00        .00      150.00      600.00        .00         .00


     INITIAL STRESSES NEXT TO ATTCHMNT
        SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
         2117.    4234.    2117.    4234.    1411.    2822.    1411.    2822.

     INITIAL STRESSES AT LOC*SQRT(R*T)
        SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
         2117.    4234.    2117.    4234.    1411.    2822.    1411.    2822.

     INITIAL STRESSES AT EDGE OF REINF
        SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
            0.       0.       0.       0.       0.       0.       0.       0.

      INT                     RADIAL PUNNCHING SHEAR STRESSES
     PRESS         NEXT TO ATTCHMNT        AT LOC*SQRT(R*T)          AT EDGE OF REINF
                    AT A,B,C, AND D        AT A,B,C, AND D           AT A,B,C, AND D
      -15.                     441.                    376.                        0.










     10" DIAMETER PUMP PORT
     930212
     ROUND  ATTCHMT 10" DIA NOZZLE                          ON A CYLINDRICAL  VESSEL
```

SUBJECT	BTS	CHKD BY RJW	REV 0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10NOV93		CHKD		SHT 32 OF
				DATE		

```
OUTPUT
BIJLAARD COEFICIENTS
          NEXT TO ATTCHMNT         AT LOC*SQRT(R*T)
           A & B      C & D         A & B      C & D
NX/P       6.727     18.388         5.151     16.181
MX/P        .032        .013*        .025        .009*
NX/MC           16.360                   16.360
MX/MC              .022                     .020
NX/ML            5.532                    4.626
MX/ML              .014                     .012
NO/P      18.388      6.727        16.181      5.151
MO/P        .013        .032*        .009        .025*
NO/MC            5.573                    4.670
MO/MC              .054                     .051
NO/ML           11.680                    9.832
MO/ML              .010                     .008

*  MX/P FROM FIG 2C-1 INSTEAD OF 2C &/OR MO/P FROM 1C-1 INSTEAD OF 1C
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                            ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY BTS	CHKD BY RJW		BY		CHARGE NO. 930212
	DATE 10 NOV 93	DATE 10 NOV 93		CHKD		
				DATE		SHT 33 OF

```
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
        (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -16840.   11665.  -16840.   11665.  -14626.   -1017.  -10841.   -1810.
SO   -12733.   -1414.  -12733.   -1414.  -19949.   14265.  -13731.    9066.
TAU      76.      76.     -76.     -76.       0.       0.       0.       0.
SI    16827.   13080.   16827.   13080.   19934.   15282.   13716.   10876.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
        (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -13278.    9315.  -13278.    9315.  -11879.   -1844.   -8830.   -2343.
SO   -10355.   -2094.  -10355.   -2094.  -15770.   11444.  -10786.    7187.
TAU      65.      65.     -65.     -65.       0.       0.       0.       0.
SI    13265.   11410.   13265.   11410.   15755.   13287.   10771.    9531.

OUTPUT INCLUDING INITIAL STRESSES
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
        (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -14723.   12370.  -14723.   12370.  -12509.    -312.   -8724.   -1105.
SO    -8499.      -4.   -8499.      -4.  -15715.   15675.   -9497.   10476.
TAU      76.      76.     -76.     -76.       0.       0.       0.       0.
SI    14709.   12375.   14709.   12375.   15700.   15987.    9482.   11581.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
        (AU)     (AL)     (BU)     (BL)     (CU)     (CL)     (DU)     (DL)
SX   -11161.   10020.  -11161.   10020.   -9762.   -1139.   -6713.   -1638.
SO    -6121.    -684.   -6121.    -684.  -11536.   12854.   -6552.    8597.
TAU      65.      65.     -65.     -65.       0.       0.       0.       0.
SI    11147.   10705.   11147.   10705.   11521.   13992.    6698.   10236.
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                        ON A CYLINDRICAL  VESSEL
```

SUBJECT

BTS
DATE 10NOV93

RJW
DATE 10NOV93

REV 0
BY
CHKD
DATE

CHARGE NO. 930212
SHT 34 OF

```
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
                (AM)          (BM)          (CM)          (DM)
SX             -2588.        -2588.        -7821.        -6326.
SO             -7073.        -7073.        -2842.        -2333.
TAU               76.          -76.            0.            0.
SI              7155.         7155.         7896.         6413.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
                (AM)          (BM)          (CM)          (DM)
SX             -1981.        -1981.        -6862.        -5587.
SO             -6224.        -6224.        -2163.        -1799.
TAU               65.          -65.            0.            0.
SI              6301.         6301.         6932.         5669.

OUTPUT INCLUDING INITIAL STRESSES
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
                (AM)          (BM)          (CM)          (DM)
SX             -1177.        -1177.        -6410.        -4915.
SO             -4251.        -4251.          -20.          489.
TAU               76.          -76.            0.            0.
SI              4407.         4407.         6845.         5665.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
                (AM)          (BM)          (CM)          (DM)
SX              -570.         -570.        -5451.        -4176.
SO             -3402.        -3402.          659.         1023.
TAU               65.          -65.            0.            0.
SI              3597.         3597.         6281.         5322.




10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                      ON A CYLINDRICAL  VESSEL
[SYSIN]
```

SUBJECT	MADE BY BTS	CHKD BY RJN	0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10NOV93	REV	CHKD DATE		SHT 35 OF

SECTION 3

LIGO PROJECT
WBS 200
FABRICATION

WBS #210 Steel Production Proces

CBI is developing the technical specification for the procurement 304L HRAP coil steel for the LIGO beam tubes. Four suppliers of 304L HRAP coil steel material have been identified and contacted:

- J&L Specialty Products Corp. can produce the coil steel weighing 25,000# in widths up to 48" and have the "in house" capability to air bake the coil steel.
- Washington Steel presently can only produce the coil steel weighing 30,000# in widths up to 24" and they also have the "in house" capability to air bake the coil steel. Washington Steel is installing a new mill and will have the capability of producing coil steel 60" wide in January of 1995. If 48" coil steel is needed for the qualification test Washington Steel could have 48" wide coil steel rolled by others.
- Armco Advanced Material Corp. can produce the coil steel weighing 40,000# in widths up to 60" but they do not have the "in house" capability or experience to air bake the coil steel.
- Allegheny Ludlum Steel has informed us that they do not produce 304L HRAP coil steel in thicknesses less than 3/16", and therefore, cannot supply the LIGO coil steel.

During December we plan to visit J&L, Washington Steel and Armco to see their facilities and to discuss their coil steel production process and the coil steel air bake process. The procurement technical specification will be finalized after these mill visits.

The LIGO Beam Tube Specification requires that all beam tube materials, that will be exposed to the vacuum, meet the requirements of the Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products. This specification requires that the materials be air baked to 440^{o}C +/- 8^{o}C for a minimum of 36 hours. The specification also requires that "material samples from all air baked raw material be tested to confirm acceptable outgassing levels for hydrogen" and that "No material shall be used for fabrication until it is acceptability is assured."

Both J&L Specialty Products and Washington Steel have indicated that they can and are willing air bake the coil steel. Armco has informed us that they do not have the experience or capability to perform the air bake. However, Armco is the only supplier that can produce the beam tube material in widths up to 60 inches. CBI is concerned as to whether or not the steel suppliers have the needed experience and qualifications to perform the air bake process as specified. The air baking temperatures must be tightly controlled and monitored for a successful bake. We do not want this to be a learning experience at added cost to the LIGO project. CBI has the "in house" experience and capability needed to perform the air bakes if the steel suppliers do not do not. During the month of December, we plan to visit the steel mills and discuss the air bake process. After the mill visits we will recommend a course of action for the raw material air bake.

The steel suppliers have informed us that the thickness variation in hot rolled material is much harder to control than in cold rolled material. To date none of the suppliers have confirmed that they can produce the beam tube material to thickness tolerances better than the ASTM specified +/- 0.010". The current beam tube design is base on an improved beam tube thickness tolerance of +/- 0.005". We will need to change the design thickness if the steel suppliers cannot provide the improved +/- 0.005" thickness tolerance.

Presently, the length of time from purchase order issue to receipt of the coil steel material from the supplier is 8 to 10 weeks. As such, CBI's schedule is currently based on purchase of the beam tube steel by mid January. This is prior to the Final Design Review. Also, as discussed in the SRR meeting, for the qualification test CBI plans to procure the material for the beam tubes and possibly the bellows directly from the steel mill instead of having the beam tube and bellows suppliers purchase the material .

WBS #220 Tube Manufacturing Process Study

Effective and economical manufacturing of the tube sections are essential to the successful implementation of the LIGO project. Recognizing the critical importance of the tube section manufacturing, CBI is identifying and developing the process requirements, procedures, and controls to economically fabricate the tube sections. To develop a knowledge o the tube manufacturing process and of the individual manufactures, CBI contacted and subsequently visited tube manufactures. In general, tube manufactures have a relatively narrow capability limited to typical pipe or tube applications. Although varying degrees of weld expertise, none have a knowledge or experience with the special welding, cleaning, and inspection requirements associated with high vacuum facilities. After considering the possibility of CBI manufacturing the tube sections, CBI is pursuing the development of the required expertise within tube manufactures. The scope of work for the pipe manufactured will be limited to the fabrication of the unstiffened tube sections only. This will include weld inspection and end preparation, but the attachment of stiffeners, leak testing, cleaning and final acceptance for installation will be executed by CBI.

CBI conducted plant tours of pipe manufacturers from October 13 to October 15. The companies toured Tubetec in Sanford, Florida, Naylor Pipe in Chicago, and Northwest Pipe in Portland, Oregon. CBI toured Roscoe Moss' facility in Los Angeles on August 26th. Of the companies toured to date, Northwest Pipe and Tubetec appear to be the most viable manufacturers for the LIGO project.

The manufacturing process used by Northwest Pipe is typical of the large diameter spiral welded pipe manufacturers. These mills typically manufacture large diameter carbon steel pipe in thicknesses ranging from 1/4" to 5/8" for 48" diameter pipe. Coil widths for this application are generally 36" to 48". Considerable force is required to form the pipe in the typical thickness range. As such the pipe mills are large units with large guides, drive rollers, and forming rollers. Northwest Pipe's greatest advantage over other similar manufacturers is their experience with stainless steel and the application of their pipe. NWP serves the chemical and pulp and paper industries which requires corrosion resistant higher quality pipe. Although not suitable for the LIGO project, NWP has a stainless steel pipe mill which produces pipe up to 30" in diameter.

Tubetec routinely makes large diameter thin wall stainless steel pipe. The pipe mill used by Tubetec is based on a free forming process. Although Tubetec has designed a mill which uses 30" wide coil, their current mill uses 16" wide coil to produce 48" diameter pipe. The use of relatively narrow coil combined with the thin wall allows the pipe to be formed without significant force. This removes the need for a large mill with heavy drive rollers and guides. The disadvantage of this process is the total length of spiral butt weld is significantly increased.

LIGO PROJECT
WBS 200
FABRICATION

Due to the unique requirements of the LIGO project and the basic differences in the two fabrication processes, CBI is pre qualifying the tube manufactures and their processes. NWP and Tubetec will each produce a 20' section of 48" diameter tube. The tube section will be welded with the Caltech specified weld procedure and the procedure developed by CBI. The unstiffened tube section will be shipped unstiffened to CBI and evaluated for dimensional conformance and weld quality. The sections will also be used by CBI to develop circumferential and stiffener weld procedures and equipment. Tubetec has completed the 20' section and it is currently being evaluated by CBI in our Houston weld laboratory. NWP will likely manufacture their 20' pre qualification section in December. No special precautions will be made to limit contamination of the pre qualification sections.

Although there are a number of difficult aspects to the pipe manufacturing process, the most difficult areas are the determination of the best weld process and the potential for contamination. CBI has conducted an in-depth study of the weld process as reported under WBS #270. The best weld process will be developed by CBI and incorporated into the pipe fabrication process. The prevention of carbon steel contamination presents a more imposing problems. It may not be feasible to completely prevent carbon steel contamination. Even costly, extreme measures may not be able to prevent contamination and maintain cleanliness. Tubetec is probably best suited to prevent contamination and even they pickle their products as part of their standard operation. CBI is looking at cleaning procedures to overcome the problems of contamination while recognizing the danger of recharging the material hydrogen content.

WBS #230 Expansion Joint Manufacturing

Due to the integrated nature of the expansion joint manufacturing and design, expansion joint manufacturing concerns are discussed in section WBS #124.

WBS #240 Tube and Expansion Joint Interface

Expansion joints will be manufactured to tightly controlled circumferences with full thickness weld ends. CBI will attach the expansion joints to the tube sections at or near the sites. Expansion joints will be placed at both ends of both modules. All seams will be welded including the final module closing seam which will be located at the corner and end stations. Personnel and equipment entry and exit will be required through the large valves.

LIGO TUBE VENDOR SURVEY SUMMARY

KHF 10/19/93

ITEM	NORTHWEST PIPE	TUBETEC
TUBE FORMING PROCESS	PRD MACHINE - FORCE FORM WITH ROLLERS & DIES	TUBETEC DESIGNED EQUIPMENT, FREE FORM
LENGTH - 40 TO 65 FEET	YES, BUT CURRENT RESIZING EQUIPMENT LIMITS LENGTH TO 60'	YES
OUT OF STRAIGHT TOLERANCE OVER 10' LENGTH	< 1/8"	< 1/8"
OUT OF STRAIGHT TOLERANCE AT 65' LENGTH	< 1/8"	< 1/8"
CIRCUMFERENCE TOLERANCE WITHOUT RESIZING	PLUS 3/64" @ ENDS, PLUS 4/64" @ BARREL MINUS ZERO	PLUS 3/16"@ENDS, PLUS 3/8"@BARREL MINUS IS SAME
CIRCUMFERENCE TOLERANCE WITH RESIZING	PLUS 1/64" @ ENDS, MINUS ZERO. MUST DEVELOP RESIZING EQUIP.	AS REQUIRED TO MATCH BELLOWS. MUST DEVELOP RESIZING EQUIP.
END TOLERANCE	PLUS OR MINUS 1/8" PLASMA BURNED, FOR $150,000 INVESTMENT CAN MACHINE SQUARE	LATHE CUT NORMAL TO AVERAGE TUBE CENTERLINE
MAXIMUM HIGH/LOW ON WELD SEAM	NOT GIVEN	1/32"
CIRCUMFERENCE MEASUREMENT	EVERY 7'	EVERY 3'
EDGES CLEANED PRIOR TO WELDING	YES, BY STAINLESS POWER BRUSHING	YES, BY STAINLESS POWER BRUSHING
WELD GAP VARIATION	JAM TO 0.020"	JAM TO 0.010"
PRODUCTION PER SHIFT	120'	100'
# SHIFTS PER DAY	2	2
ON SITE STORAGE	NOT GIVEN	2 WEEKS PRODUCTION
SET UP COSTS REQUIRED	YES	NO
CONTAMINATION SOURCES:		
COIL HANDLING	YES, BY CHAINS	NO, COIL PROTECTED
TABLES & ROLLERS	MUST REPLACE ROLLERS, GUIDES	NO, USED FOR STAINLESS ONLY
WELDING EQUIPMENT	NO, MUST MOVE EQUIPMENT FROM SMALL SS MILL	NO
NDE EQUIPMENT	NOT GIVEN	NO
PERSONNEL	YES, CARBON STEEL SHOP	NO, STAINLESS SHOP
CUTTING EQUIPMENT	YES, PLASMA BURNER	NO
PIPE HANDLING EQUIP	YES	NO
END SIZING EQUIPMENT	YES	NOT KNOWN
ATMOSPHERE	YES, AIR BORN CARBON STEEL/GRINDING DUST	YES, GRINDING DUST
END CAPPING FOR SHIPMENT	PLASTIC COVERS	CROSS TIMBER BRACING WITH PLASTIC COVERS
SHIPPING SADDLE DESIGNS	TIMBER	STAINLESS, 120 DEGREE BOLTED SUPPORT
LEAD TIME FOR MAKING PIPE	90 DAYS	1 DAY
TUBE RESIZING OVER WHAT LENGTH	MAX 6"	AS NEEDED
STARTED SPIRAL PIPE PRODUCTION	1960	LATE 1960'S
OWNERSHIP	PRESENTLY FOR SALE, LATEST BUY EFFORT UNSUCCESSFUL	PRIVATE

FACILITIES	WW2 VINTAGE, VERY LARGE COMPLEX (300,000 SF), MOSTLY CARBON STEEL WORK	TILT-UP CONCRETE WALL SHOP(65,000 SF), NEW SHOP UNDER CONSTRUCTION
HANDLING EQUIP	OVERHEAD CRANES, LIFT TRUCKS	LIFT TRUCKS
PRODUCTION WORKERS	112(PIPE SHOP)	65
QA/QC PERSONNEL	1	2
LINE INSPECTORS	4	2
LAB TECHNICIANS	4	0
ANNUAL BUSINESS	NOT GIVEN	$8MM TO $9MM
LAB EQUIPMENT CALIBRATED	YES	NO LAB
CALIBRATION TRACEABLE T NIST	YES	N/A
HEAT TREATMENT FACILITIES	0	2
CLEANING/PICKLING PROCESS (NITRIC/HYDROFLUORIC ACID)	SUBCONTRACT, LIMIT TO 20' LENGTH ($150,000 PLUS $.15/# FOR LONGER)	APPROVED BY FLORIDA EPA TO PICKLE
CAN MEET ASTM STDS	YES	YES
QA TRACEABILITY	YES, APPLYING FOR ASME SECT XIII, DIV 1 CERTIFICATION (WITHIN NEXT 45 DAYS)	YES, STARTING ON ISO 9000 CERTIFICATION PROGRAM
QA/QC INSPECTION	NOT GIVEN	IN PROCESS INSPECTION
NDE PERSONNEL	QUALIFIED TO ASNT	SUBCONTRACTED
STRIP WIDTH	NORMAL IS 36" TO 48" ON LARGE CS MILL	NORMAL IS 16", PRESENTLY INVESTIGATING SPECIAL MANDREL TO ALLOW 20-24" WIDE STRIP
WELDER QUALIFICATION	ASME SECTION IX	ASME SECTION IX
QA MANUAL OFFERED	YES	NO
WELD PROCEDURES GIVEN	YES	YES, GENERAL WRITE UP
GTA (TIG) WELDING STANDARD	YES	YES
IN PROCESS NDE	NO, LOOKING AT EDDY CURRENT AND RADIOSCOPY	NO, WILL DO WHAT CBI SPECIFIES
WELD SPEED	22 IPM	16 IPM
WELD SHIELD GAS	55 ARGON 45 HELIUM	ARGON
BACK SIDE PURGE GAS	55 ARGON 45 HELIUM	NITROGEN
AUTOGENOUS WELD-INSIDE PASS	70% @ 70-150 AMPS	80% @ 200 AMPS
2 PASS WELD-INSIDE PASS	70% @ 70-150 AMPS	80% @ 140 AMPS
2 PASS WELD-OUTSIDE PASS	COLD WIRE TIG	HOT WIRE TIG
NUMBER OF TUBES REQ'D @ 65'		
HANFORD ONLY	388	388
LIVINGSTON ONLY	388	388
COMBINED SITES	776	776
PRODUCTION IN TUBES PER SHIFT		
AT 65' LONG	2	1.5
NUMBER OF SHIFTS REQ'D		
HANFORD ONLY	194	259
LIVINGSTON ONLY	194	259
COMBINED SITES	388	517
NUMBER OF SHIFTS PER DAY	2	2
NUMBER OF WORKING DAYS		
HANFORD ONLY	97	129
LIVINGSTON ONLY	97	129
COMBINED SITES	194	259
NO. WEEKS REQ'D@ 2 SHIFTS/WK		
HANFORD ONLY	19.4	26
LIVINGSTON ONLY	19.4	26
COMBINED SITES	38.8	52
NO. WEEKS REQ'D@ 1 SHIFT/WK		
HANFORD ONLY	38.8	52
LIVINGSTON ONLY	38.8	52
COMBINED SITES	77.6	103

WBS #250 Baffle Fabrication Process

The baffles could be made by several possible methods. The baffles may be rolled from a single strip of material. The rolling process could include a geared roller to either impose a shallow serration on the inside edge, or to mesh with (and thereby protect) a serration which has already been cut on the strip. Alternatively, a slit cone could be made from two or three butt welded segments and then pulled into a spiral. If made from a thin material (~20 gauge), the baffles could be stamped as an oversized ring with serrations, coned in a die, and then slit and pulled into a spiral.

Sheet and light metal fabricators have been contacted to help develop the fabrication options. A draft specification has been developed and issued to potential fabricators for comments and budget pricing. A concern regarding the few baffles to be used for the Qualification Test is that, for economic reasons, they may need to be produced in an entirely different manner than those to be used for the actual construction of the LIGO modules. This is especially true if any stamping type operations using specially made dies are determined to be a necessary part of the fabrication process for uniform production of a large quantity (900-1000). The Qualification Test baffles therefore may not necessarily be an accurate representation of the Design.

CBI has issued a purchase order for a sample baffle from each of three potential fabricators. CBI anticipates receipt of these baffles by the end of November. The purpose is to better determine its configuration and fabrication possibilities, as well as fit to the tube wall prior to the Qualification Test. This will also assist in evaluation of what tolerances could be achieved on the aperture of the baffle when it is placed inside the tube, and give an estimate of pricing for various degrees of serration.

WBS #260 Stiffener Fabrication Process Development

The fabrication method being pursued is that of rolling bars to produce single piece stiffeners which conform to the outside of the tube. The two ends of each stiffener would overlap for short length. This overlap would be placed at the location where the stiffener ring crosses the spiral seam of the tube so that continuous fillet welding could start just adjacent to the spiral seam at one end and proceed nearly 360° around without any interruption. CBI has issued a purchase order for a several stiffeners from each of three potential fabricators. CBI anticipates receipt of these stiffeners to allow attachment to a sample tube by the end of November. This exercise is being performed for investigative and demonstration purposes.

A potential problem associated with rolling stiffeners from bar material is the occurrence of waviness on the inside edge which would be fit to the tube wall and automatically welded. The automated weld process will require a reasonably straight stiffener to provide a sound uniform fillet weld. The sample stiffeners described in the preceding will be a good indication of what can be expected.

WBS #270 Beam Tube Welding Process Development

LIGO specifications #1100004 and #1100007 contain weld procedure requirements for the beam tube modules. CBI has conducted an extensive test program to determine the most suitable weld procedure for the LIGO beam tube modules. The weld report contained in the 2nd Monthly Review Data Package is unchanged and included at the end of this section. CBI will continue to develop the most suitable weld procedure requirements in conjunction with tube and expansion joint manufactures.

WBS #280 Stiffener Weld Process Development

The attachment of the beam tube stiffeners represents a very significant cost of the beam tube section fabrication. CBI has evaluated a number of stiffener attachment options by welding stiffeners to flat plate specimens. The weld report contained in the 2nd Monthly Review Data Package is unchanged and is included at the end of this section.

A number of options exist for the stiffener attachment weld detail. CBI is developing a cost analysis to determine the most economic weld detail. Due to the large number of stiffeners, the stiffener attachment weld must be automated to be economical. Continuous and intermittent weld details are being evaluated based on the costs of the equipment weld consumables, number of stops and starts, and weld effectiveness. Equipment and procedures will e finalized through the attachment of stiffeners to the pre qualification section being manufactured by the potential tube fabricators. A continuous one sided fillet weld appears to be the most economical stiffener weld attachment detail

WBS #290 Circumferential Weld Process Development

CBI is pursuing welding the circumferential seams from the outside. Outside welding will limit the safety and contamination concerns associated with internal weld procedures and will lend itself to current automated pipe welding equipment. CBI has conducted a flat plate study to determine the most suitable weld process for the circumferential seams. The weld report from included in the 2nd Monthly Review Meeting is unchanged and contained at the end of this section.

Automated weld equipment for the circumferential seams is being evaluated by welding circumferential seams in sections cut from the 20' pre qualification tubes. The Dimetrics Gold Track II equipment has been chosen for initial evaluation. Tube section fit up devices will also be evaluated in the course of the weld development.

10/25/93

BEAM TUBE WELD PROCESS DEVELOPMENT
WBS 270

TABLE OF CONTENTS

BEAM TUBE WELD PROCESS DEVELOPMENT
WBS 270

A. BACKGROUND OF WELDING.

The welding procedure will be used to join A240 Tp. 304L stainless steel, 3.175mm in thickness. The procedure must be satisfactory in all positions and require positive reinforcement on both surfaces. For tube manufacturing, the weld may be deposited from either side due to the ease in cleaning whereas the field circumferential joints must be welded from the outside only.

Caltech has specified that all welding be done autogenous. There is a concern that by using filler metal, hydrogen can be trapped in the weld which would increase the outgassing rate. An increase in the outgassing rate would affect the level of the vacuum that can be achieved.

A.1 Description of Welding Development.

All welding development was done in the Houston Weld Lab. The weld process was an automated Gas Tungsten Arc (GTA) using a Dimetrics Gold Track II welding unit.

All welding was done on 3.175mm thick stainless steel (A240 Tp. 304L) material ranging from 0.41m to 0.61m in length. The joint detail varied in gap yet all plate edges were square butt detail. All of the plates were mounted on a purge box unit to allow a complete back purge. An oxygen analyzer was used and was consistently in the range of 0.1 to 0.5% oxygen in the purge.

B. ALTERNATIVE WELDING PROCEDURES.

The alternative welding procedures which were studied include:

1) Autogenous 1 pass welding
2) Filler metal 1 pass welding utilizing ER308L
and 3) 2 pass welding using 1st pass autogenous and 2nd pass with filler metal.

Two different welding procedures were studied, one being the circumferential butt weld and the other being the tube manufacturing spiral weld procedure.

B.1 Alternative Welding Procedures for Spiral Weld Joint.

Two processes were examined to select the best procedure to develop. One process being one pass autogenous using a copper backing bar and the second process being a two pass welding procedure. This two pass welding procedure would be an autogenous pass from side 1 and a pass with filler metal on side 2.

B.1.1 Evaluation of One Pass Autogenous Welding.

Two techniques were studied for this procedure. One being with a copper back-up bar and one without. Both procedures were welding in the downflat (1G) position using various gas mixtures.

B.1.1.1 Evaluation of Copper Back-up Bar Welding. The copper back-up bar allows for a heat sink and also allows the weld pool on the bottom side of the weld to solidify. This allows for faster travel speeds and better control of the weld appearance on the bottom side of the weld.

Several gas mixtures were used including:

	Approx. Cost ($1/ft^3)
• 100% Argon	0.06
• 75% Helium / 25% Argon	0.13
• 60% Argon / 40% Helium	0.10
• 50% Argon / 50% Helium	0.14
• 55.5% Argon / 44.5% Helium	0.26

It was found that with increasing helium in the shielding gas, the faster the travel speed of the weld. Helium has a characteristic hotter arc which gives greater penetration which allows for faster travel speeds. After carefull examination of all the welding completed, a gas mixture of 60% Argon / 40% Helium was chosen.

With all gases welding with optimum parameters, it was found that with reinforcement on the bottom side, the top side was slightly under flush. CB&I feels that in order to obtain a satisfactory weld, a two pass welding procedure must be utilized.

B.1.1.2 Evaluation of No Back-up Bar. Without a back-up bar to allow the heat to escape, a lower heat input must be used which decreases travel speed. Very similar results were shown as with B.1.1.1 above with the exception of a much slower travel speed. Shield gases had the same effect as with above. Due to the slower travels speeds, a welding procedure with a copper back-up bar would be more desirable than a procedure without one.

However, the use of a copper back-up bar may not be practical for the spiral weld tube manufacturers equipment.

B.1.2 Evaluation of Two Side Welding.

Further evaluation will be performed on this process with the selected qualified tube manufacturer.

B.1.3 Selection of Welding Procedure.

Selection of welding procedure will be based on the result of B.1.1 and B.1.2 above.

B.2 Alternative Welding Procedures for Circumferential Butt Weld.

Two processes were examined to select the best procedure to develop. One being one pass with filler metal and the second being first pass autogenous and the second pass with filler metal (ER308L). With the amount of joints to be considered, there will be variations in the gap. CB&I feels that to control this inherent problem can only be accomplished by utilizing a two pass procedure using filler metal.

CB&I also feels that with the addition of filler metal, hot cracking in the weld metal and heat affected zone (HAZ) can be minimized. Hot cracking results from internal stress developed on cooling following solidification. By welding a joint autogenously with even a slight gap, a significantly large amount of stress can be obtained due to shrinkage in the weld metal. By addition of filler metal, the amount of stress can be reduced.

B.2.1 Evaluation of 1 Pass Welding with Filler Metal.

All welding was performed in the 3G (vertical) position utilizing an automatic Gas Tungsten Arc Welding procedure. A pulsed arc technique was used to lower the net heat input put into weld. Several attempts were made using ER308L filler wire to obtain optimum results.

The weld bead contour on the back side of the weld was erratic and positive reinforcement was not obtained. Also, a poor weld bead surface was found on the front side.

B.2.2 Evaluation of 2 Pass Welding.

Again, all welding was done with the same set up as with the above process. The first pass being autogenous and the second pass using filler metal.

The autogenous first pass was deposited with excellent bead contour on the backside of the weld with positive reinforcement. The front side however was underfilled requiring a second pass using filler metal.

The second pass was welded using a synchronized pulse welded technique. This technique uses a uphill weave technique with a primary (higher) current on the edges and a background (lower) current on the excursions. This again allows for the higher heat input characteristics with a lower net heat input put into the weld. This second pass gave excellent bead appearance on the front side of the weld.

B.2.3 Selection of Welding Procedure.

By examining the welded samples, it was determined the best process was by using a two pass procedure with an autogenous first pass with a second pass with filler metal. Welding parameters for all welding done is summarized in Appendix A.

C. EVALUATE CBI & CALTECH PROCESS.

This phase of the development included comparing the Caltech Process (1 pass autogenous) with the Alternative Processes.

C.1 Comparison of Spiral Welded Joint Procedures.

Continued development is in process.

C.2 Comparison of Circumferential Butt Weld Procedures.

A comparison of 1 pass autogenous welding with a 2 pass procedure using first pass autogenous and second pass with filler metal was conducted. As was stated in B.2.1 and B.2.2 it was found that with an autogenous weld, it was very difficult to obtain a full thickness joint. The fit of the joint plays a large role in the procedure if no filler metal is used. If there is a slight gap, even at 0.010", in order to be at least flush on the inside, the outside will be under flush. In order to obtain a full thickness joint, the joint would require "zero" gap along the length of weld. With the number of joints to be encountered in the field, this task becomes impossible. The second solution would be to apply force to the joint as it is welded to upset the weld and obtain a full thickness joint. This process would be impractical in the field.

As stated in B.2.2 an autogenous root pass yielded the better results on the backside of the plates over a one pass weld using filler metal. To obtain a full thickness joint, and by having the highest quality weld both in strength and appearance, a two pass welding procedure would be utilized using the benefits of a first pass being autogenous and the second being with filler metal.

By utilizing a two pass process, the first autogenous root pass can be pushed, by changing welding parameters, through the joint to obtain the desired reinforcement on the backside of the weld. This allows room for a second pass to be welded giving adequate reinforcement on the frontside of the weld. This second pass utilizes a synchronized pulsed arc technique to obtain an excellent appearance.

D. HYDROGEN CONTENT OF WELD METAL.

To determine the hydrogen content of the weld metal for outgassing purposes will be done in two ways.

- Diffusable Hydrogen
- Total Hydrogen

Three specimens were welded and are in the process of being examined. One being a one pass autogenous weld, the second being a two pass weld using autogenous and filler metal (ER308L) and the third being a simulated weld repair using manual GTA with 2.381mm dia ER308L filler metal.

D.1 Diffusable Hydrogen.

Although no tests were done on 308L, the ESAB Group had completed two tests with Core-Bright 309L and the results were zero. Core-Bright 309L is a self shielded flux-cored stainless wire. Hydrogen will not diffuse through an austenitic microstructure. Therefore, the amount of diffusible hydrogen level of any austenitic welding consumable can not be measured. Diffusable hydrogen will be conducted in the Houston Weld Lab using a mercury capture system.

D.2 Total Hydrogen.

Total hydrogen content will be conducted at Kawin Laboratories in Chicago. The test method employed will be a Vacuum hot extraction method.

E. CHEMICAL COMPOSITION OF BASE MATERIALS.

The chemical compositions of the base materials and filler metal used during welding development are summarized in Appendix B. Trace elements, mainly sulfur, effect the welding characteristics. With sulfur levels above 0.02%, better penetration and overall welding characteristics improve.

F. FERRITE ANALYSIS OF WELD METAL.

The ferrite was taken on three samples and are shown in Appendix C:

- One Pass with ER308L in the 3G (vertical) position.
- One Pass with no Filler Metal in the 3G position.
- Two Pass Procedure: Pass 1 Autogenous and Pass 2 with ER308L.

G. SUMMARY.

Welding with a single autogenous pass, a full thickness welded joint can not be achieved. CB&I feel that by allowing the use of filler metal a higher quality weld, both geometrically and visually, can be achieved. Utilizing a two pass welding procedure with first pass autogenous and second pass with filler metal, this quality can be achieved. Hydrogen tests are in process and those tests will determine weather or not the addition of filler metal will affect the outgassing characteristics of the weld.

APPENDIX A

BEAM TUBE WELD DEVELOPMENT

Welding Operator: Jack W. Baldwin

Date: 9/21/93

Description: Development of beam tube welding process. 1 pass autogenous in 1G position with copper backing bar.
Various gases will be used along with type of backing bar detail.

W/O's H11182

Plate ID	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10		
Shielding Gas	75He-25Ar	60Ar-40He	60Ar-40He	60Ar-40He	60Ar-40He	60Ar-40He	75He-25Ar	60Ar-40He	60Ar-40He	60Ar-40He		
Flow Rate (chf)	40	40	40	45	45	45	45	45	45	45		
Start Delay (sec)	4	4	4	4	3	3	3	3	3	3		
Downslope Time (sec)	5	5	5	5	5	5	5	5	5	5		
Upslope Time (sec)	2	2	2	2	2	2	2	2	2	2		
Weld Current (amps)	175	175	175	185	200	200	200	200	200	220		
Arc Volts	11.5	11.5	10.5	10.5	10.5	10.5	11.5	10.5	11	11		
Travel Speed (cm/min)	30.5	30.5	30.5	30.5	30.5	30.5	30.5	23.6	30.5	30.5		
Heat Input (KJ/cm)	3.96	3.96	3.62	3.82	4.13	4.13	4.53	5.31	4.33	4.76		
			Note 1		Note 2	Note 3	Note 3	Notes 3, 4	Notes 3, 5 & 6	Notes 3, 5 & 6		

Note 1: Voltage increased to 10.7 near end of weld pass.
Note 2: Backing bar with 1.588mm radius groove.
Note 3: Flat copper backing bar.
Note 4: Gold Track control unit malfunctioned. Travel speed was 23.62 cm/min rather than 30.5.
Note 5: New controller for Gold Track used.
Note 6: 2.921mm thick plate used.

BEAM TUBE WELD DEVELOPMENT

Welding Operator: Jack W. Baldwin

Date: 9/21/93

Description: Development of beam tube welding process. 1 pass autogenous in 1G position with copper backing bar.
Various gases will be used along with type of backing bar detail.

W/O's H11182

Plate ID	B1	B2	B3	B4	B5							
Shielding Gas	50He-50Ar	50He-50Ar	50He-50Ar	50He-50Ar	50He-50Ar							
Flow Rate (chf)	45	45	45	45	45							
Start Delay (sec)	4	4	4	4	4							
Downslope Time (sec)	5	5	5	5	5							
Upslope Time (sec)	2	2	2	2	2							
Weld Current (amps)	200	200	200	200	200							
Arc Volts	11	11	11	11	11							
Travel Speed (cm/min)	30.5	30.5	30.5	30.5	30.5							
Heat Input (KJ/cm)	4.33	4.33	4.33	4.33	4.33							
	Note 1	Note 2	Note 3	Note 4	Note 5							

Note 1: 0.51mm gap with flat copper backing bar.
Note 2: 0.25mm gap with grooved copper bar with 100% Nitrogen purge.
Note 3: Zero gap with flat copper backing bar.
Note 4: 0.25mm gap with tight flat copper backing bar.
Note 5: 0.38mm gap with tight flat copper backing bar.

CIRCUMFERENTIAL BUTT WELD DEVELOPMENT

Welding Operator Jack W. Baldwin

Date: 9/17/93

Description: Plate material was A240-304, 3.175mm thick. All root openings 0.25mm
All pulse welding at 50%. Tungsten dia 3.175mm
Filler metal (ER308L) and uphill welding was with a tungsten angle of 8°.

W/O's: H11174
H11175

PLATE NUMBER	1	1	2	3	4	5	6	7	7	8	9		
PASS NUMBER	1	2	1	1	1	1	1	1	2	1	1		
WELDING DIRECTION	3G Up	3G Up	3G Up	3G Up	3G Up	3G Up	3G Up	3G Up	3G Up	3G Down	4G		
PULSE MODE (S or P)	Pulse	Sync.	Pulse	Pulse	Pulse	Pulse	Pulse	Pulse	Sync.	Pulse	Pulse		
WIRE SIZE	N/A	0.035	N/A	0.035	0.035	0.035	N/A	N/A	0.035	N/A	N/A		
UPSLOPE TIME (SEC)	2	2	2	2	2	2	2	2	2	2	2		
DOWNSLOPE TIME	5	5	5	5	5	5	5	5	5	5	5		
PULSE FREQUENCY	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7		
GAS FLOW (CFH)	40	40	40	40	40	40	40	40	40	40	40		
BACKING GAS FLOW	20	20	20	20	20	20	20	20	20	20	20		
TRAVEL START DELAY (SEC)	3	3	3	3	3	3	3	3	3	3	3		
PRIMARY WELD CURRENT (AMPS)	110	100	120	120	120	120	120	120	95	110	120		
PRIMARY ARC VOLTS	9.5	9	9.5	9.5	9.5	9	9	9	9	9	9		
PRIMARY WIRE FEED	N/A	76.2	N.A	76.2	76.2	76.2	N/A	N/A	76.2	N/A	N/A		
BACKGROUND CURRENT (AMPS)	76	70	76	76	76	70	76	76	70	76	76		
BACKGROUND VOLT	9	9	9	9	9	9	9	9	9	9	9		
BACKGROUND WIRE FEED (cm/min)	N/A	50.8	N/A	25.4	25.4	25.4	N/A	N/A	25.4	N/A	N/A		
TRAVEL (IPM) (TORCH SPEED)	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14		
TRAVEL (IPM) (TRACK SPEED)	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14		
OUT DWELL (PRIMARY (SEC. X.1)	1	3	1	1	1	1	1	1	3	1	1		
EXCURSION TIME	1	3	1	1	1	1	1	1	3	1	1		
IN DWELL (PRIMARY) (SEC.X.1)	1	3	1	1	1	1	1	1	3	1	1		
HEAT INPUT (KJ/cm)	5.8	5.02	6.11	6.11	6.11	5.61	5.79	5.79	4.87	5.49	5.79		
ENERGY DENSITY		0.07		0.14	0.14	0.13			0.11				
	Note 1			Note 2	Note 3	Note 4			Note 5				

Note 1: Background current increased from 70 to 76 amps.
Note 2: Primary from 38.1 to 50.8 and background from 38.1 to 25.4 cm/min.
Note 3: Copper AVW backing bar was used in center of pass.
Note 4: Primary Voltage dropped from 9.5 to 9.0.
Note 5: Wire decrease to eliminate weld reinforcement. Both primary and background dropped.
Primary weld current decreased from 100 to 95 amps.

CIRCUMFERENTIAL BUTT WELD DEVELOPMENT

Welding Operator Jack W. Baldwin

Date: 10/18/93

Description: Plate material was A240-304L, 3.175mm. All root openings less than 0.254mm

All pulse welding was 50%. Tungsten dia was 3.175mm.

All filler metal ER308L and uphill welding was down with a tungsten angle of 5 to 8°.

W/O's: H11243

PLATE ID	243A		243B		243C		243D		243E		243F	
PASS NUMBER	1	2	1	2	1	2	1	2	1	2	1	2
WELDING DIRECTION	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up
WELDING POSITION	3G	3G	3G	3G	3G	3G	3G	4G Slope	3G	3G	3G	3G
PULSE MODE (S or P)	P	S	P	S	P	S	P	S	P	S	P	S
WIRE SIZE (mm)	N/A	0.889	N/A	0.889	N/A	0.889	N/A	0.889	N/A	0.889	N/A	0.889
UPSLOPE TIME (SEC)	2	2	2	2	2	2	2	2	2	2	2	2
DOWNSLOPE TIME	5	5	5	5	5	5	5	5	5	5	5	5
OSCILLATION AMP	0.00	0.18	0.00	0.18	0.00	0.18	0.00	0.18	0.00	0.18	0.00	0.18
PULSE FREQUENCY	3	3	3	3	3	3	3	3	3	3	3	3
SHIELDING GAS	50/50	50/50	50/50	50/50	60/40	60/40	60/40	60/40	60/40	60/40	60/40	60/40
GAS FLOW (CMH)	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
BACKING GAS FLOW	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
TRAVEL START DELAY (SEC)	2	2	2	2	2	2	2	2	2	2	2	2
PRIMARY WELD CURRENT (AMPS)	110	85	110	85	110	100	120	100	120	100	120	85
PRIMARY ARC VOLTS	11.0	10.4	11.0	10.4	10.0	10.4	10.0	8.8	10.0	10.4	10.0	9.4
PRIMARY WIRE FEED	N/A	63.5	N/A	63.5	N/A	63.5	N/A	63.5	N/A	63.5	N/A	50.8
BACKGROUND CURRENT (AMPS)	76	57	76	57	76	60	76	600	76	60	85	60
BACKGROUND VOLT	11.0	9.4	11.0	9.4	10.0	9.4	10.0	8.8	10.0	9.4	10.0	9.4
BACKGROUND WIRE FEED (cm/min)	N/A	38.1	N/A	38.1	N/A	38.1	N/A	38.1	N/A	38.1	N/A	33.0
TRAVEL (cmPM) (TORCH SPEED)	12.7	10.7	12.7	10.7	12.7	10.7	12.7	10.2	12.7	10.7	12.7	10.2
TRAVEL (cmPM) (TRACK SPEED)	12.7	10.7	12.7	10.7	12.7	10.7	12.7	10.2	12.7	10.7	12.7	10.2
OUT DWELL (PRIMARY (SEC. X.1)	N/A	3	N/A	3	N/A	3	N/A	3	N/A	3	N/A	3
EXCURSION TIME	N/A	3	N/A	3	N/A	3	N/A	3	N/A	3	N/A	3
IN DWELL (PRIMARY) (SEC.X.1)	N/A	3	N/A	3	N/A	3	N/A	3	N/A	3	N/A	3
HEAT INPUT (KJ/cm)	4.83	4.15	4.83	4.15	4.39	4.68	4.63	18.19	4.63	4.68	4.84	4.02
ENERGY DENSITY		0.04		0.04		0.04		0.16		0.04		0.04

CIRCUMFERENTIAL BUTT WELD DEVELOPMENT

Welding Operator Jack W. Baldwin

Date: 10/18/93

Description: Plate material was A240-304L, 3.175mm thick. All gaps less than 0.254mm
All pulse welding 50%. Tungsten dia 3.175mm
Filler metal ER308L and all uphill welding was with a tungsten angle of 5 to 8°.

W/O's: H11243

PLATE ID	243G		243H		243I		243J	243K	243L	
PASS NUMBER	1	2	1	2	1	2	1	1	1	2
WELDING DIRECTION	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up
WELDING POSITION	4G Slope	4G Slope	4G Slope	4G Slope	4G	4G	4G	4G	4G	4G
PULSE MODE (S or P)	P	S	P	S	P	S	P	P	P	S
WIRE SIZE	N/A	0.035	N/A	0.035	N/A	0.035	0.035	0.035	N/A	0.035
UPSLOPE TIME (SEC)	2	2	2	2	2	2	2	2	2	2
DOWNSLOPE TIME	5	5	5	5	5	5	5	5	5	5
OSCILLATION AMP	0.00	0.18	0.00	0.18	0.00	0.18	0.00	0.00	0.00	0.18
PULSE FREQUENCY	3	3	3	3	3	2	1	3	3	3
SHIELDING GAS	60/40	60/40	60/40	60/40	60/40	60/40	60/40	60/40	60/40	60/40
GAS FLOW (CMH)	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	45
BACKING GAS FLOW	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	25
TRAVEL START DELAY (SEC)	2	2	2	2	2	2	2	2	2	2
PRIMARY WELD CURRENT (AMPS)	120	85	165	85	120	85	125	170	120	85
PRIMARY ARC VOLTS	9.0	9.4	11.0	8.8	9.0	8.8	9.4	9.4	9.0	8.8
PRIMARY WIRE FEED	N/A	50.8	N/A	50.8	N/A	50.8	55.9	55.9	N/A	50.8
BACKGROUND CURRENT (AMPS)	85	60	40	60	85	60	65	20	85	60
BACKGROUND VOLT	9.0	9.4	11.0	8.8	9.0	8.8	9.4	9.4	9.0	8.8
BACKGROUND WIRE FEED (cm/min)	N/A	33.0	N/A	33.0	N/A	33.0	55.9	0	N/A	33.0
TRAVEL (cm/min) (TORCH SPEED)	12.7	10.2	12.7	10.2	12.7	10.2	10.2	10.2	12.7	10.2
TRAVEL (cm/min) (TRACK SPEED)	12.7	10.2	12.7	10.2	12.7	10.2	10.2	10.2	12.7	10.2
OUT DWELL (PRIMARY (SEC. X.1)	N/A	3	N/A	3	N/A	3	N/A	N/A	N/A	3
EXCURSION TIME	N/A	3	N/A	3	N/A	3	N/A	N/A	N/A	3
IN DWELL (PRIMARY) (SEC.X.1)	N/A	3	N/A	3	N/A	3	N/A	N/A	N/A	3
HEAT INPUT (KJ/cm)	4.36	4.02	5.33	3.77	4.36	3.77	5.28	5.28	4.36	3.77
ENERGY DENSITY		0.09		0.09		0.09				0.09
		Note 1		Note 2						

Note 1: 0 response to eliminate "jerky" feel to torch.

Note 2: 42 pulse width

APPENDIX B

CHEMICAL COMPOSITION OF MATERIALS

Chemical Analysis for Base Material:

Element	Type 304L (3.175mm)	Type 304L (2.921mm)	Type 304L Northwest Pipe	Type 304L Roscoe Moss	Type 304L (3.175mm)
Carbon	0.048	0.017	0.023	0.025	0.024
Manganese	1.70	1.54	1.55	1.56	1.79
Phosphorus	0.025	0.025	0.024	0.029	0.031
Sulfur	< 0.005	< 0.005	0.009	0.005	0.012
Silicon	0.42	0.52	0.48	0.51	0.41
Nickel	8.04	8.51	8.69	8.53	8.74
Chromium	18.32	18.34	18.24	18.39	18.42
Molybdenum	0.34	0.32	0.43	0.43	0.38
Copper	0.37	0.24	0.25	0.25	0.30

Chemical Analysis for FIller Metal:

Element	0.889mm dia ER308L	2.381mm dia ER308L
Carbon	0.019	0.021
Manganese	1.54	2.00
Phosphorus	< 0.005	0.034
Sulfur	0.006	< 0.005
Silicon	0.32	0.52
Nickel	9.80	10.53
Chromium	20.62	20.80
Molybdenum	0.05	0.03
Copper	0.04	0.08

APPENDIX C

FERRITE ANALYSIS OF WELD METAL

Side 1 of Weld Metal:

Instrument	1 Pass Weld with ER308L	1 Pass Weld with no Filler Metal	2 Pass Weld with autogenous and ER308L
Severn Guage	3.5 < FN < 5.0	3.5 < FN < 5.0	3.5 < FN < 5.0
Ferrite Scope	6.6	6.8	6.2
Magnaguage	8.0	8.0	9.0

Side 2 of Weld Metal:

Instrument	1 Pass Weld with ER308L	1 Pass Weld with no Filler Metal	2 Pass Weld with autogenous and ER308L
Severn Guage	3.5 < FN < 5.0	3.5 < FN < 5.0	3.5 < FN < 5.0
Ferrite Scope	7.6	6.9	5.8
Magnaguage	7.8	8.0	6.0

AUTOMATIC WELDING DEVELOPMENT - STIFFENER
WBS 280

TABLE OF CONTENTS

AUTOMATIC WELDING DEVELOPMENT - STIFFENER
WBS 280

A. BACKGROUND OF WELDING.

The beam tube modules will be 1.22m in diameter and 3.175mm thick spiral welded tube. Stiffeners will be located approximately 0.66m apart with a thickness of 4.763mm. This stiffener spacing will provide approximately 23,000 (11,500 each site) stiffeners that will be welded to the beam tube modules. The stiffeners may be constructed of either carbon steel or of stainless steel. The welding development was done with stainless steel (A240 Tp 304L) material.

A.1 Process Selection.

Due to the number of stiffener weld attachments, the process used to weld them must have the following characteristics:
- Fast Travel Speeds
- Efficient
- Easy to Adapt to the Situation
- Ease in Operation for the Welding Operators
- Can be Used in the As-Welded Condition

Gas Metal Arc (GMA) welding was chosen as the welding process for this application. The welding torch can be easily mounted with knobs to allow the welding operator to adjust the position of the weld torch as the weld is being deposited.

By having the tube sections horizontal resting on rolls, the sections can be rotated allowing the welding to be done in the downflat (1F) position. Platforms would be set up by which the welding operator would be able to sit comfortably only having to make minor adjustments to the torch position as the section is rotated. This would also allow several stations to be set up and several stiffeners could be welding simultaneously.

A.1.1 Back Purge Selection.

Due to the 3.175mm thickness, a back purge would be necessary on the stiffener attachment weld. Welding of several stiffener attachments simultaneously, it would require that the entire tube section be purged. Because of the large volume needed to be purged, an effective purge gas that is relatively economical should be selected. For the welding development nitrogen was used for all back purge and satisfactory welding was achieved.

A.2 Description of Welding Development.

Welding was performed on flat 3.175mm thick stainless steel (A240 Tp 304L) material. The stiffener was also stainless steel being 4.763mm in thickness and approximately 5.08cm in width. GMA welding was used by mounting the torch on a track to obtain constant travel speeds. The set up was equipped with knobs to control the position of the welding torch. The same purge box that was used for WBS 270 was also used for this development with an oxygen level in the purge of 0.1 to 0.5%.

B. SHORT CIRCUITING ARC (SHORT-ARC) WELDING DEVELOPMENT.

Due to the outgassing rates required for service it is very important not to effect the inside of the tube. With high heat inputs, stainless steel will form oxide layers which can effect the outgassing characteristics of the steel. Also, being only 3.175mm in thickness, burn through must be eliminated.

For the above procedures, short-arc GMA welding was examined. Short-arc welding uses low currents which result in low heat inputs. The electrode touches (shorts) on the base material and then heats up and melts off. This process is repeated many times a second.

B.1 Results of Short-Arc Welding.

Welding was accomplished using 0.762mm diameter ER308L. The weld appearance was good and resulted in a 3.175mm fillet. There was a considerable amount of weld spatter which would require post cleaning to remove by either brushing or grinding.

The variable to be concerned with is the ease in welder operation. For this procedure, the welding torch must be positioned exactly. If there was a slight error in positioning, the fillet weld will not tie in to either the stiffener or the tube. With this process, the welding operator would need to constantly monitor and adjust the welding torch and there would have to be a considerable amount of welded repairs (pick-ups) to made.

B.2 Back Purge.

The effects of the back purge was also demonstrated during the development. Welded specimens were welded using a 100% nitrogen purge and without a purge all together.

B.2.1 100% Nitrogen Purge.

With a 100% nitrogen purge, 0.1 to 0.5% oxygen, very little oxidation (discoloration) was noticed on the back side of the 3.175mm thick material.

B.2.2 No Back Purge.

Welding without a back purge resulted in a large amount of oxidation, a blue discoloration. It is very important to obtain a quality back purge during fabrication of these stiffener attachment welds. It was shown that 100% nitrogen adequately performed this back purge.

C. FLUX-CORED ARC WELDING (FCAW) DEVELOPMENT.

Welding was accomplished with ER308LT-1 using 75%Ar / 25%CO_2 shielding gas. Wire diameter was 0.889mm in diameter. FCAW utilizing globular mode of metal transfer has the characteristics of ease in operation and relatively clean as-welded appearance.

C.1 Results of Flux-Cored Arc Welding.

Welding was accomplished as was in B.1 above at 40.6 to 45.7 cm per minute (cm/min). At 45.7 cm/min, weld appearance was good yet positioning was unstable. By slowing the travel speed to 40.6 cm/min, excellent weld appearance was obtained along with little adjustment from the operator. The final weld could be used in the as-welded condition with very little cleaning or weld repairs needed.

The chemical composition of Shield-bright 308L, used for the FCAW process are as follows:

Cr = 14 to 18%   Ni = 2 to 5%   Si = 1 to 3%
Mn = 1 to 3%   Fe = 18 to 25%   Na < 1.5%
F < 1% SiO_2 < 3% TiO_3 = 44 to 50%
ZrO_2 < 6%

C.2 Back Purge.

The same back purge requirements as with B.2 above apply with FCAW.

D. WELDING PROCEDURE SELECTION.

By comparing the welded specimens, it is obvious that FCAW produced the better appearance. Along with the weld appearance, little cleaning is required with the FCAW as compared to the short-arc method. Also, FCAW is many times easier for the welding operator than the short-arc procedure. With all things considered, FCAW would be the most efficient and economical procedure to use. A preliminary welding procedure (WPS) is attached in Appendix B for FCAW.

E. JOINT DETAIL SELECTION.

Houston Engineering has suggested three types of joint details for the stiffener weld attachment:

1) Continuous Fillet Welds
2) Intermittent Fillet Welds
and 3) Full Penetration Groove Weld

E.1 Continuous Fillet Welds.

With FCAW, a continuous fillet weld would be easy to accomplish. It was noticed in the lab that there was only a slight tilt in the stiffener of less than 2° on the welded plates. Engineering is in the process of determining the amount of weld required on the second side if a continuous fillet weld were deposited on side 1.

E.2 Intermittent Fillet Welds.

If the spacing between welds is short (on the order of 15 cm or less) continuous fillet should be considered over intermittent welds. If the space is large, intermittent welds could be accomplished simply by a switch that the welding operator would control. This could also be accomplished with a programmable controller that would automatically turn the torch on and off.

E.3 Full Penetration Groove Weld.

The full penetration groove weld design required the stiffener to have a 45° feather edge preparation. Several attempts were made in the lab to obtain a full penetration weld. None of these attempts were successful. With 0.889mm diameter wire, only 1/3 of the joint was filled leaving 2/3 incomplete penetration. With 1.143mm diameter wire, there was a slight increase in penetration leaving at least 50% with incomplete penetration. Also with the groove detail, the stiffener tilted from 8 to 10°.

E.4 Selection of Joint Detail.

Houston Welding feels that a square joint would yield the best result. If the weld spacing on intermittent welds could be large enough, intermittent welding would be best. Otherwise, a continuous fillet weld would be desirable.

F. SUMMARY.

To weld the stiffener weld attachment, GMA welding process would produce the desired weld most efficiently. FCAW would be easiest for the welding operator and would be most economical. A square joint detail with fillet welds will be the most desirable.

APPENDIX A

STIFFENER TO TUBE WELD DEVELOPMENT

Welding Operator: Otho M. Richardson

Date: 9/22/93

Description: Development of stiffener to tube weld. 4.76mm Stiffener on 3.175mm thick plate.
FluxCored and Solid Wire tested. 3.175mm fillet weld.

W/O's H11181

Plate ID	A(1)	A(2)	B(1)	B(2)	C(1)	C(2)	D(1)	D(2)	E(1)	F(1)	G(1)	J(1)	K(1)
Wire Type	ShieldBright	ShieldBright	Solid Wire	ShieldBright	ShieldBright	ShieldBright	ShieldBright	ShieldBright	ShieldBright	ShieldBright	Solid Wire	ShieldBright	Solid Wire
Wire Diameter (cm)	0.889	0.889	0.762	0.889	0.889	0.889	0.889	0.889	0.889	0.889	0.762	0.889	0.762
Mode of Transfer	Globular	Globular	Spray	Globular	Globular	Globular	Globular	Globular	Globular	Globular	Short Arc	Globular	Short Arc
Shielding Gas	75Ar-25CO2	75Ar-25CO2	98Ar-2O2	75Ar-25CO2	75Ar-25CO2	75Ar-25CO2	75Ar-25CO2	75Ar-25CO2	75Ar-25CO2	75Ar-25CO2	Tri-Mix	75Ar-25CO2	Tri-Mix
Flow Rate (cmh)	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Arc Time (minutes)	1.1	1.1	0	1.1	1	0.95	1.05	1.1	1.45	1.4	1.4		
Length of Weld (cm)	45.7	45.7	0	45.7	45.7	45.7	45.7	45.7	61.0	61.0	61.0		
Wire Feed (cm/min)	43.9	43.9	0	43.9	45.7	45.7	45.7	45.7	45.7	45.7	0		
Weld Current (amps)	141	135	0	128	154	147	147	156	151	144	0	145	
Arc Volts	23.1	23.2	0	23.4	23.1	23.3	23.1	23.1	23.1	23.3	0	23	
Travel Speed (cm/min)	41.7	41.7		41.7	45.7	48.0	43.4	41.7	42.2	43.4	43.4	40.6	
Heat Input (KJ/cm)	4.70	4.52		4.32	4.67	4.27	4.68	5.20	4.98	4.62	0.00		
			Note 1		Note 2	Note 3			Note 4	Note 5	Note 6	Note 7	Note 7

Note 1: Voltage increased to 10.7 near end of weld pass.
Note 2: Backing bar with 1.588mm radius groove.
Note 3: Flat copper backing bar.
Note 4: No purge gas.
Note 5: 100% Nitrogen purge gas.
Note 6: Tri-Mix = 90Ar-7.5He-2.5CO2.
Note 7: Staggar weld 5.1 on 20.3 cm.

APPENDIX B

CBI

WELDING PROCEDURE SPECIFICATION

IDENTIFICATION
WPS *E308LT-1*

CONTRACT *930212*

PRODUCT *LIGO BEAM TUBE MODULES*
CUSTOMER *CALTECH - NSF*

PAGE NO. *1* OF *3*
REV. NO. *0*
BY *RWP* DATE *10/21/93*

WORK THIS DOCUMENT WITH GENERAL WELD PROCEDURE SPEC. GWPS- *FCAW&GMAW*

REFERENCE PROCEDURE QUALIFICATION RECORD			SPECIFIC CONTRACT	
NO.	POSITION QUALIFIED (QW-405)	THICKNESS QUALIFIED (QW-403)	POSITION (QW-405)	THICKNESS RANGE (QW-403)
PQR to be done for LIGO at a later date.			*1F*	*1/8" to 3/16"*

SPECIFIC CONTRACT WPS REQUIREMENTS

CODE EDITION AND ADDENDA *ASME Section IX, 92 Edition and 92 Add.*

JOINTS (QW-402) SEE GENERAL WELDING TECHNIQUE PAGE *3*

BACKING MATERIAL (QW-402)

BASE MATERIAL (QW-403)

A240 Tp. 304L (ASME P-8, Gp. 1)

Any ASME P-8, Gp. 1 material may be welded together or to each other in any combination.

FILLER METAL (QW-404)

ASME SPECIFICATION NO: *SFA 5.22*
ASME CLASSIFICATION: *E308LT-1 **
ASME ANALYSIS NO: *A-8*
ASME GROUP NO: *F-6*
CONSUMABLE INSERT: *N/A*
SUPP. POWDER FILLER: *N/A*

FLUX (QW-404) *N/A*

CUSTOMER APPROVAL

PREHEAT/INTERPASS TEMPERATURE (QW-406)
SEE ATTACHED PAGE *2*

POST WELD HEAT TREATMENT (QW-407)
PWHT REQUIRED *No*
IF PWHT IS REQUIRED, SEE APPROVED CONTRACT PWHT PROCEDURE FOR DETAILS AND EXTENT OF PWHT.

GAS (QW-408)	SHIELDING	BACK UP
COMPOSITION:	*75%Ar/25%CO2*	*100%Nitrogen*
FLOW RATE:	*20-45 cfh*	*10-20 cfh*

ELECTRICAL CHARACTERISTICS (QW-409)
CURRENT: *Direct Current*
POLARITY: *Electrode Positive*
OTHER: *Reverse Polarity*
AMPERAGE AND VOLTAGE RANGE. SEE PAGE *3*
VOLUME OF WELD METAL REQUIRED *No*
SEE ATTACHED PAGE *N/A*
MODE OF TRANSFER *Globular*

TECHNIQUE (QW-410)/ SPECIAL LIMITATIONS
SEE ATTACHED PAGE(S) *2*
STRINGER OR WEAVE TECHNIQUE SEE PAGE *2, 3*
TYPE OF WELDING

MANUAL ☐ MACHINE ☐
SEMI-AUTOMATIC ☒ AUTOMATIC ☐

** Shield-bright, Alloy Rods*

REVIEWED	OB ENGR	DIST ENGR	WELDING SERVICES HOUSTON	CORP QA	REG CONST QA	REG MFG QA				BY	DATE
									PREPARED CHECKED AUTHORIZED	*RWP*	*10/21/93* / / / /

Printed in USA

WL100 REV JUL 87

LIMITATIONS:

1. Maintain a contact tip to work distance of 3/8" to 1".
2. Use gas cup nozzle sizes between 3/8" and 1" diameter.
3. Use a single pass per side technique.
4. No single pass shall exceed 1/2" in thickness.
5. This WPS is limited to the welding of the stiffener to the tube modules only.
6. Only stainless steel brushes shall be used on stainless steel.

