

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LIGO



PROJECT

**FINAL DESIGN REVIEW
DATA PACKAGE
BEAM TUBE MODULE
DESIGN & QUALIFICATION TEST
CONTRACT C146**

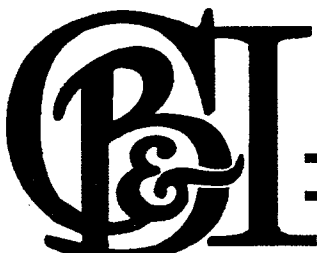
**CDRL #15
DRD #9 ITEM II**

VIEWGRAPHS & ASSESSMENT

Prepared by

**CBI TECHNICAL SERVICES COMPANY
PLAINFIELD, ILLINOIS
APRIL 11, 1994**

CBI CONTRACT 930212



Summary of the discussion

[Offspring with the purpose of this are selenium 1) Statute in how

1) ~~See~~ 0.21 X 10¹² cells with residual organs
 of 100 in elongation of primary joints, X² with
 if mean left selenium failure can be handled needs
 of movement of material properties

2) If we are mixed use elongation, ~~the~~
 series of the joint wants prepared in papers
 of the cell series of the cell X selenium.
 of the selenium series made from the material

V1

Gen 18

$$1.4 \times 10^{-12}$$

Am 244

$$4.8 \times 10^{-13}$$

$$3.8 \times 10^{-14}$$

$$1.52 \times 10^{-13}$$

AJ2

$$8.35 \times 10^{-12}$$

$$5.16 \times 10^{-12}$$

Am 228

$$3.24 \times 10^{-13}$$

$$7.60 \times 10^{-15}$$

Am 212

$$6.67 \times 10^{-13}$$

Am 257

$$2 \times 10^{-14}$$

$$2.43 \times 10^{-13}$$

$$1.06 \times 10^{-15}$$

022840. mdc

Am 211 ?

Testing Center of the RISA
 Power Hys, metal Selenium
 Robert Byers Pottery

1/2 cc $\Rightarrow \frac{6 \times 10^{-23}}{18} = \frac{1}{3} \times 10^{-23} \rightarrow 3 \times 10^{-22}$ molecules

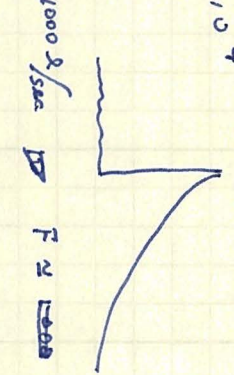
WARRANTY
 DNRCK
 IMPULSER LOAD
 DR TWP1

10 liters $\rightarrow 1 \times 10^4$

$S = \frac{3 \times 10^{22}}{3 \times 10^4} \approx 1 \times 10^{18} / \text{cc} = \frac{1}{30} \text{ ATW}$

$V_{\text{avg-TWP1}} = 30 \text{ Lit/Sec}$

DYNAMICS



$\tau = \frac{32}{1000} = 32 \text{ ms} = 1/30 \text{ sec}$

1P IMPULSER

AND

PUMP

KRAPS

GOING

1P PUMP KEEP GOING

1000 Lit/Sec

RIP

44 Lit/Sec

$\left[\rho^3 \approx \frac{1}{20} \right]$

$60 \times 10^{-1} \sim 1 \times 10^0$

2×10^{-1}
 3×10^{-1}
 4×10^{-1}
 5×10^{-1}

$\frac{2.8}{2.24} = 1.25$
 $\frac{2.8}{2.24} = 1.25$
 $\frac{2.8}{2.24} = 1.25$

HF LINES & RINGS ON

$\tau = \frac{32}{44} \approx \frac{3}{4} \text{ sec}$

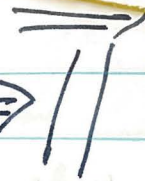
dec
 2.2
 4.4
 6.6
 8.8

~~1.1~~
 1.4
 5×10^{-2}
 2.5×10^{-4}
 1.2×10^{-5}

CBI FOR

1) Cost / per part

\$ 715 / part



\$

3975 // part

Seismic load Hazard

ASMR: code not required at either Hazard

UBC - #2 Earthquakes -

How often does this happen
18% of 7

The transient flexing of the 1g load 40 MPH

Florida for Hazard

neglect
Oval

Flexing is both a judgment and cost
argument is ultimately required steps

Calculates the regression parameters in the tolerance
for picking the tubes - measured in days in

Ovaling of the tubes is a bigger concern for
transient than bending

Tired is asking for higher stress levels at the
falls

⇒ Crowding of the tubes quarters! ~~to~~ to ground
a to float Fred Oyler

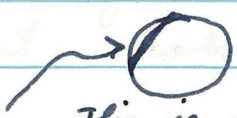
How often to ground

MICANTA also helps in stopping electrolytic corrosion

2)

Grates in the supports ~~should~~ how
fraying in the aligned - should show up in
the ST

NOTE reason for re-aligning before the hole
is the flaking of a tube section between
stiffing rings -



need and apply
this is what causes the ~~support~~
for the re-aligning prior to
hole

~~The~~ Tall is for

The chart gives for differential settlement between supports
1/2

⇒ Qualifiers part of the 48"

Fred Pyle

CRBAF would learn this 1mm over 2.6km

Amoco Sulphur 4-5p ~~ms~~ σ_{rms}

Sulphur .005% on the material we have tested

Steel Production

3 rolls of steel from ARNCO are being
made will be cancelled at Mill being
of May

⇒ AW must get on the slide with Oak Ridge resources

3)

sliding done at another facility after the
around

~~May~~ → The Coymen for the coils will be tested
in May third ~~in~~ ~~is~~ ~~work~~ in May. ←

Measure the H_2O content of the gas in the
boiler - but will not ask for special
low humidity gas.

The baseline for the tubes

16" wide coil Tubes
of BT
Any change would be viewed as a change requiring
a plan.

Part of the tolerance of the tube is taken up
by using some for welding at ends - this is
to be done by CBI

The hydroformed expansion joints look good
CBI is retained

Mayer 2, Tool + Manufacturing is highly
regarded of

The questions of the weld joint lubrication
at it being a source of hydrogen
Advocate the clean of the weld for control

Quality of welds is better ~~to~~ done
 by etching the weld and looking at the
 amount of overlap in melting - cross sections
 measured. - to look at penetration.

NSP/Pure Body .. Worried that we are closing options
 not keeping dual of fabrication, dual contractors for the
 beam tube again

asked about fixing in the field:

Regions of welds when we can no longer get
 inside - baffles are assembled. - all outside
 welding

No clear plan for the fabrication of tubes on site
 Prefer mill at

GPS has static precision	$\pm 0.5 \text{ cm}$	\$150/quarter
		65/dome
Leica	$\pm 21.5 \text{ cm}$	85/intellectus

Chuk's efforts

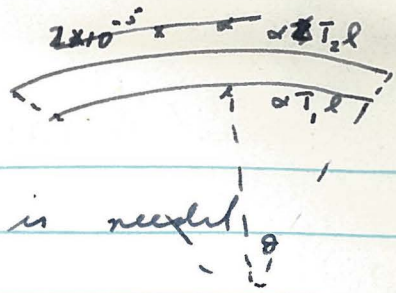
Chuk's efforts

1/20 sections have been

↓
 1/4 needs kind of flight

Paula Morgan

Serialisation of components and joints is needed



Coynes

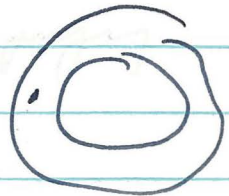
Outside edge of coil source of Coynes

Warren Coynes - 15

Coynes tank 10 days requires

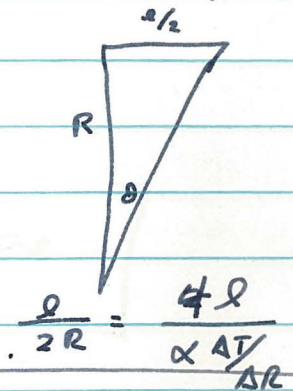
The ~~plan~~

Sequencing of the cantilevers has to be analysed



$$\frac{\alpha \Delta T / \Delta R}{2a}$$

$$\theta = \frac{2R}{\alpha \Delta T a \frac{R}{2}}$$



Diffusion ST test

Boffler - Internal to part is 5 boffler

\Rightarrow ~~RC~~ When to start the bore out

(w) Progress for the waterbeds

\Rightarrow CBI Needs the ^{vacuum} Model for the
Serialisation test

Need to make
Model
of ST
600 l/sec / H₂O

COUPO N

End May

Start May

End of June

Apt Series

end of June - July

Expenses

July

Last Slight from July 3rd and

Assembly of beam tube module End 2nd August

Start

→ 4th week of August is start of joining

3rd

There is an important agent for being

⇒ Trials in the field

Running assembly sequence

Blaney, [# of Tube Vendors is being reduced - are
we getting level in]

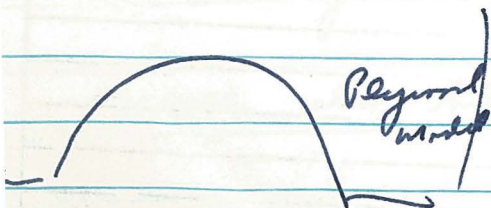
ISSUE

Sequencing of steps in the field to maintain

clearance

Make an enclosure leveler like

what is in the field



**LIGO Beam Tube Module
Final Design Review Meeting Attendees
April 26 & 27, 1994 - Plainfield, Illinois**

LIGO Review Board Members & Observers:

Rainer Weiss	617-253-4824
Thomas Eagar	617-253-3229
David Berley	703-306-1890
Fred Dylla	804-249-7450
William Tyler	818-354-7190
W. E. Gene Giberson	818-790-2289
Stan Whitcomb	818-395-2131
Bill Althouse	818-395-4481
Larry Jones	818-395-2970
Gerry Stapfer	818-395-2905
Fred Asiri	818-395-2971
Carl Lewis	814-899-5251

CBI Personnel	Initial	Position/Responsibility		Location:
Erik Brogren	EEB	Vacuum Consultant - QT Assembly, Leak Testing	815-439-6257	Plainfield
Warren Carpenter	WAC	Senior Engineer - Vacuum Systems, Outgas Test	815-439-6301	Plainfield
Bill Czaska	WJC	Senior Design Engineer - Design Configuration	815-439-6160	Plainfield
Bob Grimsley	BGG	Area Weld Manager - Welding	713-896-3776	Houston
Steve Hand	SDH	Project Engineer - Alignment & Cleaning Maint	703-731-0881	Radford
Paula Morgan	PM	Qualification Test Manager - QT Execution	815-439-6227	Plainfield
Steve Peters	SWP	Project Administrator - Coil Steel and Admin	815-439-6520	Plainfield
Rick Prior	RWP	Weld Enigeer - Welding	713-896-2916	Houston
Larry Reed	WLR	Quality Assurance - QT Procedures & Weld Ins.	815-439-6038	Plainfield
Chuck Sherlock	CNS	Leak Test Manager - Cleaning and Leak Testing	713-896-3769	Houston
Mark Such	MRS	Design Supervisor - Module Configuration	815-439-6193	Plainfield
Marty Tellalian	MLT	LIGO Design & Qual Test Project Manager	815-439-6517	Plainfield
Rob Walter	RJW	Senior Design Engineer - Design Configuration	815-439-6194	Plainfield

4/20/94

L. Jones

CONTRACT C146, LIGO BEAM TUBE MODULES: PDR BOARD RECOMMENDATIONS

PDR No.	Issue No.	Issue	TDM	LIGO Action	Comments
1.a.	PDR -1	CBI to estimate in-house coil bake	94-01 #1		Completed
1.b.	PDR -2	CBI to estimate air purge option for in-house coil bake		X	Air purge option to be considered after CBI's bake equipment and procedure are known.
2.a.	PDR -3	CBI to plan on using Caltech's coupon test method	94-01 #2		Completed
2.b.	PDR -4	CBI to investigate improvements in H ₂ outgas testing cycle time during qualification testing		X	LIGO to request proposal from CBI
2.c.	PDR -5	LIGO team to continue investigations of correlation between direct H ₂ outgassing measurements and other lab techniques		X	LIGO investigating mobile/immobile H ₂ measurements at Oak Ridge lab, open to other approaches
2.d.	PDR -6	LIGO team to review outgas testing data during Option, consider more sparse sampling rate.		X	To be reviewed after the first 20 coils have been measured
3.a.	PDR -7	CBI to include all cost variables in tube diameter decision	94-01 #3		Completed
3.b.	PDR -8	Joint group to assess the implications of CBI's desire to preserve 2 tube suppliers.		X	Closed; CBI has dropped this option.
3.c.	PDR -9	CBI to investigate locally clean environment at spiral mill	94-01 #4		Completed
3.d.	PDR -10	CBI to check transportation and handling stresses of tube	94-01 #5		Completed
3.e.	PDR -11	CBI to investigate spiral stiffener concept	94-01 #6		Completed
4.a.	PDR -12	CBI & LIGO team to develop plan to measure outgassing of welds made with treated filler wire		X	Completed: memo summarizing, 2/2/94; treated wire too expensive, checked outgassing of standard wire; memo summarizing, 4/18/94.

PDR No.	Issue No.	Issue	TDM	LIGO Action	Comments
4.b.	PDR -13	CBI to develop ring weld procedure without flux core wire		X	Completed. DCN 1202018 processed to forbid flux core wire on tube welds
5.a.	PDR -14	CBI to investigate module configuration changes to reduce expansion joint quantity	94-01 #7		Completed
5.a.1.	PDR -15	CBI to consider alternate transportation and assembly modes	94-01 #8		Completed
5.b.	PDR -16	CBI to consider material selection, process choices, potential for damage or contamination in expansion joint vendor selection	94-01 #9		Completed
5.c.	PDR -17	CBI to analyze effects of air bake on bellows life	94-01 #10		Completed
6.a.	PDR -18	Joint group to develop alternate baffle design concepts		X	No longer necessary; design has converged.
7.a.	PDR -19	LIGO team to consider increasing module leak criterion from 10^{-10} to 10^{-9} atm cc/s		X	DCN 1202016 processed and approved to make this change
7.b.	PDR -20	LIGO team to consider delaying module acceptance leak test until after field bake of module		X	CBI provided ROM \$ to add insulating and baking to Option
7.c.	PDR -21	CBI to analyze economic benefits of section time-of-flight leak test	94-01 #11		Completed
7.d.	PDR -22	CBI to document concepts and procedures for leak testing modules	94-01 #12	X	Completed
8.a.	PDR -23	CBI to consider using filtered air blower for Qualif. Test.	94-01 #13		Completed
8.b.	PDR -24	CBI to consider using I ² R heating for Qualif. Test	94-01 #14		Completed; proposal being discussed.
8.c.	PDR -25	CBI to consider use of N ₂ gas purges above LN ₂ traps for Qualif. Test	94-01 #15		Completed
8.d.	PDR -26	CBI to identify all differences between Qualif. Test and Option	94-01 #16		Completed

PDR No.	Issue No.	Issue	TDM	LIGO Action	Comments
9.a.	PDR-27	CBI to investigate local codes for pressure vessel compliance	94-01 #17		Completed
9.b.	PDR-28	CBI to cost pump port	94-01 #18		Completed
9.c.	PDR-29	LIGO team to review pump port quantity		X	Based on current data, quantity is appropriate; will review during qualification test phase.
9.d.	PDR-30	LIGO team to review CBI's plans to qualify suppliers		X	Being done as CBI documents become available.
9.e.	PDR-31	LIGO team to consider qualifying improved cleaning agents		X	Completed; changed to steam cleaning
9.f.	PDR-32	LIGO team to establish particle requirements for module air purge during field assembly		X	Completed; Class 100 HEPA filter
9.g.	PDR-33	CBI to analyze cost trade-offs on site fab. facilities	94-01 #21		Completed

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 - WBS #300 Construction
 - WBS #400 Qualification Test

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 - Beam Tube Diameter Study
 - WBS #130 Beam Tube Support Design
 - WBS #140 Pump Port Design
 - WBS #150 Baffle Design
 - WBS #170 Procurement Specification Discussion
 - WBS #180 Detailed Drawing Discussion

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 - WBS #220 Tube Manufacturing Process Study
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 - 13.0 Schedule & Costing
 - 14.0 Commissioning / Acceptance
 - 15.0 Demobilization
 - Appendix A: Proposal For The Use Of Differential Global Positions Methods
 - Appendix B: Preliminary Study: On Site Facilities vs. Leased Facilities
 - WBS #340 & #370 Material Acceptance Plans & Dimensional Control Plans
 - WBS #350 Outgas Testing
 - WBS #360 Leak Testing
 - WBS #380 Alignment Procedure
 - WBS #390 Cleaning and Cleaning Maintenance

~~V~~

Qualification Test

- WBS #410 Qualification Test Objectives
- WBS #420 Qualification Test Plan
 - 1. Items Demonstrated By Analysis Versus Test
 - 2. Qualification Test Configuration
 - 3. QT Pumping and Outgas Testing Systems
 - 4. Qualification Test Procedures
 - a). Coupon Outgas Test Procedure
 - b). Construction Plan
 - c). Leak Testing Procedures
 - d). Outgas Testing Procedures
 - e). QT Bake Out Procedure
 - f). Data Acquisition Procedures
 - 5. Qualification Test Report

From ljones@ligo.caltech.edu Mon Apr 25 13:41:38 1994
Received: from ligo (ligo.caltech.edu) by tristan.mit.edu AA02077; Mon, 25 Apr 94 13:41:36 EDT
Received: from polecat.ligo.caltech.edu by ligo (4.1/SMI-4.1)
id AA10695; Mon, 25 Apr 94 10:41:20 PDT
Received: by polecat.ligo.caltech.edu (4.1/SMI-4.1)
id AA17526; Mon, 25 Apr 94 10:41:17 PDT
Date: Mon, 25 Apr 94 10:41:17 PDT
From: ljones@ligo.caltech.edu (Larry Jones)
Message-Id: <9404251741.AA17526@polecat.ligo.caltech.edu>
To: weiss
Subject: Re: more comments on the CBI documents
Cc: ljones@ligo.caltech.edu
Status: R

A quick flash to let you know what I've heard on your issues:

The test of expansion joints

**CBI has decided that they cannot justify the \$600K or so (before G&A, fee) extra cost for hydroformed expansion joint. They are planning to change their stance and propose the mechanical formed Hyspan joint. I don't agree with you on the need for life tests (overdesign in cycyle life should be cheaper, if we have uncertainty now), but go ahead and bring it up if you feel it's important.

Communication between groups at CBI

**Marty has sent me a page of planned changes which I will fax to you this morning. This is probably in addition to the issues you raised.

WBS 100 Design Configuration

p32; Grounding of the beamtubes is considered important to reduce the hazard from lightning. This conflicts with the i^2R heating during the bake, can one consider spark gap lightning arresters?

**As I understand it, grounding is important prior to installing the enclosure. We plan to lift the grounds during bake, and Marty realizes that. We need to get CBI to tell us whether we're violating or risking anything in so doing. I would guess that the enclosure rebar eliminates the grounding need.

p41; Only transport costs are in cost parametrization, the cost optimization of section length has more factors.

**CBI is working this, plan to present at FDR.

p41; With the asymmetric baffles, the baffle orientation has to be included in the description.

**I'm not sure where you're referencing, but Note 5 on Dwg 1 (pg 65) should cover your concern.

WBS 200 Fabrication

p35; No mention of a chamfer on the stiffening ring edges to avoid galling of

the tube surface and consequent difficulty in placement of the ring.

**Rolled bar stock is used, which does not have a sharp edge; should not be a problem.

WBS 300 Construction Plan

p18; CBI assumes construction will begin at the Washington site first, is this now true?

**Yes, currently.

p28; What is planned for leak testing the sections that have pumpout T mounted on them. They no longer fit into the coffins? I don't remember discussing this with CBI. It might be best to test them in the coffin before the pumpout is cutout of the tube and then follow with the special leak test of the pumpout hardware.

**I believe that they will fit (but have not checked): the coffins also have to accomodate the expansion joints.

DGPS Appendix

p10; Is CBI aware of the equipment that might be available from the SSC.

**No.

p13; It is worth finding out if it is possible to use the GPS system through the concrete cover providing it is free of rebar and metal lath at the apex. This could eliminate the radoms.

**I'm sure they've worked this.

p74; This description in distinction to the viewgraphs leaves no ambiguity about who will do the coupon testing for the QT, it is CBI.

**Actually, both Caltech and CBI will do this. Caltech will do it first, for releasing the coil to the spiral mill. CBI will do it second, to qualify their rig.

Gotta run.

Larry

**Chicago Bridge & Iron Company**

April 18, 1994

1501 North Division Street
Plainfield, Illinois 60544-8929California Institute of Technology
Larry Jones, LIGO Project
102-33 Bridge Laboratory
Pasadena, California 91125815 439 6000
FAX: 815 439 6010

Reference: Contract No. C146 for the LIGO Beam Tube Modules

Subject: Qualification Test Procedure Format Changes and Revisions

As we discussed last Thursday, some of the Qualification Test Procedures will be revised to facilitate the test execution. The minor revisions we discussed are listed below:

QT Head Attachment

The current test plan shows one of the flat heads attached in Houston. Our present plan is to attach both heads in Plainfield to better represent the tube cleaning operation.

Trial Installation of Baffle in Houston

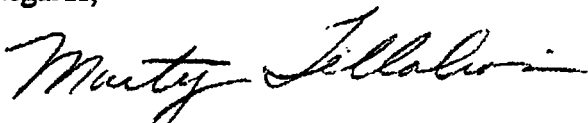
The current plan shows a trial installation of the baffle in Houston. There may be no advantage to performing a trial fit up in Houston and this task may shift to Plainfield.

Dimensional Assessment of the Unstiffened Tube

The current plan shows the dimensional measurements taken on the unstiffened tube with round out rings. Accurate longitudinal measurements can be taken with an unstiffened tube resting on a flat surface without the use of round out rings. The support may have to be continuous or at least closely spaced to prevent localized distortions. The support of the unstiffened tube during dimensional evaluation will be revised.

Similarly, there may be other revision required in the QT plans and procedures. In addition, the format of some procedures will be changed. Presently, some Qualification Test procedures consist of the Option procedure with an addendum. The addendum and the option procedure are separate documents and are difficult to understand and coordinate. As such, the procedures in this format that are difficult to use will be combined into a single separate procedure for the Qualification Test. As an example, the cleaning procedure for the Qualification Test, CL1NQT has been revised from that shown in the QT Plan. The new procedure is a revision of the option cleaning procedure, CL1N, with omissions shown as ~~lined-out items~~ and changes shown in *bold italics*. Updated plans and procedures for the QT will be provided at the FDR. Also attached is another copy of the Qualification Test Plan.

Regards,



M. L. Tellalian - Plainfield Engineering

Things To think about

1) How is external the operation of the combustion is done.

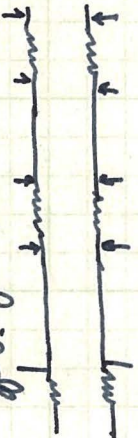
2) How can we see and select the system for a Gaining full picture

3) What is the power spectrum of the situation

4) The rule constraints in the situation that



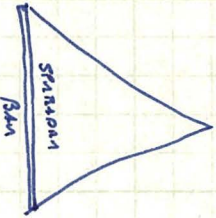
\neq



are they ideal to a selection in the field.

5) The problem

1) The question has: in it will be the adjusted beam



2) What is the description

1) Further comments

W/S #160 Beam Tube Configuration

4/29 - must decide on a rule or rules for ~~the~~ rule for applied 70' is a maximum for rule!

Schedule 2

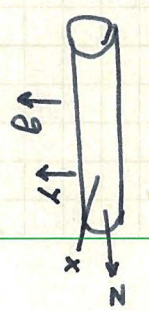
W/S 100 ~~2~~

Page 26

rule ~~is~~ regarding γ beam rule is recommended
 there a rule if there has been a different
 standard

13-782 500 SHEETS, FILLER 5 SQUARE
 42-381 50 SHEETS EYE-EASE 5 SQUARE
 42-382 100 SHEETS EYE-EASE 5 SQUARE
 42-389 200 SHEETS EYE-EASE 5 SQUARE
 42-392 100 RECYCLED WHITE 5 SQUARE
 42-393 200 RECYCLED WHITE 5 SQUARE
 Made in U.S.A.

~~adding~~: I don't understand the conduct for the
 Page 30 applied then apply in Table 1 Page 26

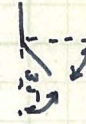


⇒ Page 28 - make steps in applied & for report
 make program gain in Table 4

⇒ Page 29 - There must be strain gauges put in the tube
 how to install the strain gauge being operation and
 testing

⇒ Page 32 Corrosion - Even when the concrete core is in
 place ~~the~~ ~~the~~ there is not carbonation should
 to the core is the tube must be protected - can use
 applied to do this with applying overcoat (spall repair)

Page 41 just transport with air in the permeability

⇒ By the alignment  not spelled out

②

Further comments

WB 3 200

Page 4 On 4 milled the cap / sand ~~the~~ difference as the the bottom line similarity

PAGE 25 Pathway for not met the lower spring rate and will need to include more consolidation. When will falling know that they can make the ~~bottom~~ expansion joint to strengthen.

PAGE 27 Do not indicated how the rebound allows in grid spring rate affect the different settlement of the foundation. As the grid faces indicated in the different settlement.

Page 35 Chapter on the slipping ring edges & arrival grouting will be needed.

Page 45 Alternative techniques proposed by ESAB for clearing as not tested & = 1.1M initial of 4.71M
The cost is in the clearing not the amending after!
(Tougher guide) for the falls mix around slint, (in well being) for the bending of the mix in the torch.

WB 5 300 Contractors plan

Page 5 How in the comments below different parts of the organization still sound out - Cognate mind of - some of the statements order like it is not well covered by the organization

Page 18 CBI has extended an order of 5.5% plan contains trying with W&A plan
Folowend § 24 acts

Page 25 W&A seem does it make a sense one of these look that needs has line of project returns if it is really needed. in the idea





to more leveling tubes to it after covering by the other red sign

Page 28 What in lane for level tails the sections that have purposed something on them. Try to not put with the "offices" also Don't see how this ends now the remaining hole plans on the outside and the do station on the outside But for the line of pipe it not to the other way around - the pressure on the inside (check HWS12)

Page 36 2×10^{-12} atm/cc/sec He would last months in this pressure?

Page 39 How long one avoid curing level with vacuum pressure in the 150' expand test by for compounding well tests.

Page 43 Whether the vacuum part test lay in well wells it rather the piping down the 56 hole testing with such parts?

Page 44 CBI pulled more really built the other the sign to a mid section

Page 48 The requiring of the clean and well shells room is control, how long it will take - ~~will take~~ Pst cover over end of hole in clean room

Bring in new full with cores

Put new shells over ends
Wash clean room to ends and
of new full within
used

at this again
There are two when the system is opened
on the new full is length in.

56 Here mid stream is really mid stream!

60 Mid stream here is really

0 GPS APPROXIMATE

PARA 1

Relative among in roughly at a rate
of shells among bottom sites is not constant
~~of the~~ try after these sites & 500 m or thereabouts
shells pattern X ~~shells~~ are seen locally
(1 pair) 300 m or

1,100
x
3x10

PARA 10 SSC GPS REQUIREMENT 15 15

APPLICABLE

13 B GPS

PARA 11 Len one new things, the cannot cores
if it is too low and have not shells both
in relation of the ~~of~~ eyes of the
cores.

WBS 350 Canyon O-Span; fossils

Page 74 O-Span's record method of sampling shells
and new shells it.



74 Years of engineering of water loss
 coupon test for seal quality, it is CB1

P76 WBS #360 full test
 Again confirm about leak against

P78 full amount of testing very to RLA
 at same price in 10 minutes in 15 min
 system
 Pen need testing for being leak under the 10-5 torr and demand
 Pen need testing for being leak test and included
 P80 Costs for make leak test in the orbit!

P83 No news to the beginning of the day, the flow/cm²
 a 20 pressure in price.

WBS #400 ~~Beginner test~~

Suggest another FOR for the

P1 WBS #410
 Beginner test of lines
 1. Make holes 3 x 1000 100 mm, all
 1. every 100 mm, test on 200 mm, test & include
~~test~~ and test of output
~~test~~ and test of output
~~test~~ and test of output

OS are better and so test - ~~and~~ ~~number~~
 at WBS will be added for the length
 Need a flow chart for the BT
 WBS #420

P2
 P1
 P2



Feed
 myfield
 antibodies

Page 3 The ~~total~~ expansion joint could be
 tested separately for cyclic life. 1 - This will
 count

Page 3 Highway engineers can be measured directly in the
 QT by applying forces hydrogen
 Page 4 will this need be hydrogen test, done by
 CB1

Page 5 The expansion joint tested will be of
 the standard material but not of the same rolling
 process as highway expansion joint. Fatigue, maybe
 a function of the material property

The ~~stress~~ expansion joints are not the same
 - is hydrophobic.

This is not a good test for the expansion joints
 and will overestimate sidewalk test of the expansion
 joints before they are by construction - hydrogen and
 specimens.

Page 9 There are differences in the methods used by
 for the QT as the field notes - the less engineering
~~data~~ more precise means in using and the
 size contents are different.

Page 11 I have made no calculation for the quantity
 variations of using a different in the plane &
 calculate the cost for the type. There is
 also a third concern that the least will
 cost the more

~~But~~ Resurfacing will be water in being considered
 and the outgoing with 5 being the piggyback/area
 the same in QT as getting

Page 12 although CEI must use ~~some~~ extend means to
allow the clean system, the project should explore
an extra vacuum system to measure the clean
system for fire systems and being operations

Page 16 Oigis: Request for extend being speed
in way needed being hole cut after X
simultaneously conditions in the fuel hole include

Page 16 The existing specifications of the piping system
~~is~~ is for hydrogen. 1 + not to make smaller
for notes as on not X measurement the
test results

Page 23 The Oigis includes an copy of the
the hydrogen which comes from the
amount of the would gas at any ~~point~~ a result of
mean numbers

Page 27 a road outline of the GT request
would help ongoing the test

Mining in the GT plan and the GT request
outline - This will need another
FOR the GT (Prel Feas in v13. edit the first and second copy)

GT P Review
Project Test Procedure Review

HMSTAN AND HMSTAN

Staff need more work: - air lock needed
Review for completion of lock needs to be included.



13-782 500 SHEETS, FILLER 5 SQUARE
42-381 50 SHEETS EYE-EASE® 5 SQUARE
42-382 100 SHEETS EYE-EASE® 5 SQUARE
42-389 200 SHEETS EYE-EASE® 5 SQUARE
42-392 100 RECYCLED WHITE 5 SQUARE
42-399 200 RECYCLED WHITE 5 SQUARE
Made in U. S. A.

IN Vol 3

Notes N/A re old calculated in Pub in
report of re sampling

Can't find N/A re Mile steps calc
just want make frequency

~ hrs / volume / filler - noise / report . ps

file:cbi042494.txt

to: L. Jones

from: R. Weiss April 24, 1994

concerning: Further comments on the CBI FDR Documents

MAJOR ISSUES

The Qualification test planning

The planning for the qualification test is fragmented and incomplete, this is not only reflected in the viewgraphs, already commented on, but also in the supporting documentation as well as the DRD #3 FINAL QUALIFICATION TEST PLAN & PROCEDURES (the thinner volume in the backup material). Expect that we will have to have a Qualification Test Procedure Review when CBI has become ready. They are now not ready.

The missing elements are:

- 1) An organization of the flow in the qualification test: steps taken, measurements made, schedule. (There are some beginnings of this in section 2 of DRD #3.)
- 2) A real outline of the qualification test final report.
- 3) An accompanying document indicating the nature of the test for each procedure: full test, partial test with similitude, test with analytic extension, prior heritage.

If CBI gets 1) and 2) into a reasonable state 3) will be a lot easier to write. We may have to have a session similar to the leak hunting one to get them to think coherently about the qualification test.

The test of expansion joints

CBI is not planning to test the expansion joints completely. The joints for the QT will most likely not be made from the same material as the beam tubes as is planned in the construction phase - cold rolled sheet rather than HRAP coil stock. The joints will be mechanically formed rather than hydroformed as they are now expected to be in the construction phase. Finally, there is no life test of the expansion joints planned. Given that the expansion joints are considered moderate risk components, it would be advisable to include a separate program to test the expansion joints for life and leaks before we commit to them.

Communication between groups at CBI

The documentation gives evidence that different parts of CBI are not communicating well with each other. Examples are the documentation for the qualification test is in places inconsistent with that associated with the construction, the leak requirements quoted in different parts of the document are not the same. I am sure Marty knows this but it might be well to say that we notice it too. Would company wide e mail help?

GENERAL COMMENTS

- 1) The overview document would benefit if the references to the backup documents were identified by section and page.

2) Reference to mid station and central station (vertex) are confused in the documentation.

SPECIFIC COMMENTS ABOUT THE FDR DOCUMENTATION

WBS 100 Design Configuration

p10; If 70ft section length is a hard limit from construction experience, this should be mentioned in the presentations.

p26; Realignment of the beam tubes to make up for settlement is urged before bakeout. Not clear that this is in the detailed schedule, first I have heard about this.

p28; Refer to mode shapes of the tube normal modes associated with the listed frequencies. I have not been able to find these in the accompanying detailed reports. Would like these for the stray light analysis.

p32; Grounding of the beamtubes is considered important to reduce the hazard from lightning. This conflicts with the i^2R heating during the bake, can one consider spark gap lightning arresters?

p41; Only transport costs are in cost parametrization, the cost optimization of section length has more factors.

p41; With the asymmetric baffles, the baffle orientation has to be included in the description.

WBS 200 Fabrication

p25; Pathway has not met the requirement for the lower longitudinal spring rate and will have to add convolutions to the expansion joint. When will Pathway produce a sample joint and will this joint be tested in the QT.

p27; Do not understand how the reduced tolerance in axial spring rate affects the differential settlement of the foundation. Suspect some bad English here.

p35; No mention of a chamfer on the stiffening ring edges to avoid galling of the tube surface and consequent difficulty in placement of the ring.

p49; The alternate filler wire cleaning proposed by ESAB was not tested.

WBS 300 Construction Plan

p18; CBI assumes construction will begin at the Washington site first, is this now true?

p25; Not persuaded by the logic of having one of the section leak testing coffins equipped with the time of flight leak location system. It seems better to have all or none include this capability.

p28; What is planned for leak testing the sections that have pumpout T mounted on them. They no longer fit into the coffins? I don't remember discussing this with CBI. It might be best to test them in the coffin before the pumpout is cutout of the tube and then follow with the special leak test of the pumpout hardware.

p39; How does CBI plan to avoid covering possible leaks in the circumferential

welds with vacuum grease at the azimuthal ends of the 190 degree arc circumferential weld leak test box?

p48; Would be interested in knowing the beamtube exposure times contemplated when the clean room is moved, a new section is brought into position for welding and the weld enclosure station is brought into position.

DGPS Appendix

p1; CBI seems to think that we are also interested in a precision angular alignment between sites as well as precision knowledge of the distance between sites. The angular alignment between sites is not critical: 1 degree is sufficient and the distance does not have to be known better than the equivalent of a 1 microsecond delay, 300 meters. The intrasite alignment is the critical part.

p10; Is CBI aware of the equipment that might be available from the SSC.

p13; It is worth finding out if it is possible to use the GPS system through the concrete cover providing it is free of rebar and metal lath at the apex. This could eliminate the radoms.

p74; The description of the coupon hydrogen tests alludes to a second method of accumulation tests but never describes it.

p74; This description in distinction to the viewgraphs leaves no ambiguity about who will do the coupon testing for the QT, it is CBI.

p76; Confusion concerning the requirements on the leak rates.

p78; Leak assessment and localization techniques using the rga are not included in the description of procedures. They are included in the leak detection logic tree diagram. Air leak calibrators have gotten lost in the description.

p78; Possible techniques that would be used to close leaks smaller than 10^{-5} torr liters/sec are not discussed.

p80; Estimated costs for the module leak testing are not included in the descriptions.

p83; No refernce is made to the conditions for cleaning: the temperature, the steam pressure, the flow rate/area

WBS #400 Qualification test

In addition to the global issue mentioned at the beginning, here are specific comments.

p1; Interchange bullets 3 and 2 and reformulate bullet associated with the philosophy of the QT

p2; Is more than one baffle to be put into the tubes for the QT.

p3; Horizontal compliances could be measured by applying forces to the beamtube in the QT. This does not require faith in calculations.

p9; There are differences in the module leak test for the construction and the QT: the leak localization will be done differently and the time constants will be greatly different.

p11; The idea of bringing the current for direct i^2R heating into the tube through a

stiffening ring has to be calculated. The spreading resistance into the tube and the thermal conduction by the input leads has to be analysed. I have not done this.

p11,16; The reason for maintaining the water pumping speed at 600 liters/sec during the bake and after (note this is not required before the bake) is to simulate the water readsorption conditions in the full LIGO, not the outgassing rate of water which has little to do with the pumping speed.

p16; The outgassing specification given here of the pumping system and associated vacuum plumbing is for hydrogen it is much smaller for water.

p23; The outgassing results anticipated include an assay of the hydrocarbons. This is why we are asking for the signals at many amu values.

THINGS FOR LIGO PROJECT TO THINK ABOUT

- 1) A technique to establish the clear aperture directly in the vacuum after external alignment; for example, a direct laser beam translation measurement with a pulsed system to determine the location of the scatterer.
- 2) Is the baffle spreader bar a new source of stray light? (Probably of no consequence)
- 3) Should the LIGO be instrumented with strain gauges to measure the stresses due to settling at critical locations.

MISIMC

INSULATION

A GOOD WRIT

SUMMARY

Need Scientific of the coglines of the supply
tripled camp with

Need Rebuilding of rollers ASME code for
and or forward

General Comments
Much redundant information
also naturally in fact
more in design and sections
for design

On site
off site
file folder
big numbered
items!

32 way in flow a difference in ~~the~~ eyes of 241
~~from~~ ~~making~~

WBS 200 FAR

Selling Pulver 1, 2

How low the ~~of~~ quantities of the Test different
Take fabrication been reviewed

When 1-24 design to not ~~the~~ around at ~~many~~ fabrication
been made - how in the design when the ~~to~~ made in the
make to be needed?

~~the~~ ~~material~~ the coglines of design the ~~material~~ F
around in V6C
English

IF ~~the~~ Take Tee in down 3 also
Shift in 16" → 30" my require another test!

V612 Shows my that it's upon & systems parts

V613, 16 12 the material ~~over~~ for systems parts
24 ~~the~~ ~~around~~ 304L



V62
24

V65
6

V69

V27 - V30 what happened to coffee
reception

V32,33 argued against
Carbon Steel - my recollection H₂ is
around at the weeks

V37 Do not include the reaction on fillers
and - we have now agreed to get fillers
and be used

V40 Filler mix needs have passed the test
has accepted and used filler mix

V41 Saw problem with agents on the
fills mix needs

V44 Must look in the week inspection ~~the~~
techniques - mix is now prepared - (today)
was directed - they sent was directed
V45 Fills is allowed to be spread to
maximum!

~~V46~~ stopping activity
V55 again history in the report the the
learn make. (max)

V57, V58 some information on both VC ?

V59 Filler still manufacturing Filler when
V65 in open Filler when

still see a large minority in

VF 28 Year built not an inner
trapping showed 70% case of H_2O and $H_n C_m O_p$

VC 30 Chgo 24 ~~SP~~ ^{W. Lake} Regent for full test
10-10 gone 10-9 regent
Only present in not a regent

VC 32 Train of Flight in 24 miles built
nearly in rd been dimmed

VC 32 a) LV₂ was ahead for 24 hours
and later being less built before build

VC 34 Don't really divide 24 hours
two rows for less built
as right

VC 36 Steel rails class 250 miles
present of cables bench miles

VC 38
GOS
coming in opposite of 4 epl's but in small engh
to be empty

VC 41 How the divisions and lines not
run 74 5250 on Don amounts



13-782 500 SHEETS, FILLER 5 SQUARE
42-381 50 SHEETS EYE-EASE® 5 SQUARE
42-382 100 SHEETS EYE-EASE® 5 SQUARE
42-389 200 SHEETS EYE-EASE® 5 SQUARE
42-392 100 RECYCLED WHITE 5 SQUARE
42-399 200 RECYCLED WHITE 5 SQUARE
Made in U. S. A.

VG 21 0. not included this weight

VG 24

Ken part of recommended procedure on it

VG 25

FR best in the other procedure as in
the other endpapers.

file:cbi042094.txt
to:Larry Jones
from: R. Weiss April 20, 1994
concerning: CBI FDR viewgarphs

GENERAL COMMENTS

1) Many of the viewgraphs on specific decisions are made confusing by reciting the history toward the decision. It would be better to give the decision and the reasons for the decision.

2) The qualification test and its uses: the listing of whether a particular process or technique is tested directly, tested by similitude, projected by analysis or not tested at all is needed. The presentation on the qualification test is the weakest of the group and needs considerable tightening in its logic and more substance in the presentation.

3) There are decisions that have been made not reflected in the viewgraphs which still leave options opened. In other places, there are options given and no steps described to close the options. These include the following major items:

- a) The decision on the use of weld wire
- b) The decision to reduce the requirements on the allowed leaks
- c) The decision to use the GPS system and eliminate the benchmarks
- d) The criteria where ASME or API standards are to be used.
- e) The fabrication of the tubes whether remote or on site
- f) The decision on where to anneal the steel
- g) How we are going to qualify two tube vendors
- h) How we are going to qualify Tubetec tubes made with different width of steel coils.
- i) Who is going to do the hydrogen outgassing coupon testing for the qualification test

SPECIFIC COMMENTS ON THE VIEWGRAPHS

WBS #100 Design

VG4,8,12,14,15: Optimization of cost vs tube section length is not well developed. VG16 shows cost for transport where are the other parameters. I suspect that the tube length was not determined by a cost minimization but rather by risk assessment and hunch. Furthermore, the discussion later in the presentation on fabricating the tubes at site must be included in such a costing exercise.

VG4 baffles at supports also to minimize baffle motion

VG9 when will CBI decide on the code they will use for the expansion joints:ASME or API

VG13 do not understand the number of baffle stiffeners

VG15,16 A real figure including the change of all the costs with length would be a good way to show if there is an optimization.

VG17,18 confusion of requirement with design conditions to meet requirement on the clear aperture. Not a fatal flaw but a lack of understanding of the meaning of a requirement.

VG17 Bullet under critical parameters "Tube lateral offset due to skewness of ends.

VG19 Need a probability of phasing of the errors, still a sum which is the absolute worst case.

VG22 A table showing the weights of tube, stiffeners, insulation would be useful here.

VG24-29 A cartoon showing the compliance directions and the compliant members in the various type of supports would be useful for a non initiate review panel.

VG32 The approximately 30 inches of stiffener spacing gives the impression that this dimension has not been fixed.

VG37 The lack perpendicularity as 0.010 inches is measured where?

WBS #200 Fabrication

VG2 How is the qualification of different vendors and even same vendor with different coil widths to be carried out

VG5,6 How is the decision of where to anneal the steel going to be made?

VG9 How will Tubetec be qualified for the wider coil width. Assume that the qualification test will be carried out with 16 inch width material.

VG12 Should indicate that the VG refers to the expansion joints

VG13-16 Material for the expansion joints is the annealed 304L steel.

VG27-30 The baffle serrations have been neglected.

VG32-33 Another reason for the choice of 304L for the stiffeners is the chance of hydrogen contamination from the cold rolled getting into the welds and into beamtube material.

VG37-41 Filler wire is allowed.

VG44 Decision at PDR was to use visual inspection. Radiography and eddy current techniques are rejected.

VG45 Filler wire can be used on vacuum side of welds

VG55 Bad case of obscuring decision by historical presentation

VG59 Filler wire again

VG65 Repair will almost certainly involve filler wire

VG66 Item c. means nothing, what are non quality welds?

VG68 Chill plate used in repair seems difficult to imagine when a repair has to be done a goodly distance from a tube end after the tube has been assembled.

VG70 The first mention of a Quality Assurance Manual in the presentation. What is it? What is its format? Who uses it?

WBS #300 Construction

VG4 Again a historical presentation. The decision is to use GPS without monuments

VG6 Viewgraph does not reflect decision to relax the leak requirement

VG12 Integration of LIGO, CBI and A&E contractor will be an issue here.

VG19 Bake out is a CBI responsibility also the final acceptance takes place after the leak assay after the bakeout.

VG24 If tube fabrication at site is the preferred option, it should be costed and put into the parametric cost analysis for tube length. Furthermore, are both the tube fabrication vendors able to accommodate on site fabrication?

VG28 Last bullet not an issue. Coupon testing is protected from hydrocarbons and water by LN2 traps at the rga.

VG30 Change the leak requirements. The operating pressure is a derived requirement not a primary one.

VG32,33 The time of flight technique applied to the section tests is like a medusa with six heads.

The LN2 traps are used for the bakeout and to improve conditions for leak detection prior to bake.

VG34 Do better using the decision tree than to show this not informative viewgraph.

VG36 Again the monuments at 250 meters, is the GPS system to be adopted?

VG38 Statement that GPS is independent of the length will be challenged. It does depend on length but the dependence is small relative to the other absolute and random errors.

VG41 Has no dimensions and also does not show the monuments at 250 meters if they are still to be used. Part of the confusion associated with alignment in the presentation.

VG45,46 History is getting in the way of the presentation.

WBS #400 Qualification Test

Least well organized section with little real content.

VG4 Coupon outgassing measurements done by LIGO or CBI?

VG3-10 Not a logical order and conveys little hard information. In these charts it would be good to lay out the philosophy of the qualification test: what is measured and tested directly, what is measured and tested by similarity and what will be modeled.

VG13 Did not realize that CBI will use a reinforced flat end cap rather than a

dished head. Has CBI done the deflection analysis for the end cap?

VG14 Bullet at bottom on the water outgassing makes no sense.

VG14-16 The rationale for the vacuum tests is also in VG24, these two VG and 24 should be combined and beefed up with more substance.

VG20 We have not put a restriction on the pumping speed prior to the bake. CBI may want to use all the pumping capacity they have during initial leak hunting and shake down of the qualification test. The restriction for the 600 liters/sec for water is intended to simulate the conditions during the bake and after in the actual 2km beam tube modules.

VG21 Do not understand the point of this VG

VG25 I²R heating is the decided method, there is no other option.

VG25,26,27 Are place holders for information

From ljones@ligo.caltech.edu Fri Apr 22 13:16:55 1994
Received: from ligo (ligo.caltech.edu) by tristan.mit.edu AA28254; Fri, 22 Apr 94 13:16:53 EDT
Received: from polecat.ligo.caltech.edu by ligo (4.1/SMI-4.1) id AA08695; Fri, 22 Apr 94 10:16:40 PDT
Received: by polecat.ligo.caltech.edu (4.1/SMI-4.1) id AA17119; Fri, 22 Apr 94 10:16:39 PDT
Date: Fri, 22 Apr 94 10:16:39 PDT
From: ljones@ligo.caltech.edu (Larry Jones)
Message-Id: <9404221716.AA17119@polecat.ligo.caltech.edu>
To: weiss
Subject: Re: comments on CBI viewgraphs
Cc: ljones@ligo.caltech.edu
Status: R

Items of clarification, FYI. For the items that I've ignored, I have no additional information to assist your understanding. Please feel free to bring up any issue you desire during the FDR.

3)c) Benchmarks apparently are not eliminated; we may need them for the slab work, besides.

3)g) There is no current plan to qualify two tube suppliers. If the first one chosen falls, that becomes a new issue.

3)h) Current plan is prepared for the worst: 16" wide skelp. We're not sure that we want to go wider.

3)i) Caltech will perform the real time coupon tests on the QT coils (3). CBI will perform confirming tests as their equipment becomes qualified.

WBS 100

VG13 These baffle stiffeners are similar to the heavy rings used at the supports, and are needed at the baffles positioned between supports (i.e., two thirds of those between 100 m & 250 m from the ends of each module at Hanford). This removes the element of tube out-of-roundness from contributing to required tube diameter.

WBS 200

VG5,6 It's been made for the QT: Metlab. It will probably stay that way for the Option unless costs change materially.

VG27-30 No serrations for now.

VG68 Chill plate seems to me to be a valid plan element. Why do you feel that it is not?

VG70 The Quality Assurance Manual is basically a standard manual used by CBI for ASME code construction; it has been reviewed by Bill Tyler, QA team support from JPL. It is incorporated in their plans and procedures by reference. I have a copy if you would like to review it (approx. 3/4" thick).

WBS 300

VG41 I believe that this is intended to represent GPS usage for site-wide positioning purposes (buildings, slabs).

WBS400

VG13 Flat end cap is a new plan. The ribs look good (gut-wise) to me, and CBI has done a lot of this in past jobs. We're concerned about sequence of assembly to prevent distortion fitup problems, and CBI will probably tack things together first and then weld in place. I've suggested making the collar around the ribs wider (assuming I2R heating) to allow current stabilization and a good end insulation pocket.

VG14 I assume that you're referring to the 1E-16 desired rate for water: this comes from our Spec 1100007 scope statement, and aids planning the equipment and procedure for measurement. Am I missing something?

VG21 This is the first page of a three page Index (as an example) to walk those interested through the details of the procedures required for the QT process. The other pages are in the backup material (Section 5) and the procedures are in the QT Plan & Procedures folder and Book One of the Detailed Design folders.

VG25 Unfortunately, we haven't reached this point yet. The PDR recommendation was to have CBI consider baking with I2R during the QT. They have done that, recently giving us a proposal of \$70K for that revision. We are now in a discussion stage, and will likely sign on for a change for somewhat less cost.

Larry

II. BEAM TUBE MODULE DESIGN

A. Overview of General Requirements

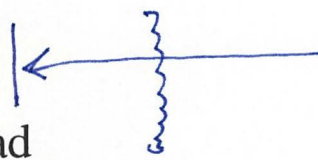
B. Summary of Beam Tube Module Configuration

- | | | |
|----|----------------------------|-----|
| 1. | Module General Plans | RJW |
| 2. | Expansion Joint | RJW |
| 3. | Tube Section Lengths | WJC |
| 4. | Tube Diameter | WJC |
| 5. | Tube Supports | WJC |
| 6. | Tube Stiffeners | WJC |
| 7. | Pump Ports | RJW |
| 8. | Tube Termination Interface | RJW |
| 9. | Foundation Loads | RJW |

BEAM TUBE MODULE DESIGN GENERAL REQUIREMENTS

Structural / Mechanical / Thermal Requirements

- Beam tube to be designed for full vacuum
- Design loads per ASCE 7-88, Uniform Building Code and Standard Building Code

- Snow Load
 - Wind Load
 - Seismic Load
- while under construction*
- 

- Expansion joints designed for cyclic loading per EJMA
- Thermal loads for daily variations
- Thermal loads for 20 bakeouts of 30 day duration at 284°F
140°C

check this #

$$\begin{array}{r}
 284 \\
 32 \\
 \hline
 252 \\
 5 \\
 \hline
 9 \overline{) 12360} \\
 \underline{140}
 \end{array}$$

Clear Aperture

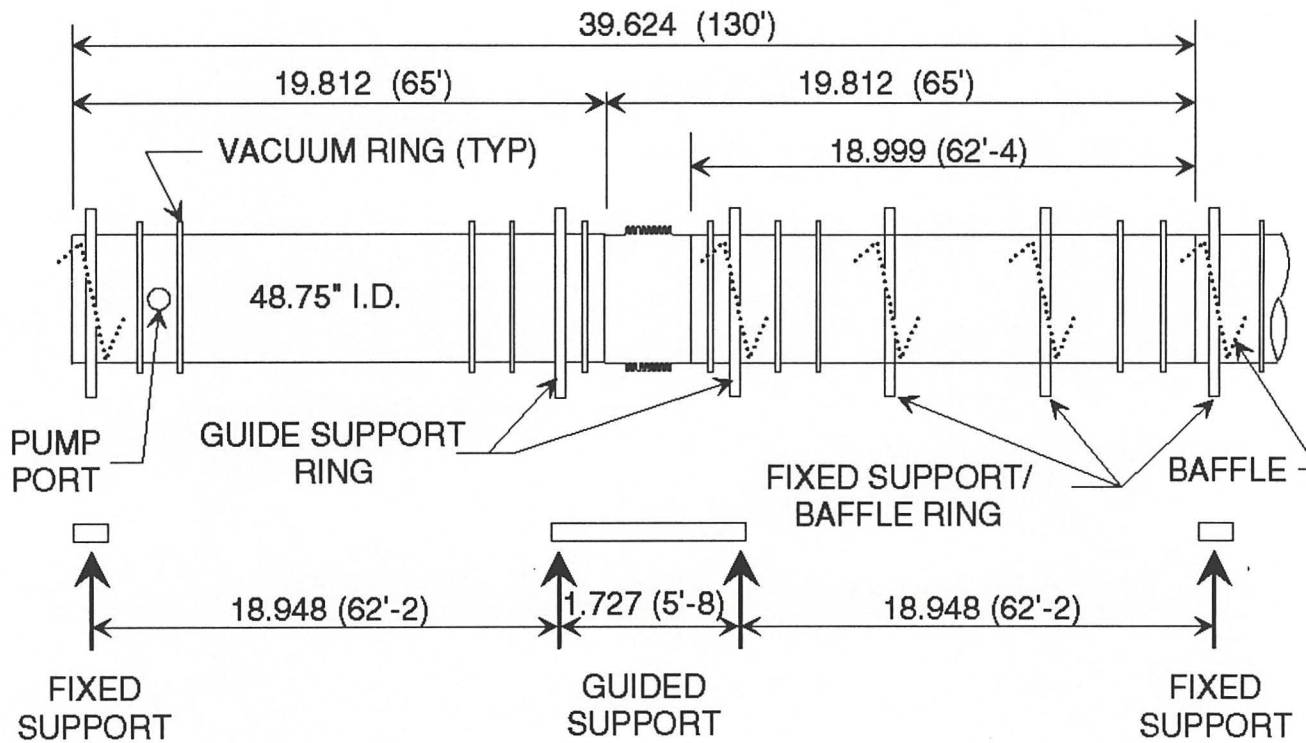
- Furnish a clear aperture of 1.07 meters between reference monuments spaced at 250 meter intervals
- Provide a method for aligning/adjusting the tubes to obtain the aperture

II.B BEAM TUBE MODULE CONFIGURATION

1.	MODULE GENERAL PLANS	RJW
2.	EXPANSION JOINT	RJW
3.	BEAM TUBE SECTION LENGTH	WJC
4.	BEAM TUBE DIAMETER	WJC
5.	TUBE SUPPORTS	WJC
6.	TUBE STIFFENERS	WJC
7.	PUMP PORTS	RJW
8.	BEAM TUBE TERMINATION INTERFACE	RJW
9.	FOUNDATION LOADS	RJW

Need know sigl #
weight of the beam +
tube stuffing in

7.52



BEAM TUBE / EXPANSION JOINT CONFIGURATION (392 REQUIRED)

DETAILED DRAWINGS ARE LOCATED AT THE END OF WBS 100
(CONFIGURATION #3)

changed

BEAM TUBE MODULE CONFIGURATION

IMPACT OF COMPONENTS ON FINAL CONFIGURATION

- OPTIMUM BEAM TUBE LENGTH 65' (19.812 m)
- BAFFLE SPACING PER SPECIFICATION; 65'-7 1/2 (20.0 m)
- LOCATE BAFFLES AT SUPPORTS TO MINIMIZE BEAM TUBE DIAMETER
- USE 65' SPACING FOR BEAM TUBES, BAFFLES, AND SUPPORTS
- USE MULTIPLE OF 65' SPACING FOR EXPANSION JOINTS

*How optimized **

*also to reduce motion baffle **

How my nutty

QCB

BEAM TUBE MODULE CONFIGURATION

EXPANSION JOINT FUNCTIONAL REQUIREMENTS

MAINTAIN THE VACUUM ENVELOPE

- HIGH VACUUM LEVEL
- MAINTAIN LEAK TIGHTNESS THROUGHOUT THE DESIGN LIFE

ACCOMMODATE THERMAL GROWTH & SHRINKAGE

- **OPERATING:** (CONFIGURATION #3)
0.43" (10.9 mm) EXPANSION JOINT COMPRESSION
1.21" (30.7 mm) EXPANSION JOINT EXTENSION
- **BAKE OUT** (302° F - 150° C):
3.26" (82.8 mm) EXPANSION JOINT COMPRESSION
- **CONSTRUCTION**
± 0.25" (82.8 mm) AXIAL
± 0.13 DEGREES ROTATION

PROVIDE FLEXIBILITY FOR DIFFERENTIAL SETTLEMENT & ALIGNMENT

- 0.20 DEGREES OF ROTATION
- EXPANSION JOINTS ACT STRUCTURALLY LIKE A PIN

5
What annual
P or α
if

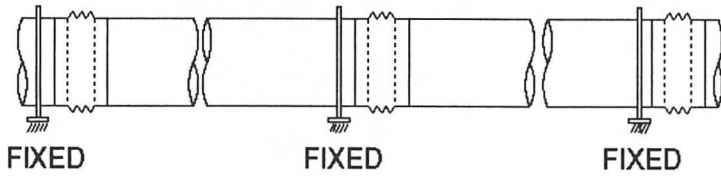
$L = 2 \times 10^{-5} / \Delta T$

39 miles
spring

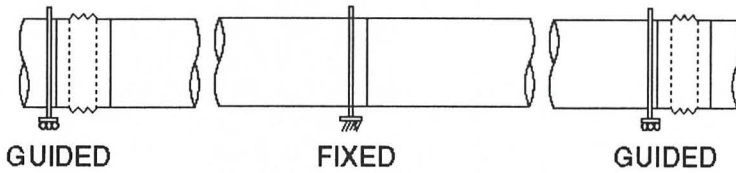
WHAT DOES
THIS MEAN?



SIX BEAM TUBE CONFIGURATIONS

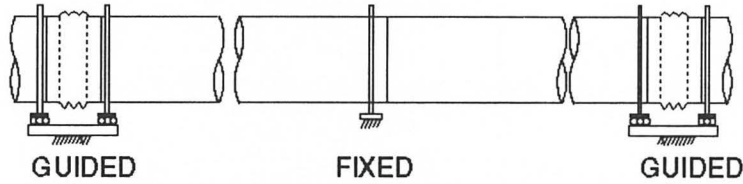


CONFIGURATION 1
EXPANSION JOINT
SPACING: 67'-8 (20.625)

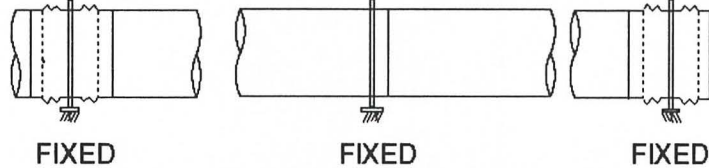


CONFIGURATION 2
EXPANSION JOINT
SPACING: 130' (39.624)

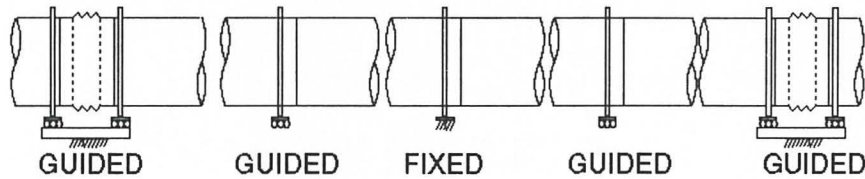
chosen configuration →



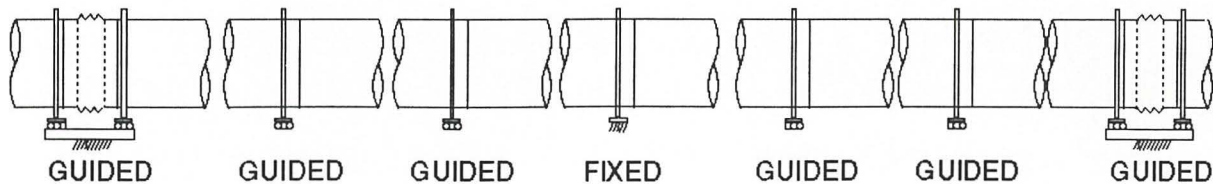
CONFIGURATION 3
EXPANSION JOINT
SPACING: 130' (39.624)



CONFIGURATION 4
EXPANSION JOINT
SPACING: 130' (39.624)



CONFIGURATION 5
EXPANSION JOINT
SPACING: 260' (79.248)



CONFIGURATION 6
EXPANSION JOINT
SPACING: 390' (118.87)

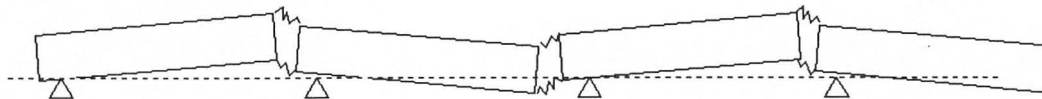
BEAM TUBE MODULE CONFIGURATION

SELECTING BEAM TUBE CONFIGURATION

DCBI
Justin:
Is it now assumed
that the shear
load is not
supported by the
expansion joint

CONFIGURATIONS 1, 2 AND 4

- UNGUIDED EXPANSION JOINT VIOLATES EJMA & B31.3
- NOT RECOMMENDED BY FABRICATORS & CONSULTANT
- ADDITION FUNCTIONS IMPOSE SIGNIFICANT FAILURE RISK
 - BECOMES A STRUCTURAL ELEMENT
 - MUST PROVIDE STABILITY
 - MUST SUPPORT TUBE IN SHEAR
 - MOVEMENTS, QUANTITY & MAGNITUDE CAN NOT BE PREDICTED (REQUIRED TO DETERMINE EXPANSION JOINT LIFE)



- CONFIGURATIONS CAUSES UNACCEPTABLE EXPANSION JOINT BEHAVIOR

QCB1

BEAM TUBE MODULE CONFIGURATION

SELECTING BEAM TUBE CONFIGURATION

How is this
substantiated

CONFIGURATION 6; EXPANSION JOINT SPACING OF 390' (118.87m)

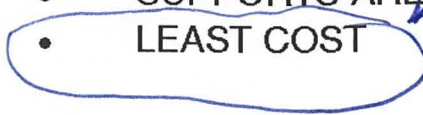
- AXIAL MOVEMENT DURING BAKE OUT IS 9.78" (248 mm)
- TO ACCOMMODATE MOVEMENT, EXPANSION JOINT BECOMES TOO LONG AND UNSTABLE.
- CAN NOT DESIGN GUIDE SUPPORTS FOR THIS MOVEMENT
- CONFIGURATION IS UNACCEPTABLE

CONFIGURATION 5; EXPANSION JOINT SPACING OF 260' (79.248m)

- AXIAL MOVEMENT DURING BAKE OUT IS 6.52" (166 mm)
- BEAM TUBE BECOMES DIFFICULT TO ALIGN, ACCEPTABLE DIFFERENTIAL SETTLEMENT IS REDUCED
- CAN NOT DESIGN GUIDE SUPPORTS FOR THIS MOVEMENT
- CONFIGURATION IS UNACCEPTABLE

CONFIGURATION 3; EXPANSION JOINT SPACING OF 130' (39.624m)

- AXIAL MOVEMENT DURING BAKE OUT IS 3.26" (82.8 mm)
- SUFFICIENT FLEXIBILITY FOR ALIGNMENT AND DIFFERENTIAL SETTLEMENT
- SUPPORTS ARE FEASIBLE
- LEAST COST



∞

BEAM TUBE MODULE CONFIGURATION

EXPANSION JOINT AXIAL SPRING RATES

USE
ASME OR
API FOR
LIGO DESIGN

LIMIT OF AXIAL SPRING RATE

- AN AXIAL SPRING RATE OF 8000 LBS/IN IS SPECIFIED
- LIMIT MAXIMUM AXIAL SPRING RATE TO +20% (9600 LBS/IN)
- LIMIT MAXIMUM VARIATION TO $\pm 10\%$ OF THE AVERAGE SPRING RATE

HOW THE LIMITS ARE DERIVED

- ASME BASES THE HOOP ALLOWABLE ON A LONGITUDINAL LOAD EQUAL TO THE PRESSURE ACTING ON THE ENDS OF THE CYLINDER
 - 27,500 LBS OF AXIAL FORCE *Pure axial*
 - 8400 LBS/IN SPRING RATE
- PER API BULLETIN 2U, AXIAL STRESS IS ACCOUNTED FOR
 - 32,800 LBS OF AXIAL FORCE
 - 10060 LBS/IN SPRING RATE

6
A =
 $\pi (24)^2$
4896
57
1.7
1.8 x 10³
1.5 x 10⁴
2.7 x 10⁴

BEAM TUBE MODULE CONFIGURATION

EFFECT OF EXPANSION JOINT SPRING RATES

BEAM TUBE STRESSES

- **BAKE OUT**
 - 1533 PSI COMPRESSION STRESS, 27 % OF CAPACITY
 - 2295 PSI BENDING STRESS, 39% OF CAPACITY, (DL + INSUL.)
 - 2072 PSI, 35% OF CAPACITY REMAINS FOR DIFFERENTIAL SETTLEMENT (0.579")
- **OPERATING CONDITION**
 - 69 PSI COMPRESSION STRESS, 1 % OF CAPACITY
 - 2251 PSI BENDING STRESS, 38% OF CAPACITY, (DL + INSUL.)
 - 3580 PSI, 61% OF CAPACITY REMAINS FOR DIFFERENTIAL SETTLEMENT (1.012")

New Vinyals

BEAM TUBE MODULE CONFIGURATION

EFFECT OF EXPANSION JOINT SPRING RATES

EFFECT OF SPRING RATE ON SUPPORTS (AXIAL LOAD)

- BAKE OUT
- ~~5959~~ 6730 LBS DUE TO $\pm 10\%$ SPRING RATE VARIATION
- NOTE: IF SPRING RATE VARIES BY $\pm 20\%$, THE AXIAL LOAD INCREASES TO 11,930 (INCREASES 5200 LBS)

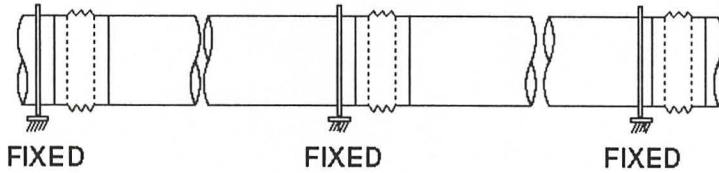
- OPERATING CONDITION -
- 771 LBS DUE TO $\pm 10\%$ SPRING RATE VARIATION

- SEISMIC LOAD
- 8900 LBS

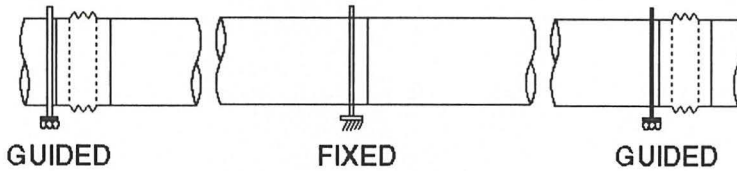
- IF THE SPRING RATE VARIATION IS HELD TO $\pm 10\%$
- ~~5959~~ 6730 LBS DURING BAKE OUT
- 6680 LBS = $8900/1.33$, (1.33 ALLOWABLE STRESS INCREASE)
- THE EXPANSION JOINT FORCE DURING BAKE OUT DOES NOT INFLUENCE THE DESIGN OF THE SUPPORTS OR FOUNDATION.