INTERPASS TEMPERATURE:

The interpass temperature shall not exceed 500øF.

PREHEAT REQUIREMENTS (ASME P-8, Gp. 1):

No preheat is required except as an aid to remove moisture unless the ambient temperature falls below 32øF. When the ambient temperature falls below 32øF, a preheat of warm to the hand (approx. 100øF) is required within 3" of where the welding is started and maintained 3" ahead of the arc.

CBI

WELDING PROCEDURE SPECIFICATION

IDENTIFICATION WPS	CONTRACT
E308LT-1	930212

PRODUCT *LIGO BEAM TUBE MODULES*

CUSTOMER *CALTECH - NSF*

PAGE NO. 3 OF 3

REV. NO. 0

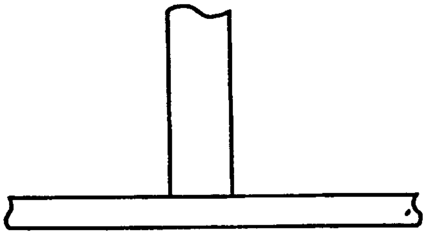
BY RWP DATE 10/21/93

GENERAL WELDING TECHNIQUE

Operation Description	Beads	Weld	Electrode		Current	Voltage	Peak	
	Layer	Proc.	Size	Type	(amps)	(Volts)	(Amps)	
Stringer Beads	*As Reqd*	*GMA*	*.035*	*ER308LT-1*	*55-130*	*24-28*		

JOINT DETAIL - See contract drawings for applicable joint details and dimensions.

Downflat



1F

Printed in USA

WL100 P Jan 89

AUTOMATIC WELDING DEVELOPMENT - CIRCUMFERENTIAL
WBS 290

TABLE OF CONTENTS

AUTOMATIC WELDING DEVELOPMENT - CIRCUMFERENTIAL
WBS 290

A. BACKGROUND OF WELDING.

Beam tube modules will be 1.22m in diameter and 3.175mm in thickness. The circumferential butt welds will have square butt joint detail with zero gap. The maximum tolerable gap would be 0.51 mm. These weld joints will be welded in the 5G (horizontal) position.

A.1 Welding Background.

With the tube in a fixed horizontal position, 5G, a welding concept must be utilized to travel around the entire circumferential joint. There will also be a height limitation on the bottom of the tube to the foundation. This height will be where on the order of 45.72 cm. The weld unit must be able to travel within this space limitation. Along with the height limitation there will be a stiffener approximately 33 cm from the weld seam on both sides.

A.2 Fit-Up Background.

The fit-up equipment must be light in weight to allow workers to set the equipment in place easily. Due to the number of these joints, approximately 800 (400 each site), it must be relatively simple to attach and be able to fit the joint quickly. With the fit-up equipment in place, it must allow room for the fitter to tack the weld joint.

The root gap plays an important role in the welding of these seams. The gap must be as near to zero as can be accomplished. A gap of more than 0.5 mm would require extra care in welding. The misalignment of the tubes also is critical. The fit-up equipment must also be able to align the tube so that there is little or no misalignment.

A.3 Purge Background.

The back purge affects the amount of oxidation on the inside of the tube. The purge must have a level of less than 0.5% oxygen. This purge system must be easily installed and easily removed with the least amount of volume to save costs on purge gas.

B. TUBE-TUBE AUTO WELD CONCEPTS.

Due to the precision and the repeatability required for these welds the Dimetrics Gold Track II was chosen and used throughout the welding development.

B.1 Dimetrics Gold Track II.

The Dimetrics Gold Track II is a synergic power unit that can sample the arc voltage and maintain and change the arc voltage during welding. All welding parameters are controlled by a control unit that can be programmed to accomplish a wide variety of welding procedures. A preliminary welding procedure (WPS) is attached in Appendix A.

B.1.1 Pulsed Arc Welding.

This unit has the capability to weld using a pulsed arc technique. The advantage of pulsing current over continuous current is that you have a higher current level to melt the base metal and/or filler wire and a lower current level to progress the torch movement and keep the weldment from sagging, also to keep from using an excessive amount of heat input that causes shrinkage.

B.1.2 Synchronized Pulsed Arc Welding.

This unit also has the capability to weld using a synchronized pulsed arc technique. Synchronized pulse enables the welding operator to continue using pulsed current, but the pulsing is synchronized with the torch oscillation movement. This enables the operator to command the extra heat where it is needed and reduces heat input where it is not required.

B.1.3 Track Description.

The track for the Gold Track consists of two halves. The two halves are placed around the tube and tightening them down is all that is needed. The tracks can be purchased in different sizes measured in diameters. Due to the stiffeners, a slightly larger track size can be used with extended legs so that the track can set over the stiffener. The welding unit will travel on this track and the stiffener will not present any interference to the welding unit. With a larger track size the travel speed at the track would need to be increased to obtain the same travel speed at the torch.

B.2 Repair Procedures.

Repairs that will be encountered include weld pick-ups and complete penetration repairs of weld joints and base material. Weld pick-ups, mainly undercut, can be welded with manual GTA welding with ER308L filler metal. Complete penetration repairs can be repaired using a copper backing device and welded with GTA welding with ER308L filler metal. A preliminary welding procedure (WPS) for tacking and repairs is attached in Appendix B.

B.2.1 Welding Procedures.

A jack type device with a copper bar on one end will be used to keep dimensional tolerances. The device will be placed inside the tube with the copper bar, with a radius to it, pressed against the repair area. The welder will then fill the repair area with ER308L and the copper device removed.

B.2.2 Tube Dimensional Tolerance.

This repair device will keep the tube from distorting when the repair area is welded. Without this device, the tube wall can suck back due to weld shrinkage.

C. TUBE-TUBE FIT-UP CONCEPTS.

Due to what was stated in A.2 above, the Deerman Chain Clamp is a candidate for fitting these circumferential butt welds. The Deerman Chain Clamp offers a method of achieving quick, easy and precise fit-ups. It can align and reform the tube for accurate welding. No lugs, hammers, or wedges are required. Jackscrews placed on the chain exert pressure on high points to eliminate "Hi-Lo" as the tubes are fit together.

Because of the tight tolerances on the weld joint, this fit-up equipment can easily keep the joint within tolerance with a minimum amount of work.

D. TUBE-TUBE WELD GAS PURGE CONCEPTS.

D.1 Weld Shielding Gas.

The shielding gas used during welding will be 60% Argon / 40% Helium. See Report for WBS 270 for development and selection of this gas. The GTA process will apply the shielding gas at approximately 1.27 cubic meters per hour.

D.2 Purge Gas.

The purge gas system is still under development. It will be accomplished using purge dams on either side of the weld joint or by an internal purge doughnut. 100% argon will be used for the purge and the oxygen level will be below 0.5%. Approximately 0.28 to 0.57 cmh will be need to assure this oxygen level.

E. SELECTION OF TUBE-TUBE CONCEPTS.

E.1 Auto Weld Selection.

The Dimetrics Gold Track II will be used for the circumferential welding. It will utilize a larger track size, approximately 1.37m in diameter to allow room for the stiffener to tube locations.

E.2 Fit-Up Selection.

The fit-up equipment is still under development and the selection will be made upon completion of this development.

E.3 Gas Purge Selection.

Purging will be done using purge dams or internal doughnuts on either side of the weld. The details of these purge dams are still under development.

F. SUMMARY.

The Dimetrics Gold Track II will be used to weld the circumferential weld joints. All welded repairs will use a jack-stand on the inside of the tube with a copper bar for backing to maintain tube dimensional tolerances. Purge dams or internal doughnuts will be used on the inside of the tube to maintain an adequate purge. Fit-up equipment is under development for use in the fit-up of the welded joint.

APPENDIX A

CBI WELDING PROCEDURE SPECIFICATION

IDENTIFICATION WPS *AUTOG/ER308L*

CONTRACT *930212*

PRODUCT *LIGO BEAM TUBE MODULES*
CUSTOMER *CALTECH - NSF*

PAGE NO. *1* OF *3*
REV. NO. *0*
BY *RWP* DATE *10/21/93*

WORK THIS DOCUMENT WITH GENERAL WELD PROCEDURE SPEC. GWPS- *GTAW*

REFERENCE PROCEDURE QUALIFICATION RECORD			SPECIFIC CONTRACT	
NO.	POSITION QUALIFIED (QW-405)	THICKNESS QUALIFIED (QW-403)	POSITION (QW-405)	THICKNESS RANGE (QW-403)
PQR to be done for LIGO at a later date.			*5G*	*1/8"*

SPECIFIC CONTRACT WPS REQUIREMENTS

CODE EDITION AND ADDENDA *ASME Section IX, 1992 Edition, 92 Add.*

JOINTS (QW-402) SEE GENERAL WELDING TECHNIQUE PAGE *3*

PREHEAT/INTERPASS TEMPERATURE (QW-406) SEE ATTACHED PAGE *2*

BACKING MATERIAL (QW-402)

POST WELD HEAT TREATMENT (QW-407)
PWHT REQUIRED *No*
IF PWHT IS REQUIRED, SEE APPROVED CONTRACT PWHT PROCEDURE FOR DETAILS AND EXTENT OF PWHT.

BASE MATERIAL (QW-403)

A240 Tp. 304L (ASME P-8, Gp. 1)

Any ASME P-8, Gp. 1 material may be welded together or to each other in any combination.

GAS (QW-408)	SHIELDING	BACK UP
COMPOSITION:	*60%Ar/40%He*	*100%Ar*
FLOW RATE:	*20-45 cfh*	*10-20 cfh*

ELECTRICAL CHARACTERISTICS (QW-409)
CURRENT: *Direct Current*
POLARITY: *Electrode Negative*
OTHER: *Straight Polarity*
AMPERAGE AND VOLTAGE RANGE. SEE PAGE *3*
VOLUME OF WELD METAL REQUIRED *No*
SEE ATTACHED PAGE *N/A*
MODE OF TRANSFER *N/A*

FILLER METAL (QW-404)
ASME SPECIFICATION NO: *SFA 5.9*
ASME CLASSIFICATION: *ER308L*
ASME ANALYSIS NO: *A-8*
ASME GROUP NO: *F-6*
CONSUMABLE INSERT: *N/A*
SUPP. POWDER FILLER: *N/A*

FLUX (QW-404) *N/A*

TECHNIQUE (QW-410)/ SPECIAL LIMITATIONS
SEE ATTACHED PAGE(S) *2, 3*
STRINGER OR WEAVE TECHNIQUE SEE PAGE *2, 3*
TYPE OF WELDING

MANUAL ☐ MACHINE ☒
SEMI-AUTOMATIC ☐ AUTOMATIC ☐

CUSTOMER APPROVAL

REVIEWED	OB ENGR	DIST ENGR	WELDING SERVICES HOUSTON	CORP QA	REG CONST QA	REG MFG QA				BY	DATE
									PREPARED CHECKED AUTHORIZED	*RWP*	*10/21/93* / / / /

Printed in USA

WL100 REV JUL 87

CBI

WELDING PROCEDURE SPECIFICATION

IDENTIFICATION WPS *AUTOG/ER308L*	CONTRACT *930212*	
PRODUCT *LIGO BEAM TUBE MODULES*	PAGE NO. *2* OF *3*	REV. NO. *0*
CUSTOMER *CALTECH - NSF*	BY *RWP*	DATE *10/21/93*

LIMITATIONS:

1. *This WPS to be used with Dimetrics Gold Track II weld unit.*
2. *Vertical welds shall be deposited uphill.*
3. *Pulsing current must be used.*
4. *Use a multiple pass per side technique.*
5. *Use a single EWTh-2 (2% thoriated Tungsten) electrode.*
6. *No single pass shall exceed 1/2" in thickness.*
7. *Only stainless steel brushes shall be used on stainless steel.*
8. *Parameters on Page 3 must be followed to use this WPS.*

INTERPASS TEMPERATURE:

The interpass temperature shall not exceed 500øF.

PREHEAT REQUIREMENTS (ASME P-8, Gp. 1):

No preheat is required except as an aid to remove moisture unless the ambient temperature falls below 32øF. When the ambient temperature falls below 32øF, a preheat of warm to the hand (approx. 100øF) is required within 3" of where the welding is started and maintained 3" ahead of the arc.

CBI

WELDING PROCEDURE SPECIFICATION

IDENTIFICATION
WPS
AUTOG/ER308L

CONTRACT
930212

PRODUCT *LIGO BEAM TUBE MODULES*

CUSTOMER *CALTECH - NSF*

PAGE NO. *3* **OF** *3*

REV. NO. *0*

BY *RWP* **DATE** *10/21/93*

WELDING PARAMETERS FOR GOLD TRACK II:

Parameter	First Pass	Second Pass
Pulse Mode	Pulsed	Sync Pulsed
Pulse Width	50%	N/A
Pulse Frequency	3.0	3.0
Wire Diamter	Autogenous	0.035"
Upslope Time	2	2
Downslope Time	5	5
Travel Start Delay	2	2
Oscillation Amplitude	0.00	0.18
Primary Weld Current	120	85
Arc Voltage	9.0	8.8
Wire Feed Speed	N/A	20
Background Weld Current	85	60
Arc Voltage	8.8	8.8
Wire Feed Speed	N/A	13
Travel Speed (torch)	5.0	4.0
Travel Speed (track)*	5.6	4.5
Out Dwell Time (sec x .1)	N/A	3
Excursion Time (sec x .1)	N/A	3
In Dwell Time (sec x .1)	N/A	3
AVC Response	20	0
AVC Mode	Samp	Cont

* *Track speed based on a 54" diamter track.*

APPENDIX B

CBI WELDING PROCEDURE SPECIFICATION

IDENTIFICATION WPS *ER308L*

CONTRACT *930212*

PRODUCT *LIGO BEAM TUBE MODULES*
CUSTOMER *CALTECH - NSF*

PAGE NO. *1* OF *3*
REV. NO. *0*
BY *RWP* DATE *10/21/93*

WORK THIS DOCUMENT WITH GENERAL WELD PROCEDURE SPEC. GWPS- *GTAW*

REFERENCE PROCEDURE QUALIFICATION RECORD			SPECIFIC CONTRACT	
NO.	POSITION QUALIFIED (QW-405)	THICKNESS QUALIFIED (QW-403)	POSITION (QW-405)	THICKNESS RANGE (QW-403)
PQR to be done for LIGO at a later date.			*All*	*1/8" to 3/16"*

SPECIFIC CONTRACT WPS REQUIREMENTS

CODE EDITION AND ADDENDA *ASME Section IX, 1992 Edition, 92 Add.*

JOINTS (QW-402) SEE GENERAL WELDING TECHNIQUE PAGE *3*

BACKING MATERIAL (QW-402)
*Copper if Needed **

BASE MATERIAL (QW-403)
A240 Tp. 304L (ASME P-8, Gp. 1)

Any ASME P-8, Gp. 1 material may be welded together or to each other in any combination.

FILLER METAL (QW-404)

ASME SPECIFICATION NO:	*SFA 5.9*
ASME CLASSIFICATION:	*ER308L*
ASME ANALYSIS NO:	*A-8*
ASME GROUP NO:	*F-6*
CONSUMABLE INSERT:	*N/A*
SUPP. POWDER FILLER:	*N/A*

FLUX (QW-404) *N/A*

PREHEAT/INTERPASS TEMPERATURE (QW-406)
SEE ATTACHED PAGE *2*

POST WELD HEAT TREATMENT (QW-407)
PWHT REQUIRED *No*
IF PWHT IS REQUIRED, SEE APPROVED CONTRACT PWHT PROCEDURE FOR DETAILS AND EXTENT OF PWHT.

GAS (QW-408)	SHIELDING	BACK UP
COMPOSITION:	*100%Ar*	*100%Ar*
FLOW RATE:	*20-45 cfh*	*10-20 cfh*

ELECTRICAL CHARACTERISTICS (QW-409)
CURRENT: *Direct Current*
POLARITY: *Electrode Negative*
OTHER: *Straight Polarity*
AMPERAGE AND VOLTAGE RANGE. SEE PAGE *3*
VOLUME OF WELD METAL REQUIRED *No*
SEE ATTACHED PAGE *N/A*
MODE OF TRANSFER *N/A*

TECHNIQUE (QW-410)/ SPECIAL LIMITATIONS
SEE ATTACHED PAGE(S) *2*
STRINGER OR WEAVE TECHNIQUE SEE PAGE *2, 3*
TYPE OF WELDING
MANUAL ☒ MACHINE ☐
SEMI-AUTOMATIC ☐ AUTOMATIC ☐

CUSTOMER APPROVAL

** Copper backing from Jack Device*

REVIEWED	OB ENGR	DIST ENGR	WELDING SERVICES HOUSTON	CORP QA	REG CONST QA	REG MFG QA				BY	DATE
									PREPARED CHECKED AUTHORIZED	*RWP*	*10/21/93* / / / /

Printed in USA

WL100 REV JUL 87

CBI

WELDING PROCEDURE SPECIFICATION

IDENTIFICATION
WPS
ER308L

CONTRACT
930212

PRODUCT *LIGO BEAM TUBE MODULES*

CUSTOMER *CALTECH - NSF*

PAGE NO. *2* OF *3*

REV. NO. *0*

BY *RWP* DATE *10/21/93*

LIMITATIONS:

1. *Vertical welds shall be deposited uphill.*
2. *Use a single EWTh-2 (2% thoriated Tungsten) electrode.*
3. *Pulsing current may be used.*
4. *Use a single pass or multiple passes per side.*
5. *No single pass shall exceed 1/2" in thickness.*
6. *This WPS is limited to tacking and weld repairs only.*
7. *If required, a copper backing may be used.*

INTERPASS TEMPERATURE:

The interpass temperature shall not exceed 500øF.

PREHEAT REQUIREMENTS (ASME P-8, Gp. 1):

No preheat is required except as an aid to remove moisture unless the ambient temperature falls below 32øF. When the ambient temperature falls below 32øF, a preheat of warm to the hand (approx. 100øF) is required within 3" of where the welding is started and maintained 3" ahead of the arc.

CBI

WELDING PROCEDURE SPECIFICATION

IDENTIFICATION
WPS
ER308L

CONTRACT
930212

PRODUCT *LIGO BEAM TUBE MODULES*
CUSTOMER *CALTECH - NSF*

PAGE NO. *3* **OF** *3*
REV. NO. *0*
BY *RWP* **DATE** *10/21/93*

GENERAL WELDING TECHNIQUE

Operation Description	Beads Layer	Weld Proc.	Tungsten Diameter	Current (amps)	Voltage (Volts)	Travel (IPM)	B.O.R. Sec/12"
*GTA weld w/Filler Metal**	*As Reqd*	*GTA*	*3/32"*	*50-220*	*10-18*	*As Reqd*	

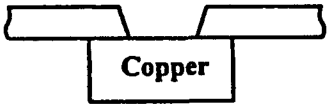
**Passes may be made with stringer or weave beads as required.*

JOINT DETAIL - See contract drawings for applicable joint details and dimensions.

Tacking

All Positions

Weld Repairs



All Positions

SECTION 4

L. I. G. O. PROJECT
CONSTRUCTION PLAN
WBS 300
TABLE OF CONTENTS

1.0 PROJECT ORGANIZATION

1.1 GENERAL

The management plan is a combination of the efforts of CBITS, CBI Na-Con, CB&I Corporate Services (Construction, Welding, Testing), and CBI Services.

The project team is involved in the design and qualification test portion of the contract, and are familiar with the project. As a result, the normal learning curve for a construction team will be minimized.

The Project Team assigned for the Option will be responsible for providing the Construction Plan and updating the budget estimate for the Option.

Key elements of the Option portion of the contract are:

- In-depth planning of all aspects of a design-build effort. Planning has already commenced and will continue through the design and qualification testing. Preparation will be made to move immediately into the construction Option of the contract upon authorization by Caltech.

- Assignment of qualified personnel. Great emphasis has been placed on utilizing people with the pre-requisite skill and experience.

- Use of proven management and scheduling techniques in order to accomplish the most cost efficient program. Project procedures will be developed addressing each area of concern from administration through construction.

- Pre-selection of major suppliers. The design and qualification testing program will facilitate the planning and start up activities.

- Implementation of a detailed quality assurance approach designed to promote quality work and products and thus prevent costly delays in the field. A positive attitude towards the quality program is essential to the product and the schedule. The QA program will be tailored to the needs of the vacuum tube work as well as the system and general contracting portions of the overall LIGO Project.

- Establish positive and effective lines of communications. With the work split between two sites and the support coming from distant CBI locations such as Plainfield and Houston, good communications procedures will be essential.

- Adoption of aggressive Small & Minority Business Plans and Subcontracting Plans to encourage and optimize minority, small, and women owned businesses throughout the program..

- The establishment of a joint Quality Improvement Team (QIT). Caltech's knowledge of the process and requirements developed over the years can be interfaced with CBI's innovative design and construction techniques to provide the best facility for the minimum cost. This arrangement needs to be established during the next month to insure that the Final Report and Construction Plan are in line with expectations.

- Provide accurate pricing estimates reflecting the processes developed in the design phase of the contract and input from Caltech in both technical and construction areas.

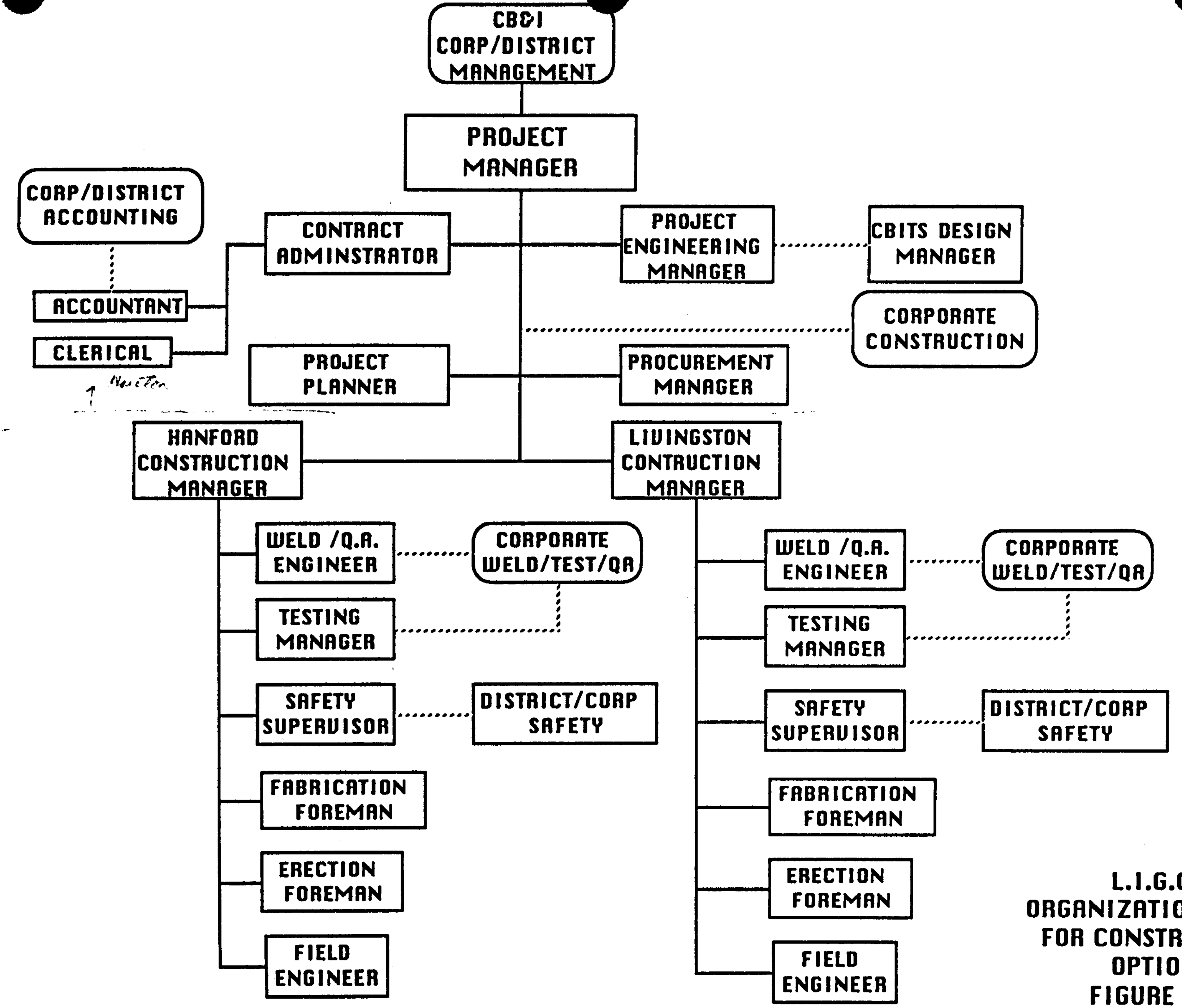
1.2 Overall Project Team

The Project Team for the Option will be organized as shown on Figure. 1.0. The team will be directed by the Project Manager who will report directly to the Senior Vice-President and Divisional General Manager of CBI Na-Con in Houston (if the Hanford site must be union manned, this will be to the CBI Services Fremont Construction office). The Project Manager will have direct lines of authority over all of CBI's subsidiaries and divisions participating in the project.

1.3 On Site Construction Organization

It appears at this time that the basic project management of the program will come out of the Houston Office. CBI will develop the minimum on site staff required to accomplish the option work. If CBI is successful in bidding and obtaining contracts for the other phases of work on the LIGO Project, the location for certain site team members will be adjusted according to need.

It is anticipated at this time that there will be adequate time for the on-site staff to move as a team form the Hanford site to the Livingston site. This will allow continuity in the program.



L.I.G.O.
ORGANIZATION CHART
FOR CONSTRUCTION
OPTION
FIGURE 1.0
OCTOBER 26, 1993

1.4 Responsibilities

Individual responsibilities of the Project Team will be developed and tailored around the unique needs of the LIGO Project at a later date. An example of the type of write up for responsibilities is given below for a few of the key team members.

1.4.1 Project Manager

The Project Manager is responsible for determining Caltech's requirements and coordinating the efforts of the Project Team and CBI's overall organization to see that all contractual requirements are met. The Project Manager is an essential part of the communication flow for a project and all communication with Caltech will be through the Project Manager. The Projects Manager's duties include the following:

- Serve as the focal point for communication with Caltech on all operational, technical, and commercial items.
- Furnish Caltech with all hardware and documentation required by the contract.
- Develop a Partnering effort between Caltech and CBI's resources. This effort will involve the development of a joint team to work together to unite the best elements of Caltech, CBI and it's suppliers using open and effective communications, responsiveness and mutual decision making to produce a quality product in a timely, cost effective, and safe manner that meets or exceeds the project requirements.
- Lead the project in planning, organizing, executing, and controlling the project activities essential for timely and satisfactory completion of the project. These include:
    - Providing effective communications channels and proper liaison throughout CBI's organization.
    - Recognizing CBI's contractual obligations and ensuring that they are properly defined within CBI's organization.
    - Providing design and engineering services.

- Providing procurement, expediting, inspection services, and transportation of equipment and project materials.

- Providing complete scheduling and other required administrative services.

- Providing reports to CBI management.

- Providing identification of changes to the contractual scope of work.

- Obtaining Caltech's agreement with the scope of any contractual changes.

- Providing Caltech with progress information in the form of bar charts and CPM schedules, progress curves, etc. to present a complete, accurate and updated view of project status.

1.4.2 Project Engineering Manager

The Project Engineering Manager is responsible for the execution of all engineering work on the project and will coordinate the flow of information between various engineering departments and Caltech. While functionally reporting to the Project Manager, he has direct lines of authority over the assigned engineering departments within CBI, he reports to CBITS Manager of Engineering on technical matters. His duties and responsibilities include:

- In cooperation with the Project Manager, prepare and maintain and engineering schedule that will assure completion of the entire project on time.

- Coordinate and direct all design and engineering efforts in CBI's engineering organization including subcontract work.

- Interpretation of contract specifications.

- Technical input to purchase requisitions.

- Production of drawings, bill sheets, specifications, and related instructions and documents.

- Resolution of technical uncertainties.

- Direction of any engineering consultants.

- Review of all vendor quotes and determination of equipment suppliers for all major equipment.
- Review and monitoring of designs for compliance with specifications.
- Development of performance test procedures.
- Determination of inspection requirements.
- Preparation of operation manuals.
- Coordinate the preparation, review and distribution of drawings with Caltech and any appropriate agencies.
- Coordinate engineering efforts of the Project Team, CBI engineering departments, suppliers, and subcontractors to be sure all involved parties understand the concept, specifications, and detail drawings.
- Act as focal point for questions and comments from Caltech concerning CBI drawings.
- Expedite the approval process to avoid schedule delays.

1.4.3 Project Construction Manager

The project Construction Manager is responsible for the construction portion of the project. His duties and responsibilities include the following:

- Serves as the focal point for all construction and site related matters.
- Assist the Project Manager in the detail planning and organizing of the project (especially in the areas related to construction) including resource planning and mobilization.
- Implement a site safety program.
- Is responsible for construction at the job site.
- Establishment of a detailed construction schedule.

- Continuous monitoring of the schedule, furnishing progress reports, and coordination of scheduling problems with Project Manager.

- Preparation for and supervision of mobilization and preparation of site facilities prior to actual construction work.

- Establishment of a scope of work for CBI field personnel.

- Providing day to day coordination among CBI's field forces and those of CBI's subcontractors and other Contractor's on site.

- Serving as the first level manager to whom the site superintendents report.

- Providing required manpower and tools to build the project in liaison with CBI's construction office and warehouse.

- Coordinates the use of all CBI furnished construction equipment.

- Managing the CBI Safety Program.

2.0 CONTRACT ADMINISTRATION

2.1 GENERAL

CBI will develop specific plans and project procedures to address the contract requirements for contact administration, the following topics will be addressed:

2.2 Project Procedures Manual
2.3 Site Security
    2.3.1 Entrance/Egress/Badging
    2.3.2 Fencing
    2.3.3 Specific Secure Areas
2.4 Insurance
    2.4.1 Workman's Compensation
    2.4.2 Liability
    2.4.3 Bonds
    2.4.4 All Risk Insurance
2.5 Project Documentation
    2.5.1 Correspondence
    2.5.2 Requests for Equitable Adjustment
    2.5.3 Contract Specific Requirements

- 2.5.4 Technical Documents
- 2.5.6 O & M Manuals
- 2.5.7 Reports
- 2.5.8 Daily Logs

2.6 Accounting/Audits/Invoicing
- 2.6.1 Records
- 2.6.2 Banking & Credit
- 2.6.3 Sales & Use Taxes
- 2.6.4 Invoice Approvals
- 2.6.5 Invoicing Procedures (DD250)
- 2.6.6 Payment Office

- 2.6.7 Audits
  - 2.6.7.1 External
  - 2.6.7.2 Internal
- 2.6.8 Change Justifications/Back Up

2.7 Substance Abuse Program
- 2.7.1 Standard Operating Procedures
- 2.7.2 Forms
- 2.7.3 Screening/Testing
- 2.7.4 Employment Records
- 2.7.5 State Requirements
- 2.7.6 Drug Free Workforce Rule

2.8 EEO Program
- 2.8.1 Minority Participation
- 2.8.2 Female Participation
- 2.8.3 Recruitment Sources/Records/Notices

2.9 Minority Subcontracts Program
- 2.9.1 Minority Owned Business
- 2.9.2 Women Owned Business
- 2.9.3 Small Business & Small Disadvantaged Business
- 2.9.4 Labor Surplus Area Concerns

2.10 Labor Policy
- 2.10.1 Payroll
- 2.10.2 Davis-Bacon Act
- 2.10.3 Department of Labor/Records

2.11 Patents / Inventions / Rights

2.12 Changes/Modifications

2.13 Certifications
- 2.13.1 Non-Segregated Facilities
- 2.13.2 Clean Air & Water

3.0 MOBILIZATION PLAN

3.1 GENERAL

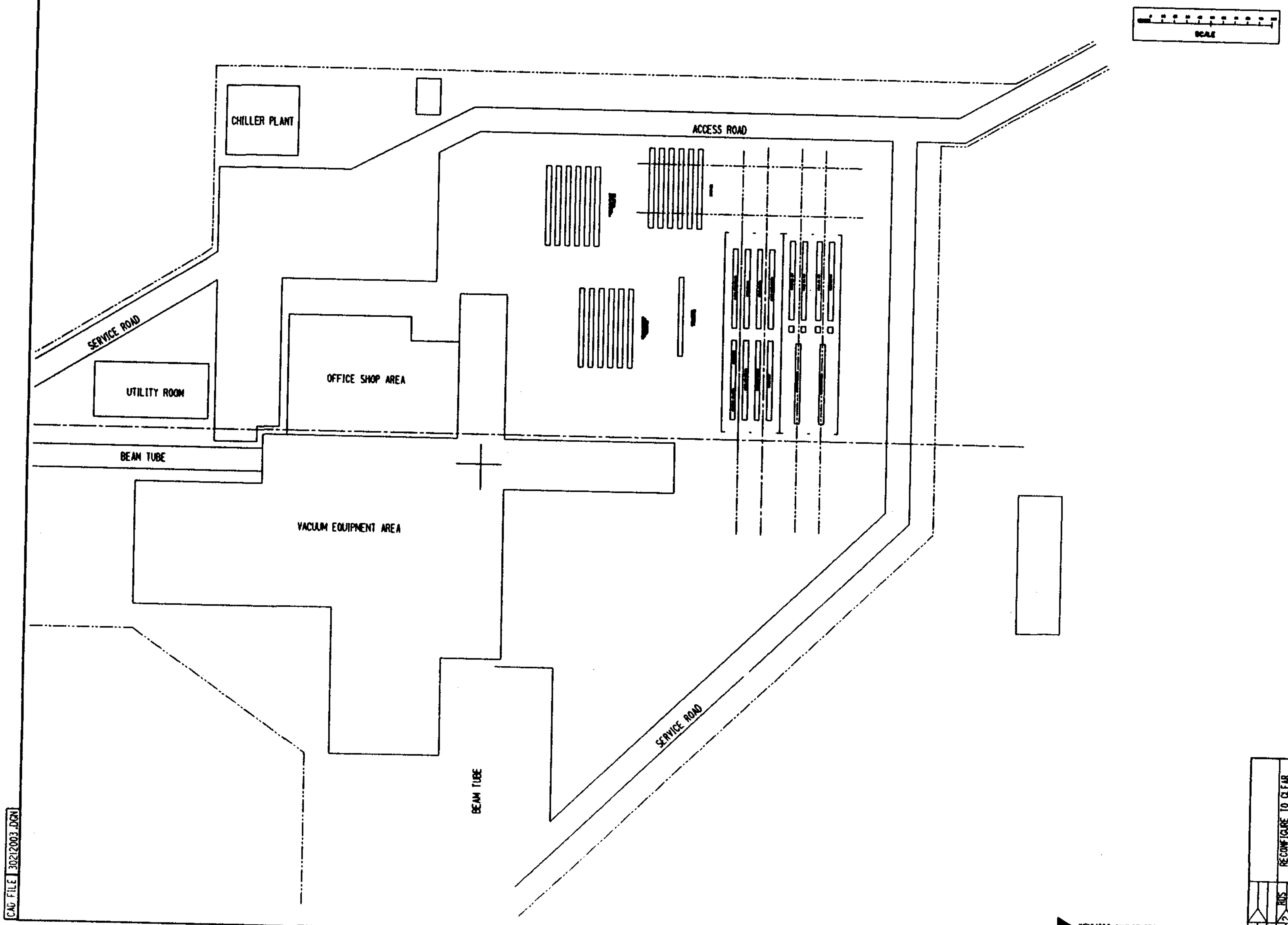
CBI will mobilize at the Hanford, WA. site with the necessary manpower and equipment to successfully complete the installation of the beam tube modules according to the project schedule. Office facilities for the on-site construction organization will be provided during the initial phase of CBI's construction effort. After completion of work at the Hanford site, the same effort will be instituted at the Livingston, La. site.

CBI is presently making complete site surveys. This should be completed within the next two weeks. At that time, more information can be gathered regarding local conditions, labor, permit requirements, local contractors, etc.

Manpower requirements will be developed with the estimate and schedule as processes and equipment become more fully defined.

3.2 FABRICATION FACILITY

The basic plan calls for a tube section fabrication facility will be erected first the Hanford then at the Livingston sites near the corner station at each site. The shop size will be determined by the final decision on the most cost effective tube module lengths to use, the number of and size of the equipment, and the production rate. Drawing ER 03, Rev. 1 illustrates a typical layout for 20 meter long tube assembly modules with various stations for fit up, welding, leak testing and cleaning that will be required at each site. The facility will be a prefabricated metal building with a



▶ INDICATES CHANGE FROM PREVIOUS ISSUE

CAD FILE 30212003.DGN

Revisions	By	Chkd	Date	Remarks
2	RDS		11/10/93	RECONFIGURE TO CLEAR FUTURE EXPANSION
1	RDS		10/22/93	40' SECTIONS TO 65'-7 9/16"

Supplier's/Purchaser's No. ____

CBI

LIGO PROJECT

HANFORD SITE LAYOUT
HORIZONTAL TUBE CONSTRUCTION

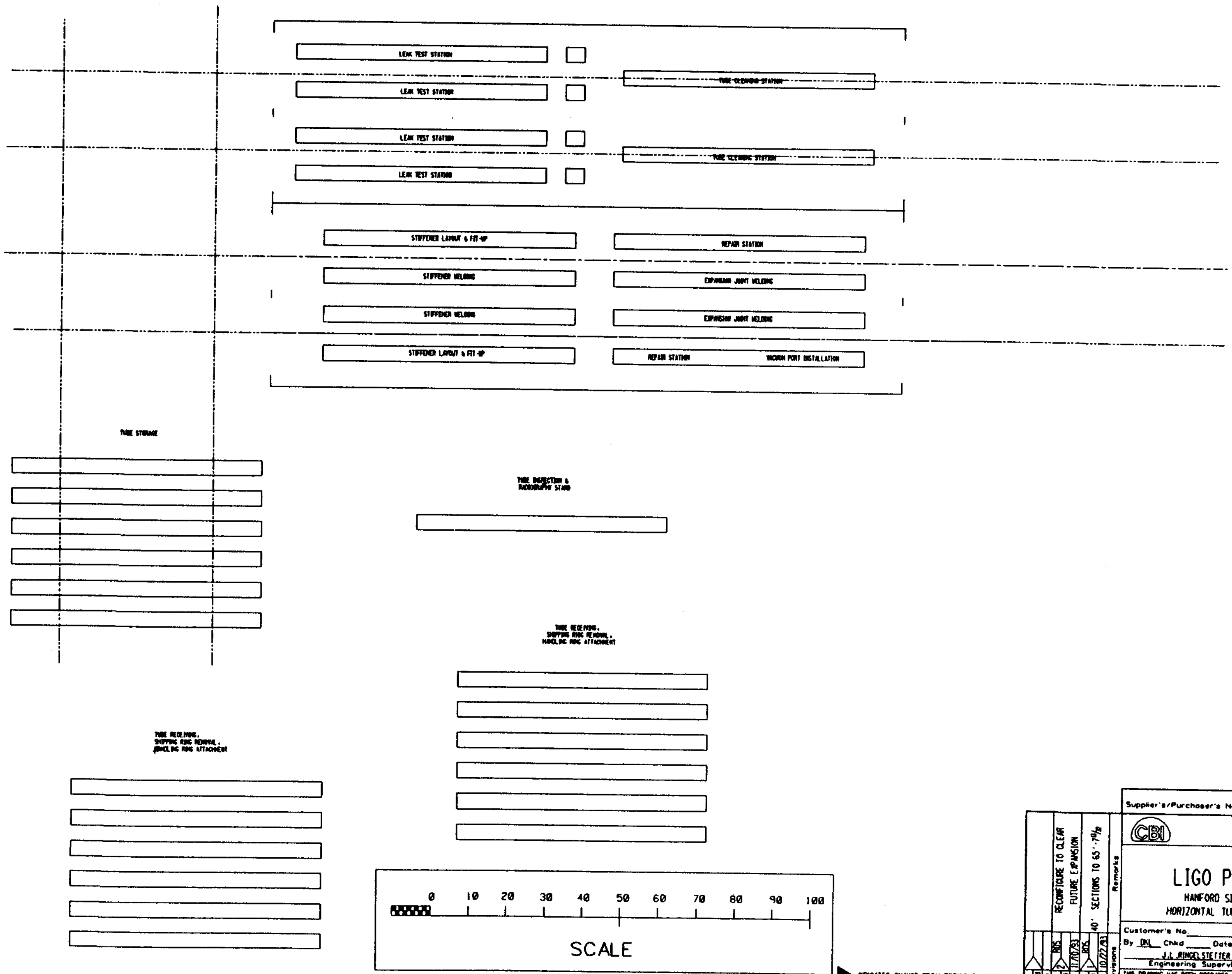
Customer's No. ____
By DKL Chkd ____ Date 9/23/93
J.L. RINGELSTETTER
Engineering Supervisor

Contract No.
Dwg. ER03
Sheet -
Rev. 2

THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI AND IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI REPRODUCTION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN.

THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES DEPT. (CHC)

FORM CHC 30 A REV SEP 93



▶ INDICATES CHANGE FROM PREVIOUS ISSUE

CAD FILE 30212004.DGN

By	Chkd	Date	Revisions	Remarks
RDS		10/22/93	1	40' SECTIONS TO 65'-7 9/32
RDS		11/10/93	2	RECONFIGURE TO CLEAR FUTURE EXPANSION

Supplier's/Purchaser's No. ________

CBI

LIGO PROJECT

HANFORD SITE LAYOUT
HORIZONTAL TUBE CONSTRUCTION

Customer's No. ________
By DKL Chkd ____ Date 9/23/93
J.L. RINGELSTETTER
Engineering Supervisor

Contract No. 930212
Dwg. ER04
Sheet -
Rev 2

THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI AND IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI REPRODUCTION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN.

THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES DEPT. (CHC)

FORM CHC 30 A REV SEP 93

concrete floor and could be retained as part of the permanent installation. There will be monorails running the full length of the fabrication shop for handling the tubes during fit up, welding, leak testing and cleaning.

Outside receiving and storage areas have yet to be defined.

The final sizing of the building cannot be completed until the equipment design has been finalized and the duration's for each activity has been determined for material flow. This should be determined in November. The size presently under consideration is 50' by 400'.

One alternative to erecting a fabrication building would be to locate an available shop in the area for lease. The handling problems associated with the fabrication are concerned with length and storage, not weight. CBI is presently working with the local real estate or economic development boards in the nearby communities to locate available facilities.

3.3 ERECTION EQUIPMENT

Because of the relatively light weight of the tube sections the primary lifting equipment will be 15-18 ton hydraulic cranes. Nylon slings would be utilized.

The tubes will be transported from the shop to the final installation area on small four wheel trailers.

Standard CBI construction equipment lists are presently being developed for welding and general construction efforts.

3.4 SPECIAL EQUIPMENT / TOOLING

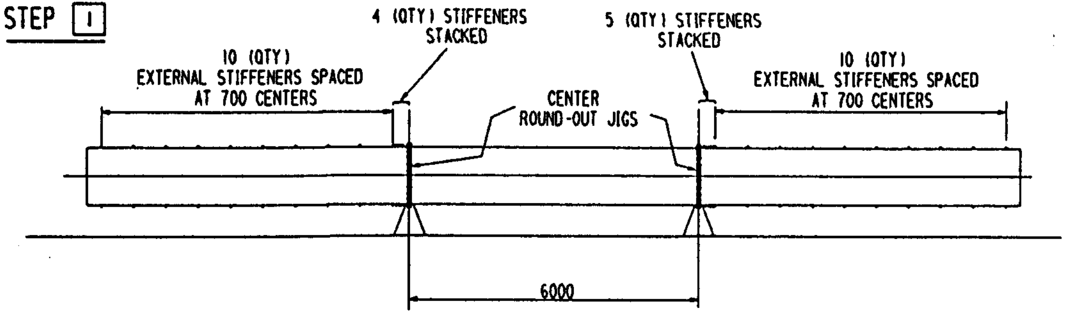
Because of the unique nature of this project much of the equipment that will be used to fabricate, erect, test and clean the cylinder sections will be designed and built specifically for each application.

3.4.1 FABRICATION

3.4.1.1 STIFFENER FIT UP

The stiffener station will be designed around the concept of a single lapped joint as suggested by Caltech. This provides for the stiffener to be expanded

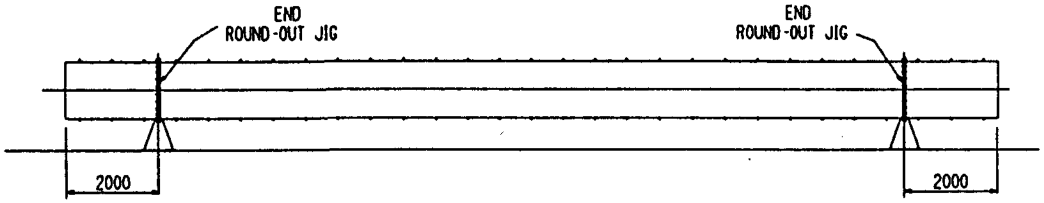
STEP 1



STEP 1:

1. SUPPORT PIPE SECTION ON TWO CENTER ROUND-OUT JIGS LOCATED AS SHOWN .
2. SLIDE STIFFENERS UP AGAINST ROUND-OUT JIGS AS FOLLOWS : 4 (QTY) UP AGAINST LEFT JIG & 5 (QTY) UP AGAINST RIGHT JIG .
3. LOCATE REMAINING STIFFENERS TO LEFT AND RIGHT OF CENTER SUPPORTS . AT THE REQUIRED CENTERS .

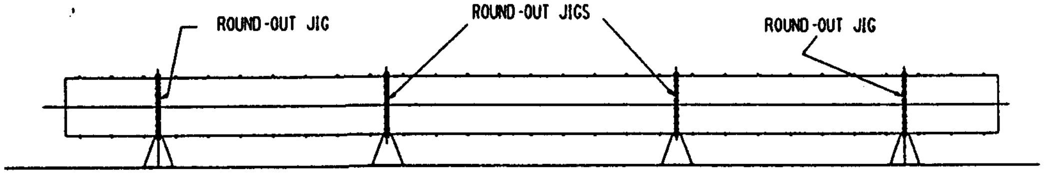
STEP 2



STEP 2:

1. ENGAGE SUPPORTS NEAR THE ENDS OF THE PIPE .
2. LOWER CENTER SUPPORTS AWAY FROM THE PIPE .
3. SLIDE THE LOOSE STIFFENERS (ADJACENT TO CENTER SUPPORTS) TO THEIR CORRECT LOCATIONS .

STEP 3



STEP 3:

1. ENGAGE THE CENTER SUPPORTS .
2. ACTIVATE ALL 4 ROUND-OUT RINGS TO ROUND-OUT THE PIPE .
3. PROCEED TO FIT ALL STIFFENERS TIGHT AGAINST THE PIPE .
4. ONLY WELD THE OVERLAP ON THE STIFFENER ONCE THE STIFFENER IS SNUG AGAINST THE PIPE .

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

By	Chk'd	Date	By	Chk'd	Date	By	Chk'd	Date	Revisions
									Remarks

Supplier's/Purchaser's No. ____________

CBI

LIGO PROJECT

EXTERNAL STIFFENER FITTING SEQUENCE

Customer's No. ____________
By AVR Chk'd JLR Date 04-NOV-93
J.J. RINCELSTETTER
Engineering Supervisor

Contract No. 930212ER
Dwg. ER20
Sheet -
Rev. 0

THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES DEPT. [illegible] FORM CHE 30 4 REV SEP 93 oversize like a spring, positioned along the tube, the expansion released, the lapped connection can be utilized to pull the stiffener tight and in contact with the tube's outside circumferential surface. The lapped joints can then be welded together without welding to the tube wall proper.

This station will have four support saddles with round up clamps built in. Two of these will located near the tube ends and two at the third points. The unstiffened tube will be initially set and rounded up on the inner saddle rings.

Sketches are attached showing this set up..

3.4.1.2 STIFFENER WELDING

The stiffener weld stand will contain the welding and purging equipment to weld the stiffeners to the cylinder sections. The weld station will have four weld heads, each mounted to move independently along the tube. The tube will be mounted on a head-stock, tail stock system to accurately drive and control the rotation for welding. The drive system will have integral purge and sealing systems for to protect the inside of the tube from oxidation during stiffener welding. One central rubber tired roll support will be used as a steady rest to minimize distortion from dead weight deflection of the tube.

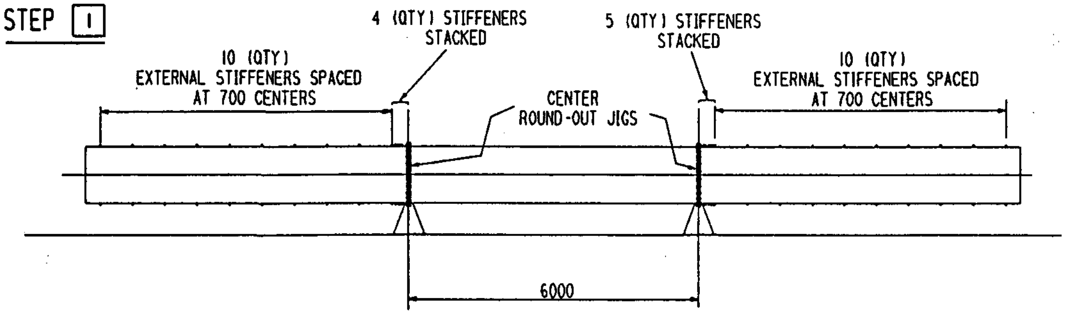
Sketches for this equipment are included.

3.4.1.3 EXPANSION BELLOWS FITTING & WELDING

The third station in the fabrication shop will be set up for fitting and welding the expansion joints to the tubes. This will consist of a stationary frame with movable purge dam. The purge dam will be inserted into the tube for purging. The welding process will rotate around the tube to expansion bellows joint.

CBI has used several types of rounding and fitting devices over the years for standard pipe joints in the field. Dearman Company, a division of Cogsdill

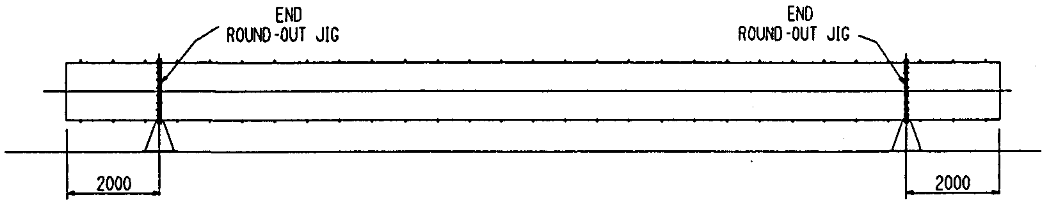
STEP 1



STEP 1:

1. SUPPORT PIPE SECTION ON TWO CENTER ROUND-OUT JIGS LOCATED AS SHOWN .
2. SLIDE STIFFENERS UP AGAINST ROUND-OUT JIGS AS FOLLOWS :
   4 (QTY) UP AGAINST LEFT JIG & 5 (QTY) UP AGAINST RIGHT JIG .
3. LOCATE REMAINING STIFFENERS TO LEFT AND RIGHT OF CENTER SUPPORTS , AT THE REQUIRED CENTERS .

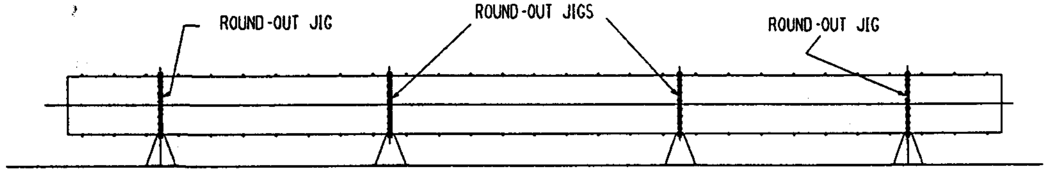
STEP 2



STEP 2:

1. ENGAGE SUPPORTS NEAR THE ENDS OF THE PIPE .
2. LOWER CENTER SUPPORTS AWAY FROM THE PIPE .
3. SLIDE THE LOOSE STIFFENERS (ADJACENT TO CENTER SUPPORTS) TO THEIR CORRECT LOCATIONS .

STEP 3



STEP 3:

1. ENGAGE THE CENTER SUPPORTS .
2. ACTIVATE ALL 4 ROUND-OUT RINGS TO ROUND-OUT THE PIPE .
3. PROCEED TO FIT ALL STIFFENERS TIGHT AGAINST THE PIPE .
4. ONLY WELD THE OVERLAP ON THE STIFFENER ONCE THE STIFFENER IS SNUG AGAINST THE PIPE .

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

By	Chkd	Date	By	Chkd	Date	By	Chkd	Date	Revisions	Remarks

Supplier's/Purchaser's No. ____

CBI

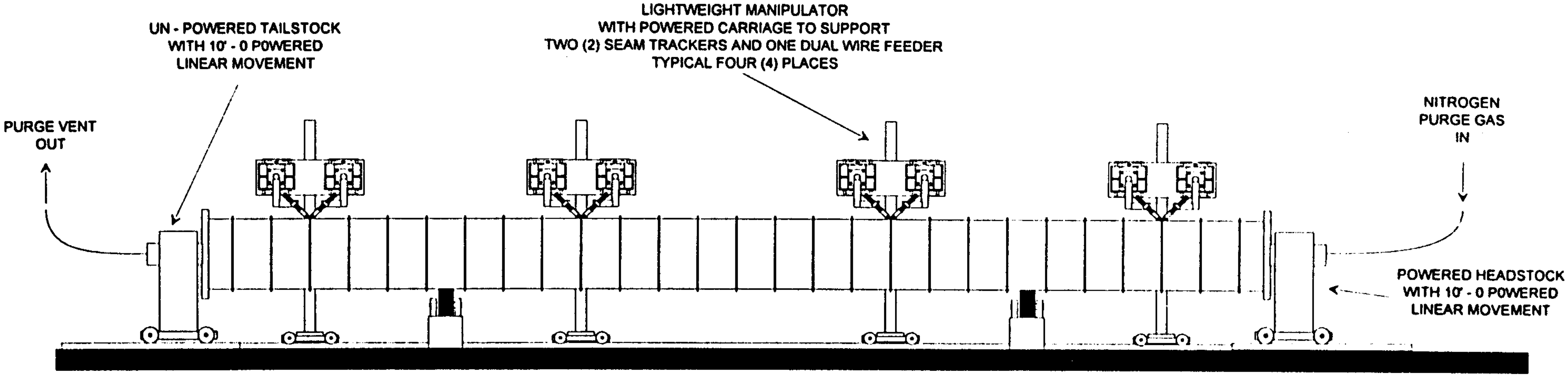
LIGO PROJECT

EXTERNAL STIFFENER FITTING SEQUENCE

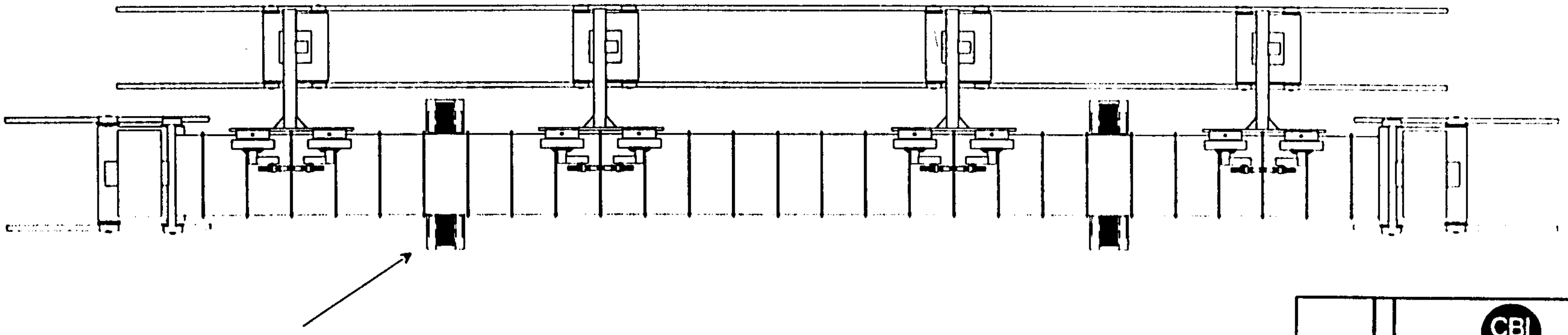
Customer's No. ____
By AVR Chkd JLR Date 04-NOV-93
J.L. RINGELSTETTER
Engineering Supervisor

Contract No. 930212ER
Dwg. ER20
Sheet -
Rev. 0

THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES DEPT. (CHO) FORM CHC 30 A REV SEP 93



ELEVATION



PLAN

NOTE: BOTH HEADSTOCK AND TAILSTOCK SHALL HAVE SEALING SURFACES
TO FACILITATE PURGING OF PIPE AND ROTARY ELECTRICAL CONNECTIONS FOR WELDING WORKPIECE LEADS.

▶ Indicates revision from previous issue

CBI

LIGO
STIFFENER WELDING FIXTURE
GENERAL CONCEPT

JDM
11/3/93
930212
1
2
0

Tool Products recently demonstrated the Dearman Chain Clamp. This lightweight device will provide the means for matching up the in and out surfaces without regard for roundness. CBI is researching the use of the Dearman Rim Clamp. This fixture rounds the tube but is not as easy to work with in matching up local deviations. It also weighs 600 pounds. Efforts are being made to obtain both devices in the 48" size to test in the Houston Lab. Once the tests are complete, an evaluation of the specific equipment that will best suit the needs of thin walled, large diameter tubing can be made. CBI is also testing our own design ring.

3.4.1.4 VACUUM PORTS

There will be a location out to the side of bellows station for installation vacuum ports in selected cylinder sections.

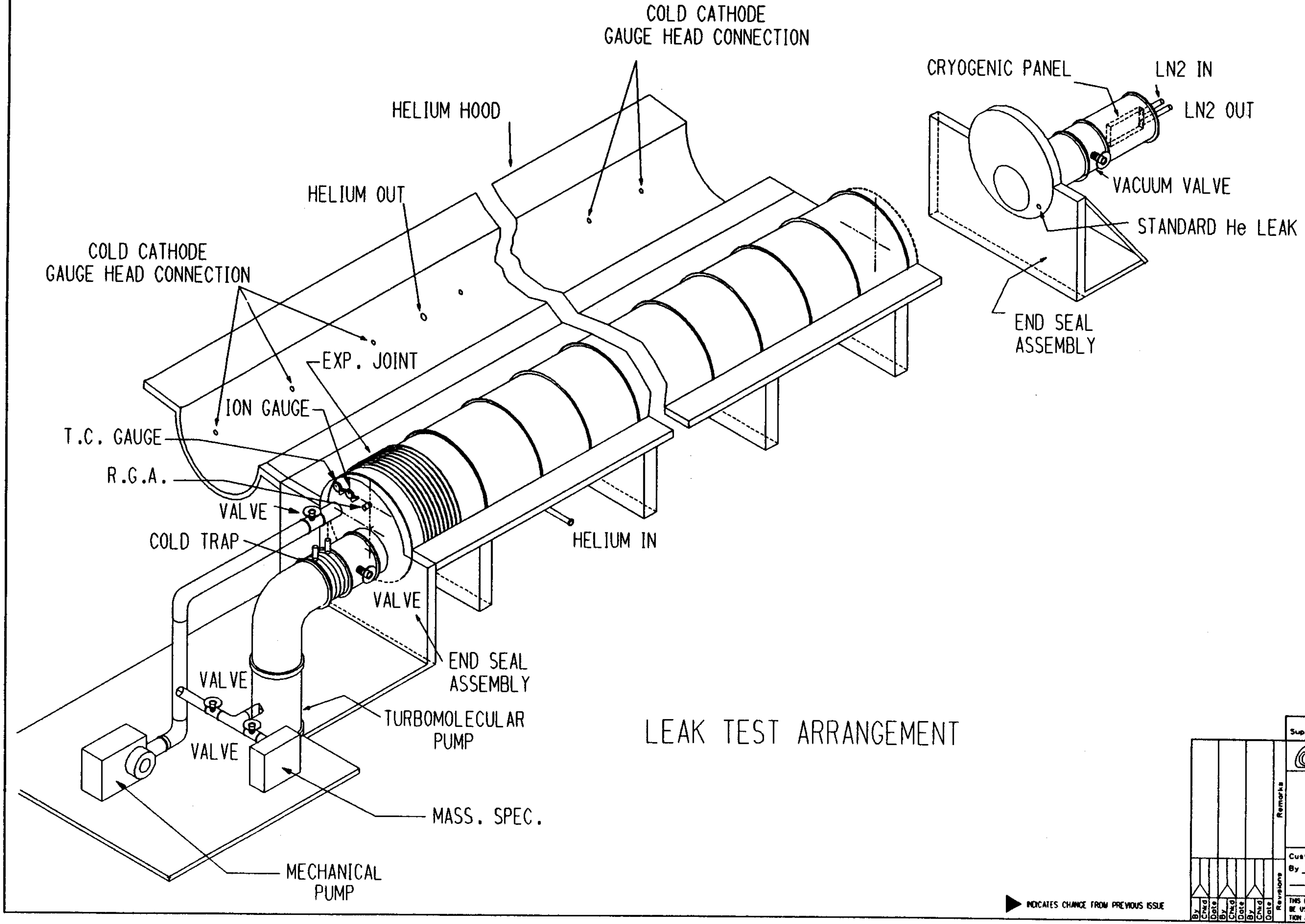
The equipment for this process is yet to be developed, but lies within CBI's present expertise to devise. This will involve an internal/external box set up to allow for stiffening, fitting and welding in an inert environment.

3.4.1.5 LEAK TESTING

The next station in the shop will be for leak testing the completed tube sections. There will be three or four (the actual number will be dependent upon the pump down rate achievable and the results of the qualification testing) stands, each with its own vacuum test equipment, set up so that several tube assemblies can be tested simultaneously. There will also be a leak repair station located out to the side of the test stands.

The leak test stations are presently under design by CBI at Houston. Attached are sketches indicating the present status of design. The hood test stand is composed of a hinged cover and end seal assemblies with attached multiple stage high speed pump system, gauging, analysis, leak testing, and calibration equipment. The equipment will designed to accomplish the pressure level required to achieve system sensitivity in two to four hours.

CBI procedures will list all of the equipment required for testing. Planning Procedure LIGOTP provides a guide for the requirements. Procedure



LEAK TEST ARRANGEMENT

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

By Chkd Date By Chkd Date By Chkd Date Revisions

Remarks

Supplier's/Purchaser's No. ____

CBI

LIGO PROJECT

LEAK TEST HOOD

Customer's No. ____

By DKL Chkd ____ Date 11-10-93

J.L. RINGELSTETTER

Engineering Supervisor

Contract No. 930212

Dwg. ER58

Sheet -

Rev. 0

THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES DEPT. (CHC)

FORM CHC 30 A REV SEP 93

HMST1N addresses helium mass spectrometer hood testing of the beam tube can sections.

All purchased equipment items shall be specified by CBI to be helium mass spectrometer (HMS) leak tested using a technique and equipment that will enable the manufacturer of that equipment to achieve a total leakage rate of less than $2x10^{-12}$ atm. cc/sec of helium. If the manufacturer cannot achieve or meet this requirement, CBI will purchase the item contingent upon the item meeting this requirement when HMS tested as part of the overall test set up. This requirement is a concern to CBI because state of the art capability of most manufacturers does not normally exist in this test sensitivity range. CBI will continue to pursue and investigate all potential sources on a world wide basis.

3.4.1.6 CLEANING EQUIPMENT (IN FABRICATION AREA)

CBI continues to investigate various design configurations of automatic rotating spray equipment. A photograph of a guided pipe spray cleaning head manufactured by Chemdet is included.

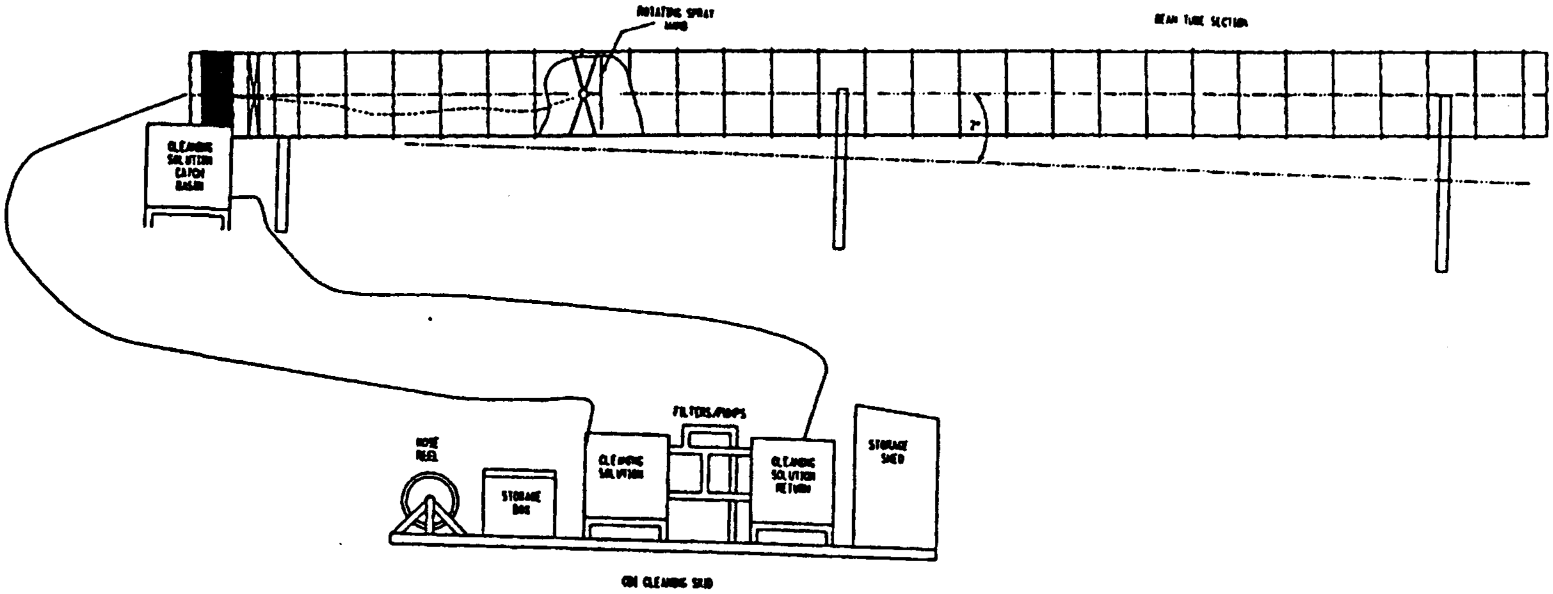
The cleaning station will have to be a self contained system with provision for capture and/or recirculation of the chemical cleaning agents. CBI has solicited input from contractors and companies in the cleaning business for suggestions in this area to assist in the design.

This will be production line cleaning as opposed to CBI's normal single vessel or batch cleaning processes.

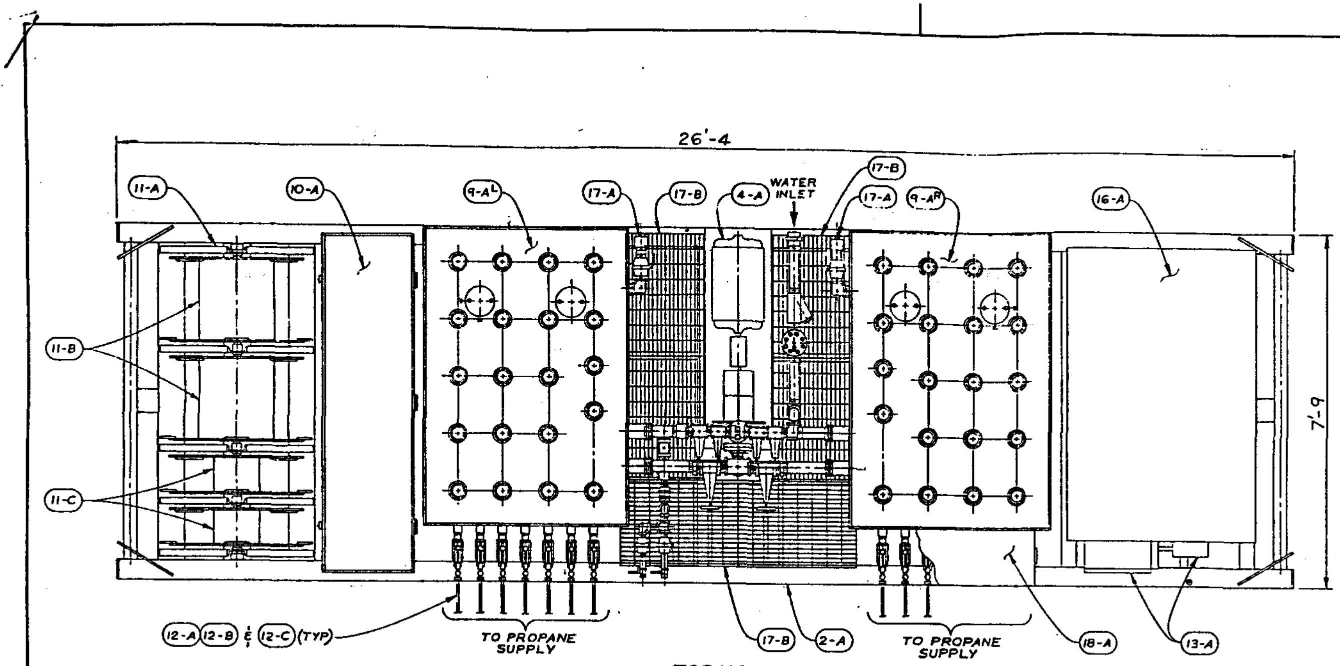
CBI will utilize it standard cleaning solution storage and pumping system. A drawing is attached.

3.4.2 ERECTION

The special erection equipment that will be necessary to assemble the cylinder sections into the beam tube module will be located on rails that will be embedded in or surface mounted on the concrete slab underneath the full length of the modules. There will be a clean room facility riding these rails that will have a change room, transition room and work room with purge equipment and baffle storage which will be positioned at the end of the module as the cylinder sections are being added. There will also be a



CLEANING ARRANGEMENT

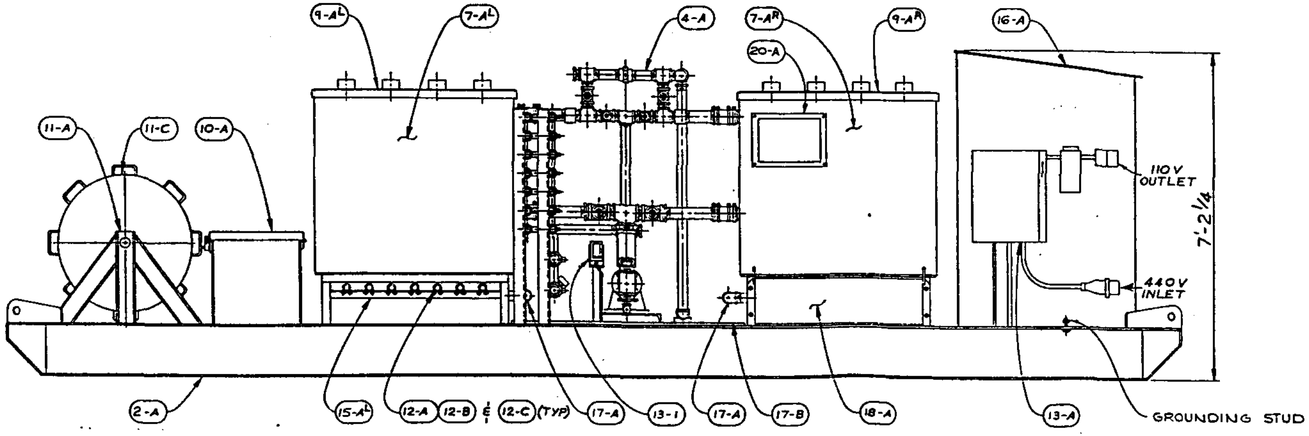


TOP VIEW

SHIP PC	MARK	ASSM PC	DESCRIPTION	LENGTH FT	LENGTH IN	SPEC	WT
1	1-A		TANK CLEANING SKID				14191
	2-A	1	MAIN FRAME				3154
	4-A	1	PUMP AND PIPING SYSTEM				683
	7-A$^{L}/_{R}$	2	CHEMICAL HEATING VAT (CAP = 606 GAL. EACH)				4676
	9-A$^{L}/_{R}$	2	COVER FOR CHEMICAL HEATING VAT				218
	10-A	1	EQUIPMENT STORAGE BOX				401
	11-A	1	HOSE REEL SUPPORT FRAME AND AXLE				236
	11-B	2	HOSE REEL W/1'-8 Ø DRUM				485
	11-C	2	HOSE REEL W/1'-0 Ø DRUM				377
	11-D	1	CHAIN ASSEMBLY (NOT SHOWN)				12
	12-A	14	PIPE BURNER				221
	12-B	14	INSPIRATOR				39
	12-C	14	HOSE ASSEMBLY (FUEL GAS)				62
	13-A	1	ELECTRICAL EQUIPMENT PACKAGE				239
	14-A	1	CLEANING HEAD ASSEMBLY (NOT SHOWN)				206
	14-B	4	2 Ø HOSE ASSEMBLY X 75'-0 LONG (NOT SHOWN)				409
	14-C	14	1"Ø HOSE ASSEMBLY X 50'-0 LONG (NOT SHOWN)				448
	14-D	1	HAND HELD CLEANING NOZZLE (NOT SHOWN)				20
	15-A$^{L}/_{R}$	2	VAT PEDESTAL AND BURNER SUPPORT				441
	16-A	1	STORAGE SHED				1582
	17-A	2	VAT DRAIN				26
	17-B	3	CLEANING SKID GRATING				183
	18-A	2	BURNER COVER				73
	20-A	1	OPERATING PROCEDURE PLAQUE				—

NOTES:

1. SEE DWGS 2 THROUGH 18 FOR ASSEMBLY DETAILS
2. SEE DRAWING 19 FOR OPERATING INSTRUCTIONS



FRONT VIEW

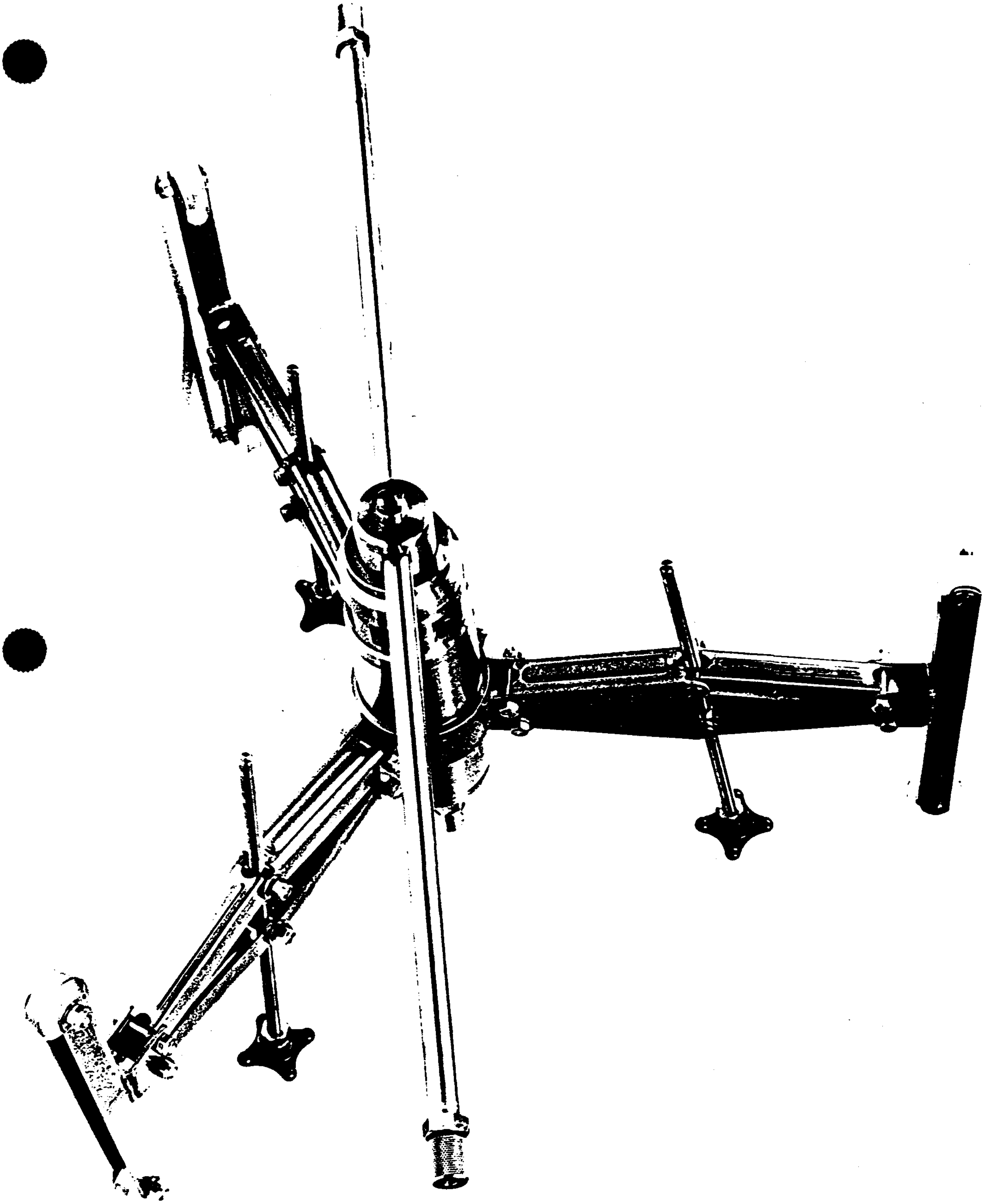
▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Chicago Bridge & Iron Company CBI

GENERAL ARRANGEMENT FOR
TANK CLEANING SKID

By AJH Chkd TJM Date 4-7-80
Approved By ________ Date ____

CONTRACT NO. BF0617
DWG 1
REV.0



horseshoe shaped enclosure that will ride of the rails and provide protection for the cylinder joints as they are being fit and welded. A similar enclosure will be used for the vacuum test equipment that will be used to leak test these seams after they are welded. Attached is a sketch illustrating this arrangement.

The design continues on this equipment, pending input from outside suppliers.

Caltech should note here that embedded or surface mounted rails are not in their present plans according to documents now at CBI, this needs to be addressed further.

3.4.3 TESTING - FIELD WELD JOINTS

CBI will design and build the external test box evacuation enclosure, and the internal combination purge gas dam/tracer gas test hood and associated equipment to leak test the cylinder sections of the field welded seams joining the tube assemblies together. This is normal CBI state of the art work.

3.4.4 CLEANING-GENERAL

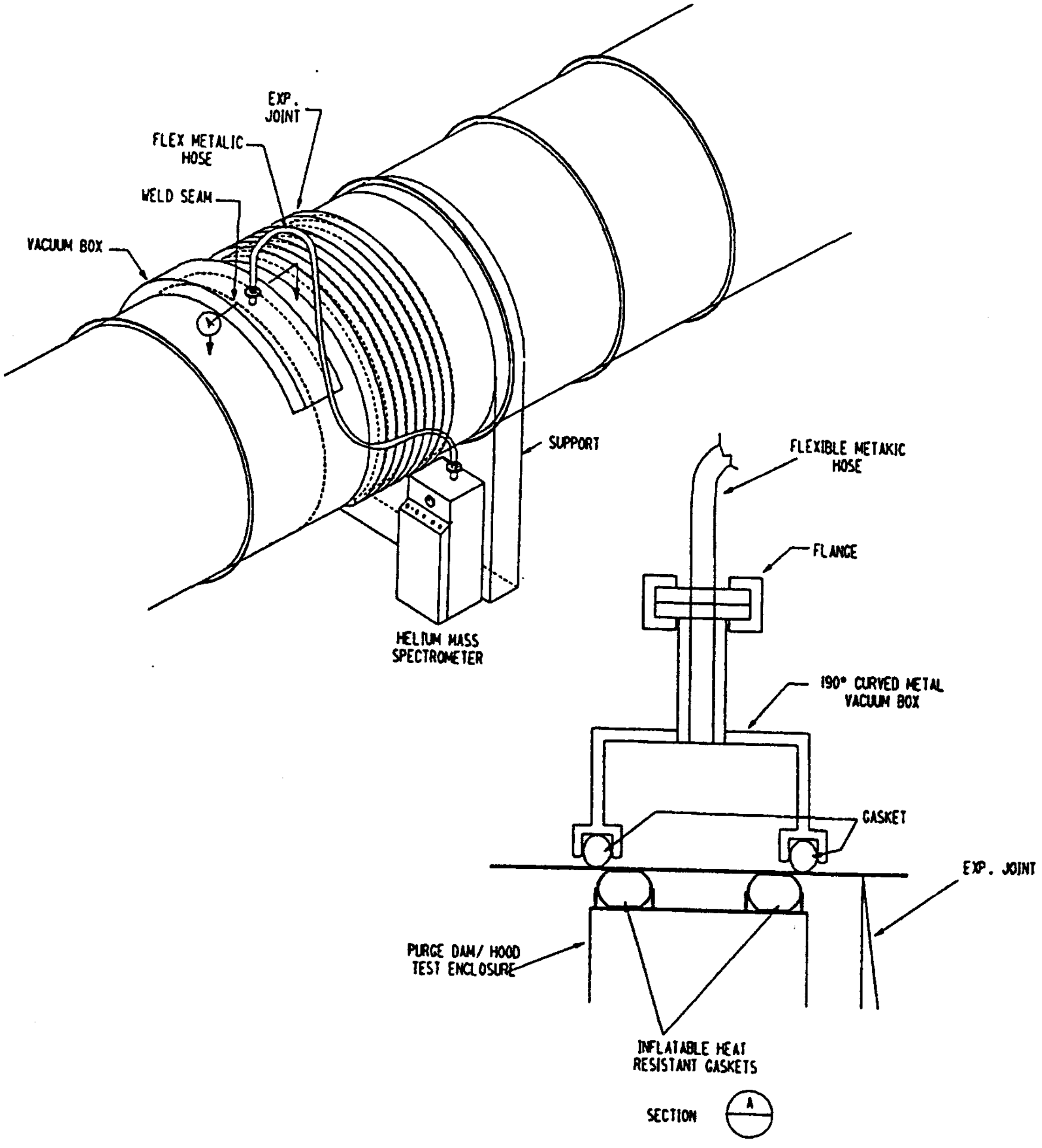
There is some discussion about the advantages and disadvantages of having the tube supplier provide a pickled product to the site. The concern for oxidation, welding discoloration (heat tint), hydrocarbon and iron contamination is great. A possible bake out of the tube prior to assembly might solve the problems addressed by Caltech regarding hydrogen that might be trapped or created (would outgas during tube testing/operation) in the tubing material as a result of pickling with dilute nitric and hydrofluoric acids. One potential tube vendor pickles as a standard part of their process. The cleaner the tubes are at the point of entry in the fabrication process, the easier the precleaning before leak testing and final cleaning operations will be.

3.5 OVERALL SITE COORDINATION

In order to maintain the schedule and adjust for any unexpected occurrences, site coordination during the installation of the tube assemblies will be of utmost importance. Responsibility for overall site coordination needs to be decided early on.

3.5.1 UTILITIES

TITLE HELIUM MASS SPECTROMETER HOOD TEST OF CLOSING WELD JOINTS BETWEEN TUBE CANS FOR LIGO PROJECT - CALTECH



TEST SET-UP SKETCH

Construction power will be provided from the permanent power substation located near the corner station at each site. Additionally construction power will be provided at the end and mid point stations at Hanford and at the end stations at Livingston. Portable generator units will be provided to supply power along the length of the beam tube modules as they are being assembled. Water will be provided at the corner station on each site. CBI will provide the necessary power panels to pick up construction power at 440 volts.

3.5.2 ROAD ACCESS

Road access will be provided along the outside of the L shaped legs of the beam tube modules for moving the tube modules, lifting equipment, etc. into place. The welding and power generation equipment will be trailer mounted and will move along the inside of the legs as the assembly progresses.

3.5.3 SHARED HANDLING EQUIPMENT

To prevent crowding of the work area, before any equipment is brought onto the site, an investigation will be made regarding the need for the equipment and if there is already equipment on the site that can be shared.

3.5.4 OTHER CONTRACTORS

CBI would prefer coordinate the work of all contractors on the site to provide for the efficient completion of the project. This must be addressed at a later date

4.0 PROCUREMENT PLAN

4.1 General

CBI will develop a procurement plan to address the following items, concerns, and requirements:

4.2 Program/ P.O. Provisions
4.3 Major Suppliers

    - 4.3.1 Tube Sections
    - 4.3.2 Expansion Bellows
    - 4.3.3 Stiffeners
    - 4.3.4 Baffles
- 4.4 Construction Equipment/Facility
- 4.5 Requirements for Notifications, Consent, or Approvals
- 4.6 Authorization
- 4.7 Expediting
- 4.8 Pricing & Analysis Requirements
- 4.9 Value Engineering
- 4.10 Use of Government Facilities by Subcontractor
- 4.11 Transportation Damage & Loss Claims
- 4.12 Supplier Corrective Action Requests
- 4.13 Disposition of Rejected or Damages Incoming Supplies
- 4.14 Stop Work Order
- 4.15 Federal Acquisition Regulations
    - 4.15.1 Contract Specific Pass Through Requirements
    - 4.15.2 Law of the Land Requirements
- 4.16 Government Furnished Equipment/Inventory
- 4.17 Release of Lien
- 4.18 Certification of Compliance
- 4.19 Termination/Liability

5.0 SUBCONTRACTING PLAN

CBI will develop a site and job specific plan for handling the subcontracting effort required. It will address the following guidelines:

- 5.1 Subcontract Provisions
- 5.2 Major Subcontract Areas
    - 4.2.1. Cleaning
    - 4.2.2. Security
- 5.3 Federal Notification

6.0 FABRICATION PLAN

6.1 General

The process flow for fabrication will follow the logic indicated on the LIGO Process Flowcharts presented at the last meeting and included here for record purposes. As specific procedures are developed, they will be added to this write up.

6.2 Fabrication Sequences

6.2.1 Stiffener Fitting Station

The tube section is moved from outdoor storage to the Stiffener Fit up Station utilizing the monorail system and placed on the inner fit up saddles.

One-half of the expanded one piece stiffeners will be placed around each end of the tube with the middle third of the stiffeners bunched up just outside of the inner fit up saddle rings. The tube is then supported on the outer fit up saddle rings and the inner rings are removed so that the remaining stiffeners can be slid into position. With the tube rounded up by all four support saddles, the stiffeners are final positioned and the fit by removing the slack, pulling the joint tight and welding the lap splice and a bead along the outer perimeter of the lap. There is no welding to the tube at this station.

6.2.2 Stiffener Welding Station

The tube is moved via the monorail system to the Stiffener Welding Station and loaded onto temporary saddles. The head stock and tail stock are moved into position, holding and sealing the tube ends. The interior is purged with inert gas. Allowing 50% of the time for set up and utilizing four weld heads, a production rate of two tubes per shift per station is anticipated. After welding, the head and tail stocks are removed and a visual inspection is performed to insure there has been no burn through.

6.2.3 Expansion Bellows Fitting & Welding Station

The tube will be moved via the monorail system to the next station and set on the stationary frame support.

The circumferential joint fit up clamp is placed around the tube then the expansion bellows is set into position utilizing the monorail.

The purge dam will be inserted into the tube, expanded around the weld seam and the volume immediately behind the weld will be purged with an inert gas mixture for welding.

The joint will be welded in accordance with the approved weld procedure in a stationary position.

After welding and removal of the equipment, the joint will be given a visual inspection.

While at this station, the interior of the tube will be black light inspected and precleaned as required in accordance with approved procedures to eliminate any hydrocarbon contamination.

6.2.4 Leak Testing Station

The tube assembly will be moved by monorail to one of the Leak Testing Stations and place in the hood assembly. The vacuum testing will be performed in accordance with the approved leak test procedure.

In the event the assembly fails the test, it will be removed to the side, repaired, retested, and inspected.

An alternative that would permit the following cleaning operation to be performed prior to leak testing is presently being explored. CBI will advise on this later.

6.2.5 Cleaning Station

The tube assembly will be moved by monorail to the cleaning station and placed into the cleaning canister. Cleaning will be done in accordance with CBI Procedure CL1N, based on the recommended agent, Oakite 33. CBI has recently been advised that a neutralizing agent is now available to render the Oakite 33 environmentally harmless, this is being explored further.

CBI Procedure CLALT lists the additional agents and tests required to qualify an alternate agent. This is desirable, not only environmentally point, but also from a personnel safety point. Cleaning agents to be reviewed include Simple Green, Mirachem 500, Triton 100, Oakite DZL, Diversey Wyndotte Aerowash, and Pierce RBS-35 Concentrate.

The tube assemblies will be sealed with plastic covers for interim storage and transport to the erection area for installation in the module.

6.2.6 Baffles

There is some discussion at this time addressing the timing on installation of the baffles. It may be possible to install the baffles after cleaning and before capping the ends for storage and/or transport. This will not be resolved until the various pieces of welding, fitting, and purging equipment are resolved for the erection portion of the work.

7.0 TRANSPORT

7.1 General

Transport and coordination of the tubes from the vendors will be a very demanding and delicate matter. CBI does not plan to have the vendor stock pile more that a two or three week supply. CBI will provide for the same at the site.

Plans will be developed to address the following items:

7.2 Incoming
7.3 On Site
  7.3.1 Equipment

8.0 ERECTION PLAN

8.1 GENERAL

In order to best utilize the special equipment for the installation of the beam tube modules, CBI will work two 40 hour shifts each week during the assembly of the modules. There will be two clean room setups so that two tube sections can be installed simultaneously.

8.2 PLACEMENT

The tube assemblies sections will be cleaned and sealed before leaving the site fabrication facility. They will be kept clean during all subsequent operations in the installation process. Sealed sections will be hauled to the beam tube module on trailers and supported between the rails very near its final position. The leading end of the section will be supported on the permanent support and the trailing end will be on a temporary support or supported by a clamping device on the previous section. Handling will utilize a hydraulic crane and nylon slings with a spreader device to spread the load. These must be adequate room along the access road to manipulate the crane, the load, the portable power sources and the clean rooms. There will be little room for other construction activities at this point.

An outstanding question is the timing of the placement of the concrete cover over the tubes. CBI's opinion, at this time, is that it should be done as soon as possible to avoid exposure to any unexpected accidents and the elements.

8.3 WEATHER PROTECTION

After the cylinder section is in position the clean room will be rolled up to the leading end and sealed to it. The horseshoe shaped enclosure will be rolled in position over the trailing end of the section to be installed and sealed to both it and the previously installed cylinder. After the cylinder section is sealed between the clean room and the previously installed portion of the beam tube module, the protective sealing covers that were installed in the fabrication facility will be removed so that final alignment, fit up and welding of the new section can proceed.

8.4 CLEAN ROOM

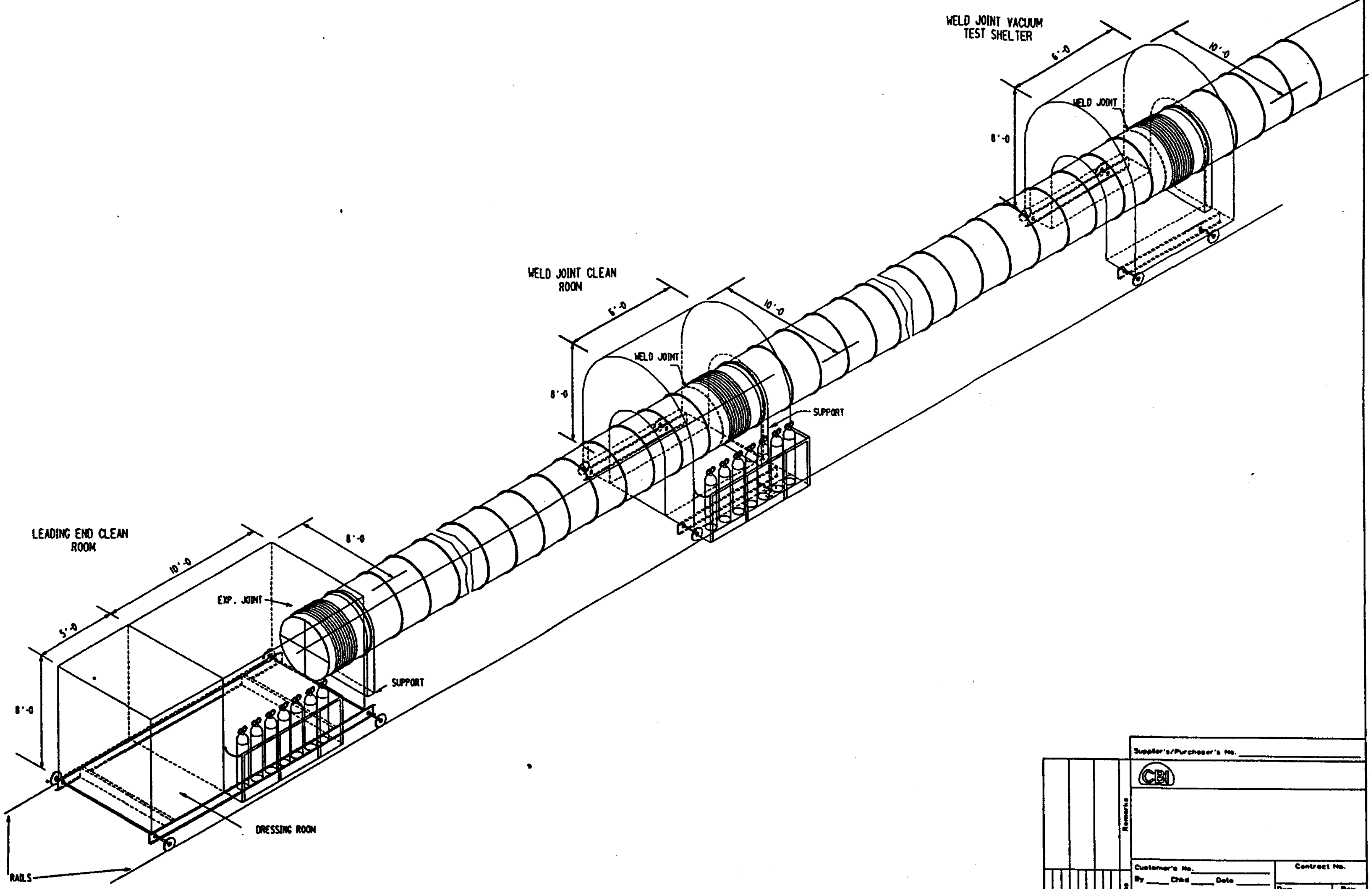
The clean room, as well as the two horse shoe shaped enclosures, (one for fitting and welding and the other for leak testing) will be mounted on rails that are embedded in the concrete slab beneath the beam tube module. The clean room will be a movable enclosure with a change room, a transition room and a work room with a sealable opening for the end of the cylinder section being installed. The work room will contain the necessary equipment for purging the inside of the seam during fitting and welding and the leak test equipment necessary for the inside of the seam. It will also have a place for baffle storage, since the baffles will be installed after leak testing of the closure seams between cylinder sections. The workroom will also contain air quality monitoring equipment and communication equipment to the two enclosures.

Procedures have been developed to address access control, final cleaning and testing. The interior of the tubes will be classified as a confined space due to limited exit and inert gas usage

There will be forced air system at the beginning of the module. This will provide filtered, dry air through the tube at all times and maintain a positive pressure to prevent infiltration.

8.5 ALIGNMENT

The following is a summary of CBI concerns relating to the alignment. A full report will be prepared on this subject for the Option package.



▶ INDICATES CHANGE FROM PREVIOUS ISSUE

By	Chkd	Date	By	Chkd	Date	By	Chkd	Date	Revisions

Remarks

Supplier's/Purchaser's No. ____________

CBI

Customer's No. ____________

By ____ Chkd ____ Date ____

Engineering Supervisor

Contract No.

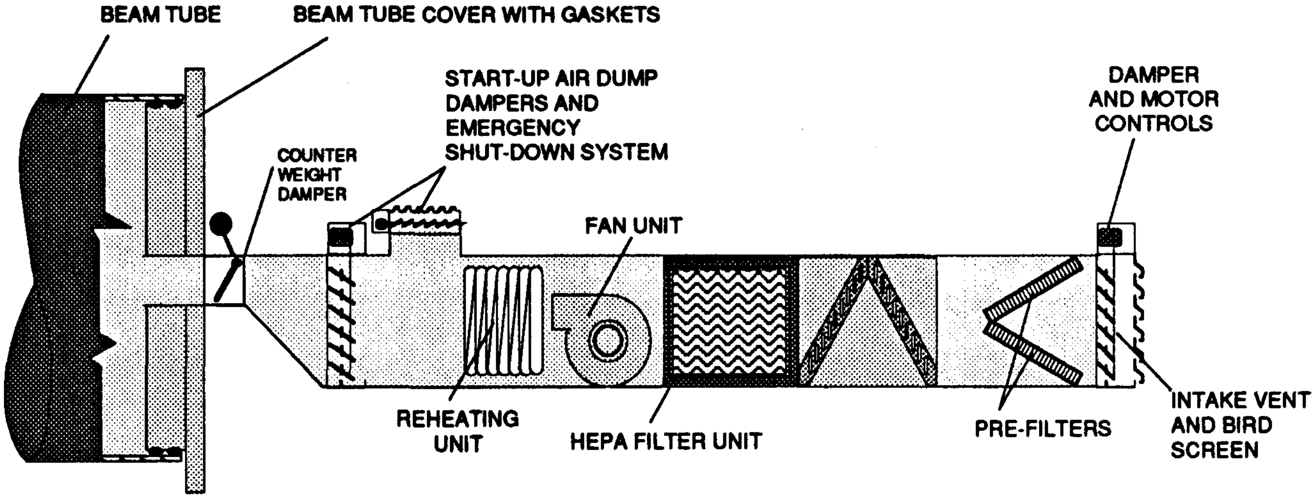
Dwg.

Sheet

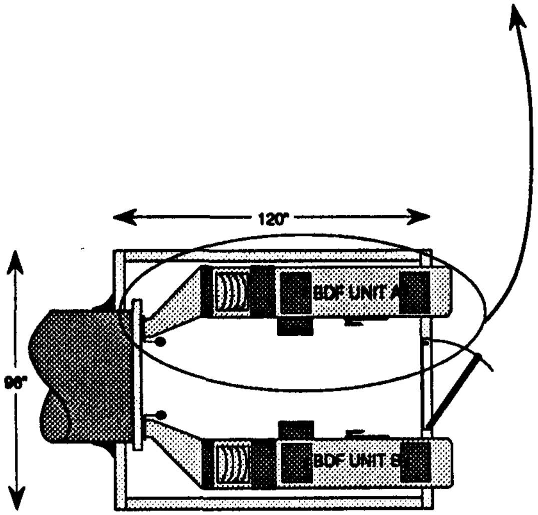
Rev.

THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI AND IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI. REPRODUCTION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN.

THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES DEPT. (CHC) FORM CHC 39 A REV SEP 93



BDF SYSTEM UNIT



BDF SYSTEM BUILDING

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. ____________

CBI

LIGO

BLOWER/DRYE
R/FILTRATION
SYSTEM

Customer's No.

Contract No.

By ______ Chkd ______ Date ______

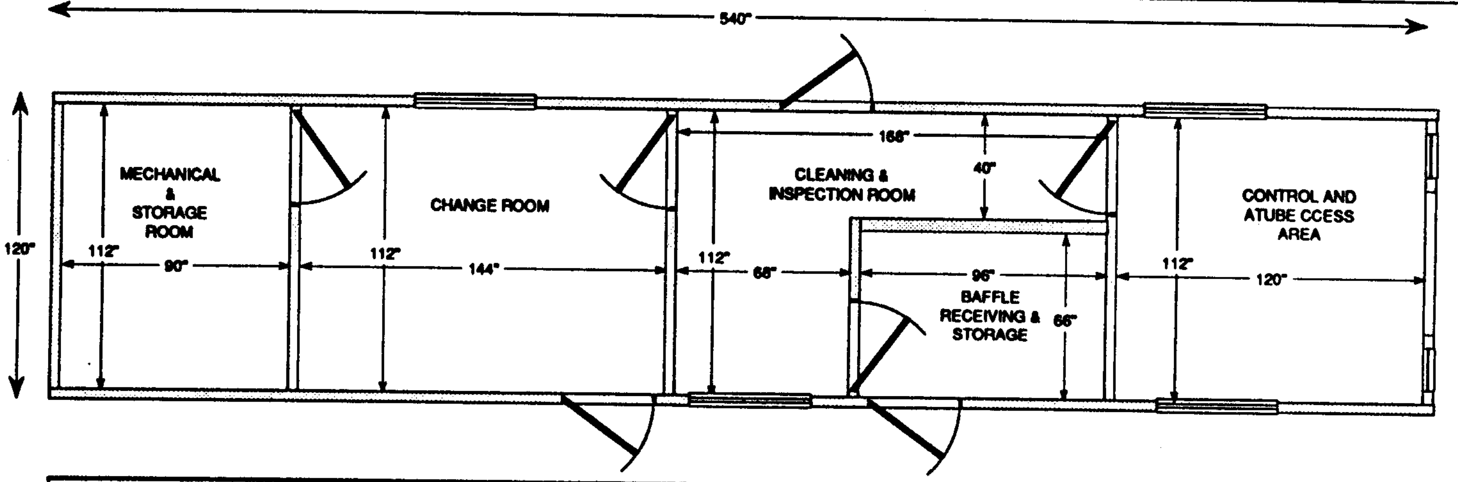
Engineering Supervisor

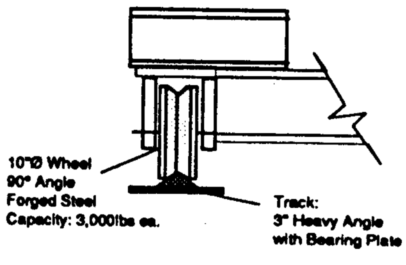
Dwg

Rev

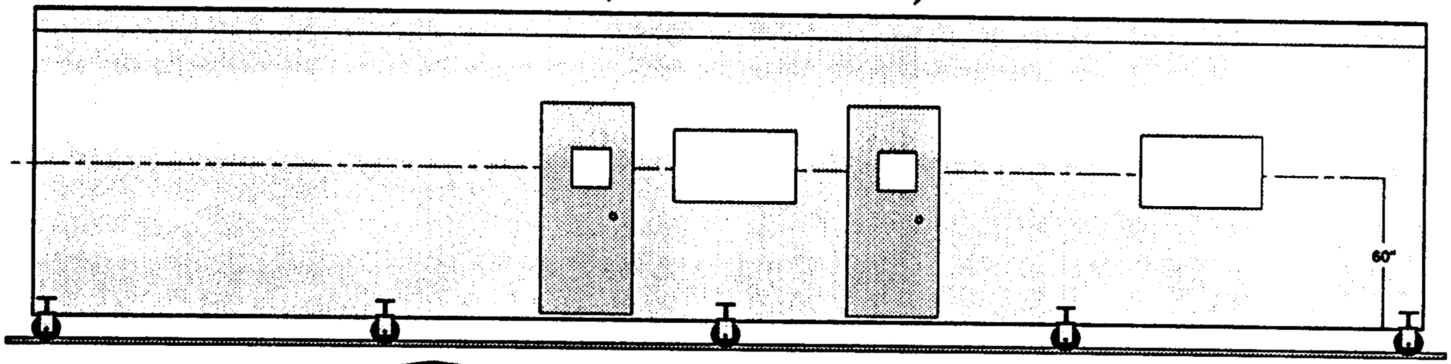
Sheet

THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CB AND IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI. REPRODUC TION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN



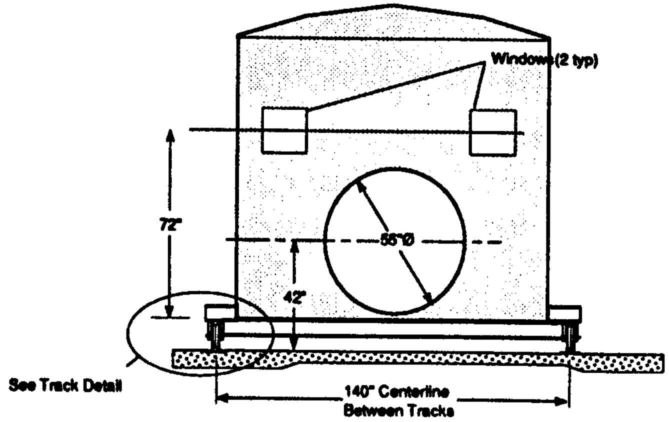


TRACK DETAIL



NOTES:

1) Clean Room is fabricated as a standard construction office trailer using metal outer covering and pitched roof.
2) Building must be designed with underframe that will support track wheels as described in the specifications. Track frame may be removed during transport to sites.
3) Inside wall surfaces shall be white Marlite® or similar material that allows for cleaning.
4) Lighting and electrical details noted on electrical drawings and specifications.
5) All windows shall be locable from side noted.
6) HVAC equipment and filter system shall be self contained and located in the Mechanical/Storage Room. Air Conditioning Condenser unit shall be mounted on frame as noted.
7) All doors are 36" Width.
8) This door is Emergency Exit Only and shall not be accessable from outside.
9) The Beam Tube Penetration shall be located per sealing drawing and shall be sipplied with a cover that fits into the seal for transporting.
10) All Dimensions are suggested. Fabrication of wall and door locations should be approx. to the dimensions noted above based on wall thickness, etc.



TUBE SIDE of CLEANROOM

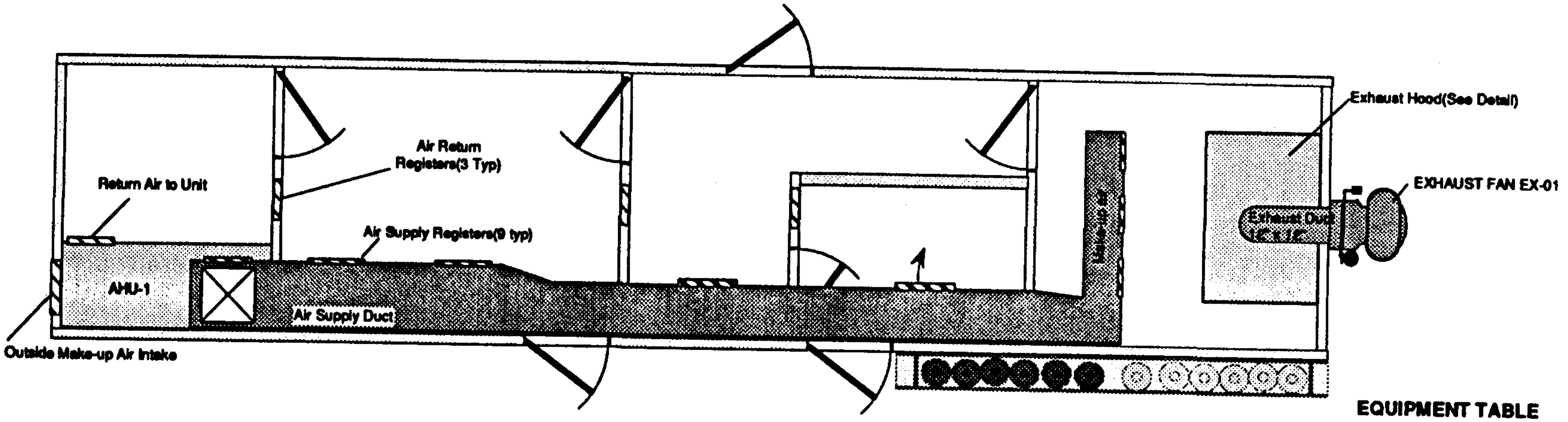
▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. ____________

CBI

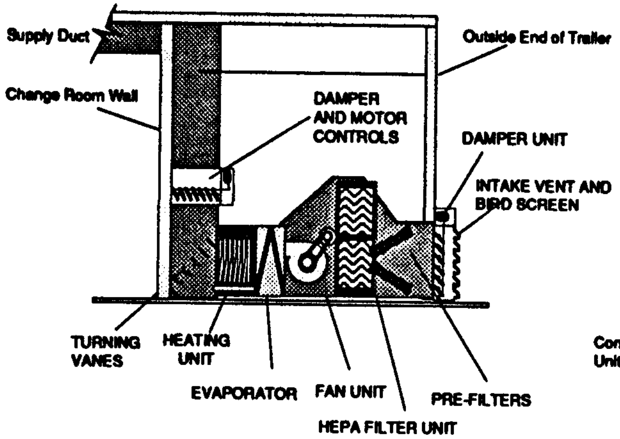
LIGO

CLEAN ROOM
Floor Plan
PLAN VIEW

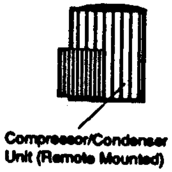


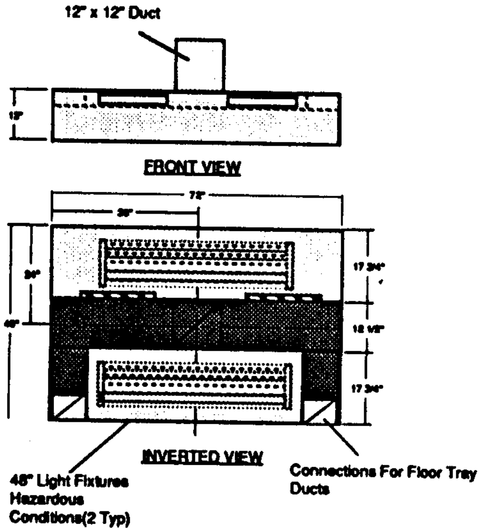
EQUIPMENT TABLE

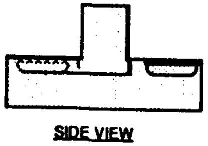
Equipment Description	SIZE	Requirements
Fan Unit	208V 10	Supplier to Determine CFM Requirements
Motorized Dampers	120VAC	Modular Positive Sealing Units
Pre-Filters	TBD	Filter Frame with Disposal Filter Elements
HEPA Filters	TBD	Filter to 0.3 Micron at 99% Min Efficiency
Evaporator Unit	208V 10	Supplier to Determine BTU Requirement
Heat Exchanger Unit	120VAC	Supplier to Determine BTU Requirement
Duct Work	TBD	Insulated and Sealed Sheet Metal
Thermostat	24VAC	Supplier to Match with System
Exhaust Fan	208V 10	Supplier to Determine CFM Requirements
Register/Diffusers	TBD	Adjustable/Lockable Direction Controls
Return Air Grille	TBD	Supplier to Determine CFM Requirements
Floor Tray	36"x48"x3"	Stainless Steel Construction 18 Ga Min.
Exhaust Air Grille	6"x8"x96"	Stainless Steel Construction 18 Ga Min.
Overhead Exhaust Hood	12"x48"x72"	Stainless Steel Construction 18 Ga Min.



AHU-1 Unit







EXHAUST HOOD DETAIL

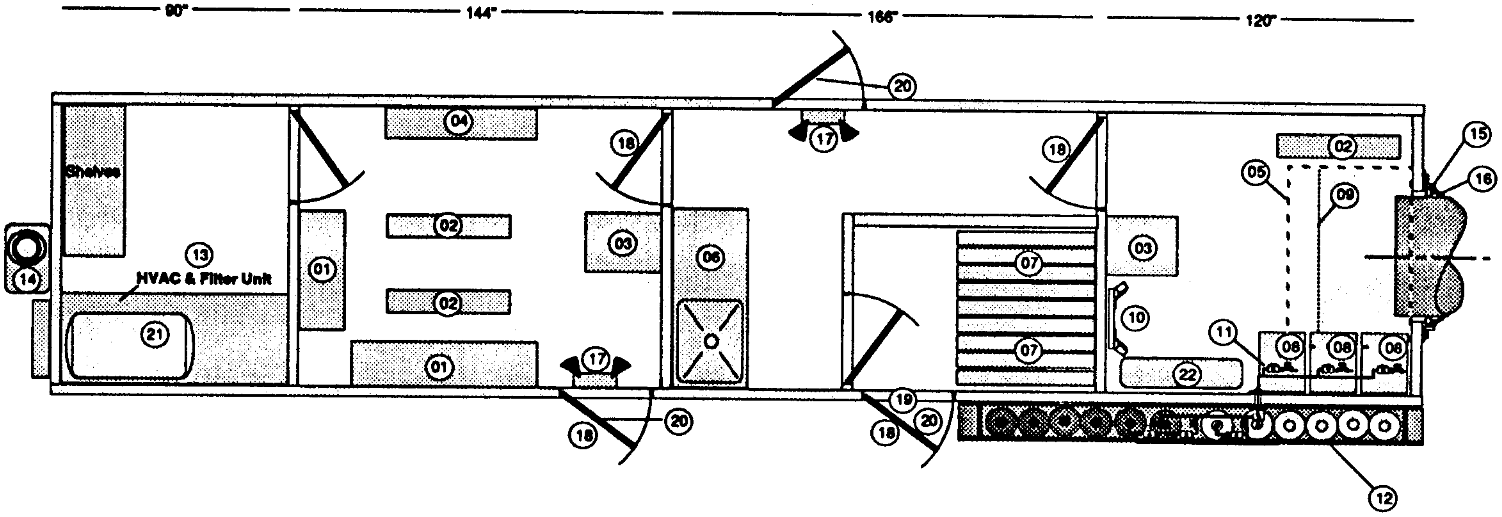
▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. ____________

CBI

LIGO

CLEAN ROOM
HVAC PLAN
PLAN VIEW



PLAN VIEW

MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.
(01)	2	Hanging Lockers	16		MMC4870T1
(02)	3	Changing Bench	48"		MMC4911T41
(03)	2	Wall Attachment Desk	24"x28"		MMC4806T18
(04)	5	Wall Attachment Shelves	12"x24"		MMC4717T38
(05)	1	Overhead Hood	48"x72"	See HVAC	HVAC EX04
(06)	1	Cleaning & Inspection Table	24"x36"	Add S.S.Top	MMC9045T18
(07)	4	Baffle Racks	27"x54"		Detail Later
(08)	2	Gas Hose Bin	18"x24"	1/8" S.S.x36"h	Detail Later
(09)	1	Floor Tray Drain Mat	36"x72"	See HVAC	HVAC EX07
(10)	2	Personnel/Equip Creepers	18"x36"	S.S. Wheels	Detail Later

MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.
(11)	2	Purge Manifold Systems	N/A	S.S.Const	Detail Later
(12)	1	Gas Bottle Rack	Later	Per OSHA	Detail Later
(13)	1	HVAC/Filter Unit	N/A	See HVAC	HVAC AHU-1
(14)	1	Compressor/Condensing Unit	N/A	See HVAC	HVAC AHU-1
(15)	1	Inflatable Seal for Tube Penet	48" Ø	See Seal Det	Detail Later
(16)	1	Secondary Gasket Seal	48" Ø	See Seal Det	Detail Later
(17)	2	Exit Sign/Emergency Lights	12"x6"	Per OSHA	MMC8367K33
(18)	6	Authorized Admittance Only	3"x5"		Global WBL43
(19)	2	Emergency Exit Only	10"x7"	Per OSHA	Global RFM2
(20)	3	Warning Step Down	10"x7"	Per OSHA	Global PSPL341
(21)	1	Potable Water Storage Tank	100 gal	Fiberglass	Detail Later
(22)	2	Inflatable Purge Dams	48" Ø		Detail Later

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. ____________

CBI

LIGO

CLEAN ROOM
EQUIPMENT
PLAN VIEW

Chicago Bridge & Iron Company is experienced and equipped to perform the alignment activities required to meet and exceed the requirements demanded in the Laser Interferometer Gravitational Observatory (LIGO) project for Caltech. CBI has developed and performed alignment techniques for both private and government projects that parallel the LIGO needs.

This project will require optical tooling procedures and equipment that use the visual line-of-sight methods. Alignment lasers and related equipment will not be accurate in this activity due to the distance of shot, closeness of equipment, and exposure to atmospheric conditions. Light bends in relationship to these concerns and the laser beam will disperse at distance, be affected by the proximity and temperature of the tube assemblies and effected by weather conditions. Visible light is less altered by these same effects and optical tooling provides the ability the quantify displacement, provides greater accuracy at these distances, and is extremely versatile in the these conditions.

The LIGO Project requirements consist of the ability to install the tube assemblies in a three dimensional envelope over a distance of 8 kilometers [4.9 miles] with a 90° turn in the center. This "L" shaped arrangement with legs reaching out at a 4 km distance requires an instrument with an accuracy of a minimum one second of an arc over each 250 meter section. Tube supports will be individually aligned at just over 12 meter intervals [40 feet]. A reference monument will be placed at each 250 meter interval and will serve as a datum for a smaller proposed "Alignment Block" that serves as reference to each tube support.

The tube sections will be placed in two dimensional references of which "X" and "Y" dimensions will be measured from the reference monuments and alignment blocks. Both references can be determined by optical tooling, however the elevation ("Y") reference may best be measured using a level indicator. This will provide an accuracy of better than ± 1 mm and will require little maintenance. The system can be filled with light oil and use a heated recirculating system to equalize the temperatures for accurate readings over the 8 km distances. Each tube support would include a sightglass and reference point. Using a micrometer with a direct measuring microscope, and accuracy of ± 0.1 mm can be obtained. If a tilting level equipped with an optical micrometer is used, an accuracy of 0,025 mm can be achieved. The "Y" dimensions will be calculated to correct for the effects of gravity. This method of reference will decrease by half, the manhours required for alignment inspections.

The "X" directions for the LIGO tube sections will be referenced from the monuments and blocks using optical tooling equipment and procedures. The procedure of long angular positioning and short lateral adjustment is the proven method for establishing long, accurate lines (within the accuracy required by LIGO). These series of alignment set-ups, shots, field checks, and re-shots will provide an accuracy that meet the ± 2.5 cm positioning requirement for each 250 meter of tubing.

CBI will begin by determining the effects of the LIGO equipment on close-in optical line-of-sight procedures. The distance from the tube section to the reference monument (& alignment blocks) must be determined through testing. This is done by measuring the effect of a large obstruction near the projected line-of-sight (LOS). The control instrument (a Paragon Jig Transit mounted with an optical micrometer is suggested) is mounted and shoots over a distance to a scale for a displacement reading. An obstruction, similar in size to a LIGO tube section, is moved to within one meter of the LOS. A displacement reading is taken by the control instrument with additional data regarding air temperature, obstacle surface temperatures, instrument stand temperature, humidity, barometric pressure, etc. and recorded for data. The obstruction is moved a distance away for the LOS and another displacement reading is taken. This is repeated at different intervals and temperatures with data taken at each obstruction location. Once the obstruction no longer effects the displacement readings, the distance will equal the minimum required from the tube section to the monument/blocks. The additional data regarding the effects of distance, direction and climatological conditions must be considered for repeatability. This information will determine test times and schedules for alignment activities for the LIGO project. Normally alignment activities are best suited for early mornings from 2:00 to 6:00 a.m. when temperature stabilization is best and local heating effects from sunlight is not factor. Additional correction factors and instrument deviations are determined in these tests in relation to operators and equipment condition.

The design for reference monuments and alignment blocks will be typical in regard to previous CBI projects. These will be standardized to provide interchangeable equipment; versatility for initial installation; and adjustable for periodic inspections. Each monument detail must provide hard points for "X" and "Y" references that will be used to position tube supports. An attachable means of adjustment and measurement will be used for determining displacement between inspections in order to monitor facility movement./ Locking bolts and possible dowel pinning of slides also be necessary for future use and inspections.

After the alignment of monuments and blocks, the method of measurement for "X: and "Y" dimensions from the references to the tube will be performed by means of micrometers and optical tooling. The elevation ("Y") can be measured in the same manner as a sightglass or a monument reference is used. The most accurate method is a tilting level equipped with an optical micrometer. Measured to a reference point on the tube outside diameter or a reference plate welded or attached to the tube and projected beyond the insulation, the "Y" dimension may be measured within the 0,025 mm range. The "X" dimension is measured from the reference monument or alignment block by means of a "stick micrometer" from the reference hard point to the tube outside diameter or a reference plate welded or attached to the tube and projected beyond the insulation. This means of measurement will provide a range of accuracy of 0.25 mm.

CBI has the equipment in-house and the experience needed to perform the alignment of the LIGO project at both sites, simultaneously. The engineering and manufacturing of alignment fixtures can be completed in short order and this activity is within the realm of CBI's long tradition of performing and excelling in special projects.

An alternate 3-D system is also being evaluated.

8.6 FIT & WELD PROCESS

When the alignment is complete, a purge collar will be installed on the inside of the seam to be welded and the fitting and welding of the joint will be accomplished from the outside using the tungsten inert gas process. When the welding is complete, the purge collar will be removed from the inside of the seam and the necessary inside leak test equipment will be installed. The leading end (clean room end) of the beam tube module will then be resealed and the clean room and horseshoe shaped enclosure with the welding equipment will be moved down the track to make way for the next cylinder section to be installed.

8.7 TESTING AND INSPECTION

Once the horseshoe shaped welding enclosure is out of the way the leak testing enclosure will be rolled into place in preparation for leak testing. After the next cylinder section has been sealed between the clean room and the welding enclosure, access to the inside of the tube is again possible and the inspection and leak testing of the seam will be accomplished.

Procedure HMST2N deals with the helium mass spectrometer hood testing of the closing weld joints between tube cans.

8.8 CLEANING

After the leak testing is complete and the inside equipment has been moved to the next seam to be tested, this cylinder section will be carefully inspected for cleanliness, cleaned as necessary, and the baffle for this cylinder section will be installed.