- IF THE SPRING RATE VARIATION IS LARGER THAN $\pm 10\%$
- THE EXPANSION JOINTS INFLUENCE THE DESIGN OF THE SUPPORTS AND FOUNDATION

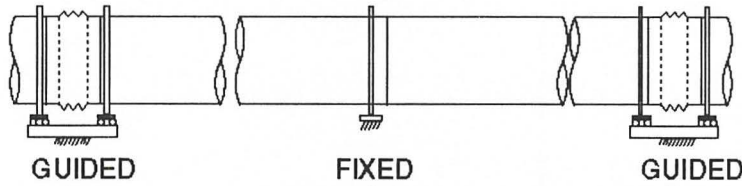
SUMMARIZING



CONFIGURATION 1
UNGUIDED - NOT RECOMMENDED

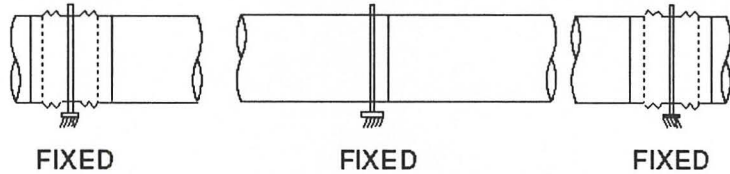


CONFIGURATION 2
UNGUIDED - NOT RECOMMENDED

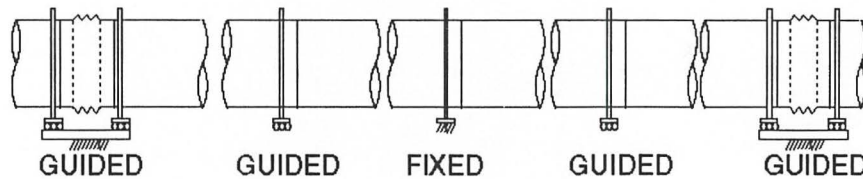


CONFIGURATION 3
MEETS PERFORMANCE REQUIREMENTS & IS LEAST COST

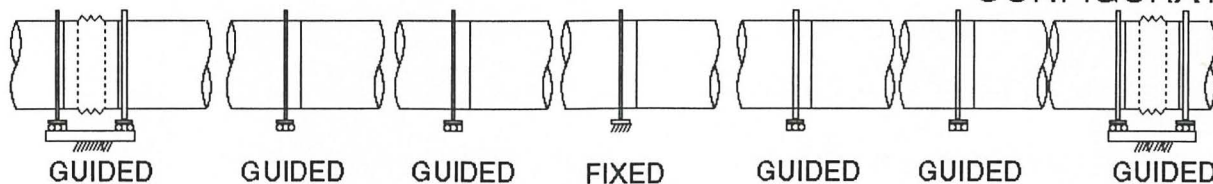
How do they know



CONFIGURATION 4
UNGUIDED - NOT RECOMMENDED



CONFIGURATION 5
BEYOND LIMITATIONS OF GUIDES



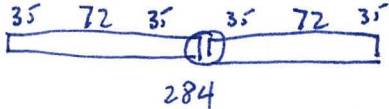
CONFIGURATION 6
BEYOND LIMITATIONS OF GUIDE & EXPANSION JOINTS

21 miles

7 Fint. 250

BEAM TUBE MODULE CONFIGURATION

SUMMARY OF BEAM TUBE COMPONENTS



ScBI
check then
#

Component Item	Total Quantities @		
	Hanford, WA Site	Livingston LA Site	Both Sites
Beam Tubes, 65'-0"	196	196	392
Beam Tubes, 62'-4"	196	196	392
Beam Tubes, Ends	8	8	16
Expansion Joints	200	200	400
Supports, Fixed	196	196	392
Supports, Guided	200	200	400
Support Rings	596	596	1,192
Baffle Stiffeners	128	64	192
Beam Tube Vacuum Stiffeners	9,712	9,840	19,552
Vacuum Ports	28	28	56

13

check
21 miles
7 miles

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SECTION LENGTH

Requirements

- Tube sections must be leak tested and dimensionally inspected prior to installation
- Tube sections must satisfy design code requirements for applicable loads and load combinations

Considerations

- Length of beam tube sections must not impose dimensional tolerance requirements which are difficult to meet
- Length of the beam tube sections should not be so great as to affect efficient fabrication, transportation, handling, testing and construction

Meconium
Sutars
14

BEAM TUBE MODULE CONFIGURATION BEAM TUBE SECTION LENGTH

*Curve of Cost
required*

Selected Length

- Two different lengths of beam tube, 65'-0" and 62'-4", based upon tube/expansion joint configuration
- Maximum tube section length of 65'-0" selected:
 - Permits baffles to be located at points of support having a controlled diameter, preventing tube dimensional tolerances and deflections from adding to the tube diameter
 - Allows sufficient allowable stress "reserve" in the beam tube that is available to withstand differential settlement
 - "Manageable" length for fabrication, handling and installation
 - Transportation costs for tube sections longer than 65' increase considerably due to a \$1.15 per mile premium to provide escort vehicles for trucks
- Tube section length of 62'-4" selected:
 - Length of tube/expansion joint assembly ~~will~~ be 65'-0"; providing a consistent length for leak testing *IN FIG*

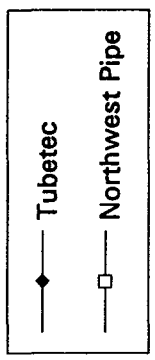
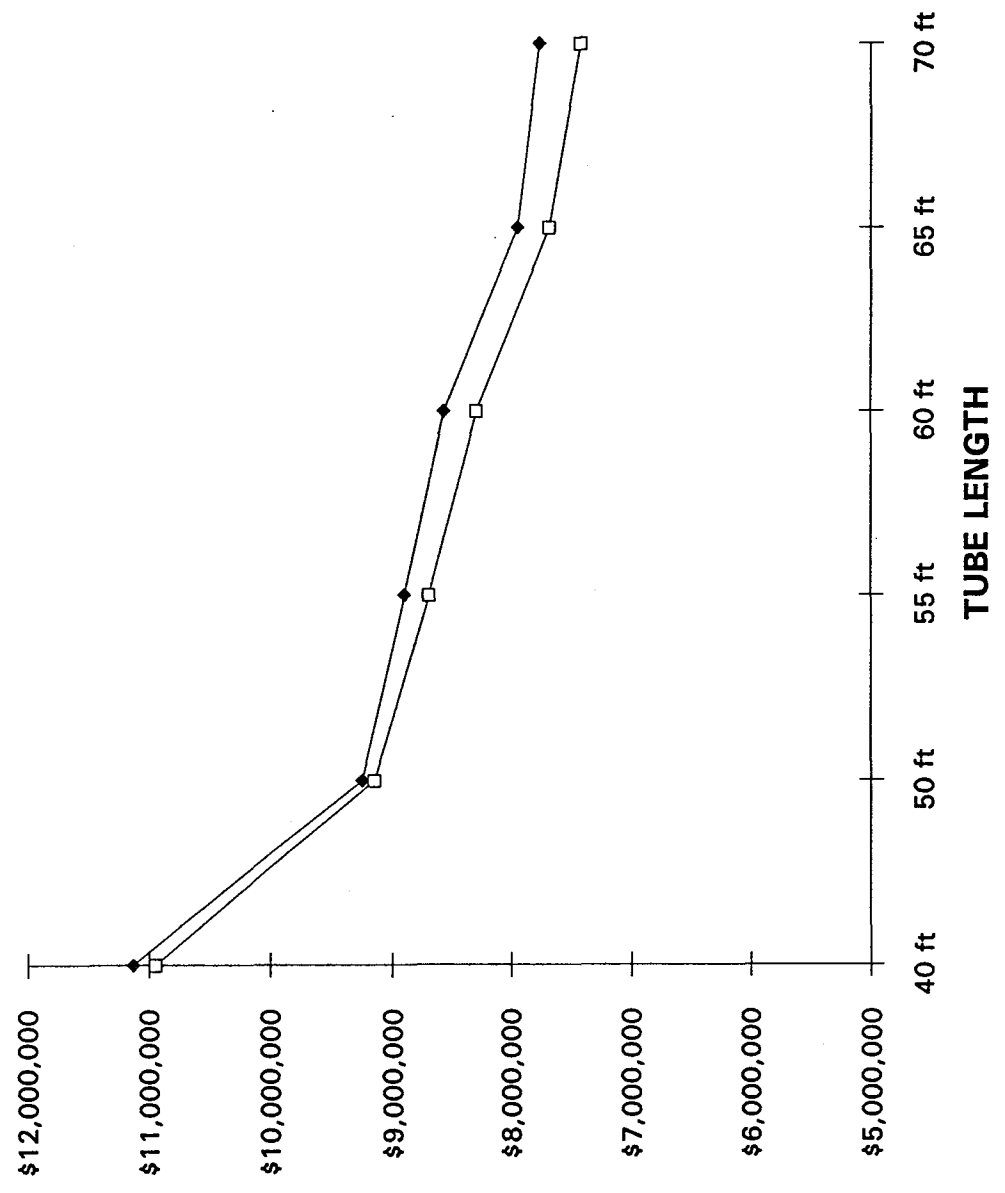
*Support pts
are at baffles*

Products are many

LIGO COST SUMMARY - TUBE LENGTH IMPACT										
KHF 4/26/84	COST PER TRUCKLOAD							PER EXP. BELOW		
	SANFORD FL. TO LIVINGSTON, LA.			MILEAGE = 657	# TUBES	# LOADS	AVG. COST	# REQ'D PER SITE	EXT. COST	INSTL'D. COST \$3,000.00
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE					
40	\$915.30	\$886.95		\$901.13	\$1.37	X 500	125	\$112,641	325	\$1,850,000
50	\$915.30	\$886.95		\$901.13	\$1.37	X 440	110	\$99,124	260	\$1,560,000
55	\$1,290.00	\$1,162.85		\$1,221.33	\$1.86	X 436	108	\$133,235	236	\$1,418,182
60	\$1,520.00	\$1,349.75	\$1,365.00	\$1,411.58	\$2.15	433	108	\$152,822	217	\$1,300,000
65	\$1,520.00	\$1,349.75	\$1,569.00	\$1,479.58	\$2.25	400	100	\$147,958	200	\$1,200,000
70	add \$1.15/mile for escort			\$2,235.13	\$3.40	372	93	\$207,867	186	\$1,114,286
	SANFORD FL. TO HANFORD WA.			MILEAGE = 2895					PER SUPPORT \$3,800.00	
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE				INSTL'D. COST	\$3,800.00
40	\$3,735.00	\$3,908.25		\$3,821.63	\$1.32	500	125	\$477,703	644	\$4,890,600
50	\$3,735.00	\$3,908.25		\$3,821.63	\$1.32	440	110	\$420,378	515	\$3,912,480
55	\$5,711.00	\$4,447.75		\$5,079.38	\$1.75	436	108	\$554,114	468	\$3,556,800
60	\$6,295.00	\$5,466.25	\$6,047.00	\$5,936.08	\$2.05	433	108	\$643,076	429	\$3,260,400
65	\$6,295.00	\$5,466.25	\$6,950.00	\$6,237.08	\$2.15	400	100	\$623,708	396	\$3,009,600
70	add \$1.15/mile for escort			\$9,566.33	\$3.30	372	93	\$889,669	368	\$2,794,629
	PORTLAND OR. TO HANFORD WA.			MILEAGE = 227					PER TUBE INST. \$1,500.00	
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE				INSTL'D. COST	\$1,500.00
40	\$650.00	\$272.40		\$481.20	\$2.03	500	125	\$57,850	499	\$1,497,000
50	\$650.00	\$272.40		\$481.20	\$2.03	440	110	\$50,732	439	\$1,317,000
55	\$790.00	\$429.15		\$609.58	\$2.69	436	108	\$66,489	435	\$1,306,091
60	\$790.00	\$497.25	\$775.00	\$687.42	\$3.03	433	108	\$74,470	432	\$1,297,000
65	\$790.00	\$497.25	\$895.00	\$727.42	\$3.20	400	100	\$72,742	399	\$1,197,000
(over 65 ft)	add \$1.15/mile for escort			\$988.47	\$4.35	372	93	\$91,927	371	\$1,113,000
	PORTLAND OR. TO LIVINGSTON LA.			MILEAGE = 2420					PER LEAK TEST \$2,200.00	
LENGTH IN FT.	CO. "A"	CO. "B"	CO. "C"	AVERAGE	COST/MILE				INSTL'D. COST	\$2,200.00
40	\$2,662.70	\$2,904.00		\$2,783.35	\$1.15	500	125	\$347,919	501	\$2,204,400
50	\$3,780.00	\$2,904.00		\$3,332.00	\$1.38	440	110	\$368,520	441	\$1,940,400
55	\$4,078.00	\$3,617.00		\$3,847.50	\$1.59	436	108	\$419,727	437	\$1,824,400
60	\$4,205.00	\$3,980.00	\$4,105.00	\$4,086.67	\$1.69	433	108	\$443,806	434	\$1,911,067
65	\$4,205.00	\$3,880.00	\$4,721.00	\$4,302.00	\$1.78	400	100	\$430,200	401	\$1,764,400
(over 65 ft)	add \$1.15/mile for escort			\$7,085.00	\$2.93	372	93	\$658,905	373	\$1,641,200
TOTAL COST-SPLIT SUPPLIERS										
		40'	50'	55'	60'	65'	70'			
SANFORD/LIVINGSTON		\$112,641	\$99,124	\$133,235	\$152,822	\$147,958	\$207,867			
PORTLAND/HANFORD		\$57,850	\$50,732	\$66,489	\$74,470	\$72,742	\$91,927			
	FREIGHT	\$170,291	\$149,856	\$199,735	\$227,392	\$220,700	\$299,795			
	BELLOWS	\$1,950,000	\$1,560,000	\$1,418,182	\$1,300,000	\$1,200,000	\$1,114,286			
	SUPPORTS	\$4,890,600	\$3,912,480	\$3,556,800	\$3,260,400	\$3,009,600	\$2,794,629			
	TUBE INSTALL	\$1,497,000	\$1,317,000	\$1,306,091	\$1,297,000	\$1,197,000	\$1,113,000			
	LEAK TEST	\$2,204,400	\$1,940,400	\$1,824,400	\$1,911,067	\$1,764,400	\$1,641,200			
COST SUMMARIES		\$10,712,291	\$8,879,736	\$8,405,207	\$7,995,858	\$7,391,700	\$6,962,909			
TOTAL COST- TUBETECH										
SANFORD/LIVINGSTON		\$112,641	\$99,124	\$133,235	\$152,822	\$147,958	\$207,867			
SANFORD/HANFORD		\$477,703	\$420,378	\$554,114	\$643,076	\$623,708	\$889,669			
	FREIGHT	\$590,344	\$519,503	\$687,349	\$795,887	\$771,687	\$1,097,538			
	BELLOWS	\$1,950,000	\$1,560,000	\$1,418,182	\$1,300,000	\$1,200,000	\$1,114,286			
	SUPPORTS	\$4,890,600	\$3,912,480	\$3,556,800	\$3,260,400	\$3,009,600	\$2,794,629			
	TUBE INSTALL	\$1,497,000	\$1,317,000	\$1,306,091	\$1,297,000	\$1,197,000	\$1,113,000			
	LEAK TEST	\$2,204,400	\$1,940,400	\$1,824,400	\$1,911,067	\$1,764,400	\$1,641,200			
COST SUMMARIES		\$11,132,344	\$9,249,383	\$8,892,822	\$8,564,464	\$7,942,667	\$7,760,651			
TOTAL COST - NORTHWEST PIPE										
PORTLAND/HANFORD		\$57,850	\$50,732	\$66,489	\$74,470	\$72,742	\$91,927	note: tubing material & mfg cost not included		
PORTLAND/ LIVINGSTON		\$347,919	\$366,520	\$419,727	\$443,806	\$430,200	\$658,905			
	FREIGHT	\$405,569	\$417,252	\$486,226	\$518,276	\$502,942	\$760,832			
	BELLOWS	\$1,950,000	\$1,560,000	\$1,418,182	\$1,300,000	\$1,200,000	\$1,114,286			
	SUPPORTS	\$4,890,600	\$3,912,480	\$3,556,800	\$3,260,400	\$3,009,600	\$2,794,629			
	TUBE INSTALL	\$1,497,000	\$1,317,000	\$1,306,091	\$1,297,000	\$1,197,000	\$1,113,000			
	LEAK TEST	\$2,204,400	\$1,940,400	\$1,824,400	\$1,911,067	\$1,764,400	\$1,641,200			
COST SUMMARIES		\$10,947,569	\$9,147,132	\$8,691,699	\$8,286,742	\$7,673,942	\$7,413,947			

**EST'D COST OF EXP'N JTS, SUPPORTS,
TUBE INSTALL'N, LEAK TESTING &
TRANSPORT**

TUBE LENGTH VS RELATIVE COST

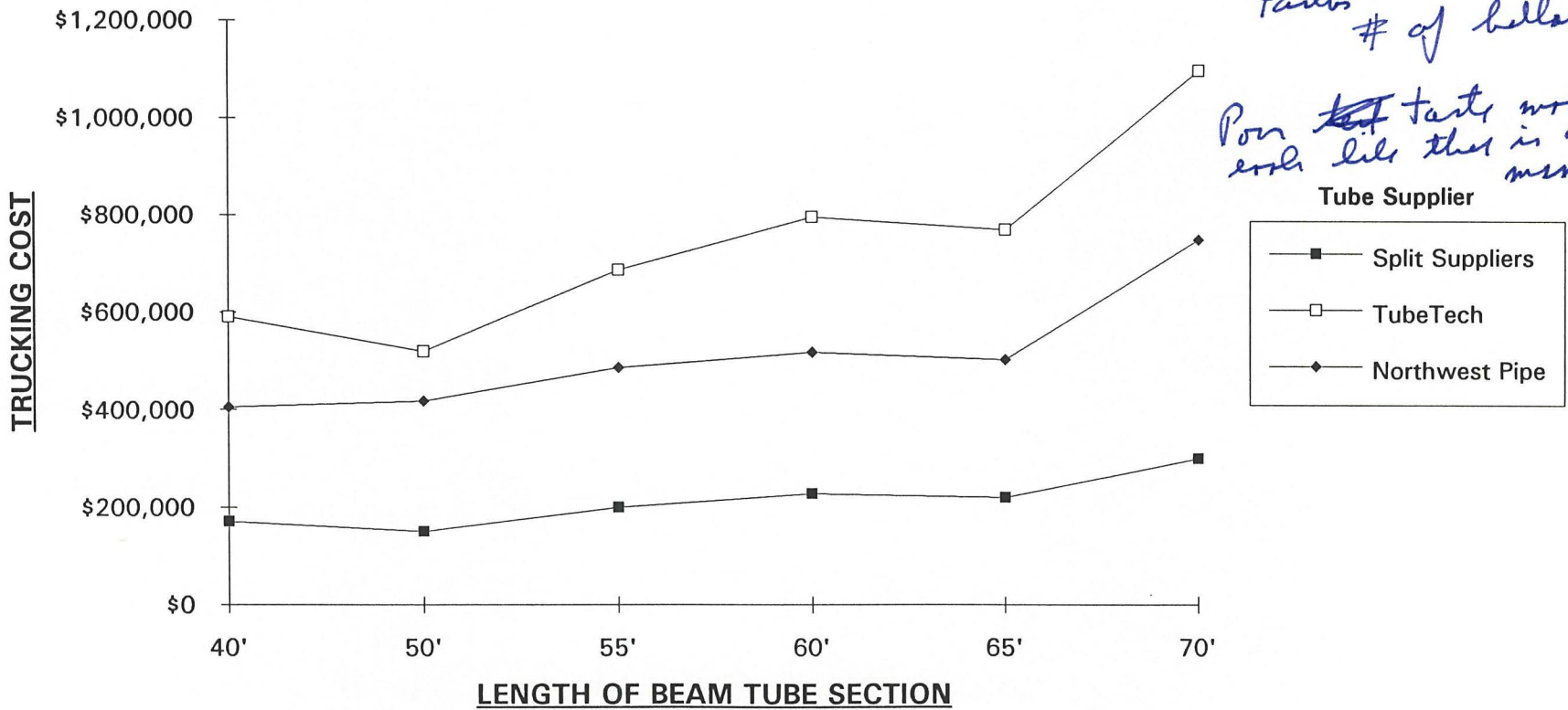


~~FFD~~
if there is no
cost of length
but as a risk
reducing this is
OK

In this all
there is in the
tube length
parameters
Does it truly
cut down
Factor
of bellows

Poor ~~but~~ tube makes it
early like that is a cost
management

LIGO PROJECT TRUCKING COST SUMMARY



BEAM TUBE MODULE CONFIGURATION BEAM TUBE DIAMETER

Requirements

- Provide a 1.07 meter clear aperture between monuments with a 250 meter spacing
- Identify and quantify all tolerances and displacements which influence the determination of the beam tube diameter

Critical Parameters

- Minimize the tube diameter while providing sufficient and accurate allowances for the following factors:
 - Required radius of clear aperture
 - Baffle radial projection
 - Baffle radial projection tolerance
 - Tube radius tolerance
 - Tube-to-support ring fitup gap
 - Support ring outside radius tolerance
 - Tube lateral offset due to end perpendicularity
 - Deflection of the beam tube
 - "Swing" of guided supports due to thermal effects
 - Support adjustment tolerance
 - Surveying accuracy tolerance
 - Out-of-straightness of the beam tube

*lack of perpendicularity
} what does this mean?*

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE DIAMETER

Only Requirement is the clear aperture

Printers of tube is a derived requirement

Required Diameter

- ~~Required~~ Inside diameter of $48\frac{3}{4}$ " is required in order to provide the clear aperture of 1.07 meters (42.13")
- Required I.D. obtained assuming a "worst case" situation of all the maximum tolerances occurring simultaneously to affect aperture

PARAMETERS AFFECTING BEAM TUBE DIAMETER

	Parameter Description	Parameter Value	Parameter Stackup, Baffle Spacing of		
			21 meters, nominal	6 meters, nominal	
	Required Clear Aperture Radius	21.065 in	21.065 in	21.065 in	←-----
Fabrication	Baffle Radial Projection	2.360 in	2.360 in	2.360 in	←-----
	Baffle Radial Proj'n Tolerance	0.080 in	0.080 in	0.080 in	
	Tube Inside Radius Tolerance	0.075 in	0.075 in	0.075 in	
	Tube-to-Support Ring Fitup Gap	0.010 in	0.010 in	0.010 in	
	Support Ring Outside Radius Tolerance	0.010 in	0.010 in	0.010 in	
	Beam Tube Out-of-Straightness	0.100 in	---	0.100 in	
Construction	Tube Lateral Offset	0.160 in	0.160 in	0.160 in	
Operation	Deflection of Beam Tube	0.080 in	---	0.100 in	
	"Swing" of Guided Support	0.007 in	0.007 in	0.007 in	
	Support Adjustment Tolerance	0.063 in	0.063 in	0.063 in	
	Surveying Accuracy Tolerance	0.354 in	0.354 in	0.354 in	←-----
		$\Sigma =$	24.184 in	24.384 in	
	Required Inside Dia of Beam Tube	$2 * \Sigma =$	48.368 in	48.768 in	

was 48.750

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SUPPORTS

Support Performance Requirements

- Provide vertical adjustment capability of ± 7.5 cm (± 3 ")
- Provide horizontal adjustment capability of ± 7.5 cm (± 3 ")
- Anchorage compatible with 4" thick foundation slab
- Configuration to accommodate placement within 7 ft radius concrete cover
- Shall not cause "stick-slip" during operation
- Shall not cause tube wall temperature to drop below 266°F (130°C) during bakeout of beam tube

*min to 3" from 3 1/2
self support*

MINIMUM 1.07 meters

*Req = 100 mty cables apertures
Tubes style -*

Flatness of the slab

Length of vms

Resil against leache

*Seal of the joints
Water seal*

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SUPPORTS

Support Design Load Combinations

- Dead Load
- Dead Load + Snow Load
- Dead Load + Construction Wind Load
- Dead Load + Insulation Load
- Dead Load + Insulation Load + Lateral Seismic Load
- Dead Load + Insulation Load + Longitudinal Seismic Load
- Dead Load + Insulation Load + Daily Thermal Load
- Dead Load + Insulation Load + Daily Thermal Load + Seismic Load
- Dead Load + Insulation Load + Bakeout Thermal Load

Governing Design Load Combinations

- Dead Load + Insulation Load + Lateral Seismic Load
- Dead Load + Insulation Load + Longitudinal Seismic Load
- Dead Load + Insulation Load + Bakeout Thermal Load

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SUPPORTS

"Fixed" Support Design Loads

- Vertical load of ~ 7,500 pounds (DL of tube, stiffeners & insulation)
- Lateral seismic load of ~ 1,300 pounds
- Longitudinal seismic load of 2,400 pounds
- Longitudinal bakeout thermal load of ~ 6,000 pounds ($\pm 10\%$ exp'n jt spring rate variance)

Guided Support Design Loads

- Vertical load of ~ 6,300 pounds (DL of tube, stiffeners & insulation)
- Lateral seismic load of ~ 1,200 pounds

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SUPPORTS

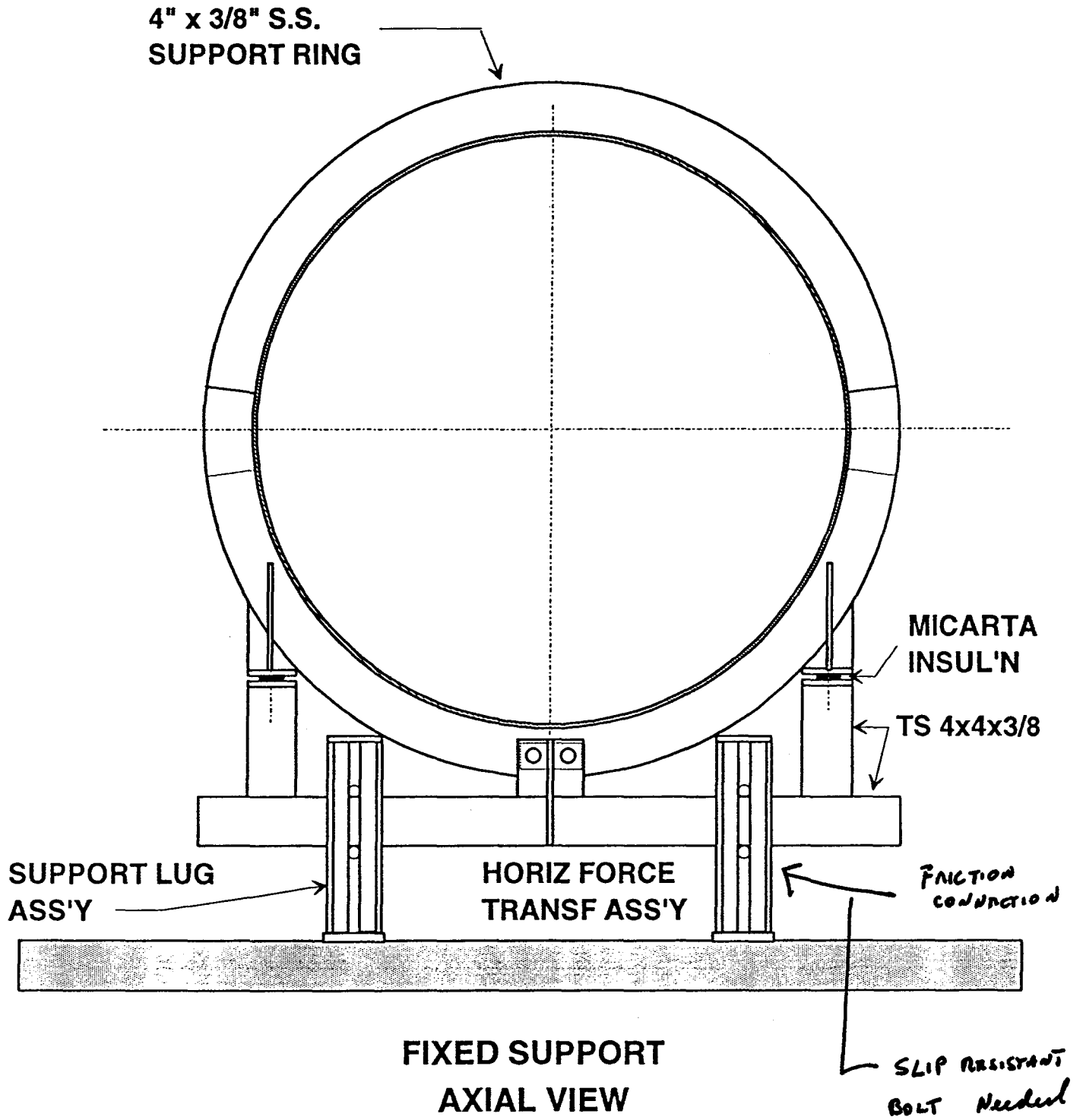
*Better to say
what were
the criteria
and how the
const.
designs
retrofit
them*

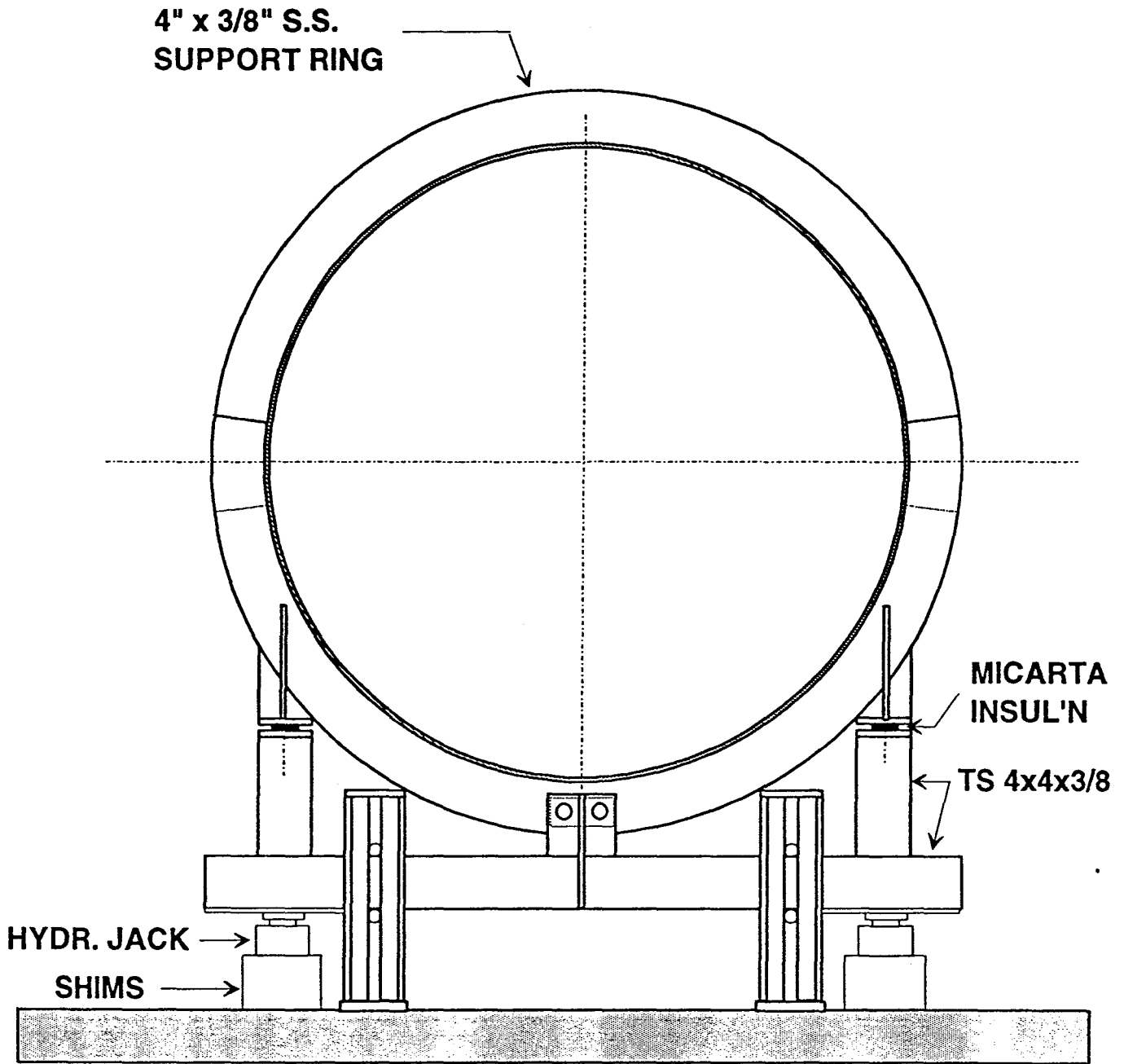
Support Design Procedure

- Supports designed per the Allowable Stress Design (ASD) Specifications of the American Institute of Steel Construction (AISC), 9th Edition
- Stainless steel support components also sized per AISC ASD Specifications

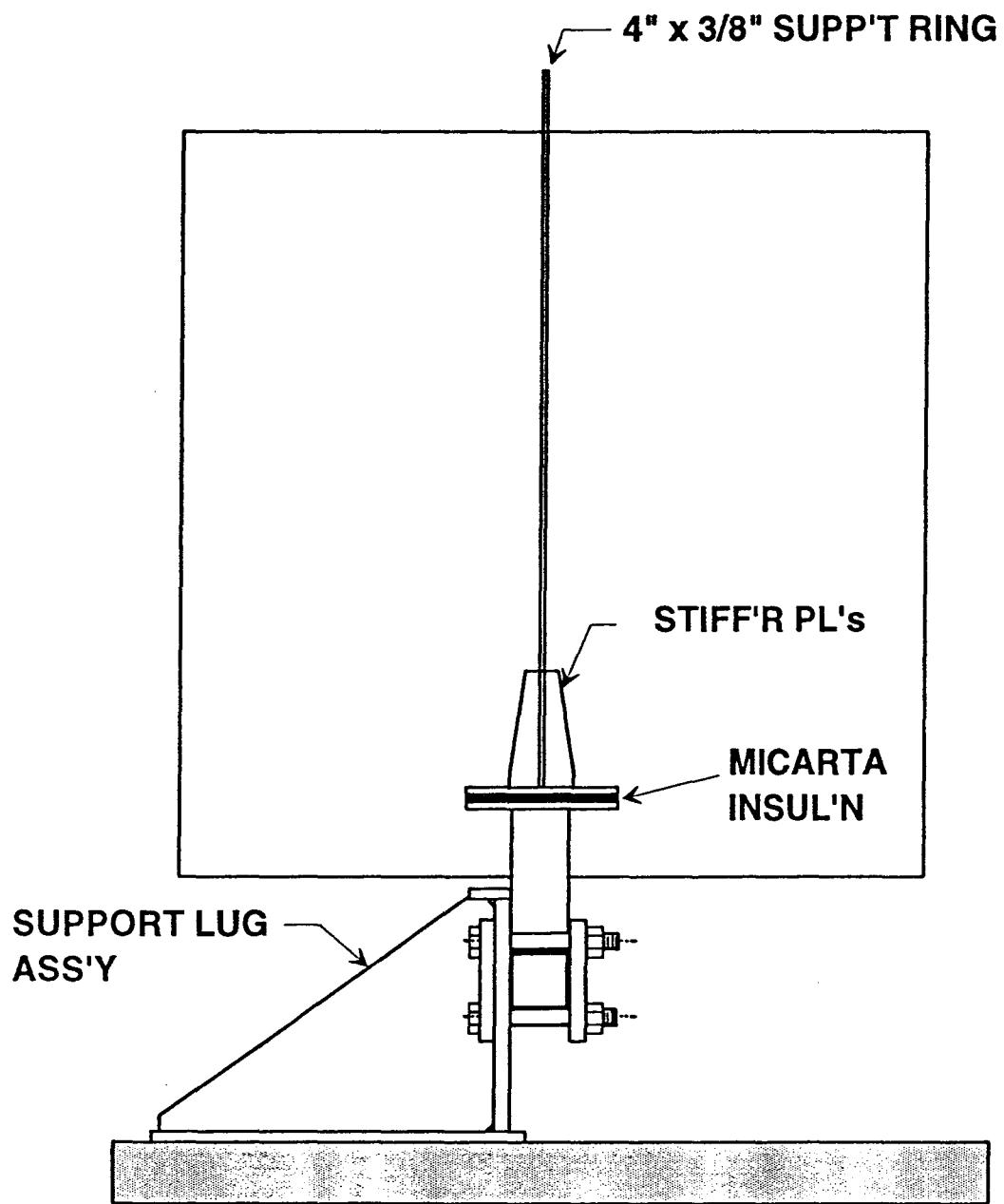
Support Configurations Evaluated

- Support configurations presented at PDR based upon a different beam tube/expansion joint configuration, inadequate or inappropriate for the selected configuration
- Support concepts and configurations evaluated for potential use:
 - Fixed supports using standard pipe hangers
 - Fixed supports using pipe clamps
 - Guided supports using flexible support skirt plates
 - Guided supports using pipe rollers
 - Guided supports using low-friction slide bearings
 - Guided supports using ball bushing bearings
- Above concepts dismissed due to
 - Complexity and associated expense
 - Potential for "stick-slip" and/or "noise"

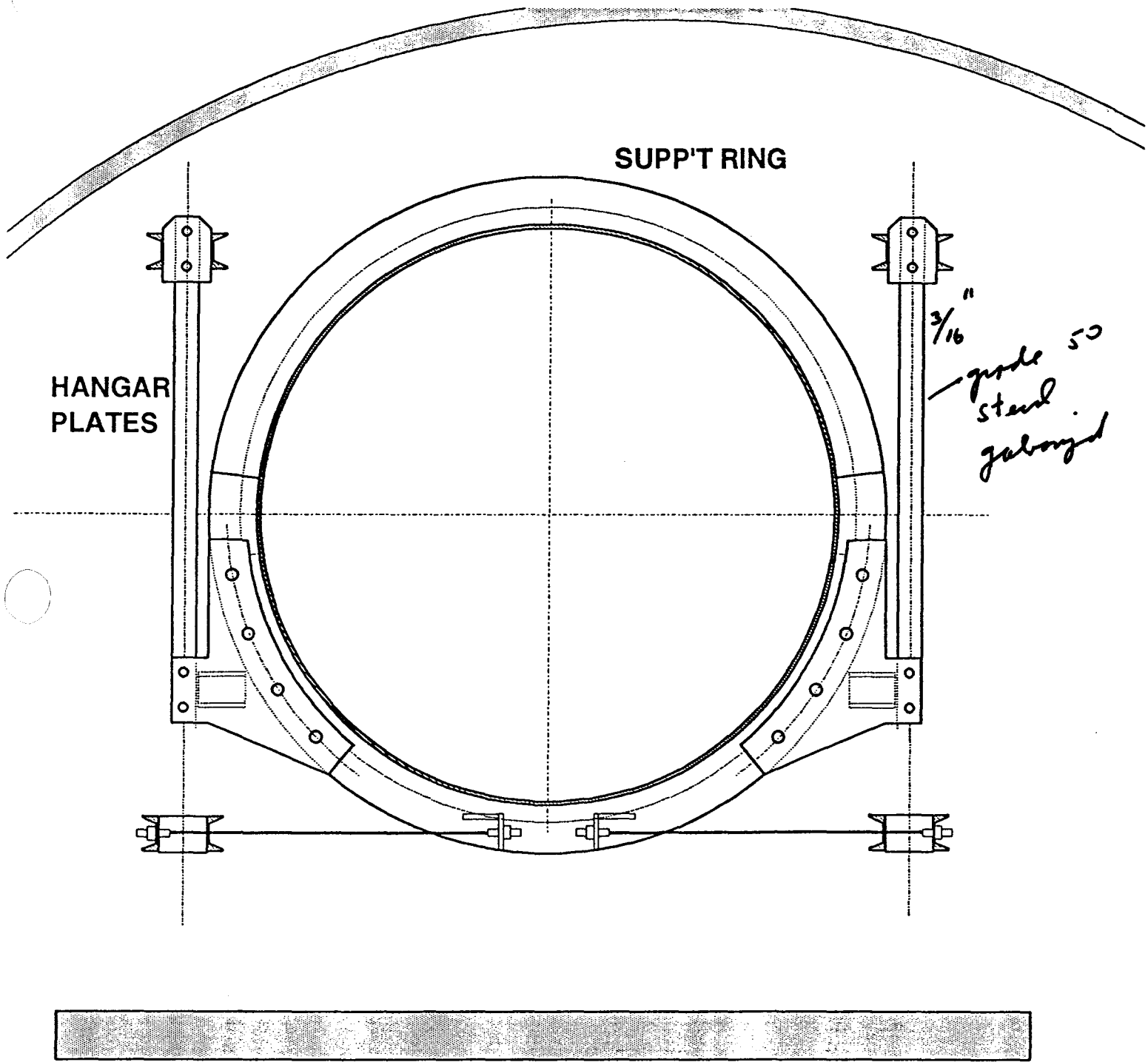




**FIXED SUPPORT
AXIAL VIEW**

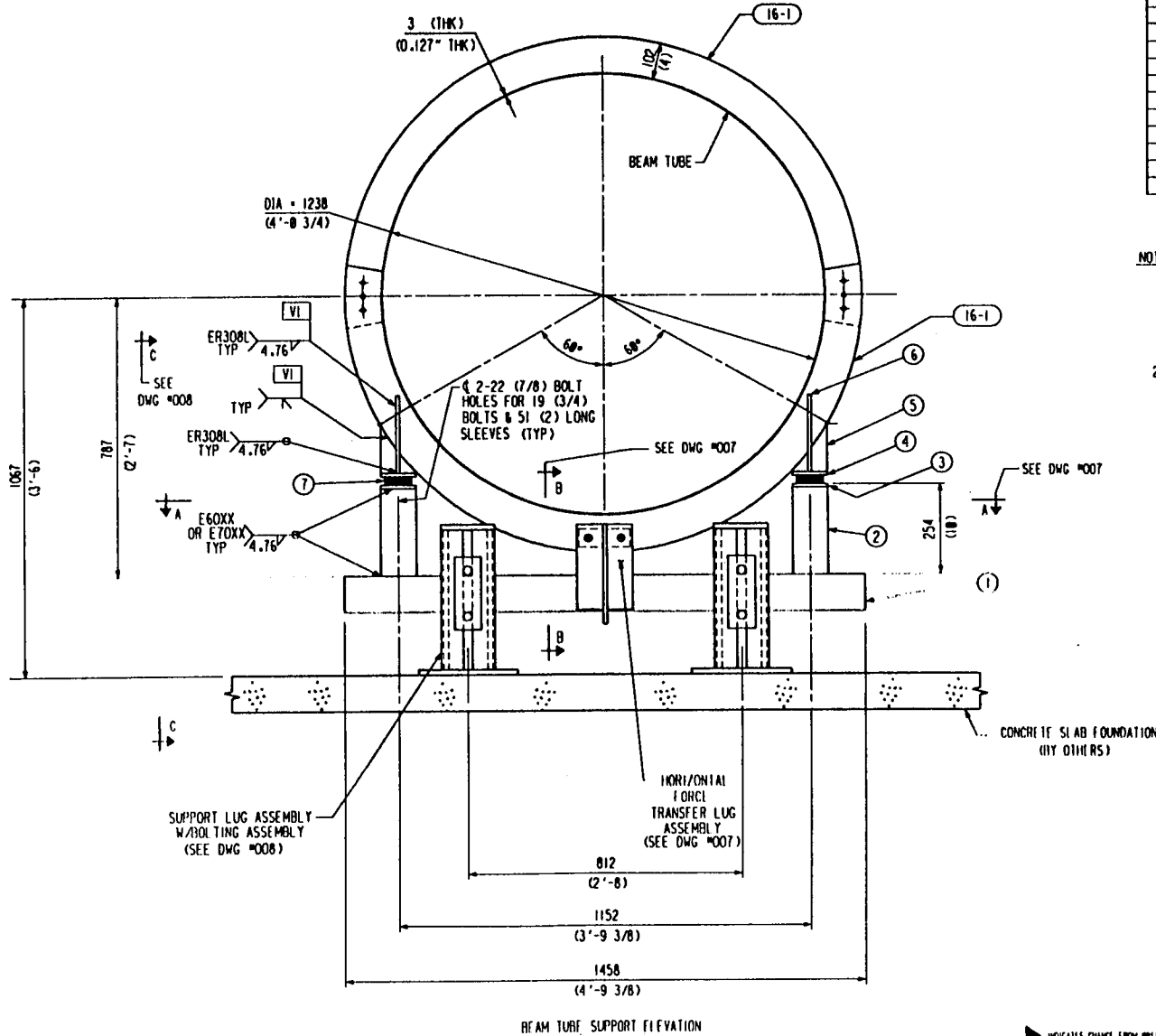


**FIXED SUPPORT
SIDE VIEW**



SECT A-A





SHIP PC	MARK	ISSUE PC	DESCRIPTION	LENGTH (FT)	SPEC
FIXED SUPPORT					
1	6-1		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8)	1458	A500 C-B
2	6-2		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8)	4'-9 3/8	A500 C-B
2	6-3		PL 102 X 10 THK (4 X 3/8) W/ HOLES	254	A36
2	6-4		PL 102 X 10 THK (4 X 3/8) W/ HOLES	254	A240-304L
2	6-5		PL 5K X 10 THK (0'-3/8)		A240-304L
4	6-6		PL 5K X 10 THK (0'-3/8)	203 (8)	A240-304L
2	6-7		MICARTA BLOCK 76 X 254 X 25 (3 X 10 X 1) (GRADE G11) W/ HOLES		

NOTES ON INSULATION OF BEAM TUBE.

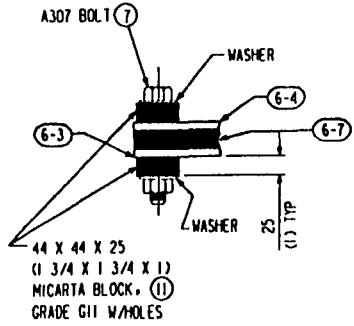
1. THE BEAM TUBE MUST BE FULLY COVERED BY AT LEAST 4 INCHES OF INSULATION HAVING THERMAL CONDUCTIVITY, K, AT 284°F LESS THAN OR EQUAL TO 0.54 BTU IN/HR FT² °F, FOR AT LEAST 36 INCHES ON EITHER SIDE OF SUPPORT RING (16-1)
2. PIECES (6-2), (6-3), (6-4), (6-5), (6-6), AND (6-7) MUST BE FULLY COVERED BY AT LEAST 2 INCHES OF THE INSULATION MENTIONED IN NOTE #1 ABOVE.

NOTES

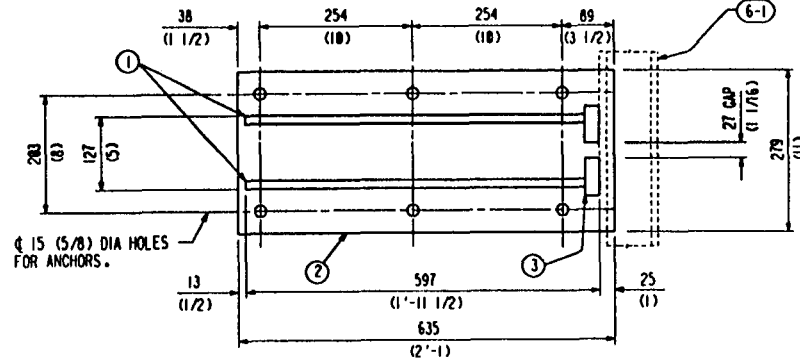
1. WORK THIS DWG WITH DWG #007 AND #008.
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 392 FIXED SUPPORTS BILLED.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

CBI		DATE: 05-17-2006	
ELEVATION			
BEAM TUBE FIXED SUPPORT			
LIGO			
HANFORD, WA., AND LIVINGSTON, LA.			
CUSTOMER'S NO		CONTRACT NO	
BY WAW CHD WJC DATE 11-1-94		930212	
BY D.L. THOMAS		DWG 006 REV C	
ENGINEERING SUPERVISOR		DATE	
THIS DRAWING HAS BEEN PREPARED FOR THE PROPERTY OF CBI AND IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI. NO OTHER USE IS PERMITTED WITHOUT THE WRITTEN PERMISSION OF CBI.			

INDICATES CHANGE FROM PREVIOUS ISSUE

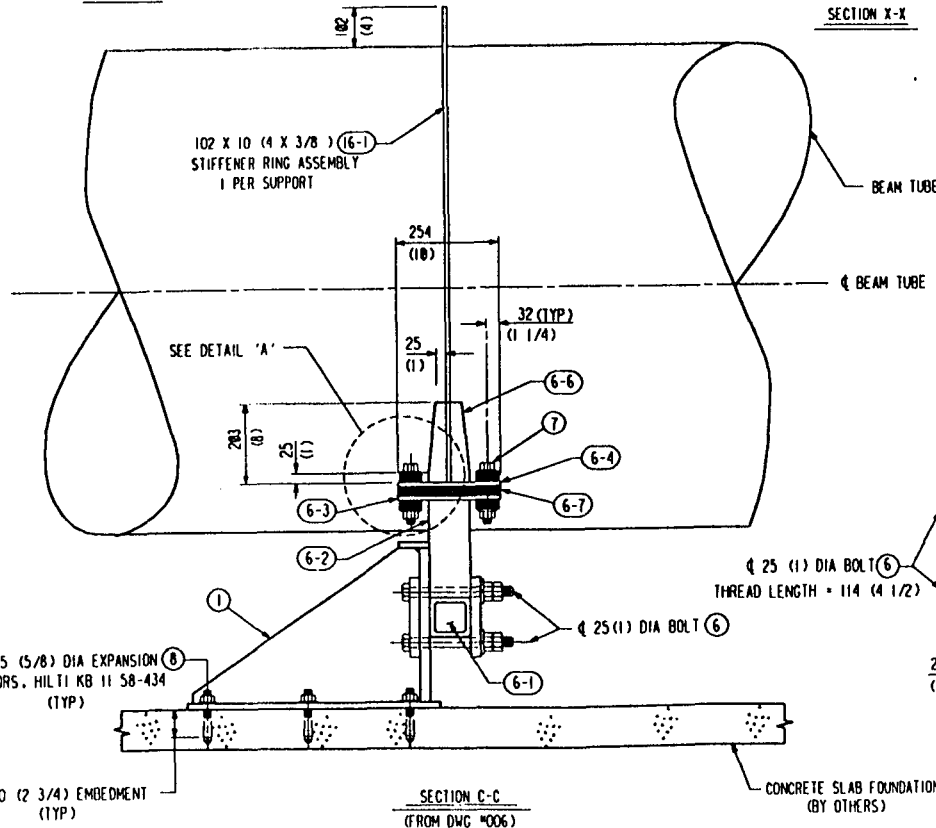


DETAIL A

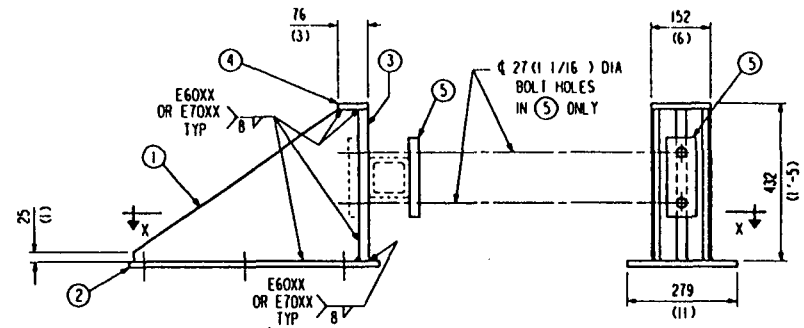


SECTION X-X

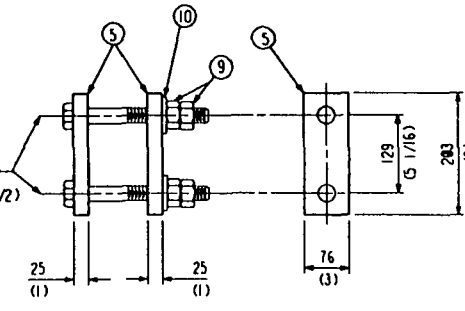
QTY	MARK	LESS PC	DESCRIPTION	LENGTH	SPEC
4	B-1		PL SK X 15 (3/8") THK		A36
2	B-2		PL 279 X 15 THK (11 X 5/8) W/HOLES	635	A36
				(2'-1)	
4	B-3		PL 63 X 25 THK (2 1/2 X 1)	390	A36
				1'-3 3/8	
2	B-4		PL 76 X 15 (3 X 5/8)	152 (6)	A36
4	B-5		PL 76 X 25 THK (3 X 1) W/HOLES	203 (8)	A36
4	B-6		BOLT 25 (1) DIA HYX HEX W/HEX NUT	267	A307
				(10 1/2)	
4	B-7		BOLT 19 (3/4) DIA HYX HEX W/HEX NUTS AND INSULATING SLEEVES	152 (6)	A307
12	B-8		EXPANSION ANCHORS 15 (5/8) DIA HILTI KB11 58-434 W/70 (2 3/4) EMBEDMENT DEPTH OR EQ.	120	CS
				(4 3/4)	
8	B-9		25 (1) HYX HEX NUT		A307
4	B-10		25 (1) WASHER		CS
8	B-11		MICARTA BLOCK 44 X 44 X 25 W/HOLES (1 3/4 X 1 3/4 X 1) GRADE G11		



SECTION C-C (FROM DWG #006)



SUPPORT LUG ASSEMBLY



BOLTING ASSEMBLY

NOTES

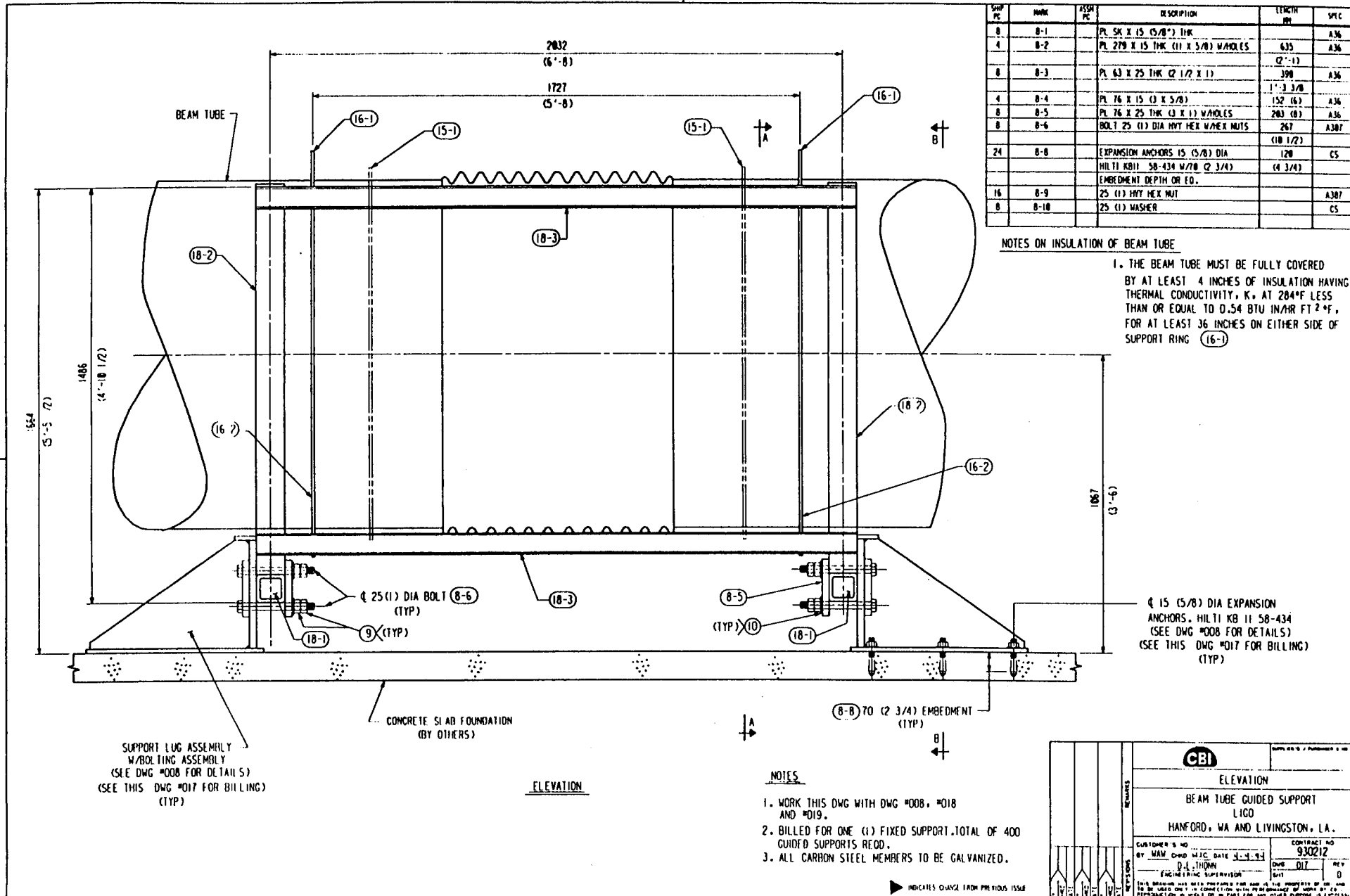
1. WORK THIS DWG WITH DWG #006, 007 AND 009.
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 392 FIXED SUPPORTS REQ'D.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED

CBI	
SUPPORT LUG ASSY & SECTION DETAILS	
BEAM TUBE FIXED SUPPORT	
LIGO	
HANFORD WA AND LIVINGSTON LA.	
CONTRACT NO. 930212 BY MAM CMCO LLC DATE 11-1-94 D.E. JONES ENGINEERING DIVISION	CONTRACT NO. 930212 DATE 008 REV 0 SHEET 1 OF 1
THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI AND IS TO BE USED ONLY IN CONNECTION WITH THE PERFORMANCE OF WORK BY CBI. NO REPRODUCTION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS PERMITTED WITHOUT THE WRITTEN CONSENT OF CBI.	

INDICATES CHANGE FROM PREVIOUS ISSUE

Need Schedule
To show where
is the confusion

27



QTY	MARK	ASMT	DESCRIPTION	LENGTH	SPEC
8	8-1		PL 5/8 X 15 (5/8") THK		A36
4	8-2		PL 270 X 15 THK (11 X 5/8) W/HOLES	635	A36
			(2'-11)		
8	8-3		PL 63 X 25 THK (2 1/2 X 11)	390	A36
			(1'-3 3/8)		
4	8-4		PL 76 X 15 (3 X 5/8)	152 (6)	A36
8	8-5		PL 76 X 25 THK (3 X 1 1/2) W/HOLES	203 (8)	A36
8	8-6		BOLT 25 (1) DIA HYV HEX W/HEX NUTS	267	A307
			(10 1/2)		
24	8-8		EXPANSION ANCHORS 15 (5/8) DIA	120	CS
			HILTI KB11 58-434 W/10 (2 3/4)	(4 3/4)	
			EMBEDMENT DEPTH OR EQ.		
16	8-9		25 (1) HYV HEX NUT		A307
8	8-10		25 (1) WASHER		CS

NOTES ON INSULATION OF BEAM TUBE

1. THE BEAM TUBE MUST BE FULLY COVERED BY AT LEAST 4 INCHES OF INSULATION HAVING THERMAL CONDUCTIVITY, K, AT 284°F LESS THAN OR EQUAL TO 0.54 BTU IN/HR FT² °F, FOR AT LEAST 36 INCHES ON EITHER SIDE OF SUPPORT RING (16-1)

Ø 15 (5/8) DIA EXPANSION ANCHORS. HILTI KB 11 58-434 (SEE DWG #008 FOR DETAILS) (SEE THIS DWG #017 FOR BILLING) (TYP)

SUPPORT LUG ASSEMBLY W/BOLTING ASSEMBLY (SEE DWG #008 FOR DETAILS) (SEE THIS DWG #017 FOR BILLING) (TYP)

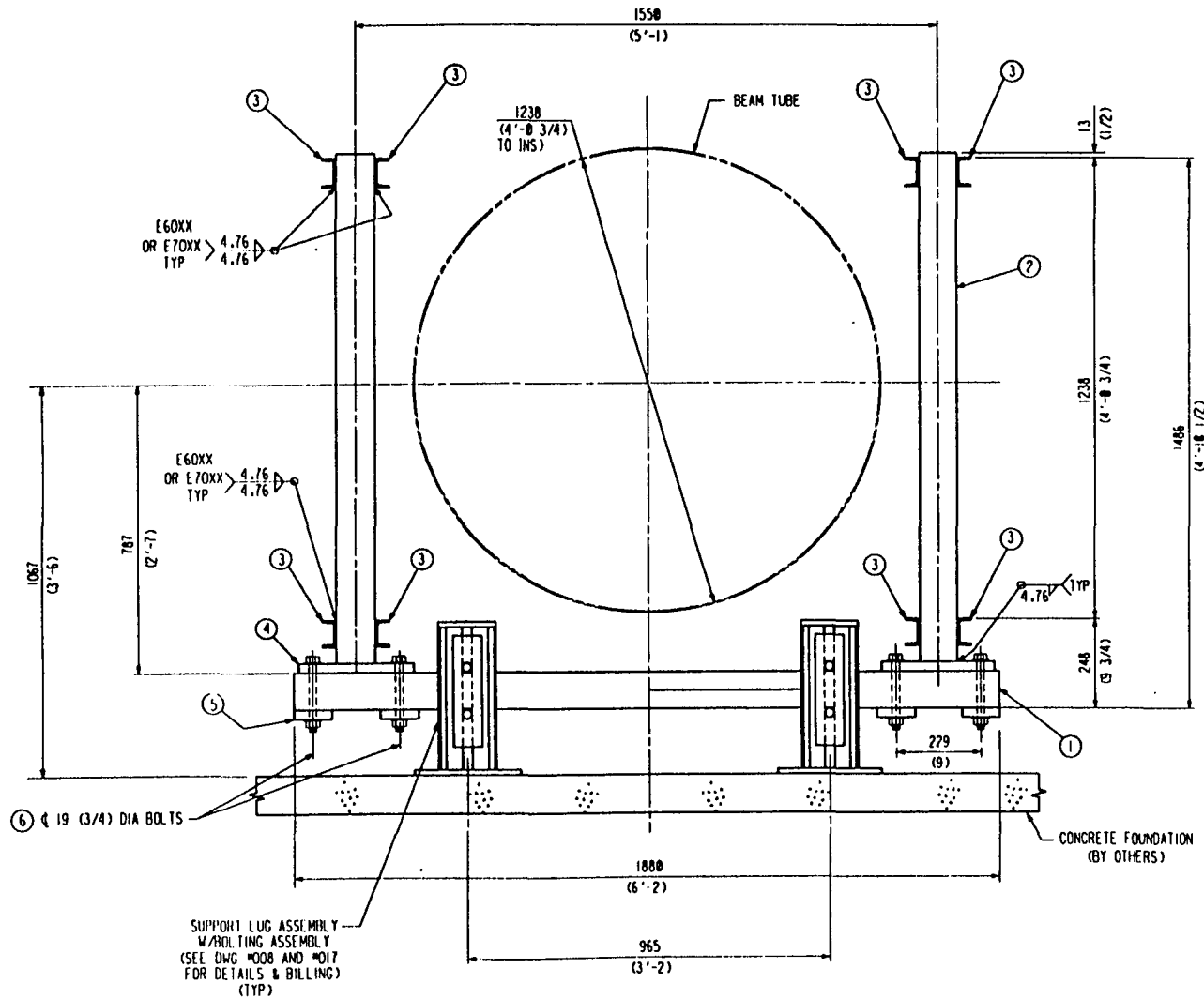
CONCRETE SLAB FOUNDATION (BY OTHERS)

ELEVATION

- NOTES
1. WORK THIS DWG WITH DWG #008, #018 AND #019.
 2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 400 GUIDED SUPPORTS REQ'D.
 3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

CBI		PART 010 - PART 010	
ELEVATION			
BEAM TUBE GUIDED SUPPORT LIGO			
HANFORD, WA AND LIVINGSTON, LA.			
CUSTOMER'S NO.	CONTRACT NO.	REV	
BY WAM	DATE 3-1-83	930212	0
BY D.L. THORN	DATE 3-1-83	DWG	REV
ENGINEERING SUPERVISOR		017	0
THIS DRAWING HAS BEEN PREPARED AND USED UNDER THE PROVISIONS OF THE CONTRACT AND IS TO BE USED ONLY IN CONNECTION WITH THE PERFORMANCE OF THE CONTRACT. IT IS NOT TO BE REPRODUCED OR COPIED IN ANY MANNER WITHOUT THE WRITTEN PERMISSION OF THE ENGINEER.			