8.9 SEALING & SECURITY

There will be a moveable seal that will be installed at the leading edge of the section after it is cleaned. This seal will progress down the tube as it is assembled and will serve notice that the area behind it has been completed and cleaned. The seal will be a donut shaped collar with a one way valve in it to allow clean, dry air to flow from the air supply unit at the end station (starting point of beam tube module assembly) toward the clean room. A positive pressure will always be maintained inside the module with air flowing from the end completed toward the end being worked.

CBI is presently developing the positive air flow system jointly with companies in that specific business.

9.0 QUALITY PLAN

Attached is a draft copy of the QA Manuals based on ANSI/ASQC Q91-1987 (ISO 9000). CBI has been using this quality system at overseas locations for several years. Within the last year CBI developed a manual for use in the US but has not yet implemented it for contracts in the US. This quality system manual addresses the 20 points of ANSI/ASQC Q91-1987 which are:

1. Management Responsibility
2. Quality System
3. Contract Review
4. Design Control
5. Document Control
6. Purchasing
7. Purchaser Supplied Product
8. Product Identification and Traceability
9. Process Control
10. Inspection & Testing
11. Inspection, Measuring, and Test Equipment
12. Inspection & Test Status
13. Control of Nonconforming Product

14. Corrective Action
15. Handling, Storage, Packaging, and Delivery
16. Quality Records
17. Internal Quality Audits
18. Training
19. Servicing
20. Statistical Techniques

This quality system manual is used for all classes of work performed by CBI including, for example, welded components, electrical systems, mechanical work, concrete, etc. It is CBI's intention to adapt this quality system manual into a contract specific manual for the LIGO project. Some changes will be required to adapt the manual for the LIGO project including organizational interfaces, and the applicable ASME Section VIII Code requirements.

CBI's quality system is a three tier system. The first tier consists of a documented quality assurance manual (QAM). The QAM provides a description of the quality management system in place which is used to administer the twenty points indicated above. The QAM describes general policy but does not provide significant detail in the operation of the quality system.

The second tier of the quality system consists of quality assurance procedures (QAP's) which provide specific details on how the quality system is administered. Responsibilities and documentation requirements are assigned in the QAP's. The QAP's are related to the appropriate section of the QAM. For example QAP's for Section 17 of the QAM (which involves internal auditing) will be designated 17.1, 17.2, etc.

The third tier of the quality system consists of specific procedures required for the contract. These procedures are used to provide detailed work instructions necessary to perform specific operations. Examples include welding procedures, examination procedures, testing procedures, and contract record procedures. For the LIGO project, these procedures would include those for Qualification Testing (QT).

In addition to the three tiers noted above, CBI also has developed a substantial number of standard procedures known as "Red Book" procedures. These procedures establish methods for performing routine operations and are used by CBI organizations throughout the world. When available, these procedures are referred to in the QAM or QAP's as the method of control in place.

CBI also uses specialized quality plans or checklists to sequence and control operations for a contract or portions of the work.

10.0 SAFETY PLAN

10.1 SAFETY GENERAL

CBI is vitally interested in the safety of its personnel. The loss that usually accompanies injuries can be avoided by diligent safety efforts of supervision. Safety is a part of everyone's job, and Production With Safety is the Company's philosophy. CBI operates on the basis that accidents are preventable and believes that the direct control of accidents must be carried out by field supervision. It is the responsibility of CBI, through the safety department, to establish and maintain the overall company safety program.

Included is a draft of the overall Safety Manual for the LIGO Project.

10.2 SAFETY RESPONSIBILITIES

10.2.1 SITE MANAGER RESPONSIBILITIES

The Hanford Site Manager and the Livingston Site Manager have the overall responsibility for accident prevention at the respective sites. They monitor the job site personnel, equipment and procedures being used to insure all operations are carried out safely. They are responsible for establishing all work methods and operational procedures. They provide the foreman with the necessary equipment, procedures and instructions for each specific task.

10.2.2 SITE SAFETY SUPERVISOR RESPONSIBILITIES

Each site will have a Site Safety Supervisor whose responsibilities include:

a. Assisting the Site Manager in training of construction personnel in safe work practices.

b. Reviewing the weekly safety questionnaire from each work area.

c. Personal inspection and reporting of all accidents and incidents, with evaluations and recommendations to the Site Manager, District Safety and Corporate Safety on how to prevent such accidents or incidents in the future.

d. Preparation and submission of periodic reports on the status of safety on the site to the Site Manage, District Safety and to Corporate Safety.

e. Visit all work areas on a regular basis. During the visit, audit the safety performance and review any noted deficiencies with the foreman or area supervisor.

f. Act as a consultant of safety matters for all project personnel.

g. Oversee the safety related activities of the subcontractors.

10.2.3 DISTRICT/CORPORATE SAFETY RESPONSIBILITIES

The responsibilities and duties of District and Corporate Safety include:

a. Formulating, administering and making necessary changes in the Accident Prevention Program with the approval of management.

b. Preparation and submission of regular periodic reports on the status of safety in the company.

c. Acting in an advisory capacity to management, supervision, purchasing and engineering on all safety matters.

d. Investigation of all fatal or serious accidents. Investigation through the Site Safety Supervisor of reports on all accidents or incidents and checking corrective action taken to eliminate future occurrences.

e. Supervising the safety training of employees through the Site Safety Supervisor.

f. Making personal inspection with the Site Safety Supervisor for the purpose of evaluation the on-site Accident Prevention Program.

g. Help initiate and supervise activities that stimulate and maintain the interests of employees in safety.

h. Maintains the Company's Safety Program up-to-date by being well informed through outside professional contacts and involvement in professional safety organizations such as the National Safety Council, American Society of Safety Engineers and the Steel Plate Fabricators Association.

10.3 SAFETY PROGRAM

CBI will develop a Project Safety Program modeled after its standard Project Accident Prevention Program and the Associated General Contractors Safety Program. This will be developed and presented as a draft manual and will include the following items:

L. I. G. O. SAFETY MANUAL

1.0	Safety Policy Statement
2.0	Safety Responsibilities
3.0	Safety Program
4.0	Motor Vehicles
5.0	Correcting Safety Violations
6.0	Accident Reporting
7.0	Occupational Disease
8.0	Medical Facilities
9.0	Housekeeping and Sanitation
10.0	Personal Protective Clothing & Equipment
11.0	Material Handling and Storage
12.0	Control of Ionizing Radiation
13.0	Ventilation
14.0	Lighting
15.0	Fire Prevention
16.0	Fire Protection
17.0	Electrical Wiring and Apparatus
18.0	Hand and Power Tools
19.0	Equipment Maintenance
20.0	Lifting Equipment
21.0	Conveyors and Cableway
22.0	Scaffolds, Platforms, and Ladders
23.0	Abrasive Blasting & Painting
24.0	Earthmoving and Handling Equipment

11.0 ENVIRONMENTAL PLAN

CBI has received Caltech's Environmental Assessment of the Hanford Site and is presently reviewing it. CB&I Corporate has produced the General Conditions of Environmental Plan to address the following issues:

11.1 Site Documentation/Contamination
11.2 Stormwater Permits
11.3 Hazardous Materials Handling
    11.3.1 Storage
    11.3.2 Disposal
    11.3.3 Manifest
11.4 Regulatory Inspections

- 11.5 Local/State Permits
- 11.6 Surface Drainage/Outfall Discharges
- 11.7 Sanitation
- 11.8 Training & Documentation
- 11.9 Emergency Communications
- 11.10 Spill Prevention
    - 11.10.1 Contamination
    - 11.10.2 Control
    - 11.10.3 Records
    - 11.10.4 Response Plan
- 11.11 Chemical Hygiene Plan
- 11.12 Fuel Storage/Handling

12.0. SCHEDULE & COST ENGINEERING

12.1 CPM Software

A preliminary schedule is attached to show the format of the TEXIM scheduling software in the barchart mode. Caltech's schedule indicate starting erection of beam assemblies only after all assemblies have been fabricated. CBI proposes that this be reviewed to permit the immediate placing of assemblies after fabrication. Space is a premium. The overall impact of tube delivery, fabrication and erection timing and sequencing is presently being evaluated.

Development of reporting formats should be resolved prior to exercising the Option portion of the contract. This will result in a minimum number of reports that will be useful to both organizations for control of the work. The following items should be considered:

- 12.2 Update Timing
- 12.3 Progress Reporting
    - 12.3.1 Format
- 12.4 Submittal Control
- 12.5 Weekly Schedule Meetings
- 12.6 Short Term Schedules

12.7 Earned Value/Progress Payment Evaluation
12.8 Dual Site Coordination

A preliminary construction WBS and network is being developed for the Option. This WBS is based on the "LIGO Process Flow" document presented at the last meeting combined with some of the detailed construction preparation activities required for mobilization and preparation to begin work.

12.9 WORK BREAKDOWN STRUCTURE

A preliminary construction WBS and network is being developed for the Option. This WBS is based on the "LIGO Process Flow" document presented at the last meeting combined with some of the detailed construction preparation activities required for mobilization and preparation to begin work.

The purpose of the WBS is to provide the means for controlling the Option Phase of the L.I.G.O. Project. It is applicable to all tasks and all CBI departments involved with the Option.

12.9.1 WBS WORK LEVELS

12.9.1.1 WBS LEVEL ONE

The Beam Tube Fabrication and Installation work is item 2.4 for the Hanford site and 3.4 for the Livingston site. These are the first levels of the WBS.

12.9.1.2 WBS LEVEL TWO

The second level of the WBS indicates the major task groupings:

Hanford site:

2.0.0	Mobilization & Special Equipment
2.4.1	Off Site Engr. & Procurement of tubes and material
2.4.2	Off Site Engr. & Procurement of stiffeners and material
2.4.3	Off Site Engr. & Procurement of expansion bellows
2.4.4	Off Site Engr. & Procurement of vacuum ports
2.4.5	Site Assembly of Beam Tube Module
2.4.6	Erection of Beam Tube Module

Livingston site:

3.0.0	Mobilization & Special Equipment
3.4.1	Off Site Engr. & Procurement of tubes and material
3.4.2	Off Site Engr. & Procurement of stiffeners and material
3.4.3	Off Site Engr. & Procurement of expansion bellows
3.4.4	Off Site Engr. & Procurement of vacuum ports
3.4.5	Site Assembly of Beam Tube Module
3.4.6	Erection of Beam Tube Module

12.9.1.3 WBS LEVEL THREE

The third level of the WBS will identify the components and tasks required under each second level item. The third level is the summary schedule issued to report progress and assemble costs. All man hours, expenses, and purchases shall identify the appropriate third level item number. The third level will be so defined as to provide traceability to unique tube module units, this is shown as the "xxx" number location in the example below.

An example of this level is as follows for the Hanford Tubes:

2.4.1.xxx.1 Prep. of Engineering Material Specifications and Bill Sheets
2.4.1.xxx.2 Order Material for Tubes
2.4.1.xxx.3 Mill Roll Material
2.4.1.xxx.4 Mill Bake out of Material
2.4.1.xxx.5 Specimen Outgas Testing
2.4.1.xxx.6 Ship to Tube Fabricator
2.4.1.xxx.7 Fabrication of Tubes
2.4.1.xxx.8 Ship to Site

A full CPM plan is presently being developed along this line.

13.0 <u>DEMOBILIZATION</u>

13.1 EQUIPMENT

Upon the completion of CBI's work at the Hanford Site, all construction equipment will be removed transported and reassembled at the Livingston site. Following completion of the work at Livingston, all equipment will be removed.

13.2 BUILDINGS

All temporary construction buildings will be removed from the job sites when CBI's work is complete. The tube fabrication buildings can be left as part of the permanent installation if Caltech agrees. If not, the building will be removed and the slab broken up and disposed of in accordance with the Environmental Plan.

13.3 PERSONNEL

CBI will maintain the necessary supervisory personnel at each job site until all CBI work has been completed and accepted by Caltech.

14.0 COMMISSIONING ACTIVITIES/PLAN

Although not in our present scope, CBI is concerned about the commissioning of the system. Without involvement it will be a source of problems is determining responsibility for any problems that might arise. It is suggested that this issue remain open for discussion pending development of the systems supplier and installer. Items to be address in this area should include at least the following activities:

14.1 Precommisioning
14.2 Inspection & Sign Off
14.3 Documentation Packages
14.4 System/Loop Checks
14.5 Mechanical Acceptance
14.6 Operational Checks
14.7 System Operations Acceptance

CHICAGO BRIDGE & IRON COMPANY
SAFETY MANUAL FOR
L.I.G.O. PROJECT

(ARTICLE IV, OPTION, CALTECH CONTRACT NO. C146)
Revision No.--Draft

TABLE OF CONTENTS

CHICAGO BRIDGE & IRON COMPANY
SAFETY MANUAL FOR
L.I.G.O. PROJECT

(ARTICLE IV, OPTION, CALTECH CONTRACT NO. C146)

Revision No.--Draft

1.0 SAFETY POLICY STATEMENT

CBI is vitally interested in the safety of its personnel. The loss that usually accompanies injuries can be avoided by diligent safety efforts of supervision. Safety is a part of everyone's job, and Production With Safety is the Company's philosophy. CBI operates on the basis that accidents are preventable and believes that the direct control of accidents must be carried out by field supervision. It is the responsibility of CBI, through the safety department, to establish and maintain the overall company safety program.

2.0 SAFETY RESPONSIBILITIES

2.1 SITE MANAGER

The Hanford Site Manager and the Livingston Site Manager have the overall responsibility for accident prevention at the respective sites. They monitor the job site personnel, equipment and procedures being used to insure all operations are carried out safely. They are responsible for establishing all work methods and operational procedures. They provide the foreman with the necessary equipment, procedures and instructions for each specific task.

2.2 SITE SUPERVISOR

Each site will have a Site Safety Supervisor whose responsibilities include:

a. Assisting the Site Manager in training of construction personnel in safe work practices.

b. Reviewing the weekly safety questionnaire from each work area.

c. Personal inspection and reporting of all accidents and incidents, with evaluations and recommendations to the Site Manager, District Safety and Corporate Safety on how to prevent such accidents or incidents in the future.

d. Preparation and submission of periodic reports on the status of safety on the site to the Site Manage, District Safety and to Corporate Safety.

e. Visiting all work areas on a regular basis. During the visit, audit the safety performance and review any noted deficiencies with the foreman or area supervisor.

f. Acting as a consultant of safety matters for all project personnel.

g. Overseeing the safety related activities of the subcontractors.

2.3 The responsibilities and duties of District and Corporate Safety include:

a. Formulating, administering and making necessary changes in the Accident Prevention Program with the approval of management.

b. Preparation and submission of regular periodic reports on the status of safety in the company.

c. Acting in an advisory capacity to management, supervision, purchasing and engineering on all safety matters.

d. Investigation of all fatal or serious accidents. Investigation through the Site Safety Supervisor of reports on all accidents or incidents and checking corrective action taken to eliminate future occurrences.

e. Supervising the safety training of employees through the Site Safety Supervisor.

f. Making personal inspection with the Site Safety Supervisor for the purpose of evaluation the on-site Accident Prevention Program.

g. Helping initiate and supervise activities that stimulate and maintain the interests of employees in safety.

h. Maintaining the Company's Safety Program up-to-date by being well informed through outside professional contacts and involvement in professional safety organizations such as the National Safety Council, American Society of Safety Engineers and the Steel Plate Fabricators Association.

3.0 SAFETY PROGRAM

3.1 GENERAL

The safety program is formulated and carried out by the safety personnel with the approval of management. The program includes:

a. Safety training and education for all site personnel.

b. Evaluation and selection of all safety equipment used on the construction sites.

c. Various safety programs for participation by construction employees with recognition and reward for no lost time accidents over specified periods of time.

d. Company-Employee communication on safety through letters, pamphlets, posters and a safety newsletter.

3.2 JOB SITE SAFETY PROGRAM

The supervisors are responsible for and completely in charge of safety on the job site through accident prevention training.

a. New employees a given instructions in the following areas:

1. Location and availability of first aid and medical facilities.
2. Method of reporting accidents of incidents.
3. Proper Site and Company safety rules.
4. Rights under the Occupational Safety and Health Act of 1970, along with notification that we will enforce the regulations along with Company safety rules.
5. Rights concerning equal employment opportunity and the Americans with Disabilities Act.

b. Each employee receives safety orientation training and a copy of the booklet entitled "Basic Safety Rules for Field Erection and Construction" as well as a Project Information Pamphlet specific to the Hanford or Livingston job site. This training includes Hazardous Communication, Substance Abuse, Confined Space and CBI Electrical Hazard Programs. The employee signs the training form as acknowledgment of this instruction.

c. Job site safety meetings are conducted every week. If special conditions require, these meetings are held more often. All employees must attend these meetings. Some subjects for these tool-box safety meetings are chosen from the "Job site Safety Meeting Guides".

d. The Supervisor's Manual contains a section which outlines Company rules and practices.

---

e. Safety literature is sent to supervisors periodically to assist them in the safety education of all employees.

f. Job site supervisors assist in monitoring job site safety. A safety questionnaire is completed weekly, and is submitted to the District Safety Supervisor. The safety questionnaire reports the current conditions found on the site.

g. Periodic job site visits are made by the District and Corporate Safety to ensure that proper safety practices are being carried out.

4.0 MOTOR VEHICLES

4.1 All drivers will be required to demonstrate their driving ability in the equipment they will be operating under actual job conditions. Applicable DOT regulations will be followed and commercial licenses will be obtained when required. Drivers will make regular inspections of their vehicles. Inspections to include steering, brakes, mirrors, lights, horn, tires and windshield wipers. Any special safety items, such as backup alarms, will also be checked. All defects will be reported so that necessary repairs can be made.

4.2 No person shall be permitted to remain in or on a truck being loaded by excavating equipment or crane unless the cab is adequately protected against impact. Material being loaded should be within the safe weight limit for the truck being used and should not project beyond the truck body when doing so presents a hazard. Loads projecting over the end of the truck should be marked with a red flag and lighted at night. Loose materials should be covered to prevent them from flying ou of the vehicle while moving.

4.3 Trucks operating on public roads must comply with weight and size limitations of the state. All drivers are required to stay within the posted speed limit and obey all traffic laws. Off highway operation may require extra precautions to prevent shifting of the load while crossing rough terrain. Trucks should be backed under the direction of a signalperson if the operator cannot clearly see the area to the rear of the vehicle and especially is the truck is not equipped with an automatic backup alarm. Windshields, mirrors and lights whould be kept clean with unobstructed views.

4.4 Construction roads will be maintained in safe operating condition at all times. Whenever possible, haul roads will be designed to avoid sharp curves, sudden changes in grade and railroad tracks. Truck traffic will be routed to avoid cross-traffic and pedestrain crossings whenever possible. One-way traffic will be utilized as much as possible.

4.5 Trucks used to transport workers will be provided with safe seating, safety belts, and side and end protection. A convenient means of mounting and dismounting will be provided. Workers will not be permitted to get on or off a moving truck at any time. Riders must ride in the spaces provided, no riding on running boards, fenders, bumpers or on tops of cabs.

4.6 Brakes, steering gears, tires and all operating ports should be inspected regularly, The driver must report any needed repairs so the the vehicles can be maintained in good operating condition. Engines must be shut off while fueling and vehicles should not be fueled from open cans. Dump-body equipped trucks must have a permanent, positive means for locking the body in the raised position.

5.0 CORRECTING SAFETY VIOLATIONS

5.1 Safety violations discovered by anyone must be reported immediately and addressed by the responsible supervisor.

5.2 Any individual repeatedly notified of the same safety violation shall be subject to suspension from the job site and/or termination of employment.

5.3 The Site Manager shall be the final authority over the enforcement of safety regulations and any disciplinary measures to be taken.

6.0 ACCIDENT REPORTING

6.1 All accidents are to be reported to the Site Safety Supervisor. He will take the necessary steps in investigating and taking corrective measures following each individual accident. The Supervisor will complete the Supervisors Accident Investigation Report.

6.2 Prompt reporting will be required for the following:

a. Disabling injuries

b. Permanent impairments

c. Deaths

d. Property damage accidents ($100 or more)

e. Any injury to the general public

f. Any damage to private property

6.3 The Site Safety Supervisor will complete the Employer's First Report of Injury, or the equivalent, on all injuries and illnesses referred to a physician.

7.0 OCCUPATIONAL DISEASES

7.1 GENERAL

Most occupational diseases do not develop from occasional exposure; they result from long and continuous exposure to a specific health hazard. Workers engaged in occupations where health hazards may exist should be examined by appropriate medical personnel when necessary and as regulatory requirements prescribe. Exposure to an occupational disease is to be regared as seriously as other job hazards. Every wffort will be made to control disease producing hazards. Close attention is given to OSHA requirements governing worker exposure to toxic substances, especially where OSHA has issued a standard addressing a specific substance.

7.2 TOXIC SUBSTANCES

a. Silica dust is found in many types of work including tunneling, sandblasting, grinding, sand and gravel pit operations, brick and stone cutting and most concrete work. Preventive measures include adequate ventilation, use of NIOSH/MSHA approved respirators, use of vacuum system to collect the dust and use of water to keep work areas wet.

b. Carbon monoxide, inert gases for purging and welding fumes wil most certainly present asphyziation hazards for both the Hanford and Livingston job sites. Preventive measures include adequate ventilation and the use of approved respirators.

c. Lead poisoning may be found in plumbing and soldering, painting, glazing, sheet lead burning, sandpapering or sandblasting of paint, welding of painted steel and removal of old paint. The poison is taken into the body by inhaling lead fumes of dust, by swallowing tiny particles of lead or by absorbing the lead through the skin. Preventive measures include respiratory protection, avoid breathing fumes or dust, proper clothing, not eating, storing food or using tobacco where lead exposure is possible and practicing good personal hygiene. Anyone suspected of having contracted lead poisoning should consult a physician immediately.

d. Certain chemicals found in cutting oils and emulsions and in lime and cement can cause dry chapped skin which may become cracked and infected. Preventive measures include avoiding exposure to these items, throughly washing exposed parts and use of lanolin ointment to prevent dryness.

8.0 MEDICAL FACILITIES

8.1 Provisions will be made prior to the beginning of work at each site for Doctor, Hospital and Ambulance service for any serious accident. Names, addresses and telephone numbers of those providing these services will be posted at conspicuous places on the job site.

8.2 Trained, qualified first aid personnel will be present on each site during each shift.

8.3 Each work area is equipped with an approved first aid kit. The kit is inspected periodically to ensure that the expended items are replaced.

9.0 HOUSEKEEPING AND SANITATION

10.0 PERSONAL PROTECTIVE CLOTHING AND SAFETY EQUIPMENT

10.1 All employees and visitors are required to wear approved head protection in the work areas during working hours.

10.2 All employees and visitors are required to wear an approved type of eye protection while in the work areas during working hours. Non-prescription safety glasses are available at no cost to employees. There is a slight fee for prescription safety glasses ordered for Company employees.

10.3 Double eye protection is required for certain operations such as welding, burning and grinding.

10.4 Company employees must obtain approval from the Site Safety Supervisor to wear contact lens on the job site during working hours.

10.5 Fall protection is required for employees working above/below ground when not protected by an approved scaffold or staging.

10.6 Hearing protection is required when in an area where the noise level exceeds that specified in the Hearing Conservation Program.

10.7 When condition require, approved respiratory equipment will be provided and employees will be instructed in the proper use of the equipment in accordance with the Respiratory Protection Program.

10.8 Confined Space Training will be provided to all employees who will be entering the cylinder sections. The Confined Space Entry Procedure will be used to control the work on the inside of the beam tube modules, clean room and the welding and leak testing enclosures.

11.0 MATERIAL HANDLING AND STORAGE

12.0 CONTROL OF IONIZING RADIATION

12.1 Daily x-ray and radiation exposure data will be maintained when radiography is being performed at the site. Each radiographer is required to wear a film badge which records radiation exposure.

12.2 A dosimeter is to be worn by each radiographer. The dosimeter reading is to be recorded on the job site log daily.

12.3 Survey meters will be used to verify and monitor the safe working areas during radiation producing operations. The 2 MR line will be roped off and posted with radiation warning signs and the area will be kept under surveillance at all times during the exposure operation.

12.4 Only trained and qualified personnel are to perform radiography work.

12.5 The Site Safety Supervisor will complete the Radiography Internal Inspection Checklist each month.

13.0 VENTILATION

13.1 Adequate ventilation will be provided to those any area where needed to provide a safe atmosphere. Ventilation units will be both portable and fixed so as to provide the necessary flexibility as work areas are changed.

13.2 Oxygen analyzers, combustible gas meters and other monitoring devices will be used to ensure that no person will be allowed to enter or work in an explosive of toxic atmosphere.

14.0 LIGHTING

14.1 Lighting intensities will be maintained in accordance with Federal and State safety requirements.

14.2 Proper consideration will be given to the type, location and installation of all sources of artificial lighting.

15.0 FIRE PREVENTION

15.1 Smoking is not permitted in areas where flammable and combustible materials are stored or handled.

15.2 Portable storage tanks containing flammable liquids will be grounded (and bonded to portable metal containers when filling).

15.3 Portable containers used for the transfer of flammable liquids shall be of approved type with self-closing valves and flame arrestors.

15.4 The use of compressed gas cylinders pose a potential hazard and their use will be governed by the following:

a. Cylinders will not be hoisted by means of magnets, slings or by the valve protection cap.

b. Cylinder valves will be closed at all times when not in use.

c. When cylinders are designed to accept valve protection caps, they will be kept in place, hand tight, except when the cylinders are connected for use.

d. Compressed gas cylinders will be secured in an upright position at all times.

e. When in storage, oxygen and fuel gas cylinders will be separated from each other by a minimum distance of 20 feet or provide a barrier equivalent to a four hour fire wall (1/4" steel plate).

f. All compressed gas cylinders will be located so as to be protected from all welding and burning operations.

g. Oxygen and fuel gas lines will be equipped with back flow prevention devices.

16.0 FIRE PROTECTION

16.1 Fully charged and operative fire extinguishers will be supplied according to the following guidelines:

a. Crane cabs: 1-5bc rated extinguisher mounted in each.

b. Office and change shacks: 1-20bc rated extinguisher within 75 feet.

c. Generator and fuel storage: 1-20bc rated extinguisher within 75 feet.

d. Motor driven weld units with fuel storage: 1-20bc rated extinguisher within 75 feet.

e. Compressor refueling: 1-20bc rated extinguisher within 75 feet.

f. In any area where work is being performed on all scaffold levels: 1-20bc rated unit within 75 feet of workmen.

NOTE: Areas of coverage in items b. thru e. can be overlapped.

16.2 Personnel will be familiar with five extinguisher locations and operation.

16.3 Extinguisher will be inspected monthly by the Site Safety Supervisor.

17.0 ELECTRICAL WIRING AND APPARATUS

17.1 All electrical wiring will be done by qualified personnel.

17.2 All temporary electrical wiring will comply with the National Electric Code.

17.3 All portable electrical equipment will be grounded.

17.4 All single phase low-voltage extension cords will be three wire conductor type.

17.5 All low-voltage hand held portable electrical equipment will be used in conjunction with GFCI's. Equipment connected by cord sets that are not protected by GFCI's will be inspected as part of the Assured Equipment Grounding Conductor Program.

17.6 High voltage electrical wiring will be either supported above ground or buried.

17.7 Lighting systems will be continuously maintained.

17.8 High voltage transformers will be protected from unauthorized access.

17.9 Tools insulated for the appropriate voltage will be used for the removal of fuses.

18.0 HAND TOOLS AND POWER TOOLS

18.1 Tools will be used only for the purpose for which they are designed.

18.2 Tools will be inspected frequently and maintained in good repair.

18.3 All grinding and brushing power tools are required to have approved guards.

18.4 All abrasive wheels will be inspected prior to use to assure they have not been damages by improper handling or mounting, and will be operated within the manufacturer's rated speeds.

18.5 Excess flow valves will be used of air systems using hose larger than 1/2" inside diameter.

18.6 Hosed will be organized so as not to create a tripping hazard on ladders and scaffolds.

19.0 EQUIPMENT MAINTENANCE

20.0 LIFTING EQUIPMENT

20.1 All rigging, hoisting or power equipment is inspected daily, prior to use, to assure the safety of the equipment and the employees.

20.2 In addition to the daily inspections, written monthly and annual reports are made of each piece of lifting equipment.

20.3 Equipment operators are instructed in our policies and rules for operation and in equipment maintenance. They are trained and certified for each type of lifting equipment.

20.4 The signal man will be specifically designated and instructed in the use of proper hand signals.

20.5 A chart containing the proper hand signals will be maintained in a prominent location on the job site. (A chart containing the proper hand signals is also contained in the safety rules booklet which is issued to each employee.)

20.6 If any piece of mobilize equipment has obstructed vision to the rear, it will be equipped with a back-up alarm system, or a signal person will be provided.

20.7 Equipment will be repaired in designated, safe locations.

20.8 The condition of all cables, slings, hooks and clamps will be inspected in accordance with the Federal or State safety requirements.

20.9 Personnel are not permitted to walk or work underneath suspended loads.

20.10 No piece of equipment is to be operated closer than 15 feet to voltage lines of 220 volts or more.

21.0 CONVEYORS AND CABLEWAYS

22.0 SCAFFOLDS, PLATFORMS AND LADDERS

22.1 Scaffolds, platforms and ladders will comply with Federal and State safety regulation.

22.2 All openings will be barricaded or fenced.

22.3 All tube and coupler scaffolding will be adequately braced and secured to prevent excessive movement.

22.4 Ladders will be inspected before use and all ladders with broken of missing rungs, defective side rails or other defects will be red-tagged and removed from use.

23.0 ABRASIVE BLASTING AND PAINTING

23.1 There are certain items pertinent to blasting and painting that are additional requirements for the Paint Foreman.

23.2 Sand and Shot Blasting

a. Respiratory Protection: All employees comply with the CBI Respiratory Protection Program for Field Paint Crews.

b. Equipment:

1. An automatic safety shut off control (deadman switch is a part of the blasting hand control.

2. Standard safety couplings are used at all joints of hose, under air pressure, or provisions are made to holds ends together.

3. The hose is kept running as straight as possible. Long radius curves are made around an object. Sharp curves cause extensive wear on the tube of the hose.

c. Enclosed Blasting Areas: Oxygen deficiency checks will be made periodically.

23.3 Painting

a. General: Painting equipment and procedures are carefully examined frequently to assure potential hazards are eliminated. Items examined are rigging, scaffolding, staging, ladders, ropes and cables. Of particular importance are vapor concentrations, fire and explosion hazards, toxic materials and corrosive liquids.

b. Respiratory Protection: All employees comply with the CBI Respiratory Program for Field Paint Crews.

c. Rigging Practices: CBI Construction Manual #46 specifically relates rigging details

d. Personal Hygiene: Protective skin cream is used to protect the worker and to aid in clean up. Materials such a thinners and solvents can cause skin irritation and are not used to clean the skin.

e. Ventilation:

1. In enclosed spaces, the atmosphere is checked for oxygen deficiency and combustible gas before starting work. Thereafter, when painting, a check is made every two hours. Findings are recorded on the Painting Safety Questionnaire.

2. Since safe limits for breathing vapors are below the minimum combustible range, ventilation is used to prevent dangerous accumulations of vapors.

3. The Foreman utilizes the Company Standard of ventilation for procedures and methods.

4. The Foreman maintains a list of threshold limit values for solvents as published by the American Conference of Government Industrial Hygienists. The values are observed when working in confined spaces.

5. Painting will cease if at any time the combustible gas reading is 10% of the lower explosive limit of the solvent vapor.

6. Air flow equipment, such as motors, fans, collectors and pipes are grounded.

f. Pressure Equipment:

1. Relief valves are tested daily.

2. Remote control deadman valves are used with pressure equipment.

3. Paint nozzle and tank are grounded.

4. Airless spray guns have a trigger guard, trigger lock, safety tip guard and built-in fluid diffuser.

g. Paint Mixing:

1. All materials are mixed in a well ventilated area away from any source of ignition.

2. Manufacturer's instructions shall be followed.

h. Fire Prevention:

1. Signs are posted specifying no smoking, fires or open lights within 50 feet of solvent handling areas.

2. No more than 25 gallons of flammable or combustible liquids are stored (in an approved storage cabinet), in office, change or equipment shanties, or trailers.

3. Storage in excess of 25 gallons is in separate equipment shanties or trailers used exclusively for storage.

4. Outside storage of paints, thinners, etc., are in containers not exceeding 60 gallons each and are placed in piles not to exceed 1,100 gallons per area. All storage areas are at least 20 feet from any building of combustible structure.

5. A 20-B rated extinguisher or an equivalent of smaller extinguishers are provided from 25 to 75 feet from the storage area.

i. Inspection: The Paint Foreman will inspect the job site no less that weekly and complete the Painting Safety Questionnaire.

23.4 Emergency Egress

a. An attendant is present at all times outside where personnel are working in an enclosure. The attendant may perform other duties, such as filling sand blast pot and mixing paint, but shall not leave the immediate area.

b. A signal system (rap, radio, alarm) will be established between painters/blasters and the attendant.

c. The attendant has rescue equipment and a self-contained breathing apparatus. In an emergency, the attendant summons aid prior to rescue.

23.5 Hazardous Waste Disposal

a. Each facility has on file with the state of its location and the Environmental Protection Agency an approved Hazardous Waste Program that complies with the Resource Conservation and Recovery Act.

b. Where hazardous wastes are not accepted by the customer/owner, the hazardous wastes will be returned to the facility for disposal.

24.0 EARTHMOVING AND HANDLING EQUIPMENT

25.0 EXCAVATIONS

25.1 Prior to opening an excavation, provisions are to be made to accommodate underground installations.

25.2 The walls and faces of all excavations, in which employees are exposed to danger from moving ground, will be guarded by a shoring system, sloping of the ground or some other equivalent means.

25.3 Excavations are to be inspected by a competent person after every rainstorm or other hazard increasing occurrence, and the protection against slides and cave-ins shall be increased if necessary.

25.4 The determination of the angle of repose and design of the supporting systems are based on careful evaluation of weather conditions, soil consistency, and other operations.

25.5 Piling, cribbing, shoring, etc., are designed by a qualified person and meet accepted engineering requirements.

25.6 In excavations which employees may be required to enter, excavated or other material shall be effectively stored and retained at least 2 feet or more from the edge of the excavation unless other effective retaining devices are used.

25.7 Support systems are planned and designed by a qualified person when excavation is in excess of 20 feet in depth, adjacent to structures or improvements, or subject to vibration or ground water.

25.8 Materials used for sheeting, sheet piling, cribbing, bracing, shoring and underpinning will be in good serviceable condition.

25.9 Except in hard rock, excavations below the level of the base of footing of any foundation or retaining wall is not permitted unless the wall is underpined and all other precautions are taken to assure the stability of the adjacent walls for the protection of employees involved in excavation work.

25.10 Precautions are to be taken to assure sidewalls are supported if heavy equipment is to be located near the edge.

25.11 Where oxygen deficiency or gaseous conditions are possible, the atmosphere in an excavation is to be tested. Where adverse atmospheric conditions may be present, emergency rescue equipment is provided.

26.0 TRENCHING AND SHORING

26.1 Shoring and/or bracing will be placed in every trench over 5 feet in depth regardless of soil type, except solid rock, unless banks are sloped to the angle of repose in accordance to soil types as based on recognized tables, e.g., OSHA regulations.

26.2 Shoring and bracing are carried down the trench.

26.3 All excavated material will be placed a minimum of 2 feet back from the trench edge.

26.4 Adequate means of exit will be provided for every 25 feet of lateral travel in trenches more than 4 feet in depth.

26.5 Where bracing of shoring trenches is not practical or economical due to unstable ground, movable steel trench shields may be used.

27.0 PIPELINES

28.0 DEMOLITION

29.0 PILE DRIVING

30.0 TUNNELS AND SHAFTS

31.0 BOILERS

32.0 UNFIRED PRESSURE VESSELS

33.0 EXPLOSIVES

34.0 WELDING AND CUTTING

35.0 STEEL ERECTION

36.0 CONCRETE CONSTRUCTION

37.0 FLOOR AND WALL OPENINGS

38.0 ROAD BUILDING

39.0 QUARRIES AND GRAVEL PITS

40.0 MOBILE ASPHALT PLANTS

41.0 RAILROAD CONSTRUCTION

42.0 MARINE EQUIPMENT

42.1 Coast Guard approved life preservers shall be worn by personnel working on or over water, when guard rail protection is not provided.

42.2 Ring life buoys equipped with 90 feet of rope will be provided every 50 feet along the waterfront.

43.0 SUBCONTRACTORS AND SUPPLIERS

43.1 All subcontractors performing work for CBI at the site will be required to abide by the Accident Prevention Plan requirements. They will be expected to have written qualified Accident Prevention Plans focusing on the specific work they execute.

43.2 Subcontractors must complete the CBI Subcontractors Safety and Health Qualification form.

43.3 Suppliers who are delivering construction equipment, tools, or other items will be briefed on specific safety and access requirements appropriate for their incidental delivery service.

44.0 REGULATORY COMPLIANCE

CBI and its Subcontractors comply with Federal OSHA Regulations

45.0 HAZARD COMMUNICATION PROGRAM

45.1 The Site Safety Supervisor is responsible for the Hazardous Communication Program, which is kept on the job site.

45.2 Personnel are trained in the program components and the training log is kept at the job site.

45.3 Material Safety Sheets (MSDS) are maintained at the job site and are available for examination from the Site Safety Supervisor.

45.4 Secondary of transfer containers will be labeled it the container contents will not be utilized in one shift.

46.0 INSPECTION CHECK LIST

47.0 BLANK FORMS

L.I.G.O. CONSTRUCTION ENVIRONMENTAL PLAN

GENERAL CONDITIONS

Environmental

The contractor shall keep and maintain the project site clean and free of any environmental hazards in accordance with federal, state, and local regulations. During all phases of construction, including supervision of work and until final acceptance of the project, the contractor shall keep the site of work and other areas by it in neat and clean condition and free from any accumulation of rubbish and debris. The contractor shall dispose of all rubbish and waste materials of any nature occurring at the work site and shall establish regular intervals of collection and disposal of such materials and waste. The contractor shall also keep its access roads free from dirt, rubbish and unnecessary obstructions resulting from its operations. Care shall be taken to prevent spillage along roads during transport. Any such spillage shall be removed immediately and the area cleaned.

Disposal of rubbish and surplus materials shall be off the site of construction, at the contractor's expense, all in accordance with local codes and ordinances governing locations and methods of disposal, and in conformance with all applicable safety laws. The contractor will be required to have a waste minimization program outlining the procedures being implemented to reuse and recycle materials so that reduction of waste generated can be achieved.

Portable chemical toilets shall be provided by the contractor whenever needed for the use of the contractor's employees. These accommodations shall be maintained in neat and sanitary condition and shall conform with 29 CFR 1926.51.

The contractor shall establish a regular schedule for collection of all sanitary and organic waste. All wastes and refuse from sanitary facilities provided by the contractor or organic waste materials from any other source related to the contractor's operations shall be disposed of from the site in accordance with all laws and regulations.

When disposing of hazardous waste the contractor is to reference the owner of the project as the generator and use the owner's EPA I.D. number assigned to the facility.

The contractor shall mitigate the adverse environmental impacts associated with the work of the contract. The contractor shall indemnify and hold harmless the owner from all fines and penalties or damages for violation of any environmental mitigation measures or permit caused by the contractor's failure to comply with environmental mitigation measures. The measures that the contractor shall take to mitigate environmental impacts include, but are not limited to, the following:

- Implement a fugitive dust and erosion control plan.
- Apply for a general construction stormwater permit and prepare a stormwater pollution prevention plan.
- Protect sensitive habitats and species through the use of fencing to prohibit construction personnel adjacent habitat areas and other such measures that may be called for by the environmental assessment report for this project. At the completion of construction activities, the contractor will be required to re-vegetate the disturbed areas to its original condition with native plants.
- Comply with the following emission control measure to minimize construction activity emissions:
    - Reduce construction equipment emissions by shutting off all equipment not in use
    - Tune and maintain construction equipment properly
    - Use low sulfur fuel for construction equipment
- The contractor, a minimum of 30 days prior to beginning work on each new major activity, shall submit a written plan for approval to the engineer detailing how the environmental impacts for the area will be mitigated. This plan shall include, at a minimum:
    - Anticipated site conditions
    - Equipment to be utilized
    - Means and methods of construction
    - Impacts likely to occur
    - Mitigation methods to be employed

Cleaning solutions brought on-site by contractors for construction/fabrication purposes are to be disposed of in a proper manner by the contractor. The contractors maintain a record of all manifests evidencing proper disposal techniques.

The use of any chlorinated solvent at this job site is banned.

Where appropriate, electrical power to the site is to be provided so that the contractor can avoid any unnecessary fuel handling.

Environmental friendly paint systems without the constituents of toluene, xylene, methyl ethyl keytone and methyl isobuetyl keytone are to be selected to reduce toxic emissions during coating operations.

During abrasive blasting operations, all expended blast grit is to be contained and removed from the site by the contractor. Any costs for monitoring for Total Suspended Particulate (TSP) or Particulate Matter under 10 microns (PM10), if required by the state, will be the responsibility of the contractor.

Since this construction site will involve more than five acres of ground surface being disturbed, the EPA requires that the owner or an authorized representative develop a stormwater pollution prevention plan and secure a stormwater permit.

Prior to the discharge of any test water, a sample must be taken and analyzed by an analytical laboratory to confirm the absence of any additives or contaminants: The contractor will be responsible to secure the necessary permission prior to any discharge.

Where possible, the dry film process for developing x-rays is to be utilized so that generation of hazardous wastes resulting from photographic fixer can be avoided.

In accordance with oil pollution prevention regulation, a Spill Prevention Control and Counter measure plan must be established for the job site in the event that the above ground fuel storage capacity exceeds 1,320 gallons total or exceeds 660 gallons in any single tank. One of the primary provisions of the SPCC is the requirement for the development of a written plan in accordance with 40 CFR 112.3. The plan must detail the equipment, manpower, procedures, and provide adequate countermeasures to an oil spill.

All portable equipment is to be operated and serviced on an impervious surface. All fueling of equipment is to be done on impervious surfaces and all fuels and lubricants are to be stored with secondary containment for 110% of the designed vessel storage capacity. All fuel areas are to be locked when not in use.

All spills of hazardous substances at this jobsite in amounts greater than normal work quantities shall be handled in accordance with 29 CFR 1910.120. The contractor is expected to have a spill response plan, the necessary equipment and trained personnel.

In the event that any hazardous chemical or mixture present at the facility exceeds 10,000 pounds or the threshold planning quantity, as indicated in 40 CFR 355 appendix A, the contractor is to notify the owner of the facility so that this information can be submitted to the Local Emergency Planning Committee, State Emergency Response Planning Commission, and Local Fire Department.

The National Primary Drinking Water Standard for Lead is 15ug/L. A sample of water from each on-site drinking water fountain is to be collected and analyzed for total lead. Any drinking fountain containing greater that 15ug/L of lead should be disconnected or replaced.

No open burning will be permitted on-site.

At the completion of the job the owner will perform an environmental audit to document the site condition at the date of completion. The contractor will be responsible for correcting deficiencies that may have resulted from construction activities.

File: C:\TEXIM\LIGO2 Date: Oct29,93 15:00
CBI Houston Construction

Project Basic Table Page: 0001
LIGO Beam Tube Modules

Hanford, WA.	Date:	MONTH Day,Year	Float:	Only Total Float	Analysis:	Time Analysis
1.2	Duration Scale:	W.Days	Requirements:	All Resources	Simulations:	1
	Cost Scale:	1	Period:	Jan1,93 - Mar17,94	Iterations:	1

Activity Name	WBS	Dur	ES	EF	LS	LF	TF
		936	Mar17,94	Oct10,95	Mar17,94	Oct10,95	0
Procurement of Beam Tube Module Material0	1	138	Mar17,94	Sep26,94	Mar17,94	Sep26,94	0
Engineering Prepare Material Specs & Bills	1	30	Mar17,94	Apr27,94	Mar17,94	Apr27,94	0
Order Tubing Material	2	20	Apr28,94	May25,94	Apr28,94	May25,94	0
Mill Produce Tube Material	3	40	May26,94	Jul20,94	May26,94	Jul20,94	0
Deliver Tube Material	4	7	Jul21,94	Jul29,94	Jul21,94	Jul29,94	0
Manufacture Tube Lengths	5	30	Aug1,94	Sep9,94	Aug1,94	Sep9,94	0
Deliver to Site	6	7	Sep12,94	Sep20,94	Sep12,94	Sep20,94	0
Receive & Inspect Tube Lengths	7	3	Sep21,94	Sep23,94	Sep21,94	Sep23,94	0
Move to Storage	8	1	Sep26,94	Sep26,94	Sep26,94	Sep26,94	0
Procurement of Stiffener Material0	2	123	Mar17,94	Sep5,94	Apr7,94	Sep26,94	63
Engineering Prepare Material Specs. & Bills	1	20	Mar17,94	Apr13,94	Apr7,94	May4,94	63
Order Stiffener Material	2	15	Apr14,94	May4,94	May5,94	May25,94	63
Mill Produce Stiffener Material	3	40	May5,94	Jun29,94	May26,94	Jul20,94	63
Mill Deliver Material to Fabricator	4	7	Jun30,94	Jul8,94	Jul21,94	Jul29,94	63
Fabricate Stiffener Segments	5	30	Jul11,94	Aug19,94	Aug1,94	Sep9,94	63
Deliver Stiffener Segments to Site	6	7	Aug22,94	Aug30,94	Sep12,94	Sep20,94	63
Site Receive & Inspect Stiffener Segments	7	3	Aug31,94	Sep2,94	Sep21,94	Sep23,94	63
Move to Storage Area	8	1	Sep5,94	Sep5,94	Sep26,94	Sep26,94	63
Procurement Exp.Bellows0	3	136	Mar17,94	Sep22,94	Mar25,94	Sep30,94	24
Engineering Prepare Material Specs. & Bills	1	30	Mar17,94	Apr27,94	Mar25,94	May5,94	24
Order Expansion Bellows	2	25	Apr28,94	Jun1,94	May6,94	Jun9,94	24
Vendor Fabricate Expansion Bellows	3	70	Jun2,94	Sep7,94	Jun10,94	Sep15,94	24
Deliver Expansion Bellows to Site	4	7	Sep8,94	Sep16,94	Sep16,94	Sep26,94	30
Site Receive & Inspect Expansion Bellows	5	3	Sep19,94	Sep21,94	Sep27,94	Sep29,94	24
Move to Storage Area	6	1	Sep22,94	Sep22,94	Sep30,94	Sep30,94	24
Procurement of Vacuum Ports0	4	101	Mar17,94	Aug4,94	May10,94	Sep27,94	162
Engineering Prepare Material Specs. & Bills	1	25	Mar17,94	Apr20,94	May10,94	Jun13,94	162
Order Vacuum Port Material	2	30	Apr21,94	Jun1,94	Jun14,94	Jul25,94	162
Mill & Fabricate Vacuum Ports	3	35	Jun2,94	Jul20,94	Jul26,94	Sep12,94	162
Deliver Vacuum Ports to Site	4	7	Jul21,94	Jul29,94	Sep13,94	Sep21,94	162
Site Receive & inspect Vacuum Ports	5	3	Aug1,94	Aug3,94	Sep22,94	Sep26,94	162
wa Move to Storage	6	1	Aug4,94	Aug4,94	Sep27,94	Sep27,94	162
Procurement of Baffles0	5	101	Mar17,94	Aug4,94	May22,95	Oct9,95	1293
Engineering Prepare Material Specs. & Bills	1	20	Mar17,94	Apr13,94	May22,95	Jun16,95	1287
Order Material for Baffles	2	30	Apr14,94	May25,94	Jun19,95	Jul28,95	1287
Mill & Fabricate Baffles	3	40	May26,94	Jul20,94	Jul31,95	Sep22,95	1287
Deliver Baffles to Site	4	7	Jul21,94	Jul29,94	Sep25,95	Oct3,95	1293
Site Receive & Inspect	5	3	Aug1,94	Aug3,94	Oct4,95	Oct6,95	1287
Move to Storage	6	1	Aug4,94	Aug4,94	Oct9,95	Oct9,95	1293
Assembly of Beam Tube Modules0	6	185	Sep27,94	May30,95	Sep27,94	Jun9,95	30
Set Tube & Fit Stiffeners	1	1	Sep27,94	Sep27,94	Sep27,94	Sep27,94	0
Steam/Solvent Clean	10	1	Oct10,94	Oct10,94	Oct10,94	Oct10,94	0
Seal Ends & Transport to Erection	11	1	Oct11,94	Oct11,94	Oct11,94	Oct11,94	0
Assemble Remaining Tube Modules	12	174	Sep29,94	May30,95	Oct11,94	Jun9,95	30
Weld Stiffeners to Tube	2	1	Sep28,94	Sep28,94	Sep28,94	Sep28,94	0
Dimensional & Weld Inspection	3	1	Sep29,94	Sep29,94	Sep29,94	Sep29,94	0
Transfer to Exp. Bellow Station.	4	1	Sep30,94	Sep30,94	Sep30,94	Sep30,94	0
Fit & Weld Exp. Bellows to Tube	5	1	Oct3,94	Oct3,94	Oct3,94	Oct3,94	0
Dimensional & Weld Inspect	6	1	Oct4,94	Oct4,94	Oct4,94	Oct4,94	0
Transfer to Test Station	7	1	Oct5,94	Oct5,94	Oct5,94	Oct5,94	0
Vacuuum Test	8	1	Oct6,94	Oct6,94	Oct6,94	Oct6,94	0
Transfer to Cleaning Station	9	1	Oct7,94	Oct7,94	Oct7,94	Oct7,94	0
Erection of Beam Tube Modules0	7	152	Mar17,95	Oct10,95	Mar17,95	Oct10,95	0
Set Tube Assy & Prep. to Weld	1	1	Mar20,95	Mar20,95	Mar20,95	Mar20,95	0
Weld Beam Module In Place	2	1	Mar21,95	Mar21,95	Mar21,95	Mar21,95	0
Inspect Permanent Support Elevations & Shim	3	1	Mar17,95	Mar17,95	Mar17,95	Mar17,95	0
Dimensional & Weld Inspect0	4	1	Oct5,95	Oct5,95	Oct5,95	Oct5,95	0
Leak Test Weld Joint0	5	1	Oct6,95	Oct6,95	Oct6,95	Oct6,95	0
Clean & Inspect Tube Module0	6	1	Oct9,95	Oct9,95	Oct9,95	Oct9,95	0
wa Install Baffles & Final Inspect0	7	1	Oct10,95	Oct10,95	Oct10,95	Oct10,95	0
Erect Remaining Beam Tube Modules	8	145	Mar22,95	Oct10,95	Mar22,95	Oct10,95	0

File: C:\TEXIM\LIGO2 Date: Oct29,93 15:00
CBI Houston Construction

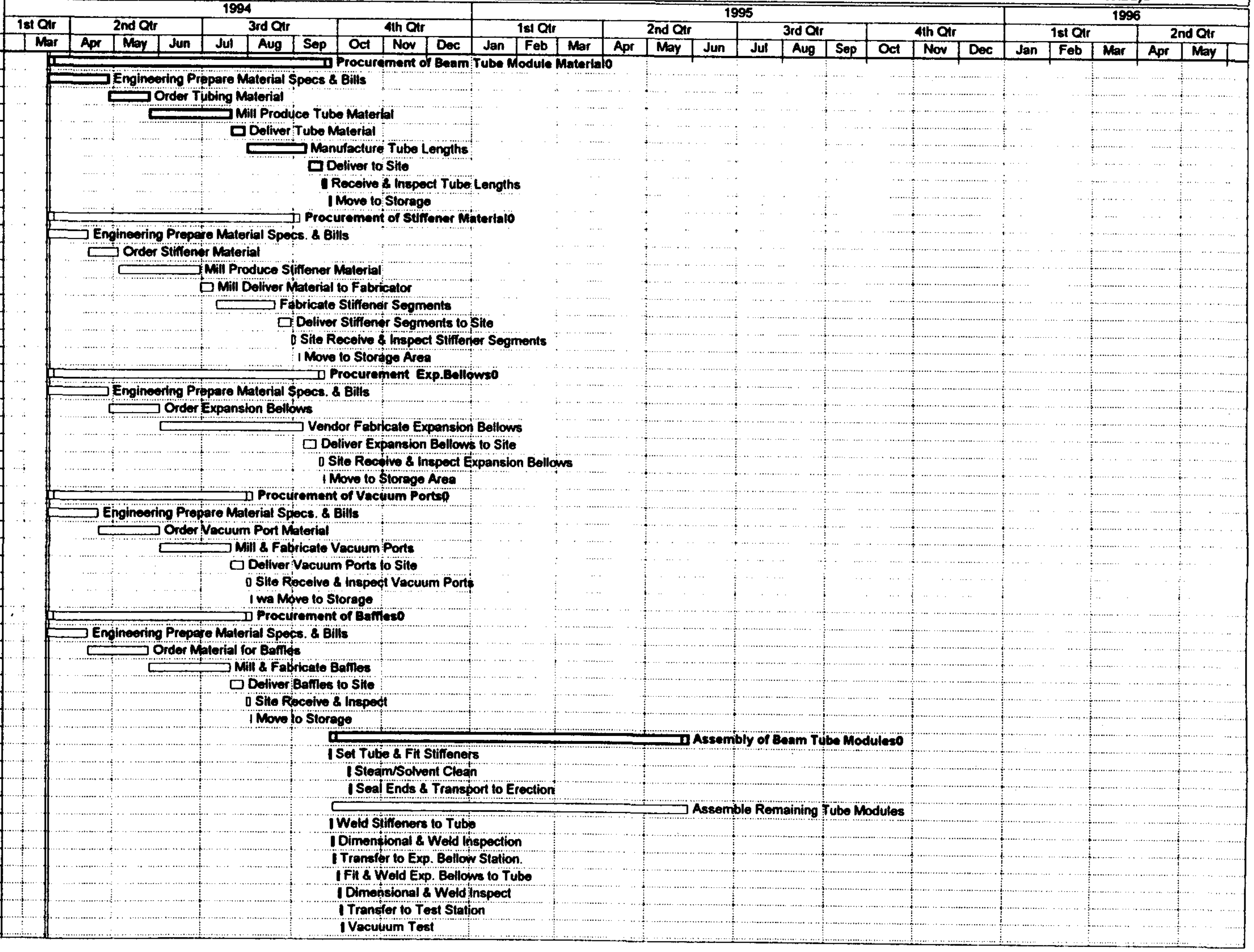
Project Date Bar Chart Page: 0001
LIGO Beam Tube Modules

Hanford, WA.
1.2

◇ Normal Milestone
▭ Normal Activity
▭ Normal Sub-project
◆ Critical Milestone
▭ *Critical Activity*
▭ Critical Sub-project
▨ ADur
▨ Free Float
— Baseline

Analysis: Time Analysis
Simulations: 1
Duration Scale: W.Days

Activity Name	WBS	Dur	LS	LF
		936	Mar17,94	Oct10,95
Procurement of Beam Tube Module Materl	1	138	Mar17,94	Sep26,94
Engineering Prepare Material Specs & Bills	1	30	Mar17,94	Apr27,94
Order Tubing Material	2	20	Apr28,94	May25,94
Mill Produce Tube Material	3	40	May26,94	Jul20,94
Deliver Tube Material	4	7	Jul21,94	Jul29,94
Manufacture Tube Lengths	5	30	Aug1,94	Sep9,94
Deliver to Site	6	7	Sep12,94	Sep20,94
Receive & Inspect Tube Lengths	7	3	Sep21,94	Sep23,94
Move to Storage	8	1	Sep26,94	Sep26,94
Procurement of Stiffener Material0	2	123	Apr7,94	Sep26,94
Engineering Prepare Material Specs. & Bill	1	20	Apr7,94	May4,94
Order Stiffener Material	2	15	May5,94	May25,94
Mill Produce Stiffener Material	3	40	May26,94	Jul20,94
Mill Deliver Material to Fabricator	4	7	Jul21,94	Jul29,94
Fabricate Stiffener Segments	5	30	Aug1,94	Sep9,94
Deliver Stiffener Segments to Site	6	7	Sep12,94	Sep20,94
Site Receive & Inspect Stiffener Segments	7	3	Sep21,94	Sep23,94
Move to Storage Area	8	1	Sep26,94	Sep26,94
Procurement Exp.Bellows0	3	136	Mar25,94	Sep30,94
Engineering Prepare Material Specs. & Bill	1	30	Mar25,94	May5,94
Order Expansion Bellows	2	25	May6,94	Jun9,94
Vendor Fabricate Expansion Bellows	3	70	Jun10,94	Sep15,94
Deliver Expansion Bellows to Site	4	7	Sep16,94	Sep26,94
Site Receive & Inspect Expansion Bellows	5	3	Sep27,94	Sep29,94
Move to Storage Area	6	1	Sep30,94	Sep30,94
Procurement of Vacuum Ports0	4	101	May10,94	Sep27,94
Engineering Prepare Material Specs. & Bill	1	25	May10,94	Jun13,94
Order Vacuum Port Material	2	30	Jun14,94	Jul25,94
Mill & Fabricate Vacuum Ports	3	35	Jul26,94	Sep12,94
Deliver Vacuum Ports to Site	4	7	Sep13,94	Sep21,94
Site Receive & Inspect Vacuum Ports	5	3	Sep22,94	Sep26,94
wa Move to Storage	6	1	Sep27,94	Sep27,94
Procurement of Baffles0	5	101	May22,95	Oct9,95
Engineering Prepare Material Specs. & Bill	1	20	May22,95	Jun16,95
Order Material for Baffles	2	30	Jun19,95	Jul28,95
Mill & Fabricate Baffles	3	40	Jul31,95	Sep22,95
Deliver Baffles to Site	4	7	Sep25,95	Oct3,95
Site Receive & Inspect	5	3	Oct4,95	Oct6,95
Move to Storage	6	1	Oct9,95	Oct9,95
Assembly of Beam Tube Modules0	6	185	Sep27,94	Jun9,95
Set Tube & Fit Stiffeners	1	1	Sep27,94	Sep27,94
Steam/Solvent Clean	10	1	Oct10,94	Oct10,94
Seal Ends & Transport to Erection	11	1	Oct11,94	Oct11,94
Assemble Remaining Tube Modules	12	174	Oct11,94	Jun9,95
Weld Stiffeners to Tube	2	1	Sep28,94	Sep28,94
Dimensional & Weld Inspection	3	1	Sep29,94	Sep29,94
Transfer to Exp. Bellow Station.	4	1	Sep30,94	Sep30,94
Fit & Weld Exp. Bellows to Tube	5	1	Oct3,94	Oct3,94
Dimensional & Weld Inspect	6	1	Oct4,94	Oct4,94
Transfer to Test Station	7	1	Oct5,94	Oct5,94
Vacuuum Test	8	1	Oct6,94	Oct6,94



File: C:\TEXIM\LIGO2 Date: Oct29,93 15:00
CBI Houston Construction

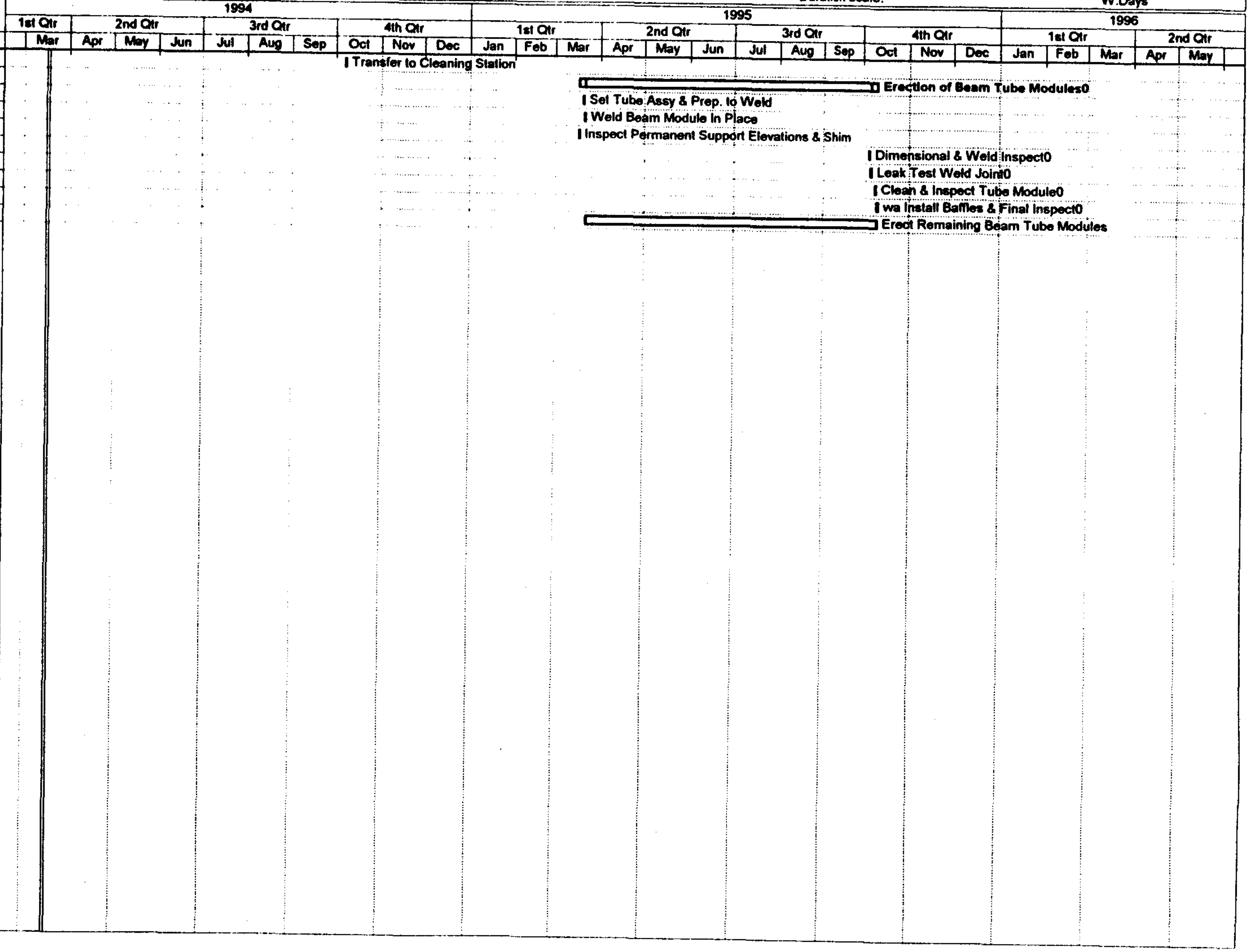
Project Date Bar Chart
LIGO Beam Tube Modules

Hanford, WA.
1.2

◇ Normal Milestone
▭ Normal Activity
▭ Normal Sub-project
◆ Critical Milestone
▭ Critical Activity
▭ Critical Sub-project
▨ ADur
▨ Free Float
⇢ Baseline

Analysis:	Time Analysis
Simulations:	1
Duration Scale:	W.Days

Activity Name	WBS	Dur	LS	LF
		936	Mar17,94	Oct10,95
Transfer to Cleaning Station	9	1	Oct7,94	Oct7,94
Erection of Beam Tube Modules0	7	152	Mar17,95	Oct10,95
Set Tube Assy & Prep. to Weld	1	1	Mar20,95	Mar20,95
Weld Beam Module In Place	2	1	Mar21,95	Mar21,95
Inspect Permanent Support Elevations & S	3	1	Mar17,95	Mar17,95
Dimensional & Weld Inspect0	4	1	Oct5,95	Oct5,95
Leak Test Weld Joint0	5	1	Oct6,95	Oct6,95
Clean & Inspect Tube Module0	6	1	Oct9,95	Oct9,95
wa Install Baffles & Final Inspect0	7	1	Oct10,95	Oct11,95
Erect Remaining Beam Tube Modules	8	145	Mar22,95	Oct10,95



SECTION 5

WBS 351 DEVELOP COUPON TEST CONCEPT

The testing of a small quantity of material to determine its outgassing characteristics can result in errors in a number of ways. One of the possible errors is introduced into the system if the outgassing rate of the empty system is not orders of magnitude less than the material sample. It is impossible to develop a system where the area or outgassing rate of the system is orders of magnitude less than the material sample. It is therefore necessary to spend as much time as possible ensuring that the system will provide a known outgassing rate time after time. It is also necessary to have a sample to system area ratio which is as high as possible. The empty system outgassing rate can then be subtracted from the total outgassing rate to determine the sample outgassing rate.

All refinements to a basic chamber such as internal cooling or heating coils, thermocouples, feedthrus, etc. result in increased surface areas, increased empty system outgassing rates and additional possibilities of leakage or permeation. The system must therefore be kept as simple as possible.

The system must also be designed to be used with the selected outgassing test technique (steady state or accumulation). Each technique has unique calibration and test procedures. The accumulation technique allows the RGA to be much less sensitive but results in a time delay which may be undesirable in order to limit the liability for unacceptable material. It is currently assumed that the accumulation technique will be utilized, due to hydrogen background levels.

Interactions between the system and the coupon hydrogen outgassing rate must also be evaluated. The interactions include manufacture of hydrogen from heavier hydrogen containing compounds including water and hydrocarbons. These interactions may come from vacuum gages in the system or from the RGA itself. The system must, therefore be capable of eliminating all of these erroneous hydrogen sources. This will be accomplished by multiple bake-outs of the system, cleaning of the coupons, shutting off the vacuum gages while measuring the outgassing rate and installation of an LN2 trap in front of the RGA.

WBS 352 SELECT COUPON OUTGAS TEST CONCEPT

The coupon testing will be conducted in a 6" diameter .083" thick stainless steel chamber 24" long. One end will have a welded closure. The other end will allow ingress and egress for samples through a conflat type port. The chamber will have only one vacuum connection to minimize surface area. This will be isolated from the pumping system by a 2½" diameter valve. Connections will be made using a cross or tee to tie into the RGA and calibrated leak systems.

The coupons will be taken from each roll of steel from the entire width of the coil. The coupons will be cut into 1" wide x 18" long strips. One of the coupons of each sample batch (one batch for CBI and two batches for Caltech) will be stamped with the coil identification numbers. The proposed surface area of 50 coupons to vessel is 5 to 1. 75 coupons will provide approximately a 7.5 to 1 ratio.

The vessel will be externally heated to 250°C with circumferential band type heaters attached to the shell. Water passages will also be attached to the shell to provide cool down after the bake out.

Vacuum gaging for the coupon test system will utilize Cold Cathode high vacuum gages and Pirani low vacuum gages to reduce hydrogen generation as much as possible. The gages will always be shut down during outgassing testing.

The coupon test chamber will be wrapped in high temperature fiberglass insulation to minimize the heat loss during testing.

L.I.G.O. PROJECT
WBS 350
OUTGAS TESTING

WBS 353 DESIGN COUPON TEST FACILITY

The coupon test system will utilize a surface area ratio of 5 to 7 between coupon surface area and vessel surface area. The CBI coupon test chamber will use the same size coupons as the Caltech system in order to provide compatibility of equipment and direct data comparison.

The coupon test vessel is 6" in diameter and has external heating and cooling coils. The vessel heating will be accomplished with three band type heaters bolted to the outside of the vessel shell. Cooling is provided by cooling jackets which are located between the heater bands. The vessel is as shown in figure 'A'.

The testing systems are designed in accordance with the attached P & I diagrams. The system provides an efficient pumping system which can accommodate a number of identical coupon chambers for the option phase of the project. The system is also provided with a high quality RGA and calibrated leak system. The entire system is designed not only to operate the current coupon test system but to also handle the future multiple coupon test systems for the option phase of the project.

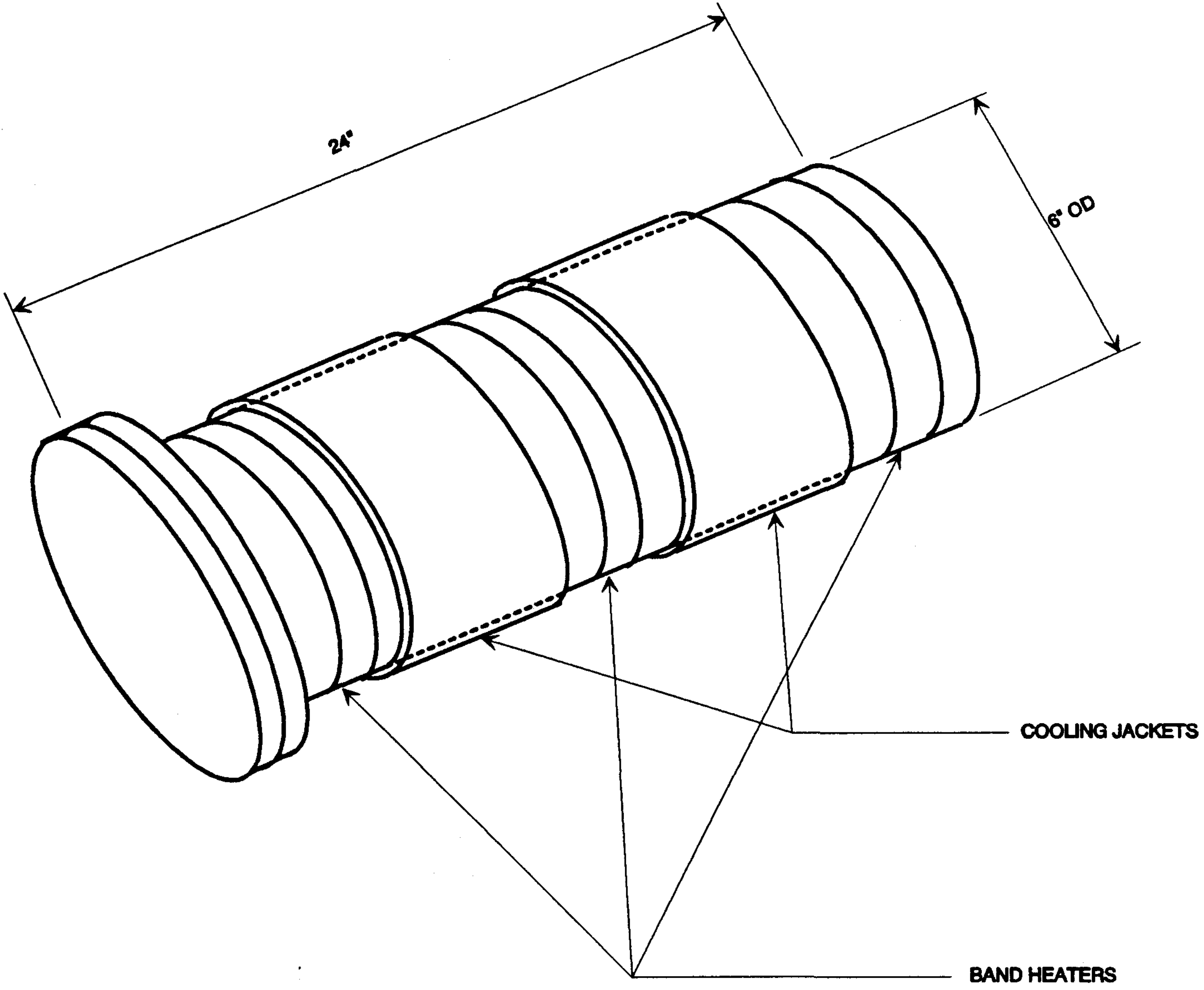
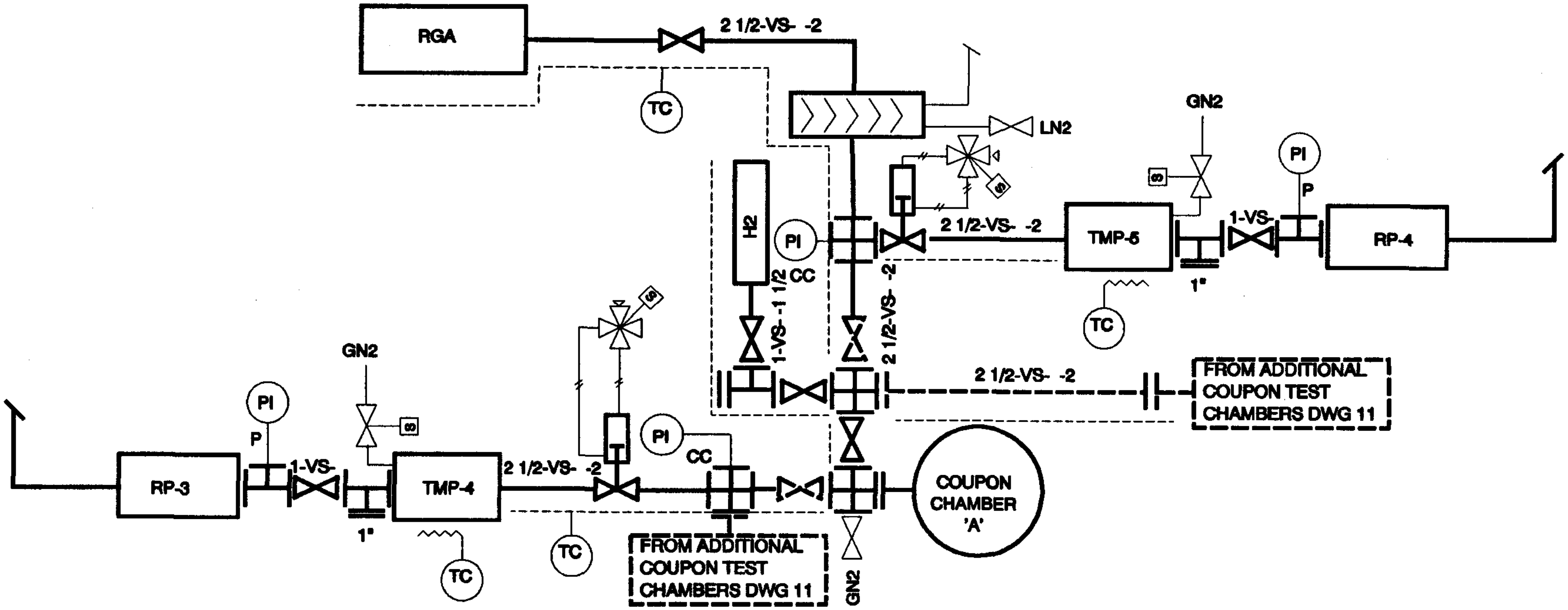


FIGURE 'A'

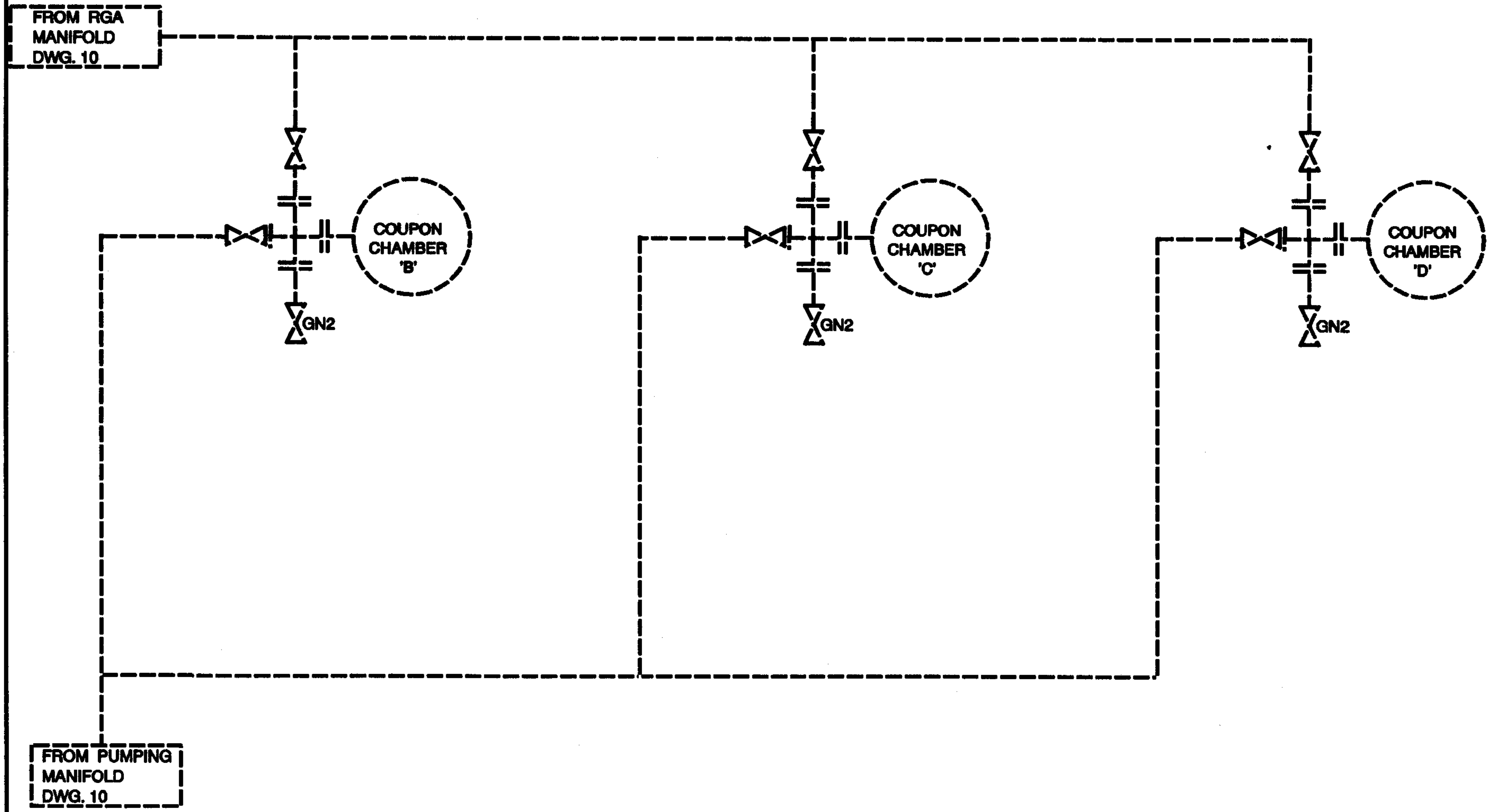


NOTE:
---------INDICATES LINES OR FITTINGS REQUIRED FOR MULTIPLE COUPON TEST CHAMBERS WHICH WOULD BE SUPPLIED FOR THE FULL CONSTRUCTION PHASE. THESE FITTINGS WILL NOT BE SUPPLIED FOR THE QUALIFICATION PHASE OF THE PROJECT.

P & I DIAGRAM
VACUUM SYSTEMS
COUPON TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/8/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212
DWG 10
SHT 1
REV 1



CBI

P & I DIAGRAM
VACUUM SYSTEMS
COUPON TEST
LIGO PROJECT
CALTECH

BY WAC CHKD _____ DATE 11/3/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.	930212
DWG	11
SHT	1
REV	0

LIGO PROJECT
WBS 350
OUTGAS TESTING

WBS 354 PROCURE OUTGASSING TEST EQUIPMENT

CBI has started the component procurement process by supplying the major equipment vendors with specifications and requests for quotation. RFQ's have been transmitted to vendors of the turbo molecular pumps, roughing pumps, liquid nitrogen traps, ultra high vacuum valves and calibrated leaks. Piping fittings, vacuum gages and other instrumentation will be treated as commodity items and purchased on a requisition basis.

Major equipment for the coupon test systems has been purchased in order to meet the schedule for coupon testing and the acceptance of the coil material for the beam tube used in the qualification test.

Attached are the specifications for the equipment discussed above.

CBI

TURBO MOLECULAR PUMP SPECIFICATION

TAG NO.: TMP-1

Design Information

1 Nominal pump speed:	1000 L/S
Gas to be pumped	hydrogen, air
Inlet / outlet flange type	Conflat
Electrical supply available	110V 60HZ 1ϕ 460V 60HZ 3ϕ

Accessories Required

power supply / controller
inlet screen
bake - out jacket
air cooling kit
vent system
cables

Information Required in Quotation

Hydrogen compression ratio
Hydrogen pump speed
Lubrication type
Installation orientation limitations
Outline drawing of pump and accessories showing overall dimensions, connection locations and sizes, and anchoring details
Electrical consumption and supply details
Warranty statement
Delivery
Price

REV	No	By	Chkd	Date	Made By	Date	Chkd By	Date	Contract No.	Sheet
	1			10/21/93		9/22/93		9/22/93	930212	801-1

CBI

FORM GO 616
ITEMS TO BE FURNISHED BY VENDOR

All items indicated are to be sent to the Purchasing Department issuing these instructions.

Final or approved copies due no later than one week after shipment, unless otherwise stipulated.

NUMBER OF COPIES REQUIRED

DESCRIPTION	FOR APPROVAL PRIOR TO FABRICATION	FINAL COPIES								TOTAL FINAL COPIES REQUIRED
		RECORD		ENGINEERING		CONSTR	PROJ MGR	PURCH		
		OWNER	CBI	DISTR	OB					
1. Drawings			2							2
2. Foundation Requirements										
3. ASME Code Calculations										
4. ASME Data Sheets										
5. COC and CTR										
6. Performance Curves			2							2
7. Welding Procedures										
8. Standard Catalog Information										
9. Spare Parts for Start-up & Yrs. Operation			2							2
10. Spare Parts List, Priced			2							2
11. Operating Data										
12. Operating Instructions			2							2
13. Installation Instructions			2							2
14. Maintenance Instructions			2							2
15.										
16.										
17.										
18.										

One additional copy each of the installation, operating & maintenance instructions are to be included with the shipment of the item.

VENDOR SHALL PUT EQUIPMENT TAG NUMBER ___*___ ON ALL DOCUMENTATION.

*SEE THE TECHNICAL SPECIFICATION.

All ASME Data Sheets & Partial Data Sheets to indicate:

Final Owner as CBI TECHNICAL SERVICES

at PLAINFIELD, IL.

REV	No						Made By	Chkd By	Contract No.	Sheet
	Chkd						WAC	RW	930212	801-2
	Date						Date 9/22/93	Date 9/23/93		

GO 616 REV FEB 77

CBI

TURBO MOLECULAR PUMP SPECIFICATION

▷2 **TAG NO.: TMP-2, thru 5**

Design Information

No. of pumps required:	4
Gas to be pumped	hydrogen, air
▷2 Nominal pump speed:	60 L/S

Note: A high hydrogen compression ratio is required for these pumps. The vendor shall select the pump based on the highest hydrogen compression ratio available.

Inlet flange type	Conflat
Electrical supply available	110V 60HZ 1ϕ 460V 60HZ 3ϕ

Accessories Required

power supply / controller
inlet screen
▷2 bake-out jacket (required on only three of the four turbo pumps)
air cooling kit
vent system
▷2 backing pump (backing pumps are required on only three of the four turbo pumps)
▷2 backing pump exhaust oil coalescer filters(required on only three of the four turbo pumps)
cables

Information Required in Quotation

Hydrogen compression ratio
Hydrogen pump speed
Lubrication type
Installation orientation limitations
Outline drawing of pump and accessories showing overall dimensions, connection locations and sizes, and anchoring details
Electrical consumption and supply details
Warranty statement
Delivery
Price

REV	No / By / Chkd	1 / WAC / RCw	2 / WAZ / Rlw				Made By WAZ	Chkd By RCw	Contract No. 930212	Sheet 802-1
	Date	10/20/93	11/12/93				Date 9/22/93	Date 9/22/93		

CBI

FORM GO 616
ITEMS TO BE FURNISHED BY VENDOR

All items indicated are to be sent to the Purchasing Department issuing these instructions.

Final or approved copies due no later than one week after shipment, unless otherwise stipulated.

NUMBER OF COPIES REQUIRED

DESCRIPTION	FOR APPROVAL PRIOR TO FABRICATION	FINAL COPIES								TOTAL FINAL COPIES REQUIRED
		RECORD		ENGINEERING		CONSTR	PROJ MGR	PURCH		
		OWNER	CBI	DSTR	OB					
1. Drawings			2							2
2. Foundation Requirements										
3. ASME Code Calculations										
4. ASME Data Sheets										
5. COC and CTR										
6. Performance Curves			2							2
7. Welding Procedures										
8. Standard Catalog Information										
9. Spare Parts for Start-up & Yrs. Operation			2							2
10. Spare Parts List, Priced			2							2
11. Operating Data										
12. Operating Instructions			2							2
13. Installation Instructions			2							2
14. Maintenance Instructions			2							2
15.										
16.										
17.										
18.										

One additional copy each of the installation, operating & maintenance instructions are to be included with the shipment of the item.

VENDOR SHALL PUT EQUIPMENT TAG NUMBER ___*___ ON ALL DOCUMENTATION.

*SEE THE TECHNICAL SPECIFICATION.

All ASME Data Sheets & Partial Data Sheets to indicate:

Final Owner as CBI TECHNICAL SERVICES

at PLAINFIELD, IL.

REV	No	Chkd	Date	Made By	Chkd By	Contract No.	Sheet
				WAC Date 9/22/93	RW Date 9/23/93	930212	802-2

ULTRA HIGH VACUUM VALVE SPECIFICATION

TAG NO.: HV-1 thru HV-13

Design Information

1	Valve size & operator type: (sizes are nominal valve bore dimensions)	
	HV-1	8" electro-pneumatic gate valve
	HV-2	8" manual valve
	HV-3, 4 & 5	2 1/2" electro-pneumatic gate or angle valve
	HV-6 thru 10	2 1/2" manual gate or angle valve
	HV-11 thru 13	1" manual angle or gate valve
	Valve type:	all metal seals, bakeable valves
	Body material:	type 304L stainless steel
	Minimum Pneumatic supply pressure:	60 psig
2	Maximum leak rate:	$1X10^{-10}$ atm. cc / s He
	Flange type:	Conflat

Information Required in Quotation

Guaranteed maximum leak rate
Guaranteed no. of cycles for leak tightness
Outline drawings showing overall dimensions, connection types; locations and sizes; and valve weight
Maximum bake-out temperature
Seal types and materials
Bellows materials
Cost of heating jacket if available
Delivery
Price for each valve, and additional discount if all valves are purchased from the same vendor

REV	No By Chkd	1 WAC RCW	2 WAC RCW				Made By WAC	Chkd By RCW	Contract No.	Sheet
	Date	10/20/93	11/12/93				Date 9/22/93	Date 9/22/93	930212	803-1

CBI

FORM GO 616
ITEMS TO BE FURNISHED BY VENDOR

All items indicated are to be sent to the Purchasing Department Issuing these instructions.

Final or approved copies due no later than one week after shipment, unless otherwise stipulated.

NUMBER OF COPIES REQUIRED

DESCRIPTION	FOR APPROVAL PRIOR TO FABRICATION	FINAL COPIES								TOTAL FINAL COPIES REQUIRED
		RECORD		ENGINEERING		CONSTR	PROJ MGR	PURCH		
		OWNER	CBI	DISTR	OB					
1. Drawings			2							2
2. Foundation Requirements										
3. ASME Code Calculations										
4. ASME Data Sheets										
5. COC and CTR										
6. Performance Curves			2							2
7. Welding Procedures										
8. Standard Catalog Information										
9. Spare Parts for Start-up & Yrs. Operation			2							2
10. Spare Parts List Priced			2							2
11. Operating Data										
12. Operating Instructions			2							2
13. Installation Instructions			2							2
14. Maintenance Instructions			2							2
15.										
16.										
17.										
18.										

One additional copy each of the installation, operating & maintenance instructions are to be included with the shipment of the item.

VENDOR SHALL PUT EQUIPMENT TAG NUMBER ___*___ ON ALL DOCUMENTATION.

*SEE THE TECHNICAL SPECIFICATION.

All ASME Data Sheets & Partial Data Sheets to indicate:

Final Owner as CBI TECHNICAL SERVICES

at PLAINFIELD, IL.

REV							Made By	Chkd By	Contract No.	Sheet
	No						WAC	RW	930212	803-2
	Chkd						Date	Date		
	Date						9/22/93	9/23/93		

ROUGHING PUMP SPECIFICATION

TAG NO.: RP-1

Design Information

Nominal flow rate:	50 CFM
Gases to be pumped:	hydrogen, air
No. of stages:	two
Automatic back flow prevention valve required:	yes
Electrical Supply Available:	110V 60HZ 1ϕ 460V 60HZ 3ϕ
Maximum Blank-off Pressure:	$5X10^{-3}$ torr
Cooling media:	air

Accessories Required

exhaust coalescing oil filter
manual ballast valve

Information Required in the Quotation

Pumping speed curve
Outilne drawing showing overall dimensions, connection sizes, types and locations, anchoring details
Motor HP and electrical supply requirements
Hydrogen compression ratio (if available)
Warranty statement
Delivery
Price

REV	No / By / Chkd						Made By	Chkd By	Contract No.	Sheet
							WAC	ZLW	930212	804-1
	Date						Date 9/22/93	Date 9/22/93		

FORM GO 616
ITEMS TO BE FURNISHED BY VENDOR

All items indicated are to be sent to the Purchasing Department issuing these instructions.

Final or approved copies due no later than one week after shipment, unless otherwise stipulated.

NUMBER OF COPIES REQUIRED

DESCRIPTION	FOR APPROVAL PRIOR TO FABRICATION	FINAL COPIES								
		RECORD		ENGINEERING		CONSTR	PROJ MGR	PURCH		TOTAL FINAL COPIES REQUIRED
		OWNER	CBI	DISTR	OB					
1. Drawings			2							2
2. Foundation Requirements										
3. ASME Code Calculations										
4. ASME Data Sheets										
5. COC and CTR										
6. Performance Curves			2							2
7. Welding Procedures										
8. Standard Catalog Information										
9. Spare Parts for Start-up & Yrs. Operation			2							2
10. Spare Parts List, Priced			2							2
11. Operating Data										
12. Operating Instructions			2							2
13. Installation Instructions			2							2
14. Maintenance Instructions			2							2
15.										
16.										
17.										
18.										

One additional copy each of the installation, operating & maintenance instructions are to be included with the shipment of the item.

VENDOR SHALL PUT EQUIPMENT TAG NUMBER ___*___ ON ALL DOCUMENTATION.

*SEE THE TECHNICAL SPECIFICATION.

All ASME Data Sheets & Partial Data Sheets to indicate:

Final Owner as CBI TECHNICAL SERVICES

at PLAINFIELD, IL.

REV	No / Chkd / Date					Made By	Chkd By	Contract No.	Sheet
						WAC	RW	930212	804-2
						Date 9/22/93	Date 9/23/93		

LIQUID NITROGEN COLD TRAPS

TAG NO.: LNT-1 thru 4

Design Information

The trap is to be of an Anti-Migration design

Sizes (nominal bore):	
LNT-1	8" I. D. nominal
LNT-2, 3 & 4	2 1/2" I. D. nominal
Flange types (vacuum connections):	Conflat
Connection type (LN2 & vent):	Vendor's standard
Body material:	Stainless steel type304L
Orientation:	Suitable for either horizontal or vertical mounting if possible
Vacuum seals:	Bakeable metal seals
Bake-out requirement (not while operating)	300° C
Maximum vacuum leak rate:	1x10^{-11} atm cc/s He

Information Required in Quotation

Guaranteed conductances for hydrogen and air (molecular flow regime)
Water pumping speed
Outline drawing showing overall dimensions, connection types and locations, weight
LN2 consumption rates (based on view to ambient temperature surfaces, not diffusion pump)
Warranty statement
Delivery
Price for each unit

REV	No / By / Chkd	1 WAC RCW	2 WAC Rcw				Made By WAC	Chkd By RCW	Contract No.	Sheet
	Date	10/20/93	11/12/93				Date 9/22/93	Date 9/22/93	930212	805-1

CBI

FORM GO 616
ITEMS TO BE FURNISHED BY VENDOR

All items indicated are to be sent to the Purchasing Department issuing these instructions.

Final or approved copies due no later than one week after shipment, unless otherwise stipulated.

NUMBER OF COPIES REQUIRED

DESCRIPTION	FOR APPROVAL PRIOR TO FABRICATION	FINAL COPIES								TOTAL FINAL COPIES REQUIRED
		RECORD		ENGINEERING		CONSTR	PROJ MGR	PURCH		
		OWNER	CBI	DISTR	OB					
1. Drawings			2							2
2. Foundation Requirements										
3. ASME Code Calculations										
4. ASME Data Sheets										
5. COC and CTR										
6. Performance Curves			2							2
7. Welding Procedures										
8. Standard Catalog Information										
9. Spare Parts for Start-up & Yrs. Operation			2							2
10. Spare Parts List, Priced			2							2
11. Operating Data										
12. Operating Instructions			2							2
13. Installation Instructions			2							2
14. Maintenance Instructions			2							2
15.										
16.										
17.										
18.										

One additional copy each of the installation, operating & maintenance instructions are to be included with the shipment of the item.

VENDOR SHALL PUT EQUIPMENT TAG NUMBER ___*___ ON ALL DOCUMENTATION.

*SEE THE TECHNICAL SPECIFICATION.

All ASME Data Sheets & Partial Data Sheets to indicate:

Final Owner as CBI TECHNICAL SERVICES

at PLAINFIELD, IL.

REV	No / Chkd						Made By	Chkd By	Contract No.	Sheet
	Date						WAC Date 9/22/93	RW Date 9/23/93	930212	805-2

GO 616 REV FEB 77

CBI

CALIBRATED LEAK SPECIFICATION

TAG NO.:CL-1 THRU CL-4

Design Information

Leak Tag No.	Gas	Leak Range (TL/S)
CL-1	H2	10^{-9} to 10^{-10}
CL-2	H2	10^{-8} to 10^{-9}
CL-3	He	10^{-9} to 10^{-10}
CL-4	N2	10^{-7} to 10^{-8}

The leaks are to be dry. The water leak rate shall be less than 1 x 10^{-13} TL/S.

The leaks shall be provided with conflat flanges.

Fill Valves shall be provided only if necessary for the vendors operations.

The leaks shall be free of hydrocarbon contamination.

The leaks shall be bakeable

Information Required in the Quotation

Outline drawing
Connection sizes
Discussion of calibration standard used
Warranty statement
Delivery
Price for each unit
Allowable bake temperature

REV	No / By / Chkd						Made By	Chkd By	Contract No. 930212	Sheet 806 1
	Date						Date 10/27/93	Date 10/27/93		

CBI

FORM GO 616
ITEMS TO BE FURNISHED BY VENDOR

All items indicated are to be sent to the Purchasing Department issuing these instructions.

Final or approved copies due no later than one week after shipment, unless otherwise stipulated.

NUMBER OF COPIES REQUIRED

		FINAL COPIES								
DESCRIPTION	FOR APPROVAL PRIOR TO FABRICATION	RECORD		ENGINEERING		CONSTR	PROJ MGR	PURCH		TOTAL FINAL COPIES REQUIRED
		OWNER	CBI	DISTR	OB					
1. Drawings			2							2
2. Foundation Requirements										
3. ASME Code Calculations										
4. ASME Data Sheets										
5. COC and CTR										
6. Performance Curves										
7. Welding Procedures										
8. Standard Catalog Information										
9. Spare Parts for Start-up & Yrs. Operation										
10. Spare Parts List, Priced										
11. Operating Data										
12. Operating Instructions			2							2
13. Installation Instructions										
14. Maintenance Instructions										
15.										
16.										
17.										
18.										

One additional copy each of the installation, operating & maintenance instructions are to be included with the shipment of the item.

VENDOR SHALL PUT EQUIPMENT TAG NUMBER * ON ALL DOCUMENTATION.

*SEE THE TECHNICAL SPECIFICATION.

All ASME Data Sheets & Partial Data Sheets to indicate:

Final Owner as CBI TECHNICAL SERVICES

at PLAINFIELD, IL.

REV	No	Chkd	Date	Made By	Chkd By	Contract No.	Sheet
				WAC Date 10/27/93	RW Date 10/22/93	930212	806 2

GO 616 REV FEB 77

SECTION 6

LIGO PROJECT
WBS 360
LEAK TESTING

WBS #360 Leak Testing

To successfully and economically meet the LIGO system requirements. the entire beam tube pressure boundary will be leak tested prior to completion of the beam tube modules. The prior testing of the pressure boundary by component or local means will minimize and hopefully eliminate the need to locate leaks after the module is completed. Although a procedure to test the entire beam tube module is being developed, leak testing the entire module to the specified leak rate will be a difficult and potentially costly task.

Expansion joints manufacturers will perform an initial leak test of the expansion joints prior shipment. After stiffener and expansion joint attachment, beam tube section will be leak tested by CBI. The leak test must be executed as soon as possible after tube fabrication but must also be executed just prior to field placement to minimize subsequent handling and associated risks. The section leak test will be incorporated into the construction process and will likely be executed at or near site just prior to tube section placement. The tube section leak test is described in the attached procedure HMST1N entitled "Helium Mass Spectrometer Hood Test of Beam Tube Can Sections For LIGO Project".

Circumferential seams made in the field will be locally tested by locally purging the seam inside the tube and establishing a vacuum on the outside of the tube with a circular vacuum enclosure. CBI has successfully used this technique to locally test penetrations and portions of high vacuum chambers. External local testing limits the personnel and equipment requirements inside the tube which provides a safe, effective and economical local test. The local circumferential leak test is described in the attached procedure HMST2N entitled "Helium Mass Spectrometer Hood Test of Closing Weld Joints Between Cans For LIGO Project".

Leak detection on the beam tube module will consist of a series of tests to locate the leak(s) in the most economical fashion possible. Ideally, module leak testing would not be required due to the achievement of system pressure goals. Initial attempts to locate module leaks if required would rely on cold cathode gauges located at the pumping port and a high speed data acquisition system. Testing would progress to incorporate helium mass spectrometer and helium tracer gas applied at suspect locations. Helium hood techniques would only be employed as a last resort. The module leak test procedure is described in the attached procedure HMST3N entitled "Final Helium Mass Spectrometer / Performance Test of Beam Tube Modules".

The basic equipment, personnel, and documentation requirements for all leak testing are described in the attached procedure LIGOTP entitled "Planned Approach to Leak Testing For LIGO Project".

LIGO PROJECT
WBS 360
LEAK TESTING

The attached preliminary procedures represent CBI's current thoughts and are being revised and updated. Future revisions will include paragraphs concerning qualification tests for establishing the definition of qualified personnel. Additional paragraphs will define "lint free" by federal clean room standards. Final versions of these procedures will incorporate thoughts, ideas, and comments from group discussions.

CBI

DOC. ID HMST1N
REV. NO. 0
CONTRACT 930212

TITLE HELIUM MASS SPECTROMETER HOOD TEST OF BEAM TUBE CAN SECTIONS FOR LIGO PROJECT CALTECH

PAGE NO. 1 **OF** 10

APPROVED	**Engr**	**Corp Weld**	**Corp QA**	**Const**	**Mfg**

	BY	**DATE**
PREPARED	CNS	11-2-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD	**REV. NO.**

1.0 SCOPE:

1.1 This procedure covers the helium mass spectrometer hood leak test of each completed beam tube can section. Perform this procedure in conjunction with the current revision of procedure LIGOTP.

1.2 Perform the leak testing outlined in this procedure:

1.2.1 On a spiral welded beam tube can section after the stiffeners and bellows assembly have been welded to that section.

1.2.2 After the beam tube can section has been visually inspected and any weld repairs have been made to correct excess undercut, lack of penetration and pinholes in either the can spiral weld or the stiffeners to can welds.

1.2.3 After the preliminary cleaning procedure has been satisfactorily completed.

2.0 LEAK TESTING EQUIPMENT TO BE USED IN THIS PROCEDURE:

All purchased equipment used in the performance of this procedure shall be specified to be helium mass spectrometer (HMS) leak tested to 2×10^{-12} atm. cc/sec. of helium. CBI will HMS leak test all purchase items during the initial leak test of the end seal assemblies during the initial test of those assemblies. If a manufacturer only has the capability to HMS leak test to a lesser test sensitivity, then the manufacturer must accept the return of that item without charge if it should fail this initial leak test by CBI at this sensitivity level.

2.1 The helium mass spectrometers used to perform the leak testing outlined in this procedure shall be the Leybold Model UL400 with the optional high sensitivity of 2 x 10^{-12} atm. cc/sec. of helium (8 x 10^{-13} atm. cc/sec. of air) or instrument of comparable capability.

2.2 Hood test enclosure stands. Each enclosure as shown in the test set-up sketch shall consist of a gasketed support cradle and cover and shall be able to structurally withstand being fully evacuated. Each test enclosure stand shall contain the following:

2.2.1 A 40 KF (1 1/2"Ø) long flange installed in the middle on the top of the cover with a valve and piping to an exhaust hood for venting helium gas from the hood.

2.2.2 A 4 1/2" or 6"Ø vacuum dial gauge with a 1/4" NPT connection threaded into a 1/4"Ø NPT coupling welded into the test enclosure cover.

2.2.3 A 40 KF (1 1/2"Ø) long flange installed in the bottom portion of the test enclosure to which is connected a vacuum valve and a Leybold D90A rotary van pump or unit of comparable capacity. Use this pump for evacuating the test enclosure to about 10 torr (29.5" Hg) before backfilling the enclosure with helium.

2.2.4 A 40 KF (1 1/2"Ø) long flange installed in the bottom portion of the test enclosure with a vacuum valve for backfilling with helium into that evacuated enclosure.

2.3 In order to be able to reasonably isolate the location of an indicated leak or leaks by time of flight measurement, at least one test enclosure stand at each jobsite shall contain additional equipment. The test cover of this stand shall contain the following:

2.3.1 Six (6) equally spaced 40 KF (1 1/2"Ø) long flanges along the top for connecting six (6) HPS cold cathode gauge tubes.

2.3.2 Two HPS Model 937 controllers for the six (6) cold cathode gauges in item 2.3.1.

2.3.3 High speed data acquisition programmed monitor for readout of the cold cathode gauge analog signals of item 2.3.1.

The underside portion of this test enclosure shall contain a:

2.3.4 Three inch (3"Ø) valved nozzle to which is connected a mechanical vacuum pump unit such as a Leybold WAU500 roots booster backed by a D90A rotary van pump or unit of comparable capacity. The pump unit connection line shall contain a valved 40 mm (1 1/2"Ø) crossover line to a turbomolecular pump foreline.

2.3.5 250 K (10"Ø) flanged port to which is mounted a Balzer Model TPH 1600 turbomolecular pump. The 40 KF (1 1/2"Ø) foreline to this pump shall be connected through the valved crossover to the mechanical vacuum pump listed in item 2.3.4.

2.4 One end double seal assembly includes the following test equipment as shown on the test set-up sketch and described below.

2.4.1 A six inch (6") Ø valved nozzle to which is connected a mechanical vacuum pump unit such as a Leybold WAU1000 roots booster backed by a DK200 rotary van pump or unit of comparable capacity. The pump unit connection line shall contain a valved 100 mm (4"Ø) crossover line to a turbomolecular pump foreline. It shall also contain a tee with a 40 KF (1 1/2"Ø) long flange valved for connecting the helium mass spectrometer.

2.4.2 A 500 K (20"Ø) flanged port to which is mounted a flanged 20"Ø LN_2 cold trap backed by a Balzer Model TPH 5000 turbomolecular pump. The 100 K (4"Ø) foreline to this pump shall be connected through the valved crossover line to the mechanical vacuum pump unit in item 2.4.1.

2.4.3 A 40 KF (1 1/2"Ø) long flange connection for a Residual Gas Analyzer (RGA) such as a Balzer quadruple mass spectrometer Model QMG 421-C control unit with QME 125-2 (200 amu) electronics and QMA125 analyzer.

2.4.4 A 40 KF (1 1/2"Ø) long flange connection for an ionization gauge tube connected to a control unit. Examples are a Varian Multi-Gauge, an HPS Model 937 or equivalent unit.

2.4.5 A 40 KF (1 1/2") long flange connection with an adapter for a thermal conductivity gauge tube connected to the control unit listed in item 2.4.4.

2.4.6 A 16 KF (5/8"Ø) long flange valved connection leading from the interspace between the end assembly double seals to a mechanical vacuum pump.

2.4.7 Leybold Trivac D4B or equivalent mechanical vacuum pump for item 2.4.6.

2.5 Second end double seal assembly includes the following test equipment as shown on the test set-up sketch and described below.

2.5.1 Twenty inch (20") Ø valved nozzle to which is mounted a flanged housing containing an LN_2 cryogenic panel with an LN_2 inlet and an N_2 outlet.

2.5.2 16 KF (5/8"Ø) long flange connection for the system permeation helium standard leak.

2.5.3 16 KF (5/8"Ø) long flange valved connection leading from the interspace between the end assembly double seals to a mechanical vacuum pump.

2.5.4 Leybold Trivac D4B or equivalent mechanical vacuum pump for item 2.5.3.

2.6 All vacuum valves 2" (50mm)Ø and smaller shall be bellows stem sealed and have KF style flange connections. Any such valves facing the evacuated space of the can section shall be stainless steel.

2.7 All valves larger than 2" (50mm)Ø shall be stainless steel vacuum slide valves with multiple chevron style stem seals.

2.8 Metallic "O" rings on seals facing the evacuated space of the can section. Elastometer "O" rings on all other seals.

3.0 PROCEDURE:

3.1 Install the beam tube can section in the test enclosure stand. Do not close top cover of the enclosure at this time. See leak test arrangement sketch for details.

3.2 Engage the end double seal assemblies at each end of the beam tube can section. Energize the Leybold Trivac D4B or equivalent mechanical pump at each end double seal assembly. When the pump blank-off pressure reaches at least 10 millitorr, open the valve to the space between the double seals.

3.3 With the Leybold WAU1000/DK200 or equivalent vacuum pump unit operating and blanking at an adequate absolute pressure in the very low millitorr range, open the 6"Ø slide valve between the pump unit and the beam tube can section and start evacuating the can section. Also open the 4"Ø crossover line valve to the Balzer TPH 5000 or equivalent turbomolecular pump and the LN_2 cold trap in front of that pump.

3.4 When the absolute pressure in the beam tube can section reaches approximately 100 millitorr, energize the turbomolecular pump and charge the cold trap with LN_2.

3.5 When the absolute pressure reaches approximately 50 millitorr, close the 6"Ø roughing line slide valve and then open the 20"Ø slide valve in front of the cold trap and turbomolecular pump.

3.6 Open the 20"Ø slide valve to the LN_2 cryogenic panel mounted to the end seal assembly on the opposite end of the can section from the mechanical pump/turbomolecular pump systems.

3.7 Put the Leybold UL400 helium mass spectrometer or equivalent instrument into operation and calibrate (peak tune) the instrument to ensure that it meets the optimum leak testing sensitivity requirements.

3.8 When the absolute pressure in the can section reaches approximately 2 x 10^{-6} torr, open the valve to the helium mass spectrometer (HMS). While monitoring the HMS sensing element absolute pressure and the can section absolute pressure, slowly close the valve to the mechanical vacuum pump unit backing the 20"Ø turbo-molecular pump. With the HMS solely backing the turbomolecular pump, monitor the can section absolute pressure to ensure that it continues to drop. Should the can section absolute pressure start to increase, indicating the throughput is too large for the HMS effective pump speed, reverse the valve arrangement and continue pumping the can section with the mechanical vacuum pump unit backing the turbomolecular pump. When the absolute pressure in the can section has reached a lower level, try again to solely back the turbomolecular pump with the HMS. When this is accomplished, proceed to step 3.10.

3.9 Should the can section absolute pressure fail to reach 2 x 10^{-6} torr and leakage is suspected and the vacuum level is low enough to operate the RGA, open the valve to that instrument and scan the nitrogen, argon and oxygen AMUs. If the levels of these three (3) gases indicate inleakage, helium tracer probe the end assembly seals for leaks.

3.9.1 If either one or both of these seals indicate inleakage, isolate and vent the test system and visually inspect the seal or seals to determine the cause of the leak or leaks. Replace, repair or modify the seal or seals as necessary and repeat steps 3.2 through 3.9 as necessary until the HMS is solely backing the turbomolecular pump.

3.9.2 If neither of the end seals indicate inleakage, close the top cover of the test enclosure. Evacuate the enclosure to approximately 10 torr (29.5" Hg). To verify the existence of inleakage, vent the enclosure with helium to atmospheric pressure by closing the valve to the enclosure vacuum pump and opening the valve to the helium gas supply.

3.9.3 When leakage in the can section has been verified, evacuate the helium from the test enclosure and backfill it with air. Then vent the can section. Remove the leaking can section from that test enclosure and place it in the test enclosure equipped with the multiple cold cathode gauge heads.

3.9.4 Evacuate the leaking can section as low as possible within a reasonable time.

3.9.5 Evacuate that test enclosure to an absolute pressure sufficiently low to enable the six (6) HPS cold cathode gauge heads to become operational. Connect the control unit outputs to the high speed data acquisition system.

3.9.6 Vent the evacuated leaking can section in order to initiate the inleakage which will produce the time of flight data that will reveal the approximate lengthwise location of that inleakage. This should enable pinpointing the location of the source of that inleakage within about ±6" lengthwise on the can section.

3.10 After the can section absolute pressure has gone below 2×10^{-6} torr and the HMS is solely backing the turbomolecular pump and the can section absolute pressure stabilizes or reaches a very slow rate of decrease, calibrate the test system as follows:

3.10.1 Record the HMS background signal in divisions. A division shall be based on the smallest increment on the most sensitive scale of the leak indicator meter.

3.10.2 While monitoring with a stop watch, open the valve to the helium permeation standard leak on the seal end assembly opposite from the pump end seal assembly. Record the elapsed time to first receive a signal if the elapsed time is even long enough to record. Then record the response time and the signal received in divisions. Close the standard leak valve and record the clean up time and the background signal after it has stabilized.

3.10.3 Subtract the post calibration background signal from the standard leak signal. Divide the air leakage rate of the standard leak by the net leak indicator signal received in the test system from that system standard to obtain the test system sensitivity.

3.10.4 The test system sensitivity must enable an operator to detect an air leak with a leakage rate of 1 x 10^{-12} atm. cc/sec. or larger. If the test sensitivity is inadequate, then the can section must either be evacuated to a lower absolute pressure that will enable it to be achieved and/or be allowed to accumulate for a sufficient length of time to achieve this required test sensitivity. This system calibration shall be repeated as necessary to establish the required absolute pressure and/or the accumulation time needed to achieve this specified system sensitivity.

3.11 After successful completion of the system calibration in step 3.10, perform the hood test of that can section as follows.

3.11.1 Evacuate the test enclosure to approximately 10 torr.

3.11.2 Close the valve to test enclosure vacuum pump.

3.11.3 Record the test system background leak indicator signal in divisions.

3.11.4 Vent the test enclosure to atmospheric pressure with helium gas by opening the valve to the helium gas supply.

3.11.5 Wait the elapsed time established during system calibration that would be necessary to detect a total leakage rate of 1 x 10^{-12} atm. cc/sec. or larger.

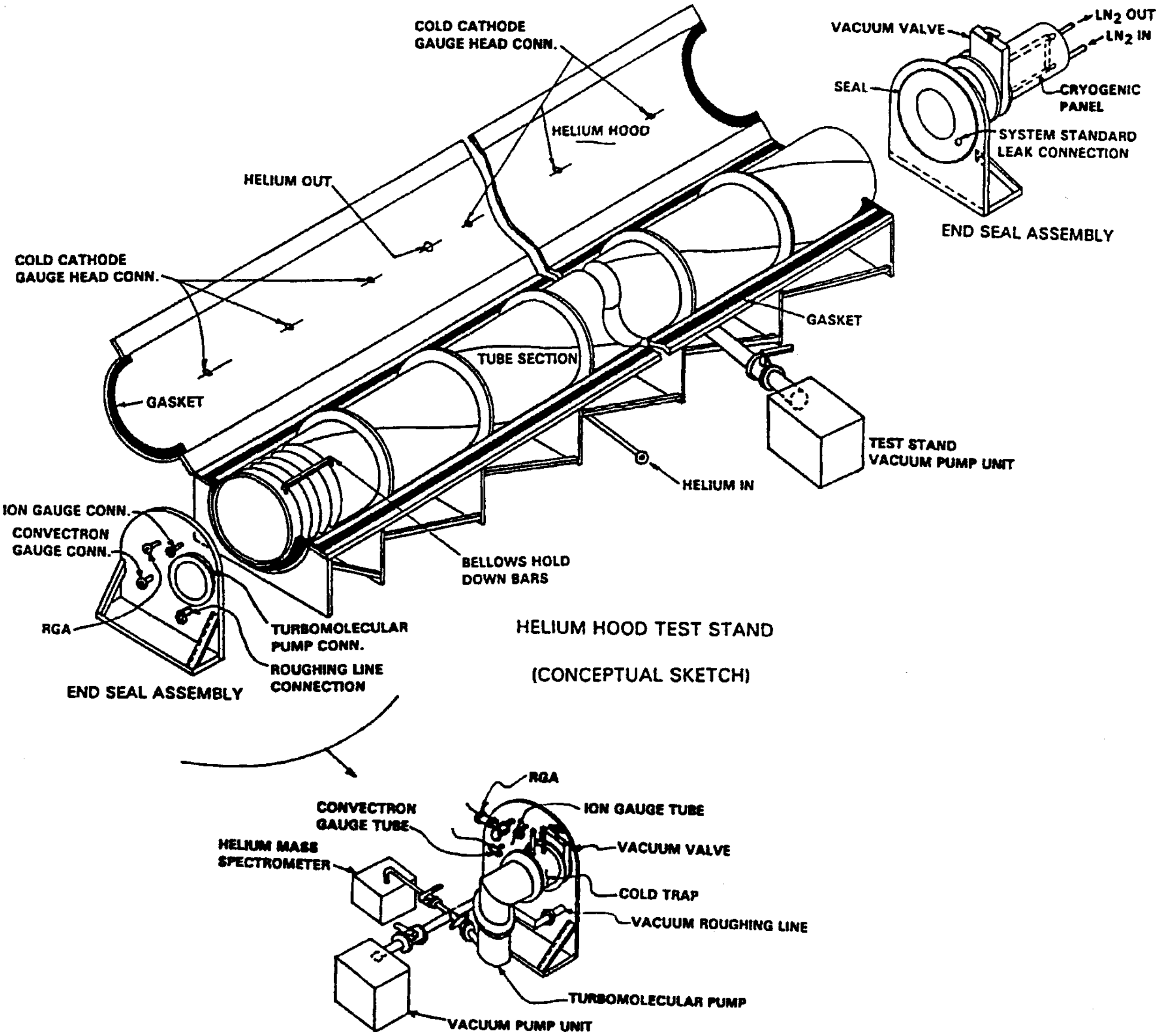
3.11.6 If the signal received indicates an unacceptable total leakage rate in a can section, then that leakage must be pinpointed either by repeating steps 3.9.3 and 3.9.4 or by using other more conventional HMS leak location techniques.

3.12 If the signal received in the established elapsed test time indicates an acceptable total leakage rate or if no signal is received in the established elapsed test time, then the can section hood test is complete.

3.13 Vent with -80°F (-62°C) dew point dry air and hermetically seal both ends of the tube section.

4.0 DOCUMENTATION

See procedure LIGOTP for documentation requirements.



TEST SETUP SKETCH

CBI

DOC. ID HMST2N
REV. NO. 0
CONTRACT 930212

TITLE HELIUM MASS SPECTROMETER HOOD TEST OF CLOSING WELD JOINTS BETWEEN TUBE CANS FOR LIGO PROJECT - CALTECH

PAGE NO. 1 **OF** 5

APPROVED	Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-3-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD **REV. NO.**

1.0 SCOPE:

1.1 This procedure covers the helium mass spectrometer hood test of the closing weld joint between each beam tube can section. Perform this procedure in accordance with the current revision of procedure LIGOTP.

1.2 Perform the leak testing outlined in this procedure after the closing weld joint between two adjacent beam tube can sections has been visually inspected and any weld repairs have been made to correct excess undercut, lack of penetration and pinholes in that weld.

2.0 LEAK TESTING EQUIPMENT TO BE USED IN THIS PROCEDURE:

2.1 The helium mass spectrometers used to perform the leak testing outline in this procedure shall be the Alcatel Model ASM 51, Leybold Model UL400, Varian Model 960, Veeco Model [illegible]AB or equivalent with an optimum high sensitivity in the range of 10^{-11} atm. cc/sec. of helium.

2.2 A channel shaped curved metal box with an inflatable perimeter seal and a 40 KF (1 1/2"Ø) long flange for connection to the HMS. The box shall be sufficiently long to cover approximately 190^0 of the outside circumference of the closing weld joint between beam tube can sections. See the test set-up sketch at the end of this procedure.

2.3 Ten (10) feet of flexible stainless steel metal hose with 16 KF (5/8"Ø) connectors on the ends for connecting the HMS to the metal vacuum box.

2.4 Combination weld purge dam/helium hood enclosure consisting of two inflatable rubber seals interconnected with a metal bar ring containing 16 KF (5/8"Ø) valved connections. One each for injecting either argon or helium gas and a third for evacuating the enclosure. See the figure at the end of this procedure.

2.5 Three vacuum valves with 16 KF (5/8"Ø) connectors attached to the metal bar ring.

2.6 Three 16 KF (5/8"Ø) hose connectors; gas hose connected to two of the valves and vacuum hose connected to the third valve.

2.7 Mechanical vacuum pump such as a Leybold Trivac D2B or equivalent.

2.8 Eight (8) clamping rings for 16 KF (5/8"Ø) flanged connectors.

3.0 PROCEDURE:

3.1 Visually inspect the outside of the closing weld joint between the beam tube can sections. Repair any excess undercut, lack of penetration or pinholes detected. Remove any rough areas adjacent to the weld in the vicinity of where the metal box seals will contact the outside surface of the tube in order to effect the best possible temporary seal.

3.2 Install the channel shaped curved metal box on a 190^0 segment over the outside of the closing weld joint between the beam tube can sections.

3.3 Pressurize the inflatable perimeter seal on the box.

3.4 Calibrate (peak tune) the HMS to obtain the optimum test sensitivity for the model instrument being used. Record the signal above the background signal in divisions. Since the volume of the metal vacuum box is insignificant, the test sensitivity for this system is the helium leakage rate of the standard leak divided by this net signal in divisions where a division is the smallest increment on the most sensitive scale of the leak indicator meter.

3.5 Vent the HMS manifold and connect the flexible metallic hose to the curved metal box and HMS.

3.6 Evacuate the curved metal box with the HMS auxilary vacuum pump. After it has evacuated to approximately 100 millitorr, throttle open the high vacuum system to the metal box. Should the vacuum in the metal box stabilize at a higher pressure indicating potential seal leakage, tracer probe the perimeter of the seal to detect and pinpoint the area of leakage. If seal leakage is detected and pinpointed, temporarily seal it with sealing compound such as Apiezon Q or electrical putty.

3.7 Install the internal helium hood enclosure if it is not already in place as a purge dam for the prior welding.

3.8 When the high vacuum absolute pressure meter of the HMS has stabilized (bottomed), evacuate the helium hood enclosure to remove the argon present during welding.

3.9 Record the HMS background signal in divisions. A division shall be based on the smallest increment on the most sensitive scale of the leak indicator meter.

3.10 Backfill the hood enclosure with helium by opening the regulated helium gas supply.

3.11 Observe the HMS leak indicator meter for one (1) minute. If there is no increase in the leak indicator signal, the closing weld joint leakage rate is acceptable and the test is complete. If there is an increase in the leak indicator signal, proceed to step 3.12 to pinpoint the location of the unacceptable leakage in this closing weld joint.

3.12 Isolate the HMS from the test system and vent the 190^0 curved metal vacuum box. Replace the 190^0 curved metal vauum box with a curved metal vacuum box approximately six inches (6") in length.

3.13 Visually inspect the 190^0 portion of the weld joint that contains the unacceptable leakage. If any area or areas are observed that appear to contain potential leaks, locally leak test that area or areas first.

3.14 Place the six inch (6") long box over the selected area of the closing weld joint. Connect the flexible metallic hose to the short metal box.

3.15 Evacuate the short metal box with the HMS auxilary vacuum pump. After it has evacuated to approximately 100 millitorr, throttle open the high vacuum system to the metal box. Should the vacuum in the metal box stabilize at a higher pressure indicating potential seal leakage, tracer probe the perimeter of the seal to detect and pinpoint the area of leakage. If seal leakage is detected and pinpointed, temporarily seal it with sealing compound such as Apiezon Q or electrical putty.

3.16 Observe the HMS leak indicator signal in divisions as the high vacuum absolute pressure meter stabilizes (bottoms). If the indicator signal shows an increase over the normal background, isolate the box. If the signal decreases, leakage is indicated in the area being tested. If the indicator signal shows no increase over normal background and/or does not change when the box is isolated, no leakage is indicated in that area.

3.17 When a leak is pinpointed, vent the vacuum box and vent the helium hood enclosure.

3.18 Repair the pinpointed leak and retest the entire previously tested 190^0 segment of the closing weld joint. When that 190^0 segment leak test shows no unacceptable leakage, the leak test of that portion of the closing weld joint is complete.

3.19 Vent the curved metallic vacuum box. Center and place this box over the outside of the 170^0 untested portion of the closing weld joint. Replace the helium hood enclosure on the inside of this weld joint.