SHOP NO	MARK	ISSUE NO	DESCRIPTION	LENGTH MM	SPEC
2	18-1		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8 W/HOLES)	1880	A500 Gr-B
4	18-2		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8)	1372	A500 Gr-B
8	18-3		C 3 X 4.1 PBE	2134	A36
4	18-4		PL 102 X 25 (4 X 1 1/2) HOLES	305	A36
8	18-5		PL 102 X 25 (4 X 1 1/2) HOLES	102	A36
8	18-6		BOLTS 19 (3/4) DIA HYT HEX W/HEX NUT AND WASHERS	203	A307

NOTES

1. WORK THIS DWG WITH DWG #008, #017 AND #019.
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 400 GUIDED SUPPORTS REQ'D.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

CBI		SUPPLY OF MATERIALS	
SECTION DETAILS			
BEAM TUBE GUIDED SUPPORT			
LUG			
HANFORD, WA. AND LIVINGSTON, LA.			
CUSTOMER NO	BY	DATE	CONTRACT NO
	D. E. THORN	4-4-95	930212
ENGINEER'S SUPERVISOR	DRW	REV	
	018	0	
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▶ INDICATES CHANGE FROM PREVIOUS ISSUE

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SUPPORTS

Thermal Analysis of Tube @ Supports

- Tube wall temperature at points of support shall not be less than 266°F during bakeout of the beam tube
- Necessary to incorporate loadbearing insulation into the "body" of the supports
- Types of insulation considered for use included calcium silicate, polyurethane, Transite® and Marinite®, found to be unacceptable for variety of reasons:
 - Low strength
 - Low recommended operating temperature
 - High thermal conductivity
- Micarta® (Grade G11) insulation selected for use in supports:
 - High compressive strength
 - Impermeable to water absorption
 - Relatively low thermal conductivity compared to other loadbearing insulators

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE SUPPORTS

Thermal Analysis of Tube @ Supports

- Finite element analysis of tube-to-support connection performed using program ADINA-T:
 - Tube wall temperature at supports during bakeout will be a minimum of 268°F

BEAM TUBE MODULE CONFIGURATION

BEAM TUBE STIFFENERS

*Resolution
of the
problem
COAR*

Stiffener Design Parameters

- Beam tube stiffener design based upon a 49.00" O.D. tube with a wall thickness of 0.127"
- Most economical stiffener size: $3/16"$ x $1\ 3/4"$ 304L stainless steel bar

Stiffener Design

- ASME Section VIII provisions used for initial stiffener design:
 - ASME factor of safety of 3 against buckling of the beam tube due to circumferential stresses will result in a maximum stiffener spacing of $26\ 1/2"$
- LIGO beam tubes are not ASME Code stamped:
 - Large number of stiffeners required justifies attempt to maximize the stiffener spacing without compromising structural integrity
 - Final spacing of stiffeners is based upon a minimum permissible factor of safety of 2.5 against buckling of the beam tube due to circumferential stresses
 - Final spacing of stiffeners (is $\sim 30"$), provides a factor of safety of 2.6 against buckling of the beam tube, and allows a consistent, equal spacing of stiffeners on the beam tube sections

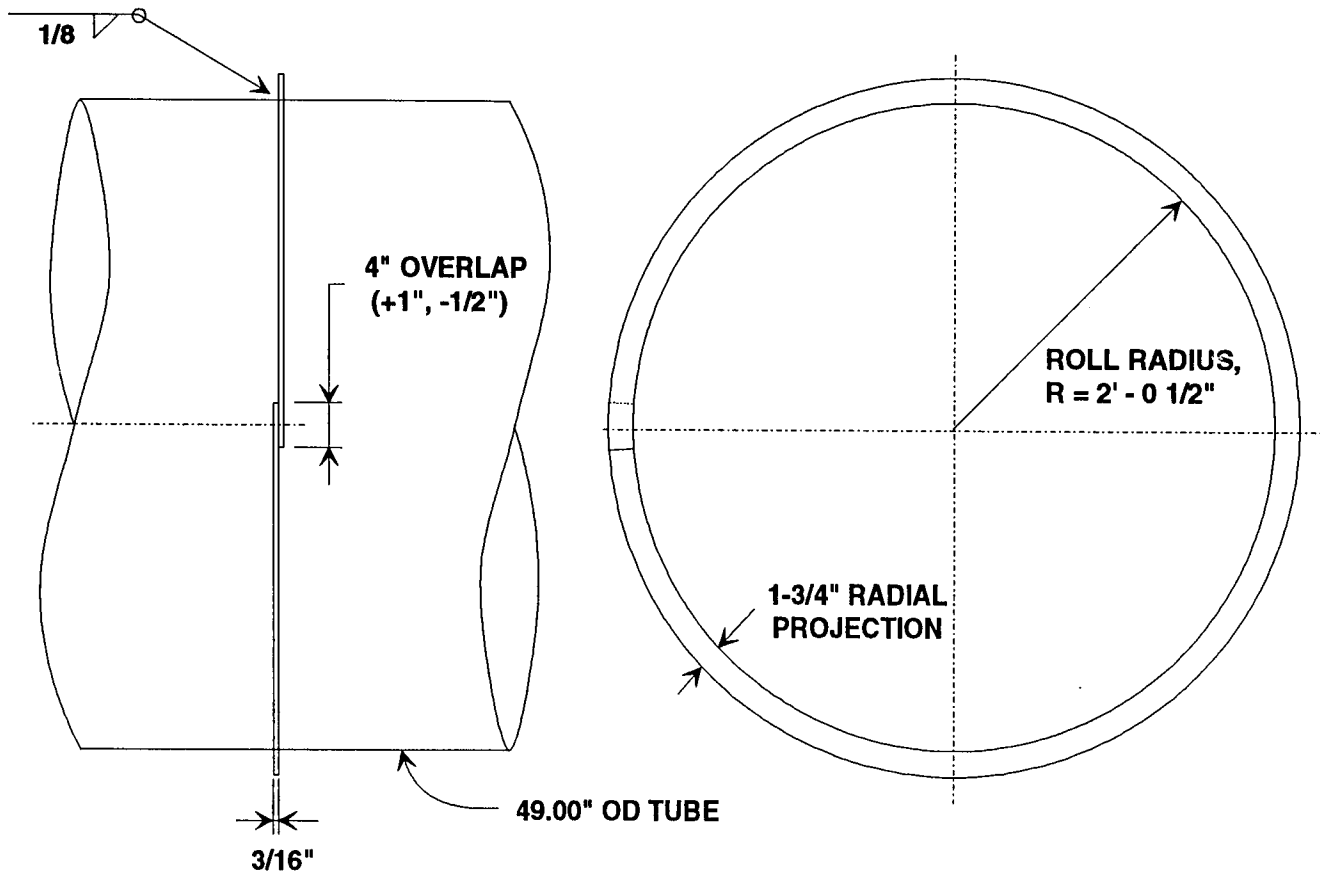
BEAM TUBE MODULE CONFIGURATION

BEAM TUBE STIFFENERS

Stiffener-to-Tube Weld Design

- Regardless of actual strength required, ASME Section VIII would require use of either:
 - Stitch weld on both sides of stiffener
 - Continuous weld on one side of stiffener, stitch weld on other side
 - Continuous full penetration weld on one side of stiffener
- LIGO beam tubes are not ASME Code stamped:
 - Stiffener-to-tube weld designed on basis of strength considerations only
 - Stiffener-to-tube weld is a 1/8" continuous fillet weld, one sided
 - Satisfies strength requirements

BEAM TUBE STIFFENERS



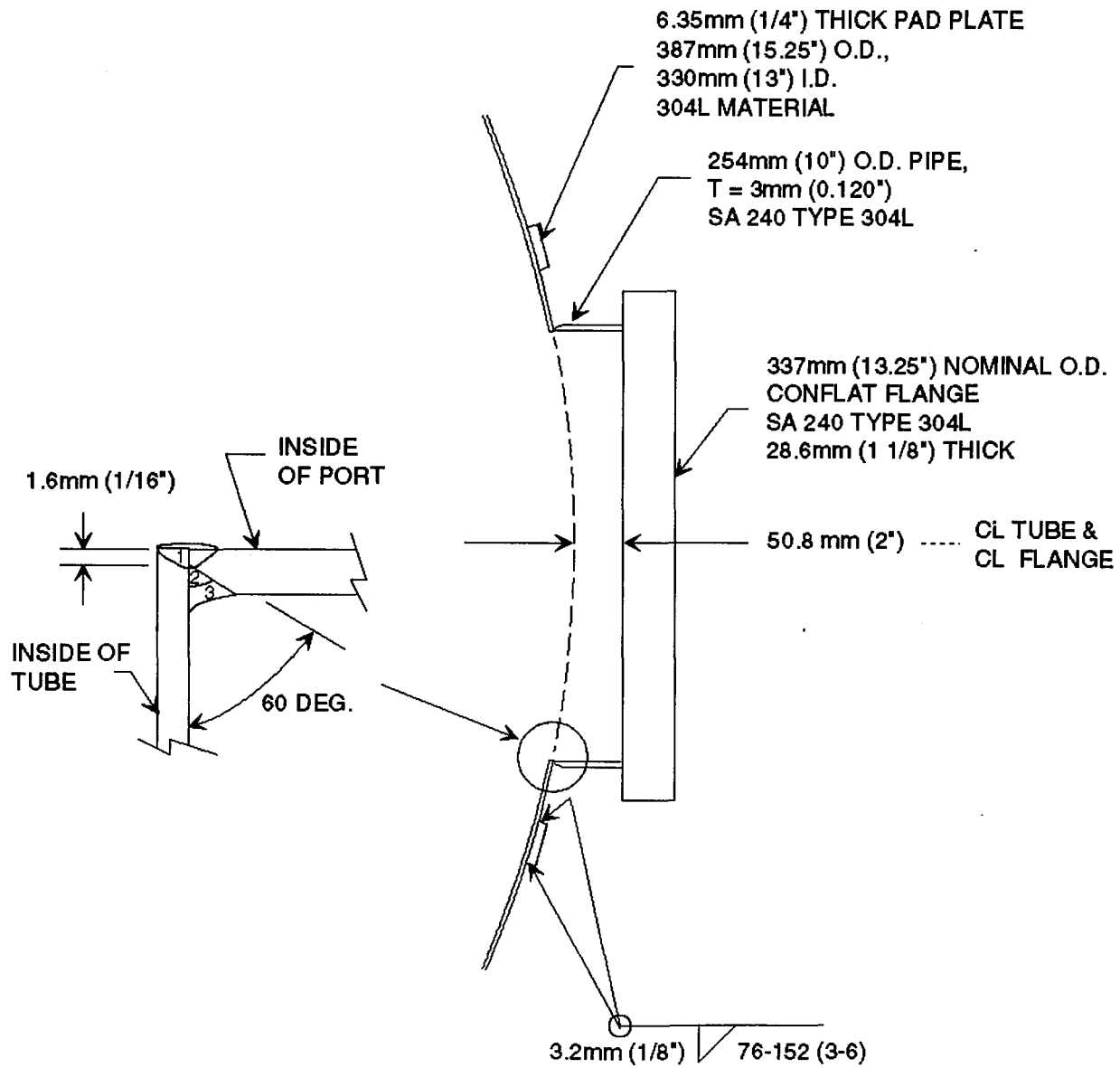
BEAM TUBE MODULE CONFIGURATION

PUMP PORT

- AREA REPLACEMENT DESIGNED PER ASME
- PAD PLATE DETAILED TO AVOID VIRTUAL LEAKS
- NOZZLE DESIGNED FOR 150 LBS (667 kN) LOAD, 3.7" (94 mm) FROM SHELL
- CONFLAT FLANGE, 13.25" (337mm) NOMINAL O.D.
- 10" O.D. (254mm) NECK, 0.12" (3 mm) THICK

\$ 3975 / Port

PUMP PORT

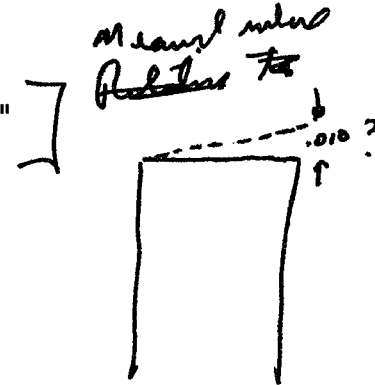


BEAM TUBE MODULE CONFIGURATION

BEAM TUBE TERMINATION INTERFACE

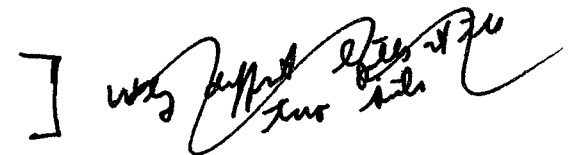
TOLERANCES REQUIRED ON CHAMBER STUBS FOR CONSTRUCTION

- CIRCUMFERENCE WITHIN $\pm 3/64$ " (± 1.19 mm)
- PERPENDICULAR TO THE CYLINDRICAL AXIS WITHIN 0.010" (0.254mm).
- FLAT WITHIN 0.005" (0.127mm)
- PROJECTION SHALL BE WITHIN $\pm 1/8$ " (± 3.18 mm)
- OPTIMUM THICKNESS IS 0.127" (3.23mm)
 - NOT BE LESS THAN 0.105" (2.67mm)
 - NOT GREATER THAN 0.150" (3.81mm)

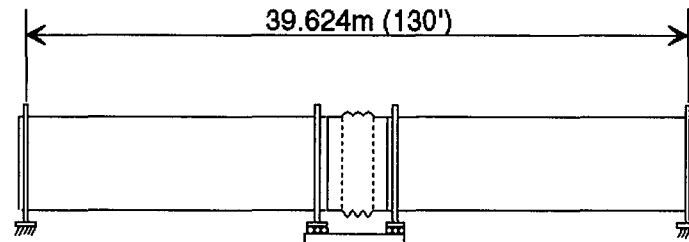


PHYSICAL REQUIREMENTS

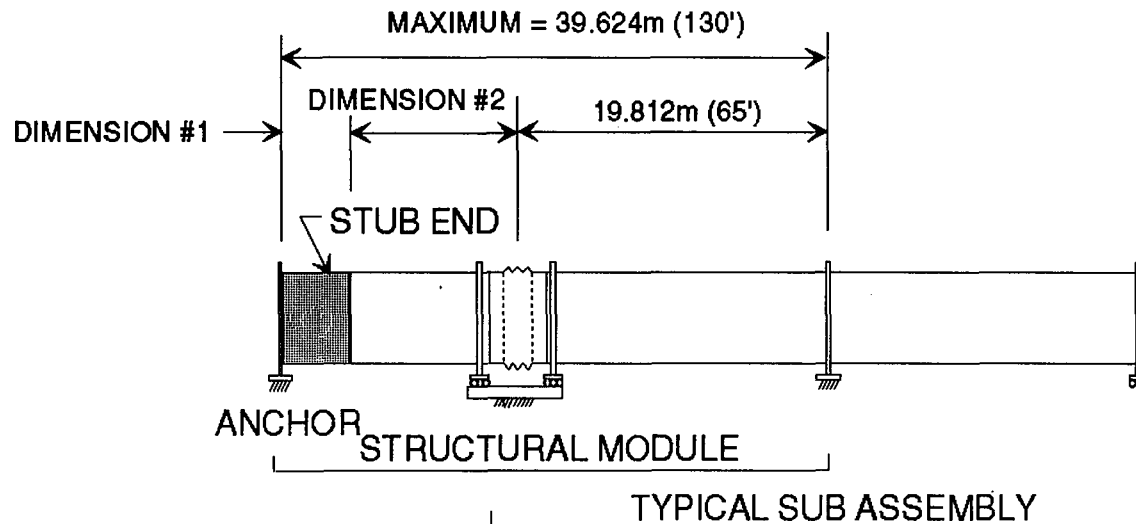
- MAXIMUM LENGTH (OPTIMUM LENGTH)
 - 51'-2 5/32" (15.600m) AT HANFORD
 - 31'-6 1/16" (9.600m) AT LIVINGSTON
- MAXIMUM STIFFENER SPACING FROM END OF STUB
 - 1'-2 5/32" (360mm) AT HANFORD
 - 1'-0 1/16" (329mm) AT LIVINGSTON
- MINIMUM STIFFENER SPACING IS 1'-0 (305mm)
- PROTRUDE 3'-0 OUT OF BUILDING
- ANCHOR MUST BE ABLE TO RESIST A 40,000 POUND AXIAL LOAD



MAXIMUM CHAMBER STUB LENGTHS



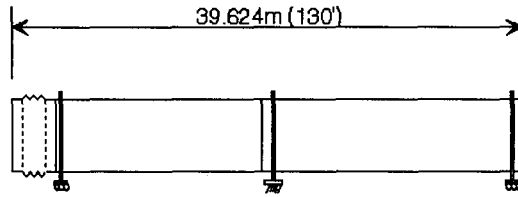
STRUCTURAL MODULE



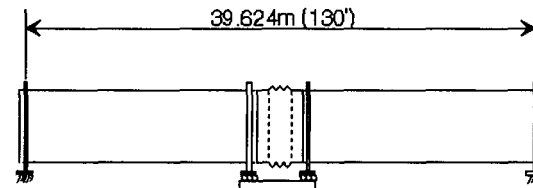
DIMENSION #1
MAXIMUM STUB LENGTH:
15.600m (51'-2 5/32) HANFORD
9.600m (31'-5 15/16) LIVINGSTON

DIMENSION #2
LENGTH BETWEEN END & EXPANSION JOINT CENTER LINE::
4.212m (13'-9 5/32) HANFORD
10.212m (33'-6 1/16) LIVINGSTON

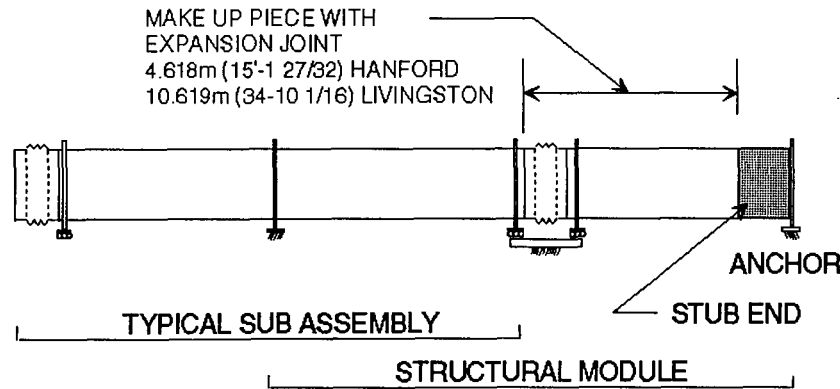
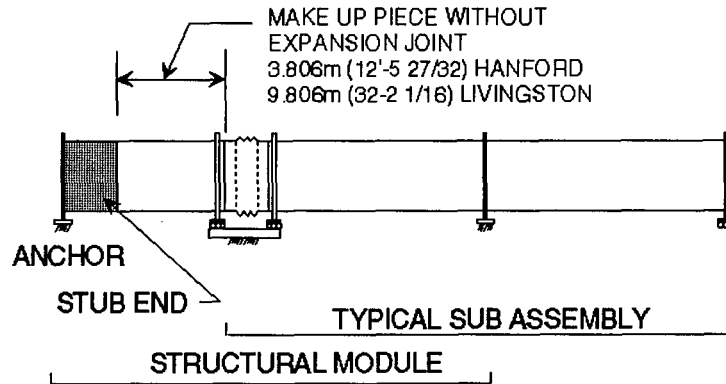
FUNCTION OF THE MAKE UP PIECES



TYPICAL SUB ASSEMBLY



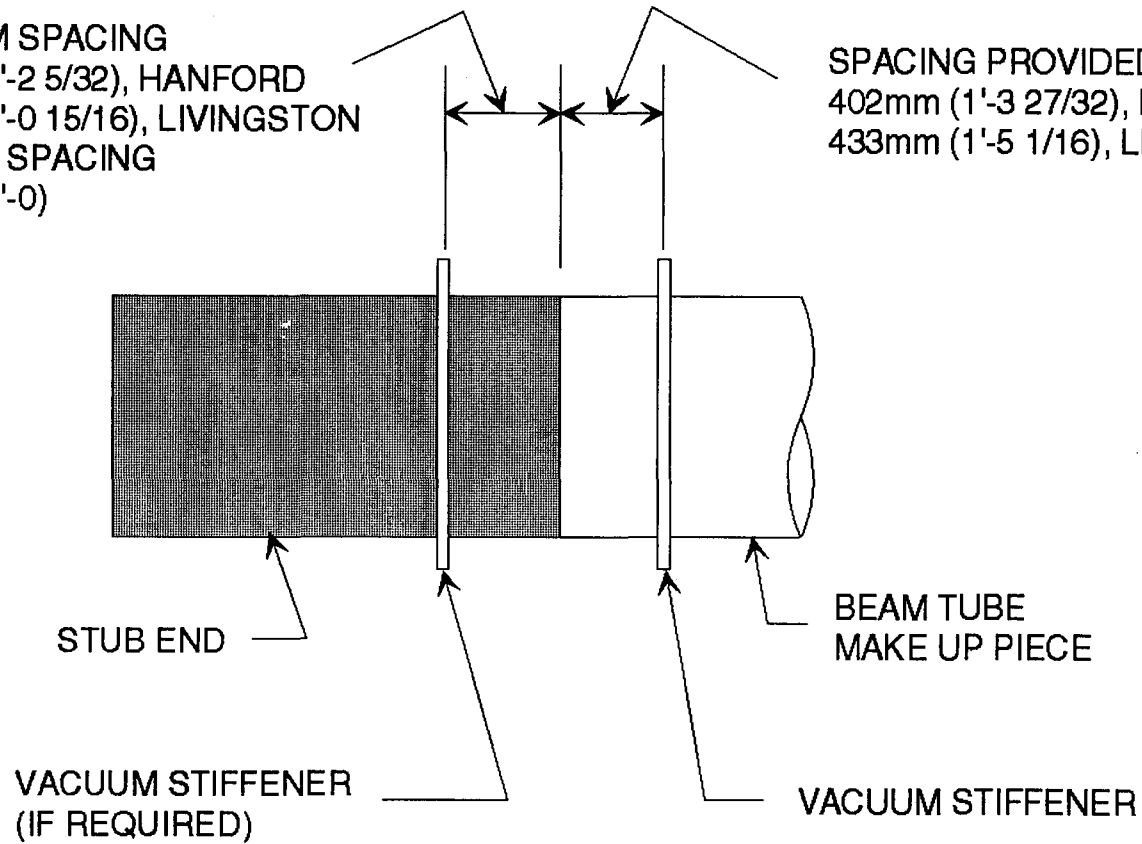
STRUCTURAL MODULE



VACUUM STIFFENER LOCATION ON STUB

MAXIMUM SPACING
360mm (1'-2 5/32), HANFORD
329mm (1'-0 15/16), LIVINGSTON
MINIMUM SPACING
305mm (1'-0)

SPACING PROVIDED
402mm (1'-3 27/32), HANFORD
433mm (1'-5 1/16), LIVINGSTON



BEAM TUBE MODULE CONFIGURATION

FIXED SUPPORT AT TERMINATION POINTS

- IF OPTIMUM STUB LENGTH IS USED, CAN USE REGULAR FIXED SUPPORT
 - 36
- IF MINIMUM (12") SUB LENGTH IS USED, REGULAR FIXED SUPPORT IS ADEQUATE FOR OPERATING LOADS
- IF MINIMUM (12") SUB LENGTH IS USED, MUST USE MODIFIED SUPPORT FOR BAKE OUT (SAME AS QT FIXED SUPPORT)
 - 36"
 - MAXIMUM BAKE OUT AXIAL LOAD IS 19,000 LBS @ HANFORD
 - MAXIMUM BAKE OUT AXIAL LOAD IS 9,500 LBS @ LIVINGSTON
 - REGULAR FIXED SUPPORT IS DESIGNED FOR 6000 LBS
- REACTION TO FOUNDATION FROM MODIFIED SUPPORT (BAKE OUT)
 - AT HANFORD, PER BASE PLATE (4 TOTAL)
 - SHEAR = 4750 LBS
 - UPLIFT OR DOWN LOAD = 1370 LBS
 - AT LIVINGSTON, PER BASE PLATE (4 TOTAL)
 - SHEAR = 2375 LBS
 - UPLIFT OR DOWN LOAD = 680 LBS
- MINIMUM STUB END LENGTH TO USE REGULAR FIXED SUPPORTS IS:
 - 27 FEET AT HANFORD
 - 9 FEET AT LIVINGSTON

New

40A

BEAM TUBE MODULE CONFIGURATION

FOUNDATION LOADS

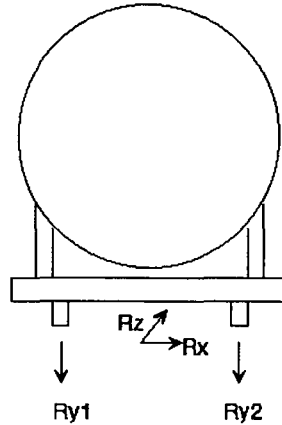
COMMENTS ABOUT FOUNDATION LOADS

- SEVERE LOADS ARE CAUSED BY DIFFERENTIAL SETTLEMENTS
- AXIAL LOAD CAUSED FROM VARIATION OF AXIAL SPRING RATE DURING BAKE OUT IS CLOSE TO AXIAL LOAD DUE TO SEISMIC WHEN FACTORED BY 1.33

MAXIMUM DIFFERENTIAL SETTLEMENT & ROTATION

- DURING BAKE OUT: $\pm 6.4 \text{ mm } (\pm 0.25")$
- DURING NORMAL OPERATING CONDITIONS: $\pm 12.7 (\pm 0.5" \text{ mm})$
- DIFFERENTIAL SLAB ROTATION: $\pm 0.15 \text{ DEGREES}$
(ANY OPERATING CONDITION)

FOUNDATION LOADS - FIXED SUPPORTS



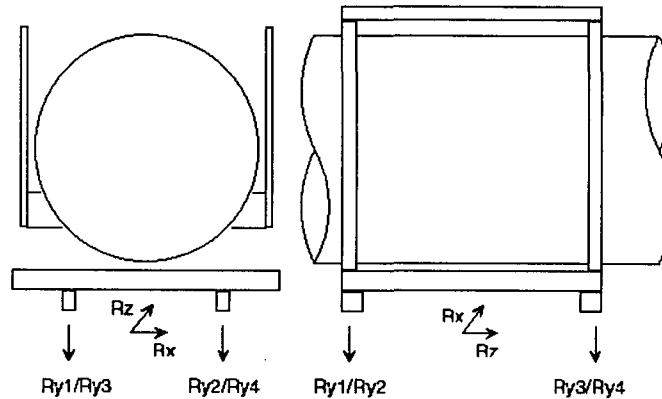
42

FIXED SUPPORT FOUNDATION LOADS Load Cases	Lateral (lbs)	Vertical (lbs)			Axial (lbs)
	Rx	Ry1	Ry2	Ry total	Rz
1. Operating	85	3870	3648	7518	771
2. Bake Out @ 302 F	656	860	-860	0	5959
3. 0.579" Dif Settlement @ Fixed Support	0	+/- 715	+/- 715	+/- 1430	0
4. 1" Dif Settlement @ Fixed Support	0	+/- 1235	+/- 1235	+/- 2470	0
5. 0.5" Horz Misalign'mt @ Fixed Support	1235	1621	-1621	0	0
6. 0.579" Dif Sett'l'mt @ Guided Support	0	+/- 356	+/- 356	+/- 712	0
7. 1" Dif Settlement @ Guided Support	0	+/- 615	+/- 615	+/- 1230	0
8. 0.5" Misalignment @ Guided Support	615	807	-807	0	0
9. Lateral Seismic (x direction)	1287	1689	-1689	0	0
10. Axial Seismic (z direction)	0	0	0	0	2169
11. Wind Load	1275	1673	-1673	0	0

Maximum Reactions Normal Operating Conditions	Maximum Reactions Seismic or Wind Conditions
Maximum Rx = 1320 lbs, 1+3+5	Maximum Rx = 2607 lbs, 1+3+5+9
Maximum Ry1= 6206 lbs, 1+3+5	Maximum Ry1= 7895 lbs, 1+3+5+9
Minimum Ry2= 1312 lbs, 1-3+5	Minimum Ry2= -377 lbs, 1-3+5+9
Maximum Ry= 9988 lbs, 1+4	Maximum Ry= 9988 lbs, 1+4+9
Maximum Rz = 6730 lbs, 1+2+3	Maximum Rz = 8899 lbs, 1+2+6+10

5959

FOUNDATION LOADS - GUIDED SUPPORTS



GUIDE SUPPORT FOUNDATION LOADS Load Case	Lateral	Vertical (lbs)				
	Rx	Ry1	Ry2	Ry3	Ry4	Ry total
1. Operating	85	1664	1553	1664	1553	6434
2a. Bake Out @ 302 F	656	598	-262	598	-262	672
2b. Bake Out @ 302 F	656	262	-598	262	-598	-672
3. 0.579" Dif Settl'mt @ Fixed Support	0	+/- 715	+/- 715	-/+ 365	-/+ 365	+/- 701
4. 1" Dif Settl'mt @ Fixed Support	0	+/- 1235	+/- 1235	-/+ 630	-/+ 630	+/- 1210
5. 0.5" Horz Misalign'mt @ Fix'd Support	605	397	-397	397	-397	0
6. 0.579" Dif Settl'mt @ Guided Support	0	+/- 162	+/- 162	+/- 155	+/- 155	+/- 635
7. 1" Dif Settl'mt @ Guided Support	0	+/- 280	+/- 280	+/- 269	+/- 269	+/- 1097
8. 0.5" Misalignment @ Guided Support	549	360	-360	360	-360	0
9. Lateral Seismic (x direction)	882	579	-579	579	-579	0
10. Axial Seismic (z direction)	0	0	0	0	0	0
11. Wind Load	874	574	-574	574	-574	0

Maximum Reactions Normal Operating Conditions		Maximum Reactions Seismic or Wind Conditions	
Maximum Rx =	740 lbs, 1+2a+3	Maximum Rx =	1622 lbs, 1+2a+3+9
Maximum Ry1=	2977 lbs, 1+2a+3	Maximum Ry1=	3556 lbs, 1+2a+3+9
Minimum Ry2=	240 lbs, 1+2b-3	Minimum Ry2=-	339 lbs, 1+2b-3+9
Maximum R3=	2627 lbs, 1+2a+3	Maximum R3=	3206 lbs, 1+2a+3+9
Minimum Ry4=	590 lbs, 1+2b-3	Minimum Ry4=	11 lbs, 1+2b-3+9
Maximum Ry =	7807 lbs, 1+2a+3	Maximum Ry =	7807 lbs, 1+2a+3+9

GENERAL FABRICATION REQUIREMENTS

REQUIREMENTS

LIGO beam tube module contract general requirements

- Caltech prior review of all outside fabricators
- Open and free competition
- Buy American Act

CRITICAL PARAMETERS

Manufacturers should work within their areas of expertise to the extent possible.

Unique requirements of LIGO must be incorporated into the manufacturer's expertise.

Process identification, control, and inspection are required to ensure that the LIGO requirements are met.

Develop a reliable and low risk configuration and suppliers.

Select the most economical [^]configuration and suppliers that meet LIGO requirements.

GENERAL FABRICATION REQUIREMENTS

CONFIGURATION DEVELOPMENT AND VENDOR REVIEW

Information exchange between potential suppliers and CBI

Preliminary specification submitted to potential suppliers for review.

Budget pricing developed by potential suppliers to select basic configurations.

Plant trips by CBI and meetings with manufacturers to assess capabilities

2 → Pre Qualification of manufacturers, configurations, and procedures through the manufacturing of 48" diameter tube section, stiffeners, and baffles.

Final specifications for the Qualification Test and the Option based on the prior development effort.

Final selection of the configuration and recommended course of action.

COIL STEEL PRODUCTION AND BAKE

Critical parameters

- 1. The material must meet the LIGO technical requirements.**
- 2. The production process must satisfy the LIGO schedule requirements.**
- 3. The production process must be economical as well as satisfy parameters 1 and 2.**

COIL STEEL PRODUCTION AND BAKE

Material Technical Requirements:

- A. Materials shall be in accordance with the latest edition of the ASME Section VIII, Div. 1.
- B. Meet ⁵ or exceed requirements specified in LIGO Specification 1100004, "Technical Specifications - Beam Tube Module Specification":
1. Materials used in the beam tube modules are subject to Caltech approval.
 2. The beam tube wall material shall have an internal surface finish no smoother than 2.5 microns rms roughness. If stainless steel is used, HRAP surface is acceptable. Any alternate finish is subject to approval.
 3. The beam tube steel shall meet the outgassing performance requirements specified in LIGO Specification 1100007, "Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products".
 - The material processed shall be conventional Type 304L stainless steel.
 - The thickness of the steel shall be 0.130" or less.
 - The material may be in sheet or coil form.
 - The raw material will be air baked at 440°C +/- 8°C for 36 hours.
 - Samples from all baked material shall be tested to confirm acceptable outgassing levels for hydrogen.
 - No material shall be used for fabrication until its acceptability is assured.

COIL STEEL PRODUCTION AND BAKE

Additional Material Requirements:

- **Minimum sulfur content of .01% to improve weldability.**
- **Maximum sulfur content of .02% to reduce fractions of manganese sulfur inclusions.**
- **Reduce the specified thickness tolerances to +/- 0.005" to improve economy. } ?**
- **Stretcher level the material to improve the flatness and camber.**

Critical parameters

1. **Develop a production process(s) that assures compliance with all the LIGO technical requirements.**
2. **Develop a steel production process(s) that produce the coil steel to meet the LIGO schedule requirements.**
3. **Select the steel production process that is most economical.**

Material Specifications:

- **"Coil Material Specification" C-240-0186, "Coil Material Specification"**
- **"Coil Material Bake Specification" C-CMBS1**

COIL STEEL PRODUCTION AND BAKE

Material Technical Requirements:

- A. Materials shall be in accordance with ASME Section VIII, Div. 1.**
- B. Materials shall meet the beam tube module technical specifications :**
 - 1. Materials used in the beam tube modules are subject to Caltech approval.**
 - 2. Internal surface finish shall be no smoother than 2.5 microns rms. If stainless steel is used, a HRAP surface is acceptable. Any alternate finish is subject to approval.**
 - 3. The beam tube steel shall meet the Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products".**
 - Use conventional Type 304L stainless steel.**
 - The thickness shall be 0.130" or less.**
 - Sheet or coil form is acceptable.**
 - Air baked the material 440°C +/- 8°C for 36 hours.**
 - The material shall be tested to confirm acceptable hydrogen outgassing levels.**
 - No material shall be used for fabrication until its acceptability is assured.**

COIL STEEL PRODUCTION AND BAKE

Additional Material Requirements:

- **Minimum sulfur content of .01% to improve weldability.**
- **Maximum sulfur content of .02% to reduce fractions of manganese sulfur inclusions.**
- **Thickness tolerances of +/- 0.005" to improve economy.**
- **Stretcher leveling to improve the materials flatness and camber.**

Material Specifications:

LIGO Specification C-240-0186, "Coil Material Specification"

COIL STEEL PRODUCTION AND BAKE

Raw Material Bake Process:

1. Will not be performed by the steel manufacturers.

2. Materials for the Qualification Test will be baked at Metlab.

- A company that performs special material heat treatments.

- Bake can be perform^{ed} ~~the~~ as specified^{ed}

- Has a furnace that can bake up to four full size coils.

3. Three full size coils will be manufactured and baked as part of the Qualification Test.

4. Thermocouples installed into the center of one coil.

5. Thermocouples will not be installed into the center of the coil in future bakes.

6. The heat up and cooldown times used to control the future bakes.

7. Coupons from all three baked coils for outgas testing .

can they ^{and}
see full L16D

?

Technical and Cost Comparison of Coil Material Procurement - Option					
ITEM COMPARED	BEAM TUBE STEEL MANUFACTURERS				
	ARMCO	J&L	WASHINGTON	AVESTA SHEFFIELD	ALLEGHENY LUDLUM
Steel made in America	YES	YES	YES	NO	YES
Material Process	HRAP	CR	HRAP	CR	CR
0.120" < Thickness > 0.130"	YES	YES	YES	YES	YES
> 2.5 micron RMS surface finish	YES	NO	YES	YES	2D
Leveled	YES	NO	YES	NO	NO
Width @ 1/32" (1/2 ASTM)	YES	YES	NO	YES	YES
Camber @ 3/64" (1/2 ASTM)	YES	YES	NO	YES	YES
Bake Material	NO	YES	NO	NO	NO
Bake @ 440 C +/- 8 C	NA	NO	NA	NA	NA
Max weight of coil produced	>30,000	<25,000	<16,000	>30,000	>30,000
Weight of coils ordered	30,000	20,000	15,000	30,000	30,000
Number of tubes made/coil	6	4	3	6	6
Total number of coils for Option	132	198	264	132	132
Base Cost/# of 304L Material	\$0.92	\$1.35	\$1.05	\$0.95	\$1.27
Base cost of unfinished material	\$27,639	\$27,020	\$15,750	\$28,500	\$38,046
Est. miles to bake facility	600	0	300	100	300
Freight cost to bake (\$/trip)	\$822	\$0	\$411	\$137	\$411
Trips to bake facility	132	99	88	132	132
Cost to perform bake (\$/coil)	\$3,000	\$0	\$2,000	\$3,000	\$3,000
Est. miles to finishing mill	300	0	300	300	300
Freight to finishing mill (\$/trip)	\$411	\$0	\$411	\$411	\$411
Trips to finishing mill	132	0	132	132	132
Cost per outgas test	\$2,650	\$2,650	\$2,650	\$2,650	\$2,650
Cost to level to 1/8" flat (\$0.05/#)	\$1,500	\$0.00	\$0.00	\$0.00	\$0.00
Cost to slit to 48" (\$0.03/#)	\$900	\$0	\$0	\$900	\$900
Extra to slit to 16 (\$0.03/#)	\$900	\$400	\$0	\$900	\$900
Est. miles to tube manufacturer	1000	1000	1000	1000	1000
Freight to tube manufacturer (\$/trip)	\$1,370	\$1,370	\$1,370	\$1,370	\$1,370
Trips to tube manufacturer	99	99	88	99	99
Value of 10% scrap steel (\$0.15/#)	(\$59,400)	(\$59,400)	(\$59,400)	(\$59,400)	(\$59,400)
Total Estimated Cost for the Option	\$5,068,734	\$6,030,090	\$5,663,768	\$4,893,966	\$6,190,206
Difference in Cost	\$0	\$961,356	\$595,034	(\$174,768)	\$1,121,472
% Difference	0%	19%	12%	-3%	22%

COIL STEEL PRODUCTION AND BAKE

Bakes for the Option

1. Plan to have Metlab perform the raw material bakes for the Option.

- Can perform Option Bakes at \$0.10/# or less
- Can meet the LIGO schedule requirements

2. Alternative 1 - Steel Tech perform bakes for the Option.

- Can perform Option bakes at about \$0.10/#
- Not certain they can meet LIGO schedule requirements

3. Alternative 2 - CBI perform the bakes.

- Can perform Option bakes at about \$0.15/#
- Can meet the LIGO schedule requirements

2. *Remove*

COIL STEEL PRODUCTION AND BAKE

Material Bake for the Qualification Test:

- 1. The beam tube materials will be baked by Metlab.**
 - A company that performs special heat treatments.**
 - Can perform the bakes to the LIGO specifications.**
 - Have a furnace available that can bake up to four full size coils.**

- 2. Three full size coils will be produced and baked.**
 - Thermocouples will be installed into the center of one coil.**
 - Coupons will be removed from all three baked coils for outgas testing .**
 - Heat up and cooldown times will be established for future bakes.**

Material Bake Specification:

LIGO Specification C-CMBS1, "Coil Material Bake Specification"

COIL STEEL PRODUCTION AND BAKE

Material Bakes for the Option

Plan to have Metlab perform the raw material bakes for the Option.

- **Can perform Option Bakes at \$0.10/# or less.**
- **Can meet the LIGO schedule requirements.**

Alternative 1 - Steel Technology perform bakes for the Option.

- **Can perform Option bakes at about \$0.10/#.**
- **Not certain they can meet LIGO schedule requirements.**

Alternative 2 - CBI perform the bakes.

- **Can perform Option bakes at about \$0.15/#.**
- **Can meet the LIGO schedule requirements.**

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. Tube mill plant tours

Naylor Tube	Chicago, Illinois
Northwest Pipe	Portland, Oregon
Roscoe Moss	Los Angeles, California
Tubetec	Sanford, Florida
- c. Pre Qualification Effort: Northwest Pipe and Tubetec

SPIRAL WELDED TUBE MANUFACTURING

NORTHWEST PIPE AND TUBETEC COMPARISON

a. Forming Process

NWP: Pinch roll forming or Cage forming. Currently uses 48" wide coil. Relatively large mill with large drive capacity for thick plate.

Tubetec: "Free forming process, Cylindrical pinch rolls. Currently uses 16" wide coil but developing capability to use 30" wide coil. Relatively small mill.

b. Standard Product Lines

NWP: Large diameter thick wall carbon steel pipe. Some small diameter stainless steel.

Tubetec: Exclusively stainless steel tube and fittings. Typical diameter and thickness.

c. Equipment Capability and Capacity

NWP: Large CS mill must be converted to SS production. Intermittent LIGO production with CS production. 226,000 square foot plant.

Tubetec: No modification of current equipment required. Considering dedicated mill. 65,000 square foot plant with additional 40,000 ft² under construction.

d. Welding Expertise

NWP: Limited experience with TIG welding. CBI assistance required.

Tubetec: Experienced in TIG process.

e. Cleanliness

NWP: Produces primarily carbon steel pipe. Carbon steel contamination will be difficult to prevent.

Tubetec: Stainless steel manufacturer and can more readily limit contamination

SPIRAL WELDED TUBE MANUFACTURING

f. Inspection

NWP: Recently developed capability to perform radioscopy

Tubetec: No experience with radioscopy

g. Tolerances:

NWP: No experience with thin wall. Difficult to predict.

Tubetec: Narrow coil should enable tighter tolerances.

h. End Preparation:

NWP: Currently can not machine or face tube end.

Tubetec: Currently can not machine or face tube end. May be able to manufacture end circumference to close tolerance.

i. Financial Condition

NWP: Rated "fair" by D & B. Currently for sale. 1992 annual sales \$65,960,000.

Tubetec: Rated "strong" by D & B. 1992 annual sales \$7,475,000.

PRE QUALIFICATION RESULTS

NWP: Initial effort on pinch roll mill failed due to inability to maintain edge alignment.

Cage mill maintained close edge alignment and satisfactorily welded from one side.

Tubetec: Acceptable pre qualification.

VENDOR SELECTION FOR QUALIFICATION TEST

Tubetec has been selected by CBI for the qualification test based on performance and cost.

Qualification Test sections will be fabricated from 16" wide coil at Tubetec mill in Sanford.

Following QT, CBI and Tubetec will discuss completion of 30" mill and investigate feasibility of site location.

SPIRAL WELDED TUBE MANUFACTURING COST COMPARISON

PROPOSAL PRICING:

	<u>Northwest Pipe</u>	<u>Roscoe Moss</u>	<u>Tubetec</u>	<u>Naylor</u>
38' Tube Section (without stiffeners)	\$5,757 (1)	---	---	\$7,220
38' Tube Section (with stiffeners)	\$9,131 (1)	\$8,698	---	---
Total Cost	9,575,185 \$7,391,988	10,285,325 ---	7,171,110 ---	\$9,270,480

- Notes:
- (1) Price included material, equipment set-up and end trimming.
 - (2) Roscoe Moss included end trimming and sizing for uniform end circumference.
 - (3) Naylor Pipe would not quote 0.125" material or use of the GTAW process.
Price was based on 3/16" wall submerged arc welded.
 - (4) Total cost is based on un-stiffened tube sections.

26, 1994

SPIRAL WELDED TUBE MANUFACTURING COST COMPARISON

CURRENT PRICING:

	<u>Northwest Pipe</u>	<u>Roscoe Moss</u>	<u>Tubetec</u>	<u>Naylor</u>
Material Costs	\$4,892,537	\$5,579,209	\$5,152,451	---
Tube Mfg. (\$/ft)	\$77	---	\$36	---
Total Tube Mfg.	\$3,870,944	\$4,303,000	\$1,809,792	---
Equipment Costs	\$548,800	\$106,650	\$0	---
11 Material Overhead	\$262,904	\$296,466	\$208,867	---
Total Costs	\$9,575,185	\$10,285,325	\$7,171,110	---

- Notes:**
- (1) Northwest Pipe did not include end trimming.
 - (2) Northwest Pipe declined control of material.
 - (3) Material cost include bake, stretcher/level, slitting, coupon preparation and complete freight to tube manufacturer.
 - (4) Tubetec material costs include 5% mark-up for procurement of materials.
 - (5) Naylor Pipe refused to bid to LIGO Specifications.
 - (6) Roscoe Moss anticipates a 30% scrap loss. 15% is allocated for NWP & Tubetec

FABRICATION PROCESSES

EXPANSION JOINT FABRICATION

REQUIREMENTS

- MAINTAIN THE VACUUM ENVELOPE
- ACCOMMODATE THERMAL GROWTH & SHRINKAGE (CONFIGURATION #3)
- PROVIDE FLEXIBILITY FOR DIFFERENTIAL SETTLEMENT AND MISALIGNMENT
- MAINTAIN CLEANLINESS DURING FABRICATION
- MINIMIZE LOADS TO SUPPORTS AND FOUNDATION BY MINIMIZING VARIATION
- MEET TOLERANCES REQUIRED TO FIELD WELD TO TUBES
- MINIMIZE OVERALL BEAM TUBE COSTS

EXPANSION JOINT TYPE

- THIN WALL EXPANSION JOINT WITH WELD ENDS
- NEAR FULL THICKNESS EXPANSION JOINT WITHOUT WELD ENDS

FABRICATION PROCESSES

THIN WALL EXPANSION JOINT

DEFINITION

- THICKNESS OF 0.048 (18 GAUGE) OR 0.036 (20 GAUGE) IS USED TO FORM THE CONVOLUTIONS

ADVANTAGE

- LOW AXIAL SPRING RATES (2000 #/IN)
- EASIER TO MECHANICALLY FORM

DISADVANTAGE

- TWO WELD ENDS ARE REQUIRED FOR EACH EXPANSION JOINT
- 2 CIRCUMFERENTIAL FILLET WELDS PER EXPANSION JOINT
 - HIGHER LEAK RISK
 - DIFFICULT TO REPAIR
 - 800 ADDITIONAL SEAMS (10,000 FEET)
 - STRESS CONTRACTIONS & RISK OF FATIGUE CRACKS
- REMOVAL OF INSULATION REQUIRED DURING BAKE OUT
- HIGHER RISK OF DAMAGE
 - DURING CONSTRUCTION
 - DURING BAKE OUT

FABRICATION PROCESSES

NEAR FULL THICKNESS EXPANSION JOINT

DEFINITION

- THICKNESS THAT CAN BE WELDED DIRECTLY TO A BEAM TUBE (THICKNESS 0.127), ELIMINATING WELD ENDS
 - 11 GAUGE (0.125")
 - 12 GAUGE (0.105")

ADVANTAGE

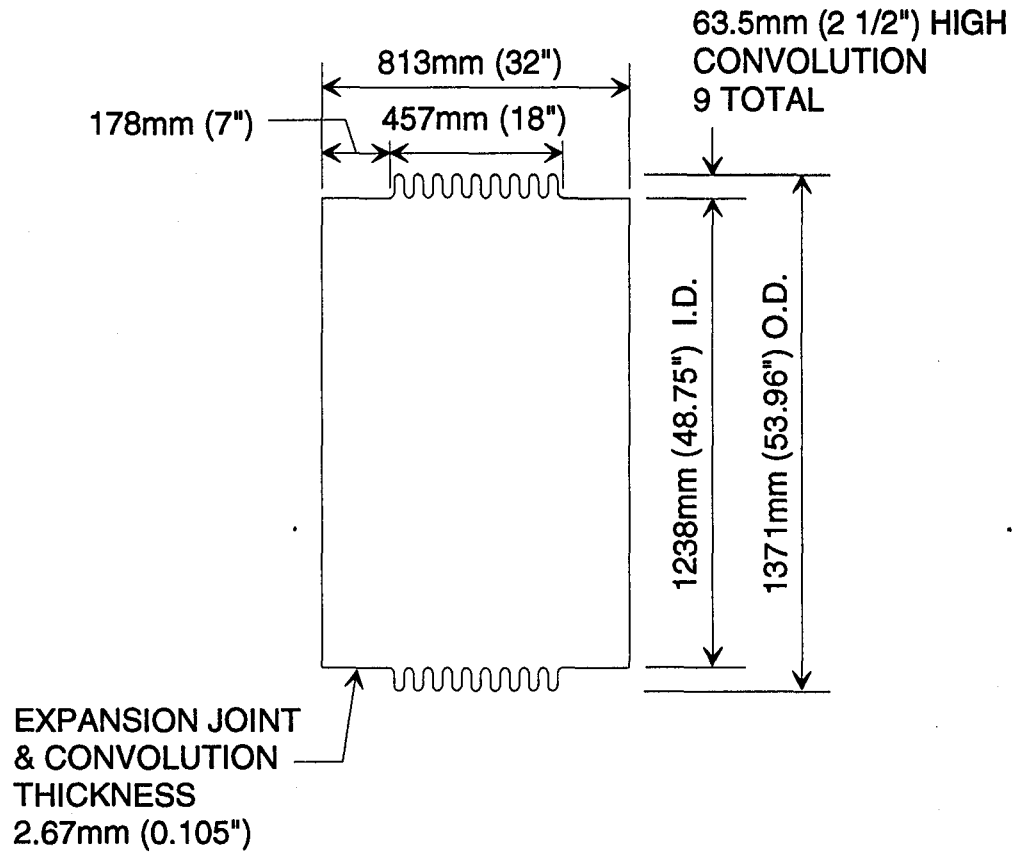
- LOWER COST (AS MUCH AS 50%)
- ELIMINATES WELD ENDS
- WELDING DIRECTLY TO TUBES ELIMINATES 2 CIRCUMFERENTIAL SEAMS, 800 TOTAL
- FAVORED BY EXPANSION JOINT MANUFACTURES
- LESS LEAK RISK
- RISK OF DAMAGE IS REDUCED
- HIGHER TORSION CAPACITY

DISADVANTAGE

- HIGHER AXIAL LOAD DURING BAKE OUT (4 TIMES HIGHER)

FABRICATION PROCESSES

NEAR FULL THICKNESS EXPANSION JOINT



FABRICATION PROCESSES

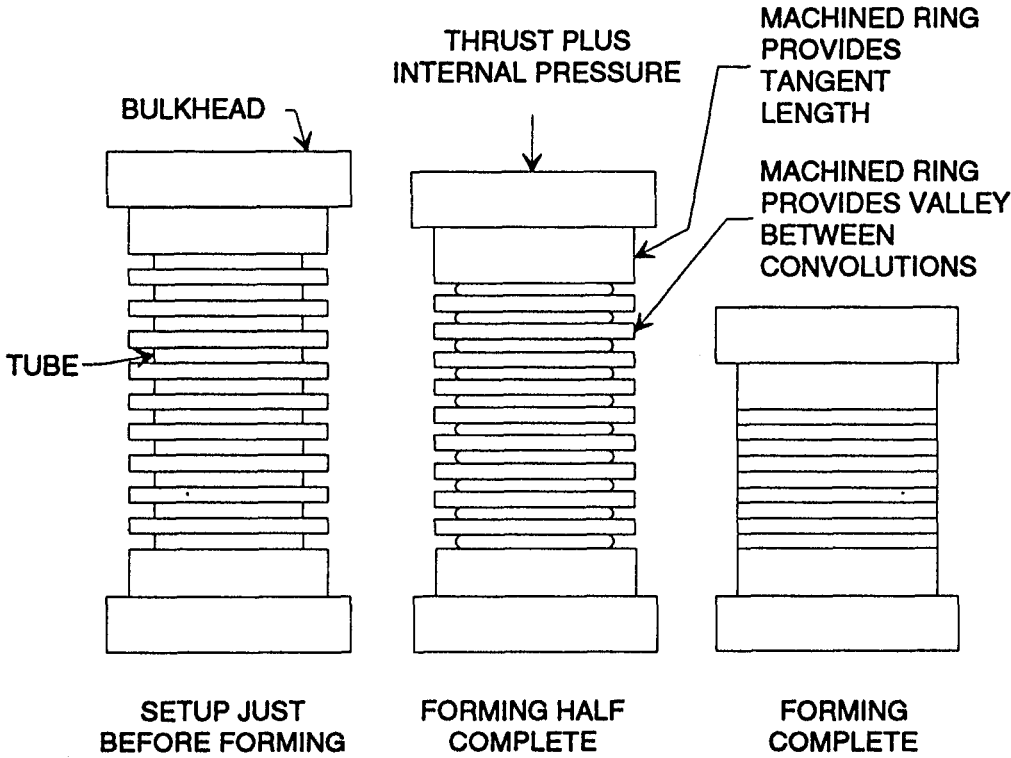
MECHANICAL FORMING OF EXPANSION JOINTS

- ROLL FORMING
 - THINS THE BASE MATERIAL
 - NOT USED FOR PRECISION PARTS
 - NOT SUITABLE FOR THE LIGO EXPANSION JOINTS

- EXPANDING MANDREL (PUNCH FORMING)
 - CONVOLUTIONS ARE FORMED BY EXPANDING AN INTERNAL MANDREL WITH SEGMENTED DIES
 - CONVOLUTIONS ARE THEN REROLLED AFTER PUNCHING
 - AXIAL SPRING RATES MAY VARY BY AS MUCH AS $\pm 30\%$
 - SIGNIFICANT AMOUNT OF CONTACT IS MADE ON THE INTERNAL SURFACE
 - CONVOLUTIONS ARE MADE INDIVIDUALLY, CONCENTRICITY ERROR ACCUMULATES

FABRICATION PROCESSES

HYDROFORMING OF EXPANSION JOINTS



FABRICATION PROCESSES

HYDROFORMING OF EXPANSION JOINTS

STEPS IN HYDROFORMING

- PLACE MACHINED RINGS ON TUBE
- PLACE TUBE BETWEEN BULKHEADS
- FULL TUBE WITH POTABLE WATER
- INCREASE PRESSURE AND LOWER TOP BULKHEAD
- EXPANSION JOINT IS COMPLETE WHEN ALL RINGS TOUCH

ADVANTAGES WITH HYDROFORMING

- CONSISTENCY
- CLEANLINESS - ONLY WATER TOUCHES THE INSIDE DURING FORMING
- HYDROFORMING HELPS PROVIDE THE PROPER CIRCUMFERENCE AT THE ENDS
- HIGHER CONFIDENCE OF LONGITUDINAL SEAM, SUBJECTED TO HIGH HYDROFORMING PRESSURE
- THE BEST METHOD TO MEET LIGO REQUIREMENTS

FABRICATION PROCESSES

EXPANSION JOINT MATERIAL

- BAKE OUT OF MATERIAL DOES NOT EFFECT EXPANSION JOINT FORMING OR FATIGUE LIFE, PER:
 - MATERIAL SUPPLIERS
 - EXPANSION JOINT FABRICATORS
 - CBI METALLURGY EXPERTS

FABRICATION PROCESSES

HYDROFORMING OF EXPANSION JOINTS

STEPS IN HYDROFORMING

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FABRICATION PROCESSES

EXPANSION JOINT MATERIAL

- BAKE OUT OF MATERIAL DOES NOT EFFECT EXPANSION JOINT FORMING OR FATIGUE LIFE, PER:
 - MATERIAL SUPPLIERS
 - EXPANSION JOINT FABRICATORS
 - CBI METALLURGY EXPERTS

FABRICATION PROCESSES

EXPANSION JOINT DESIGNS

VENDOR	MEET SPEC	Forming Method	# of con	Thickness	Con Height	Con Radius	Tangent Length	Total Length
American Boa	YES	Expand Mandrel	8	2.67mm 0.105"	70mm 2.75"	7.3mm 0.287"	178mm 6"	538mm 21.18"
Hyspan	YES	Expand Mandrel	6	2.67mm 0.105"	79 3.125	16 0.625	178 & 102 6 & 4	635 25
Microflex	NO	Expand Mandrel	6	2.67mm 0.105"	89 3.5	13 0.5	* / ?	* / ?
Pathway	YES	Hydro.	9	2.67mm 0.105"	64 2.5	13 0.5	178 7	737 29
Senior Flexonics	NO	Expand Mandrel	12	2.67mm 0.105"	57 2.25	14.3 0.5625	* 178, 6", weld end	813 32

* Does not meet CBI specification

Con = Convolutions

FABRICATION PROCESSES

EXPANSION JOINT DESIGNS

VENDOR	Spring Rates				
	Axial kN/m #/in	% Error See Note	Lateral kN/m #/in	Angular MN-m/rad #-in/Deg	Torsional MN-m/rad kip-in/Deg
American Boa	1397 7978	±10	59,573 340,172	300.3 46,392	?
Hyspan	1427 8149	±10	25,803 147,341	456.3 44,202	?
Microflex	115 7860	* ±20	40,902 233,554	300.2 46,368	?
Pathway	1443 8242	±5	17,550 100,217	305.7 47,226	206,000 31,819
Senior Flexonics	1306 7457	±10	6793 38,790	273.9 42,310	155,800 24,060

* Does not meet CBI specification

Note: % Error is the variation from the actual average of axial spring rates. The average axial spring rates may vary by ±10 from the theoretical values listed in the table.

FABRICATION PROCESSES

EXPANSION JOINT BUDGET PRICES

Vendor	10/92 Quote		2/94 Quote		4/94 Quote	
	Price Each	Total Price 1276	Price Each	Total Price 400	Price Each	Total Price 400
American Boa			\$ 3,700	\$ 1,480,000	\$ 3,226	\$1,290,231
Hyspan	\$ 900	\$ 1,148,400	\$ 1,400	\$ 560,000	\$ 2,002	\$ 800,610
Microflex	\$ 1,700	\$ 2,169,200				
Pathway	\$2,500	\$ 3,190,000	\$ 3,600	\$ 1,440,000	\$ 3,057	\$ 1,222,709
Senior Flexonics	\$ 2,900	\$ 3,700,400			\$ 4,900	\$1,960,141

FABRICATION PROCESSES

EXPANSION JOINT SELECTION

- HYSpan SELECTED TO SUPPLY QUALIFICATION TEST EXPANSION JOINT

- QUALIFICATION TEST WILL ASSESS HYSpan EXPANSION JOINT
 - CLEANLINESS
 - DIMENSIONAL TOLERANCES
 - AXIAL SPRING RATE
 - DETERMINE ACCEPTABILITY FOR CONSTRUCTION OPTION

- PATHWAY WILL BE CONSIDERED FOR THE CONSTRUCTION OPTION IF THE HYSpan EXPANSION JOINT IS UNACCEPTABLE

- QUALIFICATION TEST WILL DETERMINE IF CHANGES ARE REQUIRED IN THE EXPANSION JOINT SPECIFICATION

FABRICATION PROCESSES

BAFFLE FABRICATION

Geometry Requirements

- Installed baffles to have a helical profile with 30 cm pitch & 30 cm overlap
- Installed baffles to have a 6.0 cm (± 0.2 cm) radial projection
- Installed baffles to have a 35° ($\pm 3^\circ$) slope in relation to the beam tube wall
- Stainless steel material not to exceed 0.130" in thickness

Installation Requirements

- Baffle installation to require no welding or fastening to the tube wall
- Baffles to be sprung into place and held securely to the tube wall by friction

Baffle Configuration

- Initial baffle configuration: "V" shaped with unequal legs
- Caltech permitted optional use of single ribbon screw flight configuration
- Single ribbon screw flight configuration used for the baffles:
 - Easier to fabricate than "V" shaped baffles

FABRICATION PROCESSES

BAFFLE FABRICATION

Fabrication Methods

- Initial fabrication method pursued: rolling continuous flat bar about its strong axis, while at the same time "coning" the bar to form the helical profile
- This approach proved to be impractical:
 - All fabricators contacted stated that the required dimensions of the flat bar result in too high of a depth-to-thickness ratio ($d/t = 32 \text{ min}$) to roll the bar without damage to material.
 - Required baffle thickness --- 30% greater than the maximum permissible thickness of 0.130" in order to pursue this method of fabrication
 - Method not pursued
- Baffle to be an assembly of annular segments, slip rolled to form the required helical profile

FABRICATION PROCESSES

BAFFLE FABRICATION

First Two Prototype Baffles

- Single ribbon configurations with thicknesses of 0.059" and 0.078", consistent with intent of minimizing baffle thickness
- Fabricated from two flat annular segments, butt-welded and slip rolled to conical shape
- Too flexible, did not support own weight, did not take the shape of the fit up tube

Third Prototype Baffle

- Single ribbon configuration with thicknesses of 0.115"
- Fabricated from two flat annular segments, butt-welded and left flat (not slip rolled)
- Good tight fit to tube obtained, except at baffle ends
- Rolling only the ends of baffle attempted, poor results obtained

Conclusions from Observed Results of Prototypes

- Thin gage baffle not suitable
- A flat baffle or a partially flat / rolled baffle not suitable
- A tie ("spacer bar") required to prevent ends of installed baffle from displacing

FABRICATION PROCESSES

BAFFLE FABRICATION

Baffle Fabrication Procedure

- Baffles and spacer bars fabricated from 304L stainless steel, 0.105" thick
- Baffle material air baked in coil form, coupons tested for hydrogen outgassing
- Baffle material shipped to fabricator in sheet form
- Each baffle fabricated from four flat annular segments to minimize scrap
- Baffle segments cut from sheets by waterjet cutting in order to prevent re-introduction of hydrogen into baked material
- Annular segments butt welded together, GTAW process with inert gas purge
- Slip roll assembly to form the finished baffle
- Steam clean and seal baffles and spacer bars

BUDGET PRICING - BAFFLES

Vendor	Location	Budget Quote	
		Per Baffle	Total (932 Baffles)
Meyer Tool & Manufacturing	Oak Lawn, IL	\$284	\$264,688
Source Industrial	Chicago, IL		
Kentucky Metals	New Albany, IN	\$460	\$428

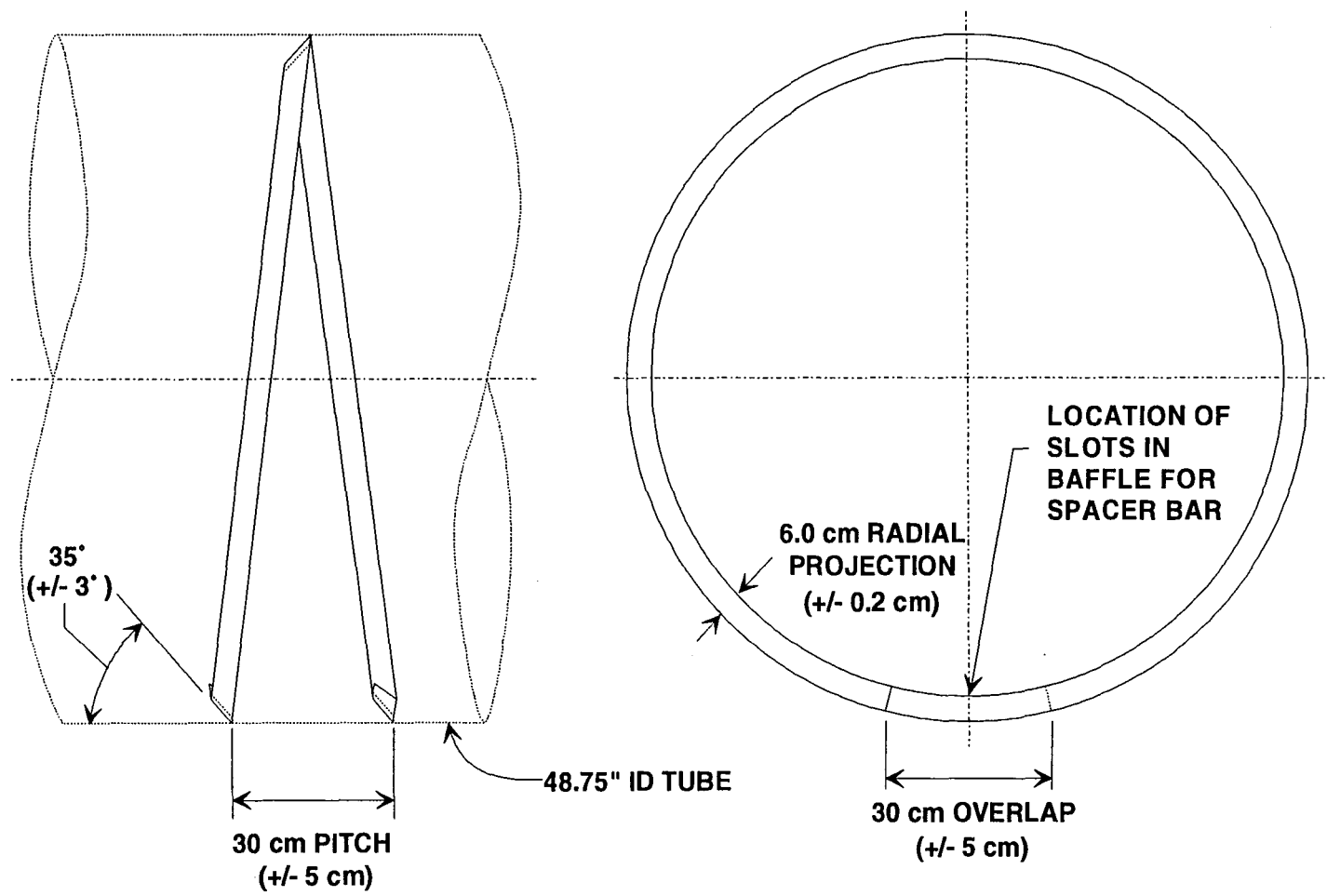
+ \$5 / baffle
for
separation

Budget Prices Include:

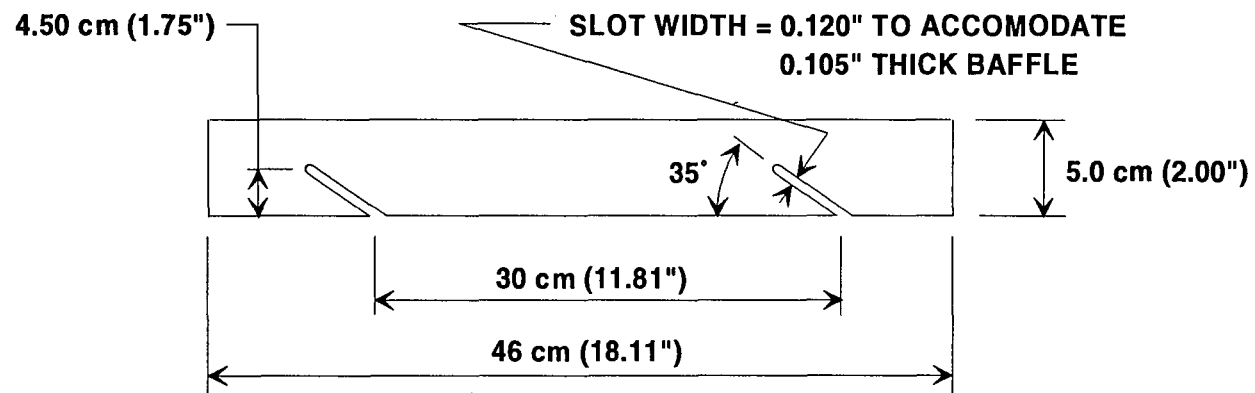
1. Cost of air-baked 304L material (\$34 per baffle, \$32,000 total)
2. Spacer bar fabrication, cleaning, packaging and shipping

BAFFLE - INSTALLED DIMENSIONS & CONFIGURATION

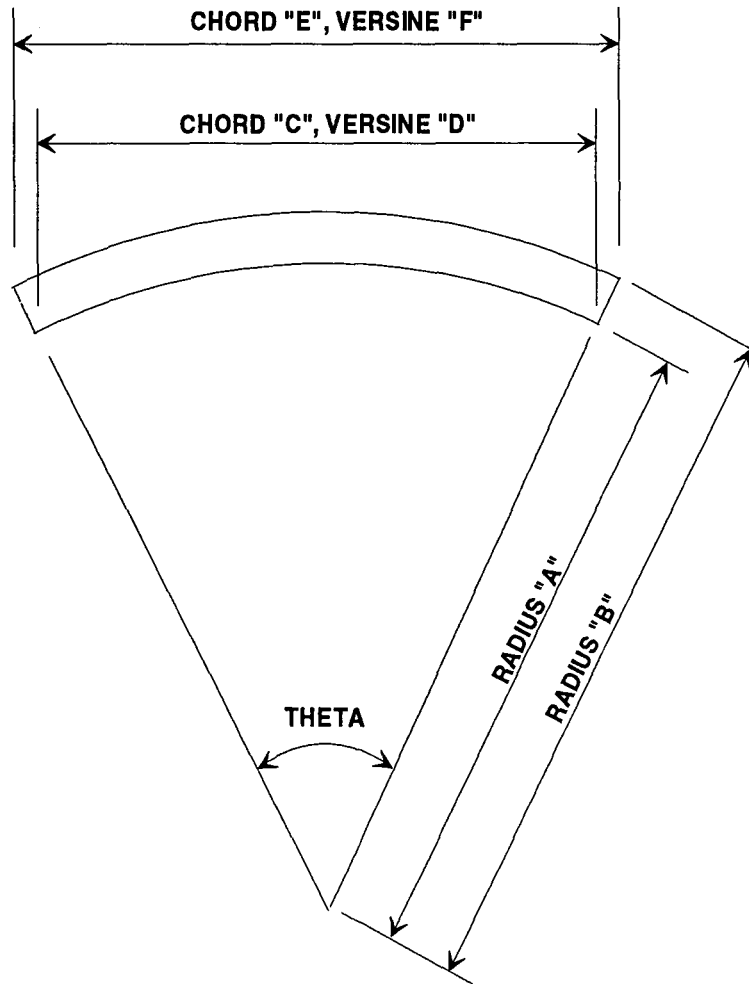
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BAFFLE SPACER BAR



DIMENSIONS OF BAFFLE ANNULAR SEGMENTS



EACH OF THE FOUR BAFFLE SEGMENTS

RADIUS "A" = 41.782"
 RADIUS "B" = 45.900"
 THETA = 51.62 degrees
 CHORD "C" = 36.384"
 VERSINE "D" = 4.168"
 CHORD "E" = 39.970"
 VERSINE "F" = 4.579"

EACH OF THE TWO BAFFLE ASSEMBLIES

RADIUS "A" = 41.782"
 RADIUS "B" = 45.900"
 THETA = 103.24 degrees
 CHORD "C" = 65.508"
 VERSINE "D" = 15.842"
 CHORD "E" = 71.964"
 VERSINE "F" = 17.403"

FABRICATION PROCESSES

BEAM TUBE SUPPORT FABRICATION

Material

- Supports to be fabricated from both carbon steel (A36, A500 Grade B) and stainless steel (304L) components
- All carbon steel will be galvanized to provide corrosion resistance

Fabrication

- All support components to be supplied by a qualified metal plate fabricator fabricator
- Support components can be fabricated using "standard" fabrication processes, no unusual processes necessary
- Shop assemblies will be used as much as possible to minimize field labor and provide a controlled fabrication environment

BUDGET PRICING - BEAM TUBE SUPPORTS

Vendor	Location	Budget Quote for One ...			
		Fixed Supp't		Guided Supp't	
Piping Accessories	Cheek, TX	\$845	(\$1.21 / lb)	\$2,091	(\$1.31 / lb)
Tri-City Fabricating	Kennewick, WA	\$1,210	(\$1.73 / lb)	\$3,460	(\$2.16 / lb)
PHS Industries	Waggaman, LA	\$1,485	(\$2.12 / lb)	\$3,582	(\$2.24 / lb)

Vendor	Location	Budget Quote for All ...		
		392 Fixed Supp'ts	400 Guided Supp'ts	Σ
Piping Accessories	Cheek, TX	\$331,240	\$836,400	\$1,167,640
Tri-City Fabricating	Kennewick, WA	\$474,320	\$1,384,000	\$1,858,320
PHS Industries	Waggaman, LA	\$582,120	\$1,432,800	\$2,014,920

Budget prices include material, fabrication shop labor, galvanizing, and shipping

FABRICATION PROCESSES

BEAM TUBE STIFFENER FABRICATION

Requirements

- Fabrication method must economically produce ~ 19,560 stiffeners
- Fabricated stiffeners must facilitate fit up and attachment to beam tube

Stiffener Material

- Stiffener material will be 304L stainless steel:
 - Excellent corrosion resistance
 - Painting not required
 - Facilitates the stiffener-to-tube welding process
 - Less expensive (installed) than carbon steel stiffeners
- Use of carbon steel stiffeners initially considered but dismissed:
 - Extremely susceptible to corrosion
 - Field painting of stiffeners required; labor- & time-intensive
 - Periodic inspection and maintenance required
 - More costly (installed) than stainless steel stiffeners

BEAM TUBE STIFFENER MATERIAL COST STUDY

Length of standard bar used for stiffener fabrication =	14.00 ft	
Unit cost of 304L stainless steel standard bar stock =	\$1.55 lb/ft	(Joseph T. Ryerson & Son, Inc.)
Unit cost of A36 carbon steel standard bar stock =	\$0.31 lb/ft	(Joseph T. Ryerson & Son, Inc.)
Unit weight of a 3/16" x 1-3/4" standard bar =	1.12 lb/ft	
Unit weight of a 3/16" x 2" standard bar =	1.28 lb/ft	
Unit weight of a 1/4" x 1-3/4" standard bar =	1.49 lb/ft	
Unit weight of a 1/4" x 2" standard bar =	1.70 lb/ft	
Unit cost of a 1-sided stiffener fillet weld =	\$15.00	(Houston Welding Estimate)

Cost Item (Per Stiff'r)	Stainless Steel Stiffener Standard Bar Size		Carbon Steel Stiffener Standard Bar Size		
	3/16" x 1-3/4"	3/16" x 2"	3/16" x 1-3/4"	1/4" x 1-3/4"	
Material	\$24.30	\$27.78	Not available	\$6.47	See Note 1
Painting	\$0.00	\$0.00	----	\$12.00	
Welding	\$15.00	\$15.00	----	\$30.00	
Σ	\$39.30	\$42.78	---	\$48.47	

Note: The following items below have not been factored into the cost study, and will increase the cost of carbon steel stiffeners:

1. Carbon steel stiffeners would be shop primed except for the inside edge for welding. The inside edge would be wire brushed prior to welding on both sides. After final leak testing, the stiffeners would be spot blasted and primed, followed by final painting. The actual cost of corrosion protection for a stiffener would likely exceed the \$12.00 shown.
2. The costs shown do not include the increase in construction time due to the need for two-sided welding on the carbon steel stiffeners.
3. The costs shown do not include the inspection and maintenance of the painted carbon steel stiffeners over the 20 year operational life of the beam tube modules.

FABRICATION PROCESSES

BEAM TUBE STIFFENER FABRICATION

Stiffener Fabrication

- Stiffeners to be fabricated from $3/16"$ x $13/4"$ x 14'-0" 304L standard bar stock
 - Small moment of inertia required for stiffener design
 - Bars of this standard size can be purchased "off-the-shelf"
- Stiffeners formed by rolling one piece bar into a full circle with a 4" overlap
 - Rolling process not a manhour-intensive operation
 - Produces a stiffener with an inside radius within $1/4"$ of the required radius
 - Tolerances achieved within bounds necessary for fitup and welding

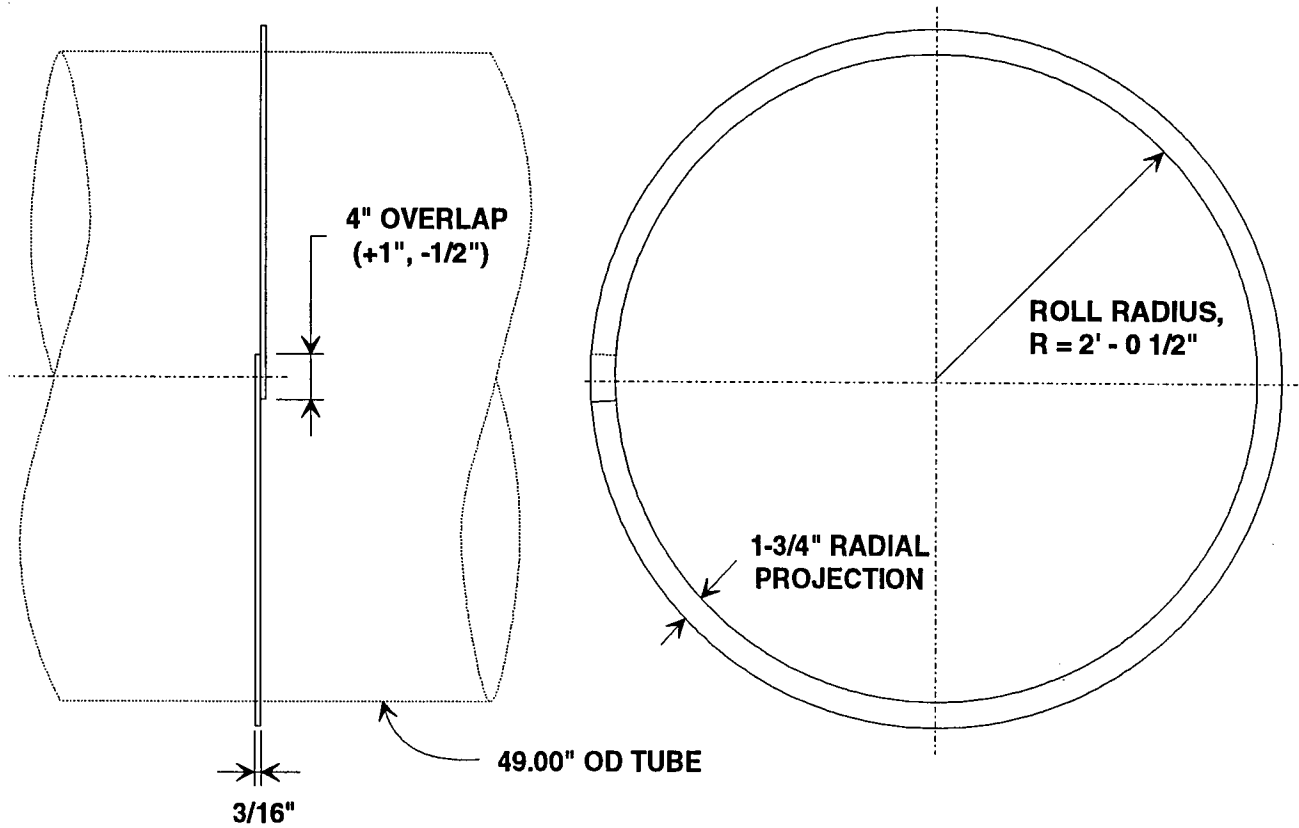
Stiffener Installation

- Expand overlapping stiffener ends
- Position stiffener on tube
- Release overlapping ends of stiffener
- Fit and weld

BUDGET PRICING - BEAM TUBE STIFFENERS

Vendor	Location	Budget Quote	
		Per Stiff'r	Total (19,552 Stiff'rs)
Monarch Machine & Tool	Pasco, WA	\$34	\$664,768
Meyer Tool & Manufacturing	Oak Lawn, IL	\$41	\$801,632
Kentucky Metals	New Albany, IN	\$80	\$1,564,160
Source Industrial	Chicago, IL		

BEAM TUBE STIFFENERS



WELDING TOPICS

- FILLER WIRE EVALUATION
- SPIRAL WELD PROCEDURE
- CIRCUMFERENTIAL BUTT WELDS
- STIFFENER ATTACHMENT WELDS
- PUMP PORT WELDING
- REPAIR WELD PROCEDURES
- STRUCTURAL WELDING PROCEDURES
- SUPPORT WELDING

FILLER WIRE EVALUATION

CLEANED AND BAKED FILLER WIRE:

- **Standard ER308L filler wire cleaned per WMS-ER308L/COUP**
 - **Remove any hydrocarbons from the surface due to the forming process of the wire manufacturer**
- **Wire baked per Caltech Specification 1100007**
 - **Reduce the hydrogen content of the weld wire**
- **Re-cleaned after bake procedure**
 - **Remove any residual contamination (oxides) due to the baking procedure to aid in the welding process**

(cleaning / bake carried out in the Houston Weld Lab)

FILLER WIRE EVALUATION

RESULTS:

- **Outgassing Results:**

- **Outgassing approximately 1 1/2 times outgassing rate of plain coupons**
- **Cleaned and baked wire acceptable per Caltech**

- **Cost Comparison of Weld Wire:**

Cleaned and baked ER308L weld wire (cleaning speed = 40 ipm)

- **The ESAB Group - \$237 per pound. (\$7,110,000 total for project)**
- **Lincoln Electric - No bid. (would not supply wire in this condition)**
- **Standard wire - \$4 per pound. (\$120,000 total for project)**

Alternate cleaning and bake procedure (faster cleaning speed = 200 ft/min)

- **The ESAB Group - \$38 per pound. (\$1,140,000 total for project)**
- **Lincoln Electric - No bid. (would not supply wire in this condition)**
- **Standard wire - \$4 per pound. (\$120,000 total for project)**

FILLER WIRE EVALUATION

WIRE FEED CHARACTERISTICS:

Cleaned and Baked Weld Wire

- **Unable to feed cleaned and baked wire through GMAW units**

Stiffener Fitting/Splices, Pump Port Ring and Supports

- **Would feed through GTAW (Gold Track) units**

Circumferential Welding Joints

STANDARD WELD WIRE:

- **Outgassing test coupons have been welded**

Outgassing rate approximately double that of the cleaned/baked weld wire

- **Standard weld wire will be used for the Qualification Test**

SPIRAL WELD PROCEDURE

REQUIREMENTS:

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

SPIRAL WELD PROCEDURE

AUTOGENOUS WELDING:

- **Advantages:**

- **Conforms to Caltech Specifications**

- **Disadvantages:**

- **Will not provide a full thickness weld joint due to weld shrinkage and gaps**
 - **Joint fit-up must be near perfect**
 - **Higher costs due to extremely tight tolerances**
 - **Higher costs due to longer fabrication time**
 - **Higher potential for repairs**

SPIRAL WELD PROCEDURE

KEY PARAMETERS:

- a. Mill capabilities.**
- b. Ability of the mills to adapt to our needs.**
- c. Fast welding rate to be economical.**
- d. High quality welds.**
- e. Repeatable (approximately 16 km of total tube length).**

SPIRAL WELD PROCEDURE

TUBE MANUFACTURER RECOMMENDED PROCEDURE:

Two pass GTAW procedure

- **Inside pass to be autogenous (without filler material)**
- **Outside pass to use ER308L filler material**
- **Shielding gas near 50:50 argon and helium mixture**

TUBE SPIRAL WELD PROCEDURE:

- **Inside pass autogenous GTAW process**
- **Outside pass using ER308L filler material**

SPIRAL WELD PROCEDURE

QUALITY CONTROL:

- **X-Ray Microscopy:**
 - **Image Intensifiers - better resolution than conventional X-ray methods**
 - **Real time (not on-line)- 100% radiography**
 - **Approx. \$100,000 for complete set-up**

- **Remote Video System:**
 - **Video record of welding arc / pool**
 - **Approx. \$20,000 for dual camera set-up**

- **Visual Inspection:**
 - **Complete visual inspection by tube supplier and on site**
 - **Bead contour and width defines depth of penetration**

- **Random Radiography:**
 - **Spot radiography to assure 100% fusion**

SPIRAL WELD PROCEDURE

QUALITY CONTROL (CONT.):

Quality Control Method:

- **Visual Inspection**
 - Complete visual inspection of tube sections
 - Variations in bead contour and width indicates suspect areas
(Previous welding development has indicated that depth of penetration can be determined from bead contour and width)
 - Variations in welding parameters can be identified as suspect areas

- **Random Radiography**

Spot radiography on the first group of tubes, by the tube manufacturer, to confirm welding procedure

Spot radiography on the first tube produced after any shut down of tube manufacturing or change in manufacturing process

Spot radiography of any suspect area found during visual inspection

CIRCUMFERENTIAL BUTT WELD

EQUIPMENT SELECTION (DIMETRICS GOLD TRACK):

- **Machine welding**
 - **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**
 - **GTAW process with or without filler metal**
- **Can weld all passes from the outside**
 - **Minimize personnel on the inside of the tube**
- **CBI has experience with this equipment**

CIRCUMFERENTIAL BUTT WELD

WELDING PROCEDURE DEVELOPMENT:

- **Determined optimum welding procedure**
 - **One (1) pass autogenous**
 - **One (1) pass with filler metal**
 - **Two (2) pass - autogenous and with filler metal**
- **Determined best shielding and purge gas**
 - **Argon and Nitrogen purge gas**
 - **Mixtures of argon with helium and 100% Argon**
- **Determined tolerances for gap variation and misalignment**
 - **Zero gap up to 0.100" gap**
 - **Zero offset up to 0.100" offset**

CIRCUMFERENTIAL BUTT WELD

FIT-UP EQUIPMENT:

- **Deerman Rim Clamp:**
 - **Large and bulky - normally used for thick walled pipe**
- **Deerman Chain Clamp:**
 - **Light weight and time consuming - normally used for smaller diameter pipe**
- **CBI Equipment:**
 - **Developed equipment to utilize both types of clamping operations due to the special requirements of the LIGO Project**
 - **Easy to attach and handle**
 - **Obtains adequate fit-up in a short amount of time**

PURGE RING DEVICE:

- **Custom made to efficiently place and purge weld joint**
- **Provides helium for HMS leak testing**

CIRCUMFERENTIAL BUTT WELD

WELDING PROCEDURE:

- **Dimetrics Gold Track Welding Unit**
- **Autogenous root pass with filler metal on second pass - all passes from outside**
- **Shielding gas to be 60% Argon - 40% Helium**
- **Purge gas to be 100% Argon**
- **Vertical welds may be welded uphill or downhill**
 - **Welding will be continuous - 360°**
- **Special fitting and purging devices**

STIFFENER ATTACHMENT WELDS

PROCESS SELECTION - GMAW:

- **Short circuit GMAW process** **14 - 15 ipm**
 - **Low heat input**
 - **Weld spatter that requires post cleaning (CBI standard practice)**
 - **Low tolerance for torch positioning**

- **Fluxed cored arc welding (FCAW) process** **16 ipm**
 - **Higher heat input than short-circuit**
 - **Clean as-welded appearance**
 - **Tolerates variations in torch position**
 - **Rejected at the PDR due to the higher moisture content of the flux**

- **Surface tension transfer GMAW process** **12 - 14 ipm**
 - **Technique minimizes weld spatter**
 - **Expensive gas mixture (Tri-Mix)**
 - **Slow travel speeds**

- **Solid wire GMAW process (vertical downhill position)** **36 - 38 ipm**
 - **High travel speeds**
 - **Clean as welded appearance**

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 than for intermittent fillet welds resulting in a higher filler wire cost**
 - **Low equipment cost and easy to weld**
- **Intermittent fillet welds on both sides**
 - **Requires less filler metal than above details**
 - **More starts/stops which are potential weld repairs (approx. 2 million)**
 - **Expensive operating equipment to backstep welding**

STIFFENER ATTACHMENT WELDS

STIFFENER FITTING DEVELOPMENT:

- **Fitting Device:**
 - **Special clamp to pull stiffener together at the splice**
 - **Rounds the tube and reduces joint gap within welding tolerances**
- **Fitting Without Tacking:**
 - **Longitudinal movement of the stiffener during welding due to weld shrinkage (nearly 2 inches)**
 - **Bracing stiffener during welding resulted in joint gaps greater than welding tolerances**
- **Fitting With Tacking:**
 - **Tacks spaced approx. 18 inches apart provided acceptable weld joint**
 - **Tacking on the same side of welding:**
 - Excessive tilt**
 - Due to the high welding speeds, the tacks present problems to welding**
 - **Tacking on opposite side of welding:**
 - Minimized tilt of welded stiffener**

STIFFENER ATTACHMENT WELDS

WELDING PROCEDURE:

- **Solid wire (ER308L) GMAW process**
 - **Most suitable and economical**
 - **CBI has experience with equipment and process**

- **Shielding gas 98% Argon - 2% Oxygen**
 - **Common and inexpensive gas mixture**

- **Purge gas 100% Nitrogen**
 - **Inexpensive**
 - **Vaporized liquid nitrogen provides fast efficient method for purging tube sections**

- **Travel speed 36 inches per minute**
 - **Two times faster than other processes evaluated**
 - **Results in approximately 4 1/2 minute arc time per stiffener**

- **Continuous fillet weld on one side only**
 - **Tacks on opposite side - minimizes tilt on as welded stiffener to max. 6°**
 - **Only one start and start per stiffener (two per support stiffeners)**

PUMP PORT WELDING

WELDING DEVELOPMENT:

- **Continuous fillet weld on inside with intermittent fillet welds on outside of tube**
 - **Must be welded from inside of tube, limited space, welder safety**
 - **Higher potential for damage to inside of tube**

- **Full penetration weld from outside of tube**
 - **Can NOT be successfully welded from the outside**
 - **Excessive heat input due to full penetration**
 - **Heat input can not be controlled due to joint configuration**

- **Combination inside/outside welding**
 - **Inside pass provides adequate metal for welding outside weld passes**
 - **Outside weld pass provide full thickness weld joint**

FITTING EQUIPMENT:

- **Jack/purge device**
 - **Applies outward pressure - quick and efficient method for inside purge**

- **Fitting device**
 - **Quick method of holding pump port tightly to tube wall for fitting**

PUMP PORT WELDING

WELDING PROCEDURE:

- **Joint detail - 1/16" land with 60° bevel**
 - **Bevel allows for a visual inspection to assure 100% penetration and fusion**
- **Inside pass welded autogenous using the GTAW process**
 - **Using manual pulsed arc GTAW process**
 - **Allows control of heat input and weld penetration**
- **First outside pass welded autogenous**
 - **Using manual pulsed arc GTAW process**
 - **Assures complete fusion of weld passes**
- **Second outside pass welded using ER308L filler material**
 - **Provides full thickness weld joint with smooth outside bead contour**

PUMP PORT WELDING

VISUAL INSPECTION:

- **Visual inspection of outside of pump port after the inside autogenous weld pass**
- **Defects that require weld repair before outside weld passes:**
 - **Any linear indication**
 - **Non fusion**
 - **Incomplete penetration of land**
 - **Any suspect area that may cause non-fusion
(i.e. not a smooth bead contour)**
- **Visual inspection will assure complete 100% penetration/fusion of weld joint**

REPAIR WELD PROCEDURES

REPAIRS:

- **Repairs shall be GTAW or GMAW process (WPS-ER308L/REPAIR)**
 - **GTAW process to be used for any weld repair exposed to a vacuum**
- **Methods to purge and reduce weld shrinkage shall be used**
 - **Any full thickness weld repair to the tube wall shall use a repair device to reduce weld shrinkage**
- **Repairs to suspect areas found after the inside pass of the pump port:**
 - **All suspect areas shall be purged and re-welded from the inside using the same technique and procedure**
- **All weld repairs shall be re-inspected and tested**
- **All weld repairs shall be documented according the Quality Assurance Manual**

STRUCTURAL WELDING PROCEDURES

SHIELDED METAL ARC WELDING PROCESSES:

- **E7018** - Used for the welding of carbon steel to carbon steel only
 - A36, A500 gr. B or similar

- **E308L** - Used for the welding of stainless steel to stainless steel only
 - A240 type 304L welded together or similar

- **E309** - Used for the welding of stainless steel to carbon steel only
 - A240 type 304L welded to A36 or similar

***** Above procedures are to be used for structural components as required *****

These procedures shall not be used to weld to the tube wall, expansion joint, pump port, etc

SUPPORT WELDING

GUIDED SUPPORTS:

- Bolted connection will require a small amount of weld metal
- This weld joint is considered structural
- Process may be either GMAW or SMAW
- (WPS-ER308L/GMA or WPS-E308L/STRUCT)

FIXED SUPPORTS:

- Gusset to tube wall - considered within pressure boundary
 - Must use GMAW or GTAW using a back purge
 - Recommend WPS-ER308L/GMA due to the higher deposition rate
 - Welded while the tube is in the stiffener welding station under purge
- Support legs to support stiffener - considered structural
 - Process may be either GMAW or SMAW
 - (WPS-ER308L/GMA or WPS-E308L/STRUCT)

PUMP PORT WELDING

RECOMENDED WELDING PROCEDURE:

- a. Joint detail - 1/16" land with 60° bevel.**

Bevel allows for a visual inspection to assure 100% penetration and fusion.

- b. Inside pass welded autogenous using the GTAW process.**

Using manual pulsed arc GTAW process.

Allows control of heat input and weld penetration.

- c. First outside pass welded autogenous.**

Using manual pulsed arc GTAW process.

Assures complete fusion of weld passes.

- d. Second outside pass welded using ER308L filler material.**

Provides full thickness weld joint with smooth outside bead contour.

PUMP PORT WELDING

FITTING EQUIPMENT:

a. Jack/purge device.

**Applies outward pressure to tube wall to minimize weld shrinkage.
Provides quick and efficient method for inside purge.**

b. Fitting device.

Quick method of holding pump port tightly to tube wall for fitting.

PUMP PORT WELDING

SUMMARY:

- a. **Manual GTAW process.**
Machine equipment too large to weld inside of pump port.
Limited number of pump ports - more economical to weld manually.
Pulsed arc technique to control heat input and weld penetration.
- b. **Visual inspection.**
Outside inspection after first inside weld pass assures complete penetration and fusion.
- c. **Fitting/purging devices.**
Quick and efficient method of fitting and purging.
Minimizes weld shrinkage.
- d. **Reinforcing ring welding.**
Welded using the gas metal arc welding (GMAW) process.
Welded while tube section is in stiffener welding station under 100% nitrogen purge.

REPAIR WELD PROCEDURES

REQUIREMENTS:

- a. All welds exposed to a vacuum must be welded by the gas tungsten arc welding (GTAW) process.**
- b. All welds must be full penetration with a finished full thickness weld joint.**
- c. All vacuum welds shall be, wherever possible, internal and continuous.**
- d. Filler wire shall not be used on welds exposed to vacuum.**

REPAIR WELD PROCEDURES

KEY PARAMETERS:

a. Location and type of repair.

Fillet weld repairs to pump port, stiffener, etc.

Full thickness weld repairs (burn throughs, etc.)

Repairs to first inside pass of pump port.

b. Shrinkage due to welding.

Full thickness weld repairs will have high shrinkage.

7. **c. Quality weld repairs.**

d. Inspection of weld repairs.

REPAIR WELD PROCEDURES

PROCEDURE SELECTION:

Repairs to fillet welds:

- a. All repairs to fillet welds may be made using either GTAW or GMAW processes.**
- b. Weld defect shall be removed to an acceptable level.**
- c. Welded using approved repair procedure (WPS-ER308L/REPAIR).**
- d. Weld repair shall be visually inspected.**

REPAIR WELD PROCEDURES

PROCEDURE SELECTION:

Full thickness weld repairs:

- a. Repair area shall be cleaned and prepared for welding.
- b. Jack device to minimize weld shrinkage.

Apply outward pressure to tube wall.

→ Use a copper back up bar.

- c. Repairs shall be made using the GTAW process. (WPS-ER308L/REPAIR)
- d. Repairs shall be visually inspected.

REPAIR WELD PROCEDURES

PROCEDURE SELECTION:

Repairs to first inside pass of pump port:

- a. Visually inspect outside of pump port.**

Any areas that show any linear indications (i.e. non-fusion, incomplete penetration, etc.) shall be repaired.

- b. Purge shall be placed on appropriate side.**

- c. Inside shall be welded using autogenous pulsed arc GTAW process.**

- d. Repair area shall be re-inspected as above.**

REPAIR WELD PROCEDURES

SUMMARY:

- a. Repairs shall be made using either GTAW or GMAW process.**
- b. Procedure WPS-ER308L/REPAIR shall be used to weld repairs.**
- c. Methods to purge and reduce weld shrinkage shall be used.**
- d. All weld repairs shall be visually inspected.**
- e. All weld repairs shall be documented according the Quality Assurance Manual.**

STRUCTURAL WELDING PROCEDURES

SHIELDED METAL ARC WELDING PROCESSES:

E7018 - Used for the welding of carbon steel to carbon steel only.

A36, A283 gr. C, A516 or similar.

E308L - Used for the welding of stainless steel to stainless steel only.

A240 type 304L welded together or similar.

E309 - Used for the welding of stainless steel to carbon steel only.

A240 type 304L welded to A36 or similar.

**Above procedures are to be used for structural components as required.
These procedures shall not be used to weld to the tube wall, expansion joint,
pump port, etc.**

SUPPORT WELDING

GUIDED SUPPORTS:

**Bolted connection will require a small amount of weld metal.
This weld joint is considered structural.
Process may be either GMAW or SMAW.
(WPS-ER308L/GMA)**

FIXED SUPPORTS:

**Gusset to tube wall - considered within pressure boundary.
Must use GMAW or GTAW using a back purge.
Recommend WPS-ER308L/GMA due to the higher deposition rate.
Welded while the tube is in the stiffener welding station under purge.**

**Support legs to support stiffener - considered structural.
Process may be either GMAW or SMAW.
(WPS-ER308L/GMA or WPS-E308L/STRUCT)**

WELDING TOPICS

- **FILLER WIRE EVALUATION**
Clean/Bake Specification - Wire Feed Characteristics - Cost Comparison
- **SPIRAL WELD PROCEDURE**
Autogenous Welding - Two Pass Welding Utilizing Filler Wire
- **CIRCUMFERENTIAL BUTT WELDS**
Welding Process - Welding Equipment - Shielding Gas - Fit-Up Equipment
- **STIFFENER ATTACHMENT WELDS**
Welding Process - Joint Details - Travel Speed - Welding Position
- **PUMP PORT WELDING**
Joint Details - Welding Process - Fitting Equipment
- **REPAIR WELD PROCEDURES**
Types of Weld Repairs - Welding Processes
- **STRUCTURAL WELDING PROCEDURES**
- **SUPPORT WELDING**
Guided Supports - Fixed Supports - Welding Processes

OPTION CONSTRUCTION PLAN

REQUIREMENTS

ESTABLISH A PROJECT MANAGEMENT SYSTEM AND ORGANIZATION

DEVELOP RELIABILITY AND QUALITY ASSURANCE PLANS

DEVELOP FABRICATION AND INSTALLATION PROCEDURES FOR TWO SITES

DESIGN SPECIAL EQUIPMENT FOR EXECUTION OF WORK

DEVELOP PLANS AND PROCEDURES FOR TESTING & ACCEPTANCE

DEVELOP FIELD INSTALLATION PLAN

DEVELOP PROCEDURE FOR OPERATIONAL ALIGNMENT TEST

PROVIDE REQUIRED DELIVERABLE DOCUMENTATION

PROVIDE A CLEAN SITE AT COMPLETION

OPTION CONSTRUCTION PLAN

MOBILIZATION

LABOR SOURCE: THE BASIC LABOR POOL WILL BE COMPOSED OF EXPERIENCED CBI FIELD PERSONNEL, CALLED "TRAVELERS". SOME LOCAL LABOR WILL BE HIRED AND TRAINED TO SUPPLEMENT THE BASE CREW.

SPECIAL EQUIPMENT: SOME EQUIPMENT WILL BE BUILT AT SITE, SOME WILL BE FABRICATED AT OUR CONSTRUCTION EQUIPMENT FACILITIES IN HOUSTON.

STANDARD EQUIPMENT: SUPPLIED FROM OUR DISTRICT CONSTRUCTION WAREHOUSES IN HOUSTON & FONTANA

OFFICE FACILITIES: - TRAILER OFFICES ON SITE

OPTION CONSTRUCTION PLAN

ALIGNMENT

REQUIREMENTS: ALLOW A 1.07m BEAM TUBE APERTURE

**MONUMENT USE: MONUMENTS FURNISHED BY CALTECH
USE FOR INITIAL CONSTRUCTION
USE FOR FINAL ALIGNMENT
USE FOR ALIGNMENT MAINTENANCE**

4 **GLOBAL POSITIONING SYSTEM (GPS) METHOD FOR ALIGNMENT:
USE OF CALTECH BASE LINE MONUMENTS FOR GPS REFERENCE
"X", "Y" & "Z" MEASUREMENT METHODS FOR REFERENCE
TUBE MOUNTED TARGET SYSTEM
DIMENSIONAL REFERENCE FOR TUBE CENTERLINES
GPS SYSTEM UTILIZED FOR ONGOING MONITORING**

**GPS PROPOSAL FOR APPLICATION TO TOTAL LIGO PROJECT:
PROPOSAL AND REPORT INCLUDED IN FDR PACKAGE**

OPTION CONSTRUCTION PLAN

CLEANING

REQUIREMENT: SOLVENT WIPE, STEAM CLEAN, HOT WATER WASH, NO VISIBLE CONTAMINANTS

OVERALL CLEANING PLAN:

"LIGOCP"

PURCHASED ITEMS:

**VENDOR TO REFERENCE "LIGOCP"
PACKAGING TO BE PRE-APPROVED**

**FACILITY INSPECTIONS BY CBI
FINAL INSPECTION AT SITE BY CBI: VT1**

FABRICATION AREA CLEANING PROCEDURE:

**BLACK LIGHT INSPECTION: VT1
HOT SPRAY & RINSE SYSTEM: CL1N**

**"CL1N"
CLEAN ROOM PROCEDURE: CL1N
AIR DRY & SEAL: CL1N**

ASSEMBLY/ERECTION CLEANING PROCEDURE:

**ROLLING CLEAN ROOM: CR1TSM
SOLVENT WIPE PROCEDURE: CL3N
TUBE SEAL FOR PROTECTION: CL1N**

**"CL2N"
POSITIVE PRESSURE AIR SYSTEM: BDF1
BLACK LIGHT INSPECTION: VT1**

OPTION CONSTRUCTION PLAN

LEAK TESTING

REQUIREMENT: HELIUM LEAK RATE NOT TO EXCEED 1×10^{-10} atm cc/s

OVERALL TEST PLAN: HSTMTP WRITTEN: EQUIPMENT SELECTED TO TEST TO 1×10^{-11} OR -12 . EQUIPMENT VENDORS TO TEST EQUIPMENT TO VERIFY.

COMPONENT TESTING: TUBE/BELLOWS ASSEMBLIES TESTED IN HELIUM MASS SPECTROMETER HOOD CHAMBER WITH TIME OF FLIGHT CAPABILITY TO LOCATE LEAK, PER PROCEDURE HSTM1N

CLOSING SEAM: JOINT WILL BE HELIUM MASS SPECTROMETER TESTED WITH LOCALLY APPLIED CURVES VACUUM BOX AND SEAL PER PROCEDURE HSTM2N.

MODULE TESTING: ALL TUBES MUST HAVE SUCCESSFULLY PASSED COMPONENT TEST AND CLOSING SEAM TEST AND CALTECH BAKE OUT COMPLETE. UTILIZES CALTECH FURNISHED PUMPING SYSTEM, PER PROCEDURE HSTM3N

OPTION CONSTRUCTION PLAN CONTENTS

**PROJECT ORGANIZATION / ORGANIZATION CHART
CONTRACT ADMINISTRATION
PROCUREMENT/SUBCONTRACTING
SECURITY
MASTER PROCEDURES LIST/MANUAL
MOBILIZATION
FABRICATION
TRANSPORT
ERECTION
QUALITY MANUAL
SAFETY MANUAL
ENVIRONMENTAL PLAN
SCHEDULE & COSTING
COMMISSIONING/ACCEPTANCE
DEMOBILIZATION**

OPTION CONSTRUCTION PLAN

REQUIREMENTS

PROJECT COORDINATION

SUBCONTRACTOR COORDINATION

SAFETY

SECURITY

ENVIRONMENT PRESERVATION

EQUIPMENT REQUIREMENTS

PERSONNEL MANAGEMENT

CRITICAL PARAMETERS

ACCIDENT PREVENTION

PRODUCTIVITY

SCHEDULE

DEFINED RESPONSIBILITIES

ACCOUNTABILITY

OPTION CONSTRUCTION PLAN

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

OPTION CONSTRUCTION PLAN

PROCUREMENT / SUBCONTRACTING

CONTRACT/P.O. PROVISIONS

AUTHORIZATION

EXPEDITING

VALUE ENGINEERING

TRAFFIC OF GOODS

DAMAGED SUPPLIES

FEDERAL REGULATIONS

RELEASE OF LIEN

TERMINATION/LIABILITY

FEDERAL NOTIFICATION REQUIREMENTS

MINORITY/SMALL BUSINESS SUBCONTRACTING

LOCAL SUBCONTRACTING

NOTIFICATION, APPROVALS

SPECIAL EQUIPMENT

PRICING & ANALYSIS

USE OF GOVERNMENT FACILITIES

SUPPLIER CORRECTIVE ACTION

STOP WORK ORDERS

GOV'T. FURNISHED EQUIPMENT

CERTIFICATIONS OF MATERIALS

SUBCONTRACT PROVISIONS

OPTION CONSTRUCTION PLAN

MASTER PROCEDURES LIST / MANUAL

PURPOSE:

TO PROVIDE ONE CENTRAL CONTROLLED SOURCE FOR ALL PROCEDURES

CONTENTS:

ALL PROJECT PROCEDURES, PLANS, AND SPECIFICATIONS

RESPONSIBILITY:

MAINTAINED BY PROJECT MANAGEMENT

DOCUMENT CONTROL:

DURING OPTION, CONTROL BY ISSUANCE OF REVISED INDEX SHEET TO CONTROLLED LIST OF USERS.

CALTECH

ONCE APPROVAL PROCESS IS AGREED, THE LIST WILL BE CONTROLLED AND APPROVALS/STATUS NOTED ON INDEX

OPTION CONSTRUCTION PLAN

MOBILIZATION

DURATION:

THREE MONTHS HAS BEEN ALLOWED FOR INITIAL MOBILIZATION

RESOURCES:

**CBI SUPERINTENDENT AND TRAVELER CREW PLUS LOCAL
SUBCONTRACTING FOR CONSTRUCTION PAVING AND CONCRETE WORK**

SCOPE:

**INSTALLATION OF BUILDINGS & SITE WIRING
ASSEMBLE & INSTALL SPECIAL EQUIPMENT
ESTABLISHMENT OF LOCAL CONTACTS FOR SUPPLIES, MEDICAL,
GENERAL SERVICES
SET UP STORES AND TOOL DISTRIBUTION
ESTABLISH LABOR RELATIONS CONTACTS**

OPTION CONSTRUCTION PLAN

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 .

MANUAL ADDRESSES FOLLOWING:

MANAGEMENT RESPONSIBILITY

CONTRACT REVIEW

DOCUMENT CONTROL

PURCHASER SUPPLIED PRODUCTS

PROCESS CONTROL

INSPECTION, MEASURING, AND TEST EQUIP

CORRECTIVE ACTIONS

HANDLING, STORAGE, PACKAGING, & DEL.

INTERNAL QUALITY AUDITS

SERVICING

QUALITY SYSTEM

DESIGN CONTROL

PURCHASING

PRODUCT ID & TRACEABILITY

INSPECTION & TESTING

INSPECTION & TEST STATUS

NON CONFORMING PRODUCT

QUALITY RECORDS

TRAINING

STATISTICAL TECHNIQUES

OPTION CONSTRUCTION PLAN

SAFETY PLAN

PROGRAM DEVELOPED BASED ON CBI STANDARD ACCIDENT PREVENTION PROGRAM AND ASSOCIATED GENERAL CONTRACTORS SAFETY PROGRAM. COVERS ALL TRADES

14 CONFINED WORKING SPACE REQUIREMENTS ARE IN SAFETY PROGRAM

FINAL MANUAL IS TAILORED FOR LIGO APPLICATION

MANUAL REFERS TO CBI "REDBOOK" STANDARDS

OPTION CONSTRUCTION PLAN

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

OPTION CONSTRUCTION PLAN

SCHEDULE & COST CONTROL

**CPM SOFTWARE: USING PC/WINDOWS DRIVEN PROGRAM, "TEXIM"
WHICH CONVERTS TO DATABASE "OPEN PLAN" PROGRAM**

REPORTING AND FORMATS :

UPDATE TIMING

SUBMITTAL CONTROL

SHORT TERM SCHEDULING

DUAL SITE COORDINATION

PROGRESS REPORTING

SCHEDULE MEETINGS

PAYMENT EVALUATION

DETAIL LEVEL OF WBS

TEXIM SUB-PROJECT ROUTINES ADDRESS 10 TUBE ELEMENTS

WBS: GENERAL

TUBE CANS

PUMP PORTS

LEG ASSEMBLY (1 & 2)

MOBILIZATION

EXP. JOINTS

STIFFENERS/SUPPORTS/BAFFLES

MODULE TEST

OPTION CONSTRUCTION PLAN

DEMOBILIZATION

EQUIPMENT: FOLLOWING COMPLETION, ALL EQUIPMENT WILL BE REMOVED FROM 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.

OPTION CONSTRUCTION PLAN

SECURITY

FABRICATION SITE: TEMPORARY FENCING WILL BE UTILIZED TO FENCE OFF CRITICAL AREAS FOR SECURITY PURPOSES

ERECTION SITE: CLEAN ROOM AND POSITIVE AIR FLOW SYSTEM CONTAIN ENTRANCE TO INSTALLED TUBES. AREAS LOCKED OUT DURING OFF SHIFT TIMES

ON SITE PRESENCE: LEAK TESTING AT THE FABRICATION AREA WILL DEMAND THE PRESENCE OF CBI PERSONNEL AT THE SITE AT ALL TIMES DURING THE WEEK, THEY WILL MONITOR SITE DURING OFF SHIFT TIMES;

WEEKEND/HOLIDAY SECURITY: CBI WILL HIRE LOCAL SECURITY SERVICE.

CONCRETE COVERS MUST BE PLACED AS BEAM TUBE IS INSTALLED

OPTION CONSTRUCTION PLAN

COMMISSIONING/ACCEPTANCE

MODULE LEAK TESTING:

PRESENT CONTRACT PROVIDES FOR TESTING AFTER ASSEMBLY, PRIOR TO BAKE OUT.

VACUUM EQUIPMENT:

NOT IN CBI SCOPE, FURNISHED AND INSTALLED BY OTHERS. EQUIPMENT WILL DETERMINE DURATION OF TESTING.

BAKE OUT:

PRESENTLY NOT IN CBI SCOPE



ACCEPTANCE:

AFTER LEAK TEST, BUT PRIOR TO BAKE OUT



SYSTEM / EQUIPMENT COMMISSIONING:

NOT IN CBI SCOPE

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 execution of the 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 and ensure worker safety
- e. Final inspection to ensure that tube access is no longer required
- f. Maintain clean and secure 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

SUBASSEMBLY INSTALLATION PLAN:

- a. Detailed process procedure "INSTALLSEQ" has been developed which describes each step of the installation sequence. flow diagram reflects the activities. Detail procedures control the work.
- b. The general sequencing of the work is:
- | | |
|--|----------------------------------|
| 1. Transport Tubes | 2. Fit Tubes Together |
| 3. Purge Circumferential Seam | 4. Weld Circumferential Seam |
| 5. Vacuum Leak Test Circumferential Seam | 6. Clean, Install Baffles & Seal |
| 7. Align Tube Using GPS | 8. Install Permanent Supports |
| 9. Place Concrete Cover For Protection | 10. Final Align Tube Using GPS |
- c. Independent traveling clean room, weld room, and testing room are moved as required to accomplish work and protect the tube interior.
- d. Positive clean filtered air flow is maintained in tube under construction as described in procedure BDF1. ← *check this*
- e. Installation of beam tube modules start at the mid station and proceeds simultaneously to corner station and end station. Two modules are under construction simultaneously.
- f. Tube sections are placed on temporary supports for fit up, welding, and testing of circumferential seams.

BEAM TUBE MODULE CONSTRUCTION

- g. Fixed and flexible supports are installed after circumferential seam is completed.
- h. Last fixed support at working end is temporarily restrained to prevent longitudinal displacements associated with daily temperature variations.
- i. Electrical grounding is required during construction for CBI safety and by Electric Codes.
- j. Simple hauling trailers will be used at site to transport cleaned and sealed tube sub assemblies to module in progress.

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

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 FABRICATION LOCATION OPTIONS CONSIDERED

- a. Tube mill fabricators location
- 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

Series slides
Eliminates OW?
Involutes Costly?

SUBASSEMBLY FABRICATION LOCATION SELECTION

On site or site vicinity required due to lack of capability of tube manufacturer and additional shipping costs associated with stiffened tubes which limit shipment to one tube per truck.

On Site In Temporary Facilities Versus Fabrication In Local Leased Facility

- 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.
- Site fabrication is presently the **preferred** location due to:

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

Fabrication process is independent of fabrication facility location.

All temporary buildings will be removed unless structures can be used for the LIGO facility. Slabs will be left in place if required or useful.

SUBASSEMBLY CONSTRUCTION

SUBASSEMBLY FABRICATION SEQUENCE

a. Detailed process procedure "FABSEQ" has been developed which describes each step of subassembly fabrication process.

b. Stations are set up for each unique process. 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

c. The general sequence of work is as follows:

1. Receive & inspect materials

3. Fit and weld pump port reinforcement

5. Drill, fit, and weld pump ports

7. Fit and weld expansion joint

9. Leak test subassembly & repair if req'd

2. Fit & weld stiffeners to tube

4. Inspect and measure stiffened tube

6. Inspect and measure

8. Inspect and measure

10. Clean subassembly and seal

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

e. Small number of as received tube sections and completed tube sections are kept on site ready for installation. Limited inventory and handling minimize risk of contamination.

MATERIAL ACCEPTANCE PLANS

Requirements

- Traceability
- Inspection and Release

Critical Parameters

Traceability

- Identification
- Tracking
- Special LIGO Processes/Requirements

Inspection and Release

- Receipt Damage Inspection
- Identification
- Dimensional Inspection
- Documentation Review

DIMENSIONAL CONTROL PLANS

Critical Parameters

- ASME Sect VIII, Div 1, Vacuum Service Requirements
- Fabrication/Installation Requirements
- Minimum Clear Aperture Requirements

Dimensional Control Procedure

- Methods
- Frequency
- Timing

} *try to have a reduction
in the # of reworks*

COUPON OUTGASSING TEST SYSTEM

Requirements

- Provide a coupon test facility to test the hydrogen outgassing rate of all material for the option and qualification phases of the project.
- Test the materials for the option and qualification phases of the project.
- Reject material with hydrogen outgassing rates $> 1 \times 10^{-13}$ T L/cm² sec.

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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 OUTGASSING TEST SYSTEM

Selected Configuration

- Chamber and system baked to reduce background outgassing rate
- Wide range turbomolecular pump used for pumping
- Cold trapped RGA for elimination of false hydrogen outgassing data
- Provide pumping system with automatic valving to minimize possible contamination.
- Use close-coupled equipment to minimize piping lengths and background outgassing rate.
- Use thermocouple on a coupon which is permanently installed in the center of the coupon chamber to provide temperature lag information.

LEAK TESTING

CRITICAL SPECIFICATION REQUIREMENT

PARAMETERS TO MEET REQUIREMENT

VENDOR LEAK TEST PROCEDURES

OVERALL LEAK TEST PLAN

COMPONENT LEAK TEST PROCEDURES

BEAM TUBE MODULE TEST PROCEDURES

BEAM TUBE MODULE TESTING DECISION TREE

LEAK TESTING

CRITICAL SPECIFICATION REQUIREMENT

Total helium leakage rate per module not to exceed 1×10^{-9} atm cc/s.

PARAMETERS TO MEET REQUIREMENT

- a. Planned Approach to Leak Testing outlining logical step by step sequence.
- b. All vendor items purchased by CBI/Caltech must be compatible with absolute pressure (ultra high vacuum) level and total helium leakage rate specification requirements.
- c. All component assemblies must be leak tested at test sensitivity that ensures that total helium leakage rate of each module meets specification requirements.
- d. Leak testing sequence for preliminary testing of component assemblies and preliminary and final testing of beam tube modules must be integral part of construction process to maintain production schedule.
- e. Helium mass spectrometer quantitative hood technique procedures for preliminary leak testing of vendor items and CBI component assemblies must be sufficiently sensitive to enable test operators to quickly and economically detect and locate leaks of required size.
- f. Leak test procedures non-contaminating to later leak testing procedures.

LEAK TESTING

VENDOR LEAK TEST PROCEDURES

Approved helium mass spectrometer (HMS) quantitative hood technique leak test procedure must be used by manufacturer to leak test expansion joints.

OVERALL LEAK TEST PLAN

Planned Approach to Leak Testing, known as LIGOTP, outlines sequence of CBI component and module leak testing procedures.

COMPONENT LEAK TEST PROCEDURES

- a. Component procedures are designed to ensure that all leakage larger than specified allowable has been detected and eliminated in component assemblies at each stage of fabrication and installation.
- b. First leak testing procedure is identified as HMST1N. It is HMS quantitative hood test performed on each completed can section assembly with stiffeners and when applicable, an expansion joint and/or pump port assembly. Performed in fabrication area after can section visually inspected and solvent wiped where necessary and before can section installed in beam tube module. HMST1N hood test performed with can section in test stand. Test stand consists of two end seal assemblies and cradle-like hinged enclosure which is hood that will provide 100% helium mixture when evacuated and backfilled with tracer gas. One end seal contains mechanical and diffusion pump system and roughing and high vacuum connections for HMS. Second end seal contains system standard leak and cryogenic panel to pump water vapor and other condensables.

LEAK TESTING

COMPONENT LEAK TEST PROCEDURES (CONT'D)

Consevative cost comparison of metal test enclosure versus polyethylene bag shows metal enclosure saves about \$13000 at first site and about \$260,000 at second site.

Other positives for metal enclosure are:

Uniform helium mixture versus non-uniform helium mixture for each can section test.

100% helium mixture versus various estimated or metered averaged helium percentage around each can section for test.

More helium leakage around hood causing potential background problems.

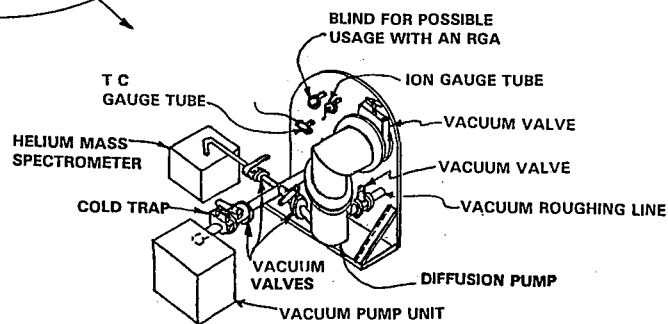
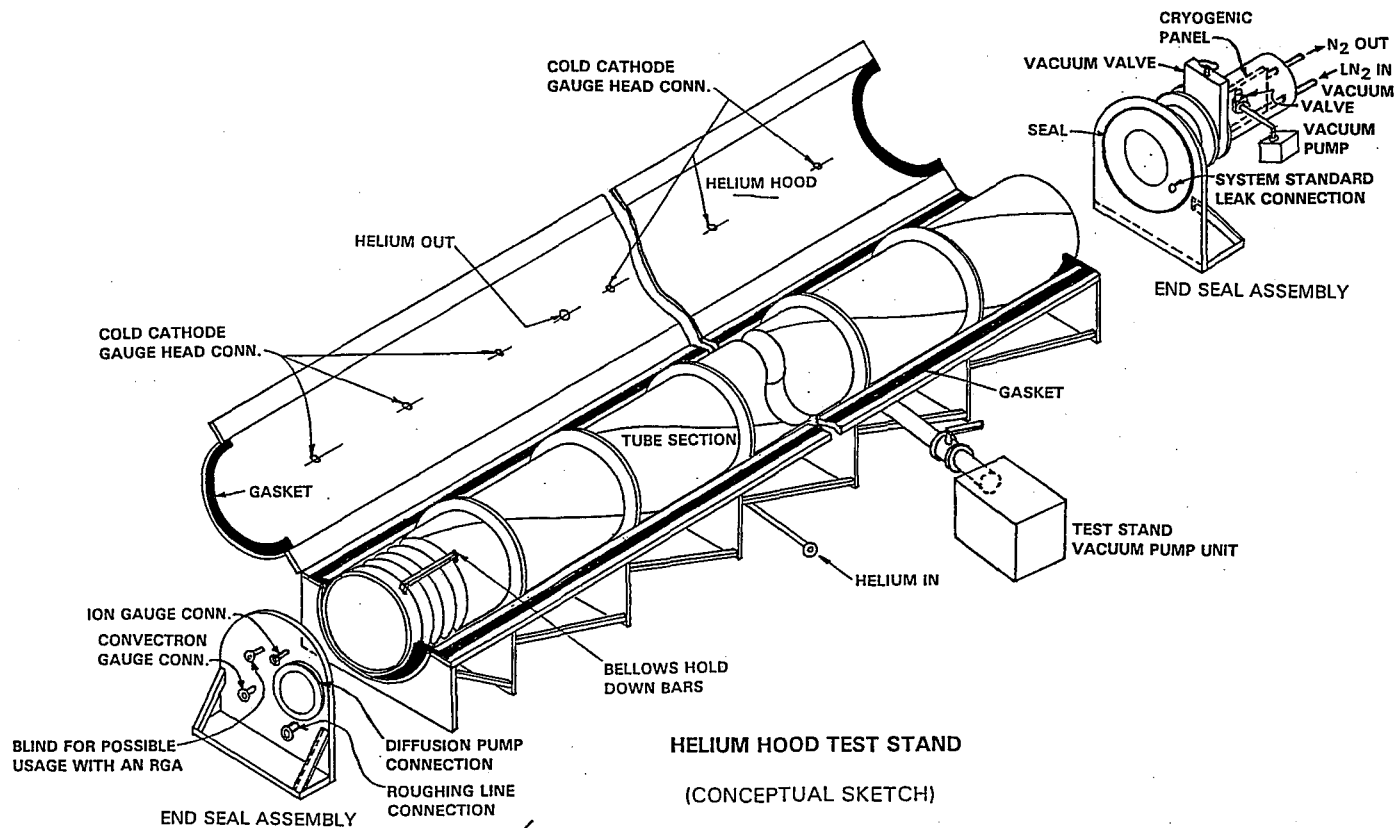
Disposal of polyethylene in such large quantities could be problem.

Time of Flight.

To more quickly locate detected leakage difficult to pinpoint by conventional means, CBI will use Time of Flight system installed in lid of one test stand enclosure to more quickly pinpoint such leakage. Estimated comparison study indicates that use of this T of F system should result in realization of considerable savings in time and money.

Since PDR, diffusion pump to be used in lieu of more costly turbomolecular pump. Same size diffusion pump will achieve greater pump speed than turbomolecular pump. Shorter evacuation time using DP instead of TP also provides more time margin for contingencies. Pump down curve for can sections shows estimated time.

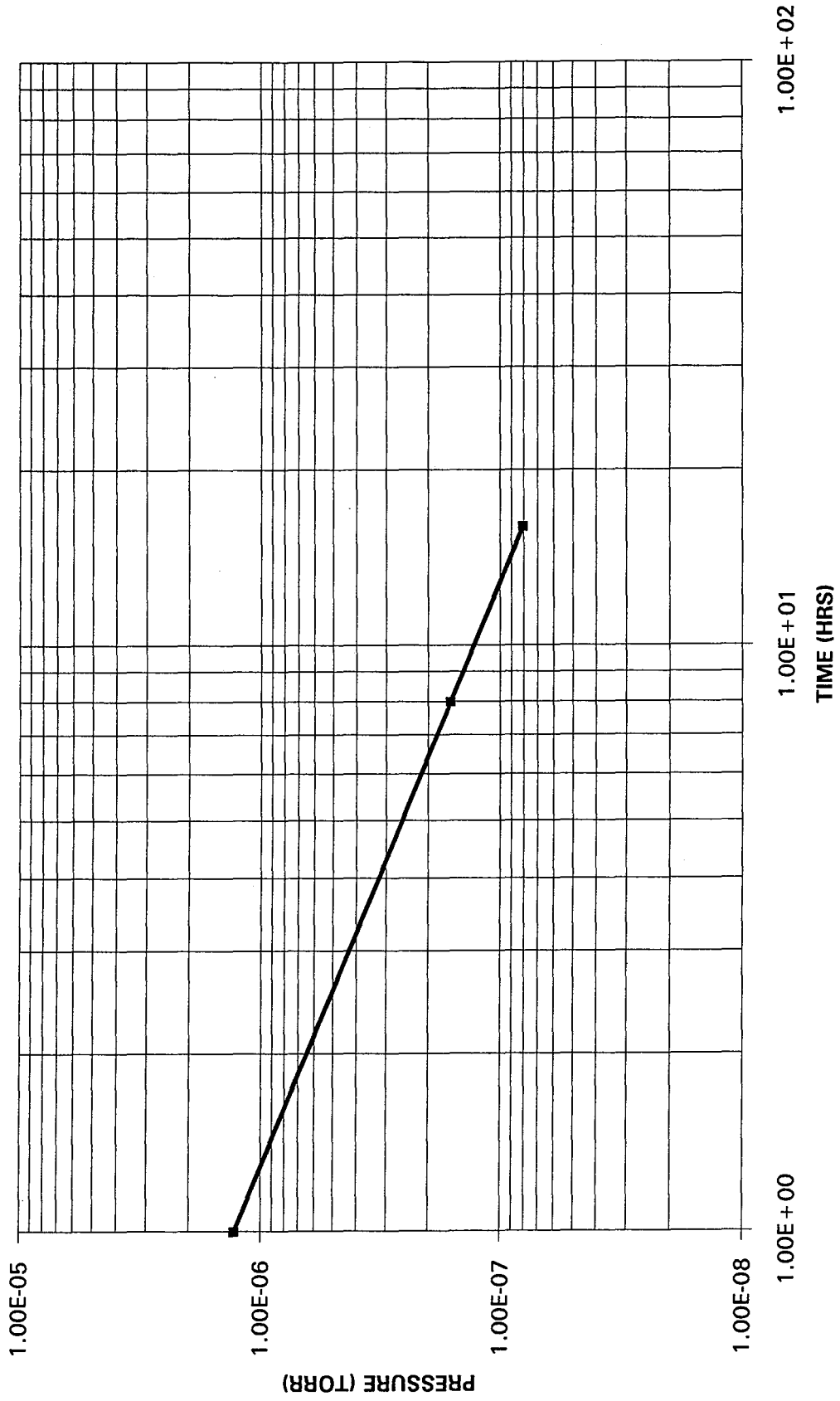
LEAK TESTING



HELIUM HOOD TEST STAND

LEAK TESTING

CAN SECTION PUMP DOWN



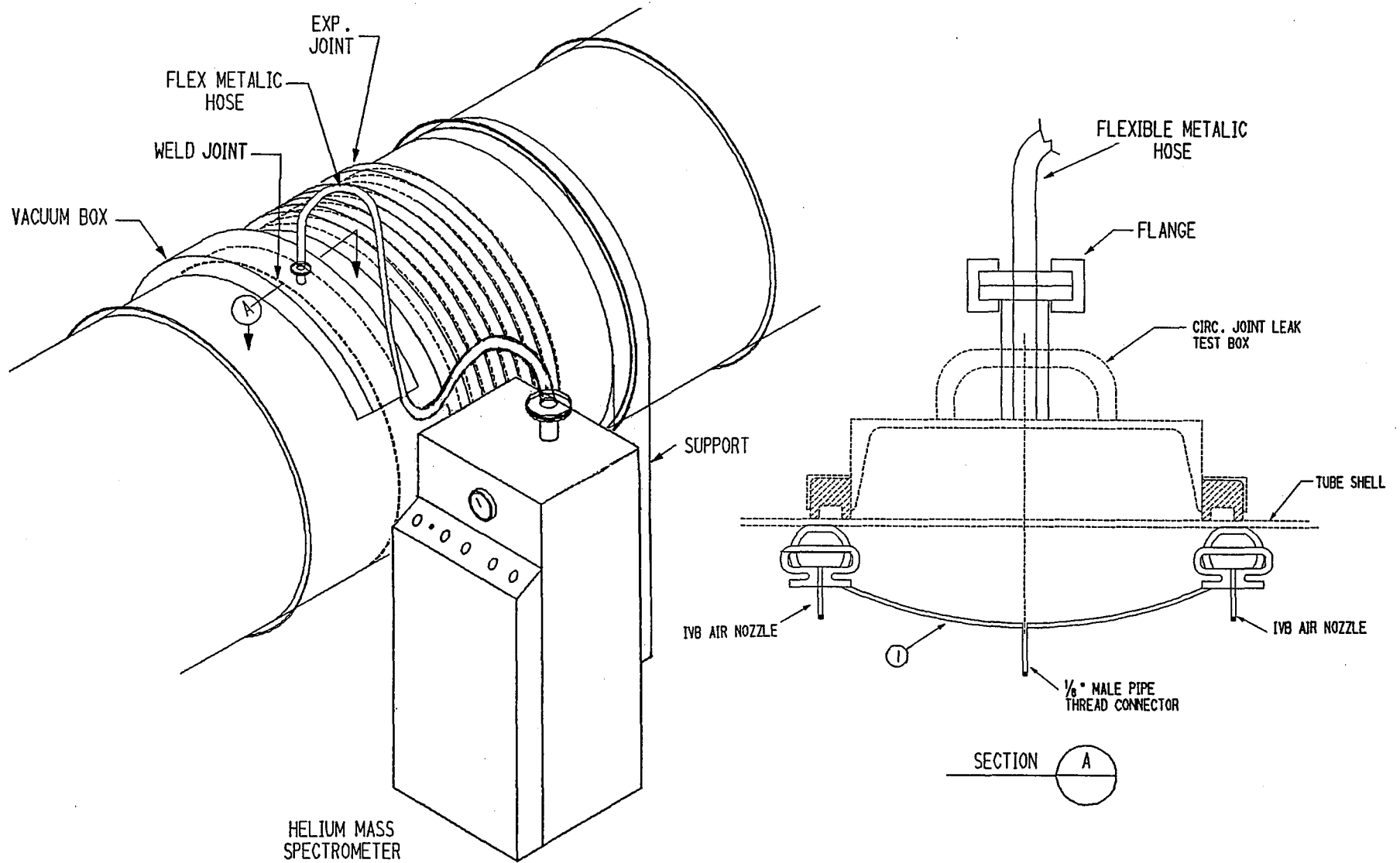
VARIAN HS-20 DIFFUSION PUMP + 20" LN2 PUMP

LEAK TESTING

COMPONENT LEAK TEST PROCEDURES (CONT'D)

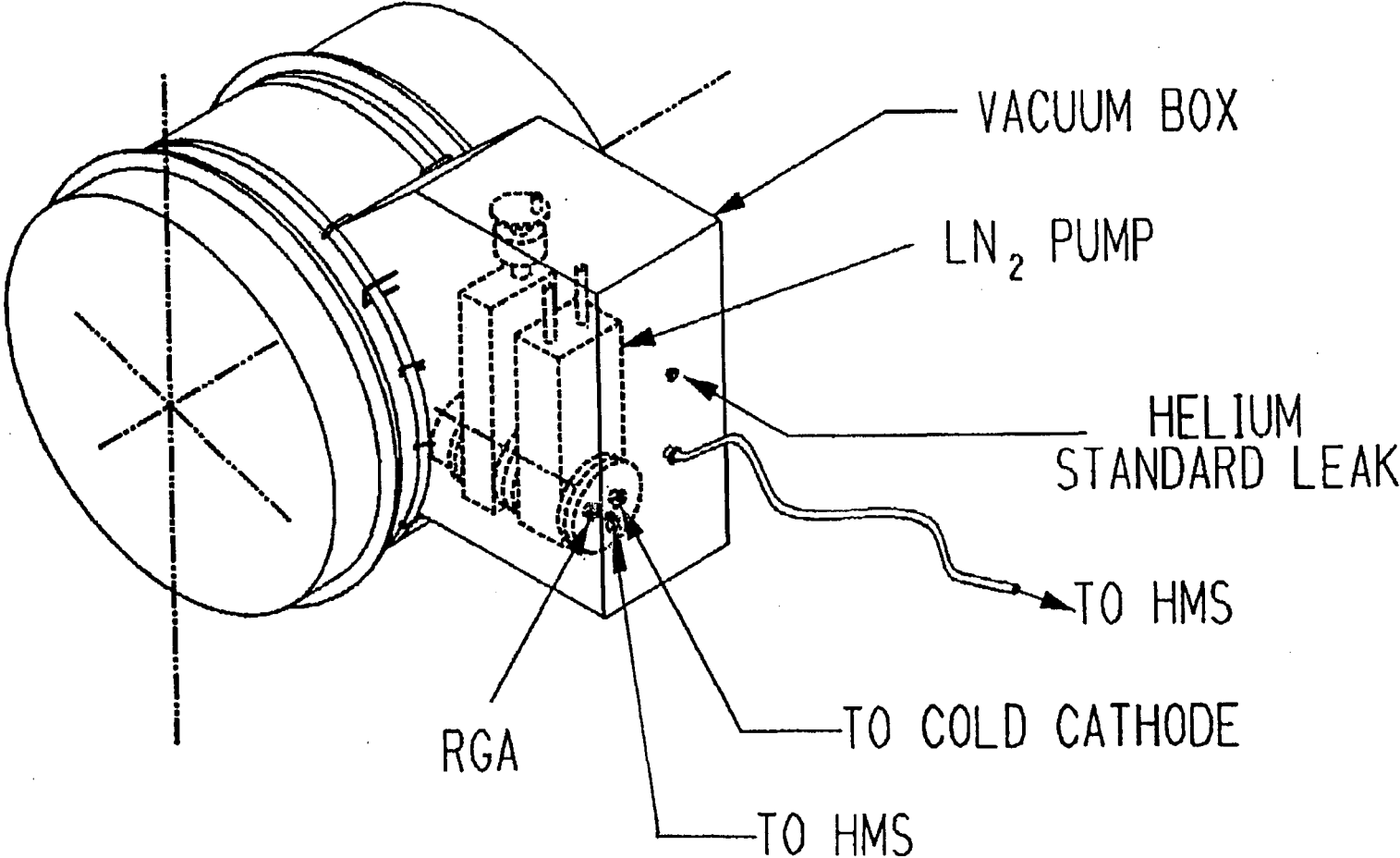
- c. Second leak testing procedure HMST2N outlines HMS quantitative hood test of each circumferential weld joint between can sections. Local vacuum box hood technique has been used successfully by CBI for over 30 years. Other than refinement of details, procedure has changed little since PDR.**
- d. Third leak test procedure in plan is HMST3N. This procedure is quantitative hood test of pump port assemblies. Since PDR, has been revised to include LN₂ pumps and RGA head and cold cathode gauge head in outer blind on pump. Because LN₂ pumps are needed to reduce pumping time during module test phase to pump vapor and other condensables, was apparent cryogenic pumps needed to be in place and leak tested before beam tube module final tests. HMS connection in the blind flange on LN₂ pumps provides capability to local hood test assemblies beyond valve seats with module evacuated during module test.**

LEAK TESTING



CIRCUMFERENTIAL WELD LOCAL HELIUM HOOD TEST SET-UP

LEAK TESTING



PUMP PORT ASSEMBLIES
LOCAL HELIUM HOOD TEST SET-UP

LEAK TESTING

BEAM TUBE MODULE LEAK TEST PROCEDURES

- a. Fourth leak test procedure HMST4N contains preliminary RGA/HMS/ET AL leak location test techniques and quantitative performance analysis techniques.
- b. If required, fifth and final HMS hood test procedure HMST5N of entire module.