3.20 Repeat steps 3.3 through 3.18 for the remaining 170^0 segment of the closing weld joint.

4.0 DOCUMENTATION:

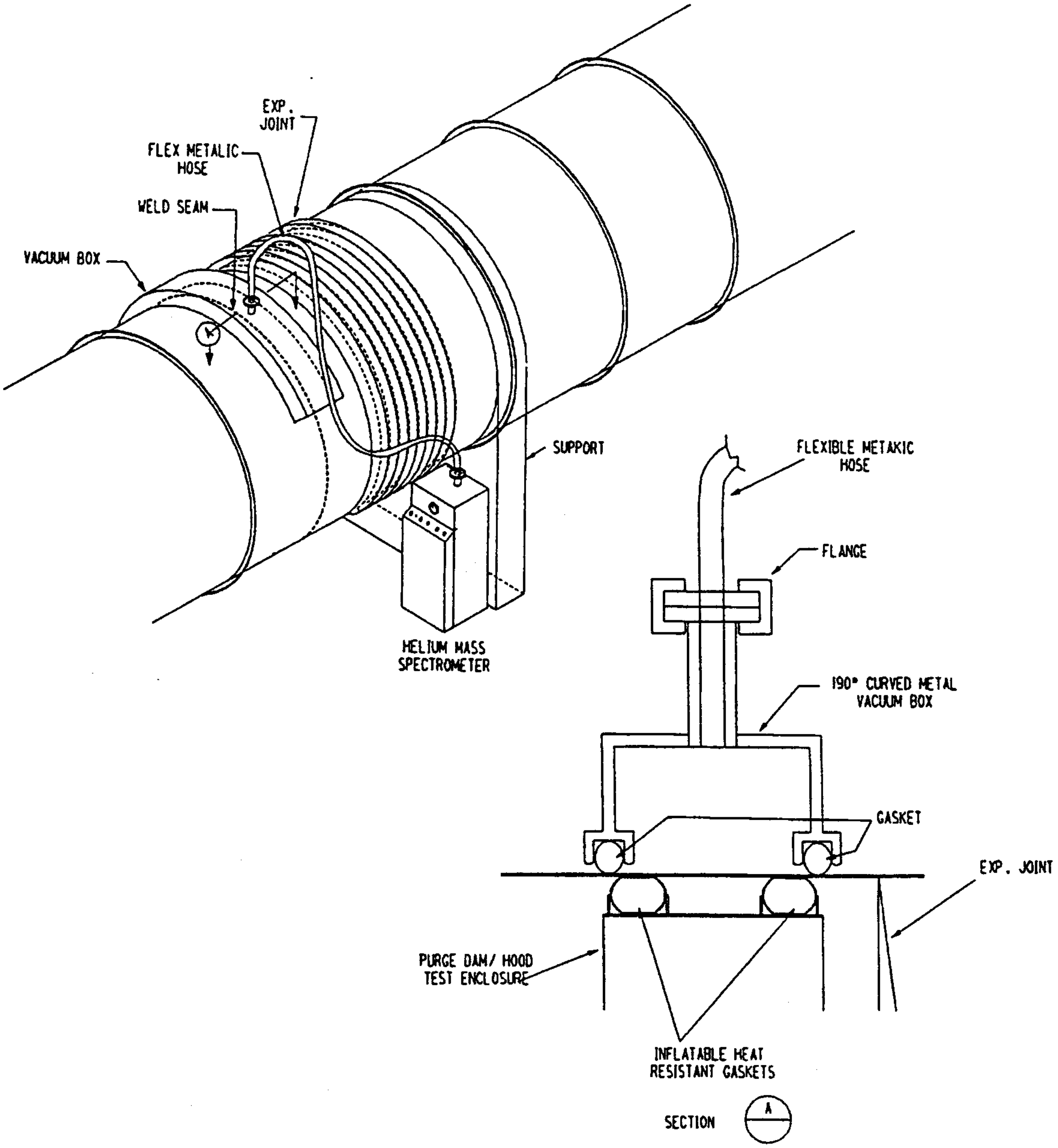
See procedure LIGOTP for documentation requirements.

CBI

DOC. ID HMST2N
REV. NO. 0
CONTRACT 930212

TITLE HELIUM MASS SPECTROMETER HOOD TEST OF CLOSING WELD JOINTS BETWEEN TUBE CANS FOR LIGO PROJECT - CALTECH

PAGE NO. 5 OF 5



TEST SET-UP SKETCH

CBI

DOC. ID HMST3N
REV. NO. 0
CONTRACT 930212

TITLE FINAL HELIUM MASS SPECTROMETER/
PERFORMANCE TEST OF
BEAM TUBE MODULES - CALTECH

PAGE NO. 1 **OF** 5

APPROVED	Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-5-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD REV. NO.

1.0 SCOPE:

1.1 This procedure covers the final helium mass spectrometer/performance test of each of the beam modules. Use this procedure in conjunction with the current revision of procedure LIGOTP.

1.2 Perform the leak testing outlined in this procedure on the applicable beam tube module after :

1.2.1 All beam tube can sections in that module have been successfully HMS leak tested, final cleaned and erected.

1.2.2 All closing weld joints in that module have been successfully HMS leak tested and locally cleaned.

1.2.3 The permanent vacuum pump system for the applicable beam tube module has been installed.

2.0 LEAK TESTING EQUIPMENT TO BE USED IN THIS PROCEDURE:

2.1 Leybold Model UL400 helium mass spectrometer leak detector with the optional high sensitivity of 2×10^{-12} atm. cc/sec. of helium (8×10^{-13} atm. cc/sec. of air) or instrument of comparable capability.

2.2 Permeation (quartz) helium standard leak with a leakage rate in the range of 10^{-8} atm. cc/sec. or smaller.

2.3 Flexible stainless steel hose for connecting the helium mass spectrometer to the test system.

2.4 CBI supplied Balzer Model QMG 421-C with an amu mass range of 1 - 512.

2.5 Ten (10) CBI supplied HPS cold cathode gauge heads.

2.6 Four (4) HPS Model 937 controllers.

2.7 CBI supplied high speed data acquisition system.

2.8 Caltech supplied vacuum pump system consisting of mechanical pumps, turbomolecular pumps and ion pumps.

3.0 <u>PROCEDURE</u>:

3.1 Install the ten (10) HPS cold cathode gauge heads at the 10"Ø parts equally spaced along the length of the beam tube module. Connect the high speed data acquisition system to the HPS gauge controllers.

3.2 Visually inspect the length of the beam tube module to be final tested.

3.3 Check off each item on the checklist as it is inspected and found satisfactory during the walkdown.

3.4 Conduct a blank-off of the mechanical vacuum pump system. When it is satisfactory, begin evacuating the beam tube module.

3.5 Start and calibrate (peak tune) the helium mass spectrometer (HMS).

3.6 When the absolute pressure in the beam tube module reaches approximately 100 millitorr, energize the module turbomolecular pumps.

3.7 Should the absolute pressure in the beam tube module stop decreasing before it reaches the level of 100 millitorr, repeat steps 3.2 and 3.3.

3.7.1 While repeating steps 3.2 and 3.3, throttle the HMS into the roughing pump line behind the booster pump.

3.7.2 If any obvious problem item is discovered during the repeat walkdown checklist inspection, HMS tracer probe the item. If leakage is indicated, isolate the HMS, vent the system, repair and/or correct the problem and start over at step 3.4.

3.7.3 If no leakage area is detected, review all can section final test reports/logs and all closing weld joint test reports/logs for statements or data that reveals potential leakage problem areas previously overlooked. List all potential problem areas revealed by these logs or reports.

3.7.4 HMS tracer probe leak test all areas or items on this list. If leakage is indicated, note the area. When all areas are tested, isolate the HMS, vent the system, repair and/or correct the problem(s) and start over at step 3.4.

3.7.5 Repeat all steps of item 3.7 until this problem is resolved.

3.8 When the system absolute pressure reaches approximately 50 millitorr, open the valve(s) between the turbomolecular pump(s) and the beam tube module. At the same time, close the valve(s) in the roughing line(s) between the mechanical pump(s) and the test system.

3.9 When the system absolute pressure reaches approximately 1×10^{-6} torr, energize the ion pumps.

3.10 Should the absolute pressure in the beam tube module stop decreasing between 10^{-4} and 10^{-6} torr.

3.10.1 Energize the HPS cold cathode gauge tube and the high speed data acquisition system.

3.10.2 Isolate the beam tube module vacuum pump system while recording the absolute pressure cold cathode gauge output readings.

3.10.3 After sufficient data has been recorded, open the valve(s) to the beam tube module pump system.

3.10.4 Analyze the pressure rise data for an indication of the approximate location(s) of the leakage problem(s).

3.10.5 Throttle the HMS into the system in the foreline of the turbomolecular pump. Throttle the valve to the mechanical pump backing the turbomolecular pump as much as possible without increasing the system absolute pressure.

3.10.6 Hood test the area or areas revealed in step 3.10.4. Mark all area or areas of leakage indications.

3.10.7 Isolate the HMS and pumps from the system, vent the system and repair all leakage areas indicated and start over at step 3.4.

3.10.8 Repeat all steps of item 3.10 until this problem is resolved.

3.11 While continuing to evacuate the beam tube module, monitor the system peak masses for nitrogen, argon and oxygen with the RGA to observe if these amu mass readings are indicating any gross leakage. For information, monitor the amu mass numbers for moisture, elements in the cleaning solvents and cleaning compounds and hydrogen, etc.

3.12 As long as the system absolute pressure continues to go down, continue to pump and monitor to determine if the amu mass peaks for nitrogen, argon and oxygen still indicate little or no significant leakage.

3.13 When the beam tube module reaches an absolute pressure in the 10^{-8} torr range, if the RGA mass readouts for oxygen, nitrogen and argon continue to indicate little or no detectable inleakage and the absolute pressure continues to decrease, even at a very very slow rate, the leakage rate of the module is satisfactory and the module is ready for bake out.

3.14 If the beam tube module will not readily evacuate below the 10^{-7} torr range because of RGA indications of high outgassing rates not attributable to inleakage, the module will also be considered ready for bake out.

3.15 If all procedure steps have been performed and the system will not evacuate to a sufficiently low absolute pressure level because of RGA high mass readouts indicating inleakage, perform a HMS hood test of the entire beam tube module in accordance with procedure HMST4N.

4.0 DOCUMENTATION:

Document in accordance with item 5.0 of procedure LIGOTP.

CBI

DOC. ID LIGOTP
REV. NO. 0
CONTRACT 930212

TITLE PLANNED APPROACH TO LEAK TESTING FOR
LIGO PROJECT
CALTECH

PAGE NO. 1 OF 2

APPROVED	Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-2-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD	REV. NO.

1.0 SCOPE:

This planned approach to leak testing covers

1.1 The helium mass spectrometer hood testing of each beam tube can section in accordance with the current revision of procedure number HMST1N.

1.2 The helium mass spectrometer hood test of the closing weld joint between each beam tube can section in accordance with the current revision of procedure number HMST2N.

1.3 The helium mass spectrometer total leakage rate test of each beam tube module in accordance with the current revision of procedure number HMST3N.

2.0 PERSONNEL:

Qualified personnel shall perform and supervise all helium mass spectrometer leak testing conducted in accordance with this planned approach and all the leak testing procedures referenced within this plan.

3.0 REFERENCE:

3.1 1992 ASME Boiler & Pressure Vessel Code, Section V, Article 10, with 1992 Addenda as a guide.

3.2 ASTM Designation E498 Test Methods for Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Tracer Probe Mode (as a guide).

3.3 California Institute of Technology Technical Specification Number 1100004 for Beam Tube Modules.

4.0 <u>LEAK TESTING EQUIPMENT USED IN ALL LEAK TEST PROCEDURES</u>:

4.1 Helium mass spectrometers (HMSs) with a high vacuum turbomolecular pump and internal auxiliary mechanical vacuum pump. Instruments must be capable of direct flow operation and may have the option of indirect flow operation. Specific instrument models and sensitivity requirements will be given in each of the applicable leak test procedures.

4.2 Permeation (quartz) helium standard leaks with leakage rates in the range of 10^{-8} atm. cc/sec. or smaller.

4.3 Commercial grade helium supplied from on-site storage trailer or container.

4.4 Helium regulators.

4.5 Helium tracer probes and hoses.

4.6 Liquid nitrogen supplied from an on-site cryogenic storage container.

4.7 Cleaning solvents such as acetone and/or isopropyl alcohol.

4.8 Clean lint free cloths or paper towels.

5.0 <u>DOCUMENTATION</u>:

5.1 On a checklist of all items to be leak tested for a beam tube module, sign-off and date the entry for each item after the leak test for that item has been successfully completed.

5.2 Maintain a log book for each beam tube module and make entries of all note worthy leak testing events, such as leaks repaired, as they occur during the leak testing of each can section and closing weld joints between can sections of that module.

5.3 Prepare a brief test report of the results of each leak test as it is completed with all information of importance to the outcome of the test listed in the report.

SECTION 7

LIGO PROJECT
WBS 380
ALIGNMENT PROCEDURE

WBS #380 Alignment Procedure

The accurate alignment of the beam tube module is required to ensure that the 1.07 meter minimum clear aperture is maintained. During the construction process the beam tube must be aligned to a level of accuracy that permits final alignment and provides +/- 7.5 cm horizontal and vertical adjustment for later re-alignment. Immediately following the construction process the beam tube module will be final aligned to provide the 1.07 meter minimum clear aperture. Also, a system will be installed for the operational re-alignment of the beam tube module.

Permanent monuments will be located at 250 meter spacings along each arm of the beam tube and approximately 15 meters from the beam tube centerline. The coordinates of these monuments will be relative to the centerline of the beam tube. The monuments and monument coordinates will be furnished by Caltech. The beam tube will be aligned using the coordinates of the permanent monuments.

Two different beam tube alignment concepts are currently being pursued. One concept is centered around using conventional optical tooling equipment and techniques. The second concept is centered around using the newer 3D coordinate measuring equipment and techniques. Both systems can be used to perform the alignment. The accuracy of the systems, the equipment cost and the cost to operate the systems are being assessed to establish which system is the preferred system for use on the LIGO project.

Concept Using Optical Tooling System

Optical tooling equipment and techniques can be used to align the beam tube modules. CBI has developed and performed alignments using optical tooling equipment for both private and government projects that parallel the LIGO needs. In the current concept a series of vertical and horizontal alignment blocks or targets will be established near each beam tube support that define the beam tube alignment The coordinates from the permanent monuments, located about 15 meters from the beam tube, will be used to position temporary monuments located near the tube just inside the concrete cover at the openings for the pump ports. These temporary monuments will be used to align the alignment blocks and targets located at each beam tube support. Horizontal and vertical measurements will be taken directly from the beam tube to the alignment blocks to determine location of the beam tube. If needed optical tooling equipment ,a tilting level and jig transit, can also be used to measure the position of the beam tube to the alignment blocks or targets. The following is the procedure for aligning the beam tube using the optical tooling equipment and techniques.

1. Install Temporary Monuments TM1 & TM2.

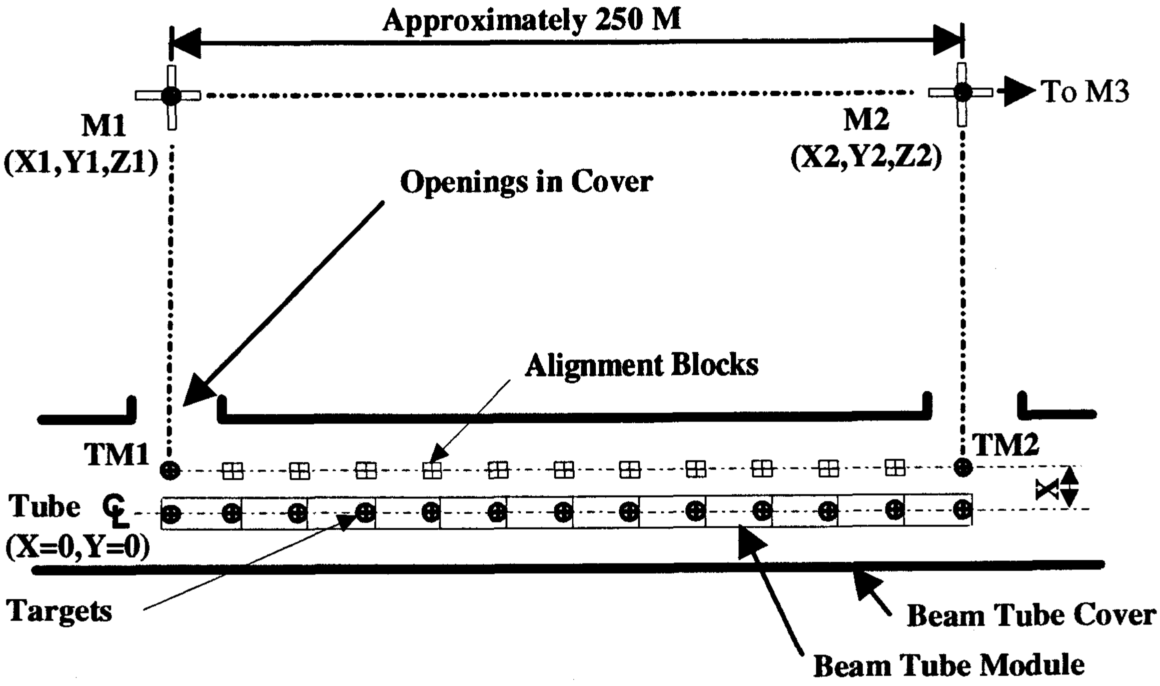
2. Using the Permanent Monument M1 & M2 to set the TM1 and TM2 to a pre-determined vertical and horizontal distance from the beam tube centerline.

3. Install adjustable alignment blocks or targets at each beam tube support.

4. Using optical tooling equipment and techniques align the alignment blocks or targets to be in line with TM1 and TM2. Align both vertically and horizontally. A tilting level with an optical micrometer will be used to set the alignment blocks or targets in the vertical direction and a jig transit with an optical micrometer will be used to set the alignment blocks or targets in the horizontal direction. As an option, we are also considering using a precision level indicator (oil/water level) to set the vertical alignment.

5. Hard measurements will be taken between the alignment blocks and the beam tube reference point to determine the alignment of the beam tube. As an option, optical tooling equipment can be used to determine the position of the beam tube to the alignment targets.

6. The beam tube will be adjusted vertically and horizontally using the adjustable supports until the as measured dimension to the alignment blocks or targets agree with the calculate values.



Final Alignment Inside Cover
Optical Tooling System

LIGO PROJECT
WBS 380
ALIGNMENT PROCEDURE

Concept Using 3D Coordinate Measuring System

CBI is currently working with Kara Company, a local supplier of optical alignment and 3D coordinate measuring equipment, to develop a 3D coordinate measuring system for comparison with the optical alignment system. Kara Company feels the 3D coordinate measuring system is valid and possibly the preferred system for aligning the beam tube. Below is the current alignment concepts using the 3D coordinate measuring equipment and procedures

CONSTRUCTION ALIGNMENT USING THE 3-D SURVEYING SYSTEM:

1. Set up the instrument between two Permanent Monuments (M1 & M2) with line of sight to the target attached to the beam tube section.

2. Site the targets attached to M1 and M2 and input the respective coordinates of M1 and M2. These coordinates of the permanent monuments will be with respect to the theoretical beam tube module centerline.

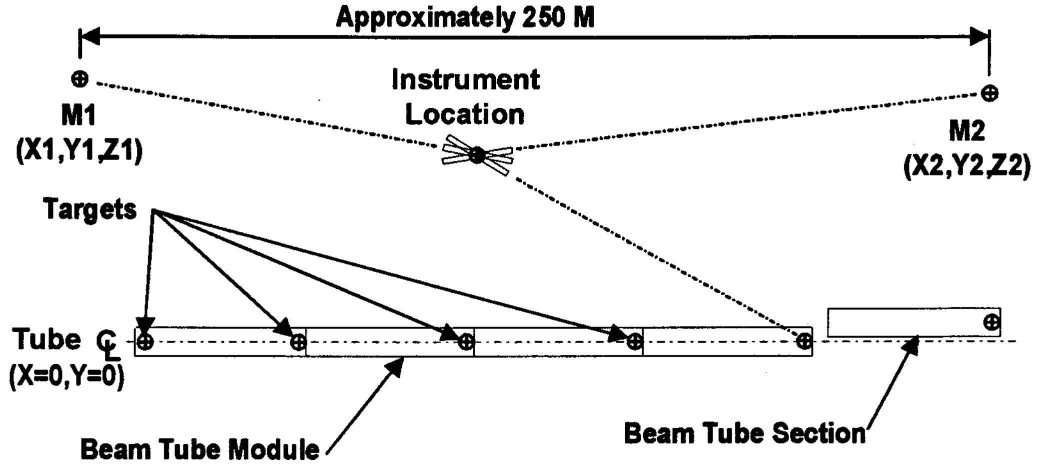
3. Site the target and read the measured coordinates. The targets attached to the beam tube will be positioned with respect to the beam tube center at that location.

4. Calculate the adjustment needed to center the tube.

5. Adjust the beam tube in the vertical and lateral directions until the measured and calculated target coordinates agree.

6. Repeat steps 1 through 5 to center the end of each beam tube section as it is installed.

LIGO PROJECT
WBS 380
ALIGNMENT PROCEDURE



Construction Alignment
3-D Coordinate Measuring System

ESTABLISH TEMPORARY MONUMENT COORDINATES USING THE 3-D SURVEYING SYSTEM:

1. Set up the instrument with line of sight to the Permanent Monument (M1) and the Temporary Monument (TM1) just inside the opening in beam tube cover. Sight the target attached to the M1 and input elevation of M1. Sight the target attached to the TM1 and record the target elevation of TM1.

2. Set up and center the instrument over the M1 and site the target at M2. Input the coordinates of the M1 and M2. Sight the target attached to TM1. Record the measured coordinates of TM1.

3. Repeat steps 1 and 2 at the other Temporary Monuments.

LIGO PROJECT
WBS 380
ALIGNMENT PROCEDURE

FINAL ALIGNMENT USING THE 3-D SURVEYING SYSTEM:

1. Set up the instrument between two Temporary Monuments (TM1 & TM2) with line of sight to the target attached to the beam tube section.

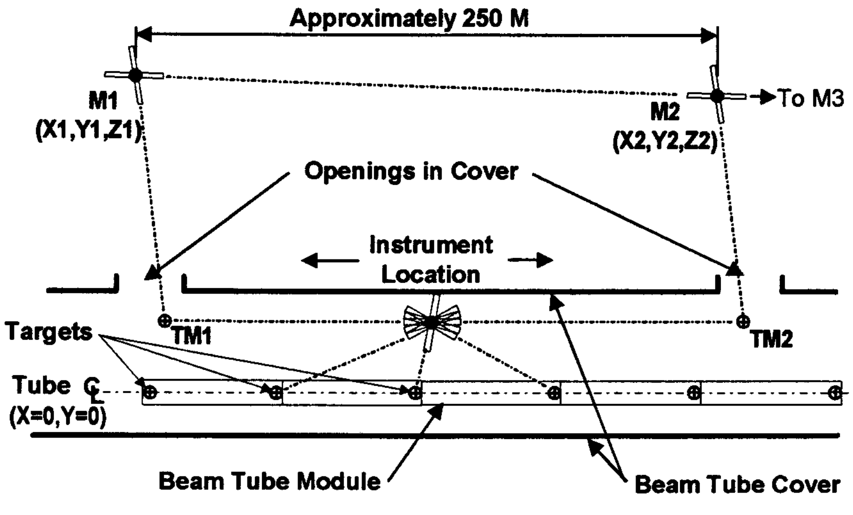
2. Site the targets attached to Temporary Monuments (TM1 & TM2) and input the respective coordinates. These coordinates will be with respect to the theoretical centerline of the beam tube module.

3. Site the target and read the measured coordinates.

4. Determine the adjustment needed to center the beam tube.

5. Adjust the beam tube in the vertical and lateral directions until the measured and calculated coordinates of the target agree.

6. Repeat steps 1 through 5 to center the end of each beam tube section.



Final Alignment Inside Cover
3-D Coordinate Measuring System

The newer and more accurate 3D coordinate measuring systems can measure vertical and horizontal angles to accuracy's equal to one second of arc and distance accuracy's equal to one millimeter plus one part per million of the distance measured. This level of accuracy is adequate for aligning the beam tube modules. Kara Company has demonstrated the 3D equipment to CBI and have agreed to perform a field test of the equipment to confirm the 3D system performs as specified. The test is scheduled to be performed at CBI in Plainfield on November 19, 1993.

After the 3D equipment performance test is completed the two systems, the 3D coordinate measuring alignment system and the optical tooling alignment, will be compared to determine which of the systems is most appropriate for use on the LIGO project.

PURPOSE

This document is a discussion of alignment procedures and equipment for the 8 kilometer run of tubing for the Laser Interferometer Gravitational Observatory(LIGO) of Cal Tech. The following suggested procedures and alternates are based on the prior experience of CBI Na-Con and other vendors/subcontractors of Chicago Bridge & Iron Company.

SCOPE

This outline encompasses procedures, techniques, equipment and references needed to meet the goals of the LIGO Program. The following suggestions and alternatives are results of CBI's experience in optical tooling measurement techniques acquired during various projects such as nuclear component fabrication, large structure installation(wind tunnels, rocket test facilities, shaft and vessel supports) and foundation displacement/deformation studies.

GENERAL

The alignment of the LIGO equipment requires the installation of permanent reference points used for both initial and periodic inspection of the tube "clear aperture" during the facility's 20 year life. This activity will be separated into two(2) aspects. The first being alignment of two straight Datums included in a right angle. The second being the elevation of the references which can include two methods of determination, optical and/or water level systems.

Straight Line Datum Determination

Two considerations for the LIGO Project alignment are distance and temperature. For these reasons, the use of *laser alignment* equipment has been determined inadequate for the LIGO project.

Laser distance equipment may be valuable for triangulation exercises and used for determining support distances. These exercises are discussed later in these procedures. However the use of lasers for alignment activities is not suggested.

It is understood that the alignment activities associated with the LIGO project are two fold:

> The first is the setting and alignment of the reference monuments and proposed alignment blocks. These are the structures used as an "X" reference for aligning the tube supports. This is the most difficult activity for the LIGO project in that it involves "long shot" techniques and can result in greater inaccuracies.
>
> The second phase is the measurement of the "X" dimensions from the reference monuments to the tube section reference point. This activity will use standard techniques and involve higher accuracies.

The first activity alignment concerns are divided into three areas;

- *Scheduling* for reputability,
- *Techniques* to achieve repeatability, and
- *Equipment and Structures* required for rigidity and repeatability.

Monument establishment includes two axis adjustment. The following is a description of straight line and right angle determination of the LIGO beam module alignment lines. Note that reference point elevation is described later under the leveling of the tube sections.

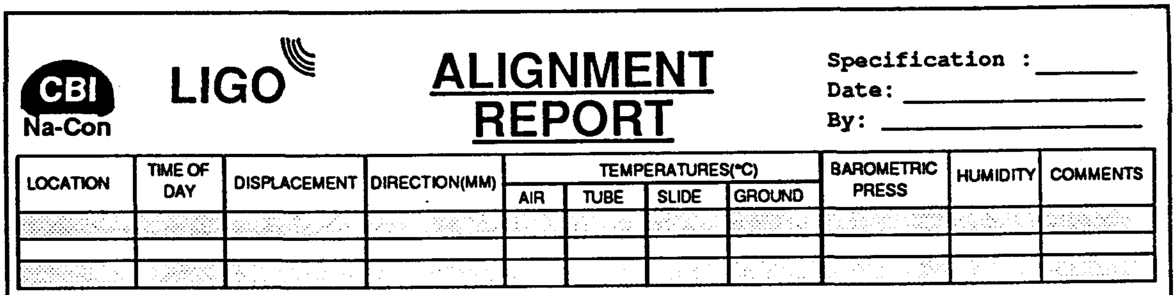
1) Schedule

The LIGO Project will be a study in climatological effects on measurement. Atmospheric conditions will directly influence the repeatability of alignment readings and could create delays during construction. The scheduling of an alignment activity is critical and should follow the pre-determined criteria:

a. Readings to be taken during stable temperature conditions
b. Direct sunlight should be avoided
c. Similar conditions such as humidity, barometric pressure, temperature, etc. should be sought after, and at all locations should be recorded.

This usually means work during the midnight to dawn time frame when stable temperatures are possible. Overcast days could also used during final alignment provided the humidity and other factors are found to be favorable(determined from measurement tests).

The recording of data taken during measurements will require both dimensional and environmental information. A sample form is shown below.



CBI Na-Con LIGO

ALIGNMENT REPORT

Specification : ______
Date: ______
By: ______

LOCATION	TIME OF DAY	DISPLACEMENT	DIRECTION(MM)	TEMPERATURES(°C)				BAROMETRIC PRESS	HUMIDITY	COMMENTS
				AIR	TUBE	SLIDE	GROUND			

FIGURE 1.0

This information should be formatted to log into a database spreadsheet in order to compare initial readings based on dimensional displacement and direction, temperature(air, ground and monument), atmospheric conditions, time of day, etc. An analysis for determining relationships, trends and patterns will provide an ability to achieve repeatable measurements.

Measurements will also provide data for determining other possible anomalies such as soil stability, ground water effects, seismic problems, etc. that can effect the alignment condition of the LIGO reference monuments. This will require a design analysis for the monument foundations in regard to piling depth, support pad interference, etc. in order to achieve the most stable condition for reference monuments and thus a repeatable measurement. These monument designed are discussed later in further detail.

A schedule of alignment inspections during both LIGO facilities construction and operation will be necessary after seasonal changes, natural events(hurricanes, flooding, seismic activity, etc.) and design changes that effect critical alignment. This will add to the data base for determining their effects on monument displacement and will provide an accurate reference for the LIGO tube(s).

2) Techniques - Straight Line Monuments

The activity of monument alignment will require techniques developed for applications such as the Huntsville, Al 2,000 foot laser tube and the Army Corps of Engineers' dam deformation programs. Based on these examples, the most effective technique can be summarized as,

> **"long shot angular targets with short shot lateral adjustments."**

This is achieved by using a multiple of "lateral blocks" between further spaced "angular monuments." The 250 meter distance between pumping ports should be acceptable for angular monuments.

A spacing no greater than 30 meters apart is acceptable for lateral "alignment blocks." A detail is shown below.

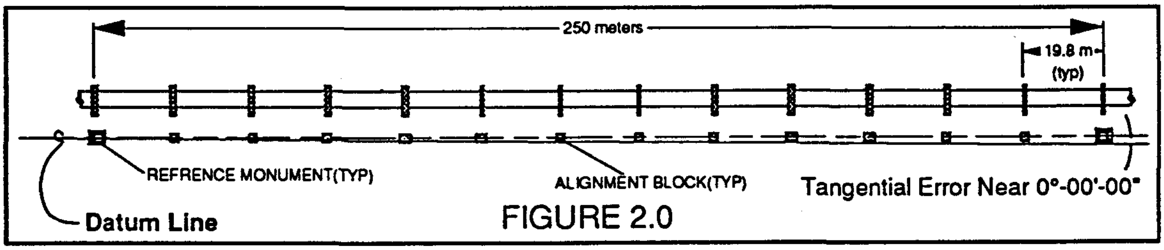


FIGURE 2.0

The reasons for this method of "angular alignment/lateral adjustment" is due to the optical instrument's resolution. The equipment's "one second of an arc" accuracy is limited to the ability to distinguish the reticle pattern on a target. The alignment process begins by centering the instrument between the angular targets and adjusting the instrument's angular and lateral settings(called bucking-in). The targets mounted at the angular monuments should be back lighted or collimators may be used. If a target is used, the split between paired lines should be calculated before use and determined to equal or exceed the maximum distance of the reticle pattern. The greater the angular target distance, the better angular position the instrument will achieve(see below).

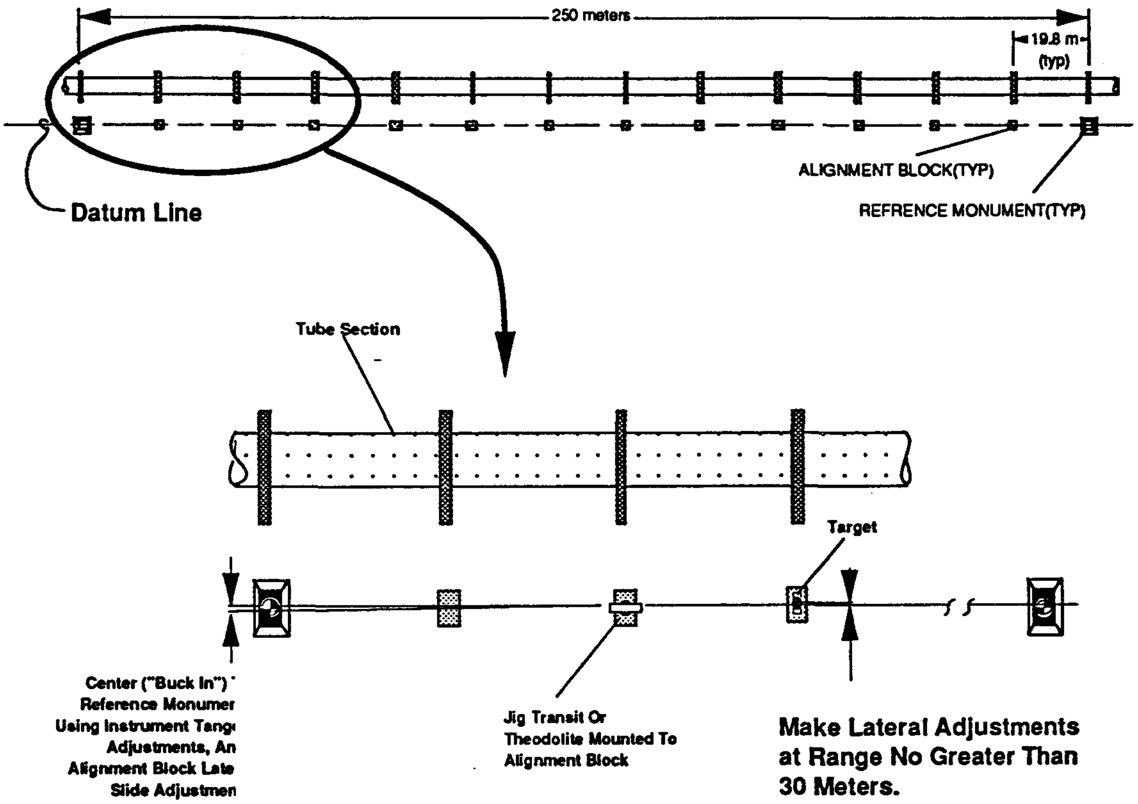
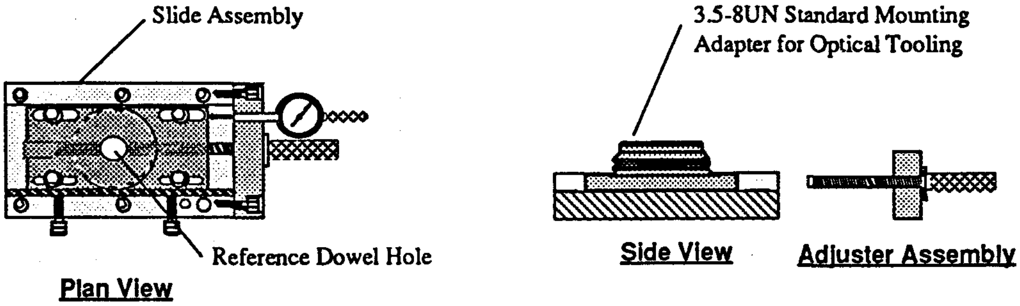


FIGURE 3.0

When making lateral adjustments, the opposite is true. Resolution must be fine enough to distinguish 0,25 millimeters(0.010 inch.) in order to achieve the accuracy capable of optical tooling. This is done by adjusting a lateral target at each monument(it is best to adjust the target because optical micrometers do not have an acceptable resolution beyond 30 meters). Each lateral adjuster should be a permanent fixture to its monument/block and capable of supporting a target and an instrument.



Plan View

Side View

Adjuster Assembly

FIGURE 4.0

The adjustment should be no more than 2.0 mm per rotation. A micrometer or dial indicator should be mounted to read displacement during and after adjustment. Locking bolts should be provided and capable of securing the slide. The locking bolts may be allen or torx head to discourage tampering.

The technique of alignment noted will be performed for one beam module "line." The second line will be performed in a similar fashion after the establishment of the 90° turn and the associated angular monuments.

2) Techniques, cont. - 90 Degree Turn

The LIGO tube arrangement requires a right angle turn. this can be performed by triangulation and by auto-collimation. It is suggested that each method be used for verification during construction.

Triangulation can be performed using a standard surveying procedure and could include laser distance equipment. The set-up would require the use of a theodolite similar to the current accuracy levels of the K&E AIMS II, Wilde T4 or the Zeiss units available today. This includes accuracies to 0.5 sec RMS and resolution of 0.0001 grad. Also, consideration should be given to the effective aperture diameter of the objective lens. The long distances will require maximum light and the larger the objective lens, the better the resolution. The Army Corps of Engineers use an old model of a Wilde theodolite(T-3) which is no longer in production. This scope has a large objective lens for long shots and meets their needs for dam studies where one to three mile runs are not uncommon. The current equipment available today reach up to 54mm effective aperture and will provide the accuracies needed.

The optical tooling method of auto-collimation can be used as a checking activity for short distances. This will require the use of a jig transit equipped with a right angle optical mirror mounted perpendicular to the scope axis, on a stand with a lateral adjuster or, if available, an optical tooling bar. This "control" instrument will be "bucked-in" to the first aligned beam tube module line. The second instrument will be equipment with an auto-collimating light source and mounted along the second beam module line. The second instrument will auto-collimate to the control instrument mirror to achieve a 90° angle(± 1.0 second of an arc). The line will be measured using both lateral and angular shots for comparison to the triangulation method.

2) Techniques, cont. - shooting around obstacles

The LIGO Project buildings present problems to the alignment procedures. The initial set-up of the alignment lines and establishment of alignment monuments should be scheduled before buildings or at lest building walls are in place. The lines can then be re-established using alternate reference monuments.
The locations of alternate monuments will be adequate to re-establish the beam module line from a distance beyond the building perimeters. The monuments will be equipped similar to the angular monuments described previously.

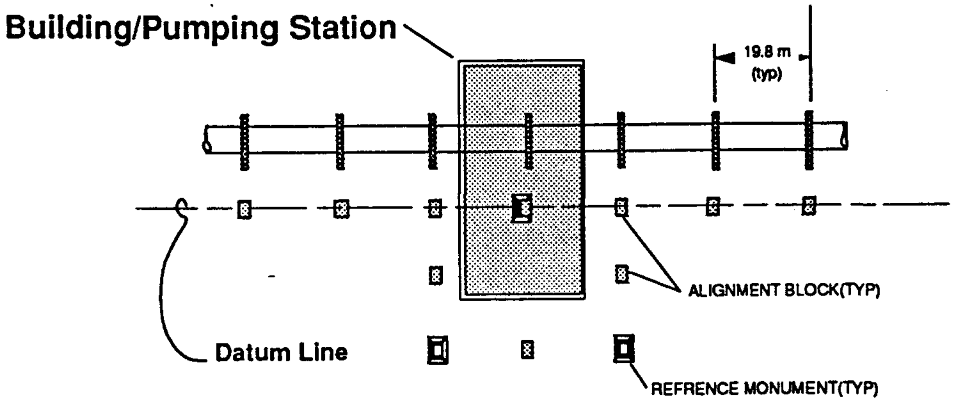


FIGURE 5.0

2) Techniques, cont. - Miscellaneous

The reasons that alignment lasers are discounted for this project also present problems for sight alignment practices. Experience with laser alignment equipment found that use in close or enclosed areas such as trenches, pipelines, etc. tend to affect the laser's ability to run a straight line. Distance of shot disperses the beam where the receiving cell can be effected by the beam frequency and provide erroneous data. These same principles effect sight also, but in smaller degrees. During LIGO procedure qualifications, an exercise to determine the effects of these interferences should be quantified.

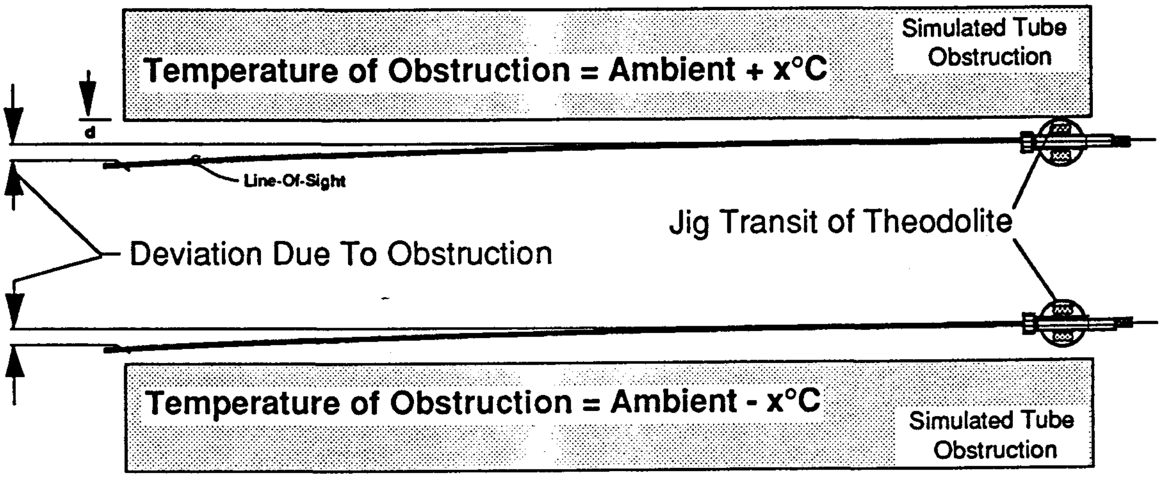


FIGURE 6.0

The tendency of light to bend in relationship to heat and its ability to distort shots when close to objects are two concerns that will effect the alignment activities. During procedure testing, a determination of the effects of objects(such as the LIGO tubes) influencing light will be measured. This can be done by setting two optical tooling stands at each end of obstruction. The obstruction can be best served with a 48" pipe similar to the LIGO tubes. Use a jig transit mounted with an optical micrometer as the "control instrument". Mount the reference (a Wyteface optical scale) on a stand on the other end of the obstruction(tube). Shoot and record data on a sheet similar to the one previously shown with temperature and weather conditions. Move the obstruction a few centimeters away from the control instrument's line of sight(LOS). Re-shoot and record data Repeat these steps until the difference in surface readings do not change. This will represent the minimum distance the LIGO reference monuments can be to the beam tube structures, enclosures, walls, etc. Repeat the test with varying degrees of obstacle/air temperatures. This will determine the maximum limits for temperature differences for repeatable readings.

This exercise will also determine the placement of optical monuments/blocks in or outside of the tube cover.

Tests for obstructions, ie.; valves, flanges, supports, etc., should use the same procedures noted above to determine the effects of point interference on the line-of-sight. These tests will also need to be qualified for a range of temperature differences that best meet expected conditions at both LIGO sites.

3) Equipment and Structures

The ability to sight a straight line for a minimum of four(4) kilometers with a tolerance of ±2.5 centimeters/250 meters is an achievable goal with current equipment and can be performed with better than average surveying equipment. CBI has the experience and equipment in hand to achieve the LIGO requirements.

Reference Monuments

The LIGO reference monuments will be located near each 250 meter pumping station. This monument will consist of a cast in place or precast concrete monument with an attachment plate located on top of the reinforced structure.

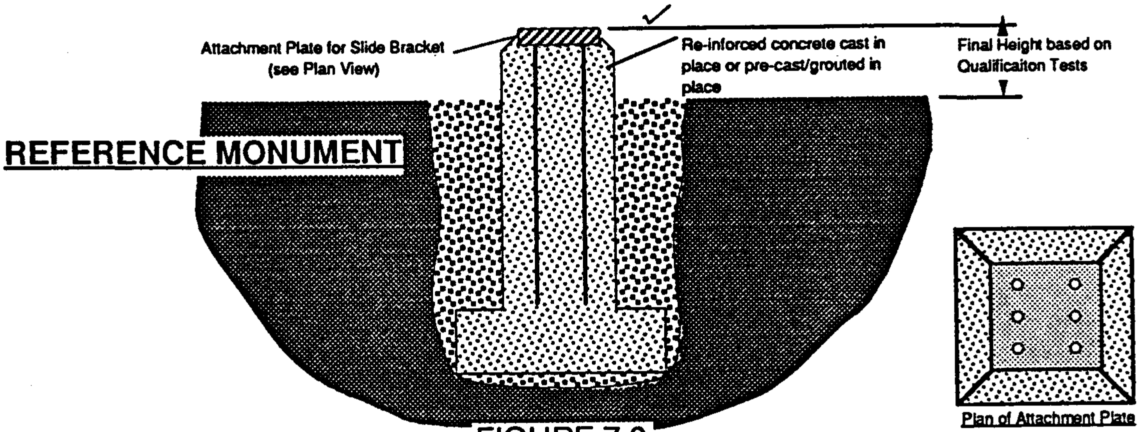
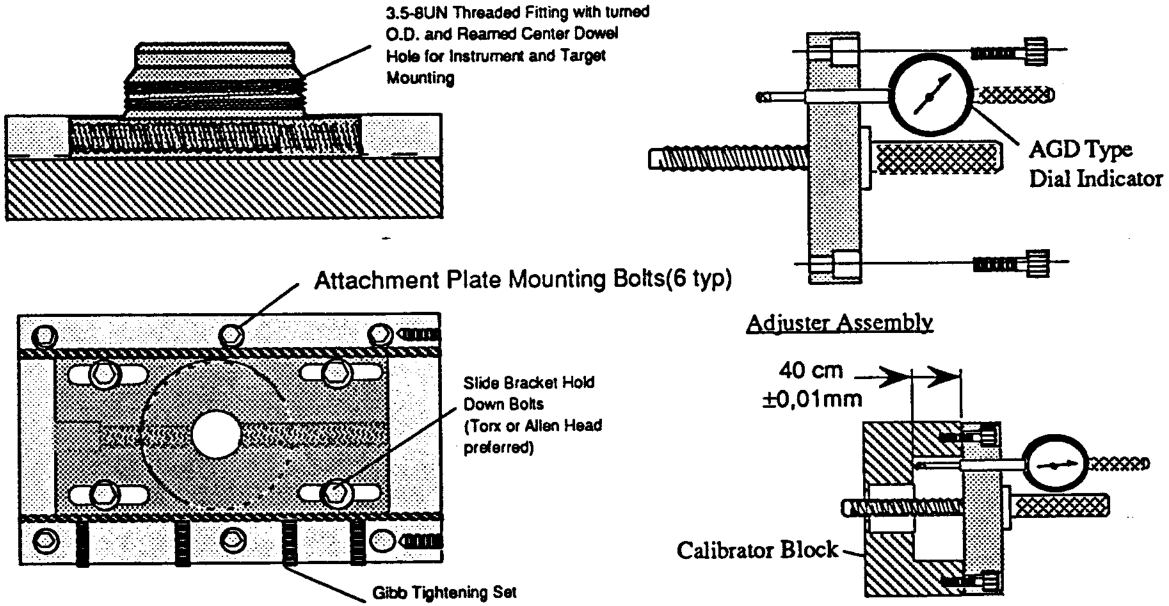


FIGURE 7.0

This attachment plate will accept a standard slide assembly with a 3 1/2"-8un standard instrument mount.



Adjuster Assembly

Calibration of Assembly

FIGURE 8.0

The standard slide will be mounted to the monument attachment plate with bolts(Torx or Allen head). The detachable slide adjuster and dial indicator or micrometer mounts to the slide assembly during alignment activities. This assembly is used as both an instrument and target stand. After the position is set and the location reading is taken, the slide is secured with bolts(Torx or Allen head). Each time an alignment survey is conducted the location of the slide is read using the slide adjuster assembly. Any re-location of the slide after initial setting should be recorded and analyzed for temperature and other affects that would cause a shift.

Alignment Blocks

Alignment blocks are smaller monuments used for short shot, lateral adjustments. These blocks should be positioned in line with the reference monuments and located at each tube support for "X" & "Y" reference points. The blocks are pre-cast concrete units with mounting tabs and attachment plates identical to those on the monuments.

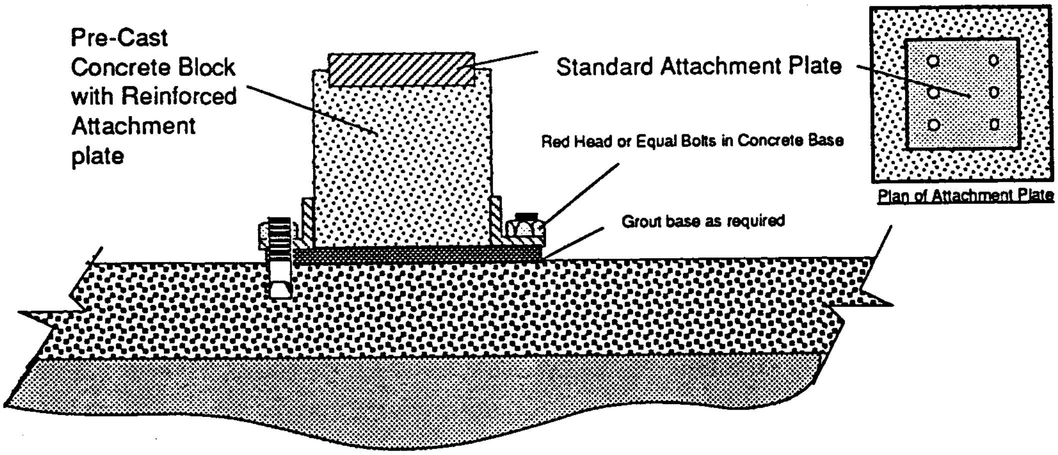


FIGURE 9.0

This attachment plate will accept a standard slide assembly with a 3 1/2"-8un standard instrument mount.

The standard slide will be mounted to the block attachment plate with bolts(Torx or Allen head). The detachable slide adjuster and dial indicator or micrometer mounts to the slide assembly during alignment activities. This assembly is used as both an instrument and target stand. After the position is set and the location reading is taken, the slide is secured with bolts(Torx or Allen head). Each time an alignment survey is conducted the location of the slide is read using the slide adjuster assembly. Any re-location of the slide after initial setting should be recorded and analyzed for temperature and other affects that would cause a shift.

Reference Monument Targets

Reference monument targets used for angular positioning purposes will consist of alignment scopes mounted on brackets at each 250 meter span. The scopes will be equipped with light sources for collimating and have a built-in auto reflection target. Two scopes are required and will mount into an alignment bracket and attach to the slide assembly using the 3 1/2"-8un standard attachment.

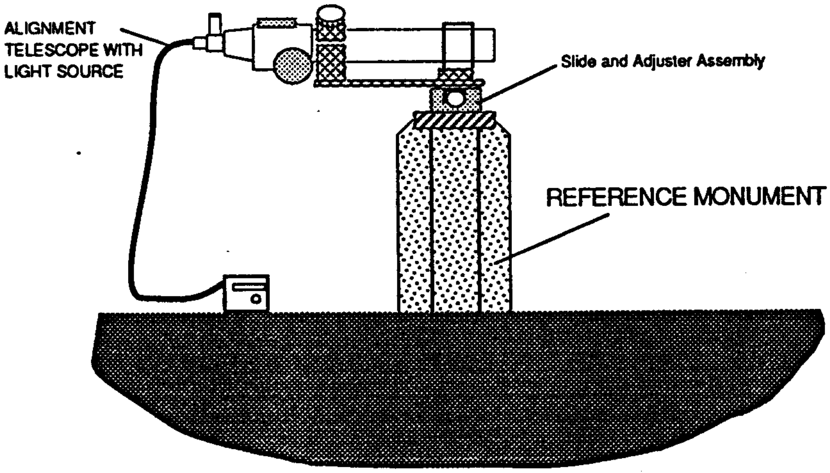


FIGURE 10.0

Each alignment scope will be collimated co-axial with the opposing monument scope and serve as the "bucking in" reference points for the reference instrument(jig transit or theodolite). If alignment activities occur during the daylight hours, a target may be positioned laterally with the reference instrument(jig transit or theodolite). Positioning techniques for repeatability will be developed during the qualification tests.

Alignment Block Targets

Alignment block targets used for lateral adjustment purposes will be standard paired lines with the pairs being no more than 2mm clear distance apart.

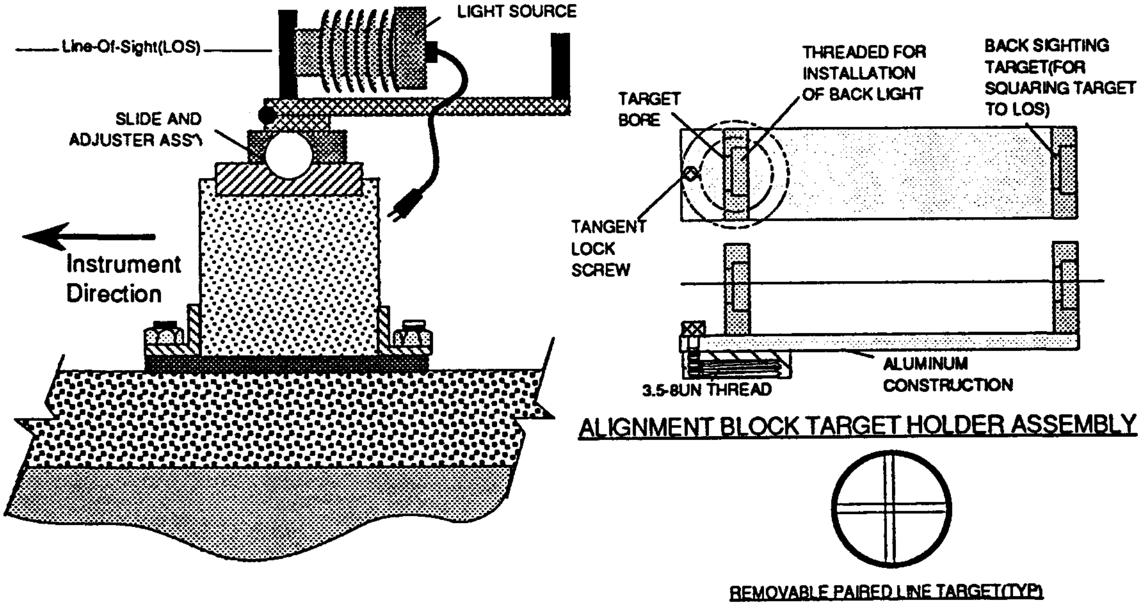


FIGURE 11.0

These targets will mount into an alignment bracket with a backlight and attach to each slide assembly using the 3 1/2"-8un standard attachment. The target will be aligned with a dowel pin located in the center of the slide and rotated to square with the tube section via the aligner target(see detail). Each target will be positioned laterally with the reference instrument(jig transit or theodolite).

Positioning techniques for repeatability will be developed during the qualification tests.

Optical Tooling & Equipment

The optical tooling and equipment discussed in these procedures are currently available to CBI and perform the necessary functions required for these activities. Below is a listing of standard equipment discussed in this procedure:

Qty	Model No.	Manufacturer	Description
2	71-2022	Cubic Precision	Alignment Scope
2	71-1241	Cubic Precision	Auto-Coll/Rt Angle Eyepiece
2	71-3220	Cubic Precision	Coincidence Striding /Cross Level
4	71-5100	Cubic Precision	Spherical Adapter(with Collet)
2	71-5511	Cubic Precision	Auto-Collimating Illumination Kit
2	71-5170	Cubic Precision	Alignment Telescope Brkt Ass'y
2	71-5520	Cubic Precision	Lamp Housing for targets
2	71-1010	Cubic Precision	Jig Transit & Coincidence Level
2	71-1113	Cubic Precision	Metric Optical Micrometer
4	71-1130	Cubic Precision	Circular Auto-Reflection Mirror
2	71-5030	Cubic Precision	Portable Instrument Stand
2	71-5085	Cubic Precision	Lateral Adjuster
4	71-6010	Cubic Precision	Wyteface Scale
2	71-5015	Cubic Precision	Instrument Trivet
2	71-1241	Cubic Precision	Combination Rt Angle/Light
1	71-3010	Cubic Precision	Tilting Level

Equipment discussed in these procedures that will require manufacturing are listed below:

Qty	Ref No.	Manufacturer	Description
36	CBI -001	Chicago Bridge & Iron	Reference Monuments
368	CBI -002	Chicago Bridge & Iron	Alignment Blocks
420	CBI -003	Chicago Bridge & Iron	Std Slide Assembly
12	CBI -004	Chicago Bridge & Iron	Slide Adjuster
2	CBI -005	Chicago Bridge & Iron	Slide Adj. Calibrator
12	CBI -006	Chicago Bridge & Iron	Lateral Target Ass'y

Elevation Determination

The LIGO tube section elevation can be determined using two different systems of measurement. The adjustment for gravity and the curvature of the earth will be necessary for either systems.

The first is the use of optical tooling coincidence tilting levels with an accuracy of 1 second of an arc. In addition to coincidence levels the use of automatic leveling in some very accurate theodolites can achieve the same results. The field measurement techniques and procedures are similar to those used for developing straight datums and the concerns regarding temperature and atmospheric conditions will be the same. This is a fundamentally sound method of leveling the reference monuments and can be easily incorporated in the equipment already discussed.

However, for the case of long shot optical practices, the use of water(or a light fluid) leveling system will best meet the installation and periodic inspection needs of the facilities. This method of level surveying will be a stand alone feature of the LIGO facility and can be installed with a few appurtenances that make the unit a full functional system regardless of season.

The system consist of stainless tubing, sightglass gauges, PVC or equal tubing guards, pump, heater and thermostatic controls. The pump circulates the water(or fluid) thru the water heater and around the LIGO system.

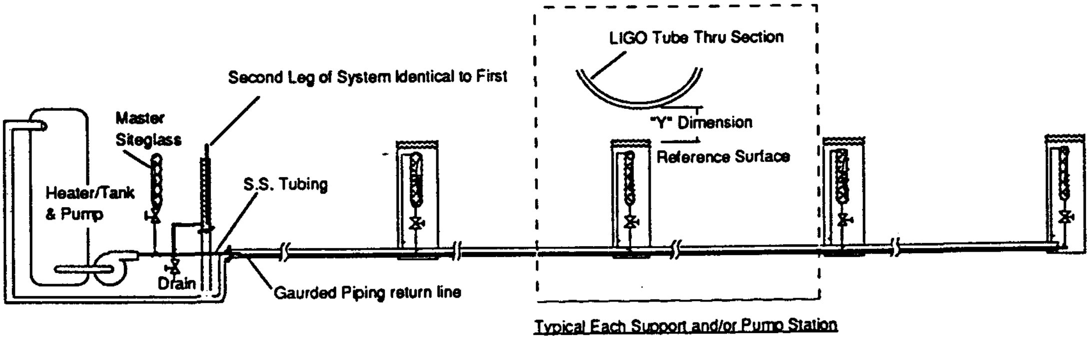


FIGURE 12.0

The Pumping station contains a master level gauge so the water can be drained after the temperature is equalized thru the perimeter to a predetermined elevation. The sightglass water level is measured at each support using a hand held microscope and micrometer. An alternate means of level readings is using a tilting level. The accuracy will be determined during qualification tests.

The tubing is run thru plastic guarded piping running under or near the LIGO tube sections. It can also be run near the reference monuments and alignment blocks if they are located near the tube covers. A tube elevation reference can be located at the level sightglass and readings can be taken directly as required.

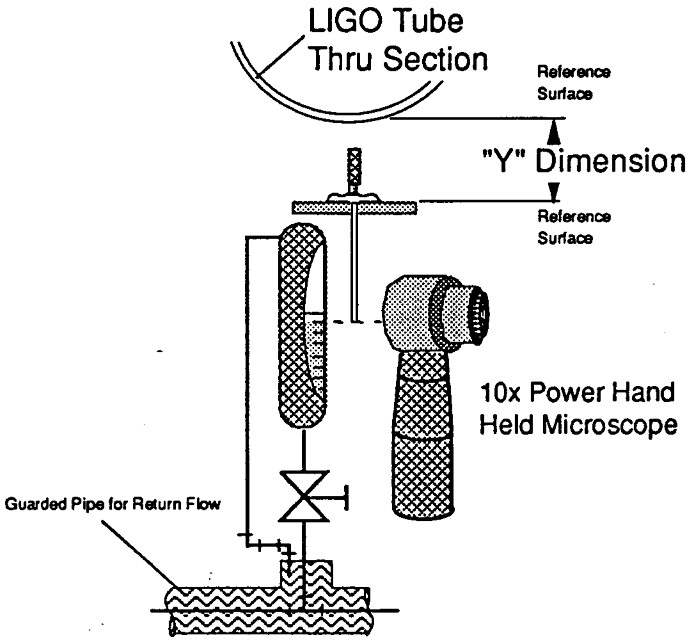


FIGURE 13.0

The fluid used in the system can be water, oil, etc. however an environmentally safe material will be necessary.

This document is a suggested starting point for the discussion and creation of procedures for the alignment of the LIGO project. This activity must be planned, coordinated and worked within the overall and specific installation procedures for the tube sections, structures and buildings.

L.I.G.O. PROJECT
CONSTRUCTION PLAN

WBS 300

OPTIONAL 3D ALIGNMENT CONCEPT

We are assessing the current surveying/alignment technologies for alignment of the LIGO beam tube modules. Two alignment concepts are being pursued, a concept that uses optical tooling procedures and equipment and a second concept that uses conventional 3D surveying procedures and equipment.

Arrangements have been made to perform a demonstration test on the optional 3D surveying equipment to determine whether or not the 3D system is a valid option for aligning the beam tubes. Once the 3D demonstration test is completed an assessment will be made of the two systems and a system selected. The attachments briefly describe the concept using the 3D procedures and equipment.

SECTION 8

WBS #390 CLEANING AND CLEANING MAINTENANCE

Economical and successful cleaning of the tube sections and maintenance during the construction process are critical elements to the beam tube module development. The specified cleaning process is judged by CBI to be effective but may present problems with handling and disposal which are not cost effective. CBI has developed alternate cleaning procedures which have been successfully used on high vacuum facilities but have not been evaluated for the effects on the sensitive outgassing characteristics required for the LIGO project. Once the cleaning procedure has been selected, the procedure must be automated and incorporated into the construction process. Cleaning of the beam tube sections will be performed by CBI at or near the site just prior to installation. A key question to resolve regarding incorporation of the cleaning process is whether to clean the tube sections before or after leak testing. Cleaning before leak testing helps ensure that high vacuum levels and therefore high leak sensitivity can be achieved. However cleaning before leak testing will require increase the risk of contamination and could mask the presence of leaks or require drying prior to leak testing. Although this issue has not been resolved, the selected approach may consist of a solvent wipe prior to leak testing and solvent steam cleaning after leak testing. In any case, incorporation of the cleaning process into the construction process requires a effective cleaning maintenance plan and an effective final inspection.