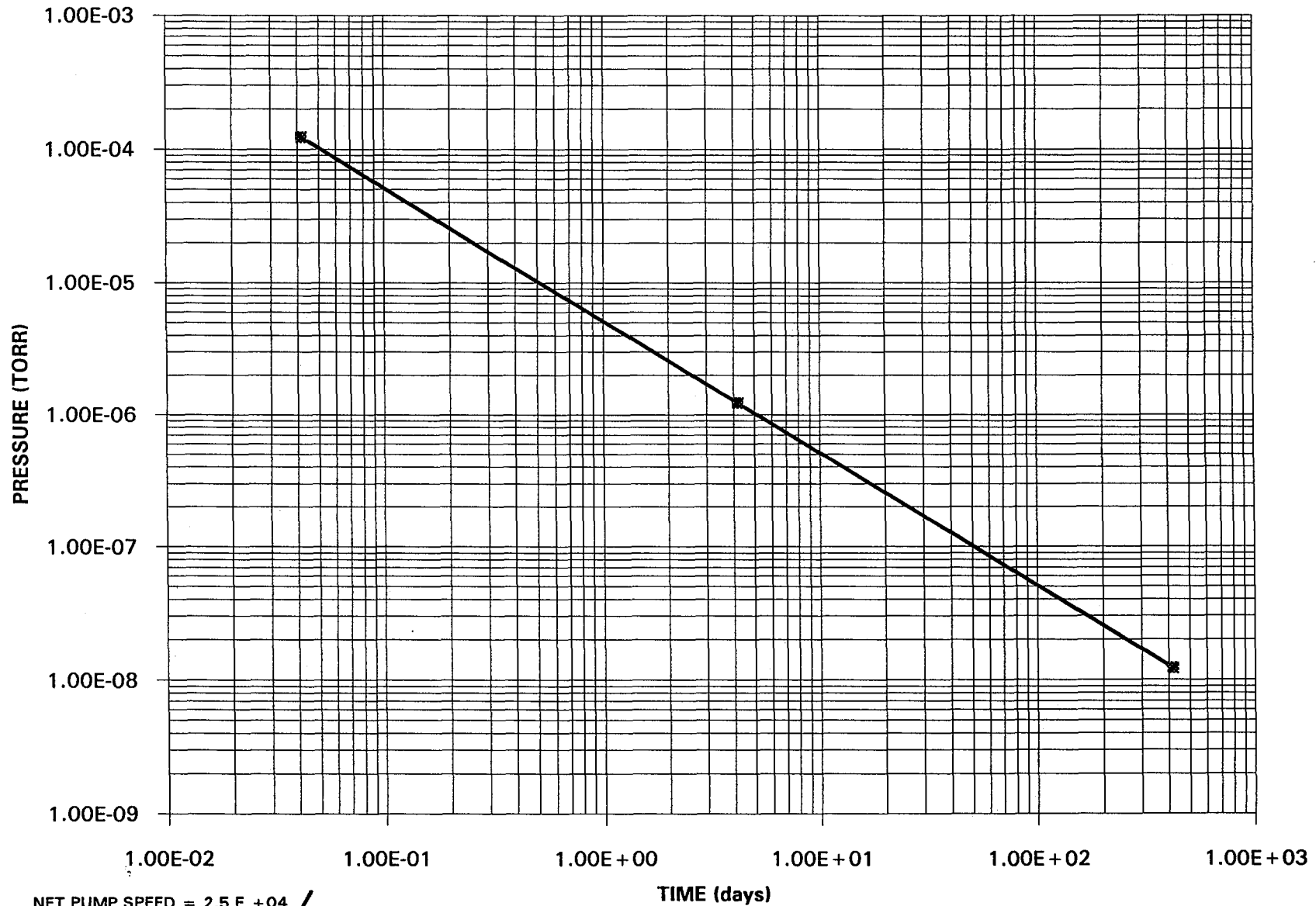
Pump down curves for beam tube module show estimated times to various pressures for before and after bake out.

BEAM TUBE MODULE TESTING DECISION TREE

- a. To better utilize more advantageous leak location and quantitative techniques in final testing of completed beam tube module, Leak Detection Decision Tree was developed by CBI and further refined by both CBI and Caltech/MIT. Decision tree provides for unique leakage sizing techniques for leakage larger than 10^{-5} atm cc/s and for leakage smaller than 10^{-5} atm cc/s. Also provides for quantitative signature analysis techniques.

LEAK TESTING

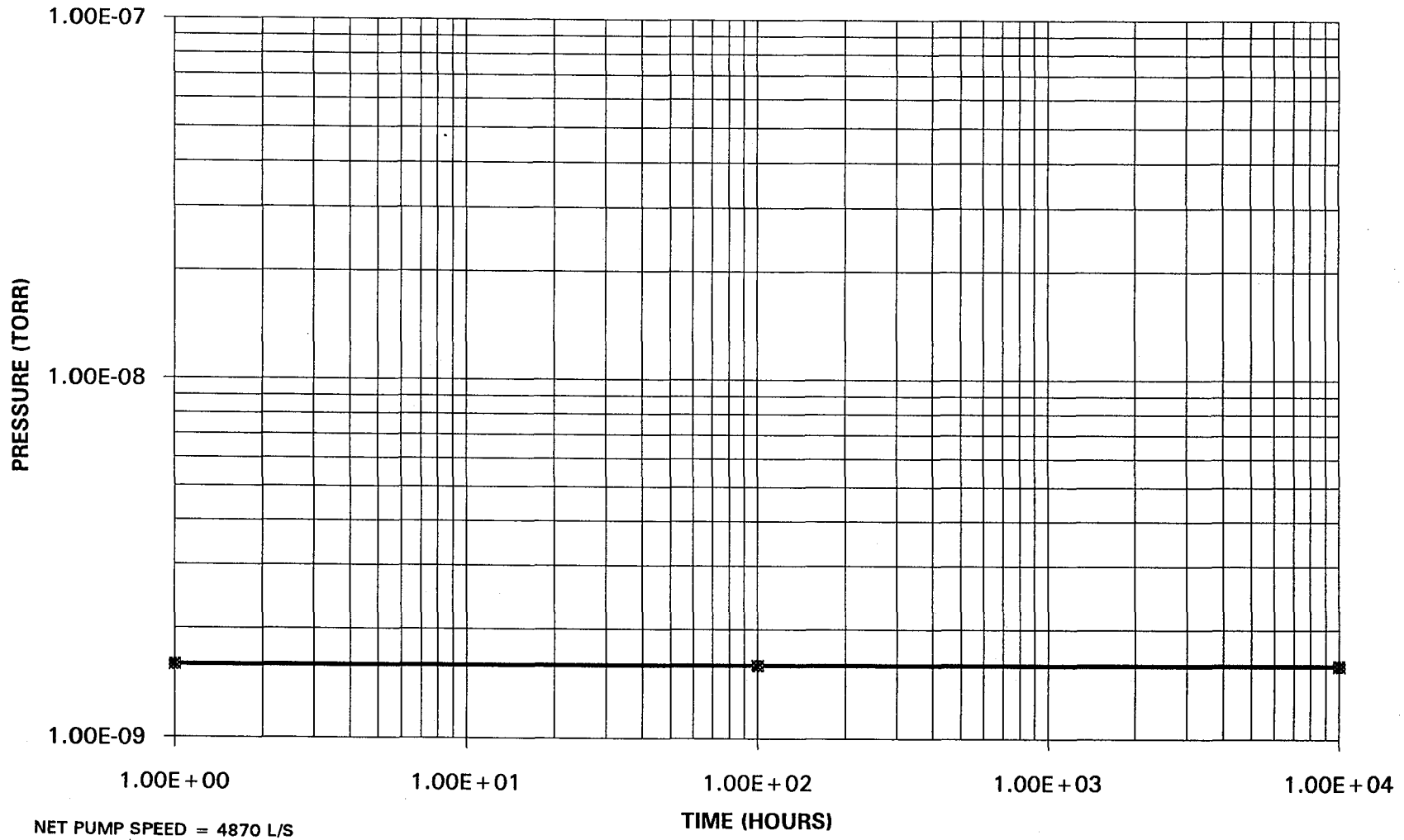
MODULE PUMPDOWN - PRIOR TO BAKE



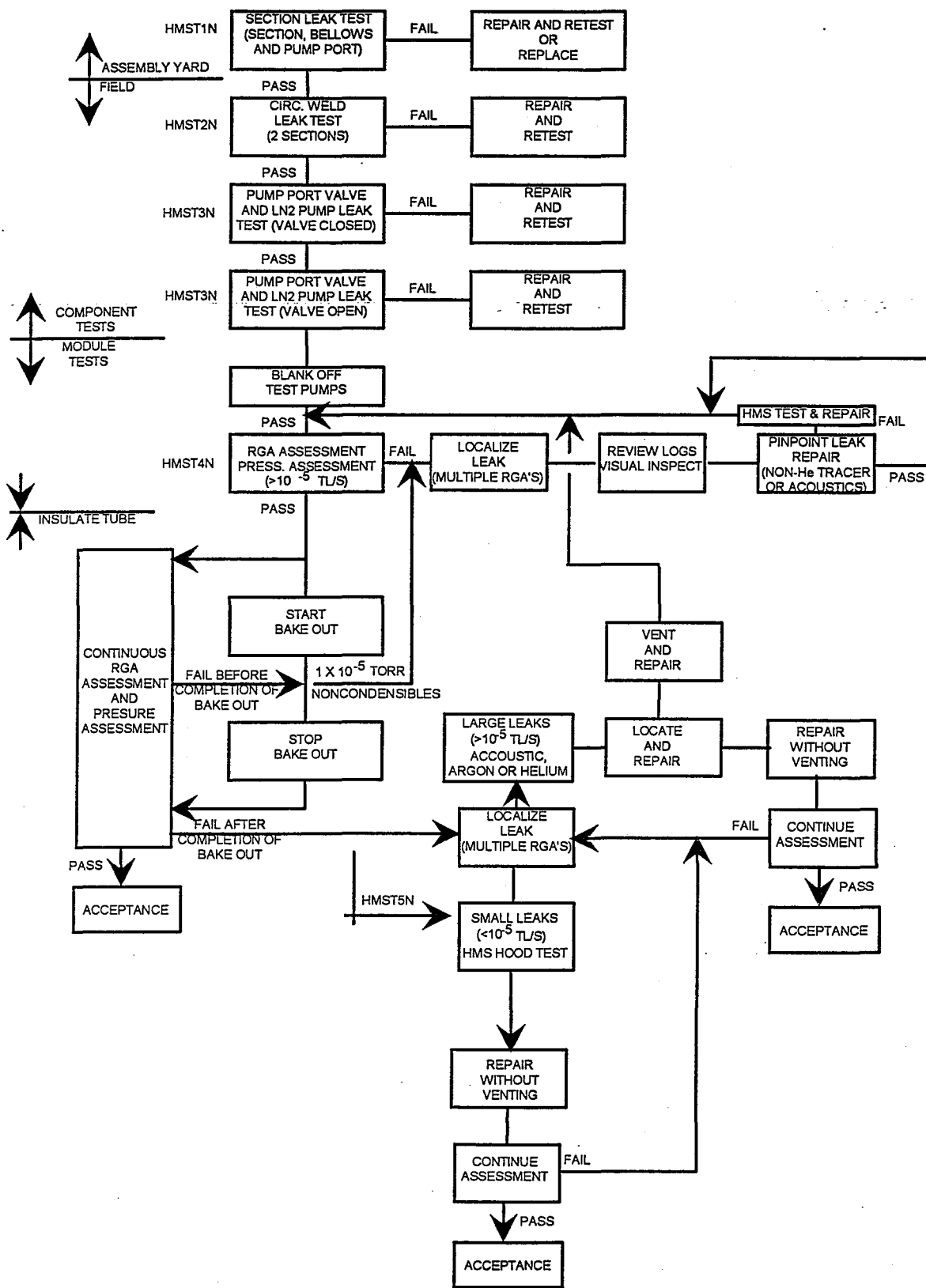
NET PUMP SPEED = $2.5 \text{ E } +04 / A_2 \text{ } ^\circ$

LEAK TESTING

MODULE PUMPDOWN - AFTER BAKE OUT



LEAK TESTING



DECISION TREE

LEAK TESTING

BEAM TUBE MODULE TESTING DECISION TREE (CONT'D)

- b. For before or after bake out leakage larger than 10^{-5} atm cc/s, following test techniques will be used in approximate order as listed.

Review of log books, PC entries for each preliminarily tested component

Visual walk down

Acoustic Emission

Ultrasonic leak detector

Acetone-pressure gauge deflection

Argon-pressure gauge deflection

RGA pressure assessment

Time of Flight

Argon mass spectrometer (non-helium) tracer probe test

- c. For before or after bake out leakage smaller than 10^{-5} atm cc/s, the following test techniques will be used in the approximate order as listed.

Review of log books, PC entries for each of the preliminary tested components

Visual walk down

Time of Flight

Argon mass spectrometer for (non-helium) tracer probe test

If required, helium mass spectrometer as the final test technique



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7. Dead Load + Insulation Load + Daily Thermal Load
8. Dead Load + Insulation Load + Daily Thermal Load + Seismic Load
9. Dead Load + Insulation Load + Bakeout Thermal Load

Note that, in accordance with standard design code practice and procedure, the effects of snow load, wind load and seismic load are nonconcurrent, and thus are not combined. Also note that the bakeout thermal load is not combined with seismic load, since the probability of these two events occurring together is extremely small.

In any load combination involving either lateral or longitudinal seismic load, a $\frac{1}{3}$ increase in the allowable stresses of the support members is permitted in accordance with standard design code practice. For all other load combinations, this allowable stress increase was not permitted.

Six of the above load combinations, either through inspection or by calculation, were found to be non-governing, i.e., they did not control **any** aspect of the support design. The three remaining load combinations that were thus investigated as governing some or all aspects of the support design are as follows:

5. Dead Load + Insulation Load + Lateral Seismic Load
6. Dead Load + Insulation Load + Longitudinal Seismic Load
9. Dead Load + Insulation Load + Bakeout Thermal Load

The magnitudes of the loads associated with the above load cases and load combinations can be found in the Detailed Design.

Support Design Considerations & Performance Characteristics

Therefore, the design considerations and performance characteristics of the fixed (i.e., non-guided) supports are as follows:

- Support a vertical load of 7,100 pounds resulting from the weight of the beam tube, stiffeners and beam tube insulation.
- Resist a lateral seismic load of 1,200 pounds and a longitudinal seismic load of 2,400 pounds. Based upon a UBC Zone 2B earthquake for the Hanford, WA site.
- Resist a maximum longitudinal load of 5,300 pounds resulting from the 300°F bakeout of the beam tube modules.
- Support to perform without the occurrence of "stick-slip".
- Provide +/- 3 $\frac{1}{2}$ " vertical adjustment capability.
- Provide +/- 3 $\frac{1}{2}$ " lateral adjustment capability.
- Anchorage to be compatible with a 4 inch thick foundation slab.
- Configuration to accommodate placement within a 2.13 meter radius concrete weather cover.

$\frac{1}{6} g$
 $\frac{1}{3} g$



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Similarly, the design considerations and performance characteristics of the guided supports are as follows:

- Support a vertical load of 5,700 pounds resulting from the weight of the beam tube, stiffeners and beam tube insulation.
- Resist a lateral seismic load of 1,200 pounds. Based upon a UBC Zone 2B earthquake for the Hanford, WA site.
- Resist a lateral "stability" load of 500 pounds from restraint of the tube.
- Provide for the "noiseless" longitudinal movement (i.e., no "stick-slip") of the beam tube under thermal loads.
- Provide +/- 3¹/₂" vertical adjustment capability.
- Provide +/- 3¹/₂" lateral adjustment capability.
- Anchorage to be compatible with a 4 inch thick foundation slab.
- Configuration to accommodate placement within a 2.13 meter radius concrete weather cover.

Support Design

The structural members of both the fixed and guided supports were designed per the Allowable Stress Design (ASD) Specifications of the American Institute of Steel Construction (AISC), 9th Edition. The AISC ASD provisions were applied to the design of all stainless steel components of the supports, although the AISC Specifications are not specifically intended for use in stainless steel design. The overall stresses in the stainless steel components are low enough to justify this approach. Detailed calculations for the design of the components of the fixed and guided supports are contained in the Detailed Design.

Support Configurations Evaluated

In an effort to provide both fixed and guided supports that satisfy the design considerations and performance characteristics previously noted, a number of possible support configurations were considered and evaluated. The original support concepts presented at the Preliminary Design Review were based on a beam tube/expansion joint configuration that differed from the final tube/expansion joint configuration, and thus were found to be inadequate or inappropriate for the current configuration.

Some of the fixed and guided support concepts that were evaluated for potential use are as follows:

- Fixed supports using standard pipe hangars.
- Fixed supports using clamping devices.
- Guided supports using flexible support skirt plates.
- Cable-suspended guided supports.



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- Guided supports using pipe rollers.
- Guided supports using Hillman rollers.
- Guided supports using ball bushings bearings.

All of these concepts were found to be inadequate for a variety of reasons, but the most prevalent reasons for dismissing the potential support concepts listed above were:

- Complexity and associated expense. Many of the support concepts listed above involved a large number of members and/or complicated details that would have been prohibitively expensive.
- "Stick-slip" and "noise". Most of the support concepts above presented the potential for the occurrence of stick-slip or noise that would compromise the operation of the LIGO beam tube modules.

The support configurations that were finally developed (refer to Drawings 6 thru 8, and 17 thru 19 attached at the end of the WBS 100 series of text) satisfied the required performance characteristics, are relatively simple in configuration, and do not induce noise into the beam tube modules.

Final Support Configurations

The components of the fixed (i.e., non-guided) supports have been designed for a vertical load of 7,100 lbs (weight of beam tube, stiffeners and insulation), a maximum lateral load of 1,200 lbs (UBC Zone 2B seismic load), and a maximum longitudinal load of 5,300 lbs (support load during tube bakeout). The fixed supports have **not** been designed for the simultaneous occurrence of seismic load and bakeout load, since the probability of these two events occurring together is extremely small. Thus, the maximum lateral load and the maximum longitudinal load are not applied to the support at the same time.

Refer to Drawings 6 thru 8 attached at the end of the WBS 100 series of text for the configuration of the fixed support. These drawings for this support can also be found in the Detailed Design.

A 4" x 3/8" 304L stainless steel support ring is welded to the beam tube at the support location. Welded to this support ring are support stubs, fabricated from 304L stainless steel plate, that transfer only vertical loads due to self weight and the overturning moment due to lateral seismic loads. Underneath each support stub is a 3" wide x 10" long x 1" deep Micarta (Grade G11) insulating block, the purpose of which will be discussed later. Two 7/8" diameter holes drilled thru each of the blocks will permit the installation of stainless steel bolts (and insulating sleeves) to attach the support stubs to the support frame. Refer to Drawings 6 thru 8 for specific details.



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Also attached to the bottom of the support ring is a transfer lug assembly which transmits the lateral seismic shear load and the longitudinal bakeout load from the tube into the support frame. Two 2" x 6" x 1" Micarta (Grade G11) insulating blocks are placed between the support ring and the transfer lug. Two 7/8" diameter holes drilled thru these blocks will permit the installation of stainless steel bolts (and insulating sleeves) to attach the support ring to the transfer lug assembly. Refer to Drawings 6 thru 8 for specific details.

The support frame consists of an assembly of three 4" x 4" x 3/8" structural tubes, A500 Grade B, which transfers all vertical, lateral and longitudinal loads into the two support lug assemblies. The tube steel support frame is attached to the support lug assemblies by a friction connection bolting assembly consisting of four 1" diameter A307 bolts and four 8" x 3" x 1" bolting plates. Refer to Drawings 6 thru 8 for specific details.

The support lug assemblies transfer all loads from the support frame to the foundation. Each support lug assembly is anchored to the foundation with six 5/8" diameter Hilti expansion anchors having an embedment depth of 2.75". These anchors are capable of being installed in a 4" slab. The support lug assemblies are slotted to permit the vertical alignment of the beam tube. Refer to Drawings 6 thru 8 for specific details.

Vertical and lateral alignment is accomplished by means of two portable hydraulic jacks and one hydraulic piston that will be carried from support to support. The jacks, with shims, are inserted beneath the vertical tubes of the support frame. A pair of teflon coated plates is placed between the jack and the horizontal tube. Once a snug fit is obtained between the jacks and the support frame, the 1" diameter bolts of the support lug assembly are loosened, and the support can then be moved up or down by means of the hydraulic jacks, and/or laterally by means of the hydraulic piston. Once the support is aligned, the 1" diameter support lug assembly bolts are torqued to 200 ft-lbs to provide the clamping force necessary to support the tube. The jacks, piston, shim plates and teflon coated plates are then removed for aligning the next support.

The components of the guided supports have been designed for a vertical load of 5,700 lbs (weight of beam tube, stiffeners and insulation), and a maximum lateral load of 1,750 lbs (UBC Zone 2B seismic load plus a lateral stability load). The guided support consists of hangar / frame system which permits the tube to move in the longitudinal direction.

Refer to Drawings 17 thru 19 attached at the end of the WBS 100 series of text for the configuration of the fixed support. These drawings for this support can also be found in the Detailed Design.



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A 4" x 3/8" 304L stainless steel support ring is welded to the beam tube at each of the two support locations near the expansion joint. Bolted to the support rings are gusset plates, fabricated from 304L stainless steel, that transfer vertical loads due to 2" x 3/16" hangar bars, A572 Grade 50 steel. Between each gusset plate and hangar bar is a 3" wide x 5-1/2" long x 1" deep Micarta (Grade G11) insulating block, the purpose of which will be discussed later. Two 7/8" diameter holes drilled thru each of the blocks will permit the installation of stainless steel bolts (and insulating sleeves) to attach the gusset plate to the hangar bars. Refer to SK-GS2 for specific details. During bakeout and daily transient thermal loads, the 2" x 3/16" hangar bars will flex about their weak axis, providing a noiseless method by which to permit movement of the beam tube.

The hangar bars are attached to pairs of horizontal channels, which in turn attach to the vertical posts of the two support frames, constructed of 4" x 4" x 3/8" structural tubes, A500 Grade B. Each support frame is supported by a pair of support lug assemblies, identical in behavior and configuration to those for the fixed support. Refer to Drawings 17 thru 19 for specific details.

Alignment of the guided support is accomplished in the same manner as alignment of the fixed support, which has been discussed previously.

All carbon steel members of both the fixed and guided supports will be galvanized in order to provide corrosion resistance.

Support Insulation

One of the critical requirements of the LIGO beam tube modules is that, during the 30 day bakeout of the beam tubes, the tube wall temperature at points of support shall not drop below 266°F. As such, in addition to insulating the beam tube in order to meet this requirement, it becomes necessary to incorporate insulation of some type into the "body" of the support designs in order to isolate, or decouple, the support from the beam tube. By doing this, the flow of heat from the wall of the beam tube into the supports is reduced, allowing the beam tube wall temperature to remain above the required minimum temperature of 266°F.

The insulator that is incorporated into the supports is Micarta, Grade G11, having a thermal conductivity, K, of 1.8 BTU*in / hr*ft²*°F. Micarta was selected for its excellent mechanical properties (compressive strength of 50,000 psi), impermeability to water absorption, widespread availability, relatively low cost (approximately \$0.70 per cubic inch) as well as its insulating properties. Grade G11 Micarta has a maximum recommended operating temperature of 310°F, well within the boundary of the maximum operating temperature of the LIGO beam tube modules. CBI has in the past used Micarta as a load-bearing insulator in a variety of cryogenic and low-temperature applications, and has not experienced any performance difficulties. Refer to the attached



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sketches of the support configurations, as well as the detailed drawings contained in the Detailed Design, for the locations of the Micarta insulation within the supports.

Prior to selecting Grade G11 Micarta other insulators were considered, among them calcium silicate- and polyurethane-based insulators, Transite and Marinite. However, all of these insulators were found to be unacceptable for a variety of reasons, among them being: susceptibility to water permeation, low load-bearing strength, low recommended operating temperatures, and high thermal conductivity values (as compared to Micarta). Given the importance of the beam tube wall temperature requirements during bakeout and the loads imposed on the insulators, Micarta proved to be superior to all other insulators considered.

To verify that the amount and placement of the Micarta insulation used in the supports is adequate, the fixed (non-guided) support was subjected to a thermal analysis in order to determine the tube wall temperature at the tube-to-support ring connection during bakeout. A two-dimensional, axisymmetric finite element analysis of the beam tube and support was performed using ADINA-T.

A detailed presentation of the thermal analysis and its results are contained in the Detailed Design. In brief, the analysis indicates that the minimum tube wall temperature will be 268°F at the support locations near the side of the tube and 278°F at the support location at the base of the tube.

Page # ?

WBS #140 Pump Port Design

The pump port is designed for the vacuum load and external load specified by Caltech. For the vacuum loads, ASME Section VIII, Division 1 is used to determine area replacement requirements. A reinforcing pad plate having a thickness of 6.4mm (1/4") will be used. The reinforcing pad plate has an outside diameter of 387mm (15.25") and an inside diameter of 330mm (13"). The inside diameter of the reinforcing pad plate does not join into the neck of the port. This detail is typically used for penetrations used in vacuum vessels. This separation assures that a virtual leak is not created from the weld detail between the reinforcing pad plate and the neck. The reinforcing pad plate is welded to the beam tube with intermittent welds. This assures that a virtual leak is not created by the reinforcing pad plate.

A special CBI in house analysis program is used to analyze the pump port for the external loads. The external load used in the analysis was 667.2N (150 pounds). The load acts vertically downward located approximately 94mm (3.7") radially outward from the outside diameter at the horizontal center line. The stresses obtained from the analysis are less than the allowable stress per ASME Section VIII, Division 1.



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Figure 1 illustrates the pump port. Per Caltech, a 377mm (13 1/4") nominal outside diameter Conflat flange is used. The neck will have a nominal outside diameter of 254mm (10"). The wall thickness of the neck will be 3.0mm (0.120"). The projection between the outside diameter at the horizontal center line and the back side of the flange will be 50.8mm (2"). Together with the flange, the total projection is 79mm (3 1/8") at the horizontal center line. The pump ports will be centered between the first two vacuum stiffeners, which locates the pump ports 1543mm (5'-0 3/4") from the fixed support.

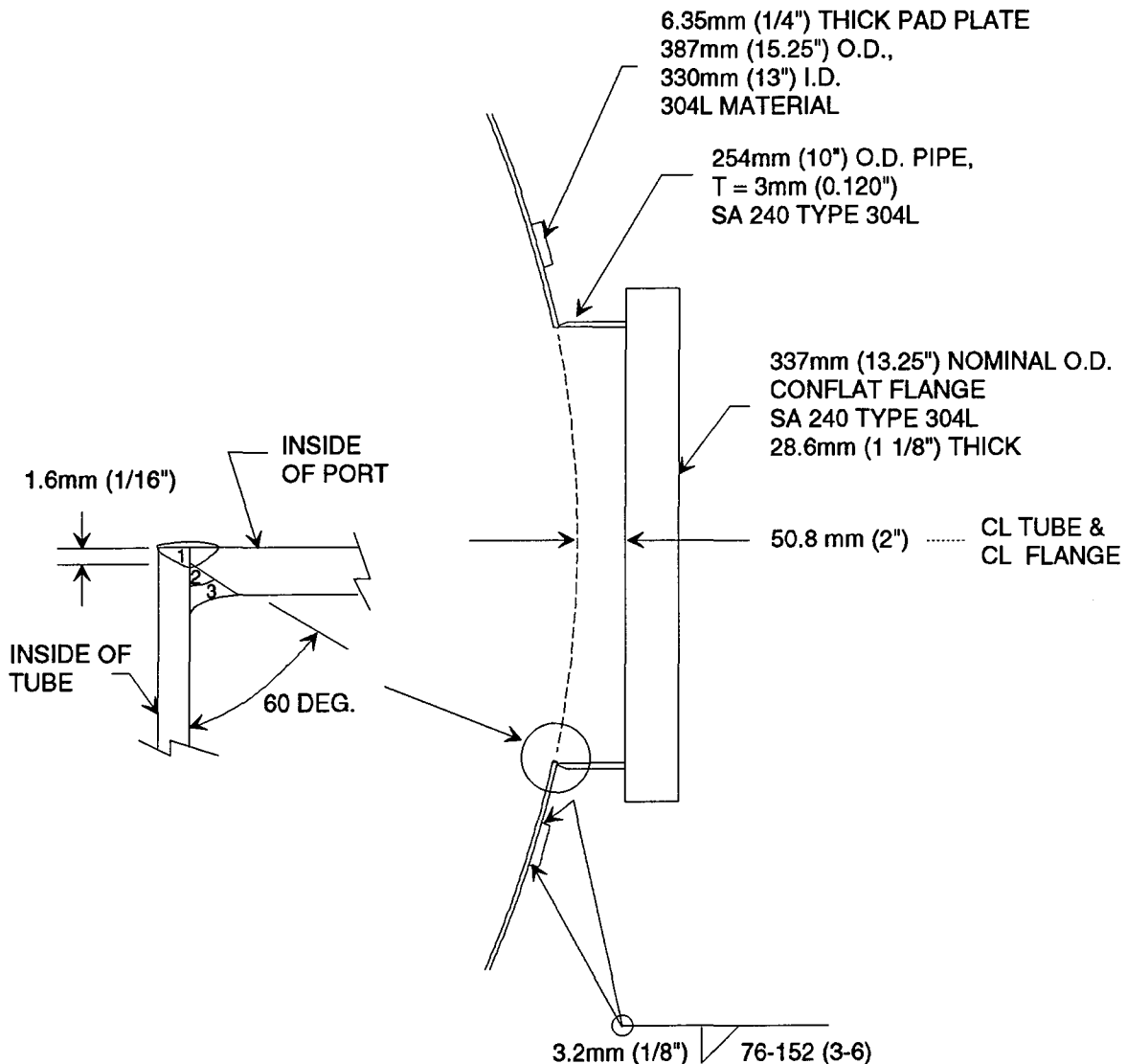


FIGURE 1
PUMP PORT DETAIL



WBS #150 Baffle Design

Due to the integrated nature of the baffle design and fabrication processes, internal baffle design considerations are addressed in WBS #250, "Baffle Fabrication Process".

WBS #170 Procurement Specifications

A number of procurement specifications for components of the LIGO beam tube modules have been prepared, are listed in the LIGO Master Procedure Listing, and are contained in the Detailed Design. These procurement specifications are intended for submittal to fabricators of beam tube components, and contain detailed information regarding the required materials, fabrication procedures and tolerances, welding procedures, cleaning procedures, handling procedures and shipping procedures that are to be followed during fabrication of the particular component.

The following component procurement specifications are contained in the Detailed Design:

Specification Designation	Specification Description
C-BT-QT	Qualification Test Beam Tube Sections
C-BT-CO	LIGO Beam Tube Sections
C-EJ-QT	Expansion Joint, Qualification Test
C-EJ-CO	Expansion Joints, Construction Option
C-BAF-1	Baffle Fabrication Specification
C-VAC-1	Vacuum Stiffener Fabrication Specification
C-SUPT-1	Structural Support Fabrication Specification
C-SUPSTF-1	Support Ring/Baffle Ring Fabrication Spec'n
C-PORT-QT	Pump Port Fabrication Spec'n, Qual'n Test
C-PORT-OP	Pump Port Fabrication Spec'n, Constr'n Option
C-PORTPAD-1	Pump Port Reinforcing Pad Fab'n Spec'n

WBS #180 Detailed Drawing Discussion

A total of sixteen (16) detailed design drawings for components and assemblies of the LIGO beam tube modules have been prepared and are contained in the Detailed Design. These design drawings contain detailed information regarding the required quantity of the components and assemblies, materials, dimensions, fabrication procedures (if applicable), weld descriptions and other information.



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The following drawings have been prepared and can be found in the Detailed Design:

Drawing Number	Drawing Description
1, Rev 0	General Beam Tube Module Configuration
2, Rev 0	Beam Tube Sub-Module Details
3, Rev 0	Beam Tube Sub-Module Details
4, Rev 0	Beam Tube Sub-Assembly Details
5, Rev 0	Beam Tube Sub-Assembly Details
6, Rev 0	Fixed Support Details
7, Rev 0	Fixed Support Details
8, Rev 0	Fixed Support Details
9, Rev 0	Beam Tube Sub-Assembly Details
13, Rev 0	Pump Port Details
14, Rev 0	Baffle Details
15, Rev 0	Vacuum Stiffener Details
16, Rev 0	Support Ring / Baffle Stiffener Details
17, Rev 0	Guided Support Details
18, Rev 0	Guided Support Details
19, Rev 0	Guided Support Details

There are very specific material, fabrication, welding and cleaning procedures that must be followed for the fabrication of many of these components. Therefore, it is intended that the provisions of the appropriate procurement specification (refer to WBS #170, "Procurement Specifications") be followed. Due to the limited space available on the design drawings, it was not possible to summarize on these drawings the detailed information found in the procurement specifications. The drawings, therefore, refer the fabrication shop to the fabrication specification for this information.

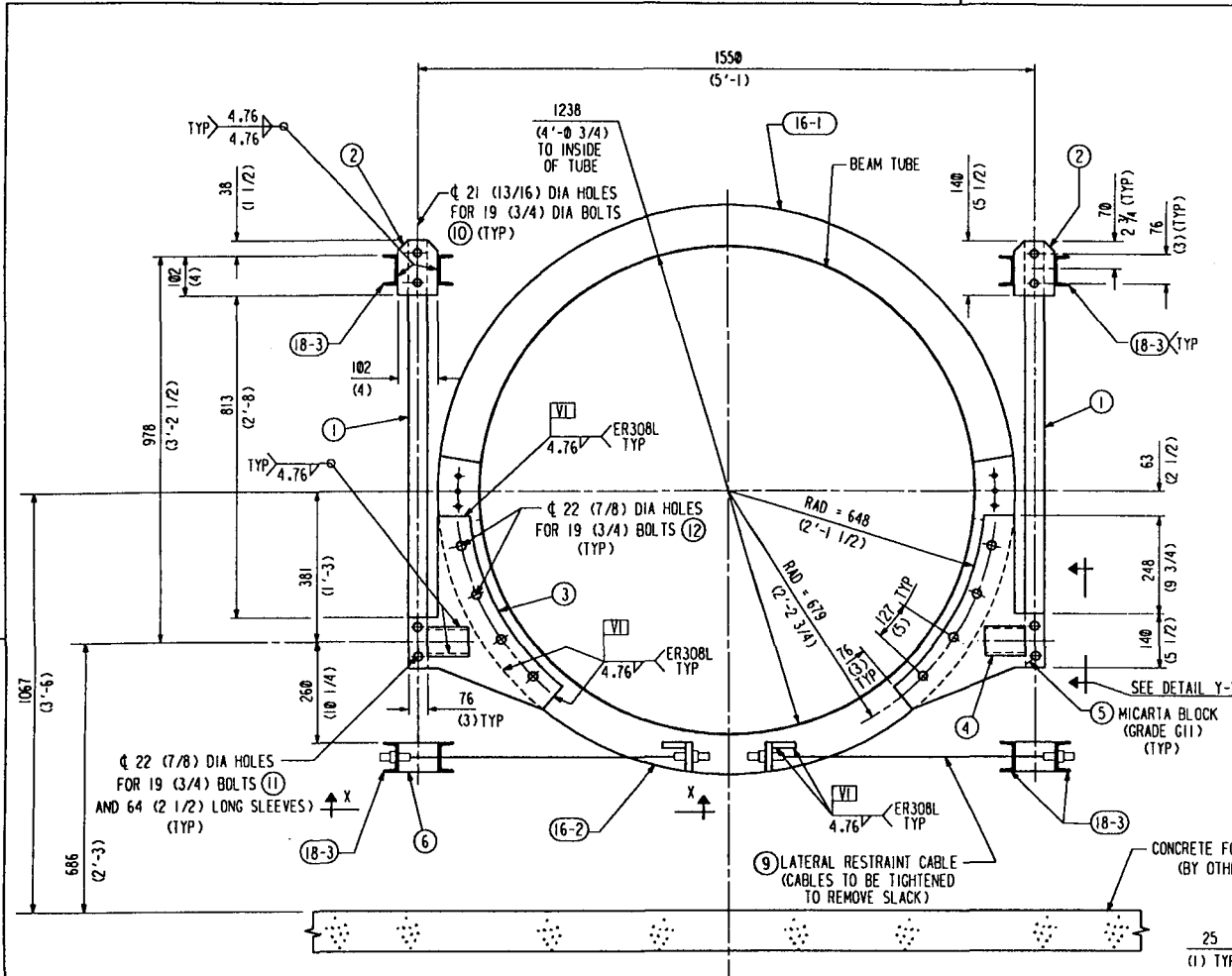
How is this to be conveyed to the vendor

Not incorporated into the Detailed Design are the specific vendor or fabricator shop drawings that will be required for certain components, such as:

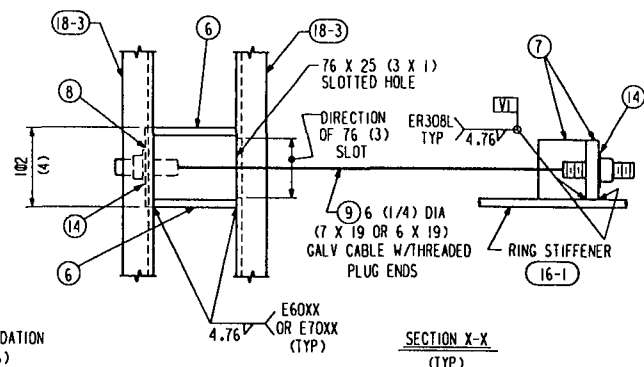
- Expansion Joints
- Beam Tube Supports
- Beam Tube Support Rings

The need for these specific drawings from the vendor or fabricator is called for in the appropriate Procurement Specification. These drawings, once received, should be made part of the Detailed Design.

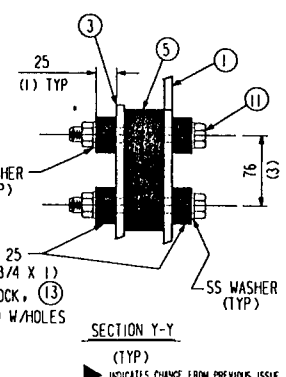
MISSING FROM DESIGN AT PASTOR



SECTION A-A
(FROM DWG #017)
(SECTIONS NOT SHOWN FOR CLARITY)



SECTION X-X
(TYP)



SECTION Y-Y
(TYP)

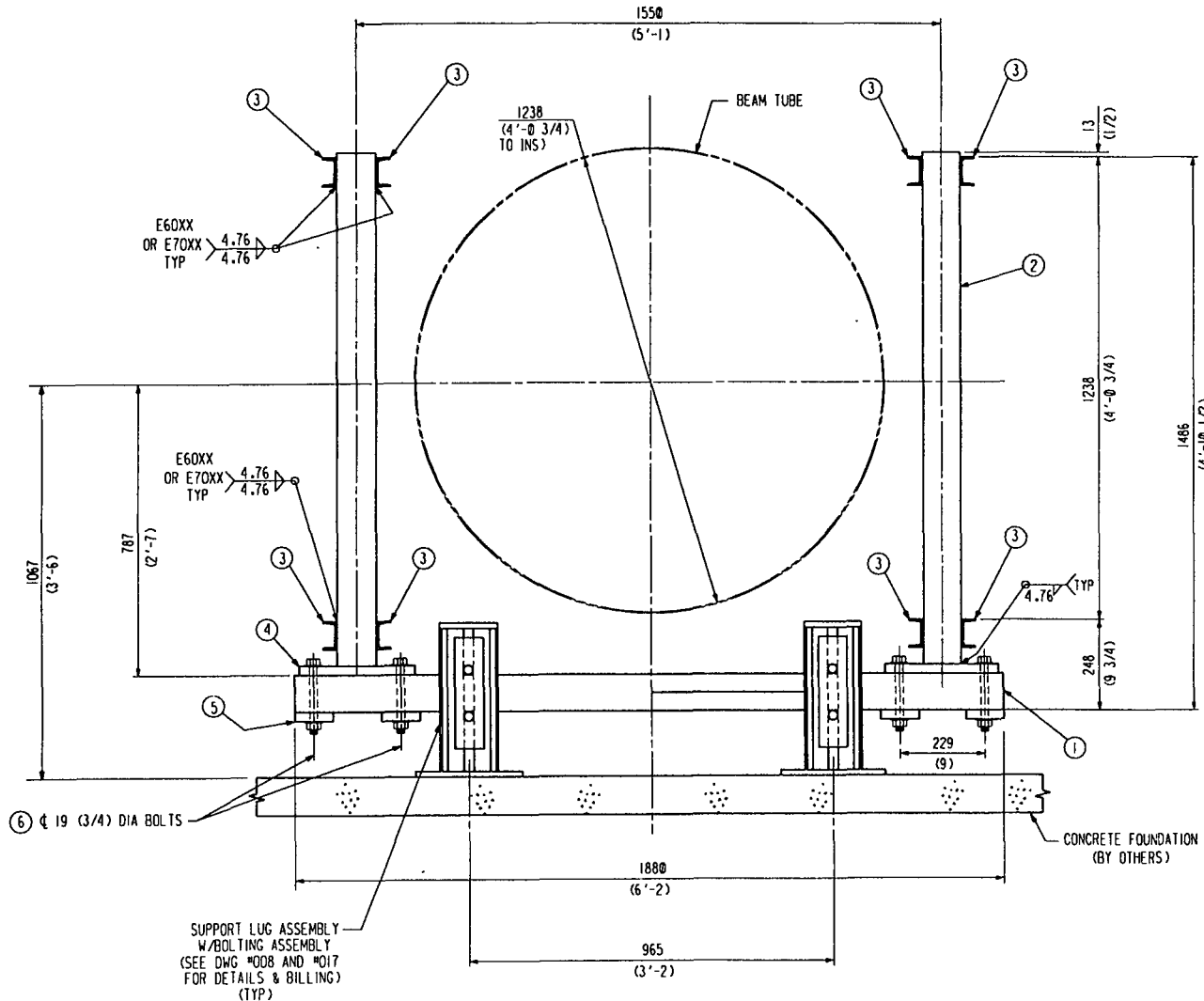
INDICATES CHANGE FROM PREVIOUS ISSUE

SHOP PC	MARK	ASSN PC	DESCRIPTION	LENGTH MM	SPEC
4	19-1		BAR 50 X 4.76 (2 X 3/16) W/HOLES	1093 (3'-7")	A572 Gr50
4	19-2		PL SK X 10 (3/8) THK W/HOLES	140	A36
4	19-3		PL SK X 10 (3/8) THK W/HOLES	0'-5 1/2	A36
4	19-4		C 3 X 4.1		A240-304L
4	19-5		MICARTA BLOCK 50 X 102 X 25 W/HOLES (2 X 4 X 1) (GRADE G11)		A36
8	19-6		PL 76 X 10 (3 X 3/8)	102 (4)	A36
8	19-7		PL 76 X 16 (3 X 5/8)	76 (3)	A240-304L
4	19-8		PL 38 X 6 (1 1/2 X 1/2) W/HOLES	102 (4)	A36
1	19-9		RUN 6 (1/4) DIA (7 X 19 OR 6 X 19)	3660	
1	19-10		GALV CABLE W/THREADED PLUG ENDS	(12'-0)	
8	19-10		BOLT 19 (3/4) DIA HYX HEX W/HEX NUT AND WASHERS.	50 (2)	A307
8	19-11		BOLT 19 (3/4) DIA HYX HEX W/HEX NUT AND 1/32 THK X 64 (2 1/2) LONG NYLAR INSULATING SLEEVE. (FROM F.H.MALONEY CO.)	152 (6)	304 SS
16	19-12		BOLT 19 (3/4) DIA HYX HEX W/HEX NUT AND STAINLESS STEEL WASHERS	64	304 SS
16	19-13		MICARTA BLOCK 44 X 44 X 25 W/HOLES (1 3/4 X 1 3/4 X 1) GRADE G11	(2 1/2)	
8	19-14		3 (1/8) THK RYTON INSULATING WASHER (FROM F.H.MALONEY CO.)		

NOTES

1. WORK THIS DWG WITH DWG #008, #017 AND #018
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 400 FIXED SUPPORTS REQD.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

		CONTRACT NO 930212	
		CUSTOMER'S NO BY MAN, DMD WJC DATE 4-4-94	
SECTION DETAILS BEAM TUBE GUIDED SUPPORT LIGO HANFORD, WA. AND LIVINGSTON, LA.		ENGINEERING SUPERVISOR D. E. THORN	
Dwg 019 Rev 0		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.	



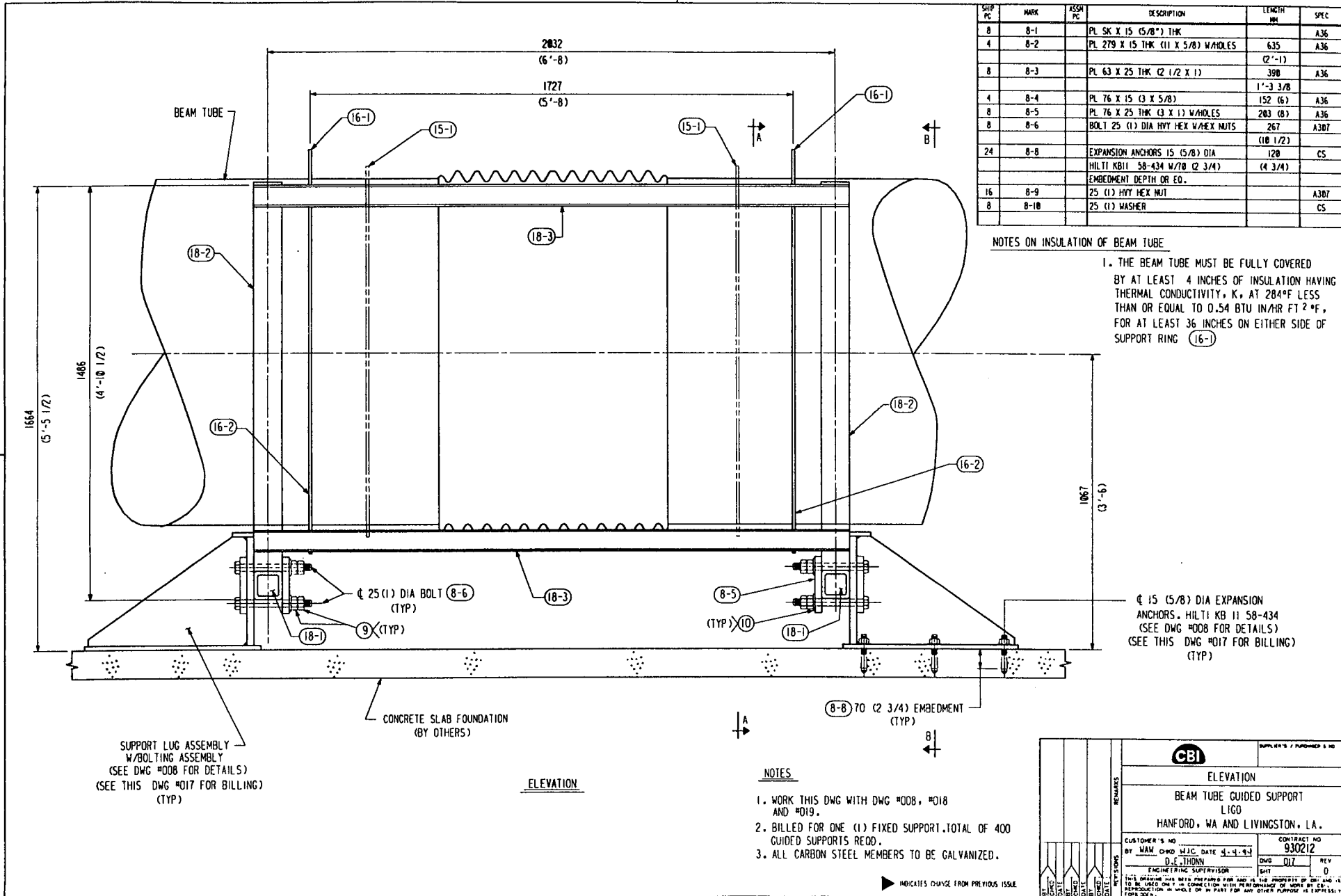
SHP PC	MARK	ASSY PC	DESCRIPTION	LENGTH	SPEC
2	18-1		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8 W/HOLES	1880	A500 Gr-B
4	18-2		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8	1372	A500 Gr-B
8	18-3		C 3 X 4.1 PBE	2134	A36
4	18-4		PL 102 X 25 (4 X 1) W/HOLES	305	A36
8	18-5		PL 102 X 25 (4 X 1) W/HOLES	182	A36
8	18-6		BOLTS 19 (3/4) DIA HYV HEX W/HEX NUT AND WASHERS	283	A307

NOTES

1. WORK THIS DWG WITH DWG #008, #017 AND #019.
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 400 GUIDED SUPPORTS REQD.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

REVISIONS		REVISIONS				SUPPLIER'S / PURCHASER'S NO	
						SECTION DETAILS	
BEAM TUBE GUIDED SUPPORT LUG HANFORD WA. AND LIVINGSTON LA.		CUSTOMER'S NO		CONTRACT NO			
		BY WAW CHKD MJC DATE 1-1-91		930212			
ENGINEERING SUPERVISOR D.E. THONN		DATE		REV			
		SHT		0			
<small>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.</small>							

INDICATES CHANGE FROM PREVIOUS ISSUE



SHIP PC	MARK	QSSA PC	DESCRIPTION	LENGTH MM	SPEC
8	8-1		PL SK X 15 (5/8") THK		A36
4	8-2		PL 279 X 15 THK (11 X 5/8) W/HOLES	635	A36
				(2'-1)	
8	8-3		PL 63 X 25 THK (2 1/2 X 1)	398	A36
				1'-3 3/8	
4	8-4		PL 76 X 15 (3 X 5/8)	152 (6)	A36
8	8-5		PL 76 X 25 THK (3 X 1) W/HOLES	283 (8)	A36
8	8-6		BOLT 25 (1) DIA HYV HEX W/HEX NUTS	267	A307
				(10 1/2)	
24	8-8		EXPANSION ANCHORS 15 (5/8) DIA	120	CS
			HILTI KB11 58-434 W/10 (2 3/4)	(4 3/4)	
			EMBEDMENT DEPTH OR EQ.		
16	8-9		25 (1) HYV HEX NUT		A307
8	8-10		25 (1) WASHER		CS

NOTES ON INSULATION OF BEAM TUBE

1. THE BEAM TUBE MUST BE FULLY COVERED BY AT LEAST 4 INCHES OF INSULATION HAVING THERMAL CONDUCTIVITY, K, AT 284°F LESS THAN OR EQUAL TO 0.54 BTU IN/HR FT 2 °F, FOR AT LEAST 36 INCHES ON EITHER SIDE OF SUPPORT RING (16-1)

Ø 15 (5/8) DIA EXPANSION ANCHORS, HILTI KB 11 58-434 (SEE DWG #008 FOR DETAILS) (SEE THIS DWG #017 FOR BILLING) (TYP)

SUPPORT LUG ASSEMBLY W/BOLTING ASSEMBLY (SEE THIS DWG #008 FOR DETAILS) (SEE THIS DWG #017 FOR BILLING) (TYP)

CONCRETE SLAB FOUNDATION (BY OTHERS)

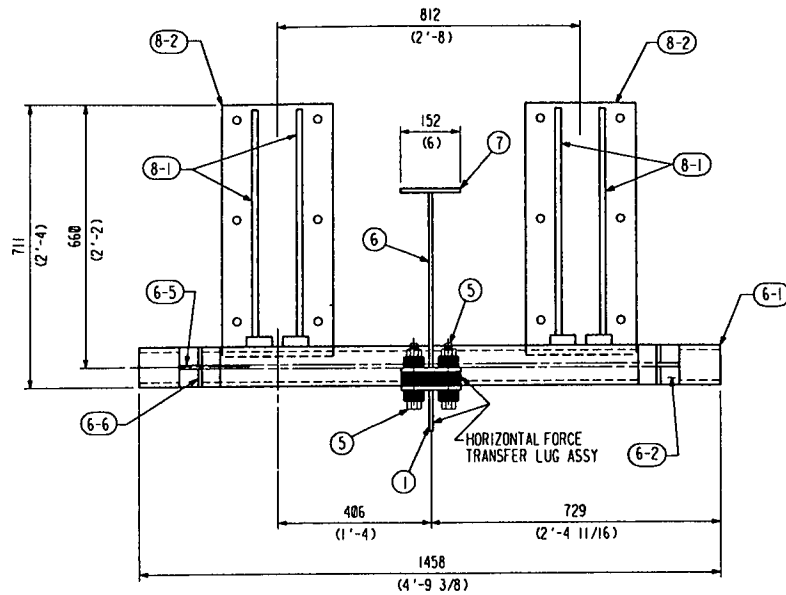
ELEVATION

NOTES

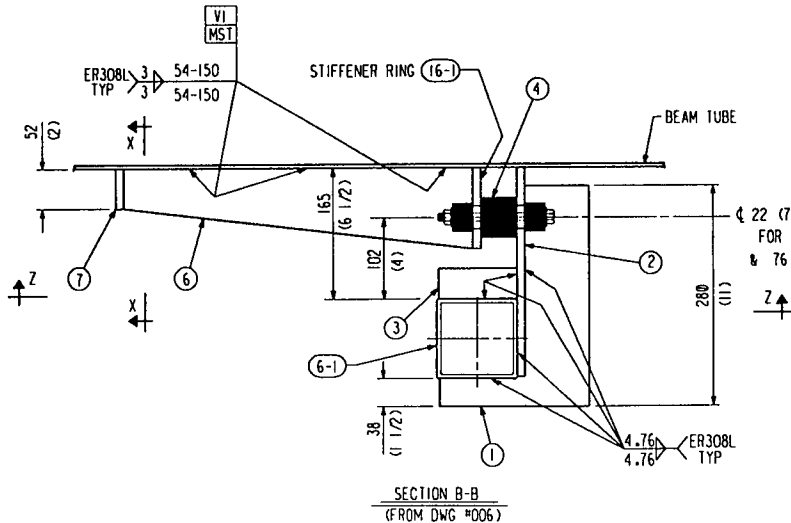
1. WORK THIS DWG WITH DWG #008, #018 AND #019.
2. BILLED FOR ONE (1) FIXED SUPPORT, TOTAL OF 400 GUIDED SUPPORTS REQ.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

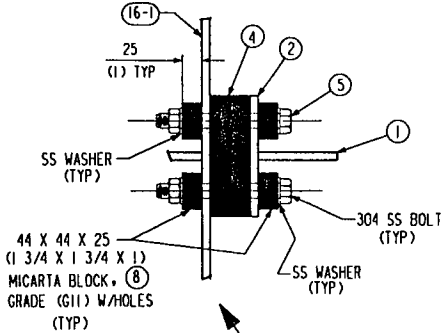
		SUPPLIERS / PROVIDED BY NO	
		ELEVATION	
BEAM TUBE GUIDED SUPPORT		LIGO	
HANFORD, WA AND LIVINGSTON, LA.		CONTRACT NO. 930212	
CUSTOMER'S NO.		DATE 3-4-93	
BY WAW OMD WJC		DWG 017 REV 0	
D. C. THORN		ENGINEERING SUPERVISOR	
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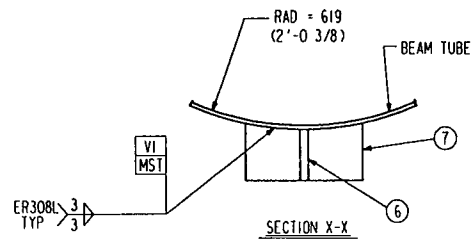
PLAN VIEW "A-A"
(FROM DWG #006)
(SUPPORT BASE)



SECTION B-B
(FROM DWG #006)



SECTION Z-Z



SECTION X-X

SHIP PC	MARK	ASSN PC	DESCRIPTION	LENGTH MM	SPEC
FIXED SUPPORT					
1	7-1		PL SK X 10 (3/8) THK	288	A240-304L
			(1)		
1	7-2		PL 150 X 10 (0'-6 X 3/8) THK	241	A240-304L
			W/HOLES	0'-9 1/2	
1	7-3		PL 38 X 10 (0'-1 1/2 X 3/8) THK	83	A240-304L
				0'-3 1/4	
2	7-4		MICARTA BLOCK 50 X 152 X 25 W/HOLES (2 X 6 X 1) GRADE (G11)		
2	7-5		BOLT 19 (3/4) DIA HVT HEX W/ HEX NUT AND 1/32 THK X 76 (3) LONG NYLAR INSULATING SLEEVE (FROM F.H. MALONEY CO.)	178	304 SS
				0'-7	
1	7-6		PL SK X 10 (3/8) THK	457	A240-304L
				(1'-6)	
1	7-7		PL 50 X 10 (0'-2 X 3/8) THK	152	A240-304L
				0'-6	
2	7-8		MICARTA BLOCK 44 X 44 X 25 W/HOLES (1 3/4 X 1 3/4 X 1) GRADE G11		

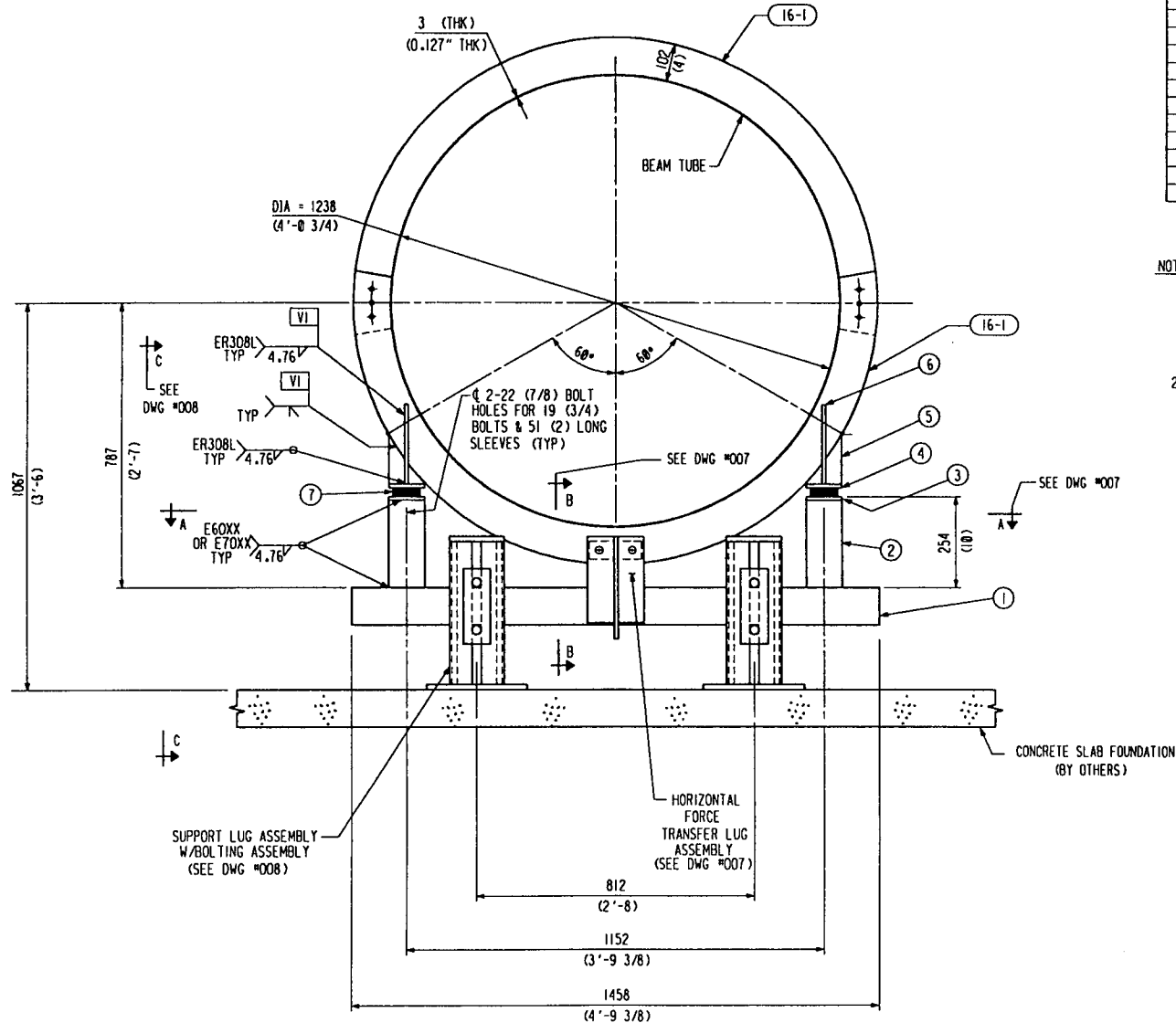
NOTES

1. WORK THIS DWG WITH DWG #006 AND #008.
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 392 FIXED SUPPORTS REQD.

CBI		SUPPLIER'S / PURCHASER'S NO.	
PLAN VIEW AND DETAILS			
BEAM TUBE FIXED SUPPORT			
LIGO			
HANFORD, WA AND LIVINGSTON, LA.			
CUSTOMER'S NO.		CONTRACT NO.	
BY: MAH OMD DATE: 4-4-94		930212	
D.C. THOMAS		DWS	
ENGINEERING SUPERVISOR		REV	
		0	
		0	

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SHIP PC	MARK	ASSY PC	DESCRIPTION	LENGTH MM	SPEC
FIXED SUPPORT					
1	6-1		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8)	1458	A500 Q-B
2	6-2		TUBULAR STEEL 102 X 102 X 10 (4 X 4 X 3/8)	244	A500 Q-B
2	6-3		PL 102 X 10 THK (4 X 3/8) W/HOLES	254	A36
2	6-4		PL 102 X 10 THK (4 X 3/8) W/HOLES	254	A240-304L
2	6-5		PL 5K X 10 THK (0'-3/8)	(0'-10)	A240-304L
4	6-6		PL 5K X 10 THK (0'-3/8)	203 (8)	A240-304L
2	6-7		MICARTA BLOCK 76 X 254 X 25 (3 X 10 X 1) (GRADE G11) W/HOLES		

NOTES ON INSULATION OF BEAM TUBE

1. THE BEAM TUBE MUST BE FULLY COVERED BY AT LEAST 4 INCHES OF INSULATION HAVING THERMAL CONDUCTIVITY, K, AT 284°F LESS THAN OR EQUAL TO 0.54 BTU IN/HR FT² °F. FOR AT LEAST 36 INCHES ON EITHER SIDE OF SUPPORT RING (16-1)
2. PIECES (6-2), (6-3), (6-4), (6-5), (6-6), AND (6-7) MUST BE FULLY COVERED BY AT LEAST 2 INCHES OF THE INSULATION MENTIONED IN NOTE #1 ABOVE.

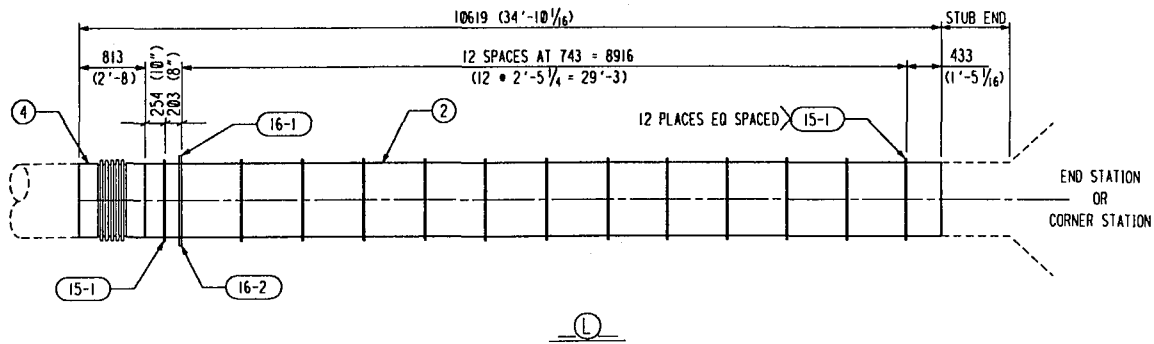
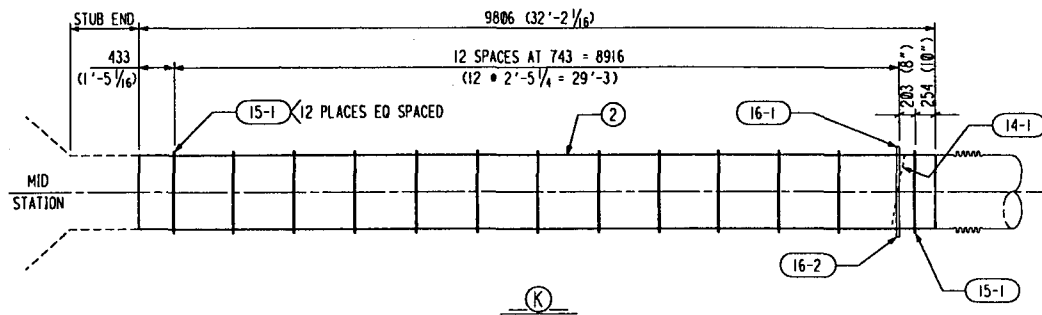
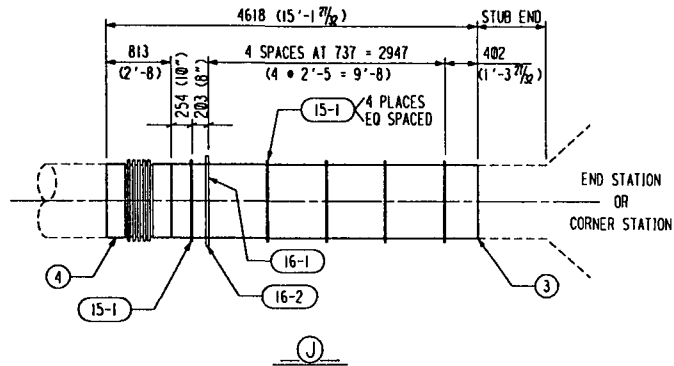
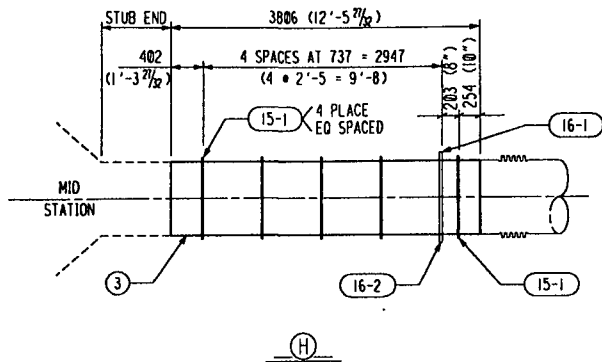
NOTES

1. WORK THIS DWG WITH DWG #007 AND #008.
2. BILLED FOR ONE (1) FIXED SUPPORT. TOTAL OF 392 FIXED SUPPORTS REDD.
3. ALL CARBON STEEL MEMBERS TO BE GALVANIZED.