The basic requirements, materials and documentation for all cleaning procedures are described in the attached preliminary procedure LIGOCP entitled "Planned Approach For Cleaning And Cleaning Maintenance For LIGO Project". CBI is considering the use of de ionized water instead of the currently stated potable water. All lint free clothes and paper towels will be suitable for class 10,000 cleaning.

CBI has identified alternative cleaning procedures and developed a methodology to evaluate these alternative procedures. The alternative procedures and evaluation process are identified in the attached procedure CLALT entitled "Method For Qualifying Alternate Cleaning Approaches For Final Cleaning Before Helium Mass Spectrometer Testing".

Attached is preliminary procedure CL1N for cleaning the completed tub sections entitled "Cleaning of Completed Beam Tube Can Sections Before Leak Testing and Final Assembly". The procedure will likely be revised into two separate procedures for cleaning before and after leak testing. The clean room classification for execution of this procedures will be quantified. Class 100 is being considered. The re circulation of cleaning fluids may be deleted due to the potential for contamination. Humidity indicators will be placed in the cleaned tube sections prior to sealing to ensure that the sealed environment is maintained. De ionized water may be required in place of the potable water presently specified. CBI will propose that the specified cleaning process temperature of 60 degree C be increased to truly steam clean. Rinse temperature may remain 60 degree C. CBI feels that steam cleaning does a much better job and has been our high vacuum cleaning process for years.

Once installed, the cleanliness of partially completed beam tube modules will be maintained through a system of traveling clean room enclosures combined with a constant flow of filtered dry air through the installed tube sections.

Attached is preliminary procedure CL2N entitled "Maintenance Of Partially Completed Beam Tube Modules After Final Assembly During Construction". This procedure describes the basic incorporation of the cleaning maintenance plan into the placement, welding, leak testing, and final exit from the installed beam tube sections. Personnel clothing and cleanliness requirement will be quantified. Class 100 is again being considered.

The flow of air through the partially completed tubes will be provided by a unit located at the starting end of the beam tube module. CBI's present plan is to start at the mid station between the modules and use the same system for the construction of both module on each side of the mid stations. The attached procedure BDF1 entitled "Blower / Dryer / Filtration System Operation and Maintenance Procedure" describes the activities associated with the pressurized air unit.

The cleanliness of the working end of the beam tube modules will be maintained by traveling clean room enclosures which cover the closing seams and the open end of the beam tubes. The basic configuration and operation of the traveling clean rooms are shown in the attached procedure CR1TSM entitled "Clean Room Transporting, Storage and Maintenance Procedure".

The last activity in the beam tube module installation will be the removal of the welding and leak testing purge gas system and final exit and inspection from the tube. Although personnel entry will be limited, CBI feels that the elimination of personnel entry into cleaned tube section is not feasible. Limited, restricted and controlled entry into cleaned and installed tube sections be performed to the attached procedure CL3N entitled "Final Cleaning and Inspection of LIGO Beam Tube Inner Surfaces Including Baffles".

CBI

DOC. ID LIGOCP
REV. NO. 0
CONTRACT 930212

TITLE PLANNED APPROACH FOR CLEANING AND CLEANING MAINTENANCE FOR LIGO PROJECT FOR CALTECH

PAGE NO. 1 **OF** 2

APPROVED	Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-2-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD	**REV. NO.**

1.0 SCOPE:

This planned approach to cleaning covers

1.1 Offsite cleaning requirements for manufacturers of purchased components or subassemblies.

1.2 Cleanliness maintenance requirements for the manufacturer of the beam tube can sections.

1.3 Onsite initial spot cleaning followed by final cleaning using procedure number CL[illegible] for completed beam tube can sections after they are helium mass spectrometer leak tested, but before they are installed and welded in final position.

1.4 Cleaning maintenance procedure number CL2N for maintaining the cleanliness integrity of partially completed beam tube modules during construction. Included as an integral part of this procedure is the spot cleaning requirements for the closing weld joints between can sections after welding of those joints is complete.

2.0 PERSONNEL:

Experienced personnel shall perform and supervise all cleaning and cleaning maintenance performed in accordance with this planned approach and the cleaning and cleaning maintenance procedures referenced within this plan.

3.0 REFERENCES:

3.1 California Institute of Technology Technical Specifications Number 1100004 for Beam Tube Modules and Number 1100007 for Type 304L Stainless Steel Vacuum Products.

3.2 ASTM Designation A 380 Standard Practice for Cleaning and Descaling Stainless Steel Parts, Equipment and Systems (as a guide).

4.0 MATERIALS USED IN ALL CLEANING PROCEDURES:

4.1 Potable tap water with a chlorine content in the range of 0.02 to 200 ppm.

4.2 Technical grade solvents such as acetone or alcohol.

4.3 Lint free cloths or paper towels.

4.4 100 Watt blacklights with 3650 Angstrom unit wavelength.

4.5 Blacklight meters capable of measuring at least 800 uw/cm^2.

5.0 DOCUMENTATION:

5.1 On a checklist of all purchase items for a beam tube module, sign-off and date the entry for each purchase item indicating that the item was received in a clean condition. Note each purchase item received in a non-clean condition. List them on a separate checklist of items still to be cleaned or on a checklist of items returned to the manufacturer for cleaning or recleaning

5.2 Maintain a cleaning log book for each beam tube module listing the sign-offs and dates of entry for:

5.2.1 Satisfactory completion of the initial spot cleaning followed by the satisfactory completion of the final cleaning per procedure CL1N for each beam tube can section.

5.2.2 Satisfactory cleaning maintenance during construction per procedure CL2N of each partially completed beam tube module. This covers the local cleaning of closing weld joints after successful completion of the local HMS leak testing of those weld joints.

CBI

DOC. ID CLALT
REV. NO. 0
CONTRACT 930212

TITLE METHOD FOR QUALIFYING ALTERNATE CLEANING APPROACHES FOR FINAL CLEANING BEFORE HELIUM MASS SPECTROMETER TESTING

PAGE NO. 1 OF 3

APPROVED	Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-3-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD REV. NO.

1.0 SCOPE:

The purpose of this cleaning qualification procedure is to compare the outgassing properties of the 304L low hydrogen stainless steel after coupons of that material have been cleaned with different cleaning agents.

2.0 MATERIAL & EQUIPMENT TO BE USED WITH THIS PROCEDURE:

2.1 Based on the contents of the MSDS for each of the cleaning agents reviewed, select and test those optional cleaning agents such as:

2.1.1 Simple Green

2.1.2 Mirachem 500

2.1.3 Oakite [illegible]ZL

2.1.4 Triton [illegible]

2.1.5 Diversey Wyandotte Aerowash

2.1.6 Pierce RBS-35

2.2 A two percent (2%) by volume mixture of Oakite 33 as the control against which all other cleaning agents are compared.

2.3 Seven (7) 304L stainless steel outgas coupons that are one inch (1") x eighteen inch (18") x one eighth (1/8") in size. With a steel stencil, mark each coupon with an ID that identifies it with the cleaning agent used on that coupon.

3.10 Individually conduct an outgassing test on each of the cleaned coupons including the coupon cleaned with the Oakite 33 cleaning mixture.

3.11 Compare the outgassing data for each of the cleaning agents.

3.12 Select the cleaning agent with the lowest outgassing rate and Caltech's concurrence.

4.0 DOCUMENTATION:

4.1 Complete an outgassing rate report for each cleaning agent tested and the conclusion reached based on a summary of that data.

CBI

DOC. ID CL1N
REV. NO. 0
CONTRACT 930212

TITLE CLEANING OF COMPLETED BEAM TUBE CAN SECTIONS BEFORE LEAK TESTING AND FINAL ASSEMBLY - CALTECH

PAGE NO. 1 OF 8

APPROVED

Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-3-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD	REV. NO.

1.0 SCOPE:

This procedure covers the onsite initial spot cleaning followed by the onsite final cleaning for completed beam tube can sections before they have been helium mass spectrometer leak tested and installed and welded into final position. Use this procedure with procedure LIGOCP.

2.0 PERSONNEL CLOTHING REQUIREMENTS:

2.1 Personnel entering beam tube can sections prior to, during or following initial spot or final cleaning, must be wearing white clean room style coveralls, shoe covers over soft soled shoes or clean room type boots, caps and gloves. Shoes with nails or other sharp projections must be removed.

2.2 Clean room clothing for use by anyone entering a beam tube can section must be cleaned on a regular weekly basis when in use or anytime it becomes obviously soiled with deposits of dirt, oil or grease.

3.0 EQUIPMENT AND MATERIALS TO BE USED WITH THIS PROCEDURE:

3.1 Materials listed in procedure LIGOCP.

3.2 White nylon coveralls, shoe covers (booties), head covers and gloves.

3.3 Cleaning Skid with stainless steel gas fired heaters for a rinse tank and wash tank with circulation pumps, valves, hose, hose reels and jet cleaning head with adjustable tensioning legs for each can section cleaning station.

3.4 Receiving tank equipped with a valved rinse water return and a valved cleaning water return.

3.5 Recirculation pumps and filter systems at each cleaning station for retrieval of both rinse effluent and cleaning solutions.

3.6 One set of power turning rolls and one set of idler rolls for each cleaning station.

3.7 One variable speed power winch (tugger) with cable for each cleaning station for pulling the jet cleaning head through the can sections.

3.8 Propane gas or natural gas for firing the heaters.

3.9 A minimum of two high volume air movers at each cleaning station.

3.10 Drums of Oakite 33 cleaning compound.

3.11 Litmus paper.

3.12 No Smoking and Flammable Liquids signs.

3.13 Plastic covers for sealing the ends of each can section after satisfactory final cleaning and drying.

3.14 Two inch (2") wide duct tape.

4.0 PROCEDURE:

See the cleaning set-up at the end of the procedure for a conceptual sketch of the following.

4.1 Post "No Smoking" and "Flammable Liquids" signs around the entire cleaning area while cleaning operations are being performed.

4.2 Install high flow volume input and output fans at the opposite ends of each of the can section cleaning stations.

4.3 Install vent hoods above each cleaning station to rapidly remove cleaning solvent vapors from the cleaning area.

4.4 Place a beam tube can section in the center of the cleaning station area on two (2) sets of power rolls spaced about forty feet (40') apart with the output fan end of the can section elevated approximately six foot (6') above the input fan end.

4.5 Initially spot clean each can section as follows:

4.5.1 Wipe the blacklight and blacklight power lead cables with alcohol solvent to remove deposits of dirt, grease and oil before taking this equipment into the can section to be cleaned.

4.5.2 Put on white nylon coveralls, shoe covers, head cover and gloves before entering the can section to be cleaned.

4.5.3 Starting at the end of the can section with the input fan, inspect the interior surface of the entire length of the can with the blacklight. Remove all deposits of hydrocarbons indicated by the blacklight using acetone or alcohol soaked lint free clean rags and/or paper towels.

4.5.4 Document completion of the initial spot cleaning of each can section by entry in the cleaning log book.

4.6 Final clean each can section as follows:

4.6.1 Mix a two percent (2%) by volume solution of Oakite 33 and potable tap water (see 4.1 of procedure LIGOCP) in one of the two gas heated cleaning tanks on the CBI cleaning skid. Check the acidity of the solution using litmus paper.

4.6.2 Fill the second gas heated cleaning tank on the CBI cleaning skid with potable tap water (see 4.1 of procedure LIGOCP).

4.6.3 At the low end of the can section to be final cleaned install a receiving tank with two valved connections.

4.6.4 To one of the valves on the receiving tank, install a potable tap water recirculation pump and filter system to recycle the used tap water from the receiving tank through the filter and back to the potable tap water heater tank for reuse.

4.6.5 On the other receiving tank valve, install a cleaning solution recirculation pump and filter system to recycle the used Oakite 33 cleaning solution from the receiving tank through the filter and back to the cleaning solution heater tank for reuse.

4.6.6 Turn on the heaters under the potable tap water tank.

4.6.7 Turn on the heaters under the Oakite 33 cleaning solution tank.

4.6.8 Connect a clean rubber hose from the potable tap water tank through a pump to the jet cleaning head.

4.6.9 Place the jet cleaning head at the low end of the can section to be cleaned. Adjust the jet cleaning head tensioning legs so that it is centered in the can.

4.6.10 Connect the cable from a power winch (tugger) to the end of the jet cleaning head. Connect the energy supply to the power winch.

4.6.11 When the temperature of the potable tap water reaches 60°C (140°F), start the potable tap water circulation pump.

4.6.12 When the jet cleaning head starts to rotate, energize the power winch (tugger) to start the jet cleaning head moving through the can section toward the higher end at a rate of approximately two (2) feet per minute. At the same time, energize the power turning rolls to start the can section slowly turning as the jet cleaning head moves through the can. Also energize the potable tap water recirculation pump and open the valve on the receiving tank to carry the water from the receiving tank through the filter back to the potable tap water heater tank for reuse.

4.6.13 When the jet cleaning head reaches the far end of the can section, turn off the power to the potable tap water circulation pump, recirculation pump, the winch pulling the cleaning head and the power turning rolls. Close the valve in the tap water recirculation line from the receiving tank.

4.6.14 Disconnect the jet cleaning head from the potable tap water circulation hose and the winch cable and move it to the other end of the can section. Reel up the hose back through the can section. Switch the hose from the potable tap water tank to the Oakite 33 cleaning solution tank.

4.6.15 Vacuum all standing potable tap water from each of the bellows convolutions of the can section expansion joint. Wipe the convolutions dry using lint free rags or paper towels. The personnel doing this work must be wearing white nylon coveralls, booties, head covers and gloves.

4.6.16 Place the jet cleaning head at the low end of the can section being cleaned. Adjust the jet cleaning head tensioning legs so that it is centered in the can. Reconnect the hose and the power winch cable to the jet cleaning head.

4.6.17 When the temperature of the Oakite 33 cleaning solution reaches 60°C (140°F), start the cleaning solution circulation pump.

4.6.18 When the jet cleaning head starts to rotate, energize the power winch (tugger) to start the jet cleaning head moving through the can section toward the higher end at a rate of approximately one (1) foot per minute. At the same time, energize the power to the turning rolls to start the can section slowly turning as the jet cleaning head moves through the can. Also energize the Oakite 33 cleaning solution recirculation pump and open the valve on the receiving tank to carry the cleaning solution from the receiving tank through the filter back

4.6.18 (cont'd)

to the cleaning solution heater tank for reuse. During the cleaning, periodically check the acidity of the cleaning solution with litmus paper. If the check indicates that the solution is becoming too neutral, add Oakite 33 to the cleaning solution to return the acidity to its original level

4.6.19 When the jet cleaning head reaches the far end of the can section, turn off the power to the cleaning solution circulation pump, recirculation pump, the winch pulling the cleaning head and the power turning rolls.

4.6.20 Disconnect the jet cleaning head from the cleaning solution circulation hose and the winch cable and move it to the other end of the can section. Reel up the hose back through the can section.

4.6.21 Vacuum all standing cleaning solution from each of the bellows convolutions of the can section expansion joint. Wipe the convolutions dry using lint free rags or paper towels. The personnel doing this work must be wearing white nylon coveralls, booties, head covers and gloves.

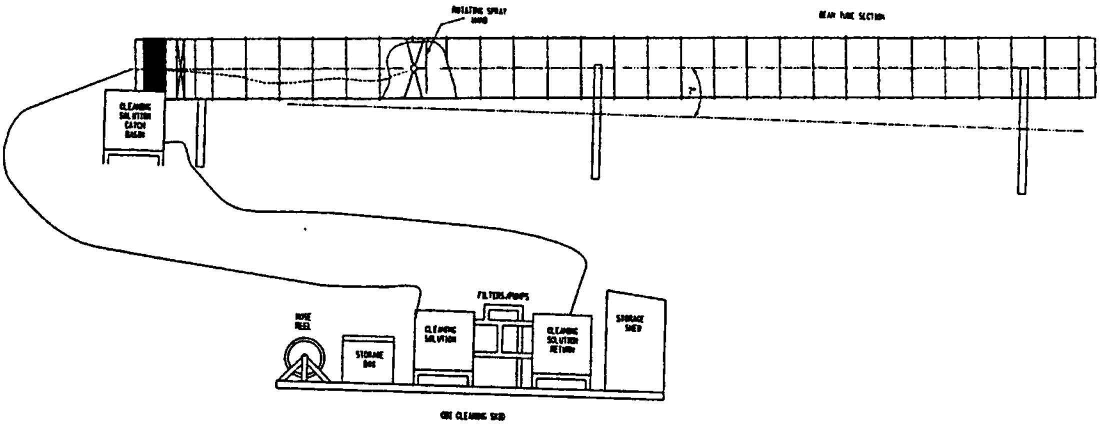
4.6.22 If an internal visual inspection of the can section indicates the cleaning is not adequate, repeat steps 4.6.16 through 4.6.21 as necessary until the internal visual inspection indicates the cleaning is adequate.

4.6.23 When the internal visual inspection of the can section indicates that the cleaning is adequate, repeat steps 4.6.8 through 4.6.15 except that the recirculation pump line from the receiving tank shall be connected to a large vat container for later disposal.

4.6.24 As soon as the can section has air dried, install plastic covers over the ends and seal the covers to the outside of the can with duct tape to keep out all dirt and other contaminates. Move to the helium mass spectrometer test area to await leak testing.

4.0 DOCUMENTATION:

Document the satisfactory completion of both the preliminary and the final cleaning operations as outlined in 5.0 of procedure LIGOCP.



CLEANING ARRANGEMENT

CBI

DOC. ID CL2N
REV. NO. 0
CONTRACT 930212

PAGE NO. 1 OF 6

TITLE MAINTENANCE OF PARTIALLY COMPLETED BEAM TUBE MODULES AFTER FINAL ASSEMBLY DURING CONSTRUCTION

APPROVED	Engr	Corp Weld	Corp QA	Const	Mfg

	BY	DATE
PREPARED	CNS	11-3-93
REVISED		
AUTHORIZED		

REFERENCED STANDARD	REV. NO.

1.0 SCOPE:

This procedure covers the maintenance required to maintain the cleanliness integrity of partially completed beam tube modules during construction. Included is the spot cleaning requirements of the closing weld joint between can sections after welding of those joints is complete. Use this procedure with procedure LIGOCP.

2.0 PERSONNEL CLOTHING REQUIREMENTS:

Personnel entering the beam tube module and/or performing local internal cleaning of closing joints after local HMS hood testing of those joints is complete shall wear clean room type clothing consisting of lint free white overalls, head covers, shoe covers and gloves. No objects shall be carried in the pockets of individuals.

3.0 EQUIPMENT TO BE USED WITH THIS PROCEDURE:

3.1 A blower/[illegible] filtration system to be used at the starting end of the initially placed beam tube module. This system shall be capable of continually maintaining a positive flow of clean dry air through the partially completed beam tube module to ensure that no contaminants enter the beam tube module during construction.

3.2 A portable clean room to be used during the construction of each beam tube can section. This clean room will have an inflatable seal for sealing around the can section on the beam tube side of the clean room. This clean room will always be over/around the exposed open end of the last can section put in place for the beam tube module. The portable clean room will have a space between the work area and the outer exit that will act as a change room. The change room shall contain:

3.2.1 A storage area for unissued clean room clothing consisting of lint free white overalls, head covers, shoe covers and gloves.

3.2.2 Lockers or hooks for storing worn still clean clothing.

3.2.3 Materials for cleaning and bagging any construction equipment to be taken into the beam tube module.

3.2.4 An area for storing the cleaned internal baffles for later installation in applicable can sections after the closing weld joint between those can sections are completed and leak tested.

3.2.5 Rack containing purge gas for welding and purge gas for HMS leak testing with associated hoses and valves.

3.2.6 Rolls of polyethylene and duct tape for wrapping any cleaned equipment to be taken into the beam tube module.

3.2.7 Items 4.2 and 4.3 of procedure LIGOCP.

3.3 All-weather portable welding enclosure containing the fit-up and welding equipment for use on the exterior of all closing weld joints being fit-up and welded between can sections.

3.4 All-weather portable testing enclosure containing the helium mass spectrometer and associated leak testing equipment for use on the exterior of all completed closing weld joints between can sections.

3.5 Internal doughnut shaped inflatable purge dam/test hood enclosure for use for purging during welding of closing joints between can sections and for use as a helium hood during the helium mass spectrometer leak testing of closing joints between can sections.

3.6 Clean room clothing.

4.0 PROCEDURE:

See the conceptual cleaning maintenance set-up sketch at the end of this procedure.

4.1 Set up the blower/drier/filtration system at the start end of the beam tube module. As soon as the blower/drier/filtration system is ready to be energized, remove the plastic cleaning cover from the start end of the first beam tube can section and place it in position at the joint to the interconnecting station which will be housing the blower/drier/filtration system.

4.2 Install the portable clean room over the leading end of that beam tube can section. Pressurize the inflatable seals that seal the can side of the clean room around the can section. Remove the plastic cleaning cover from the leading end of that beam tube can section. Also immediately energize the blower/drier/filtration system so that dry filtered air is now passing through the first beam tube can section and escaping at the leading end through the check valve like flaps in the doors of the portable clean room.

4.3 Post a security guard inside the change room portion of the clean room with a sign-in and sign-out log for all personnel and a list of each item of equipment entering and leaving the beam tube module. Maintain the security guard 24 hours a day unless there is a physical barrier that can be locked to prevent personnel from entering the beam tube module. All personnel entering the beam tube module must have empty pockets. The posted security guard shall move with the portable clean room as it is moved from can section to can section.

4.4 Transport to the site the next beam tube can section to be installed.

4.5 Install a plastic cleaning cover on the leading end of the beam tube can section. If this cover will totally block the flow of clean dry air through the beam tube, make a slit in the plastic cleaning cover and tape a piece of polyethylene over the slit with the tape on only one edge so the polyethylene so that it can flutter to leave the air pass through. Deflate the inflatable seal around the can section. Then roll the portable clean room about 70' down the line away from the leading end of the can section.

4.6 Set the next can section within about 6" to 8" of the end of the beam tube can section to which it is going to be fit. Move the all-weather portable welding enclosure into place around the closing weld joint between these two can sections. After this welding enclosure is in place, remove the end cap on the trailing end of the new beam tube can section and then move it against the other can section in preparation for weld fit-up.

4.5 Roll the portable clean room back over the end of the leading can section and pressurize the circular inflatable seal around that can section.

4.6 Once the portable clean room is in place at the leading end of that next can section, remove the plastic cleaning cover from the leading end of that can section.

4.7 Once the plastic cover is removed from the leading end of the new beam tube can section, fit-up the weld joint between those two can sections. Then install the internal purge dam/test enclosure doughnut with inflatable seals. Inflate the purge dam seals and purge and weld the joint.

4.8 After the weld joint is welded complete, move the all-weather welding enclosure containing the fit-up and welding equipment part of the way down the leading can section to await the placement of the next can section.

4.9 Move the all-weather testing enclosure containing the helium mass spectrometer and associated leak test equipment into position over the completed weld joint. Perform the helium mass spectrometer final test of that weld.

4.10 After completion of the local helium mass spectrometer of the closing weld joint between the can sections, deflate the seals and remove the internal purge dam/test enclosure from that joint. Move the purge dam/test enclosure with hoses toward the leading end of the tube module to the next weld joint. Locally clean the inside of the completed and leak tested weld joint area to remove all contaminates that may have resulted from these operations.

4.11 While the HMS test in steps 4.9 and 4.10 is being performed, transport to the site the next can section to be installed.

4.12 Repeat steps 4.5 through 4.11 for each of the can sections as they are installed.

5.0 DOCUMENTATION:

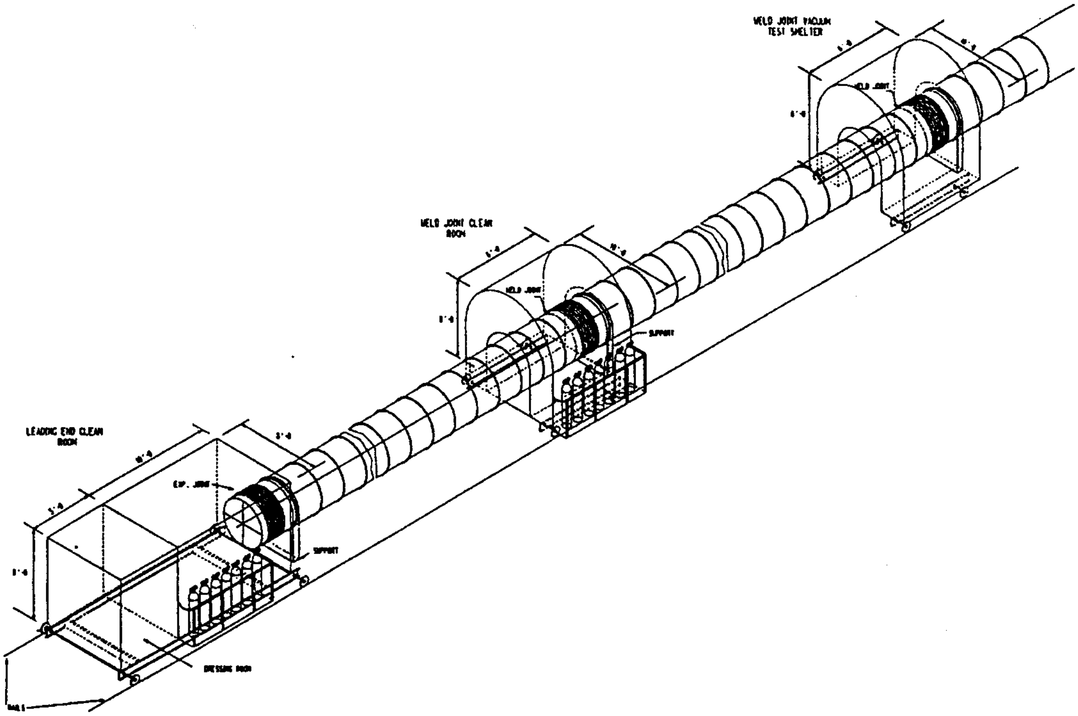
Document the completion of all events associated with this procedure in accordance with 5.0 of procedure LIGOCP.

CBI

DOC. ID CL2N
REV. NO. 0
CONTRACT 930212

TITLE MAINTENANCE OF PARTIALLY COMPLETED BEAM TUBE MODULES AFTER FINAL ASSEMBLY DURING CONSTRUCTION

PAGE NO. 6 OF 6



CLEANING MAINTENANCE SET-UP SKETCH

CBI

DOC ID BDF1
REV. NO. 0
CONTRACT 930212

TITLE: BLOWER/DRYER/FILTRATION SYSTEM OPERATION AND MAINTENANCE PROCEDURE - CALTECH

PAGE NO. 1 OF 6

ENGR	WELD	Corp QA	Corp CONST	MFG

	BY	DATE
PREPARED	SDH	06-Nov-93
REVISED	0	
AUTHORIZED		
REFERENCE STANDARD		**REV. NO.**

1.0 SCOPE:

1.1 This procedure cover the activities associated with the Blower/Dryer/Filtration System(BDF) located on the stationary end of the beam tube module during the construction activities.

1.2 The BDF System provides a positive air flow of clean, warm, dry air through the tube during construction activities.

1.3 Two(2) redundant BDF systems will be used for each tube module during construction. One system will run at all times during the construction period with the second on automatic stand-by.

2.0 REFERENCES:

2.1 The construction and operation of the clean room is based on the following references:

- 2.1.1 Summary of concepts and Reference Design for a Laser Gravitational-Wave Observatory, CAL TECH; Feb-92.
- 2.1.2 Chicago Bridge & Iron Safety Manual for L.I.G.O. Project.
- 2.1.3 CBI Cleaning Procedure CL1N
- 2.1.4 CBI Cleaning Procedure LIGOCP

3.0 EQUIPMENT:

3.1 Equipment referenced in other CBI procedures will be incorporated into this procedure. For specific items, see applicable references.

3.2 Equipment specific to the BDF System are listed as systems or specific equipment noted below. See BDF System Specifications for detailed listing of components.

3.2.1 Free Standing Enclosure
3.2.2 Anchoring System
3.2.3 Filter System
3.2.3 Dryer Equipment
3.2.4 Heating Equipment
3.2.5 Blower Equipment
3.2.7 Electrical and Instrumentation Control System
3.2.9 Tube Attachment and Sealing Equipment

4.0 CONFIGURATION:

4.1 The BDF Systems will be housed in a portable 8' x 10' building secured to the concrete foundation slab at the open of the first tube.

4.2 The system will consist of the following equipment connected by insulated duct to a tube end cover.
4.2.1 Bird and insect screen intake with a motorized damper closed when system is not functioning.
4.2.2 Disposable Pre-Filters mounted in sealed duct.
4.2.3 HEPA filters sized for 0.3 microns at 99.97% minimum efficiency.
4.2.4 Air dryer sized for CFM requirements with capacity of 35°F dew point.
4.2.5 Air blower assembly with sealed shafts so that motor is not in contract with air stream. Blower and motor is sized for CFM and static pressure requirements.
4.2.6 By-Pass start-up damper with timer circuit for start-up period air dumping.
4.2.7 Forced air, gravity assisted damper mounted at the tube cover.
4.2.8 Fire/smoke detector in air stream for shutdown of system.
4.2.9 Control system and instrumentation for redundant operations of both units.
4.2.10 Pressure drop sensing instrumentation for control of both units.

4.4 The beam tube module cover will be fabricated from aluminum and sealed to the tube by means of o'rings and/or inflatable seals. The building will be sealed to the tube by means of an outer seal or gasket.

5.0 **Storage of BDF Systems Building**:

5.1 The BDF Building shall be received from the manufacturer in a "conference room" cleaned condition.

- 5.1.1 All interior surfaces shall be wiped down with an approved cleaning agent.
- 5.1.2 A Cover shall be placed over the tube penetration opening and sealed with a gasket material to prevent any leakage into the building.
- 5.1.3 All Motorized dampers shall be closed on HVAC ducts.
- 5.1.4 The door shall be locked before transportation and/or storage.

5.2 Short term storage shall shall comply with all activities noted per 4.1.

5.3 Long term storage shall comply with all activities in 5.1 and include the following:

- 5.3.1 Remove all tools and materials from inside the building.
- 5.3.2 Remove batteries from emergency control equipment in the building.
- 5.3.3 Remove all filters and seal HVAC intake and supply vents with taped covers.

6.0 **Transportation of the BDF System**:

6.1 The BDF portable building shall be transportable from one area or site to another. This may be accomplished by load out on a flatbed trailer.

- 6.1.1 Lift the BDF Building from foundation slab and install on flat bed trailer
- 6.1.4 Secure all equipment inside the building before moving.
- 6.1.5 Clean all surfaces of the room and lock and seal doors for transportation.

6.1.6 For transporting over public roadways, obtain all required permits and licenses.

6.2 The BDF Building may be loaded, unloaded and transported on site with a forklift truck.

7.0 Maintenance of the BDF System:

7.1 The maintenance of the BDF Building and Systems are broken down into the following categories:
7.1.1 Cleaning and janitorial functions
7.1.2 HEPA filter maintenance and replacements
7.1.3 Dryer Maintenance & Repair
7.1.4 Blower Maintenance and Repair
7.1.5 Re-Heater Maintenance and Repair
7.1.6 Electrical and Control Maintenance
7.1.7 Safety Equipment Inspection and Maintenance

7.2 Cleaning and janitorial functions shall be performed at the end of each week or as required. These include the following tasks:

7.2.1 Wipe down all external surfaces pf the BDF systems with an approved cleaning agent and lint free cloths or paper towels.
7.2.2 Wipe down all tables and inspection surfaces in the cleaning and inspection area.
7.2.4 Perform general cleaning, sweep and mop room floor.
7.2.5 Inspect all intakes and clean as required.

7.3 Lubricate all damper bearings, bushings and linkages each 20 days of clean room use. Do not over lubricate.

7.4 Filter replacement shall be as required based on condition of filter elements.
7.3.1 Replace pre-filters when 50% blockage of light is observed.
7.3.2 Replace HEPA filter elements when pressure drop is in excess of specified range.
7.3.3 Dispose of filter elements as required in environmental site plan.

7.5 Perform periodic maintenance on Air dryer system. Follow equipment manufacturer's O&M Manual for greater detail.

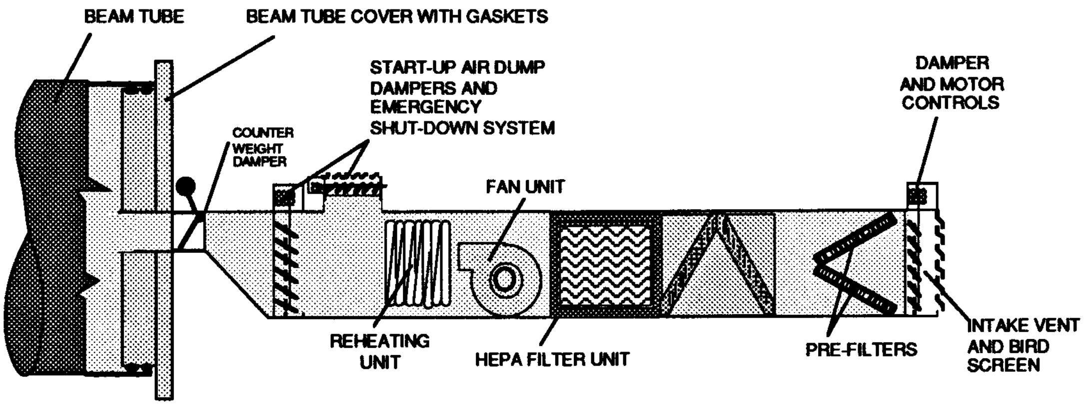
7.6 Perform periodic maintenance on blower assembly and motor. Follow equipment manufacturer's O&M Manual for greater d detail.

7.7 Perform periodic maintenance on re-heater. Follow equipment manufacturer's O&M Manual for greater detail.

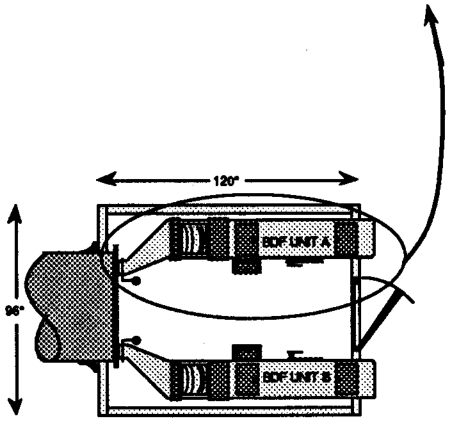
7.8 Perform electrical inspections for loose connections, electrical loads, etc. each 20 days of operation. Document loads for reference.
all gages each 6 mo. of operation.

7.9 Safety Systems shall be tested each day. These systems consist of the following:

- 7.9.1 Fire/Smoke alarm and control system shall be tested.
- 7.9.2 Test system failure and assure redundant unit start-up.



BDF SYSTEM UNIT



BDF SYSTEM BUILDING

CBI

DOC ID CR1TSM
REV. NO. 0
CONTRACT 930212

TITLE: CLEAN ROOM TRANSPORTING, STORAGE AND MAINTENANCE PROCEDURE - CALTECH

PAGE NO. 1 OF 10

ENGR	WELD	Corp QA	Corp CONST	MFG		BY	DATE
					PREPARED	SDH 06-	Nov-93
					REVISED	0	
					AUTHORIZED		
					REFERENCE STANDARD		REV. NO.

1.0 SCOPE:

1.1 This procedure covers the activities associated with clean room operations.

1.2 The following activities are described in this procedure:

1.2.1 Transportation of the clean room modules

1.2.2 Storage of clean room modules at site.

1.2.3 Maintenance Procedures for clean room equipment.

2.0 REFERENCES:

2.1 The construction and operation of the clean room is based on the following references:

2.1.1 Summary of concepts and Reference Design for a Laser Gravitational-Wave Observatory, CAL TECH; Feb-92.
2.1.2 Chicago Bridge & Iron Safety Manual for L.I.G.O. Project.
2.1.3 CBI Cleaning Procedure CL1N

3.0 EQUIPMENT:

3.1 Equipment referenced in other CBI procedures will be incorporated into this procedure. For specific items, see applicable references.

3.2 Equipment specific to the clean room are listed as systems or assemblies below. See Clean Room Specification for detailed listing of components.

- 3.2.1 Clean Room Module & Transporting Trucks
- 3.2.2 Rolling frame and Track Assembly
- 3.2.3 HVAC System
- 3.2.4 Exhaust System
- 3.2.5 Storage and Shelving Equipment
- 3.2.6 Safety Systems
- 3.2.7 Electrical & Lighting System
- 3.2.8 Purge Gas Manifold and Rack System
- 3.2.9 Inflatable & Secondary Sealing System
- 3.2.10 Compressed Air System

4.0 Storage of Clean Room Module:

4.1 The clean room shall be received from the manufacturer in a "conference room" cleaned condition.

- 4.1.1 All interior surfaces shall be wiped down with an approved cleaning agent.
- 4.1.2 A Cover shall be placed over the tube penetration opening and sealed with a gasket material to prevent any leakage into the building.
- 4.1.3 All Motorized dampers shall be closed on HVAC and Exhaust ducts.
- 4.1.4 All Doors and windows shall be locked before transportation and/or storage.

4.2 Short term storage shall shall comply with all activities noted per 4.1.

4.3 Long term storage shall comply with all activities in 4.1 and include the following:

- 4.3.1 Remove all working equipment and materials from inside the building.
- 4.3.2 Remove battery powered emergency lighting equipment from the building.
- 4.3.3 Seal HVAC and Exhaust vents with taped covers.

5.0 <u>Transportation of Clean Room Module</u>:

5.1 The clean room shall be transportable from one area or site to another. This may be accomplished by design of the clean room to load out on a flatbed trailer or be assembled with removable wheel assemblies.

- 5.1.1 Remove bottle racks from rolling frame.
- 5.1.2 Remove steps assemblies from rolling frame.
- 5.1.3 Lift the clean room module from the rolling frame and install transporting wheel assemblies. If the module is to be transported on flat bed trailers, the rolling may be mounted permanently to the building.
- 5.1.4 Secure all equipment inside the building before moving.
- 5.1.5 Clean all surfaces of the room and lock and seal doors for transportation.
- 5.1.6 For transporting over public roadways, obtain all required permits and licenses.

5.2 The Clean Room will be moved using a tow vehicle along a track system during construction activities at site.

- 5.2.1 Remove transporting wheel assemblies(if used) and mount clean room module onto rolling frame. The frame is equipped with 10"Ø 45° Vee groove wheels and moves on an angle frame turned on support plates. See attached detail.
- 5.2.3 Install bottle racks and step assemblies to rolling frame.

5.2.2 The tow vehicle shall be connected to the clean room module with a bar sized for towing and breaking forces.
5.2.3 The clean room shall be vacated during the moving and positioning activities.

6.0 Maintenance Clean Room Module:

6.1 The maintenance of the clean room is broken down into the following categories:

6.1.1 Cleaning and janitorial functions
6.1.2 HVAC and Exhaust System Preventative Maintenance, troubleshooting and Repair
6.1.3 HEPA filter maintenance and replacements
6.1.4 Roller Frame and wheel maintenance.
6.1.5 Purge gas System maintenance
6.1.6 Compressed air system Maintenance
6.1.7 Electrical and Control Maintenance
6.1.8 Safety Equipment Inspection and Maintenance

6.2 Cleaning and janitorial functions shall be performed at the end of each shift. These include the following tasks:

6.2.1 Wipe down all surfaces including walls, storage bins, hoses, tools, etc., in the controlled area with an approved cleaning agent and lint free cloths or paper towels.
6.2.2 Return all solvents to their containers for proper storage and dispose of all wiping cloths and/or paper towels.
6.2.3 Wipe down all tables and inspection surfaces in the cleaning and inspection area.
6.2.4 Perform general cleaning, sweep and mop change room and storage room floors.
6.2.5 Re-stock all inventories and remove all soiled clothing from clean room module.
6.2.6 Remove all soiled wiping cloths and paper towels from the clean room module.

6.3 Perform periodic maintenance on clean room module HVAC systems. These include but are not limited to the following. See equipment manufacturer's O&M Manual for greater detail.

- 6.3.1 Perform air balance tests and adjustments each 20 days of clean room use.
- 6.3.2 Lubricate all equipment bearings, bushings and linkages each 20 days of clean room use. Do not over lubricate.
- 6.3.3 Perform electrical inspections for loose connections, electrical load, etc. each 20 days of operation.

6.4 The following is a listing of filter requirements for the clean room module HEPA and Pre-filter maintenance.

- 6.4.1 Pre-filters will be inspected each day and replaced when an estimated 50% blockage is noted. This will be determined by a method of holding the filter to a light and comparing it to a clean filter.
- 6.4.2 HEPA filters will be replaced when the pressure drop between the up and down stream HEPA filter reaches 1.0" or greater.

6.5 Roller Frame inspection and maintenance is to be conducted each week. These activities include but are not limited to the following:

- 6.5.1 Inspect the frame for any damage due to handling, corrosion, etc. Repair and paint areas as required.
- 6.5.2 Inspect alignment of all wheels on the track assembly. Check wheel grooves for foreign material and clean as required.
- 6.5.3 Lubricate wheel axles as required. Do not over lubricate. Wipe any excess noted.

6.6 Inspect purge and test gas systems, bottle racks, handling equipment, etc.

- 6.6.1 Calibrate all gages every six(6) months.
- 6.6.2 Leak test by means of solution film testing of each joint on a periodic basis.
- 6.6.3 Inspect all hoses for leaks and breaks in the stainless steel braid on a <u>DAILY</u> basis. Replace as required.
- 6.6.4 Inspect chains and guards on the bottle racks for damage periodically. Repair as required.

6.7 Inspect the compressed air system, bottles and racks.

- 6.7.1 Calibrate all gages every six(6) months.
- 6.7.2 Leak test by means of solution film testing of each joint on a periodic basis.
- 6.7.3 Inspect all hoses for leaks and breaks in the stainless steel braid on a <u>DAILY</u> basis. Replace as required.
- 6.7.4 Inspect chains and guards on the bottle racks for damage periodically. Repair as required.

6.8 Electrical and control systems include the electrical distribution system, lighting and HVAC control system. These item will require minimum inspection and maintenance but not be limited to the following.

- 6.8.1 Perform an initial load test on each circuit and record on log sheet.
- 6.8.2 Inspect all connections for heat and corrosion each 30 days of operation.
- 6.8.3 Test all indicating lights, alarms, and calibrate all gages each 6 mo. of operation.

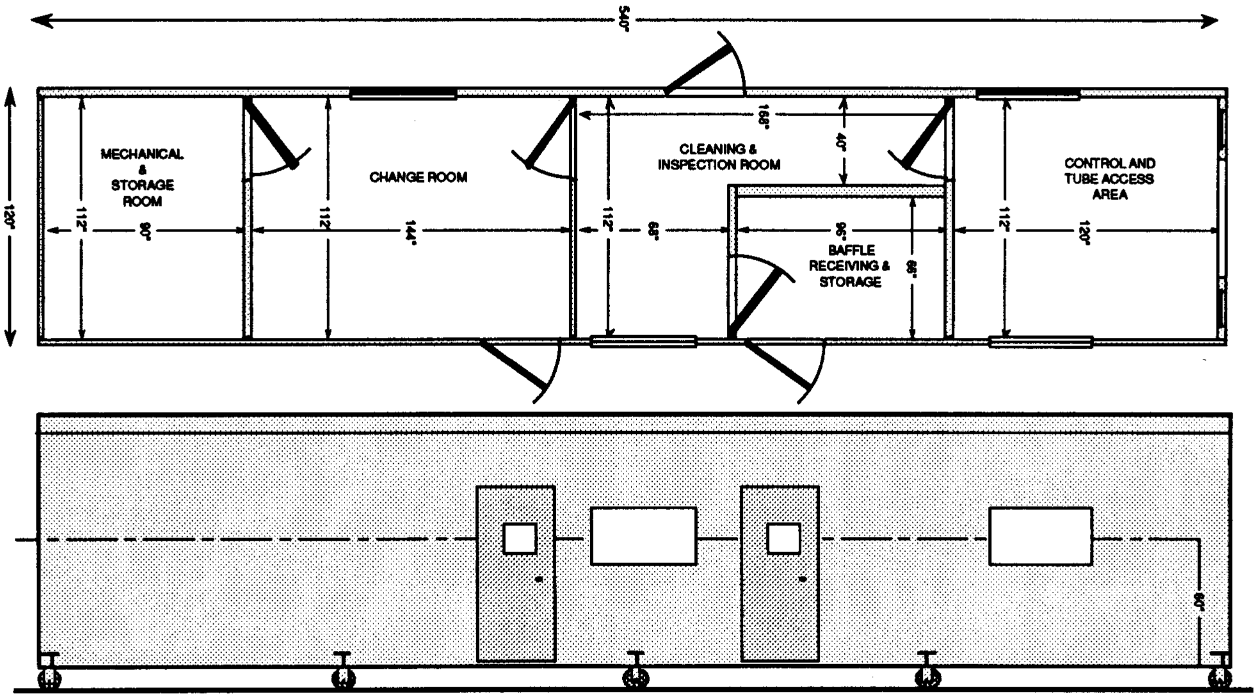
6.9 Safety Systems shall be tested each day. These systems consist of the following:

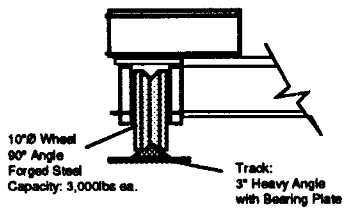
- 6.9.1 Fire alarms shall be tested. Replace batteries each 30 days of operation or per the manufacturer's instructions(which ever is less).
- 6.9.2 Test emergency lighting/exit system. Replace batteries as suggested by the manufacturer.

6.9.3 Test the emergency exit door to assure hardware and alarm work properly. Replace battery each 30 days of operation or per the manufacturer's instructions(which ever is less).

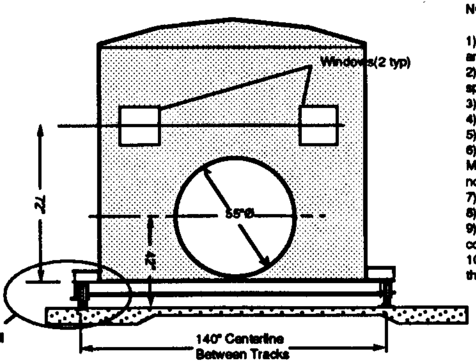
DOC ID	CR1TSM
REV. NO.	0
CONTRACT	930212

TITLE: CLEAN ROOM TRANSPORTING, STORAGE AND MAINTENANCE PROCEDURE - CALTECH





TRACK DETAIL



TUBE SIDE of CLEANROOM

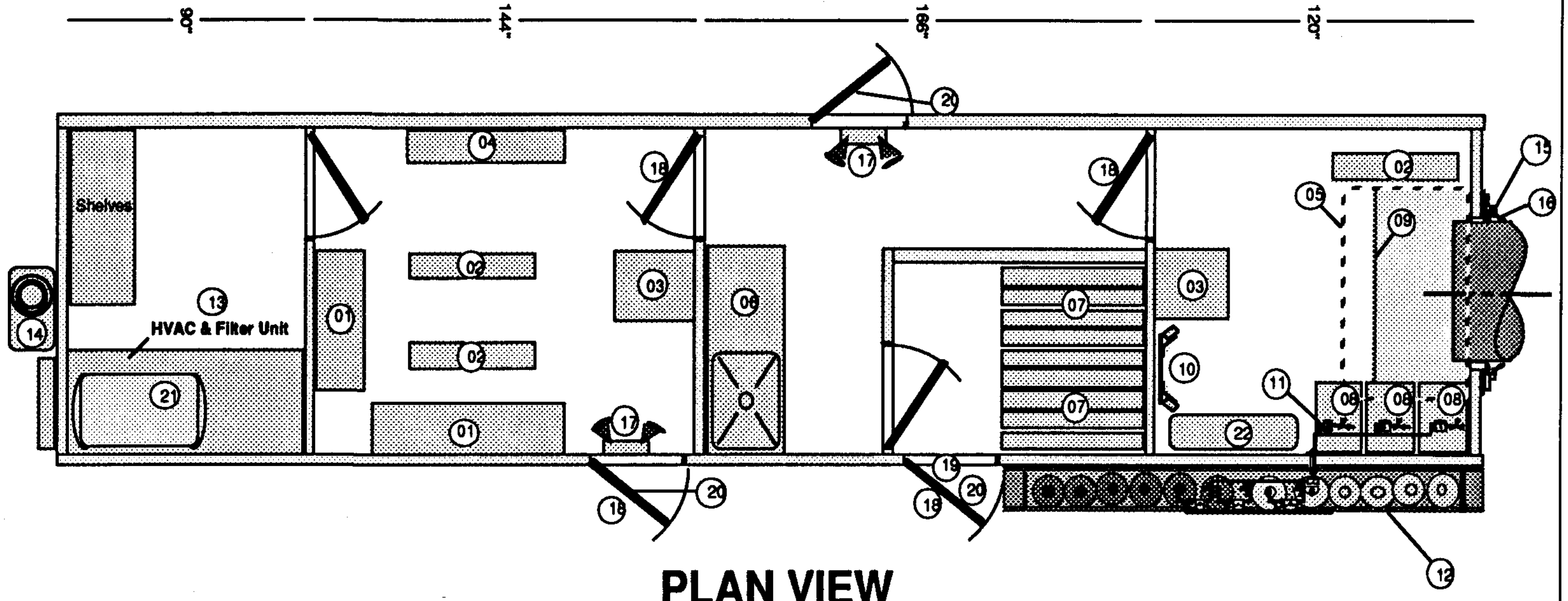
NOTES:

1) Clean Room is fabricated as a standard construction office trailer using metal outer covering and pitched roof.
2) Building must be designed with underframe that will support track wheels as described in the specifications. Track frame may be removed during transport to sites.
3) Inside wall surfaces shall be white Marlite® or similar material that allows for cleaning.
4) Lighting and electrical details noted on electrical drawings and specifications.
5) All windows shall be locable from side noted.
6) HVAC equipment and filter system shall be self contained and located in the Mechanical/Storage Room. Air Conditioning Condenser unit shall be mounted on frame as noted.
7) All doors are 36" Width.
8) This door is Emergency Exit Only and shall not be accessable from outside.
9) The Beam Tube Penetration shall be located per sealing drawing and shall be sipplied with a cover that fits into the seal for transporting.
10) All Dimensions are suggested. Fabrication of wall and door locations should be approx. to the dimensions noted above based on wall thickness, etc.

CBI

DOC ID CR1TSM
REV. NO. 0
CONTRACT 930212

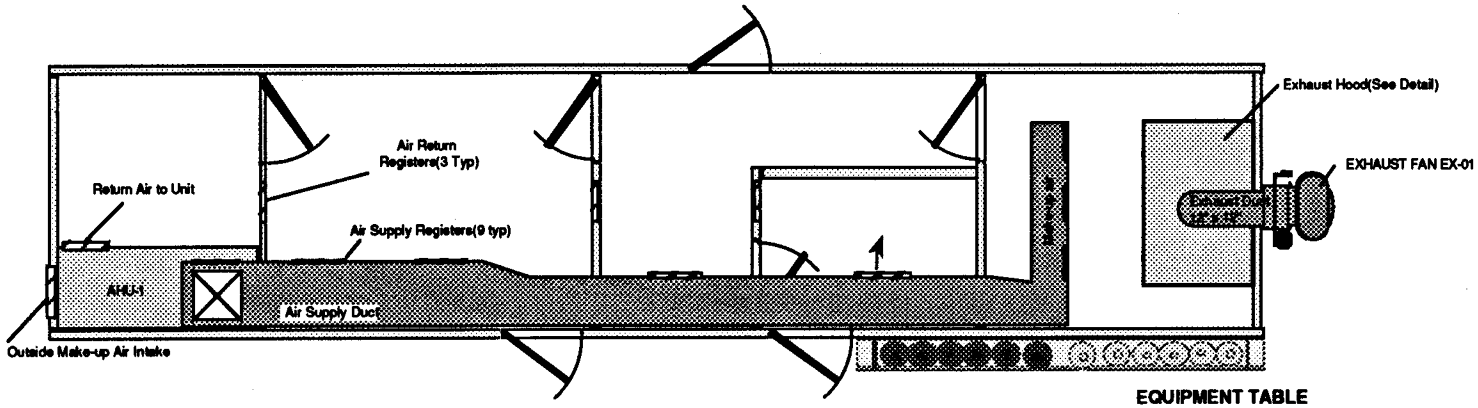
TITLE: CLEAN ROOM TRANSPORTING, STORAGE AND MAINTENANCE PROCEDURE - CALTECH

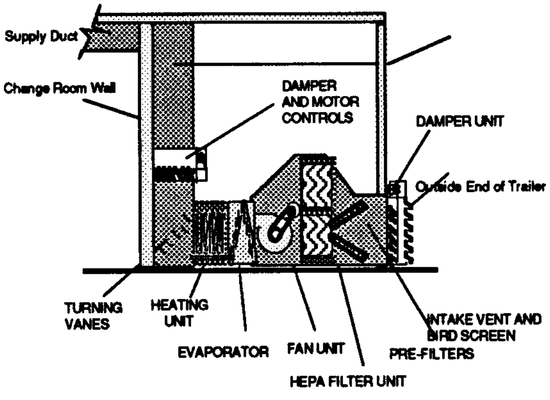


PLAN VIEW

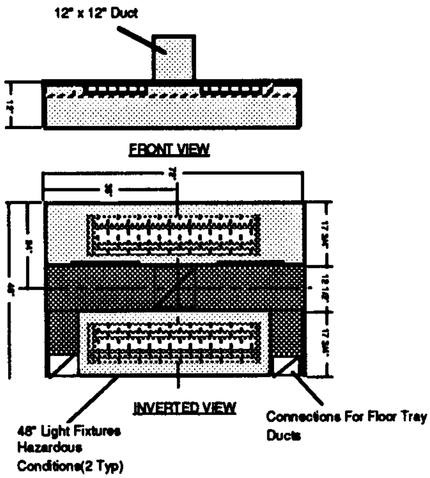
MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO
01	2	Hanging Lockers	16		MMC4870T1
02	3	Changing Bench	48"		MMC4911T41
03	2	Wall Attachment Desk	24"x28"		MMC4808T18
04	5	Wall Attachment Shelves	12"x24"		MMC4717T38
05	1	Overhead Hood	48"x72"	See HVAC	HVAC EX04
06	1	Cleaning & Inspection Table	24"x36"	Add S.S.Top	MMC9045T18
07	4	Baffle Racks	27"x54"		Detail Later
08	2	Gas Hose Bin	18"x24"	1/8" S.S.x36"	Detail Later
09	1	Floor Tray Drain Mat	36"x72"	See HVAC	HVAC EX07
10	2	Personnel/Equip Creepers	18"x36"	S.S. Wheels	Detail Later

MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO
11	2	Purge Manifold Systems	N/A	S.S.Const	Detail Later
12	1	Gas Bottle Rack	Later	Per OSHA	Detail Later
13	1	HVAC/Filter Unit	N/A	See HVAC	HVAC AHU-1
14	1	Compressor/Condensing Unit	N/A	See HVAC	HVAC AHU-1
15	1	Inflatable Seal for Tube Penet.	48" Ø	See Seal Det	Detail Later
16	1	Secondary Gasket Seal	48" Ø	See Seal Det	Detail Later
17	2	Exit Sign/Emergency Lights	12"x8"	Per OSHA	MMC8367K33
18	6	Authorized Admittance Only	3"x5"		Global WBL43
19	2	Emergency Exit Only	10"x7"	Per OSHA	Global RFM2
20	3	Warning Step Down	10"x7"	Per OSHA	Global PSPL341
21	1	Potable Water Storage Tank	100 gal	Fiberglass	Detail Later
22	2	Inflatable Purge Dams	48" Ø		Detail Later





AHU-1 Unit



EXHAUST HOOD DETAIL

EQUIPMENT TABLE

Equipment Description	SIZE	Requirements
Fan Unit	208V 1Ø	Supplier to Determine CFM Requirements
Motorized Dampers	120VAC	Moduler Positive Sealing Units
Pre-Filters	TBD	Filter Frame with Disposal Filter Elements
HEPA Filters	TBD	Filter to 0.3 Micron at 99% Min Efficiency
Evaporator Unit	208V 1Ø	Supplier to Determine BTU Requirement
Heat Exchanger Unit	120VAC	Supplier to Determine BTU Requirement
Duct Work	TBD	Insulated and Sealed Sheet Metal
Thermostat	24VAC	Supplier to Match with System
Exhaust Fan	208V 1Ø	Supplier to Determine CFM Requirements
Register/Diffusers	TBD	Adjustable/Lockable Direction Controls
Return Air Grills	TBD	Supplier to Determine CFM Requirements
Floor Tray	36"x48"x3"	Stainless Steel Construction 18 Ga Min.
Exhaust Air Grills	6"x8"x96"	Stainless Steel Construction 18 Ga Min.
Overhead Exhaust Hood	12"x48"x72	Stainless Steel Construction 18 Ga Min.

CBI

DOC ID CL3N
REV. NO. 0
CONTRACT 930212

TITLE: FINAL CLEANING AND INSPECTION OF LIGO BEAM TUBE INNER SURFACES INCLUDING BAFFLES - CALTECH

PAGE NO. 1 OF 6

ENGR	WELD	Corp QA	Corp CONST	MFG		BY	DATE
					PREPARED	SDH	09-Nov-93
					REVISED		
					AUTHORIZED		
					REFERENCE STANDARD		REV. NO.

1.0 SCOPE:

1.1 This procedure details the requirements for final cleaning of the LIGO tube section from the weld area back to the end open to the clean room.

2.0 PERSONNEL:

2.1 Experienced personnel shall perform and supervise all cleaning in accordance with this planned approach and the cleaning referenced in this plan.

2.2 Personnel entering the inspection and cleaning room and/or the controlled area of the beam tube access penetration during final assembly operations shall meet the following conditions:

- 2.2.1 Participate in a training course in which this procedure is presented by an authorized instructor. The course shall be documented by means of a written examination.
- 2.2.2 Wear clean white lint free clean room style coveralls with pockets sewn closed.
- 2.2.3 Wear white, lint free "Hood" type head covering sealed around the neck and into the coverall collar.
- 2.2.4 Wear white lint free gloves secured into the sleeves of the coveralls.
- 2.2.3 Log all articles into the controlled area and prepare to account for all articles when leaving the control area.

2.3 Personnel entering the beam tube during final assembly operations shall meet the requirements of para. 2.2 and the additional requirements:

- 2.3.1 Wear protective coverings on shoes.

2.3.2 Any personnel with facial hair(beard or mustache) must wear a dust mask.

2.4 Clean room clothing for use by anyone entering a beam tube can section must be cleaned on a regular weekly basis or when it becomes obviously soiled with deposits of dirt, oil or grease.

3.0 **REFERENCES**:

2.1 The following documents detail operations in conjunction to this activity. All references should be followed during the execution of this procedure.

3.1.1 California Institute of Technology Technical Specification Number 1100004 for Beam Tube Modules and number 1100007 for Type 304L Stainless Steel Vacuum Products.
3.1.2 ASTM Designation A 380 Standard practice for Cleaning and Descaling Stainless Steel Parts, Equipment and Systems (as a guide).
3.1.3 CBI Procedure:LIGOCP; "PLANNED APPROACH FOR CLEANING AND CLEANING MAINTENANCE FOR LIGO PROJECT FOR CALTECH."
3.1.4 CBI Cleaning Procedure CL1N; "CLEANING OF COMPLETED BEAM TUBE SECTIONS BEFORE LEAK TESTING AND FINAL ASSEMBLY - CALTECH."
3.1.5 CBI Cleaning Procedure CL2N; "CLEANING OF PARTIALLY COMPLETED BEAM TUBE MODULES AFTER FINAL ASSEMBLY AND DURING CONSTRUCTION - CALTECH."
3.1.6 CBI Procedure LIGOVT1; "CLEANLINESS PROCEDURE USING BLACKLIGHT."
3.1.7 CBI Procedure LIGOCR1; "CLEAN ROOM TRANSPORTING, STORAGE AND MAINTENANCE."

4.0 **EQUIPMENT**:

4.1 The following is a listing of equipment required for final inspections.
4.1.1 White nylon coveralls, shoe covers, head covers and gloves.
4.1.2 OSHA approved storage containers for solvents and cleaning agents.

4.1.3 Safety equipment meeting the requirements for confined Space entry, ie: Oxygen Analyzer, personnel lines, etc.
4.1.4 Clean room and associated equipment.
4.1.5 100 watt blacklight with 3650 Angstrom unit wavelength.
4.1.6 Blacklight meter capable of measuring 800 uw/cm2.
4.1.7 Documentation forms for recording final acceptance and inventory.

4.2 The following is a listing of materials used for final cleaning of LIGO beam tube inner surfaces.

4.2.1 Potable tap water with a chlorine content in the range of 0.02 to 200 ppm.
4.2.2 Technical grade solvents as listed on an approved materials listing.
4.2.3 Lint free wiping cloths and/or paper towels.

5.0 PROCEDURE:

WARNING
ALL FACTORS GOVERNING "CONFINED SPACE" ENTRY INCLUDING DOCUMENTATION SHALL BE STRICTLY ENFORCED.