		SUPPLIER'S PURCHASE NO	
		ELEVATION	
BEAM TUBE FIXED SUPPORT LIGO HANFORD, WA. AND LIVINGSTON, LA.		CUSTOMER'S NO	CONTRACT NO
		BY MAM CHD VICE DATE 4-4-94	930212
ENGINEERING SUPERVISOR D. E. THOMAS		DWG 006	REV C
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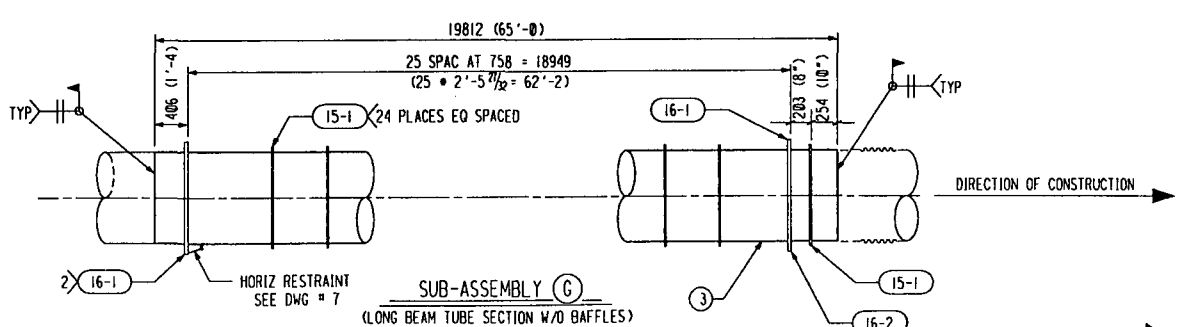
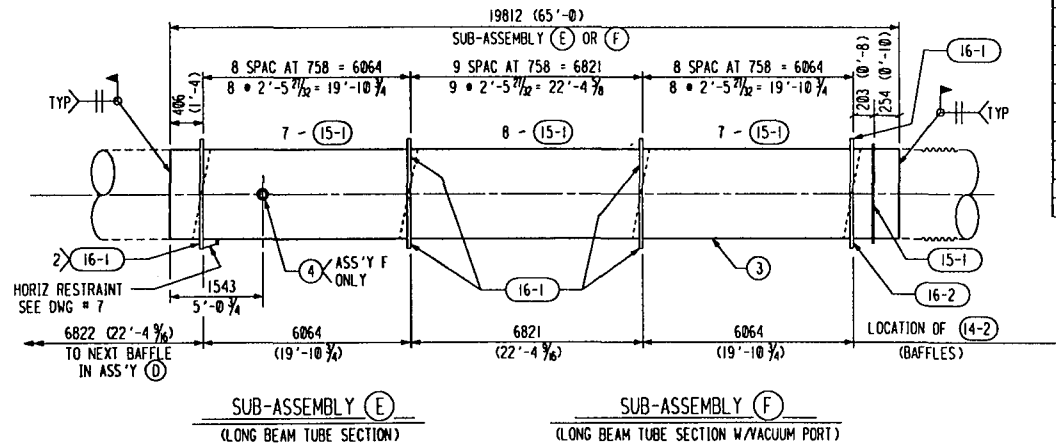
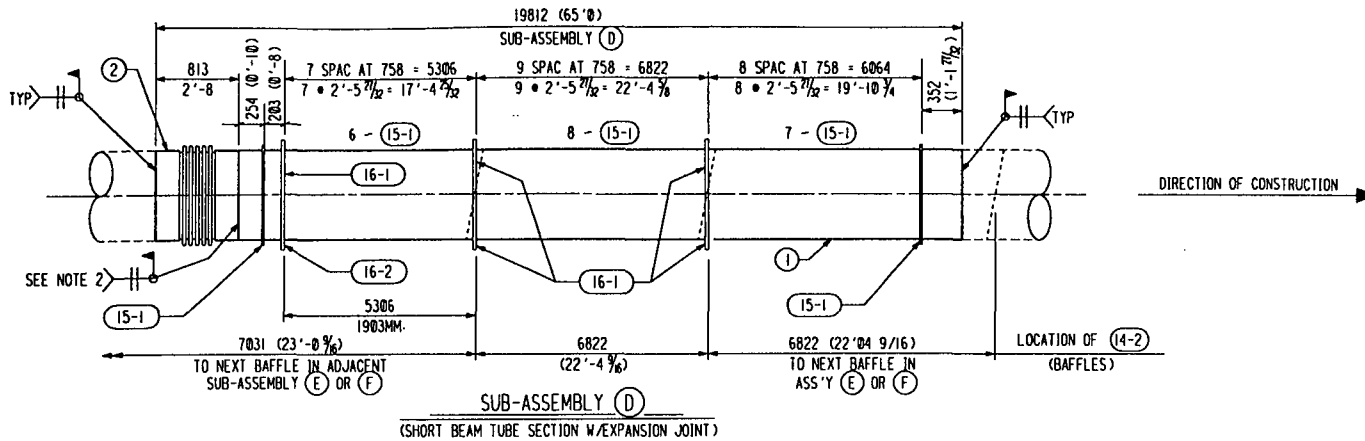
▶ INDICATES CHANGE FROM PREVIOUS ISSUE

BEAM TUBE SUPPORT ELEVATION



SHIP PC	MARK	ASSM PC	DESCRIPTION	LENGTH INCH	SPEC
	9-H		- BEAM ASSEMBLY -		
	9-3	1	BEAM TUBE 1245 x 3.2	3806	
	15-1	5	VACUUM STIFFENERS		
	16-1	1	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	9-J		- BEAM ASSEMBLY -		
	9-3	1	BEAM TUBE 1245 x 3.2	4618	
	9-4	1	EXPANSION JOINT		
	15-1	5	VACUUM STIFFENERS		
	16-1	1	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	9-K		- BEAM ASSEMBLY -		
	9-2	1	BEAM TUBE 1245 x 3.2	9806	
	14-1	1	BAFFLE		
	15-1	13	VACUUM STIFFENERS		
	16-1	1	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	9-L		- BEAM ASSEMBLY -		
	9-2	1	BEAM TUBE 1245 x 3.2	9806	
	9-4	1	EXPANSION JOINT		
	15-1	13	VACUUM STIFFENERS		
	16-1	1	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		

REVISIONS		REMARKS		CBI		SUPPLIER'S / PURCHASER'S	
				LIGO BEAM TUBE MODULES HANFORD, WA & LIVINGSTON, LA			
REVISIONS		REMARKS		SUB-ASSEMBLIES		CONTRACT NO	
				(H) (J) (K) (L)			
REVISIONS		REMARKS		CUSTOMER'S NO		CONTRACT NO	
				BY: <u>K.R. CHOD MJC</u> DATE: <u>4-2-94</u>		930212	
REVISIONS		REMARKS		D.J. THOM		DWC	
				ENGINEERING SUPERVISOR		9	
REVISIONS		REMARKS		THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI & IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK AT CBI. REPRODUCTION OR USE IN ANY PART FOR ANY OTHER PURPOSE IS STRICTLY FORBIDDEN.		SPEC	
						SMT	

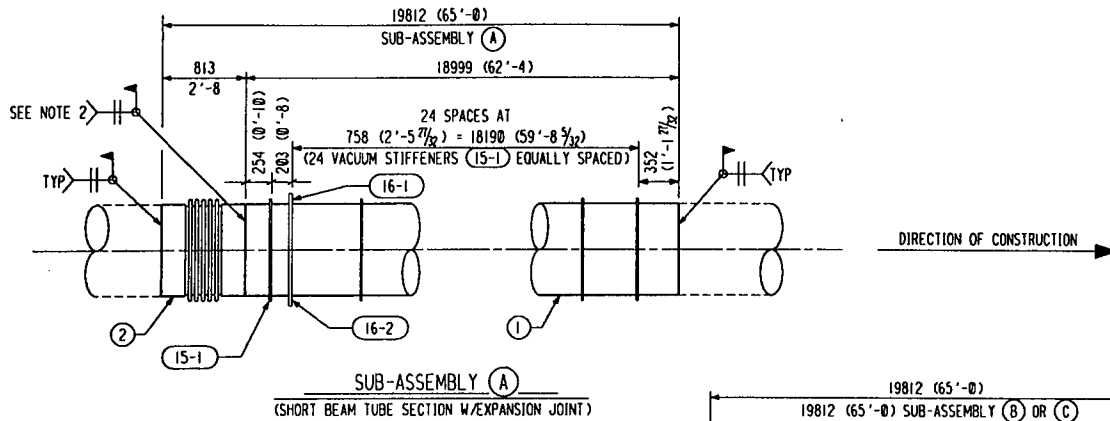


SHIP PC	MARK	ASSN PC	DESCRIPTION	LENGTH MM	SPEC
	5-D		- BEAM ASSEMBLY -		
	5-1	1	BEAM TUBE 1245 x 3.2 (49.00 OD x 0.127" THK x 62'-4 LG)	18999	
	5-2	1	EXPANSION JOINT	813	
	14-1	2	BAFFLES		
	15-1	23	VACUUM STIFFENERS		
	16-1	5	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	5-E		- BEAM ASSEMBLY -		
	5-3	1	BEAM TUBE 1245 OD x 3.2 THK (49.00 OD x 0.127" THK x 65'-0 LG)	19812	
	14-1	4	BAFFLES		
	15-1	23	VACUUM STIFFENERS		
	16-1	7	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	5-F		- BEAM ASSEMBLY -		
	5-3	1	BEAM TUBE 1245 OD x 3.2 THK (49.00 OD x 0.127" THK x 65'-0 LG)	19812	
	5-4	1	VACUUM PORT		
	14-1	4	BAFFLES		
	15-1	23	VACUUM STIFFENERS		
	16-1	7	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	5-G		- BEAM ASSEMBLY -		
	5-3	1	BEAM TUBE 1245 OD x 3.2 THK	19812	
	15-1	25	VACUUM STIFFENERS		
	16-1	3	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		

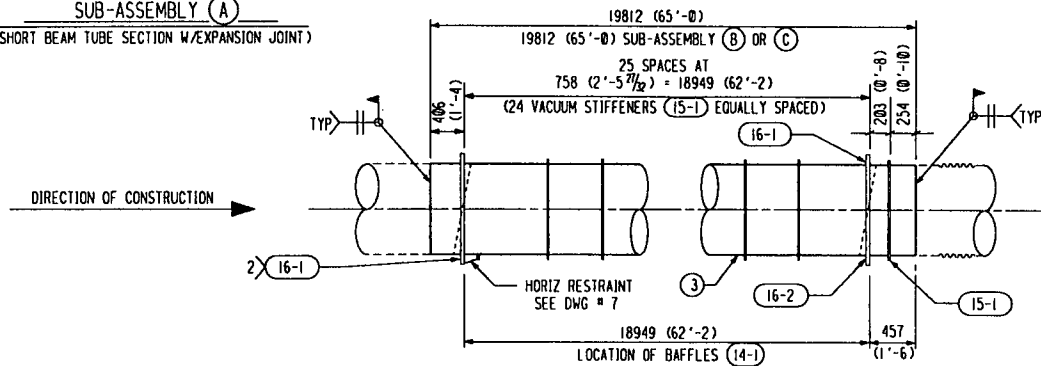
- NOTES:
1. DURING CONSTRUCTION, THE CLEAN ROOM WILL SLIDE OVER ENDS WITHOUT AN EXPANSION JOINT.
 2. CIRCUMFERENTIAL SEAM WILL BE WELDED BEFORE CLEANING AND LEAK TESTING.

REVISIONS		REMARKS				LIGO BEAM TUBE HANFORD, WA & LIVINGSTON, LA SUB-ASSEMBLIES (D, E, F & G)	
						CUSTOMER'S NO	CONTRACT NO
DATE	BY	DATE	DATE	DWG	SHEET	REV	NO
DATE	BY	DATE	DATE	DWG	SHEET	REV	NO
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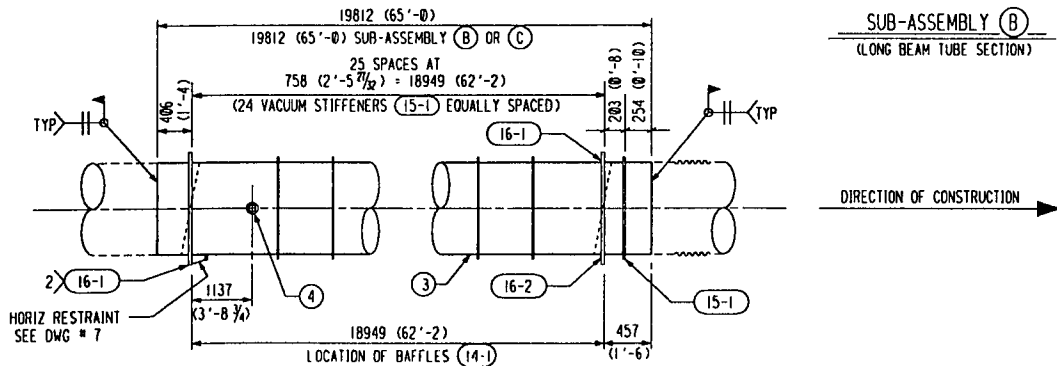
► INDICATES CHANGE FROM PREVIOUS ISSUE



SUB-ASSEMBLY (A)
(SHORT BEAM TUBE SECTION W/EXPANSION JOINT)



SUB-ASSEMBLY (B)
(LONG BEAM TUBE SECTION)



SUB-ASSEMBLY (C)
(LONG BEAM TUBE SECTION W/VACUUM PORT)

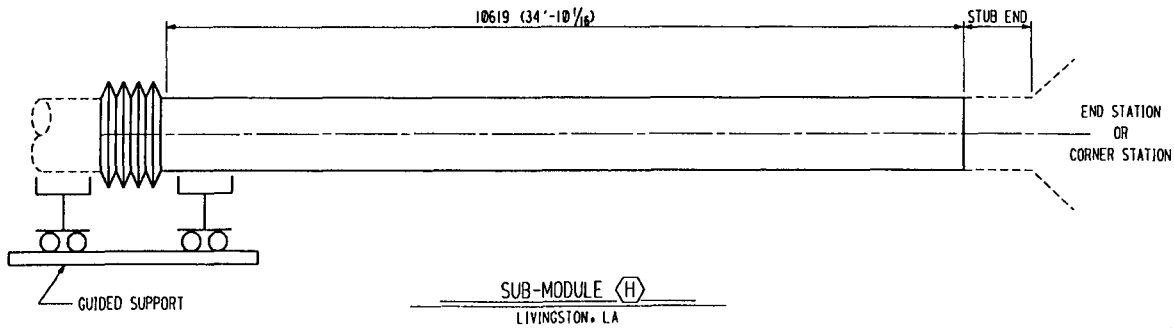
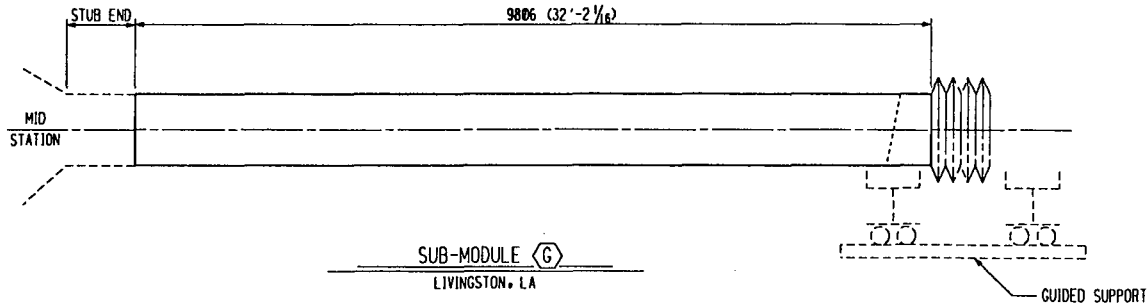
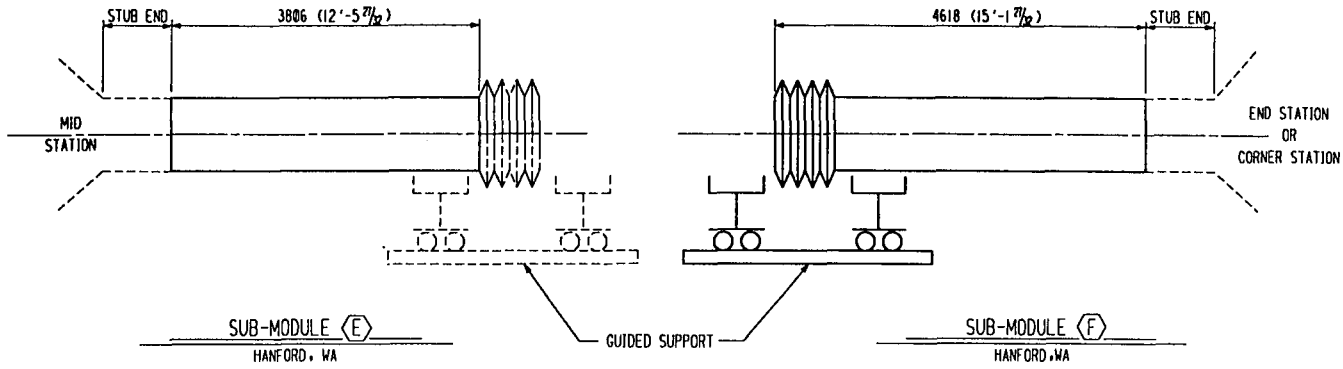
SHIP PC	MARK	ASSN PC	DESCRIPTION	LENGTH MM	SPE
	4-A		- BEAM ASSEMBLY -		
	4-1	1	BEAM TUBE 1245 x 3.2 (49.00 OD x Ø.127" THK x 62'-4 LG)	18999	
	4-2	1	EXPANSION JOINT	813	
	15-1	25	VACUUM STIFFENERS		
	16-1	1	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	4-B		- BEAM ASSEMBLY -		
	4-3	1	BEAM TUBE 1245 OD x 3.2 THK (49.00 OD x Ø.127" THK x 65'-0 LG)	19812	
	14-1	2	BAFFLES		
	15-1	25	VACUUM STIFFENERS		
	16-1	3	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		
	4-C		- BEAM ASSEMBLY -		
	4-3	1	BEAM TUBE 1245 OD x 3.2 THK (49.00 OD x Ø.127" THK x 65'-0 LG)	19812	
	4-4	1	VACUUM PORT		
	14-1	2	BAFFLES		
	15-1	25	VACUUM STIFFENERS		
	16-1	3	SUPPORT RING/BAFFLE STIFFENER HALF		
	16-2	1	SUPPORT RING HALF		

NOTES:

1. DURING CONSTRUCTION, THE CLEAN ROOM WILL SLIDE OVER ENDS WITHOUT AN EXPANSION JOINT.
2. CIRCUMFERENTIAL SEAM WILL BE WELDED BEFORE CLEANING AND LEAK TESTING.

REVISIONS	CBI		SUPPLIER'S PART NUMBER
	LIGO BEAM TUBE HANFORD, WA & LIVINGSTON, LA		
	SUB-ASSEMBLIES (A) (B) & (C)		
	CUSTOMER'S NO		CONTRACT NO
BY	CHKD	WJC	DATE
DATE	10/09	DWG	938212
ENGINEERING SUPERVISOR		REV	
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INDICATES CHANGE FROM PREVIOUS ISSUE

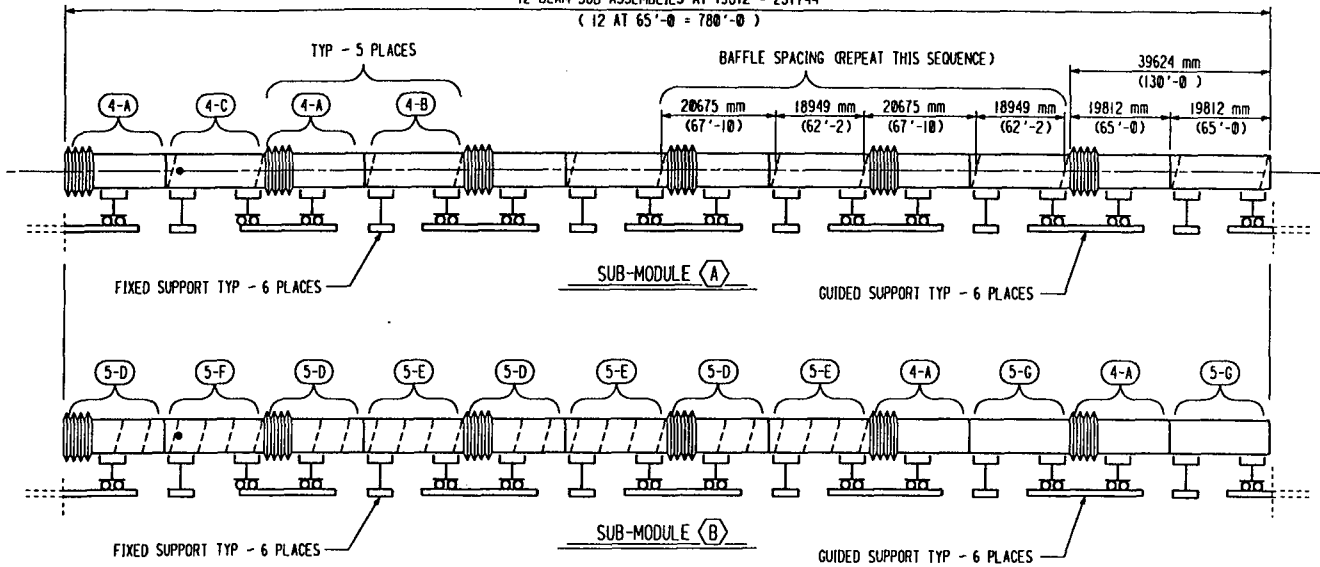


- (E) SUB-MODULE CONSISTING OF THE FOLLOWING:
 - (9-H) BEAM ASSEMBLY
- (F) SUB-MODULE CONSISTING OF THE FOLLOWING:
 - (9-J) BEAM ASSEMBLY W/EXPANSION JOINT
 - GUIDED SUPPORT (DWG # 17, 18, & 19)
- (G) SUB-MODULE CONSISTING OF THE FOLLOWING:
 - (9-K) BEAM ASSEMBLY W/BAFFLE
- (H) SUB-MODULE CONSISTING OF THE FOLLOWING:
 - (9-L) BEAM ASSEMBLY W/EXPANSION JOINT
 - GUIDED SUPPORT (DWG # 17, 18, & 19)

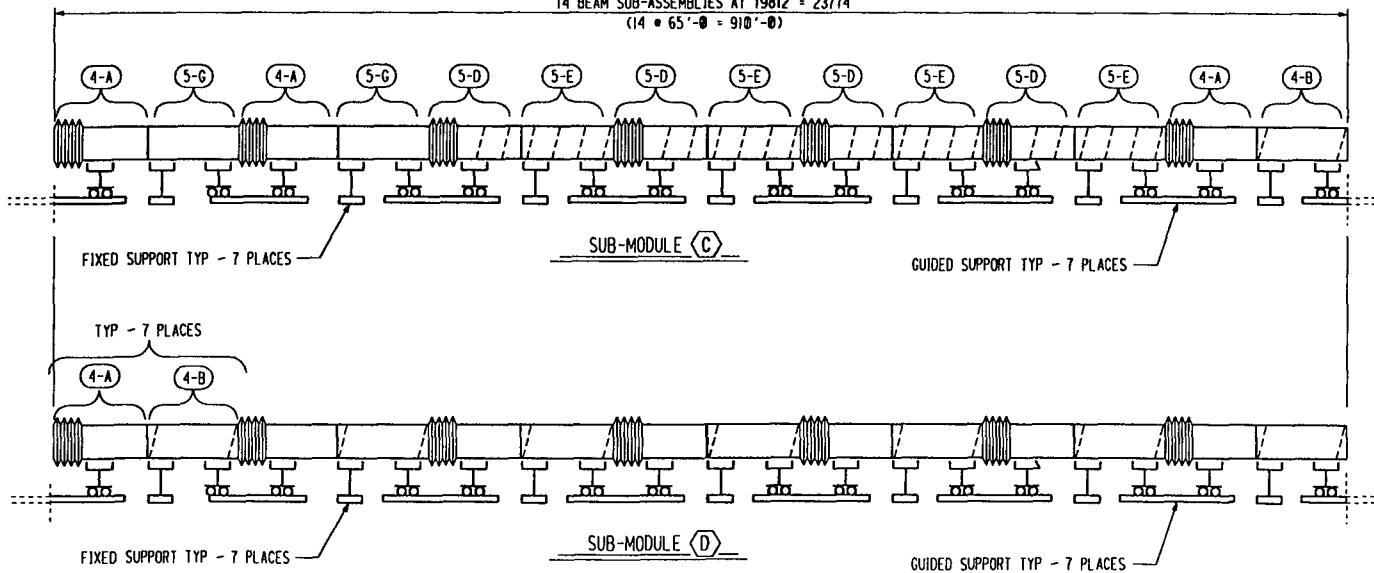
▶ INDICATES CHANGE FROM PREVIOUS ISSUE

REVISIONS	CBI		SUPPLIER'S / PURCHASER'S NO.
	LIGO BEAM TUBE MODULES HANFORD, MA & LIVINGSTON, LA		
	SUB-MODULES (E) (F) (G) (H)		
	CUSTOMER'S NO.	CONTRACT NO.	
BY: K.R. CHOD	DATE: 11-4-94	930212	
ENGINEERING SUPERVISOR	DWG: 3	REV: 0	
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12 BEAM SUB-ASSEMBLIES AT 19812 = 237744
(12 AT 65'-0" = 780'-0")



14 BEAM SUB-ASSEMBLIES AT 19812 = 23774
(14 • 65'-0" = 910'-0")

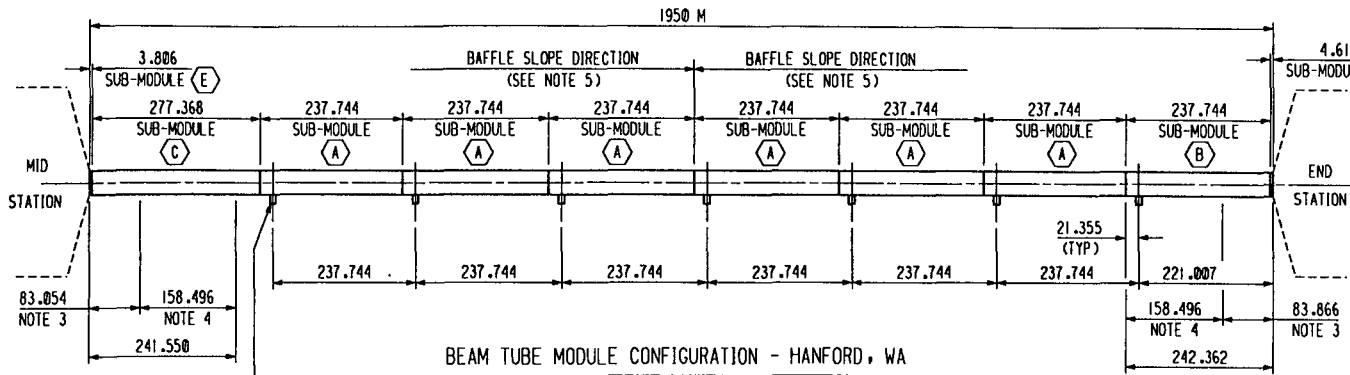


- (A) SUB-MODULE CONSISTING OF THE FOLLOWING:**
- 6 (4-A) BEAM ASSEMBLY W/EXPANSION JOINT
 - 5 (4-B) BEAM ASSEMBLY W/2 BAFFLES
 - 1 (4-C) BEAM ASSEMBLY W/VACUUM PORT
 - 6 - FIXED SUPPORT (DWG # 6.7, 8 & 9)
 - 6 - GUIDED SUPPORT (DWG # 17, 18, & 19)
- (B) SUB-MODULE CONSISTING OF THE FOLLOWING:**
- 2 (4-A) BEAM ASSEMBLY W/EXPANSION JOINT
 - 4 (5-D) BEAM ASSEMBLY W/EXPANSION JOINT AND 2 BAFFLES
 - 3 (5-E) BEAM ASSEMBLY W/4 BAFFLES
 - 1 (5-F) BEAM ASSEMBLY W/4 BAFFLES AND VACUUM PORT
 - 2 (5-G) BEAM ASSEMBLY - NO BAFFLES
 - 6 - FIXED SUPPORT (DWG # 6.7, 8 & 9)
 - 6 - GUIDED SUPPORT (DWG # 17, 18, & 19)
- (C) SUB-MODULE CONSISTING OF THE FOLLOWING:**
- 3 (4-A) BEAM ASSEMBLY W/EXPANSION JOINT
 - 1 (4-B) BEAM ASSEMBLY W/2 BAFFLES
 - 4 (5-D) BEAM ASSEMBLY W/EXPANSION JOINT AND 2 BAFFLES
 - 4 (5-E) BEAM ASSEMBLY W/4 BAFFLES
 - 2 (5-G) BEAM ASSEMBLY - NO BAFFLES
 - 7 - FIXED SUPPORT (DWG # 6.7, 8 & 9)
 - 7 - GUIDED SUPPORT (DWG # 17, 18, & 19)
- (D) SUB-MODULE CONSISTING OF THE FOLLOWING:**
- 7 (4-A) BEAM ASSEMBLY W/EXPANSION JOINT
 - 7 (4-B) BEAM ASSEMBLY W/2 BAFFLES
 - 7 - FIXED SUPPORT (DWG # 6.7, 8 & 9)
 - 7 - GUIDED SUPPORT (DWG # 17, 18, & 19)

- BAFFLE (AS SHOWN INDICATES SLOPE TO RIGHT)
- - VACUUM PORT
- FIXED SUPPORT (6-A)
- GUIDED SUPPORT (10-A)

REVISIONS	CBI		SUPPLIER'S / PROJECT'S NO	
	LIGO BEAM TUBE MODULES HANFORD, WA & LIVINGSTON, LA			
	SUB-MODULES (A) (B) (C) (D)			
	CUSTOMER'S NO	CONTRACT NO	BY <i>MR CHOD</i> DATE <i>4-4-94</i>	
BY <i>MR CHOD</i> DATE <i>4-4-94</i>	DWG 2	REV B	930212	
ENGINEERING SUPERVISOR	SMT	THIS DRAWING HAS BEEN PREPARED FOR AND IS THE PROPERTY OF CBI AND IS NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM.		

INDICATES CHANGE FROM PREVIOUS ISSUE

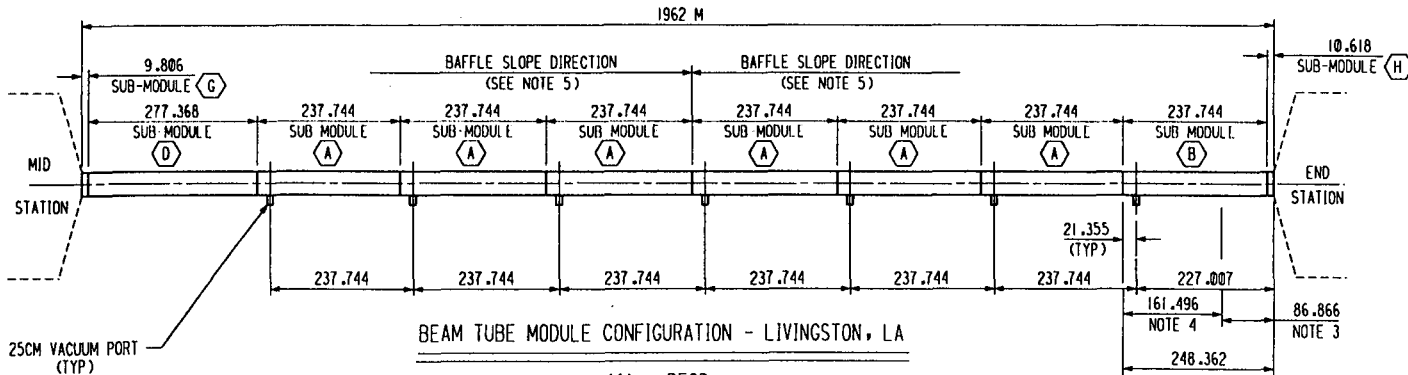


BEAM TUBE MODULE CONFIGURATION - HANFORD, WA

(4) - REQD
(DIMENSIONS IN METERS)

DIRECTION OF CONSTRUCTION →

- (49) - BEAM TUBE SECTIONS, LONG
- (49) - BEAM TUBE SECTIONS, SHORT
- (2) - END SECTIONS
- (50) - EXPANSION JOINTS
- (2428) - VACUUM STIFFENERS
- (149) - SUPPORT RINGS
- (32) - BAFFLE STIFFENERS
- (122) - BAFFLES
- (7) - VACUUM PORTS
- (49) - SUPPORTS, FIXED
- (50) - SUPPORTS, GUIDED

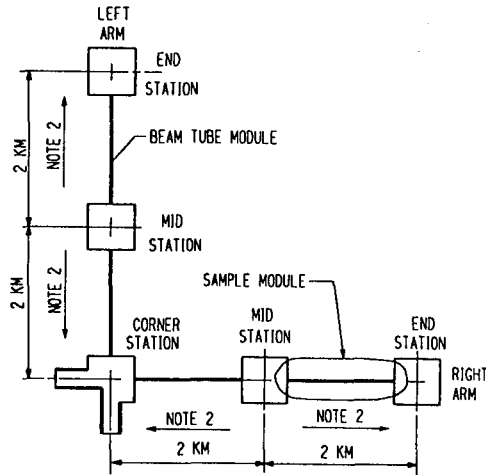


BEAM TUBE MODULE CONFIGURATION - LIVINGSTON, LA

(4) - REQD
(DIMENSIONS IN METERS)

DIRECTION OF CONSTRUCTION →

- (49) - BEAM TUBE SECTIONS, LONG
- (49) - BEAM TUBE SECTIONS, SHORT
- (2) - END SECTIONS
- (50) - EXPANSION JOINTS
- (2460) - VACUUM STIFFENERS
- (149) - SUPPORT RINGS
- (16) - BAFFLE STIFFENERS
- (111) - BAFFLES
- (7) - VACUUM PORTS
- (49) - SUPPORTS, FIXED
- (50) - SUPPORTS, GUIDED



NOTES:

1. PUMP PORTS TO FACE OUT BOARD OF THE ANGLE BETWEEN THE ARMS.
2. CONSTRUCTION WILL START AT MIDSTATIONS AND PROCEED BOTH WAYS SIMULTANEOUSLY TOWARDS THE END STATION AND THE CORNER STATION.
3. NO BAFFLES.
4. BAFFLES LOCATED AT SUPPORTS & THIRD POINTS BETWEEN SUPPORTS. SEE SUB MODULE DETAILS FOR SPECIFIC LOCATIONS.
5. PROJECTING EDGE OF BAFFLE SHALL ALWAYS FACE FROM TUBE WALL TO THE CENTER OF THE MODULE.

REVISIONS	CBI		APPLICANT / PURCHASER'S NO.
	LIGO BEAM TUBE MODULES HANFORD, WA & LIVINGSTON, LA		
GENERAL MODULE CONFIGURATION AND VACUUM PORT LOCATION			
CUSTOMER'S NO.	DATE		CONTRACT NO.
BY	DATE		930212
ENGINEERING SUPERVISOR	D. J. THOM		DWG
			REV
			8
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INDICATES CHANGE FROM PREVIOUS ISSUE



LIGO PROJECT
WBS 200
FABRICATION
FINAL DESIGN REVIEW PACKAGE

WBS #210 - Steel Production Process

A steel production process has been developed that satisfies all the technical requirements for the LIGO project. The steel for the beam tube modules must be produced to meet both the high vacuum and laser requirements of the LIGO beam tube modules. The following is a listing of the requirements for the beam tube material as specified in LIGO Specification 1100004, "Technical Specifications - Beam Tube Module Specification" and LIGO Specification 1100007:

1. The materials shall be in accordance with the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, as applicable, and its subsequent addenda.
2. All materials used in the beam tube modules are subject to Caltech approval.
3. The beam tube wall material shall have an internal surface finish no smoother than 2.5 microns rms roughness. If stainless steel is used, HRAP (Hot Rolled Annealed & Pickled) surface is acceptable. Any alternate finish is subject to approval.
4. The beam tube steel shall meet the outgassing performance requirements specified in LIGO Specification 1100007, "Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products".
 - The material processed shall be conventional Type 304L stainless steel.
 - The thickness of the steel shall be 0.130" or less.
 - The material may be in sheet or coil form.
 - The raw material will be air baked at 440°C +/- 8°C for 36 hours. During the bake, the material shall be positioned on a raised grating with its surface vertical to promote convective flow over the surface. If the oven is fuel fired, the combustion products shall not come in contact with the baked material.
 - Material samples from all air baked raw material shall be tested to confirm acceptable outgassing levels for hydrogen.
 - No material shall be used for fabrication until its acceptability is assured.

The critical parameters, concerning the steel production process, addressed during the design of the LIGO beam tube modules are:

1. Develop a steel production process(s) that ~~will~~ assures compliance with all the LIGO technical requirements.



LIGO PROJECT
WBS 200
FABRICATION
FINAL DESIGN REVIEW PACKAGE

2. Develop a steel production process(s) that will produce the coil steel to meet the LIGO schedule requirements.
3. Select the steel production process that is most economical.

The beam tube material specification C-240-0186, "Coil Material Specification" and the beam tube material bake specification C-CMBS1 have been written, reviewed and issued for use on the Qualification Test. These specifications meet all the technical requirements for the LIGO beam tube module material. The specifications have been written with technical input from various CBI departments (engineering, materials, welding, construction and purchasing), the coil steel manufacturers and the beam tube manufacturers. It is planned that these specifications be used for the Option.

Restrictions have been added to the sulfur content of the conventional SA 240 Type 304L stainless steel. To enhance the weldability of the material, a minimum sulfur content of .01% has been specified. Also, a maximum sulfur content of .02% has been specified to reduce the fractions of manganese sulfur inclusions. The manganese sulfur inclusions are effective traps for hydrogen. The sulfur content can be controlled within the limits specified above without additional cost.

The thickness tolerances for the beam tube material has been restricted to +/- 0.005" instead of the +/- 0.010" as specified in ASTM for the conventional SA 240 Type 304L HRAP material. The thickness tolerance for conventional cold rolled per ASTM specification is +/- 0.005". The more restrictive thickness tolerance effectively increases the thickness for designing the beam tube. The result is that stiffeners can be spaced farther apart requiring fewer stiffeners and thus significantly reducing the cost of fabricating the beam tube. Both Armco and Washington can produce the HRAP material to the more restrictive +/- 0.005" thickness tolerance at no extra cost. J&L cannot produce the HRAP material to +/- 0.005" thickness tolerance and have elected to cold work the material in order to obtain the more restrictive thickness tolerance.

To improve the beam tube fabrication welding process we have also included in the beam tube material specification the requirement that the material be stretcher leveled to improve the flatness and camber of the material. Without stretcher leveling the ASTM specified maximum out of flatness tolerance is 1/2". With stretcher leveling the specified out of flatness is 1/8". Also, it is expected that the stretcher leveling will reduce the amount of camber that occurs during the slitting process. The cost of leveling the material is approximately \$0.05/#.

During December of 1993, CBI representatives visited and toured the Armco, J&L and Washington Steel manufacturing facilities. The purpose of the trip was to gain more knowledge into the coil steel production process before writing the beam tube material specification. The CBI representatives toured the coil steel manufacturing facility to see the steel production process. During the visits, the CBI representatives met with the management, sales representatives, engineers and steel production personnel to discuss the LIGO project. This afforded CBI the opportunity to review ~~the~~ the LIGO requirements and received comments, concerns and information about the requirements and the steel manufacturing process.



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Two other suppliers of stainless steel coil material, Allegheny Ludlum and Avesta Sheffield, have submitted quotations for the LIGO beam tube steel. These two companies do not produce HRAP stainless steel as thin as 0.130". They have quoted cold rolled material. Also, it should be noted that the steel from Avesta Sheffield would not be "made in America".

Armco has been chosen to provide the material for the Qualification Test. See the Technical and Cost Comparison of Coil Procurement for the Option for the comparison information of the five suppliers of beam tube steel. Except for performing the raw material bake, Armco and Avesta Sheffield conformed best to the current LIGO specifications. Armco and Avesta Sheffield also provided the best overall costs for procurement of the Option steel. The cost for Armco to supply the Option steel was approximately 2% greater than Avesta Sheffield. However, the steel from Avesta Sheffield would be not be "Made in America".



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Technical and Cost Comparison of Coil Material Procurement
LIGO Beam Tube Module - Option

Note: All prices are in today's dollars

	Armco - 1	J&L - 1	Washington	Avesta	Allegheny
Steel made in America	YES	YES	YES	NO	YES
Material Process	HRAP	CR	HRAP	CR	CR
0.120" < Thickness > 0.130"	YES	YES	YES	YES	YES
> 2.5 micron RMS surface finish	YES	NO	YES	YES	2D
Leveled	YES	NO	YES	YES	YES
Width @ 1/32" (1/2 ASTM)	YES	YES	NO	YES	YES
Camber @ 3/64" (1/2 ASTM)	YES	YES	NO	YES	YES
0.01% < Sulfur > 0.02%	YES	?	?	YES	?
Carbon < 0.02%	YES	?	?	YES	?
Bake Material	NO	YES	NO	NO	NO
Bake @ 440 C +/- 8 C	NA	NO	NA	NA	NA
Max weight of coil produced	>30,000	<25,000	<16,000	>30,000	>30,000
Weight of coils ordered	30,000	20,000	15,000	30,000	30,000
Number of tubes made/coil	6	4	3	6	6
Total number of coils for Option	132	198	264	132	132
Base Cost/# of 304L Material	\$0.92	\$1.35	\$1.05	\$0.95	\$1.27
Base cost of unfinished material	\$27,639	\$27,020	\$15,750	\$28,500	\$38,046
Est. miles to bake facility	600	0	300	100	300
Freight cost to bake (\$/trip)	\$822	\$0	\$411	\$137	\$411
Trips to bake facility	132	99	88	132	132
Cost to perform bake (\$/coil)	\$3,000	\$0	\$2,000	\$3,000	\$3,000
Est. miles to finishing mill	300	0	300	300	300
Freight to finishing mill (\$/trip)	\$411	\$0	\$411	\$411	\$411
Trips to finishing mill	132	0	132	137	411
Cost per outgas test	\$2,650	\$2,650	\$2,650	\$2,650	\$2,650
Cost to level to 1/8" flat (\$0.05/#)	\$1,500	\$0.00	\$0.00	\$0.00	\$0.00
Cost to slit to 48" (\$0.03/#)	\$900	\$0	\$0	\$900	\$900
Extra to slit to 16 (\$0.03/#)	\$900	\$400	\$0	\$900	\$900
Est. miles to tube manufacturer	1000	1000	1000	1000	1000
Freight to tube manufacturer (\$/trip)	\$1,370	\$1,370	\$1,370	\$1,370	\$1,370
Trips to tube manufacturer	99	99	88	99	99
Value of 10% scrap steel (\$0.15/#)	(\$59,400)	(\$59,400)	(\$59,400)	(\$59,400)	(\$59,400)

Total Estimated Cost for the \$5,068,734 \$6,030,090 \$5,663,768 \$4,893,966 \$6,190,206
Option



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The raw material bake of the beam tube material will not be performed by the steel manufacturers. Four of the five steel suppliers have declined to bake the beam tube material. J&L was the only steel supplier that agreed to bake the material and J&L took exception to the specified +/- 8°C temperature tolerance. J&L would perform the bake to +/- 40°C temperature tolerance.

CBI plans to have the materials for the Qualification Test baked at Metlab in Philadelphia, PA. Metlab is a company that performs special material heat treatments. CBI has contacted and discussed the LIGO raw material bake with Metlab. Metlab has the experience, capability and capacity to perform the raw material bakes for both the Qualification Test and the Option. The LIGO "Coil Material Bake Specification", C-CMBS1, has been reviewed by Metlab and they have confirmed that they can perform the bakes as specified. Metlab has a furnace that can bake up to four full size coils (30,000#) at one time. They have estimated that they can perform the Option bakes for \$0.10/# or less. Metlab will provide a firm price for baking the Option material after they have baked the material for the Qualification Test.

As part of the Qualification Test, three full size coils (48" wide x 30,000#) will be manufactured and baked. One of the three coils will have thermocouples installed into the center of the coil to measure and monitor the temperature at the center of the coil during the bake process. These thermocouples will be monitored to determine when the material at the center of the coil reaches the 440°C and to assure that the material at the center of the coil receives 36 hours of bake at 440°C. During this initial bake the times required to heat up and cooldown will be confirmed. Thermocouples will not be installed into the center of the coil in future bakes. The heat up and cooldown times from this first bake will be used to control the future baking process. Also, coupons will be removed from all three coils after baking for hydrogen outgas testing.

We plan to have Metlab perform the raw material bakes for the Option. Steel Tech, another heat treating firm, has been contacted and can perform the bakes for the Option. Steel Tech has also confirmed that they can perform the raw material bakes as specified. Steel Tech has furnaces that can bake four full size coils (30,000#) at one time. However, Steel Tech is not certain they can commit their resources to performing all the bakes for the Option. They have limited furnace capacity and a number of regular customers that they need to satisfy.

CBI can perform the bakes as a second alternative. Our current estimates indicate that this alternative is not as cost effective as having the bakes performed by Metlab or Steel Tech. CBI's cost are estimated to be about than \$0.15/# as compared to less than \$.10/# for Metlab. CBI would need to purchase the furnaces and temperature controllers to perform the bakes.



WBS #220 Tube Manufacturing Process

Summary

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 has identified and developed the process requirements, procedures, and controls to fabricate the tube sections. The process development consisted of an identification of the critical parameters and requirements, a review of the mill processes, tours and evaluations of potential manufacturers, and pre qualification of the most capable fabricators through the manufacturing of short sections of beam tube. As a result of the study, CBI has identified two potential LIGO beam tube manufacturers which are Northwest Pipe of Portland, Oregon and Tubetec of Sanford, Florida. Of these two potential suppliers, Tubetec is judged by CBI to be more capable of producing beam tube sections for the LIGO project and is more economical. As such, CBI has selected Tubetec for supply of the tube sections for qualification test.

Critical Parameters

The fabrication of spiral welded tube sections from coil material is a proven and successfully used process. Basically, the process consists of forming the material into a spiral and welding the seam as it bases by the weld apparatus. The diameter of the pipe is determined by the forming process and the angle of the strip to the pipe. There are a number of basic forming processes and with proper fit up, TIG welding can produce a welds with excellent characteristics. However, the unique requirements and characteristics of the LIGO beam tube sections makes this relatively simple process very demanding. The critical parameters and requirements for the tube manufacturing process are listed in the view graphs. The most important parameters for the LIGO beam tube modules are the ability to maintain very close edge alignment and ability to produce high quality welds.

Plant Tours and Initial Evaluation

CBI conducted plant tours of the following pipe manufacturers:

Naylor Pipe	Chicago, Illinois
Northwest Pipe	Portland, Oregon
Roscoe Moss	Los Angeles, California
Tubetec	Sanford, Florida

These tours enabled CBI to develop a knowledge of the industry and an initial comparative evaluation of the manufacturers capabilities. In general, large diameter spiral welded tube manufacturers have a relatively narrow capability primarily limited to the fabrication of tube or pipe applications. Although manufacturers have varying degrees of welding expertise, none have a knowledge or experience with the special welding, cleaning, and inspection requirements associated with high vacuum facilities. They are also not engaged in general steel fabrication and, as such, are not well suited for the attachment of a large number of stiffeners required for the LIGO beam tube sections. The scope of work for the pipe manufactured will be limited to the fabrication of the unstiffened tube sections only. This may include weld inspection and end preparation,



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but the attachment of stiffeners, leak testing, cleaning and final acceptance for installation will be executed by CBI at or near the LIGO sites.

Naylor, Northwest Pipe, and Roscoe Moss are the dominant large diameter spiral pipe manufacturers in the United States. These companies are primarily engaged in the manufacturing of relatively thick wall carbon steel pipe for fluid and gas transmission. The pipe is made on a mill which takes material from a coil, straightens the sheet, and forms the sheet into a spiral to produce 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 this typical thickness range. As such, the pipe mills are large units with large guides, drive rollers, and forming rollers. There are basically three types of forms used. The material can be formed with triangular pinch rolls, by a outside die, or with an external cage containing rollers. Pinch rolls and cages are generally used for large diameter pipe. Northwest Pipe's greatest advantages over Naylor and Roscoe Moss are 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. Naylor has manufactured stainless steel pipe and, in fact, supplied approximately 900' of 24" diameter 1/4" thick pipe sections for the HELSTF vacuum facility built by CBI in White Sands, New Mexico. However, Naylor has no experience with TIG welding or with relatively thin walled tube. Roscoe Moss has only limited experience with TIG welding.

Tubetec manufactures large diameter relatively thin wall stainless steel tube and fittings. Tubetec works exclusively with stainless steel and routinely manufactures 48" diameter tube with thicknesses between .140" and .250". The forming process used by Tubetec can best be described as "free forming" even though the forming is accomplished by cylindrical pinch rollers. The mill used by Tubetec 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 weld which is three times longer than that produced with 48" wide coil. Tubetec is currently expanding their capacity and has designed a pipe mill which uses 30" wide coil. Some of the mill components have been procured and completion of the mill can be accomplished in time for use on the beam tube module sections.

16" → 30"
wide
coil

Pre Qualification Sections

After the plant tours of the four potential spiral welded pipe manufacturers, CBI selected Tubetec and Northwest Pipe for further development and study. Tubetec and Northwest pipe each produced a pre qualification section of 48" diameter tube which was then shipped to CBI's Houston Weld Laboratory for evaluation.

The pre qualification section from Tubetec was manufactured from 16" wide 304L stainless steel with a thickness of .135". The section from Tubetec was visually acceptable in every way. The weld was uniform, continuous, and formed a consistent



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spiral around the tube. The maximum plate mismatch at any location on the tube section was easily less than 1/32". Tubetec stated that they could limit the edge mismatch to .020". Although not leak tested, the welds were visually acceptable and would be ready for leak testing. A two pass weld procedure was used with the inside pass made first without filler wire and the outside pass made with filler wire. Tubetec did not locally repair any portion of the weld. CBI took a number of weld sections and all locations showed complete penetration. Circumferential measurements were made every foot and the circumference varied by +/- 5/16". Tubetec feels that the circumference at the ends can be produced to a tolerance of +/- 5/32" but even this tolerance at the ends exceeds the requirements for the circumferential welds. No accurate measurements of the longitudinal dimensional variations were made but the tube section appeared to be straight with a true surface.

Northwest Pipe produced two pre qualification sections. The first section was produced on a bottom feeding mill with pinch forming rollers. The mill had never been used for TIG welding and was modified for TIG welding for the pre qualification section. The pre qualification section was made with 48" wide 304L stainless steel with a thickness of .125. The edges of the material were slit as a part of the fabrication process with approximately 1/2" of material taken off each side. The first pre qualification section was made with a two pass process with the inside pass made first with out filler wire and the outside pass made with filler wire. The coil edge alignment could not be maintained during the fabrication process resulting in gross welding flaws. Holes greater than 1/8" in diameter were common in areas of the maximum plate mismatch which exceeded the plate thickness of 1/8". In addition, the tube contained slight spiral indentations which were obviously caused by the forming rollers. The second pre qualification section manufactured by Northwest pipe was made on their cage mill. The external cage consists of a number of cylindrical rollers around the outside of the tube. The coil material feed from the top and the first pass is made at the top of the tube on the outside with filler wire. Northwest Pipe did not use a second pass for the pre qualification section but will execute a second inside pass without filler wire on any tubes made for the LIGO project. Very close edge alignment was produced with the cage mill and the maximum mismatch was easily less than 1/32". Weld studies conducted by CBI indicate that alignment within 1/32" is required to produce satisfactory welds. The weld profile was approximately 1/2" wide but the depth of penetration was only approximately 1/2 the thickness. Northwest Pipe requested assistance on developing the proper weld parameters to increase the weld penetration and decrease the width.

The pre qualification effort identified a number of critical items and enabled an evaluation of the manufacturers capabilities as they relate to the LIGO project. The single most important aspect of the tube manufacturing is the ability to incorporate very precise edge alignment into the tube forming process. Regardless of the forming process, continuous support of the plate edges is required in the immediate vicinity of the weld. The weld expertise of the tube manufacturer is also critical.. Tubetec works exclusively with thin wall stainless steel and thus has the expertise to perform the welding with little or no assistance from CBI. Northwest Pipe will need assistance and guidance from CBI to



perform the welding satisfactorily. 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.

Vendor Selection

Tubetec has demonstrated their ability to manufacture beam tube sections suitable for the LIGO project without modification to existing equipment and with limited assistance from CBI. In addition, even with their current capacity, Tubetec is significantly more economical than any other supplier. As such, CBI has selected Tubetec for the supply of the Qualification Test beam tube sections. Northwest Pipe can likely produce beam tube sections suitable for the LIGO project but will require CBI's assistance with the weld procedure development and execution. Roscoe Moss was not selected for the pre qualification effort based on the initial evaluation of their capabilities and product lines. Naylor Pipe did not quote the specifications based on their concerns relating to the material thickness and their inexperience with TIG welding.

Beam Tube Section Specification

Based on the results of the plant tour and pre qualification section fabrication, CBI has prepared specification C-BT-OP for the LIGO beam tube sections. Critical elements of the specification is the plate edge alignment requirement, minimum depths of weld penetration from each side of 70%, mill cleanliness requirements, and tube dimensional requirements. The qualification test will serve to demonstrate the tube manufacturing process and will establish the characteristics of the spiral welded tube section.

WBS #230 Expansion Joint Manufacturing

This section describes the considerations made for selecting the type of expansion joint and the manufacturing method. Issues include material thickness, weld ends, circumferential seams, longitudinal seams, forming methods and cleanliness. The design and type of the expansion joint depend on the configuration of the beam tube and supports. Likewise, limitations of the expansion joint also influence the beam tube and support design. These issues are addressed in WBS 160.

RELATIONSHIP BETWEEN COMPONENTS

The design of the expansion joints is interrelated to the beam tube, baffle spacing and the supports (See WBS 160). By keeping the baffles at the beam tube support point, the location of the baffle is controlled. Thus, with control of the baffle location, the required clear aperture can be maintained with a minimum beam tube diameter. The beam tube optimum shipping length, and length that can be effectively handled during construction is 19.812 m (65'-0). Since a beam tube length of 19.812 m nearly matches the required baffle spacing of 20m (65'-7 3/8), the most optimum spacing of supports, baffles and tube sections is 19.812 m. Thus, the expansion joint spacing must be a multiple of this 19.812 m spacing.

The baffle spacing was modified to align to the tube length



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The initial configuration used a support spacing and an expansion joint spacing of 12.192m (40'-0). By increasing the spacing to 19.812m (65'-0), the total cost of the expansion joints and other beam tube components decreases. To determine what the most cost effective spacing of the expansion joint is, six beam tube configurations were investigated. See figures 1 through 6. Each of these configurations uses a multiple of the 19.812m support spacing. A different expansion joint design is required for each configuration.

- Configuration #1 - the expansion joint is unguided (behavior of the expansion joint is unacceptable).
- Configuration #2 - the expansion joint is unguided (behavior of the expansion joint is unacceptable).
- Configuration #3 - the expansion joint is properly guided and the behavior is acceptable.
- Configuration #4 - the expansion joint is unguided (behavior of the expansion joint is unacceptable).
- Configuration #5 - the expansion joint is properly guided. However, the radial movements are too large for the guide supports.
- Configuration #6 - the axial movement is too large for the expansion joint (configuration is unacceptable).

On the basis of the discussion provided in WBS 160 and the previous discussion, configuration #3 with an expansion joint spacing of 39.624m (130') is the preferred and optimum configuration.

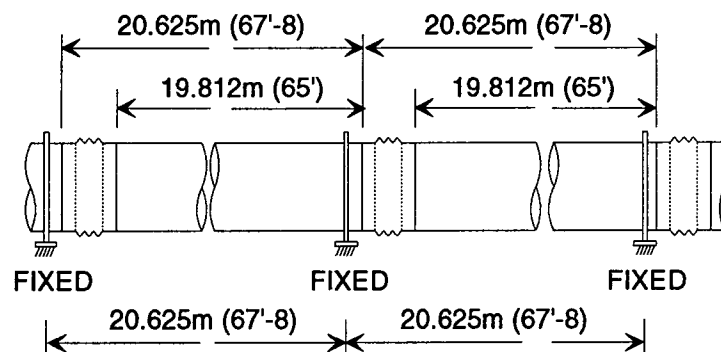


FIGURE 1
CONFIGURATION #1
Unguided expansion joint @ 20.625 m (67'-8)



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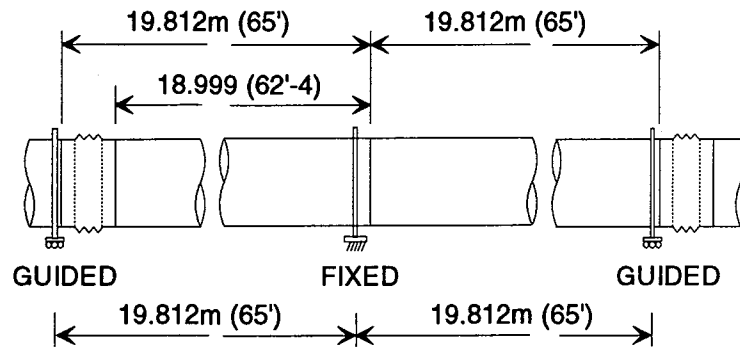


FIGURE 2
CONFIGURATION #2
Unguided expansion joint @ 39.624 m (130 Ft)

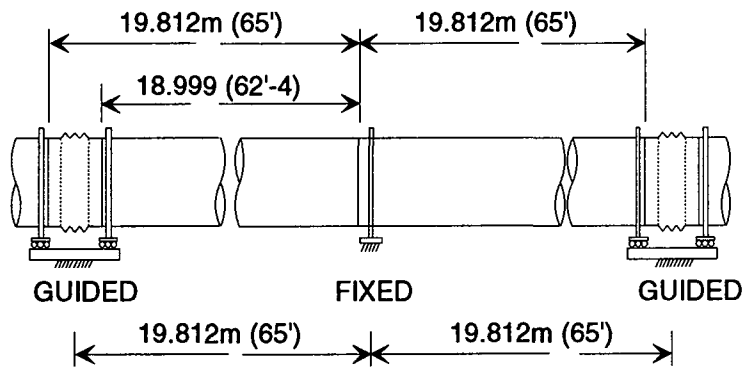


FIGURE 3
CONFIGURATION #3
Guided expansion joint @ 39.624 m (130 Ft)

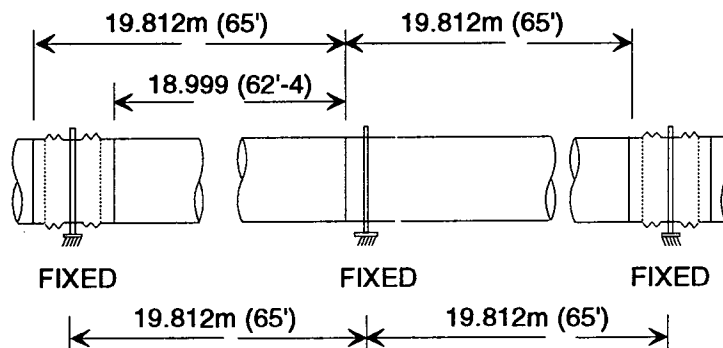


FIGURE 4
CONFIGURATION #4
Double expansion joint @ 39.624 m (130 Ft)



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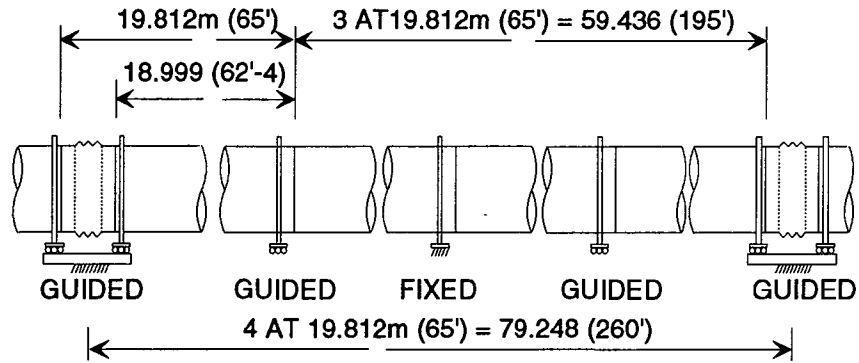


FIGURE 5
CONFIGURATION #5
Guided expansion joint @ 79.248 m (260 Ft)

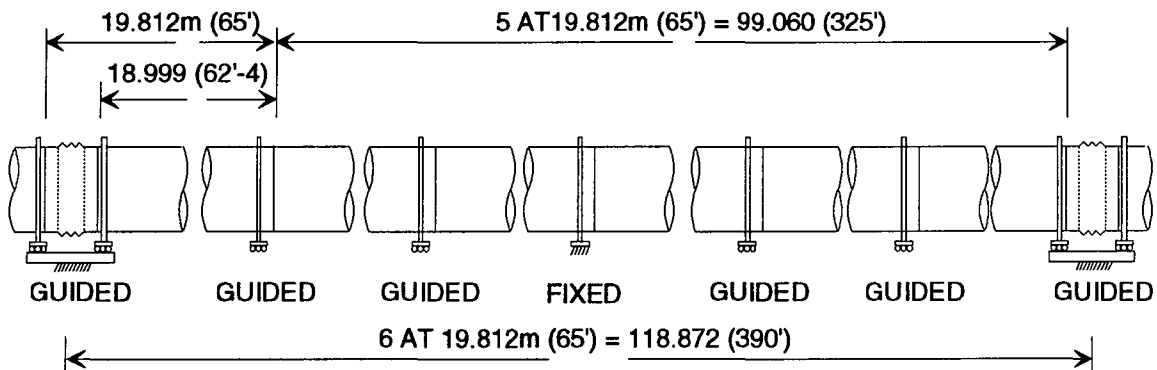


FIGURE 6
CONFIGURATION #6
Guided expansion joint @ 118.87 m (390 Ft)

FUNCTIONAL REQUIREMENTS

Since the expansion joints are an integral part of the beam tube, the requirements of Specification 1100004 apply. From the specification, there are three functional requirements of the expansion joint.

- **Maintain The Vacuum Envelope**
The high level of vacuum required for LIGO requires the expansion joints to maintain leak tightness throughout the design life and design cycles.



- Accommodate Thermal Growth and Shrinkage

During the operating condition, the design temperature range is -27° to 38° C (-16° to 100° F), which is the ambient temperature range for both sites. The number of complete thermal cycles (-27° to 38° C) has conservatively been taken as 7300, one cycle per day for 20 years. On the basis of the vendors' design per the EJMA sixth edition (Expansion Joint Manufacturers Association), the 7300 cycles do not control the expansion joint design.

The bake out condition imposes the most severe condition on the expansion joint. The specified bake out temperature is 140° C \pm 10. The expansion joints are designed to accommodate the thermal growth from 21° C to 150° C (70° to 302° F) for 20 complete cycles.

- Provide Flexibility Due to Differential Settlement

To protect the beam tube from excessive differential settlement the expansion joint provides sufficient flexibility. By providing some degree of flexibility, the stresses in the beam tube, the forces in the supports and foundation are reduced. Sufficient flexibility is provided to insure that structural components are not overstressed before the clear aperture tolerance is violated.

PHYSICAL REQUIREMENTS

The following is a description of the functional and fabrication requirements of the expansion joint. The requirements are based on the configuration #3 layout. These requirements all appear in the expansion joint specifications. For the construction option, see specification C-EJ-CO. For the Qualification test, see specification C-EJ-QT.

- Expansion Joint Material

The material will be 0.105" thick (12 Gauge). It will be SA-240 Type 304L stainless steel. It will be air baked per as required per LIGO specification 1100007. Although it would be preferred, the expansion joint material may not meet the finish requirement of the beam tube. The material will be purchased per CBI specification C-240-00194.

- Expansion Joint Design Movements

The axial movements are based on thermal expansions, contractions and tolerances need for construction. The lateral movements are based on the possibility of differential settlement. It is not likely that the expansion joints will undergo the specified lateral movements. The expansion joint lateral spring rate is approximately 17,500 kN/m (100,000 lbs/in). The supports and the weight of the beam tube can not create a load high enough to create such an offset. The rotations are based on finite analysis results. The rotations are based on actual expansion joint stiffness. The



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analysis takes into account dead load, including insulation and the possible misalignments or differential settlements.

Operating

Axial:	0.43"	Contraction, 70 ^o to 100 ^o F
	1.21"	Extension, 70 ^o to -16 ^o F
		7300 total cycles
Lateral:	0.125"	(5 cycles) The 5 cycles of lateral movement may be caused by differential settlement between supports.
Rotational:	0.10	degrees (1 cycle) due to dead load of tube
	0.20	additional degrees (5 cycles)

Transient (Bake out)

Axial:	3.26"	Contraction (20 cycles) 70 ^o to 302 ^o F.
Lateral:	0.00"	
Rotational:	0.10 to 0.20	degrees (20 cycles)

Additional movement due to construction and fit up

Axial:	± 0.25"	in addition to other specified axial movements.
Lateral:	0.0"	
Rotational:	± 0.13	degrees in addition to other specified rotations.

- Expansion Joint Spring Rates

The lateral and rotational spring rates do not affect the design of the beam tube and the supports. Sufficient flexibility is provided in the expansion joint to accommodate misalignment and differential settlements. However, the axial spring rate has an influence on the beam tube and support design. The axial spring rate is important during the bake out condition when the expansion joint is compressed. The beam tube must resist the axial force due to the expansion joint compression distance times the spring rate. Per ASME Section VIII, Division 1, the limit on the axial beam tube stress is the PR/2t stress (stress caused by the pressure over the ends). This limits the axial spring rate to approximately 1400 N/m (8000 lbs/in). On the basis of the API Bulletin 2U, the beam tube can resist an axial load approximately 20% higher. Thus, the spring rate is limited to 1400 N/m ± 20% (1700 N/m, 9600 lbs/in). Spring rates can not be much higher than this. As the axial spring rate increases the factor of safety of the beam tube decreases. To offset this, the vacuum stiffener spacing must be decreased, adding cost to the beam tube faster than the savings provided by the expansion joints. A second dilemma of a higher axial spring rate is that the



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maximum differential settlement the beam tube can withstand decreases. If the axial spring rate is as high as 2630 N/m (15000 lbs/in), there is no capacity in the beam tube to handle any differential settlement or misalignment. See WBS 160 for the discussion on what axial and bending stresses are imposed on the beam tube from the various loading conditions.

Depending on the manufacturing method of the expansion joint, a wide range of variation of the axial spring rates may occur. To minimize the variation, the expansion joint specification limits the variation between expansion joints to ± 10 percent of the average measured spring rates. As the variation of the spring rates increases, the loads to the adjacent beam tube sections become unbalanced. The unbalanced force must be resisted by the fixed supports and foundation. During bake out, the load to the foundation for every 10% of variation is 23.2 kN (5200 lbs). If the limit of the axial spring rate variation is increased, the cost of the foundation and supports is increases greater than the cost savings of the expansion joint. A larger variation will also increase the risk of greater differential settlement of the foundation. This will require more frequent realignments, increase the long term cost of the facility.

The expansion joint spring rates will vary because of the following:

- Error between calculated and actual spring rates. This is usually ± 10 percent.
 - Variation in material property. This variation is reduced if the material is all of the same heat and the same rolling process.
 - Longitudinal welds. Considering the welding procedure is constant, the effect on the spring rate from expansion joint to expansion joint will be insignificant. However, the stiffness of the convolutions varies around the circumference of the expansion joint.
 - Variation during forming. When expansion joints are mechanically formed, the physical shape and thickness of the convolutions may vary. Some expansion joint fabricators expect the variation to be as high as ± 30 percent. Hydroforming significant reduces this variation, to an estimated ± 10 percent.
- Cleanliness

The expansion joints are subject to the same cleaning and cleanliness requirements as are the beam tube sections. Contact with carbon steel will be avoided during fabrication.

- Tolerances

The following tolerances were specified in the expansion joint specifications. All measurements are to be made while the temperature is between 16^o and 27^o C (60^o and 80^o F). Most of the dimensional requirements are needed to obtain the required fit up for welding to the beam tube sections.



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- The outside circumference of the ends of the expansion joints shall be within $\pm 1.19\text{mm}$ ($\pm 3/64"$), of the theoretical circumference corresponding to the specified inside diameter.
- The ends of the expansion joint shall be flat within 0.127mm ($0.005"$).
- The overall length shall be within $\pm 3.18\text{mm}$ ($\pm 1/8"$).
- The ends of the expansion joint shall be concentric within 4.76mm ($3/16"$). This is required to simplify alignment and help maintain the required aperture

EXPANSION JOINT TYPE

There are two different expansion joint types that can be used. The two types are based on the thickness of the material used to make the expansion joint convolutions. One type uses a thin wall design for the convolutions and requires weld ends. The second type is a near full thickness design that uses one thickness for the entire expansion joint. The thin wall design uses material which is too thin to field weld directly to the 3.23mm ($0.127"$) thick beam tube. The factors that dictate the thinnest material that can be field welded to the beam tubes are weldability and ASME limitations. In this situation the material is considered too thin if it is thinner than 12 gauge material (2.67mm $0.105"$). For the near full thickness design, material including 12 gauge and thicker will be used.

The design of the thin wall expansion joint is illustrated in Figure 7. A 3.23mm ($0.127"$) thick weld end is required on each side of the convolutions. The convolutions are formed from 18 or 20 gauge material (0.048 or $0.036"$). A fillet weld on the inside of the tube is typically used to join the convolutions to the weld ends. Figure 8 illustrates the fillet weld detail as well as another suggested weld detail. The second detail presents cleaning problems as well as questionable performance. The thin wall configuration has the following two advantages:

- The expansion joint has a low axial spring rate. The spring rate is approximately 350 N/m (2000 lbs/in). During bake out, the axial compression force imposed on the beam tube is approximately 7% (2.64 MPa , 383 psi) of the overall stress capacity of the beam tube; and
- With the thinner material, it is easier to mechanically form the convolutions, resulting in slightly less variation in the axial spring rate between expansion joints.



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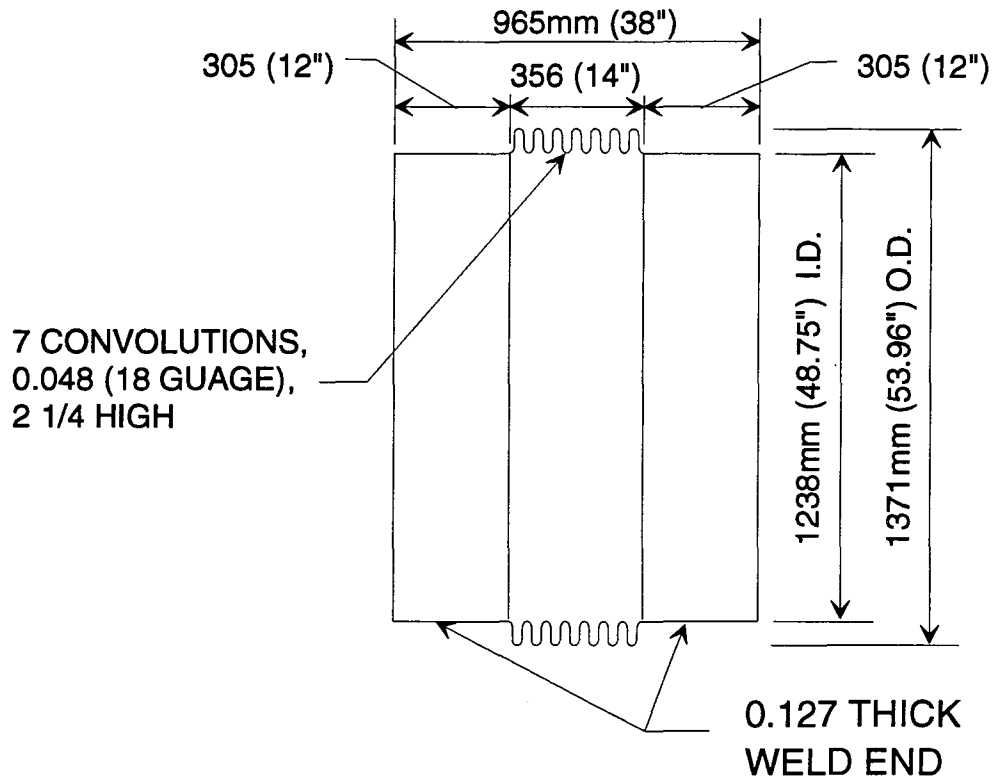


FIGURE 7
THIN WALL EXPANSION JOINT
Axial Spring Rate = 2000 lbs/in
(Configuration # 3 Design)

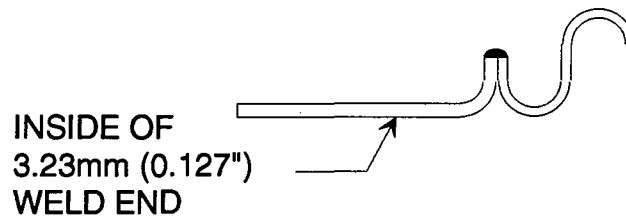
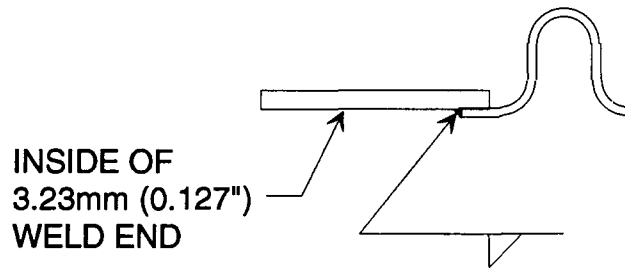


FIGURE 8
Weld Detail Joining Weld
Ends to Convolutions



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The expansion joints using thin wall convolutions have some significant disadvantages:

- The expansion joint requires weld ends. The weld ends require two additional circumferential welds for each expansion joint.
- The additional 800 circumferential seam welds impose a higher leak risk.
- Most expansion joint fabricators must use filler wire to make the weld between the convolutions and the weld end.
- Given the type of weld details between the convolutions and the weld ends, there is an inherent weakness. The fillet weld is made on relatively thin and thick material. The configuration of the fillet weld causes stress concentrations. These stress concentrations increase the risk of fatigue failures. As the fatigue risk increases, the long term risks of leakage increases.
- The welds between the convolutions and the weld ends are difficult to repair. Welding to thinner material increases the risk of burn through. Some weld details proposed by expansion joint fabricators are fillet welds made from the inside of the expansion joint. Thus, once the expansion joint is in place, access to repair the weld requires access to the inside of the beam tube. This will be expensive and be a potential to contaminate the inside of the beam tube. A fillet weld can not be used on both the inside and the outside of the expansion joint because this creates the possibility of a virtual leak. Other weld details made from the outside of the expansion joint are difficult to clean on the inside vacuum surface.
- The convolute material used will be 18 or 20 gauge (0.048 or 0.036"). This thinner material is susceptible to damage. Damage can occur during construction and during the alignment process that may occur anytime within the 20 year life. A small dent in one convolution will significantly reduce the fatigue life of the expansion joint, possibly require replacement.
- The torsional capacity of the expansion joint is less than a near full thickness expansion joint. The torsion capacity is limited by the strength of the fillet weld between the convolutions and the weld ends.
- The thinner expansion joint will require the insulation to be removed from the expansion joint during the bake out, to prevent over heating. Removing the insulation increases the risk of damaging the expansion joint.
- The thin wall expansion joints are more expensive than the near full thickness expansion joints. The additional cost of the weld ends and circumferential welds is more than the added cost of forming thicker material.

The design of the near full thickness expansion joint is illustrated in Figure 9. The best thickness to use is the minimum thickness that can be welded directly to the beam tube. Based on experience, mismatch of thicknesses, ASME limitations and alignment, the thinnest acceptable material is 12 gauge (2.67mm, 0.105"). By reducing the thickness from 3.23mm (0.127") to 2.67mm (0.105"), the axial spring rate and the cost of the expansion joint is reduced.

The near full thickness (2.67mm) expansion joint has the following advantages compared to the thin wall convolution expansion joint.



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- The expansion joint is less expensive;
- The expansion joint is favored by most fabricators;
- The expansion joint can be welded directly to the beam tube, eliminating the weld ends and 800 circumferential welds. Eliminating the 800 circumferential welds reduces the vulnerability of the expansion joint and local stress concentrations;
- Eliminating circumferential welds reduces the probability of leaks;
- The thicker convolutions reduce the risk of damaging the expansion joint during construction;
- The insulation does not need to be removed from the expansion joint during bake out; and
- The torsion capacity is higher.

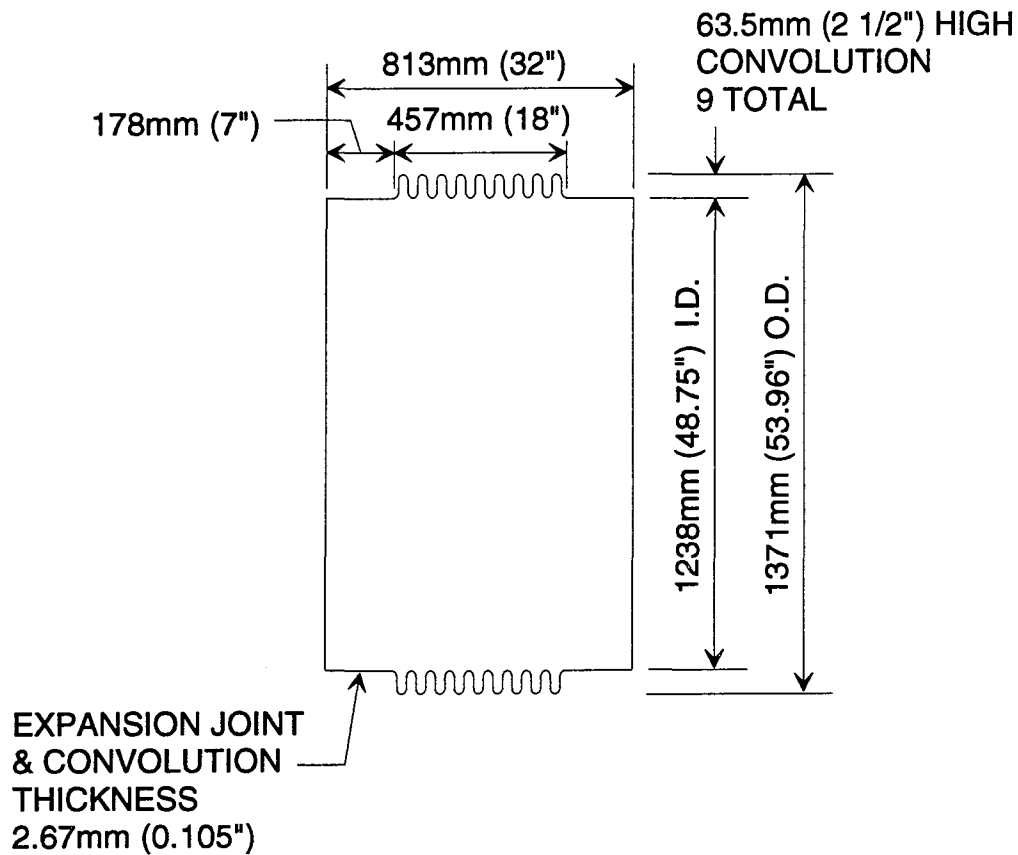


FIGURE 9
Near Full Thickness Expansion Joint
(Configuration # 3 Design)



The near full thickness expansion joint has two disadvantages.

- The axial spring rate is higher, resulting in an axial force during bake out approximately four times of the thin wall expansion joint. The axial compression force imposed on the beam tube is approximately 26% (10.57 MPa, 1533 psi) of the overall stress capacity of the beam tube. A thin walled expansion joint only requires 7% (2.64 MPa, 383 psi) of the overall stress capacity of the tube. Note that during operation condition, the stress caused by the near full thickness expansion joint is only 1% (0.48 MPa, 69 psi) of the beam tube capacity. See WBS 160 for a full discussion.
- The 1400 N/m (8000 lbs/in) spring rate limitation plus the required tangent lengths makes it difficult fit a sufficient number of convolutions on commonly available material. Stainless steel sheets are available in 60" wide sheets. This requires up to three longitudinal weld seams to make the required number of convolutions. However, the added longitudinal seams pose a lower leak risk and cost less than the circumferential fillet welds required for the weld ends of a thin wall expansion joint.

And are not fillet welds: so can be tested under same conditions

Based on the cost and performance advantages, the near full thickness expansion joint will be used, resulting in 20% cost savings. — *also reduced risk!*

FABRICATION METHODS

There are two distinct methods in which the expansion joints can be manufactured. The most common method is to mechanically form the expansion joint. The second method is to hydroform the expansion joint.

Mechanical forming can be accomplished by a variety of methods. The two most common methods are "roll forming" and "expanding mandrel" (punch forming). Roll forming is a process by which convolutions are formed by pressure being exerted by forming wheels to roll the convolution shape into the cylinder. This method thins the base material and is a method that is not used for precision parts. This method is not suitable for the LIGO expansion joint because repeatability is difficult to achieve. The expanding mandrel method is a two step method. The first step is to form individual convolutions by expanding an internal mandrel with a set of segmented dies. After the convolutions are punched, the convolutions are rerolled to specific size by a set of specially contoured inner and outer rollers.

Mechanically forming expansion joints creates the opportunity for variation and contamination. Variation, which effects the axial spring rate, may be caused by the following:

- Excessive tool wear may occur, resulting in uneven convolutions and or higher tooling cost;
- The bellows cylinder must be rotated to avoid flat spots;
- The expansion joint requires rerolling to get final convolution shape;



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- Each convolution must be individually formed. Thus, as the number of convolutions increases, the error of concentricity adds up; and
- The circumference on the ends of the expansion joint may need to go through a beelling operation to meet the required tolerance.

During the forming process, the material must be handled often. This increases the possibility of contamination. Contact is made on both the inside and the outside of the expansion joints. To prevent carbon steel contamination, all contact points are either made of stainless steel material or chrome plated. Forming oils are typically not used during the forming operation and will not be allowed for fabricating the LIGO expansion joints.

The second manufacturing method is hydroforming. Hydroforming is a method suitable for manufacturing a large number of identical expansion joints. The initial setup costs are higher than for mechanical forming. However, hydroforming requires less labor than mechanically forming. Labor costs are a significant percentage of the expansion joint cost. Thus, as the number of expansion joints increases, the overall cost decreases. The second advantage is repeatability. Many expansion joints can be made with closer tolerances. Variation in forming is almost eliminated. Concentricity errors do not add up. The convolution shapes are identical. The cause of variation between expansion joint stiffness is a function of the variation in material thickness and material properties. A third advantage is cleanliness. The only thing that makes contact with the inside of the expansion joint during forming is potable water. The chloride levels are below 50 PPM and it is not a problem. The fourth advantage, the hydroforming process also aids in providing the correct circumference at the ends of the expansion joints. This is critical since a tight tolerance is required to provide the proper fit up for welding to the beam tube. The final advantage is the longitudinal weld seam is subject to the high hydrostatic pressure (as high as 1000 psi). The magnitude of this pressure assures that the longitudinal weld seam is sound. Therefore, a hydroformed expansion joint provides superior performance compared to one that is mechanically formed. The performance is better from a physical behavior standpoint and a cleanliness standpoint.

1000 psi
= 6.8×10^7
dynes/cm²

The steps in hydroforming are simple. A tube is fabricated at a predetermined length and diameter. The tube is placed between two bulkheads. See Figure 10. Machined stainless steel rings are placed on the outside of the tube. The rings are precision machined in the shape of the convolutions. The tube is then filled with potable water. The pressure of the water is increased. As the pressure increases, the exposed areas of the tube begin to bulge. The bulkhead is lowered as the tube shortens. The convolutions are formed by the internal water pressure and are shaped by the rings outside of the expansion joint. The forming is complete when all the rings make contact between the bulkheads. The expansion joint remains clean and handling is minimized.

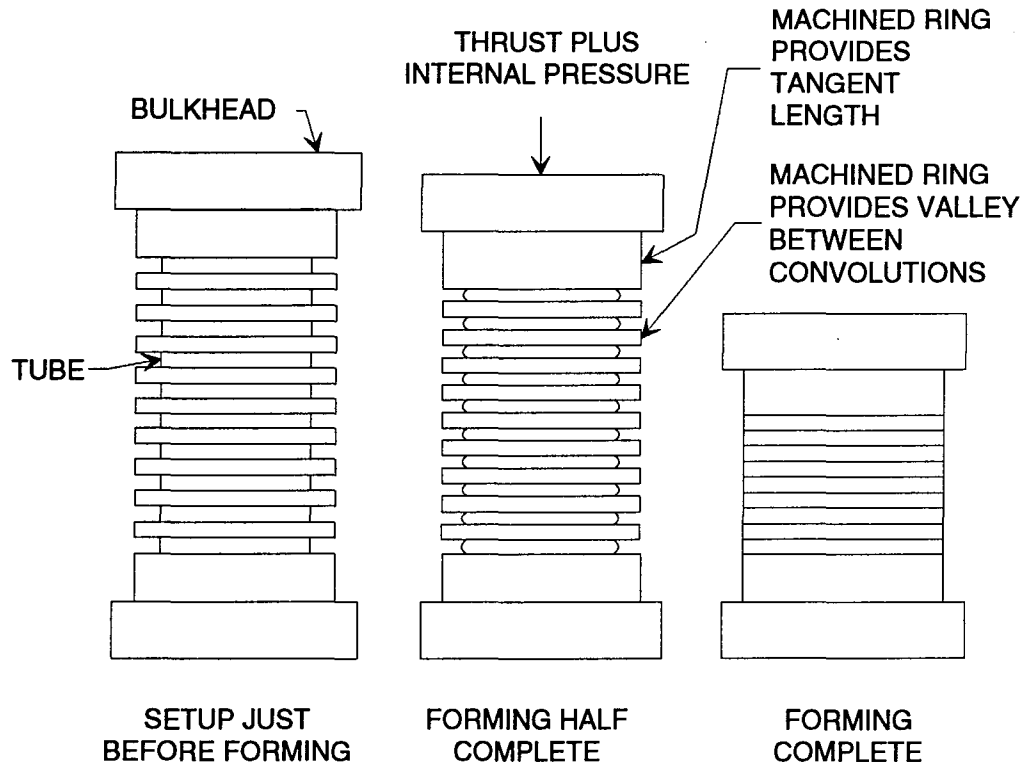


FIGURE 10
Hydroforming Expansion Joints

On the basis of the cleanliness requirement and the consistency required for axial spring rates, hydroforming is the preferred method of fabricating the expansion joints.

EXPANSION JOINT BUDGET PRICE AND DESIGN SUMMARY

To investigate the expansion joint costs for various beam tube configurations, budget prices were provided for configurations 1, 3 and 5. These budget prices were obtained during February of 1994 and are tabulated in Figure 1. Although the total price for Configuration 5 seems to be most favorable, other considerations must be included. As mentioned before, the axial movements in Configuration #5 are too large for guide supports to be feasible.



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CONFIGURATION		1	3	5
Quantity		768	400	200
American Boa	Each	\$2,800	\$3,700	\$7,500
	Total	\$2,150,400	\$1,480,000	\$1,500,000
Hyspan	Each	\$1,200	\$1,400	\$1,600
	Total	\$921,600	\$560,000	\$320,000
Pathway	Each	\$3,300	\$3,600	\$5,200
	Total	\$2,534,400	\$1,440,000	\$1,040,000

Table 1

Budget Prices for Configurations 1, 3 and 5

Three fabricators provided budget prices for the three configurations. Hyspan provided the lowest budget price, but did not meet the specification. Their design has an axial spring rate exceeds the specification by 70%. Thus, the initial design provided by Hyspan was unacceptable for the beam tube and supports. Hyspan must add additional convolutions to their expansion joint design. As expected, Hyspan's price increased when the second budget price and design were provided.

After configuration #3 was chosen as the final configuration, five expansion joint fabricators supplied budget prices and designs. Tables 2 and 3 summarize the final designs for configuration #3. American Boa and Pathway are the only two fabricators that meet the specification. The axial spring rate for the Pathway design is higher than the specified limit of 1400 N/m (8000 lbs/in). However, it still meets the specified tolerance of 1400 N/m plus 20%. Hyspan did not meet the specification by using a slightly thinner material of 2.54mm (0.100) instead of 2.67mm (0.105). Hyspan believes they can obtain material with a +.005" and - 0 thickness tolerance. Having a thickness of less than 2.54mm (0.100) will cause weldability problems and increase the risk of leaks. Using the correct thickness in their design will cause the axial spring rate to be over the specified limit. The Microflex design is incomplete since they were having difficulty obtain material in the width they need. Their axial spring rate will vary by $\pm 30\%$, and does not meet the specification. Senior Flexonics did not meet the specifications because they need to use weld ends to meet the minimum tangent length requirements.



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VENDOR	Forming Method	# of con	Thickness	Con Height	Con Radius	Tangent Length	Total Length
American Boa	Expand Mandrel	8	2.67mm 0.105"	70mm 2.75"	7.3mm 0.287"	178mm 6"	538mm 21.18"
Hyspan	Expand Mandrel	6	* 2.54mm 0.100"	79 3.125	16 0.625	178 & 102 6 & 4	635 25
Microflex	Expand Mandrel	6	2.67mm 0.105"	89 3.5	13 0.5	* / ?	* / ?
Pathway	Hydro.	9	2.67mm 0.105"	64 2.5	13 0.5	178 7	813 32
Senior Flexonics	Expand Mandrel	12	2.67mm 0.105"	57 2.25	14.3 0.5625	* 178, 6", weld end	813 32

* Does not meet CBI specification

Con = Convolutions

Table 2
Final Expansion Joint Design for Configuration 3
(Geometry)

VENDOR	Spring Rates				
	Axial kN/m #/in	% Error See Note	Lateral kN/m #/in	Angular MN-m/rad #-in/Deg	Torsional MN-m/rad kip-in/Deg
American Boa	1397 7978	±10	59,573 340,172	300.3 46,392	?
Hyspan	1427 8149	±10	25,803 147,341	456.3 44,202	?
Microflex	115 7860	* ±20	40,902 233,554	300.2 46,368	?
Pathway	1456 8316	±5	17,537 100,141	305.5 47,191	119,900 18,518
Senior Flexonics	1306 7457	±10	6793 38,790	273.9 42,310	155,800 24,060

* Does not meet CBI specification

Note: % Error is the variation from the actual average of axial spring rates. The average axial spring rates may vary by ±10 from the theoretical values listed in the table.

Table 3
Final Expansion Joint Design for Configuration 3
(Spring Rates)



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According to the expansion joint fabricators the following items are the major cost contributors to the expansion joints:

- Labor, includes forming and welding, typically 40%.
- Tooling, as much as 25%.
- Material, including air bake, as much as 25%.
- Matching the ends to meet specified tolerances.
- Adjustable shipping devices, and devices to resist vacuum.
- Cleaning and helium testing.

The latest budget prices, provided in April, are an improvement to the initial budget estimates from October of 1992. The following is a summary of what has changed since the initial budget price from October of 1992.

- Spacing of expansion joints increased from 40' to 130'.
- The number of expansion joints dropped from 1276 to 400.
- A larger amount of axial movement requires additional convolutions, thus there is additional forming. This is the most significant reason why the configuration #3 expansion joints cost more per unit.
- The end tolerances have been tightened.
- Previously, the limiting axial spring rate was specified too high. Lowering the spring rate increases the number of convolutions required.

Table 4 illustrates how the budget prices compare.

Vendor	10/92 Quote		2/94 Quote		4/94 Quote	
	Price Each	Total Price 1276	Price Each	Total Price 400	Price Each	Total Price 400
American Boa			\$ 3,700	\$ 1,480,000	\$ 3,171	\$1,268,360
Hyspan	\$ 900	\$ 1,148,400	\$ 1,400	\$ 560,000	\$ 2,002	\$ 800,610
Microflex	\$ 1,700	\$ 2,169,200				
Pathway	\$2,500	\$ 3,190,000	\$ 3,600	\$ 1,440,000		
Senior Flexonics	\$ 2,900	\$ 3,700,400			\$ 4455	\$1,782,200

Table 4
Configuration #3 Budget Prices



SELECTION OF EXPANSION JOINT FABRICATOR

The selection of the expansion joint fabricator is based on performance, effects on other components, meeting the specification, the fabrication method, and price. Listed below are the considerations used to decide which vendor is the preferred vendor for the construction option.

Microflex

- Can not meet the specification for the variation of axial spring rates.
- Not enthusiastic about bidding on this type of expansion joint.
- Preferred the thin walled expansion joint because they lacked equipment to do the near full thickness design.
- Final bid price was not provided.

Conclusion: It is recommended that Microflex should not be used for the construction option.

Senior Flexonics

- Uses weld ends in the design to meet the required tangent lengths.
- The highest price.

Conclusion: It is recommended that Senior Flexonics should not be used for the construction option.

Hyspan

- The specification is not met by using thinner material.
- The thinner material will cause weldability problems and increase the risk of leaks.
- Using the correct thickness will cause the axial spring rate to be higher than is allowed by the specification.
- The latest two quotations did not meet the specifications. To meet the specification the price will increase.
- Compared to other vendors, their price is much lower.
- A disadvantage is the expansion joint is mechanically formed.

Conclusion: It is recommended that Hyspan should not be used for the construction option.



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American Boa

- Meets the specification.
- Has a relatively low price.
- A disadvantage is the expansion joint is mechanically formed.

Conclusion: They are the second choice a the vendor supplier. They meet the specification, however, they do not use the preferred forming method (hydroforming).

Pathway

- Meets the specification.
- Utilize hydroforming that is the preferred forming method.
- Hydroforming reduces the risk of contamination.
- Provide the most consistent expansion joint.
- Provide the least range in axial spring rates. This will reduce differential settlement of the foundation, reducing the long term costs of the facility.
- Have a reasonable price considering the gain on performance.

Conclusion: Pathway is the preferred expansion joint vendor. They meet the specification, and they use the preferred forming method (hydroforming) which produces the best performing expansion joint.

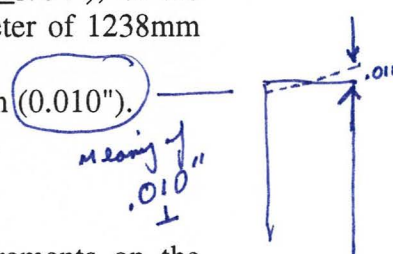
WBS #240 Tube and Expansion Joint Interface

The tubes and expansion joints have dimensional requirements to assure that they can be properly joined during construction. There are two sets of requirements. First, there are requirements based fit up and welding between the tubes and the expansion joints. Second, there are requirements outside the tubes and expansion joint to provide clearances during helium leak testing, fit up and welding.

To successfully weld the expansion joints to the beam tubes, tolerances have been specified for both the expansion joints and beam tubes. The following tolerances apply only to the ends of the expansion joints and beam tubes between the temperatures of 16^o and 27^o C. (60^o and 80^o F)

- The outside circumference of the ends shall be within $\pm 1.19\text{mm}$ ($\pm 3/64"$), of the theoretical circumference corresponding to the specified inside diameter of 1238mm (48.75").
- The ends shall be perpendicular to the cylindrical axis within 0.254mm (0.010").
- The ends of the expansion joint shall be flat within 0.127mm (0.005").
- The overall length shall be within $\pm 3.18\text{mm}$ ($\pm 1/8"$).

To enable leak testing, fit up and welding, there are clearance requirements on the outside of the expansion joints and tubes. During leak testing, the expansion joint





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together with a tube section must fit within the helium test hood. This limits any stiffener or shipping device to a concentric outside diameter of 1568mm (61.75"). The remaining requirements are based on what is required by the fit up and welding equipment. These requirements are illustrated in Figure 1.

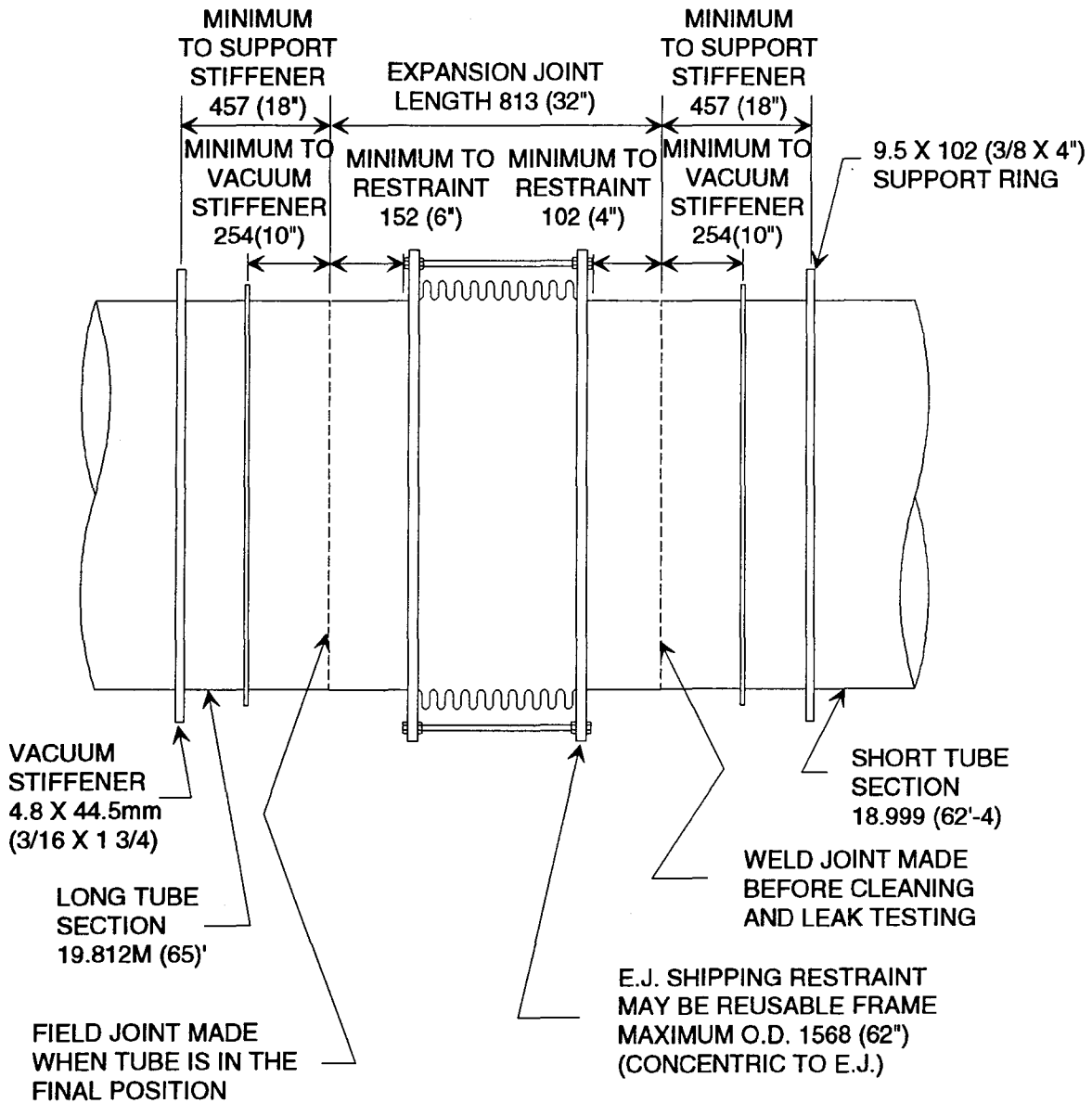


FIGURE 1
TUBE AND EXPANSION JOINT INTERFACE



WBS #250 Baffle Fabrication Process

The fabrication procedure for the baffles has been controlled, in large part, by the following statement from Section 3.1.4, "Baffles", of LIGO Specification 110004, "Technical Specifications":

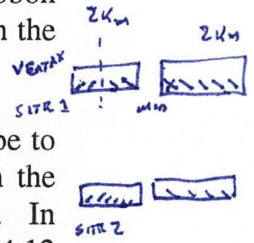
"Baffle installation shall require no fastening; free design parameters, such as baffle thickness and unconstrained helix diameter shall provide sufficient friction and stability for secure positioning."

Thus, the baffles are not to be held in place against the tube wall by welding or any type of mechanical attachment such as tabs and screws, but rather solely by a radial "clamping" force exerted by the baffle, along its entire perimeter, against the inside wall of the beam tube.

Initially, the baffles were to have an "inverted V" configuration, with the baffle "legs" of equal length and at 90 degrees to each other (refer to LIGO Drawing 1101004, dated 03-11-92). However, Caltech has allowed the optional use of a single ribbon screw flight at an angle of 35 degrees with respect to the tube wall.

The orientation of the baffles must be allowed to change in the tube

CBI chose to pursue a baffle with a single ribbon screw flight configuration for economic reasons. Based upon discussions with potential fabricators and personnel from CBI's manufacturing facility in Kankakee, Illinois, it was determined that the single ribbon screw flight configuration would be easier to fabricate, and would thus cost less, than the "inverted V" baffle configuration with unequal legs.



The preferred method for fabrication of the single ribbon screw flight baffle would be to roll a flat bar about its strong axis, while at the same time coning the bar to form the helical profile of the baffle. However, this proved to be an impractical approach. In order to achieve the installed shape of the baffle, the flat plate would need to be 4.12 inches wide. With a maximum permissible baffle thickness of 0.13", the resulting depth-to-thickness (d/t) ratio is 31.7. A thinner baffle would result in an even larger d/t ratio. All the fabricators that were contacted regarding this approach advised us that it was not possible -- the deep, thin bar, could not be rolled about its hard axis without extensive damage to the baffle material. In order for the 4.12" wide bar to be bent about its strong axis without damage, the thickness of the material would have to be approximately 0.17", which would provide the minimum "manufacturable" d/t ratio of 25. This minimum thickness required for manufacturing purposes exceeds the 0.13" maximum permissible thickness of stainless steel plate. Therefore, this method of baffle fabrication was not pursued.

Initially two prototype baffles, having the single ribbon configuration, were fabricated. Both prototype baffles were fabricated from ASME SA-240 Type 304L stainless steel plate, with thicknesses of 0.059" and 0.078". These thicknesses were consistent with the initial intent of fabricating the baffles from thin gage material in an effort to minimize



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baffle weight and material costs. Each prototype baffle was fabricated from two pieces of material, butt welded end-to-end, and slip rolled to a conical shape with an outside diameter of approximately 54".

However, when inserted in a tube with an inside diameter of 48", the baffles proved to be too flexible -- they collapsed upon themselves under their own weight instead of taking the shape of the beam tube and exerting a radial clamping force against the tube wall. The problem was twofold -- the thin gage baffles did not have enough weak axis stiffness (a function of the cube of the thickness) to both support its own weight and exert an outward radial force, and the initial rolled diameter of 54" was too small.

Based upon these results, a third prototype baffle was fabricated. Again, this baffle had the single ribbon configuration and was fabricated from 304L stainless steel. The thickness of this baffle, however, was increased to 0.115". Additionally, this baffle was fabricated unrolled -- the intent being to see how well a "flat" baffle fit inside the beam tube.

This baffle, when inserted into the 48" I.D. tube, exerted a considerable radial clamping force against the tube wall. The baffle fit the tube very well except at the baffle ends. The ends of the baffle, being unrolled, did not take the shape of the tube and remained straight. The ends of the baffle were then rolled, the remainder of the baffle staying unrolled, in an attempt to make the baffle ends take the shape of the tube. This approach was not successful, however. The rolled baffle ends, when transitioning into the unrolled interior part of the baffle, deformed the transition areas enough that the radial projection of the baffle was well below the required 6.0 cm in these regions. This approach, of having a partially flat, partially rolled baffle, was thus not pursued.

Based upon the observed results of the three fabricated prototype baffles, however, several conclusions were drawn:

- A thin gage baffle is not stiff enough to both support its own weight and, at the same time, exert a radial clamping force against the wall of the beam tube. A thicker baffle, however, will be adequate.
- An unrolled (i.e., "flat") baffle is not a viable option, since the ends of such a baffle will remain flat when inserted into the beam tube, and will not take the shape of the tube.
- A partially unrolled, partially rolled baffle is also not a viable option, since the discontinuity at the rolled/unrolled transition region deforms the shape of the baffle.
- In order to prevent "walking", or longitudinal movement, of the baffle ends from the prescribed 30 cm pitch, a spacer bar, which ties the baffle ends together, will be required.



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It had been established that a thin gage baffle would not be suitable, and that a thicker baffle would be adequate. Therefore, in order to minimize the overall number of different material thicknesses in use for the LIGO Project, it was decided to provide a baffle having a thickness identical to either the beam tube wall (0.127") or the expansion joint (0.105"). Based upon the observed results of the 0.115" thick prototype baffle, it was decided that a 0.105" thick baffle would be adequate.

Based upon these results, the fabrication process for the baffles and spacer bars, as outlined in Specification C-BAF-1, "Baffle Fabrication Specification", will be as follows:

Baffles and spacer bars shall be fabricated from stainless steel plate, with a surface finish no smoother than 2.5 microns RMS and a material thickness of 0.105". The material for the baffles and spacer bars shall meet the chemical and mechanical requirements outlined in Specification C-240-0187, "Baffle Material Specification". In order to reduce the hydrogen outgassing characteristics of the material for the baffles and spacer bars, the material will be air baked in coil form per the procedure outlined in Specification C-CMBS1, "Coil Material Bake Specification". After baking, hydrogen outgas testing coupons will be prepared and tested. Once the coupons have been tested and have been found to exhibit an acceptably low rate of hydrogen outgassing, the baked material for the baffles and spacer bars will be shipped to the fabricator in sheet form.

In order to minimize the amount of scrap plate material, each baffle shall be fabricated from a total of four (4) annular segments, which provides for a material-efficient "nesting" of the baffle segments. To prevent the re-introduction of hydrogen into the air baked baffle material, both the annular segments of the baffle and the spacer bars will be cut from sheet by waterjet cutting. All phases of the baffle and spacer bar fabrication processes will avoid carbon steel contamination of the stainless steel.

*alternatives
in plasma
torch cutting
which run the
risk of
dissolving H₂O*

Each of the four (4) annular baffle segments, cut from flat plate, shall have the dimensions as tabulated below. Refer to the attached sketch, "Dimensions of Baffle Annular Segments", for clarification of the dimensions tabulated below.

<u>Baffle (with 6.0 cm Radial Projection)</u>	
Tangent Radius, "A"	= 3' - 5 3/4"
Tangent Radius, "B"	= 3' - 9 7/8"
Inside Chord, "C"	= 3' - 0 3/8"
Outside Chord, "E"	= 3' - 4"
Inside Versine, "D"	= 0' - 4 3/16"
Outside Versine, "F"	= 0' - 4 9/16"
Angle in the Flat, Theta	= 51.62°



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After the four annular segments of a baffle have been cut, butt weld two of these annular segments together, end to end, to form a larger, flat annular segment. Repeat this process with the two remaining annular segments, so that two larger, flat annular segments are obtained. All welding shall be done by the gas tungsten arc welding (GTAW) process, without the use of filler wire. All welds shall be full fusion welds. An inert gas purge will be used for all welding.

After welding and forming the above assemblies, slip roll the baffle segments to a conical shape with an unconstrained outside diameter of 60". Weld the two assemblies together, using the GTAW process described above, to form the finished baffle.

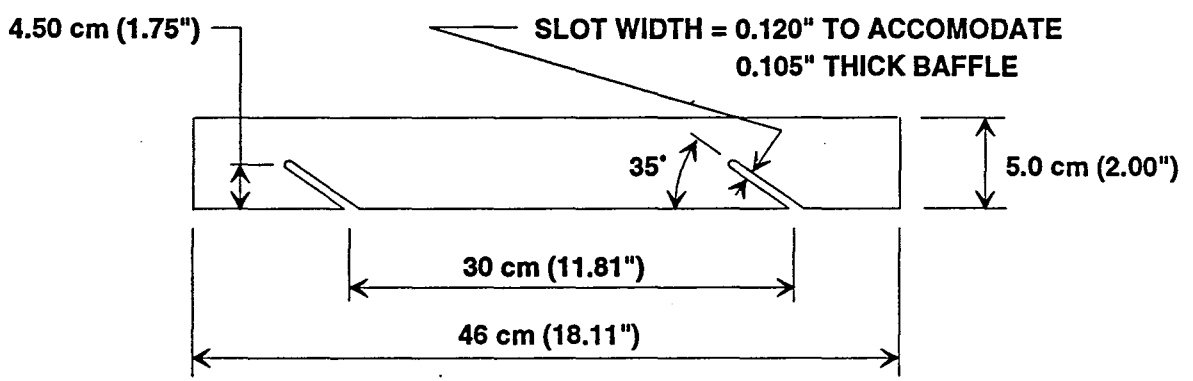
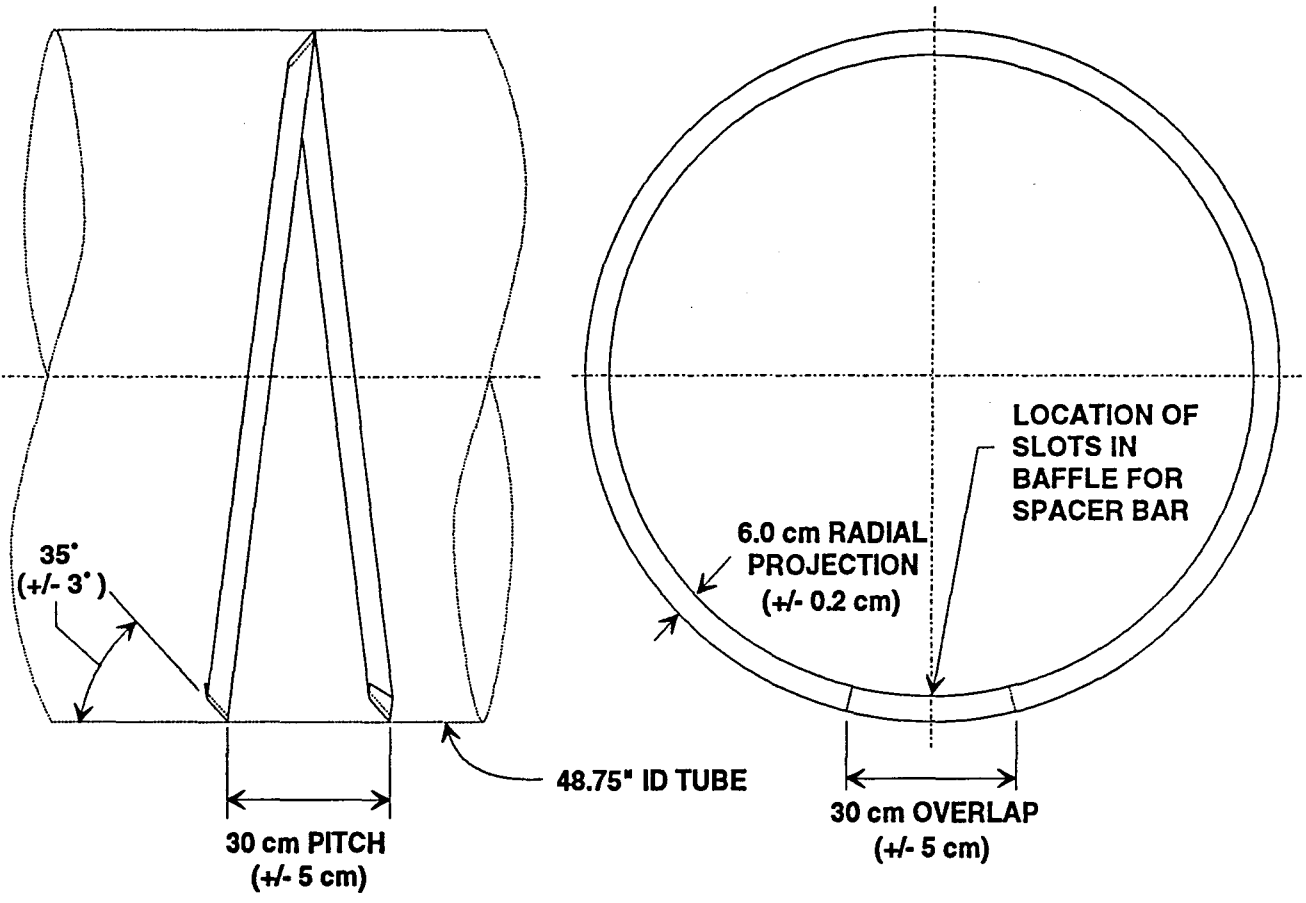
The spacer bars will be fabricated from a rectangular piece of stainless steel plate, and will have slots as shown on the attached sketch, "Baffle (As-Installed Dimensions and Tolerances) and Spacer Bar".

After forming the baffle and spacer bar, the baffle and spacer bar will be "steam" cleaned per Section 5.0 of Specification CLCOUPA0, "Cleaning of Plain Coupons, Alternate Method #0, For Surface Analysis and Outgassing Tests", to remove any hydrocarbon contamination that may be present. Once the cleaning process has commenced, the baffles and spacer bars will be handled only by personnel wearing chemical resistant gloves in order to prevent recontamination of the material.

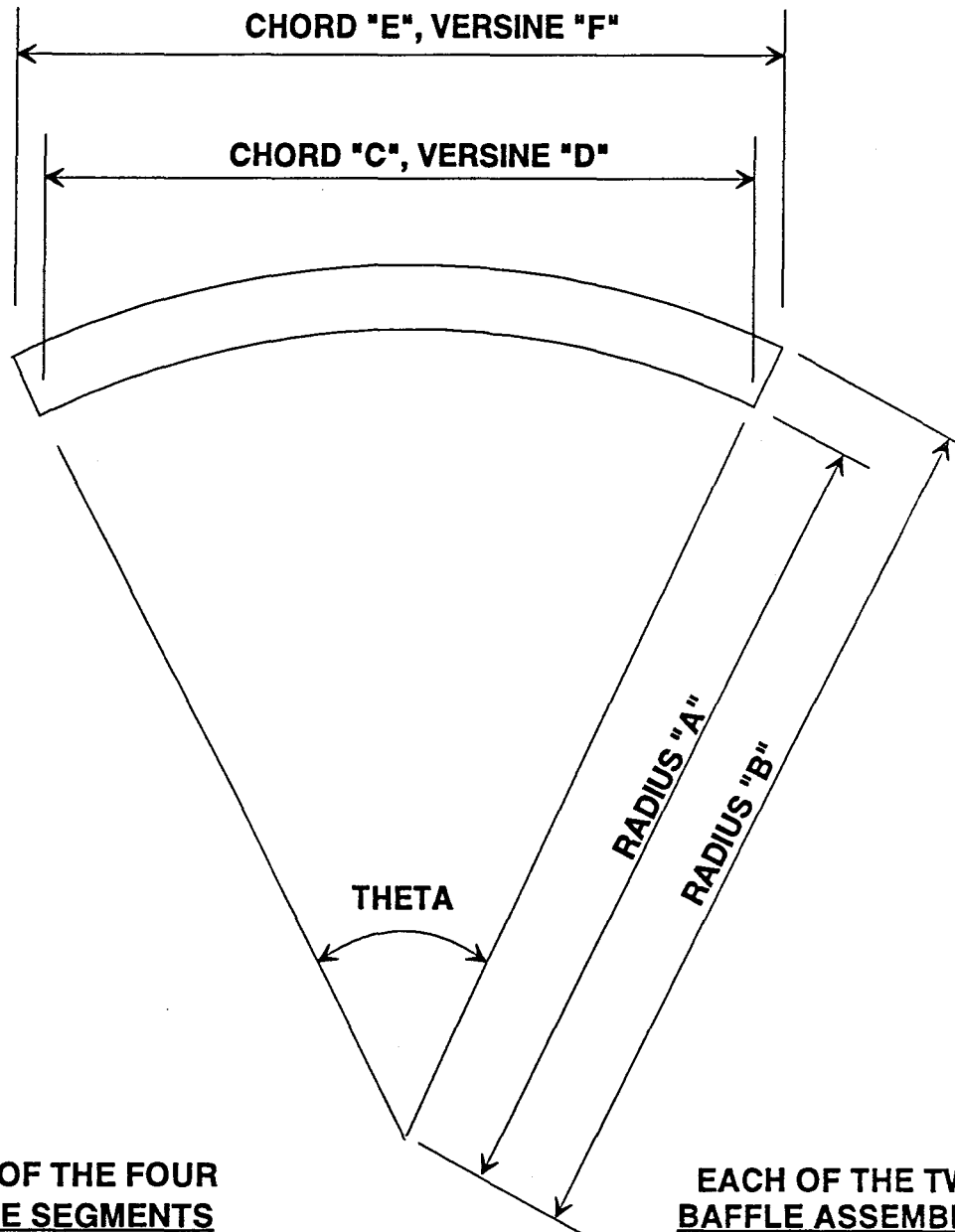
After cleaning, the fabricator will attach to the baffle ends stainless steel banding that restrains the baffle to an outside diameter of 40 inches to facilitate shipment and installation within the beam tube. This stainless steel banding, prior to being attached to the baffles, will undergo the same cleaning procedures as the baffle and spacer bar to remove any hydrocarbon contamination that may be present. The cleaned baffles and spacer bars will be sealed within polyethylene shrink wrap to avoid contamination and shipped to the site in a secure container to prevent damage.

One baffle and one spacer bar will be sealed together after cleaning -- sealing of multiple baffles and/or spacer bars within the same sealed package will not be permitted. Since the baffles will be installed within the beam tubes assemblies one at a time, with an indeterminate time interval between installation of adjacent baffles, the opening of a sealed package containing multiple baffles and/or spacer bars for the purpose of installing a single baffle and spacer bar presents the potential of contamination of the remaining, cleaned baffles and spacer bars.

Installation of the baffles within the beam tube is straightforward. The sealed package containing one baffle and one spacer bar is carried into the beam tube to the prescribed location. At this time, the package is opened, and the baffle and spacer bar removed. The steel band constraining the baffle ends is cut, allowing the baffle to expand and contact the inside wall of the tube. After the baffle ends are positioned to achieve the proper 30 cm overlap and 30 cm longitudinal pitch at the base of the tube, the spacer bar is inserted into the two slots located in the inside edge of the baffle to secure the baffle



BAFFLE (AS-INSTALLED DIMENSIONS AND TOLERANCES)
AND SPACER BAR



**EACH OF THE FOUR
BAFFLE SEGMENTS**

RADIUS "A" = 41.782"
RADIUS "B" = 45.900"
THETA = 51.62 degrees
CHORD "C" = 36.384"
VERSINE "D" = 4.168"
CHORD "E" = 39.970"
VERSINE "F" = 4.579"

**EACH OF THE TWO
BAFFLE ASSEMBLIES**

RADIUS "A" = 41.782"
RADIUS "B" = 45.900"
THETA = 103.24 degrees
CHORD "C" = 65.508"
VERSINE "D" = 15.842"
CHORD "E" = 71.964"
VERSINE "F" = 17.403"

DIMENSIONS OF BAFFLE ANNULAR SEGMENTS



ends from "walking" above or below the specified longitudinal pitch of 30 cm. The remains of the packaging and the stainless steel banding is then removed from the beam tube.

The inside edges of the baffles will be continuously serrated to a nominal depth and pitch of 0.35 cm. However, the specific manner by which the serrations are imposed upon the edge of the baffle is on hold pending the formation of a joint LIGO/CBI Work Group as recommended by the LIGO Review Board following the Preliminary Design Review.

*serrations
not
decided.*

WBS #260 Stiffener Fabrication Process

From the onset of the LIGO Project it was realized that, due to the large number of beam tube stiffeners that would be required for the stiffening of the 15.6 kilometers of beam tube, the overall material and fabrication cost of the beam tube stiffeners would be a significant cost item. As such, every effort has been made to develop a method of beam tube stiffener fabrication that minimizes the costs associated with material, fabrication and installation. Each of these three items will be discussed individually.

Stiffener Material

The two choices available for use for the stiffener material were carbon steel and stainless steel. The relative benefits and drawbacks associated with the use of each of these materials was considered and will be discussed.

Carbon steel, while inexpensive, is extremely susceptible to corrosion. Given the corrosive marine environment that would be encountered at the Livingston, LA site, unprotected carbon steel stiffeners would experience a high degree of corrosion, perhaps to the point of compromising their structural integrity. Carbon steel stiffeners, therefore, would have to be field painted in order to prevent corrosion.

Field painting of carbon steel beam tube stiffeners would be performed after leak checking of the beam tube sections, and will add unnecessary additional costs to the LIGO Project, both from the standpoint of the painting process itself in addition to the following factors:

- Grit blasting of the stiffeners would be required to remove scale and rust. One-sided welding of the stiffener to the beam tube would leave crevices from grit and oxidized carbon steel in contact with the shell, forming a corrosion pocket. Thus, two sided welding of these stiffeners would likely be required.
- Due to the humid operating conditions of the beam tubes, the paint system required would most likely be a three-coat, two part epoxy system. Application of this coating, or even a one-coat system, would be expensive and time-consuming.



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- To ensure adequate performance of the coating system, periodic inspection and maintenance of the painted stiffeners would be required over the 20 year operational life of the beam tubes. This would require removing all tube insulation for a visual inspection of each stiffener. The expense associated with this would be considerable.
- The high, sustained temperature (300^oF) associated with beam tube bakeout could be detrimental to the painted surfaces of the stiffeners. This would indicate the possible need for a specialized and expensive paint system capable of withstanding these temperatures.

Stainless steel has the advantage of superior corrosion resistance. Any corrosion that might occur on stainless steel stiffeners would be in the form of scattered superficial rust patches which would have no effect on the mechanical properties of the stainless steel, or the structural integrity of the stiffeners. Therefore, costly measures such as galvanizing or painting of the stainless steel stiffeners are ^{not} necessary. The stainless steel stiffeners, like the exterior of the stainless steel beam tube, can be left uncoated with no effect on their performance. The welding procedure of the stainless steel stiffeners to the stainless steel beam tube is straightforward, with none of the problems associated with welding a coated carbon steel stiffener to the stainless steel beam tube or painting the stiffeners after attachment. Primarily, a stainless steel beam tube stiffener would **not** require welding on both sides of the stiffener, unless structurally required, simply to avoid the potential for corrosion.

A brief cost trade study has been performed to show that the use of stainless steel stiffeners is economically justified. The trade study takes into consideration **only** material costs, painting costs and welding costs for stainless steel and carbon steel stiffeners. Refer to the attached table, "Beam Tube Stiffener Material Cost Study" for details. The results of the study indicate that the unit cost of a stainless steel stiffener is substantially less than the unit cost of a painted carbon steel stiffener.

In conclusion, given the large quantity of beam tube stiffeners required for the LIGO Project, their critical role in the design of the beam tube, the projected 20 year operational life of the LIGO Beam Tube Modules in a corrosive atmosphere, and welding considerations, the use of stainless steel stiffeners poses very few problems from the standpoint of performance, corrosion and welding in comparison to carbon steel stiffeners. It is for this reason that stainless steel beam tube stiffeners will be utilized.

Stiffener Fabrication

Once again, the large number of beam tube stiffeners that are required for the LIGO Project requires that the method by which the stiffeners are fabricated make efficient use of material with little or no waste, lends itself to repeatability, and minimizes the number of fabrication operations and associated manhours.



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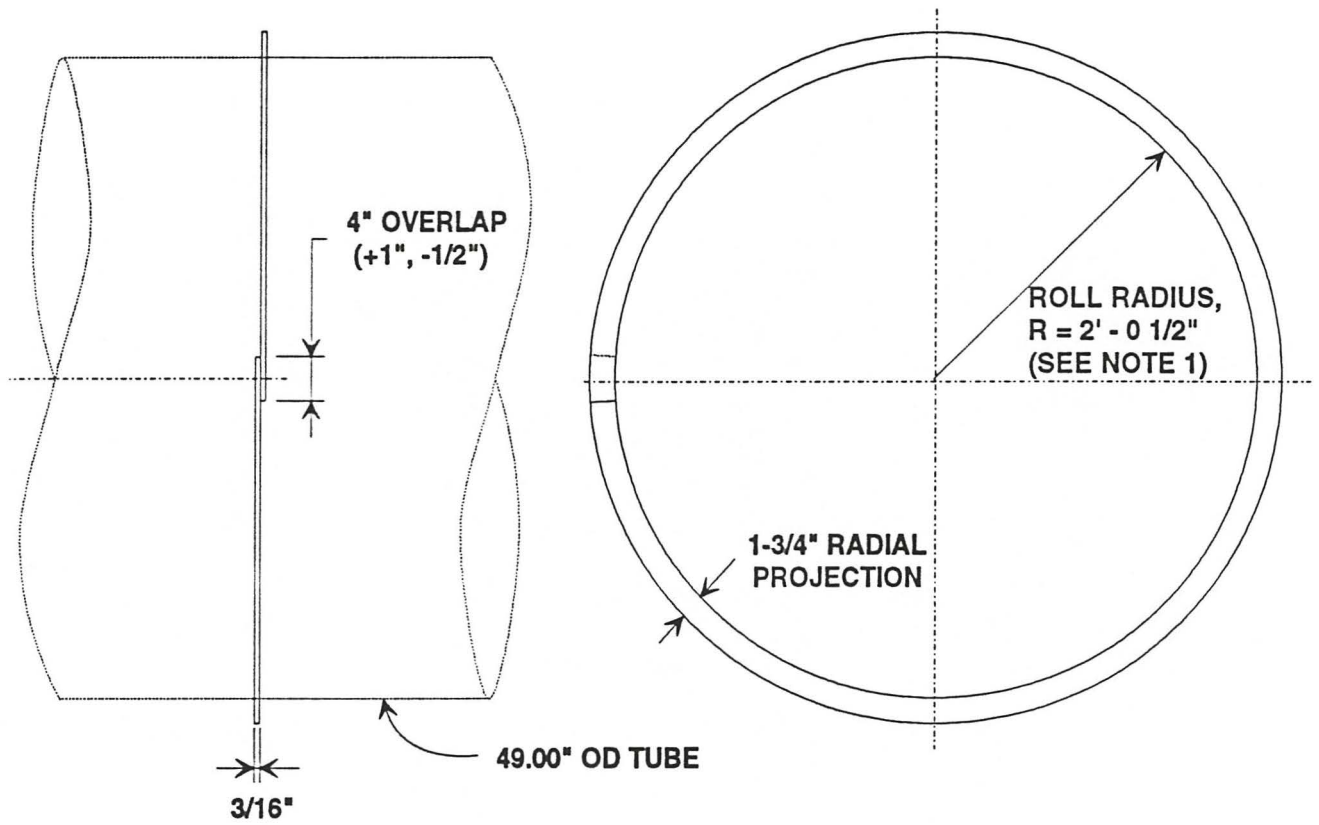
The use of a rectangular stiffener, as opposed to a stiffener composed of an angle or a tee section, offered the most latitude in selecting the most cost-effective overall stiffener fabrication, installation and welding process. Additionally, the stiffener design process indicated that a stiffener with a relatively small moment of inertia was required. As such, it was decided that a rectangular beam tube stiffener would be utilized.

For a rectangular stiffener, there were two possible options by which a rectangular stiffener could be fabricated. First, an "off-the-shelf" standard piece of stainless steel bar stock, having the depth, thickness and length required for the stiffener design, could be purchased. Second, bars having the required depth and length for the stiffener design could be cut from stainless steel plate having the thickness required for design. The first option, purchase of a standard piece of bar stock, is the most cost-effective method for procuring the stiffener material, since the costs associated with cutting the 19,560 beam tube stiffeners from individual plates would not be incurred. Therefore, the beam tube stiffeners will be "off-the-shelf" standard pieces of stainless steel bar stock, $1\frac{3}{4}$ " deep x $\frac{3}{16}$ " thick. Design requirements for a $\frac{3}{16}$ " thick stiffener require a stiffener depth of at least 1.71", so the use of a $1\frac{3}{4}$ " deep stiffener provides for an efficient use of material. The next largest standard piece of stainless steel bar stock that would be available would be 2" deep x $\frac{3}{16}$ " thick.

The determination of the size, spacing and welding of the beam tube stiffeners was discussed in WBS 160, "Final Beam Tube Configuration".

The fabrication method for the beam tube stiffeners should also minimize the amount of labor involved. The fabrication method selected is that of rolling the $1\frac{3}{4}$ " x $\frac{3}{16}$ " stainless steel bars about the strong axis to produce single piece stiffeners which conform to the outside diameter of the tube. Refer to the attached Figure, "Beam Tube Stiffeners", for details. The two ends of each stiffener overlap for approximately 4 inches. This overlap will be placed at the location where the stiffener ring crosses the spiral seam of the tube so that continuous fillet welding could start adjacent to the spiral seam at one end and proceed nearly 360° around without interruption, and without crossing the tube spiral seam.

The above method of stiffener fabrication is the most cost-efficient method of mass producing the 19,560 (+/-) vacuum stiffeners that will be required for the LIGO Project, since the rolling process for these stiffeners is not a manhour-intensive operation, and yet produces a fabricated stiffener with an inside radius within $\frac{1}{4}$ " of the required inside radius of $24\frac{1}{2}$ ". This fabrication tolerance is well within the bounds necessary for fitup and installation of the stiffeners.



STIFFENER MATERIAL: A240 TYPE 304L STAINLESS STEEL
ROLL RADIUS, R = 2' - 0 1/2" (+1/4", -0")

NOTES:

1. STIFFENERS TO BE A SINGLE CONTINUOUS PIECE FORMED BY ROLLING 3/16" x 1-3/4" BARS; ONLY THE ENDS OF THE STIFFENER TO BE CUT EDGES.

What about a chamfer on the stiffener edges

BEAM TUBE STIFFENERS

BEAM TUBE STIFFENER MATERIAL COST STUDY

Length of standard bar used for stiffener fabrication =	14.00 ft	
Unit cost of 304L stainless steel standard bar stock =	\$1.55 lb/ft	(Joseph T. Ryerson & Son, Inc.)
Unit cost of A36 carbon steel standard bar stock =	\$0.31 lb/ft	(Joseph T. Ryerson & Son, Inc.)
Unit weight of a 3/16" x 1-3/4" standard bar =	1.12 lb/ft	
Unit weight of a 3/16" x 2" standard bar =	1.28 lb/ft	
Unit weight of a 1/4" x 1-3/4" standard bar =	1.49 lb/ft	
Unit weight of a 1/4" x 2" standard bar =	1.70 lb/ft	
Unit cost of a 1-sided stiffener fillet weld =	\$15.00	(Houston Welding Estimate)

Cost Item (Per Stiff'r)	Stainless Steel Stiffener Standard Bar Size		Carbon Steel Stiffener Standard Bar Size		
	3/16" x 1-3/4"	3/16" x 2"	3/16" x 1-3/4"	1/4" x 1-3/4"	
Material	\$24.30	\$27.78	Not available	\$6.47	See Note 1
Painting	\$0.00	\$0.00	----	\$12.00	
Welding	\$15.00	\$15.00	----	\$30.00	
Σ	\$39.30	\$42.78	----	\$48.47	

Note: The following items below have not been factored into the cost study, and will increase the cost of carbon steel stiffeners:

1. Carbon steel stiffeners would be shop primed except for the inside edge for welding. The inside edge would be wire brushed prior to welding on both sides. After final leak testing, the stiffeners would be spot blasted and primed, followed by final painting. The actual cost of corrosion protection for a stiffener would likely exceed the \$12.00 shown.
2. The costs shown do not include the increase in construction time due to the need for two-sided welding on the carbon steel stiffeners.
3. The costs shown do not include the inspection and maintenance of the painted carbon steel stiffeners over the 20 year operational life of the beam tube modules.



Stiffener Installation

The fabricated, one-piece stiffeners are very flexible, and are installed on the beam tube by expanding the overlapping ends of the stiffener, locating the stiffener at the proper location on the beam tube, and releasing the overlapping ends of the stiffener to bring the stiffener in contact with the outside wall of the tube.

Other argument against carbon steel stiffeners is the ferritic content of the austenitic steel.

Stainless steel beam tube stiffeners, $1\frac{3}{4}$ " x $\frac{3}{16}$ ", procured from three separate suppliers and fabricated per the above procedures have been fitted and welded to a prototype beam tube at CBI's Weld Laboratory in Houston. The welding of these stiffeners to the tube has established that this method of stiffener fabrication provides an adequate fit to the beam tube, facilitates fitup to the beam tube, and produces a stiffener-to-tube weld of good quality. The procedure for fitting and welding the stiffeners to the beam tube is discussed in WBS #280, "Automatic Stiffener Weld Development".

WBS #270 Beam Tube Weld Process Development

Autogenous Welding

Two techniques were evaluated. One being with a copper back-up bar and the other being without the copper back up bar. Both procedures were welded in the downflat position using various gas mixtures.

Copper Back-Up Bar Development: 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 back side of the weld joint.