5.1 After welding and testing activities are complete all inflatable purge dams shall be removed from the tube. All hoses shall be coiled in their respective bins and equipment stored inside the controlled area of the clean room..

5.2 All cleaning and inspection equipment entering the tube shall be inventoried and logged for accountability.

5.3 During final cleaning activities, the beam tube baffles shall be installed. work this procedure for all surfaces of the tube and baffles.

5.4 One cleaning person shall be allowed in the tube. Materials shall be mounted onto a dolly and moved down the tube to the weld seam. A black light shall be used to inspect the tube surfaces per the approved procedure

5.5 Using a blacklight in the darkened tube area, the cleaner shall inspect the inner tube wall area directly in front of his location for dirt, debris and any deposits of hydrocarbons and chemicals. Areas found shall be contaminated shall be locally wiped with an approved solvent and allowed to dry. After inspection, the areas shall not be disturbed without re-inspection.

5.6 Document the tube designation and the final acceptance of the cleaning before moving from the tube location. Inventory all wiping cloths, solvent containers and equipment removed from the tube and compare with the initial inventory to assure all articles are removed from the tube. Document this inventory.

5.7 Close the tube end using a sealed cap equipped with a one direction vent flap to allow pressure to escape the tube.

6.0 DOCUMENTATION:

6.1 Documentation of the confined entry activities are required per OSHA and CBI safety procedures. Report forms shall be available from the site safety department.

6.2 Checklists shall be used for personnel entering the clean room areas, inventories of the equipment entering these areas, and inventories of equipment and materials entering the beam tube. See attached inventory form CR-01, page 5.

6.3 A Cleaning Inspection Report shall be completed with results of the final cleanliness inspection. This report shall document personnel performing cleaning, results of inspection and signed by the authorized inspector. See attached inspection form CR-02, page 6.

6.4 These records shall be turned into the QC Manager at the end of each shift. The final inspection turnover documents shall include these reports.

LIGO

INVENTORY FOR
CLEAN ROOM

	DESCRIPTION OF EQUIPMENT/MATERIAL	BY	TIME	DATE
Line 01				
Line 02				
Line 03				
Line 04				
Line 05				
Line 06				
Line 07				
Line 08				
Line 09				
Line 10				
Line 11				
Line 12				
Line 13				
Line 14				
Line 15				
Line 16				
Line 17				
Line 18				
Line 19				
Line 20				
Line 21				
Line 22				
Line 23				
Line 24				
Line 25				
Line 26				
Line 27				
Line 28				
Line 29				
Line 30				
Line 31				
Line 32				
Line 33				
Line 34				
Line 35				
Line 36				
Line 37				
Line 38				

Inspection/Date ______________ **Location:** ______________ **Auditor** ______________

SUBJECT

CLEAN ROOM INVENTORY

SHT _____ **OF** _____

CBI

CHICAGO BRIDGE & IRON
LIGO PROJECT
CONTRACT No. 930212

Specification : CL3N
Date: ____
Time: ____ **Beginning**
____ **Ending**

TEST REPORT

TUBE LOCATION/POSITION ____
TUBE IDENTIFICATION ____

TEST EQUIPMENT:

BLACK LIGHT METER CALIBRATION:
INSTRUMENT IDENTIFICATION: ____ CALIBRATION DATE: ____

BLACK LIGHT CALIBRATION:
LIGHT SERIAL/REFERENCE No. ____ CALIBRATION DATE: ____

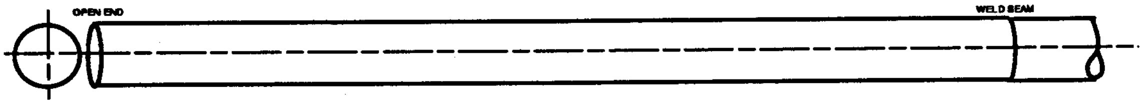
INSPECTION OF BEAM TUBE AS NOTED ABOVE HAS BEEN FOUND TO BE CLEAN AND ALL EQUIPMENT AND MATERIALS REMOVED. ____ INITIALS

TUBE END HAS BEEN SEALED AND POSITIVE AIR FLOW IS OBSERVED THRU THE ONE WAY VENT FLAP. ____ INITIALS

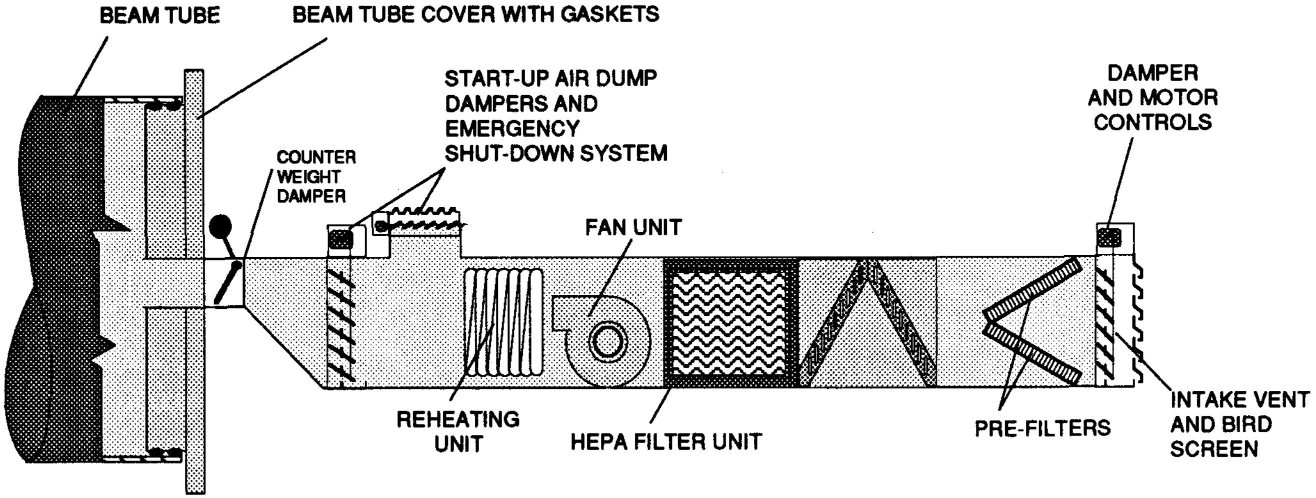
NAME ____
DATE: ____
SIGNATURE ____

REMARKS: ____

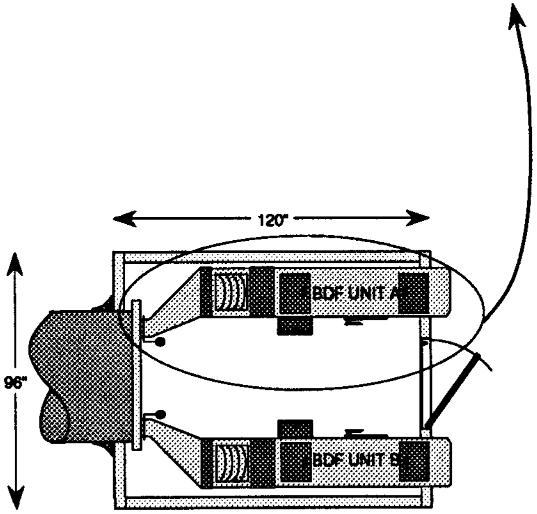
MAP ANY ANOMALIES BELOW



BEAM TUBE



BDF SYSTEM UNIT



BDF SYSTEM BUILDING

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

By Chkd Date
By Chkd Date
By Chkd Date
Remarks
Revisions

Supplier's/Purchaser's No. ____________

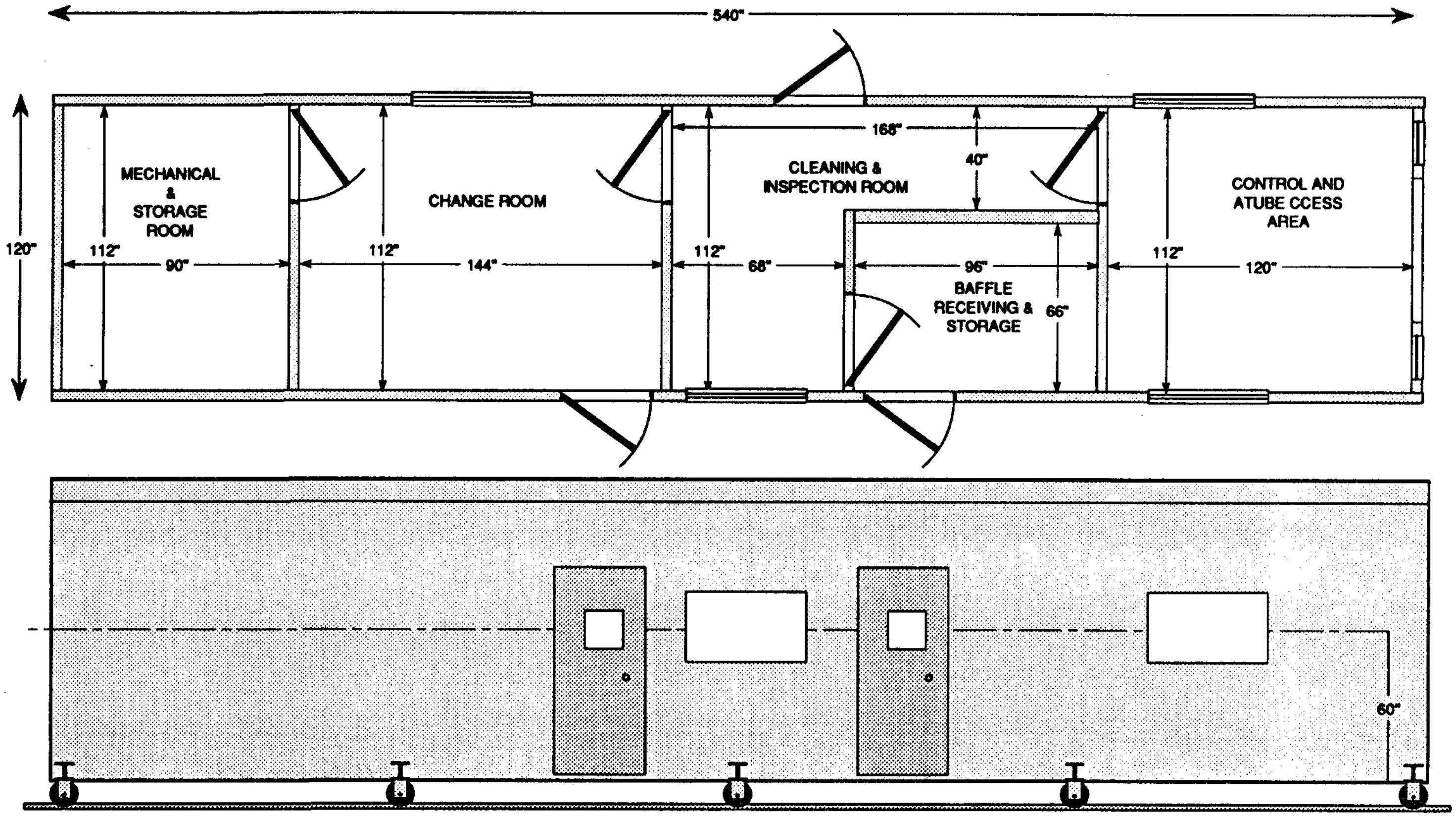
CBI

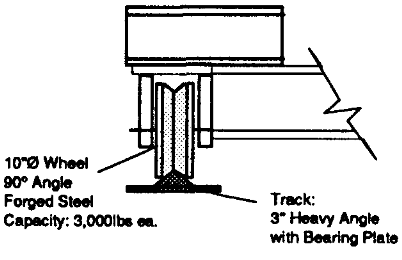
LIGO

BLOWER/DRYER/FILTRATION SYSTEM

Customer's No.
By ______ Chkd ______ Date ______
Engineering Supervisor
Contract No.
Dwg.
Sheet
Rev.

THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI AND IS T
BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI. REPRODUC
TION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN

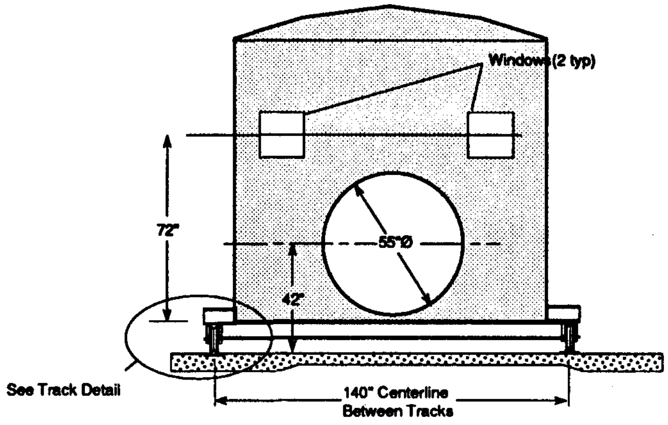




TRACK DETAIL

NOTES:

1) Clean Room is fabricated as a standard construction office trailer using metal outer covering and pitched roof.
2) Building must be designed with underframe that will support track wheels as described in the specifications. Track frame may be removed during transport to sites.
3) Inside wall surfaces shall be white Marlite® or similar material that allows for cleaning.
4) Lighting and electrical details noted on electrical drawings and specifications.
5) All windows shall be locable from side noted.
6) HVAC equipment and filter system shall be self contained and located in the Mechanical/Storage Room. Air Conditioning Condenser unit shall be mounted on frame as noted.
7) All doors are 36" Width.
8) This door is Emergency Exit Only and shall not be accessable from outside.
9) The Beam Tube Penetration shall be located per sealing drawing and shall be sipplied with a cover that fits into the seal for transporting.
10) All Dimensions are suggested. Fabrication of wall and door locations should be approx. to the dimensions noted above based on wall thickness, etc.



TUBE SIDE of CLEANROOM

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

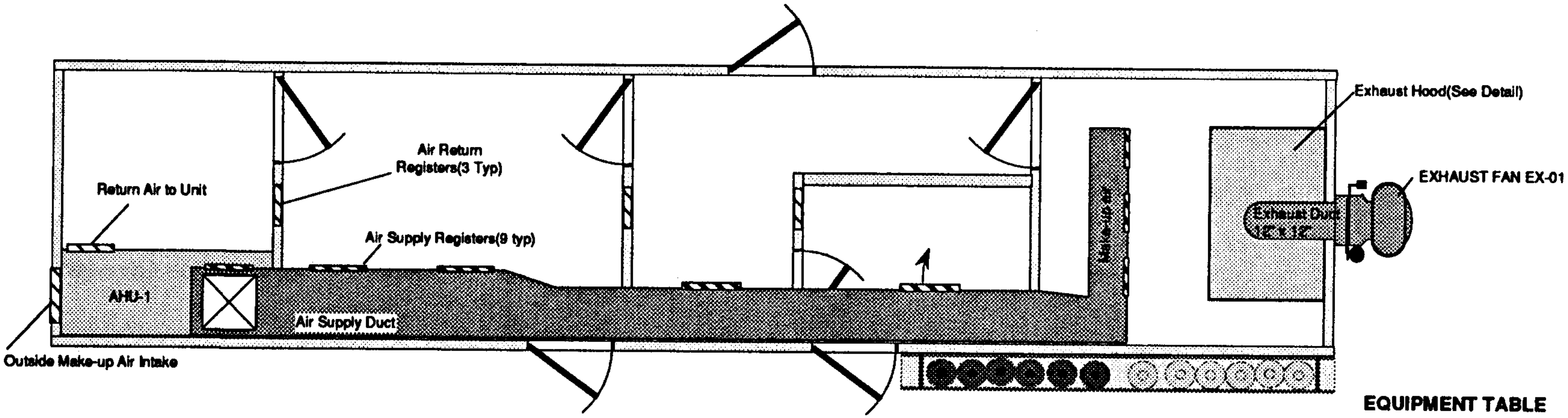
Supplier's/Purchaser's No. ____________

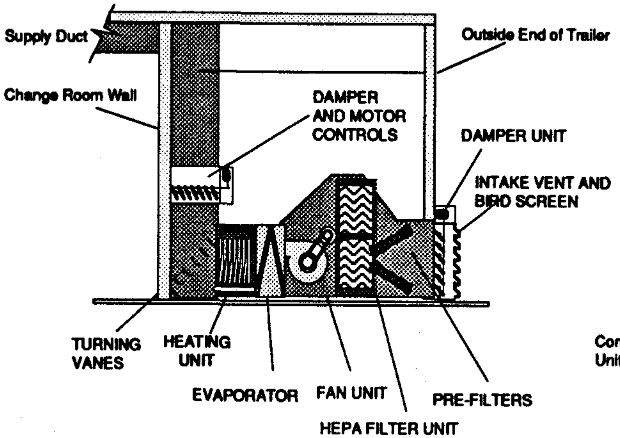
CBI

LIGO

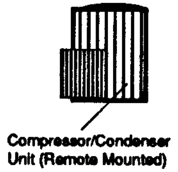
CLEAN ROOM
Floor Plan
PLAN VIEW

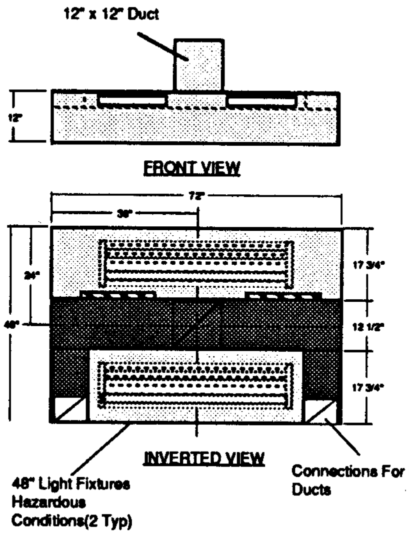
Customer's No
By ______ Chkd ______ Date ______
Contract No.
Dwg
Sheet
Rev

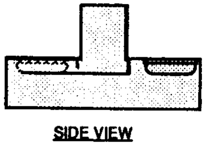




AHU-1 Unit







EXHAUST HOOD DETAIL

EQUIPMENT TABLE

Equipment Description	SIZE	Requirements
Fan Unit	208V 1Ø	Supplier to Determine CFM Requirements
Motorized Dampers	120VAC	Modular Positive Sealing Units
Pre-Filters	TBD	Filter Frame with Disposal Filter Elements
HEPA Filters	TBD	Filter to 0.3 Micron at 99% Min Efficiency
Evaporator Unit	208V 1Ø	Supplier to Determine BTU Requirement
Heat Exchanger Unit	120VAC	Supplier to Determine BTU Requirement
Duct Work	TBD	Insulated and Sealed Sheet Metal
Thermostat	24VAC	Supplier to Match with System
Exhaust Fan	208V 1Ø	Supplier to Determine CFM Requirements
Register/Diffusers	TBD	Adjustable/Lockable Direction Controls
Return Air Grills	TBD	Supplier to Determine CFM Requirements
Floor Tray	36"x48"x3"	Stainless Steel Construction 18 Ga Min.
Exhaust Air Grills	6"x8"x96"	Stainless Steel Construction 18 Ga Min.
Overhead Exhaust Hood	12"x48"x72"	Stainless Steel Construction 18 Ga Min.

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

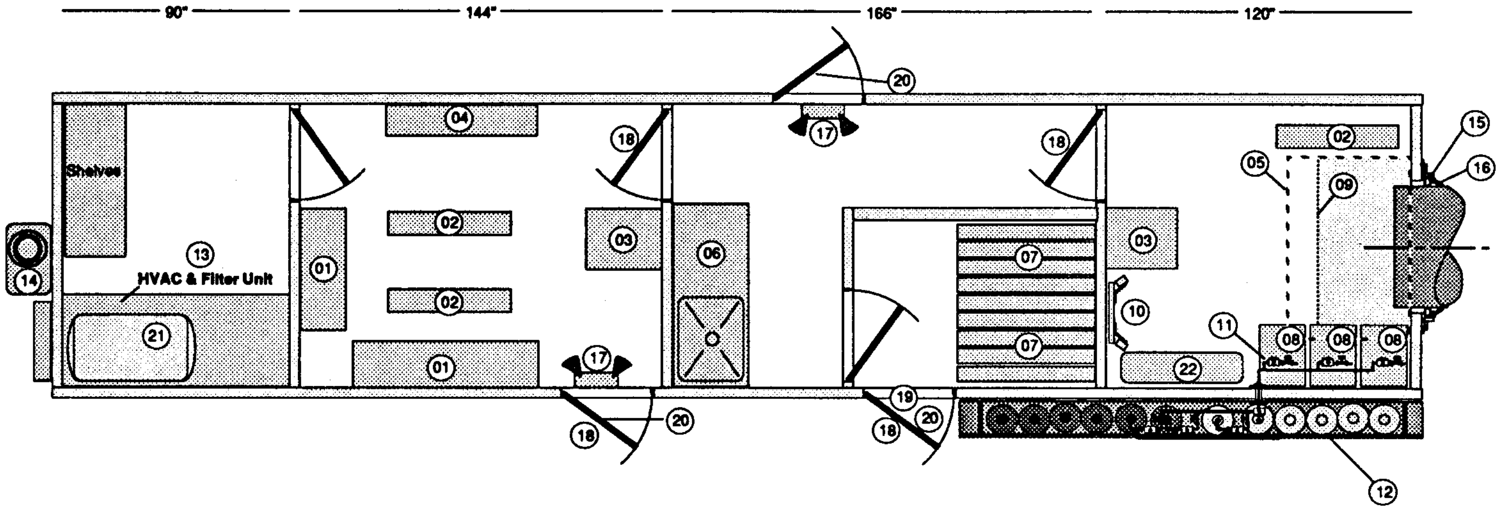
Supplier's/Purchaser's No. ____________

CBI

LIGO

CLEAN ROOM
HVAC PLAN
PLAN VIEW

Customer's No
By ______ Chkd ______ Date ________
Engineering Supervisor
Contract No
Dwg
Rev
Sheet



PLAN VIEW

MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.
01	2	Hanging Lockers	16		MMC4870T1
02	3	Changing Bench	48"		MMC4911T41
03	2	Wall Attachment Desk	24"x28"		MMC4808T18
04	5	Wall Attachment Shelves	12"x24"		MMC4717T38
05	1	Overhead Hood	48"x72"	See HVAC	HVAC EX04
06	1	Cleaning & Inspection Table	24"x36"	Add S.S.Top	MMC9045T18
07	4	Baffle Racks	27"x54"		Detail Later
08	2	Gas Hose Bin	18"x24"	1/8" S.S.x36"h	Detail Later
09	1	Floor Tray Drain Mat	36"x72"	See HVAC	HVAC EX07
10	2	Personnel/Equip Creepers	18"x36"	S.S. Wheels	Detail Later
11	2	Purge Manifold Systems	N/A	S.S.Const	Detail Later
12	1	Gas Bottle Rack	Later	Per OSHA	Detail Later
13	1	HVAC/Filter Unit	N/A	See HVAC	HVAC AHU-1
14	1	Compressor/Condensing Unit	N/A	See HVAC	HVAC AHU-1
15	1	Inflatable Seal for Tube Penet.	48" Ø	See Seal Det	Detail Later
16	1	Secondary Gasket Seal	48" Ø	See Seal Det	Detail Later
17	2	Exit Sign/Emergency Lights	12"x8"	Per OSHA	MMC8367K33
18	6	Authorized Admittance Only	3"x5"		Global WBL43
19	2	Emergency Exit Only	10"x7"	Per OSHA	Global RFM2
20	3	Warning Step Down	10"x7"	Per OSHA	Global PSPL341
21	1	Potable Water Storage Tank	100 gal	Fiberglass	Detail Later
22	2	Inflatable Purge Dams	48" Ø		Detail Later

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. ____________

CBI

LIGO

CLEAN ROOM EQUIPMENT PLAN VIEW

Customer's No

By ______ Chkd ______ Date ________

Engineering Supervisor

Contract No

Dwg

Rev

Sheet

SECTION 9

LIGO PROJECT
WBS 400
QUALIFICATION TEST

Qualification Test Objectives

The qualification test will demonstrate the critical elements of the beam tube module design. The test plan will be developed to limit the risks associated with unknown factors and parameters of the beam tube module design, fabrication, and installation.

Items Verified by Testing
- Structural and mechanical performance of the beam tube configuration
- Coil Manufacture and Traceability
- Coupon outgas test procedure and equipment
- Beam tube manufacturing process and welding procedure
- Expansion joint design and manufacturing process.
- Dimensional verification and inspection procedures
- Stiffener manufacturing process
- Baffle configuration and manufacturing process
- Stiffener attachment process and equipment
- Circumferential seam preparation and fit up process and equipment
- Circumferential weld process and equipment
- Beam tube section leak test procedure
- Circumferential seam leak test procedure and equipment
- Cleaning procedure
- Qualification test outgas characteristics
- Alignment verification and procedures

Items Verified by Analysis
- Thermal performance of beam tube supports
- Structural and mechanical performance of beam tube configuration under environmental loads
- All beam tube handling and transportation
- Clean room enclosure environment and effectiveness
- Automated cleaning equipment performance
- Beam tube section leak test cask equipment performance

Qualification Test Plan

The qualification test plan consists of the test configuration and the procedures for fabrication, installation, and testing of that configuration. This plan will demonstrate conformance of the LIGO beam tube module design testing items with the performance requirements.

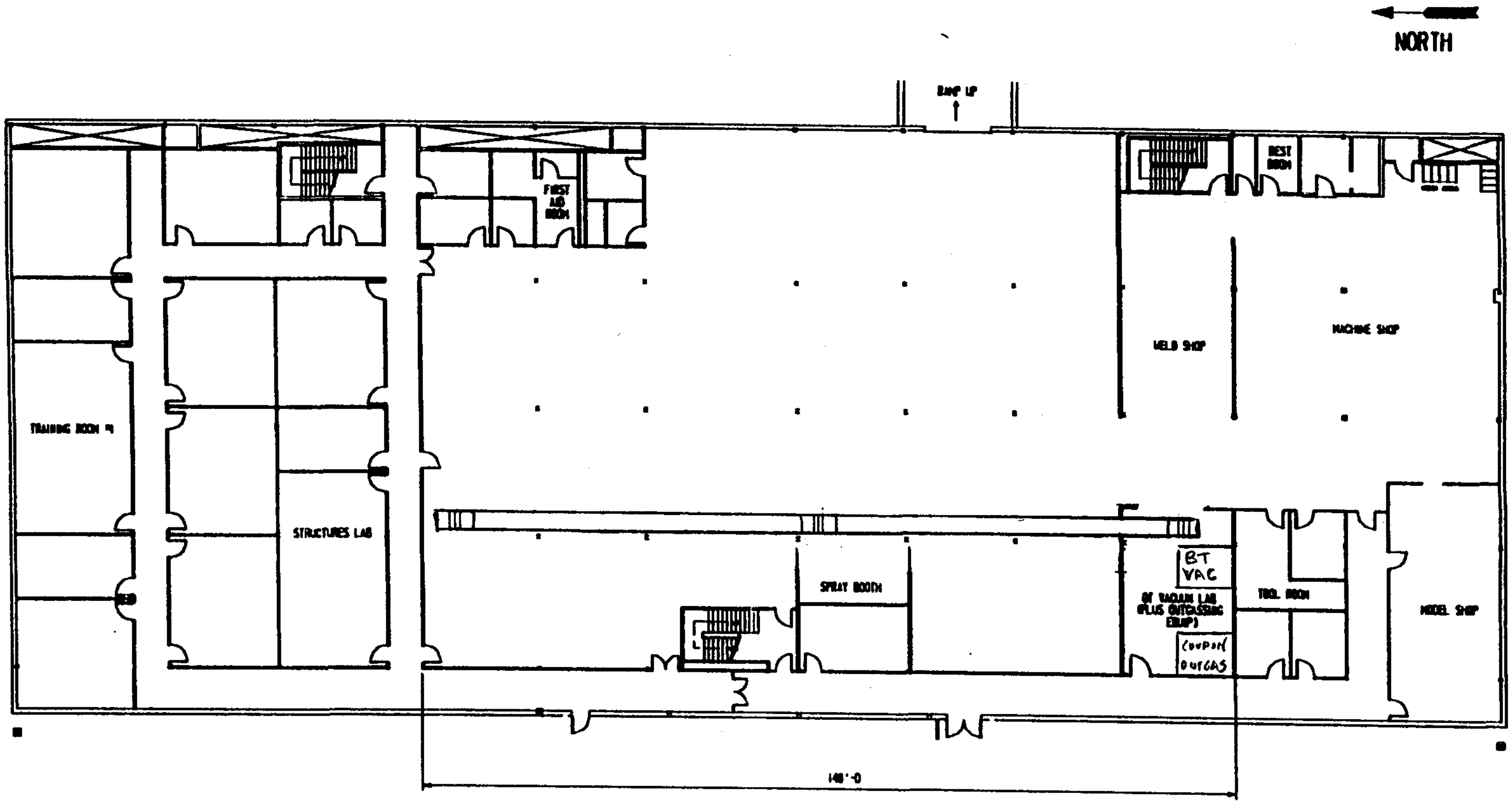
Test Configuration

The qualification test beam tube module will be composed of two full length beam tube sections, each with an expansion joint and a third expansion joint. This configuration will represent the LIGO Beam Tube Module configuration. Supports under the beam tube section will be identical to supports to be used in the modules. Short tube sections will be anchored at the ends of the beam tube to provide end restraint for test specific end loads. As shown on Sheet 1, the qualification test will be conducted in the basement of the Research and Development Center. The coupon outgassing facility and the QT Beam Tube Module vacuum and outgassing system will be located in the Qualification Test Vacuum Lab. The current configuration for the coupon outgassing facility and beam tube vacuum/outgassing system are reflected in the P and I's for these systems. The P&I's are currently being used to configure these systems into fabrication/ installation drawings. The Preliminary Coupon Outgassing Test Procedure (WBS 434), Preliminary Beam Tube Outgassing Test Procedure (WBS 435), and Design of the Qualification Test Pumping System (WBS 451), including these P&I's, follow Sheet 1 - QT Beam Tube Configuration.

Procedures for Fabrication, Installation, and Testing

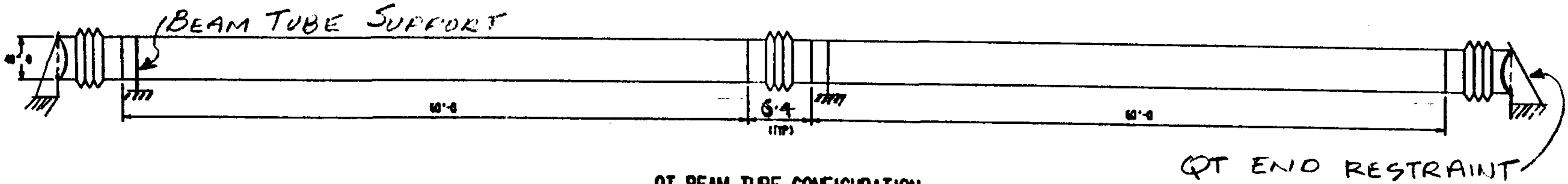
The process for fabrication, installation and testing of the QT beam tube sections is accomplished by following procedures designed to produce a beam tube which meets performance requirements. The QT process procedures are sequentially listed or described in WBS 420 in a preliminary form to describe the test plan.

Specific plans/procedures for cleaning (QT-CLN-B) and bakeout (BO-QT) have been developed as stand-alone documents specifically for the Qualification Test. These procedures and applicable option procedures are referenced in the Preliminary QT Plan. Procedures QT-CLN-B and BO-QT are included as part of this package.



BASEMENT (RESEARCH AND DEVELOPMENT CENTER)

PLAINFIELD, ILLINOIS



QT BEAM TUBE CONFIGURATION

LIGO BEAM TUBE MODULE
QUALIFICATION TEST

CHICAGO BRIDGE AND IRON

ENG ASSIGNED	DSGN BY	MADE BY	CHKD BY	DATE
DCE		SAS		

REV.
BY
CHKD
DATE

CONTRACT NO.
930212

SHEET 1
PAGE ____

FILENAME: pfxbsmt.dgn

WBS 434 PRELIMINARY COUPON OUTGASSING TEST PROCEDURE

1. Clean and assemble all components.
2. Leak check the system.
3. Insulate the system.
4. Evacuate the vessel and all ancillary systems
5. Bake out the system for a minimum of one week at 300°C (the turbomolecular pumps will be baked at only 120°C due to equipment temperature limitations).
6. Cool to ambient temperature.
7. Leak check flanges to confirm leak tightness after bake-out.
8. Fill the RGA cold trap.
9. Activate the RGA and record the hydrogen outgassing rate.
10. Repeat steps 5 through 9 until the hydrogen outgassing rate stabilizes.
11. Calibrate the system using the calibrated leaks after each outgassing measurement.
12. Repressurize the chamber with nitrogen.
13. Clean the coupons with the approved cleaning procedure, stamp the coil identification into one of the coupons, record the I.D. and load into the vessel.
14. Bake the vessel at 250°C for 24 hours. The 24 hour timing starts after the coupons are all up to 250°C.
15. Cool to ambient temperature. Possible backfill with helium or nitrogen to enhance the cooling and reduce waiting perion for cooling.
16. Evacuate the chamber if backfilled. Record the outgassing rate.
17. Repressurize the vessel with nitrogen and remove the coupons. Package the coupons and store until after beam tube module acceptance.
18. Evacuate the vessel and bake for 24 hours at 250°C.
19. Cool to ambient temperature.

19. Cool to ambient temperature.

20. Fill the RGA cold trap

21. Record the hydrogen outgassing rate for the empty system.

22. Calibrate the RGA

23. Average the outgassing rates for the empty system taken prior to the coupon test and after the coupon test. Subtract the average empty system background outgassing rate from the coupon test outgassing rate.

WBS 435 PRELIMINARY BEAM TUBE OUTGASSING TEST PROCEDURE

1. Clean and assemble all components.

2. Leak check the system.

3. Insulate the system.

4. Evacuate all ancillary systems

5. Bake out the analysis and pumping systems for a minimum of one week at 300°C (the turbomolecular pumps will be baked at only 120°C due to equipment temperature limitations).

6. Cool to ambient temperature and record the temperature.

7. Measure and record the water outgassing rate.

8. Fill the RGA cold trap.

9. Measure and record the hydrogen outgassing rate.

10. Repeat steps 5 through 8 until the hydrogen and water outgassing rates stabilizes. The hydrogen partial pressure should be less than $1\text{x } 10^{-11}$ torr and the water partial pressure should be less than $1 \text{ x } 10^{-14}$ torr.

11. Calibrate the system using the calibrated leaks after each outgassing measurement.

12. Evacuate the beam tube.

13. Bake the beam tube for 30 days at 140°C. The analysis and pumping systems will also be baked during the 30 day period.

14. Cool to ambient temperature and record the temperature.

15. Record the hydrogen and water outgassing rates as discussed above.

16. Isolate the beam tube from the analysis and pumping systems and bake the systems for 24 hours at 250°C. The RGA will always be heated prior to heating the cold trap in order to prevent condensation of contaminants on the RGA.

17. Allow the RGA to return to ambient temperature and check the closed system outgassing rates for hydrogen and water vapor as discussed above.

18. Calibrate the RGA

19. Subtract the final recorded system background outgassing rates from the recorded beam tube outgassing rates.

WBS 451 DESIGN OF THE QUALIFICATION TEST PUMPING SYSTEM

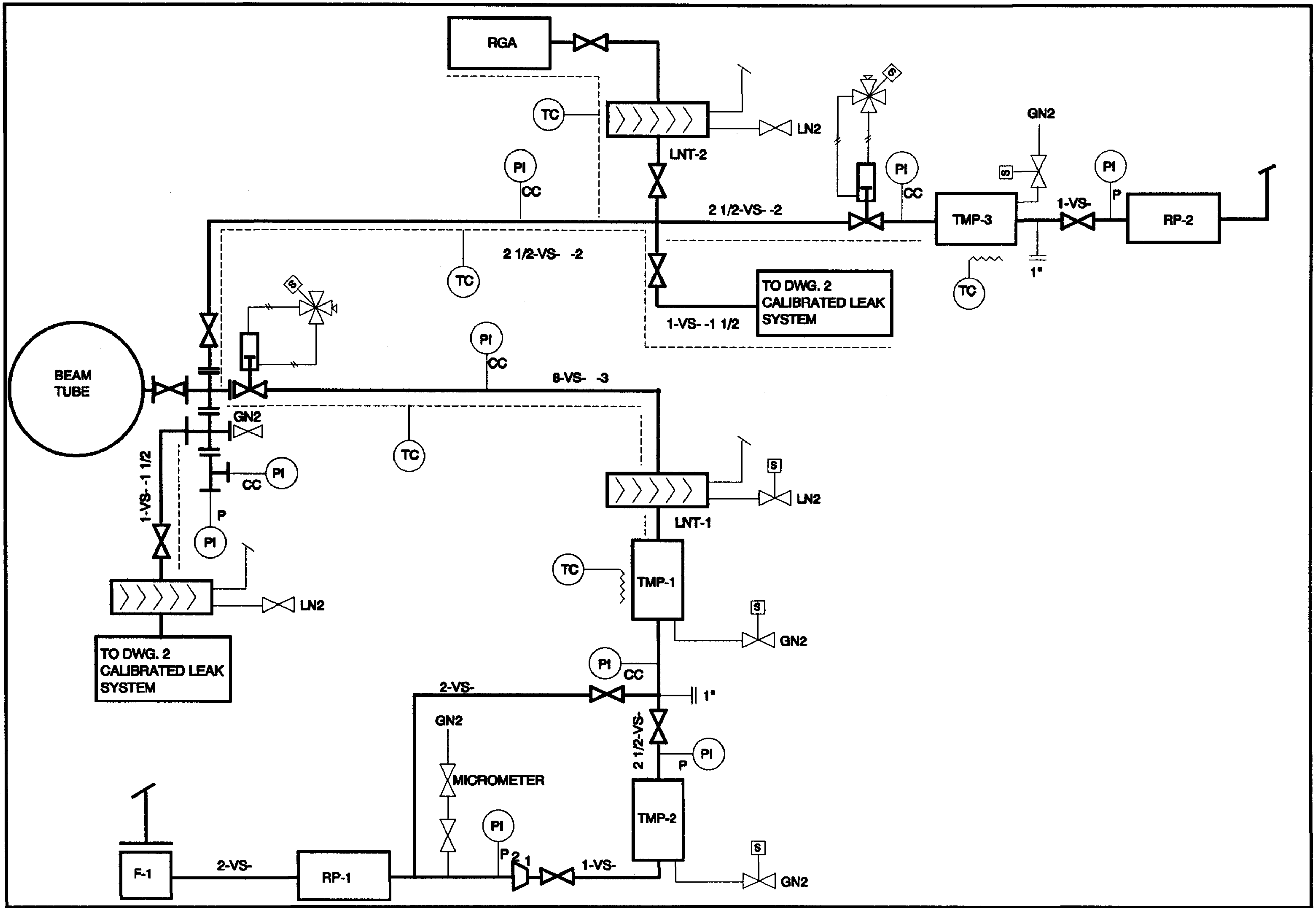
The design of the Qualification Test pumping system is represented by the attached P & I (Piping and Instrumentation) Diagrams. The system is provided with an ultra high vacuum pumping system, a cold trapped RGA and a calibrated leak system.

The ultra high vacuum pumping system consists of a cold trapped turbomolecular pump which is backed by another turbomolecular pump and a roughing pump. The system is provided with two turbomolecular pumps in series in order to supply sufficient hydrogen compression ratio for ultra high vacuum service. The pumping system is provided with a large (50 CFM) roughing pump to quickly rough down the large beam tube volume. This pump will be provided with an inbleed in order to maintain the pump in the viscous flow regime to prevent oil backstreaming.

A high quality RGA will be provided to measure the hydrogen and water vapor outgassing rates. The unit is provided with a cold trap to collect hydrogen containing compounds such as water and hydrocarbons. The RGA as well as the calibrated leak system have been connected to a secondary pumping system so that the RGA or the calibrated leak system can be baked out independently from the rest of the system. Calibrated leaks will be specifically selected to be free of water vapor.

The water pumping speed during the beam tube bake-out will be held to a maximum of 600 L/S in order to simulate the full beam tube module pumping system speed.

The entire system (to the first turbomolecular pumps) is designed to be baked-out to the temperature limitations of the components. All seals (to the first turbomolecular pump) are metal seals to facilitate bake-out and to minimize permeation and diffusion of gases.



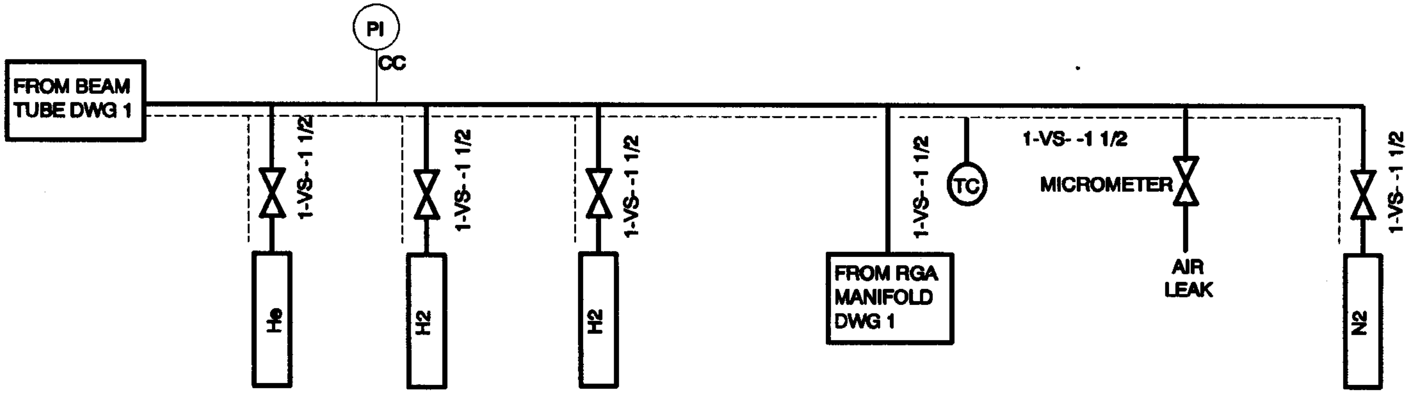
CBI

P & I DIAGRAM
VACUUM SYSTEMS
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/3/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 1
SHT 1
REV 3



CBI

P & I DIAGRAM
CALIBRATED LEAK SYSTEM
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/3/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 2
SHT 1
REV 3

P & I SYMBOLS

COLD CATHODE VACUUM GAGE

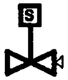
PIRANI VACUUM GAGE

MANUAL VALVE

ELECTROPNEUMATEC VALVE

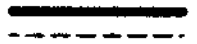
TWO WAY SOLENOID VALVE

FOUR WAY SOLENOID VALVE WITH PNEUMATIC SUPPLY



TWO WAY SOLENOID VALVE WITH PNEUMATIC SUPPLY

TEMPERATURE CONTROL

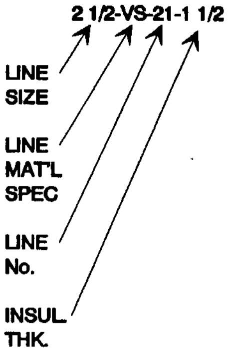


HEAT TRACED PIPING

PRELIMINARY EQUIPMENT SIZING

TMP -1	1000 L/S
TMP-2	60 L/S
TMP-3	60 L/S
TMP-4	60 L/S
TMP-5	60 L/S
RP-1	50 CFM
RP-2	1 CFM
RP-3	1 CFM
RP-4	1 CFM
LNT-1	8" TRAP
LNT-2	2 1/2" TRAP
LNT-3	2 1/2" TRAP

LINE DESIGNATION



CBI

P & I DIAGRAM
P & I SYMBOLS
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/10/93
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 3
SHT 1
REV 4

WBS 420 PRELIMINARY QT PLAN FOR FABRICATION, INSTALLATION, AND TESTING

1. Coupon Testing

    a. Prepare And Install Coupon Outgas System Including Leak Check, Bakeout And Calibration
    b. Clean Coupons Per Procedure
    c. Bake Coupons And Vessel To 250°C, Then Cool
    d. Record Outgas Rate
    e. Remove Coupons, Evacuate, Bake, And Cool Vessel
    f. Record Outgassing Rate
    g. Outgassing Rate = Coupon Outgassing Rate - System Background Outgassing Rate

2. Fabricate Beam Tube Sections

    a. Fit-Up And Weld Stiffeners One At A Time To Beam Tube Sections Using CBI Procedure WPS 308LT-1 (Stiffener Fit-Up Will Simulate Construction Plan Stiffener Fit-Up)
    b. Perform Dimensional Inspection Per CBI Procedure (See Section 3)
    c. Weld Expansion Joint To Beam Tube To Create A Beam Tube Section Per CBI Weld Procedure WPS AUTOG/ER 308L
    d. Weld Qt End Cover To Beam Tube Section Per CBI Weld Procedure (To Be Developed)
    e. Weld Vacuum Pump Port To Beam Tube Section Per CBI Weld Procedure (To Be Developed)
    f. Leak Test Beam Tube Section Per CBI Procedure HMST1N - Modified To Use A Bag For The Hood Instead Of An Enclosure As Shown In HMST1N
    g. Clean Beam Tube Section Per CBI Procedure and QT CLN-BT
    h. Place Temporary "Clean" Cover On Open End Of First Beam Tube Section

    (Baffle Installation Sequence Has Not Yet Been Decided Upon)

3. Dimensional Testing

    a. Beam Tubes
        (1) Size
        (2) Straightness
        (3) Thickness
        (4) Spiral Weld Peaking And Offset
        (5) Length
        (6) Squareness Of Ends
        (7) Flatness Of Ends

b. Stiffened Bean Tube
   (1) Roundness
   (2) Straightness
   (3) Length
   (4) Squareness Of Ends
   (5) Flatness Of Ends

c. Expansion Joints
   (1) Roundness
   (2) Size
   (3) Length
   (4) Squareness Of Ends
   (5) Flatness Of Ends

d. Beam Tube Sections
   (1) Straightness
   (2) Squareness Of Ends
   (3) Sag

4. Beam Tube Section Installation

a. Install First Beam Tube Section On End Restraint And Support 1
b. Align This Section Per CBI Procedure (See Section 5)
c. Bring In Second Beam Tube Section
d. Weld Circumferential Beam Tube Section To Beam Tube Section Per CBI Weld Procedure WPS AUTOG/ER308l
e. Leak Test Circumferential Seam Per CBI Procedure HMST2N
f. Clean Circumferential Seam Per CBI Procedure and QT CLN-BT
g. Weld QT Beam Tube Module End Expansion Joint. Leak Test And Clean Per e. And f.
h. Weld In Closure End To Seal Off Qt Beam Tube Module In Accordance With CBI Weld Procedure (To Be Developed) Which Will Include A Back Purge.

5. Alignment Demonstration

a. Outdoor Long Distance +250 M Demonstration
   (1) Construction Alignment
      - Establish Semi-Permanent Monuments At 250 M Spacing
      - Set Intermediate Location On Line Of Sight Between Monuments
      - Transfer Line Defined By 2 Monuments To A Parallel Line Defined By Targets Placed At Approximately 66' Spacing (Represents Beam Tube Support Spacing)
      - Record Readings And Accuracies

(2) Final Alignment And Realignment
  (a) Set Temporary 250 M Monuments Under Cover
    - Set Up On Monument (M1) And Sight To Second Monument (M2) 250 M Away. Then Sight On And Set Temporary Location To Represent Monument (TM1) Inside Of Cover.
    - Move Instrument To Sight On Both TM1 And M1. This Will Establish Y Dimension.
    - Repeat Above Steps To Set Position Tm2.
  (b) Establish Tube Location To Provide Clear Aperture
    - For 3-D Coordinate System - Sight TM1 And TM2 From Between Them And Inside Cover. Adjust Tubes To Bring Targets Into Calculated Line To Achieve Clear Aperture.

b. Construction Alignment
  (1) Establish Temporary Monuments In Basement At ~ 150ft.
  (2) Perform Construction Alignment As In a(1) Above

c. Final Alignment
Perform Final Alignment As In a(2) Above

d. Realignment
Perform Final Alignment As In a(2) Above

6. Qt Beam Tube Module Outgas Testing

a. Prepare And Install The Beam Tube Vacuum/Outgas System
b. Leak Test The Vacuum System
c. Insulate, Evacuate, And Bake Out The Vacuum System
d. Measure And Record Water And Hydrogen Outgassing Rates
Requirements: Hydrogen Partial Pressure < $1x10^{-11}$ Torr
Water Partial Pressure < $1x10^{-14}$ Torr
e. Evacuate And Bake Out The Q Beam Tube Module. Bakeout Shall Be In Accordance With Procedure BO-QT.
f. Cool And Record Hydrogen And Water Outgas Rates
g. Isolate, Bake, Then Cool The RGA
h. Measure And Record Hydrogen And Water Outgas Rates
i. Outgassing Rate (OR) = QT Beam Tube Module OR - System Background OR

7. Bakeout - CBI Procedure BO-QT

Occurs After Qt Beam Tube Module Is Assembled, Leak Checked, Cleaned, And An Initial Pre-Bakeout Measurement Of Ambient Temperature Outgas Rate

a. Wrap The Beam Tube With Resistance Heating Cable In A Helical Pattern. Each Beam Tube Section Will Have A Separate Circuit And The Bellows Convolutions Will Have No Heater Cable Directly Applied.
b. Install Thermocouples At Critical Locations
c. Insulate The Beam Tube With 4" Of Knauf Duct Wrap Or Equal
d. Evacuate The Beam Tube To 10^{-5} Torr
e. Over 24 Hours, Raise Beam Tube Temperature To 140°C
f. Hold The Beam Tube At 140°C For 30 Days While Upholding The Vacuum And Recording Temperatures And Outgassing Rates
g. After The 30 Days, Turn Off Heaters And Allow Tube To Return To Ambient Temperature.

8. Acceptance Testing/Final Leak Test

After Qt Beam Tube Module Has Been Built, Leak Tested, Cleaned, Baked Out And Outgas Rates Measured, It Will Be Leak Tested.

a. Evacuate The QT Beam Tube Module
b. Bag The QT Beam Tube Module
c. Evacuate The Bag And Backfill With Helium
d. Monitor The Leak Testing Equipment For Helium Leaks Into The QT Beam Tube Module
e. Acceptable Helium Leak Rate = 0 ($< 10 \times 10^{-11}$ Atm cc/S)

9. Realignment

After Final Leak Checking Of Qt Beam Tube Module, Alignment Will Be Checked. The Tube Will Be Realigned To The Position Providing The Initial Clear Aperture. This Will Be Accomplished By Reestablishing Tube Target Positions Relative To Temporary Benchmarks Proved On Slab. These Benchmarks Represent A Line Parallel To The Clear Aperture Axis. Tube Supports Will Be Adjusted To Bring Fixed Targets Into Position.

CLEANING PLAN FOR QUALIFICATION TEST

This plan covers recommendations for cleaning stainless steel parts, equipment and installed vacuum components for the Laser Interferometer Gravitational-Wave Observatory (LIGO).

General cleaning includes all the operations necessary for the removal of surface contaminants to ensure prevention of product contamination and erroneous data results in high vacuum testing. Cleanliness is also a perishable condition. Careful planning is necessary to achieve and maintain clean surfaces at all times. If careful control is exercised during the fabrication processes and operations, very little special cleaning may be required.

The LIGO project will utilize at least two preventive procedures to ensure that all the surface contaminants have been removed from the system. They are as follows:

- Onsite final cleaning procedure of beam tube sections after they are helium mass leak tested, but before they are installed and welded in final position.
- Procedure to maintain the cleanliness integrity of partially completed beam tube modules during construction. Included as an integral part of this procedure is the spot cleaning requirements of the closing weld joints between tube sections after welding.

CLEAN ROOMS

On Site:
Portable rail mounted clean rooms will be constructed in the field. These facilities will contain a dressing room, a transition room, and a work room with a sealable opening around the work that is being conducted. Two rail mounted horse shoe shaped enclosures will be used as clean rooms, one for fitting and welding and the other for leak testing. The work rooms will contain the necessary equipment for purging the inside of the weld seam during construction and leak testing. The workrooms will also contain the necessary equipment for monitoring air quality and communication with the other enclosures.

Vacuum Laboratory and Equipment:
Similar to the field, cleanliness will be maintained in the high vacuum lab facility during the Qualification Test at CBI's Research and Development Center.

Vacuum Laboratory-Instrumentation Area:
1. Class 10 000, overall dimensions (10' H x 20' W x 30' L).
2. Hepa filtered air provided by (10) 2' x 4' fans with filters.
3. 2 x 4' Clean room troffer lights (12 qty.).
4. Module wiring.
5. Air Conditioning-temperature and humidity controlled.

MATERIAL PREPARATION

Cleaning Beam Tube Can sections:
Beam tube section will be placed on two power rollers spaced approximately forty feet apart with high volume ventilation fans at opposite ends. The initial cleaning process will start at one end of the tube and proceed to the opposite end of the tube using Black Light Inspection techniques to spot clean the interior surface. Black light can detect certain oil films and other transparent films that are not detectable under white light. A fluorescence glow on the surface or wipe cloth indicates the presence of contaminants, and should be recleaned and retested. The following is a list of approved materials that should be used during the cleaning process:

- Deionized water
- Technical grade solvents such as acetone or isopropyl alcohol.
- Lint free wipers (Class 100).
- 100 Watt black light with 3650 Angstrom unit wavelength.
- Black light meter capable of measuring at least 800 uw/cm^2.

Cleaning Weld Joints:
The joint area and surrounding metal for several inches back from the joint will be cleaned immediately before starting the weld. Cleaning may be accomplished by brushing with a clean stainless steel wire brush, or scrubbing with a clean, lint-free cloth moistened with solvent, or both. When the joint has cooled after welding, remove all weld splatter, and arc strikes by grinding or sanding. The same techniques and materials for cleaning the beam tube can section will also be applied to the weld joints.

Measures to protect cleaned surfaces of new stainless steel parts, and equipment will be taken as final cleaning is completed, and will be maintained during fabrication, shipping, inspection, storage, and final installation. The following is a list of precautions that will be taken when handling cleaned items.

- Do not remove wrappings and seals from incoming materials and components until they are ready to be used or installed.
- Cleaned components for vacuum service will be handled with clean room gloves.
- Cleaned materials and components should not be stored directly on the ground or floor. Do not allow the materials or components to come in contact with the following: asphalt, galvanized, carbon steel, mercury, zinc, lead, and cadmium.

- Store materials and components on wood skids or pallets. Keep hollow openings on items (pipe, tubing, pumps, etc.,) capped or sealed.

DOCUMENTATION

On a checklist of all purchase items for a beam tube module, sign-off and date the entry for each purchase item indicating that the item was received in a clean condition. Note each purchase item received in a non-clean condition. List them on a separate checklist of items still to be cleaned or on a checklist of items returned to the manufacturer for cleaning or recleaning. Maintain a cleaning log book for each beam tube module, listing the sign-offs and dates for entry for:

- Satisfactory completion of the final cleaning per procedure of each beam tube can section.

- Satisfactory cleaning maintenance during construction per procedure of each partially completed beam tube module. This covers the local cleaning of closing weld joints after successful completion of the local HMS leak testing of those weld joints.

PERSONNEL

Only designated personnel shall perform and supervise all cleaning and cleaning maintenance performed in accordance with this planned approach.

PERSONNEL CLOTHING REQUIREMENTS

Personnel performing this cleaning shall wear clean nylon gloves. Care will be taken not to leave any fingerprints, which contain oils, on the inside surface of the beam tube can section or on any vacuum surface (baffles etc.).

Personnel performing this cleaning shall wear clean, soft-soled shoes with shoe covers or clean room type boots.

PERSONNEL SAFETY

Cleaning operations often present numerous hazards to both personnel and facilities. Data sheets of the Manufacturing Chemist Association should be consulted to determine the hazards of handling specific chemicals. The following is a list of precautions to be used during the cleaning procedures.

- Provisions should be made for venting of explosive or toxic reaction-product gases, safe disposal of used solutions, warning signs, and methods for the safe transfer of dangerous chemicals during the cleaning operation.

- Whenever possible, chemicals having explosive, toxic, or obnoxious fumes should be handled outdoors or inside a ventilated booth.
- Keep the area in which the cleaning operation is being conducted clean and free of debris at all times.

BO-QT
0
930212

PRELIMINARY PROCEDURE FOR BAKEOUT OF QUALIFICATION TEST BEAMTUBE LIGO PROJECT FOR CALTECH

1.0 SCOPE:

1.1 This procedure covers the bakeout of the Qualification Test beamtube at 140 C under vacuum for the purpose of removing water and hydrocarbons from the tube inside surfaces.

1.2 This bakeout will occur after the Qualification Test beamtube has been assembled, leak checked and cleaned. A post-bakeout outgas rate measurement will follow.

2.0 OBJECTIVES OF THE ACTIVITY

2.1 The objective of this Qualification Test bakeout is to emulate the parameters of the field bakeout of complete beamtube modules that affect the level of post bake outgassing. This then will contribute to the accuracy of predictions of outgassing rates and pumping requirements on the complete modules.

2.2 The procedure will hold a temperature of 140 C within a range of +30/-0 C at all points and at all times on the beamtube. Closer temperature tolerances will be sought as much as possible within the limitations of such things as the spacing of the heater cables.

2.3 The means of heating will not necessarily be the same on the qualification test as is planned for the complete modules.

2.4 Data will be collected during the bakeout period on the rate of outgassing.

3.0 EQUIPMENT:

3.1. Electric Resistance Heating Cable: About 1700 feet of cable is needed. Cable shall have braided nickel-plated copper heating elements with silicone rubber dielectric jacket having about 0.006 ohms/ft resistance at 140 C. The cable shall be temperature rated to 200 C or higher. i.e. Cooperheat Versatrace VTC or equal. If two 850 F circuits are used, then they will be powered by 240 volt AC. If four 425' circuits are used, they will be powered by 120 volt AC.

3.2 About 10 Thermocouples.

3.3 Temperature control equipment: One time proportioned thermal regulator per circuit. Honeywell Dialatrol or equal.

3.4 Temperature monitoring and recording equipment: One data acquisition personal computer.

3.5 Equipment for vacuum pumping and measurement of outgassing rates is described in the Outgassing Test Procedure (No. XXXXXX). Note that the liquid nitrogen trap is sized for 600 liters/sec water pumping speed.

4.0 TEST PREPARATION:

4.1 The Qualification Test beamtube will have been assembled, leak checked and cleaned prior to bakeout.

4.2 The assembled Qualification Test beamtube will be located in the basement of the Plainfield Research Center and will be in its final bakeout/outgas test position where about 10 feet of the beamtube extends into the vacuum lab where the vacuum pumping and instrumentation will be located.

4.3 Wrap the beamtube with resistance heating cable in a helical pattern. Space turns of cable at 12" on the tube sections and the bellows stubs. Each of the nominally 60' long tube sections along with the adjacent end bellows will have a separate circuit. The bellows convolutions (approximately 1/2 foot in length) will have no heater cable directly applied.

4.4 Install thermocouples in contact with the beamtube at locations midway between cables. Thermocouple leads shall be run under the insulation for at least 2' in order to ensure minimal conduction from room ambient temperature to thermocouple. Locate thermocouples at the following positions.

4.4.1 Topside of the tube at mid length of each tube section
4.4.2 Bottomside of the tube at mid length of each tube section
4.4.3 Top center of each bellows
4.4.4 At the base of a vacuum stiffener
4.4.5 At one location, a pair of thermocouples, one centered between conductors, the other about 0.5" from a conductor

4.5 Insulate the beam the beamtube with Knauf Duct Wrap or similar insulation to a total thickness of 4". Cut the insulation so that the first layer of insulation fits between the vacuum stiffeners.

4.6 Connect the heater cable to thermal controller described in the EQUIPMENT section of this procedure.

4.7 Connect thermocouples to data acquisition computer.

4.8 Preparation of the vacuum pumping system is covered in procedure XXXXXXXX.

PRELIMINARY PROCEDURE FOR BAKEOUT OF QUALIFICATION TEST BEAMTUBE LIGO PROJECT FOR CALTECH

5.0 TEST EXECUTION:

5.1 Evacuate the beam tube to 10^{-5} torr.

5.2 Over a period of 24 hours, raise the temperature of the beamtube to 140 C.

5.3 Hold the beamtube at 140 C for 30 days. During which time:

5.3.1 Vacuum pumping will take place continuously.

5.3.2 Temperature data from all thermocouples will be passed to a data acquisition personal computer. Data will be displayed continuously and recorded to disk on a hourly basis. This task will be done automatically by simple software.

5.3.3 Review temperature data daily and adjust the thermal controller settings as needed

5.3.4 Measure and record outgassing rate at the following points in time

i) TBD
ii) TBD
iii) TBD
iv) TBD

5.3.5 Record all significant events in a lab notebook

5.4 At the end of 30 days turn off the heaters and allow the tube to return to ambient temperature.

LIGO PROJECT
WBS 400
QUALIFICATION TEST

Report Format

1. Cover
2. Executive Summary
3. Table Of Contents
4. Nomenclature
5. Glossary
6. Introduction
7. Test Configuration
8. Equipment And Procedures
9. Data/Results
10. Discussion Of Results
11. Summary And Conclusions
12. Recommendations
13. Acknowledgments
14. References
15. Appendices