It was found that with increasing the helium percentage of the shielding gas, the travel speed may be increased. Helium has a characteristic hotter arc which gives greater penetration which allows for faster travel speeds.

Welding with optimum parameters for each gas mixture, it was found that after obtaining positive reinforcement on the back side of the weld joint, the top side was slightly under flush in all cases.

Welding development without the copper back-up bar: Without a back-up bar to allow the heat to escape, a lower heat input must be used which decreases the welding travel speed. Very similar results were shown as with welding with the copper back-up bar with the exception of a much slower travel speed. The shielding gas had the same effect as mentioned above. Due to the slower travel speeds, a welding procedure with a copper back-up bar would be more desirable.

In either case, a full thickness weld joint is not possible welding autogenously. In order to obtain a full thickness weld joint, filler wire must be used. It was also determined from the Preliminary Design Review that welding autogenously would add considerably



to the total cost of the project. For these reasons, alternate welding procedures were developed utilizing filler wire.

Alternative Welding Procedures

Two procedures were evaluated including a one (1) pass weld using filler wire and a two (2) pass procedure with the first pass being autogenous and the second pass using filler wire.

One pass procedure: By welding with one (1) pass using filler wire, no satisfactory welds could be made. Difficulties arise in control of welding penetration. Bead contour on both surfaces was unacceptable with erratic results.

Two pass procedure: A two pass procedure was very weldable. The first being an autogenous pass from side 1 with approximately 70% penetration. The second pass being welded from side 2 with 70% penetration resulting in a bead overlap of 40%. This procedure is repeatable with smooth bead contour on both sides. With tight control of welding parameters, 100% fusion can be maintained.

WBS #271 Select Alternative Process for Development

CBI has developed an alternate welding procedure utilizing a combination of autogenous welding and ER308L filler wire. For the spiral weld of the tube and the circumferential weld joints, no filler wire will be used on all surfaces exposed to the vacuum. This is the preferred procedure for both CBI and tube manufacturers.

WBS #272 Evaluate CBI & Caltech Process

Outgassing tests have been carried out using cleaned and baked ER308L filler wire. These outgassing coupons show good results, yet no formal acceptance has been received. A second set of outgassing test coupons have been welded using standard ER308L filler wire due to the extremely high cost of the cleaned and baked wire. These coupons are currently being evaluated. See report on WBS #710 for details of the filler wire evaluation.

WBS #280 Automatic Welding Development - Stiffener

Process Selection: Due to the number of stiffeners, the process used to weld these stiffeners must have the following characteristics:

- Fast Travel Speeds
- Efficient
- Easy to Adapt to the Situation
- Ease in Operation for the Welding Operator
- Good as Welded Condition



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Gas metal arc welding (GMAW) was chosen as the welding process for this application. The welding torch can be easily mounted to allow the welding operator to adjust the position of the weld torch as the weld is being deposited.

By having the tube sections resting on horizontal rolls, the tube sections can be rotated allowing the welding to be done in a fixed position. This would allow several weld stations to be set up and multiple stiffeners may be welded simultaneously.

Short Circuiting Arc (short-arc) Welding Development: Short-arc welding uses low currents which result in low net heat inputs. The electrode touches (shorts) on the base material and the filler wire is melted off. This process is repeated many times per second. This process resulted in a small 1/8" fillet weld with quite a bit of weld spatter. Post cleaning would be required to remove the weld spatter. Also, the weld operator must constantly maintain correct torch positioning as minor changes will result in unacceptable fillet welds.

Flux-Cored Arc Welding (FCAW) Development: FCAW utilizes tubular wire with granular flux on the inside. This flux, along with shielding gas, provides an inert purge for the weld pool. At a travel speed of 16 ipm, slightly faster than with short-arc, a satisfactory weld can be made. Minor post cleaning is required to remove the flux and results in a clean as-welded appearance. The welding operator has better control over torch position with this process than with short-arc.

Solid Wire GMAW (1G position) Development: Due to the higher moisture content of flux-cored electrodes, solid wire was evaluated. It was found that a satisfactory weld with excellent as-welded appearance can be made at the same travel speeds as with FCAW.

Surface Tension Transfer GMAW Development: With this process, a lower heat input would be achievable than with conventional GMAW. The optimum travel speed was only 12 ipm, lower than with FCAW or GMAW, and uses a shielding gas mixture that is higher in cost than the gas used for solid wire GMAW. Due to the slower travel speeds and higher gas cost, it would be more economical to use the solid wire GMAW process.

Solid Wire GMAW (3G position) Development: The surface tension transfer was welded in the vertical downhill (3G) position. Solid wire GMAW was evaluated in this 3G downhill position. It was found that the travel speed could be increased to 36 ipm.

Welding Process Selection: From the above development, the solid wire GMAW process was selected. This process is nearly two times faster than the others with no post cleaning required.

Joint Detail Selection



Three types of joint details were considered. One being a continuous fillet weld on one side only, the second being a intermittent fillet weld on both sides, and the third being a full penetration groove weld detail.

The groove weld detail was unable to obtain a full penetration weld without applying excessive heat input into the tube wall. With the intermittent fillet welds, expensive equipment would be required and every start and stop has possibilities of weld defects. The continuous fillet weld on one side only was chooses as the best method.

Purge Development

Nitrogen was evaluated and resulted in a satisfactory inside appearance. Nitrogen is less expensive than other inert gases and can be used in liquid form to decrease the time required to purge the tube sections.

Fitting Development

Several attempts were made to weld the stiffeners without tacking. All attempts were unsuccessful. It was found that tacking every 18", approximately 8 equally spaced tacks, would hold the stiffener in place during welding.

WBS #282 Select Stiffener Auto Weld Concept

The stiffeners will be welded using the gas-metal arc welding (GMAW) process with ER308L filler wire. The equipment will use a seam tracker to allow for high travel speeds. The welding position will be in the vertical (3G) downhill position also to increase travel speed and decrease weld size to the required 1/8" fillet. The inside of the tube will be under a 100% nitrogen purge during all tacking and welding.

WBS #283 Welding Procedure

The following paragraphs outline the purging, fitting and welding procedures:

Purging: The entire can section will be purged with 100% nitrogen before any tacking or welding is to take place. Liquid nitrogen will be pumped through a vaporizer and into the can section to obtain adequate purge in a reasonable amount of time. See fitting/purging procedure FPSTIFFENER for details. Due to the large volume of the 65' tube sections, obtaining an oxygen level of less than 0.5%, as stated in previous review meetings, would be impracticable. We will purge to less than 1.0% oxygen level which according to ANSI/AWS D10.11-87, is an acceptable level.

Fitting: The stiffeners will be pulled together using a fitting device similar to the one shown in Sketch 6 (a). The device will pull together the stiffener at the splice by clamping to either side of the splice. This pulling action helps round the tube and illuminate excessive joint gap. The stiffener will be tack welded approximately every



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18" on the opposite of welding. Tack welding on the same side as welding would cause welding problems due to the high travel speeds and would also result in excessive tilt in the welded stiffener. After the stiffener is tack welded in position, the splice will be welded as shown in Sketch 6 (b). The 1" minimum welded length on the top of the stiffener splice is due to 1/4" unwelded length against the tube wall on the fillet welds.

Welding: The welding of the stiffeners will be by two (2) welding units. Each welding unit will consist of a manipulator, wire feeder, power source and joint tracker. Welding will begin at the stiffener splice and continue around the tube and stop at the other side of the stiffener splice. The splice will be located over the tube spiral weld to eliminate welding over the tube spiral weld. The tube section will be turned at a constant speed to provide approximately 35 inches per minute (ipm) at the welding torch. Welding will be in the vertical (3G) downhill position and result in approximately a 1/8" fillet weld. Welding time for each stiffener is approximately 4 1/2 minutes with a completed tube every 4 hours.

WBS #288 Finalize Stiffener Weld Process

Welding will be accomplished using the GMAW process in the vertical (3G) downhill position. This process is capable of welding at travels speeds up to 38 ipm with 35 ipm optimum. Using a joint tracking unit, the welding operator will only have to make minor adjustments during welding resulting in repeatable quality welds at optimum travel speeds.

WBS #290 Automatic Welding Development - Circumferential

WBS #291 Develop Tube-Tube Auto Weld Concepts

As stated in WBS #270, welding autogenously will not provide a full thickness weld joint. Also, welding one (1) pass with filler wire does not provide an acceptable weld. A combination of both process has been developed. Both passes will be from the outside with the first pass being autogenous. This pass provides positive reinforcement on the inside of the tube wall with good bead contour. The second pass using filler wire and provides the required weld joint thickness.

WBS #294 Select Tube-Tube Fit-Up, Purge and Weld Concepts

The welding of the circumferential weld joints, tube-to-tube and tube-to-expansion joints, will be welded using a machine welding unit. This welding unit will be the Dimetrics Gold Track. A two pass welding technique from the outside will be used. The first pass being an autogenous GTAW pass at a travel speed of 4 ipm. This pass will penetrate the weld joint and provide a smooth contour with reinforcement on the inside of the tube. The second pass will use ER308L filler wire at a travel speed of 5 ipm to provide the required 1/8" thickness. The type of shielding gas will be 60% argon - 40% helium and the purge gas will be 100% argon.



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Shielding Gas: Many mixtures of gases were evaluated during weld development. The addition of helium to the shielding gas increases weld penetration resulting in faster travel speeds. By adding 40% helium, the travel speed was increased nearly 30%.

Dimetrics Welding Unit: The Dimetrics welding unit has the capability to weld using standard, pulsed arc or synchronized pulsed arc welding techniques. Pass 1 will use the pulsed arc technique while pass 2 will use a synchronized pulsed arc technique.

The pulsed arc technique is simply a pulse of high weld current followed by a lower background weld current. The advantage of pulsing current over continuous current is that there is a higher current level to melt the base metal and/or filler wire and a lower current level to progress the torch movement. Pulsing keeps the weldment from sagging and lowers the net heat input reducing shrinkage.

Synchronized pulsed arc technique enables the welding operator to continue using pulsed current, but the pulsing is synchronized with the torch oscillation movement. This enables the welding operator to command the extra heat where it is needed and reduces the heat input where it is not required.

The Dimetrics weld unit can be programmed with these specific welding parameters and locked. This will result in repeatable quality weld joints.

Welding Sequence

The following paragraphs outline the procedures for purging/fitting/welding of the circumferential weld joints:

Purging: The two sections to be welded, tube-to-tube or tube-to-expansion joint, will be positioned together. By means of a fitting device developed by CBI, the joint will be rough aligned and held in place. The purge ring will be placed on the inside of the tube wall as shown in Sketch 7. The purge area will be purged with 100% argon as specified in fitting/purging procedure FPCIRCUMFERENTIAL, included in the Master Procedure Package.

Fitting: Fitting will only take place after an adequate purge level has been reached. The fitting device will be used to align the weld joint within tolerances given in FPCIRCUMFERENTIAL. Small manual GTA autogenous "button" weld tacks will be used spaced approximately 4" apart.

Welding: After the weld joint is completely tack welded, the welding track will be placed in position. The track will be positioned 9" from the weld joint. The first pass will be welded using a pulsed arc technique without filler metal at a travel speed of 4 ipm. This weld pass is accomplished by starting at any point along the weld joint and continuing 360° around the tube. The second pass will use a synchronized pulsed arc technique with ER308L filler wire at a travel speed of 5 ipm. This pass may also be started at any point along the weld joint and continue 360° around the tube.



WBS #297 Finalize Tube-Tube Weld Procedure

Finalization of the welding development was carried out in the Houston Weld Lab. Two 18" sections of Northwest Pipe's pre-qualification tube were fit and welded together. The welded results were satisfactory and the welding procedure has ~~be~~ ^{been} finalized.

The temperature of the tube wall along the weld joint was measured and found that a temperature of 250°F, the maximum temperature the inflatable purge ring can withstand, was found approximately 3" on either side of the weld joint. The circumference was measured prior to welding and after welding was complete. It was found that the total circumference shrinkage was approximately 3/8".

Cross sections were taken at four points around the weld joint: on the top of the tube (1G position), on the sides of the tube (3G uphill and downhill) and on the bottom of the tube (4G position). Due to the forces of gravity, the overhead position (4G) had slight underfill as would be expected. The amount of this underfill was only 0.004". The amount of reinforcement on the outside of this section was positive 0.032" with a through thickness value greater than the nominal 1/8" thick tube wall. This satisfies ASME Section VIII Code requirements.

Summary

The welding process for the circumferential weld joints will be the GTAW process. The first pass shall be deposited without filler wire and the second pass will use ER308L filler wire to obtain a full thickness weld joint. A mixture of 60% argon - 40% helium shielding gas will be used to aid in penetration and increase travel speed. A Dimetrics Gold Track welding unit will be used taking advantage of the pulsed arc and synchronized pulsed arc welding techniques. This welding system will perform satisfactory by providing repeatable quality welds

WBS #142 Develop Pump Port Weld

Many weld details were attempted by welding a full penetration weld from the outside only with little or no successes. Although welding a continuous fillet weld on the inside of the pump port is weldable, there exist several problems. The welder must weld from within the tube and the detail requires at least a 1/4" projection on the inside of the tube wall. Due to these problems, a joint detail allowing for the inside pass to be welded while the welder is on the outside of the tube has been developed.

The pump port neck will have a 1/16" land with an outside bevel of 60°. The inside will be welded first using the gas-tungsten arc welding (GTAW) process using no filler metal, i.e. autogenous. This detail can be seen in Sketch 1. The purpose of this weld pass is to penetrate through the 1/16" land and provide sufficient weld metal for subsequent outside passes. After a satisfactory visual inspection, the second pass will be deposited using



autogenous GTAW from the outside. The purpose of this second pass is to assure complete fusion of the weld joint. The final pass will be deposited from the outside using GTAW with the addition of ER308L filler metal to obtain the required reinforcement.

Automatic Welding Process

Dimetrics Welding Unit: The Dimetrics welding unit can be modified to fit within the pump port and weld the inside and outside passes. The weld operator would still be required to manipulate the weld torch in line with the weld joint. Due to the small diameter of the pump ports, a method of joint tracking may be required.

Two methods of joint tracking were considered. One being a cam follower system. This system would require extensive modifications to the weld unit and required exact joint configurations. The second method of joint tracking would be by using video to view the weld joint. This method would be costly and due to the number of pump ports, would not be cost effective.

Tube-Sheet Welder: A tube-sheet welder was evaluated, manufactured by Dimetrics, and was found that it would not be suitable for our needs. It was determined to modify the existing Dimetrics Gold Track welding unit and manually control the weld torch positioning.

Finalization of Weld Development

Finalization of the welding development was carried out in the Houston Weld Lab. A mock up of the pump port was welded to a section of stiffened tube. The pump port consisted of a 10" diameter stainless steel pipe machined to 0.120" in thickness. This pump port was installed between two stiffeners as shown in Sketch 4. Measurements were taken before and after welding to analyze shrinkage and distortion.

Results: The Dimetrics Gold Track welding unit was modified and initially tried to weld the inside pass. After placing all the required components of the weld unit, it became difficult to see the weld joint. It was determined that in order to weld this joint with automatic equipment, a type of joint tracking device shall be used. Due to the limited number of these pump ports, it would be more economical to weld these joints by hand.

|| hand
welded
ports

The decrease of the diameter due to weld shrinkage was approximately 1/4" measured from the centerline of the pump port to the opposite of the tube wall. The longitudinal shrinkage of the tube was zero after the pump port was installed. Cross sections were cut and etched from the pump port and show complete penetration and fusion.

Recommended Procedure



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The following paragraphs detail each step required for installation of the pump port to a stiffened can section:

Reinforcing Ring: The reinforcing ring is 1/4" thick and 1 1/4" wide manufactured from A240 type 304L material. The ring will be tacked and welded in position while the can section is in the stiffener welding station under a 100% nitrogen purge. After the stiffeners are completely welded to the can section, the reinforcing ring will be positioned according to contract drawings, i.e. located at midpoint between two (2) stiffeners and midpoint between adjacent spiral tube welds.

The reinforcing ring will be welded using WPS-ER308L/GMA. This procedure uses the gas-metal arc welding (GMAW) process with ER308L filler wire. A stitch 1/8" fillet weld will be on both sides of the reinforcing ring. The welds are to be 2" in length with 6" between centers of adjacent welds. WPS-ER308L/GMA can be seen in the Master Procedure Package.

Drilling: The stiffened can section with reinforcing ring will be moved from the stiffener welding station to the pump port welding station. A jack/purge device, illustrated in Sketch 2, will be placed within the tube. The jack/purge device will apply outward pressure to the tube wall to minimize shrinkage due to welding. The hole for the pump port will be drilled and the edges cleaned and prepared for welding.

Fitting: To aid during the fitting operation a fitting device, illustrated in Sketch 3, is connected to the jack/purge device. The pump port is placed in position and the fitting device is used to push the pump port against the tube wall. If the maximum allowable gap from fitting/purging procedure FPPUMPPORT, located in the Master Procedure Package, is exceeded, the pump port shall be removed and mitered to obtain a satisfactory fit. Tacking of the pump port will consist of small autogenous GTA "button" weld tacks on the inside of the pump port. Each weld tack shall be manually back purged with 100% argon per FPPUMPPORT.

Welding: As stated above, welding will consist of three (3) weld passes using WPS-ER308L/PORT, included in the Master Procedure Package.

The outside of the pump port will be purged using plastic bags or other suitable means to obtain adequate purge level. The inside pass will be welded using a manual autogenous GTAW process. The weld current will be pulsed arc to allow better control of penetration without excessive heat input to the weld joint.

After completion of the first inside weld pass, the outside purge will be removed and a visual inspection will take place. The 60° bevel on the outside allows for this visual inspection. Any indications of non-fusion or any areas that may cause incomplete fusion will require repairing before welding of the second pass begins.



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Any repair areas found during the visual inspection will require addition of the 100% argon purge. Using the same welding technique, another weld pass will be deposited from the inside at every repair area. The visual inspection will be repeated until no suspect areas exist.

The opening of the pump port will be covered and the purge area of the jack/purge device will be purged with 100% argon per FPPUMPPORT. The first outside pass will be welded with the same parameters as the inside pass, i.e. manual autogenous GTAW. This second pass will assure complete fusion with no trapped volumes. The second outside pass will use standard GTAW techniques using ER308L filler wire to obtain a smooth contour with adequate reinforcement.

Summary

The reinforcing ring will be welded using WPS-ER308L/GMA under a 100% nitrogen purge at the stiffener welding station. A jack/purge device will be placed within the tube to minimize shrinkage before drilling and during welding. After the first inside weld pass, a visual inspection will take place to assure complete fusion. The pump port will be welded using WPS-ER308L/PORT which is a manual GTAW process. These welding procedures are included in the Master Procedure Package. Sketch 5 shows a complete detail of the pump port.

Repair Procedures

WPS-ER308L/REPAIR will be used for welded repairs, not including structural components, that may not be welded using existing WPS for the specific weld joint. This procedure is a combination WPS for both GMAW and GTAW. GTAW may be used for all welded repairs while GMAW may only be used for welded repairs to the stiffener attachment welds only.

Gas Tungsten Arc Welding (GTAW) Repairs

All repairs may be made with or without filler wire. There are three (3) types of welded repairs: general repairs, full thickness repairs and repairs to the first pass of the pump port.

General Repairs: All general repairs may be made using GTAW. Either continuous or pulsed current techniques may be used. If continuous current is used for repairs, WPS-ER308L/PORT may be substituted in place of WPS-ER308L/REPAIR. Welding with or without filler wire may be employed.

Full Thickness Repairs: A full thickness repair would be any repair that would require the full thickness of the base materials to be welded, i.e. burn throughs. These repairs shall be welded with manual GTA using a copper back-up bar attached to a jack device. This jack device is shown in Sketch 8. The area for welding shall be cleaned by grinding



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or chipping to allow manipulation of the weld torch. The repair jack shall be placed within the tube, with the copper bar flush to the inside of repair area, to help reduce shrinkage. No purge gas is necessary when the copper is used as a back-up bar. The repair shall be welded using WPS-ER308L/REPAIR with ER308L filler wire.

Repairs to Pass 1 of the Pump Port: Any suspect area found during the visual inspection after the first pass is deposited in the pump port shall be repaired using either WPS-ER308L/PORT or WPS-ER308L/REPAIR. A manual autogenous GTA pass shall be deposited on the inside of the pump port in the suspect area. After the repair is completed, the area shall be visually inspected. This process is completed until no suspect areas exist.

Gas Metal Arc Welding (GMAW) Repairs:

The only welded repairs that the GMAW process may be used will be to the stiffener attachment welds.

Structural Welding Procedures

Three structural welding procedures have been written for any welding that may take place on structural components outside the pressure boundary, i.e. supports. These procedures all use the Shielded Metal Arc Welding (SMAW) process.

E7018: This procedure is for welding of carbon steel material together. Carbon steel material consists of A36, A283 gr. C, A516 or any material classified as P-1, Group 1 or 2 by the ASME Section IX Code.

E308L: This procedure is for welding of stainless steel material together. Stainless steel material consists of A240 type 304L, A240 type 304 or any material classified as P-8, Group 1 by the ASME Section IX Code.

E309: This procedure is for welding of stainless steel material to carbon steel material. Typical materials are shown above.



Supports

There are two (2) types of supports for the LIGO project. One being Fixed and the other being Guided. These supports will be manufactured by outside vendors with attachment to the tube at installation by CBI.

Fixed Supports: The fixed supports have two different welds to be made during installation. The first type of weld are the support legs to the support stiffener. This weld falls out of the pressure boundary and may be welded using a structural procedure. This weld may be made using either WPS-ER308L/GMA or WPS-E308L/STRUCT.

The second type of weld will take place during fabrication. A gusset must be welded to the tube wall against the support stiffener. This weld is within the pressure boundary and must utilize a back purge. WPS-ER308L/GMA will be used to weld this gusset to tube weld while the tube is in the stiffener welding station under a 100% nitrogen purge.

Guided Supports: The guided supports use bolted connections that require a small amount of weld metal. These welds fall out of the pressure boundary and may be welded using a structural procedure. This weld may be made using either WPS-ER308L/GMA or WPS-E308L/STRUCT.

To use the GMAW process, which is faster than the SMAW process, a wire feeder must be within 15 feet from the weld to be made. Although the GMAW process is faster, it may be more efficient to use the SMAW process as a welding lead may run several hundred feet.

WBS #710 Filler Wire Evaluation

Within Specification 1100007, Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products, it was stated that the use of filler wire is prohibited on welds exposed to vacuum. The total hydrogen content of base metals and filler wire was evaluated in as rolled and baked condition.

Total Hydrogen Analysis

There are two ways to measure the hydrogen in weld material. One being the diffusable hydrogen test and the second being the total hydrogen test. Diffusable hydrogen will be nearly zero as austenitic matrix of stainless steels will not allow the hydrogen to diffuse from the weld metal.

Total hydrogen was measured from various materials and summarized as follows: As rolled plate material (A240 type 304L) had a hydrogen content of 4 ppm. Baked plate material, per Caltech Specifications, had hydrogen levels of approximately 1 ppm. The same results were true with ER308L filler wire. The baking indeed reduces the hydrogen level by a factor of 4.

We did not see such a consistent change



Total hydrogen was also measured from weld samples. Welds made using only autogenous were nearly the same hydrogen level as welds made using a two pass procedure with the second pass using ER308L. The weld sample entirely of ER308L, duplicating a repair, was nearly two times higher than the others.

After discussions with Caltech at the PDR, it was determined to qualify the use of filler wire by cleaning and baking the filler wire and welding outgas coupons for evaluation. No formal result has been received from Caltech as to the outcome of the test, but preliminary results are favorable to the use of cleaned and baked weld wire. CBI has contacted several filler wire suppliers to obtain quotes for the cost of supplying wire in the cleaned and baked condition. The ESAB Group and Lincoln Electric Co. have been contacted to estimate the cost to supply 30,000 pounds of ER308L, 0.035" diameter weld wire. Due to the high cost of the cleaned and baked weld wire, a second set up outgas coupons were welded using standard weld wire and are currently being evaluated.

Cleaned and Baked Filler Wire

The procedure used to clean and bake ER308L filler wire can be found in WMS-ER308L/COUP. This procedure was complete in out Houston Weld Lab. This procedure consisted of spooling the wire through Scotch Brite, Mirachem 500 cleaner/degreaser and followed by Scotch Brite. The wire was then baked per Specification 1100007 section 2.2. After bake, the wire was re-spooled through Scotch Brite. The cleaning speed at which this operation was carried out was approximately 40 ipm. To try to duplicate the cleaning procedure complete in the Houston Weld Lab, the suppliers were given the procedure used by CBI.

Results from The ESAB Group: ESAB stated at the beginning that this was a procedure they had never attempted. They stated that the slow cleaning speed, 40 ipm, would create problems. Listed below are several problem areas that ESAB came upon:

Cleaning: Due to the specialized cleaning procedure required, ESAB would have to set up a new specialized cleaning station.

Bake: The Caltech Specification requires that if the oven for the bake was fuel fired, combustion products shall not come into contact with the baked material. The only type of ovens ESAB has are fuel fired. In order to comply with the specification, ESAB would have to purchase bags to place the weld wire in during the bake to keep them from contacting combustible products. Standard size bags are too small for the spools of wire so specialized bags would have to be made for this procedure. Also, stainless baskets would have to be made for the bake.

Re-Cleaning: Again, a specialized cleaning station would have to be set-up.



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Due to the slow cleaning speed, 40 ipm, the output of cleaned and baked wire would be approximately two pounds per day. The total time required to supply the requested amount of weld wire would be tens of years. The cost of the wire would be \$238 per pound and the total cost of the weld wire for the job, excluding any wire to be used by expansion joint manufacturers would be \$7,140,000!

Alternate cleaning process: The ESAB Group also supplied an estimate for the process using the optimum cleaning speed of their equipment. This cleaning speed was approximately 200 feet per minute, approximately 60 times faster than was done in the Houston Weld Lab. At this cleaning speed, weld wire could be supplied faster than the rate that would be required at a cost of \$37 per pound, total of \$1,110,000.

Alternate cleaning tech for filler wire

Standard filler wire: To purchase standard "off the shelf" ER308L, 0.035" diameter, weld wire from The ESAB Group, it would cost \$4 per pound. The total cost for weld wire would be \$120,000.

Results from Lincoln Electric Co.: Lincoln Electric stated a "no-bid". They would not quote a price for weld wire in this condition.

Wire Feed Characteristics

Through conversations with filler wire manufacturers, the cleaned and baked wire was evaluated for wire feed characteristic using the GMAW process. It was found that the cleaned and baked wire would not feed correctly in the GMAW process. The wire would, however, feed satisfactory for the GTAW process. The reason being that the wire must only feed a length of two (2) feet for GTAW. Semi-automatic GMAW must feed through a 12 foot welding torch. Also, during the GTAW process, the filler wire does not carry the welding current as it does in the GMAW process.

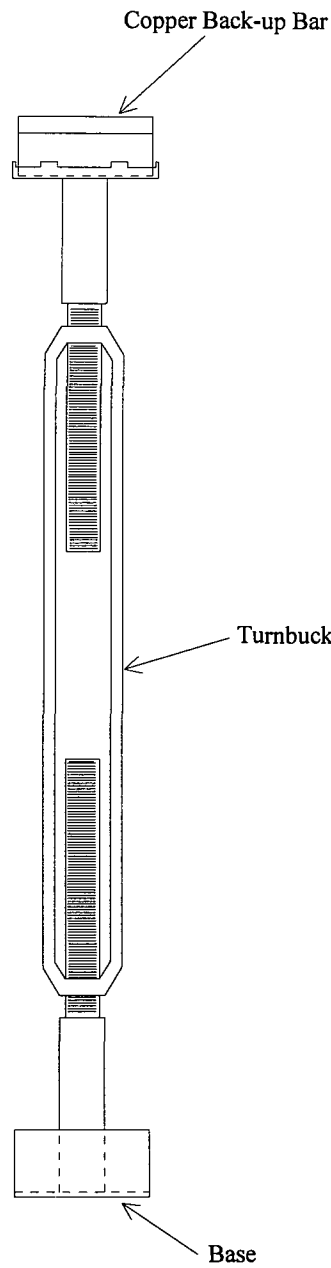
Summary

The cost comparison can be seen in Table 1:

	<u>Cost per pound</u>	<u>Total Cost</u>
Standard weld wire	\$4	\$120,000
Cleaned per WMS-ER308L	\$238	\$7,140,000
Alternate cleaning	\$37	\$1,110,000

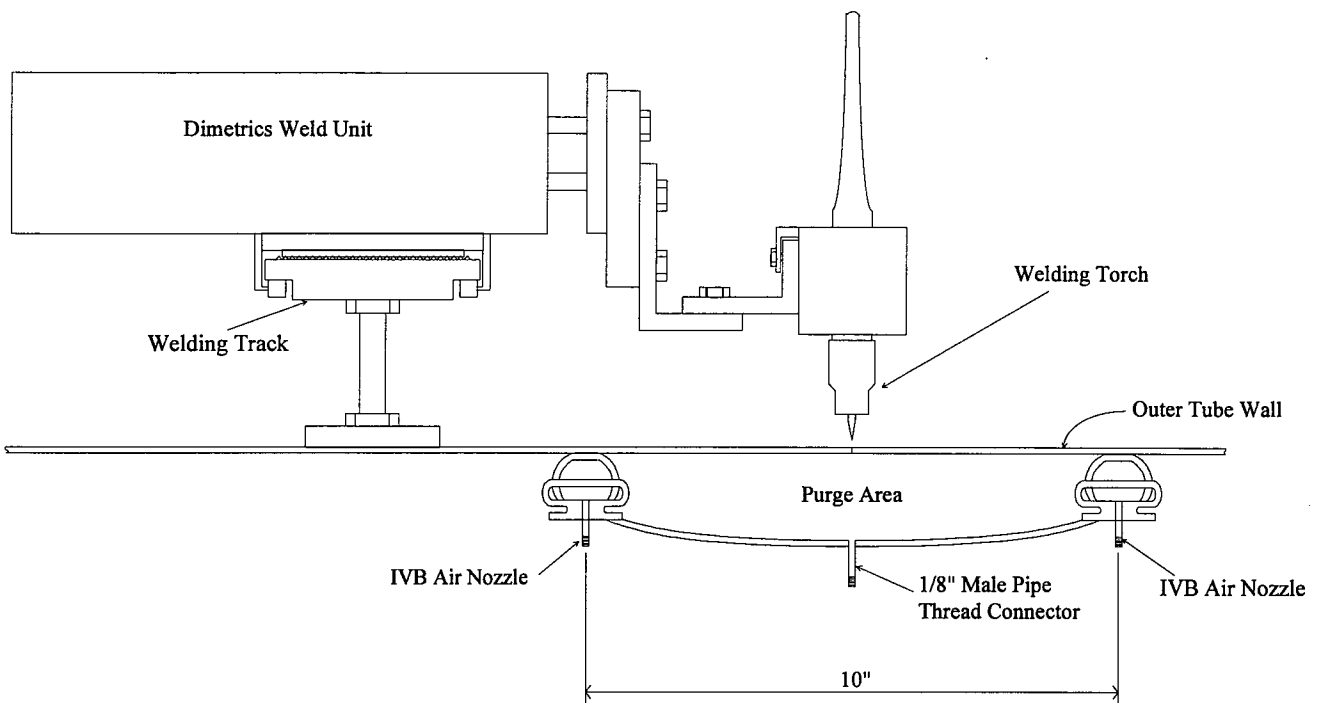
Table 1: Weld Wire Cost Comparison


As can be see in Table 1, the additional cost of baking and cleaning the weld wire is 60 times the cost of standard wire. Even with altering the cleaning procedure, the cost is still 9 times the cost of standard wire.

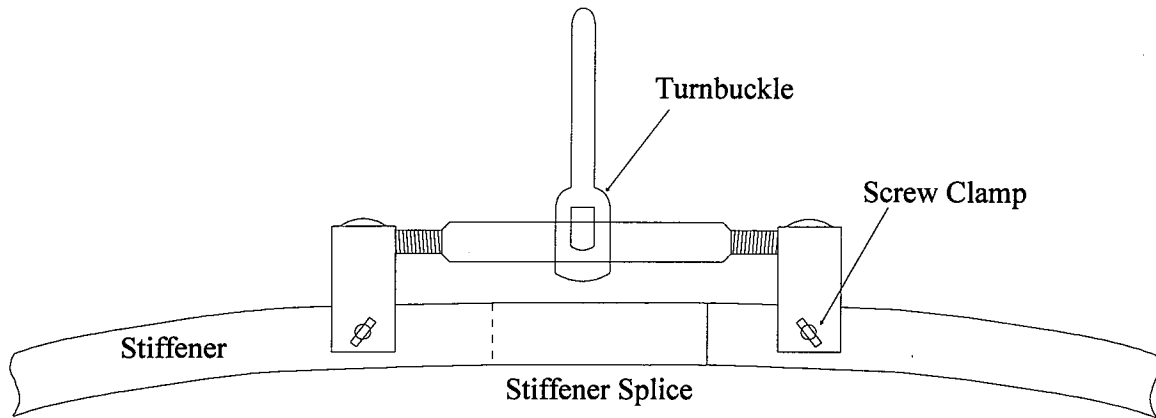


CORPORATE WELDING

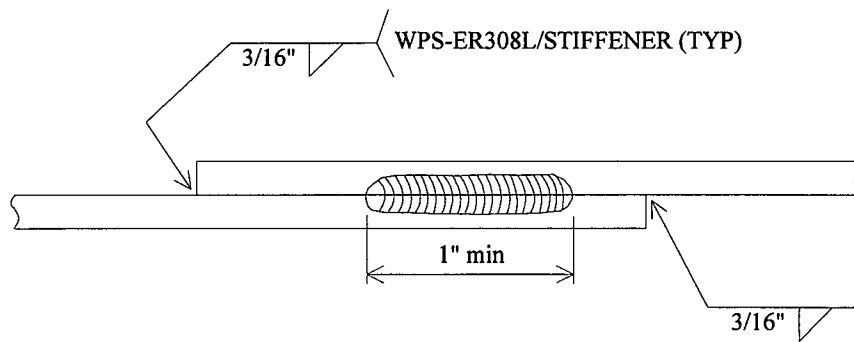
RWP	3/9/94	LIGO	930212	
MADE BY	DATE	JOB NAME	CONTRACT NO.	
JACK/PURGE REPAIR DEVICE			8	0
			SKETCH NO.	REV




 CORPORATE WELDING	RWP	3/8/94	LIGO	930212
	MADE BY	DATE	JOB NAME	CONTRACT NO.
	PURGE RING			7 0
				SKETCH NO. REV

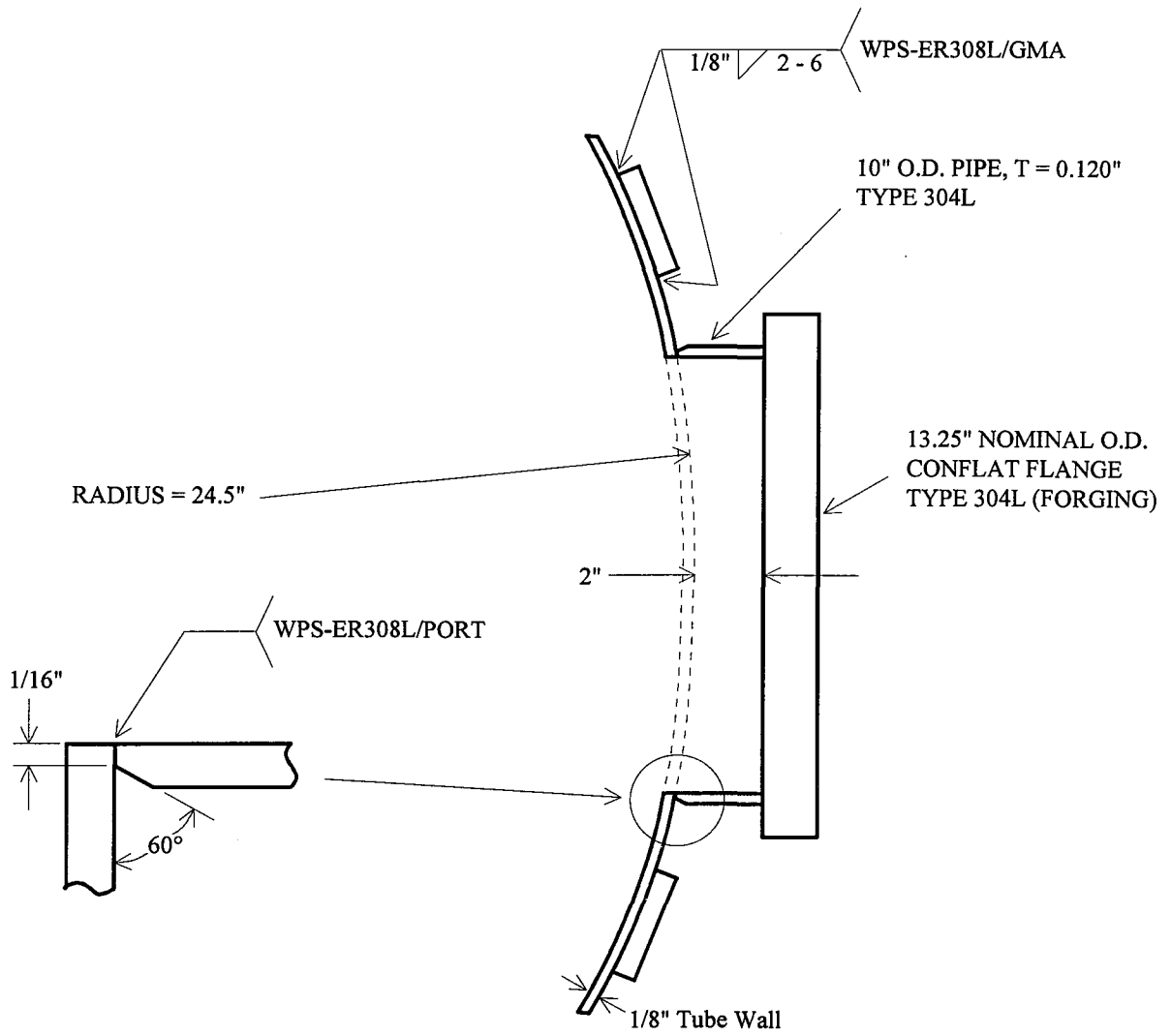



Stiffener Fitting Device
(a)

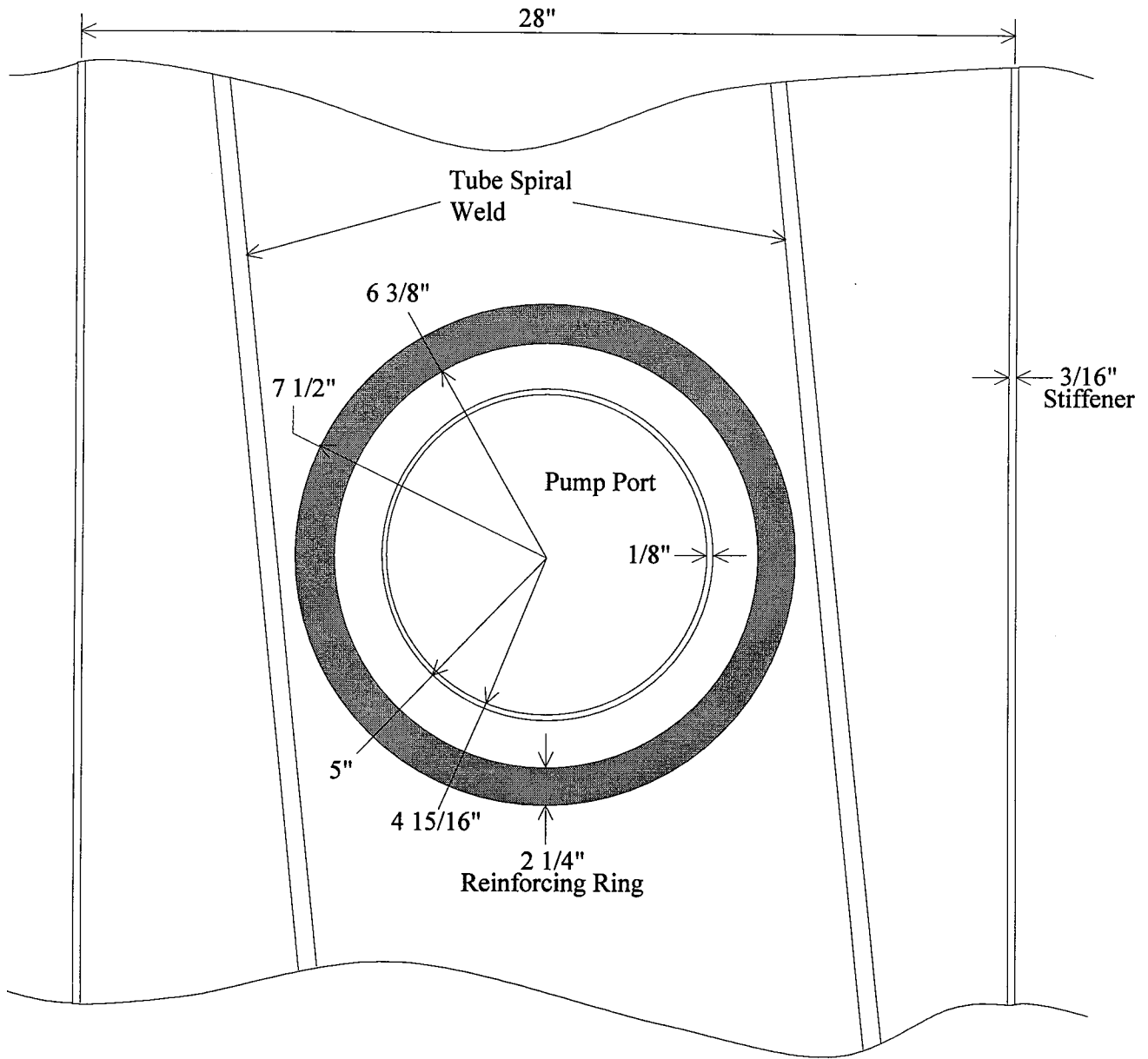


Splice Weld Details
(b)

 CORPORATE WELDING	RWP	3/8/94	LIGO	930212	
	MADE BY	DATE	JOB NAME	CONTRACT NO.	
	STIFFENER FITTING DEVICE			6	0
				SKETCH NO.	REV

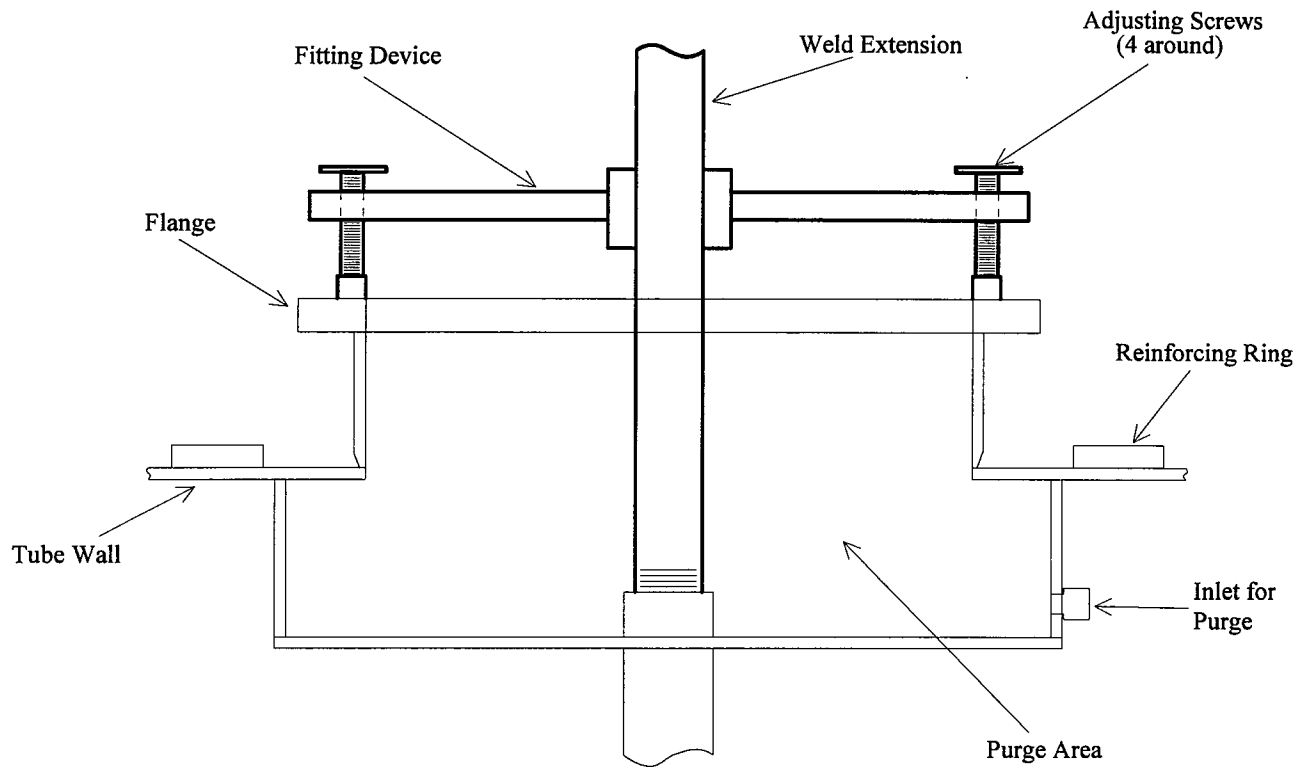


 CORPORATE WELDING	RWP	3/8/94	LIGO	930212
	MADE BY	DATE	JOB NAME	CONTRACT NO.
	PUMP PORT WELD DETAILS			5 0
			SKETCH NO.	REV



CEI
CORPORATE WELDING

RWP	3/8/94	LIGO	930212	
MADE BY	DATE	JOB NAME	CONTRACT NO.	
PUMP PORT LAYOUT			4	0
			SKETCH NO.	REV



CORPORATE WELDING

RWP	2/25/94	LIGO	930212	
MADE BY	DATE	JOB NAME	CONTRACT NO.	
FITTING DEVICE			3	0
			SKETCH NO.	REV

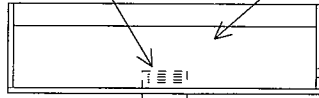
Adaptor for Weld Extension

Purge Area

Inlet for Purge

Turnbuckle

Base



RWP

2/25/94

LIGO

930212

MADE BY

DATE

JOB NAME

CONTRACT NO.

JACK/PURGE DEVICE

2

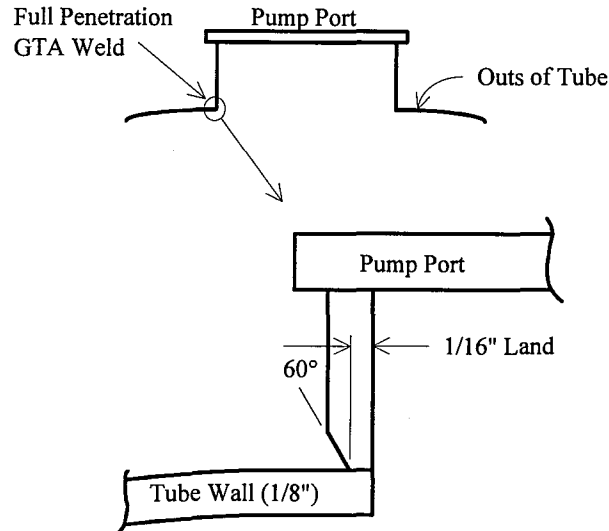
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SKETCH NO.

REV

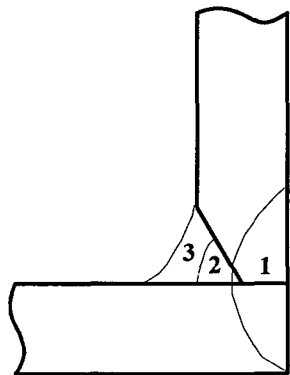
Pump Port Welding Details:

Pump port neck to have 1/16" land with 60° bevel.




Welding Procedure:

All welding to be done using manual gas-tungsten arc welding (GTAW) process.
 Pass 1 to be from the inside welded without filler metal. The bevel allows for a visual inspection to assure complete fusion.
 Pass 2 to be from the outside welded without filler metal.
 Pass 3 to use ER308L filler metal to obtain required reinforcement.



Pass 1: Autogenous from inside of port
 Pass 2: Autogenous from outside of port
 Pass 3: ER308L filler metal from outside of port

 CORPORATE WELDING	RWP	3/8/94	LIGO	930212	
	MADE BY	DATE	JOB NAME	CONTRACT NO.	
	PUMP PORT WELDING PROCEDURE			1	0
				SKETCH NO.	REV



LIGO PROJECT
WBS 300
CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

- 1.0 Project Organization
 - 1.1 General
 - 1.2 Overall Project Team
 - 1.3 On-Site Construction Organization
 - 1.4 Responsibilities

- 2.0 Contract Administration
 - 2.1 General
 - 2.2 Project Procedures Manual including:
 - Site Security Insurance
 - Project Documentation Accounting/Audits/Invoicing
 - Substance Abuse Program EEO Program
 - Minority Subcontracts Program Labor Policy
 - Patents / Inventions / Rights Changes/Modifications
 - Certifications Local Permitting
 - Termination/Liability

- 3.0 Procurement Plan
 - 3.1 General, including for:
 - Program/ P.O. Provisions Major Suppliers
 - Construction Equipment Notifications, Consent, Approvals
 - Authorization Expediting
 - Pricing & Analysis Requirements Value Engineering
 - Use of Government Facilities Damage & Loss Claims
 - Supplier Corrective Action Requests
 - Disposition of Rejected or Damages Incoming Supplies
 - Stop Work Order Federal Acquisition Regulations
 - Government Furnished Equipment/Inventory
 - Release of Lien Certification of Compliance
 - Termination/Liability Subcontract Provisions
 - Major Subcontract Areas Federal Notification

- 4.0 Security
 - 4.1 Fabrication Site
 - 4.2 Erection Site
 - 4.3 Off Shift Security

- 5.0 Master Procedures List / Plan
 - 5.1 Purpose
 - 5.2 Content
 - 5.3 Control



LIGO PROJECT
WBS 300
CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

- 6.0 Mobilization
 - 6.1 General & Erection Drawings
 - 6.2 Fabrication Facility (Hanford & Livingston Sites)
 - 6.3 Erection Equipment
 - 6.4 Special Equipment/Tooling
 - 3.4.1 Fabrication
 - 3.4.2 Erection
 - 3.4.3 Testing
 - 3.4.4 Cleaning (General)
 - 6.5 Overall Site Coordination
 - 6.5.1 Utilities
 - 6.5.2 Road Access
 - 6.5.3 Shared Handling Equipment

- 7.0 Fabrication Plan
 - 7.1 General

- 8.0 Transport
 - 8.1 General

- 9.0 Erection Plan
 - 9.1 General
 - 9.1 Placement
 - 9.3 Weather Protection
 - 9.4 Clean Room
 - 9.5 Alignment
 - 9.6 Fit & Weld Process
 - 9.7 Testing & Inspection
 - 9.8 Cleaning
 - 9.9 Sealing & Security

- 10.0 Quality Plan, ISO 9000

- 11.0 Safety Plan
 - 11.1 Safety Policy Statement
 - 11.2 Safety Responsibilities
 - 11.3 Safety Program



LIGO PROJECT
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CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

- 12.0 Environmental Plan
 - 12.1 Site Documentation/Contamination
 - 12.2 Stormwater Permits
 - 12.3 Hazardous Materials Handling
 - 12.4 Regulatory Inspections
 - 12.5 Local/State Permits
 - 12.6 Surface Drainage/Outfall Discharges
 - 12.7 Sanitation
 - 12.8 Training & Documentation
 - 12.9 Emergency Communications
 - 12.10 Spill Prevention
 - 12.11 Chemical Hygiene Plan
 - 12.12 Fuel Storage/Handling

- 13.0. Schedule & Cost Engineering
 - 13.1 CPM Software
 - 13.2 Update Timing
 - 13.3 Progress Reporting
 - 13.4 Submittal Control
 - 13.5 Weekly Schedule Meetings
 - 13.6 Short Term Schedules
 - 13.7 Earned Value/Progress Payment Evaluation
 - 13.8 Dual Site Coordination
 - 13.9 WBS

- 14.0 Commissioning Activities/Plan
 - 14.1 Precommissioning
 - 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

- 15.0 Demobilization
 - 15.1 Equipment
 - 15.2 Buildings
 - 15.3 Personnel

Appendix: Proposal For The Use OF Differential Global Positioning Methods



1.0 PROJECT ORGANIZATION

1.1 GENERAL

The project management plan is a combination of the efforts of CBITS, CBI Na-Con, and CB&I Corporate Services (Construction, Welding, Testing).

Some of the individuals on the project team are 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 is responsible for providing the Construction Plan and the revised 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: Construction planning is complete, but will remain open to lessons learned through the design and qualification testing. Preparation has been 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: Key project procedures and schedules have been developed addressing each area of concern for construction, the balance of administrative type procedures will be developed at award of the Option.
- Pre-selection of major suppliers: Pre-qualification of key vendors and 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: The QA program is tailored to the needs of the vacuum tube work as well as the system and general contracting portions of the overall LIGO Project. The QA Manual is based on the requirements of ISO 9000 and was submitted to Caltech earlier, under separate cover.

have not seen this



- 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 are essential.
- Adoption of aggressive Small & Minority Business Plans and Subcontracting Plans to encourage and optimize minority, small, and women owned businesses throughout the program: Site specific procedures and plans will be drawn up when the Option is exercised.
- 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. Budget pricing is still driving the estimate, at the completion of the qualification tests, firm pricing will be solicited, based on the learning experience.

*Not well
evident
in 200
designs*

1.2 Overall Project Team

The Project Team for the Option is organized as shown on Figure. 1.0. The team is directed by the Project Manager who will report directly to the Senior Vice-President and Divisional General Manager of CBI Na-Con in Houston. 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

The basic project management of the program will be administered from the Houston Office. CBI will assign 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 from the Hanford site to the Livingston site. This will allow continuity in the program.

1.4 Responsibilities

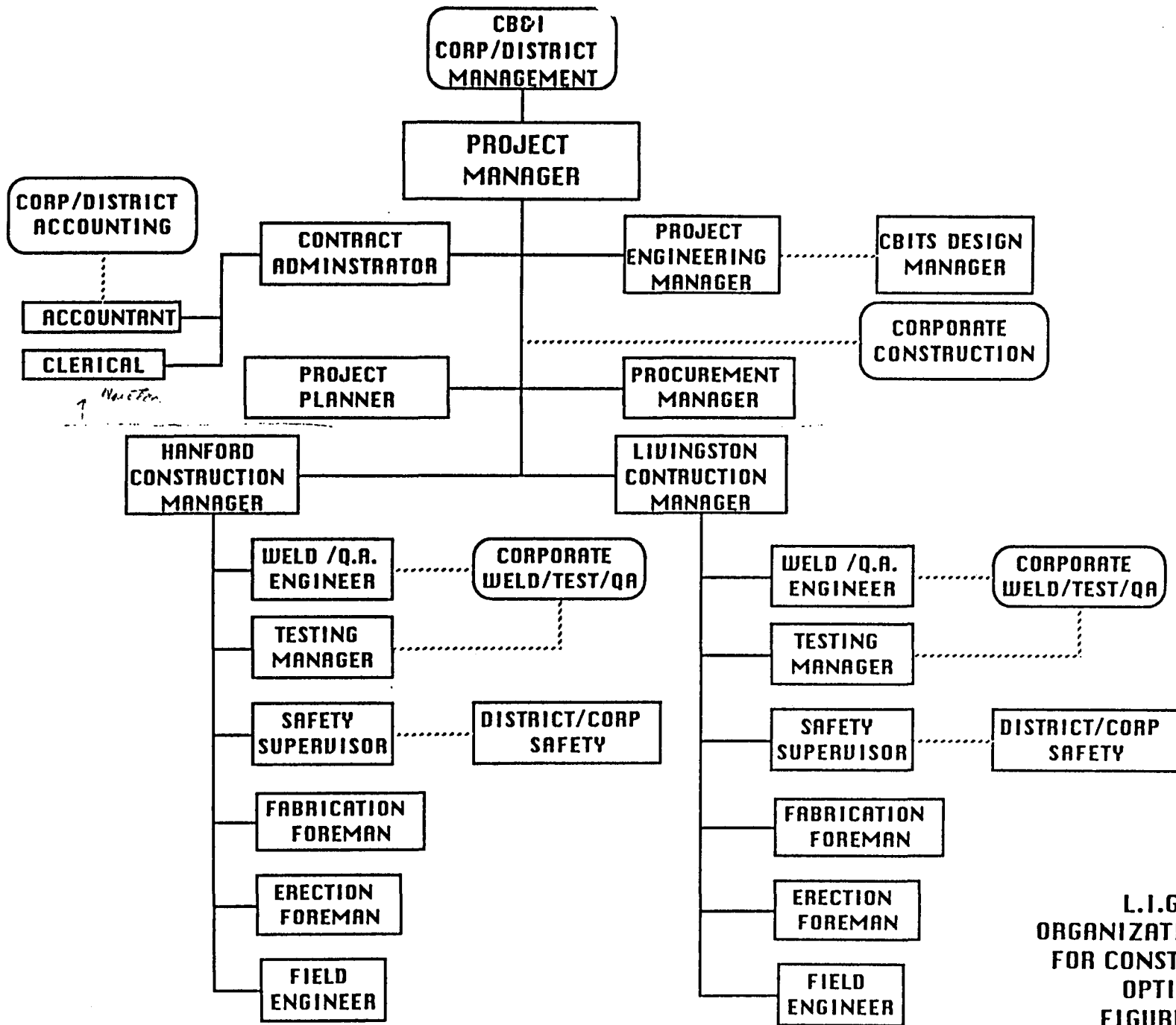
Individual responsibilities of the Project Team have been developed and tailored around the unique needs of the LIGO Project. An example of the type of write up for responsibilities is given below for a few of the key team members.



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.
- 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.



L.I.G.O.
 ORGANIZATION CHART
 FOR CONSTRUCTION
 OPTION
 FIGURE 1.0
 OCTOBER 26, 1993



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 to 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.



LIGO PROJECT
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CONSTRUCTION PLAN
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- 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 and manage the site safety program.
- Is responsible for construction and security 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.

1.4.4 Project Quality Assurance/Quality Control Manager

The Project Quality Control Manager is responsible for overall workmanship and quality control on the project and for the recording, documentation, and verification of all examinations and testing performed both on-site and off-site, by Subcontractors and Vendors. The QA/QC Manager is a member of the Project Team on all project related matters. He is responsible to CBI's Corporate QA/QC Corporate Officer on a technical basis. His duties and responsibilities include:

- Supervision and verification of all on-site QC procedures.
- On-site inspection of all material as required to ensure compliance with CBI procurement specifications as well as contractual requirements.
- Supervision of on-site welding quality through the use of previously established welding procedures and welder qualifications as required by the specifications, codes, and CBI requirements.
- Responsibility for all on-site non-destructive examination and documentation as well as general welding instruction, testing, and quality.
- Serving as first level management to whom the QA/QC technicians and inspectors report.
- Preparation of final inspection and testing reports for the completed facility.
- Arrange for and review subcontractor/supplier inspection programs, inspections, and quality control procedures as required.

1.4.5 Project Field Engineer

The Project Field Engineer is responsible for field engineering, and planning, on the project. After familiarization with the project during the design stage, he will locate at the site. His duties and responsibilities include the following:

- Serves as first level manager to whom the field survey team reports.



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- Maintains up to date drawings, specifications and bill of materials for the project.
- Monitors and reports on actual engineering progress versus scheduled progress.
- Coordinates requests for assistance from other field personnel concerning field changes, inspection, testing, and construction layout.
- Responsible for assigning all on-site engineering functions such as layout, dimensional checks and inspection assistance to the field engineers.
- Is responsible for all as-built drawing and records.
- Reviews and monitors the flow of project engineering data.
- Insures that appropriate engineering instructions are issued to the field engineers.

The Project Field Engineer will be directly accountable to the Project Manager. He will be indirectly accountable to the Project Engineering Manager.

1.4.6 Subcontracts Manager

The subcontracts Manager will report directly to the Project Manager. His responsibilities include:

- Award and administration of all subcontracts.
- Input of subcontract production information into overall schedule and project reports.
- Monitor progress of all subcontractors.
- Verify and approve all invoices.
- Handling of contract changes.
- Manage subcontract efforts in achieving and monitoring disadvantaged minority and women-owned businesses, etc., in accordance with applicable federal and corporate rules, regulations, and guidelines.



- Coordinate audits of subcontractors records for cost or pricing data and compliance to FAR's as required.
- Assist the Project Manager in matters affecting the definition of the contract and in negotiations of any contract changes.

1.4.7 Cost and Scheduling Engineer

The Cost and Scheduling Engineer reports directly to the Project Manager. His duties and responsibilities include:

- Prepare and maintain cost analysis for the projects.
- Prepare and maintain overall project schedule including CPM evaluations.
- Monitor and report on actual progress versus scheduled progress.
- Develop detailed work schedules as required and monitor progress.
- Provide schedule and cost data and reports as required for Caltech.
- Maintain scheduling/costing software system.
- Provide CPM progress for progress payment system.

1.4.8 Procurement/Traffic Manager

The Procurement Manager reports directly to the Project Manager. His duties include:

- Coordinate and monitor CBI purchasing and expediting to insure that material and equipment deliveries are compatible with the project schedule.
- Develop local sources of materials, tools, and equipment, execute appropriate purchases and insure passage of invoices for payment.
- Responsibility for receiving, unloading, and storing materials and equipment at the job-site and coordinating the use of warehouse facilities.



- Develop sources and procure contract hardware, including expediting and coordination with QA/QC for vendor inspection.
- Responsible for the material control system for the project.
- Responsible for transportation management of all shipments from fabricators to the site.

1.4.9 Project Administrator

The Project Administrator reports directly to the Project Manager. his duties include:

- Establishment and management of on-site project office administrative, clerical and payroll staff.
- Establishment of on-site controls and administrative procedures and Contract Handbook.
- Maintains site personnel records.
- Maintains contract files.
- Executing site payroll.
- Coordinate progress reports and other information required by Caltech for the project reports.
- Coordinate company progress reports.
- Assist the Project Manager in matters affecting the definition of the original contract and in negotiations of any contract changes.
- Responsible for Contract Administration

2.0 CONTRACT ADMINISTRATION

2.1 GENERAL



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Upon exercising the Construction Option by Caltech, CBI will provide specific plans and project procedures to address the contract requirements for contract administration, this will include:



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- 2.2 Project Procedures Manual addressing the following:
 - 2.2.1 Site Security
 - 2.2.1.1 Entrance/Egress/Badging
 - 2.2.1.2 Fencing
 - 2.2.3.3 Specific Secure Areas
 - 2.2.2 Insurance
 - 2.2.2.1 Workman's Compensation
 - 2.2.2.2 Liability
 - 2.2.2.3 Bonds
 - 2.2.2.4 All Risk Insurance
 - 2.2.3 Project Documentation
 - 2.2.3.1 Correspondence
 - 2.2.3.2 Requests for Equitable Adjustment
 - 2.2.3.4 Contract Specific Requirements
 - 2.2.3.5 Technical Documents
 - 2.2.3.6 O & M Manuals
 - 2.2.3.7 Reports
 - 2.2.3.8 Daily Logs
 - 2.2.4 Accounting/Audits/Invoicing
 - 2.2.4.1 Records
 - 2.2.4.2 Banking & Credit
 - 2.2.4.3 Sales & Use Taxes
 - 2.2.4.4 Invoice Approvals
 - 2.2.4.5 Invoicing Procedures (DD250)
 - 2.2.4.6 Payment Office
 - 2.2.4.7 Audits
 - 2.2.4.7.1 External
 - 2.2.4.7.2 Internal
 - 2.2.4.8 Change Justifications/Back Up
 - 2.2.5 Substance Abuse Program
 - 2.2.5.1 Standard Operating Procedures
 - 2.2.5.2 Forms
 - 2.2.5.3 Screening/Testing
 - 2.2.5.4 Employment Records
 - 2.2.5.5 State Requirements
 - 2.2.5.6 Drug Free Workforce Rule
 - 2.2.6 EEO Program
 - 2.2.6.1 Minority Participation
 - 2.2.6.2 Female Participation
 - 2.2.6.3 Recruitment Sources/Records/Notices



- 2.2.7 Minority Subcontracts Program
 - 2.2.7.1 Minority Owned Business
 - 2.2.7.2 Women Owned Business
 - 2.2.7.3 Small Business & Small Disadvantaged Business
 - 2.2.7.4 Labor Surplus Area Concerns
- 2.2.8 Labor Policy
 - 2.2.8.1 Payroll
 - 2.2.8.1.1 Site Agreements (i.e. @ Hanford, Davis Bacon Rate Application)
 - 2.2.8.1.2 Labor Records
- 2.2.9 Patents / Inventions / Rights
- 2.2.10 Changes/Modifications
- 2.2.11 Certifications
 - 2.2.11.1 Non-Segregated Facilities
 - 2.2.11.2 Clean Air & Water
 - 2.2.11.3 Anti-Kickback Compliance
 - 2.2.11.4 Lobbying
 - 2.2.11.5 Debarment
 - 2.2.11.6 National Science Foundation Compliance
 - 2.2.11.7 Americans with Disabilities Act
- 2.2.12 Local Permitting
- 2.2.13 Termination/Liability

3.0 PROCUREMENT PLAN

3.1 General

Upon execution of the Option, CBI will develop an Option Procurement Plan to address the following items, concerns, and requirements:

- 3.1 General
- 3.2 Program/ P.O. Provisions
- 3.3 Major Suppliers
 - 3.3.1 Tube Sections
 - 3.3.2 Expansion Bellows
 - 3.3.3 Stiffeners
 - 3.3.4 Baffles
 - 3.3.5 Structural Supports
 - 3.3.6 Weld Wire
- 3.4 Construction Equipment/Facility
- 3.5 Requirements for Notifications, Consent, or Approvals
- 3.6 Authorization



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- 3.7 Expediting
- 3.8 Pricing & Analysis Requirements
- 3.9 Value Engineering
- 3.10 Use of Government Facilities by Subcontractor
- 3.11 Transportation Damage & Loss Claims
- 3.12 Supplier Corrective Action Requests
- 3.13 Disposition of Rejected or Damages Incoming Supplies
- 3.14 Stop Work Order
- 3.15 Federal Acquisition Regulations
 - 3.15.1 Contract Specific Pass Through Requirements
 - 3.15.2 Law of the Land Requirements
- 3.16 Government Furnished Equipment/Inventory
- 3.17 Release of Lien
- 3.18 Certification of Compliance
- 3.19 Termination/Liability
- 3.20 Subcontract Provisions
- 3.21 Major Subcontract Areas
 - 3.21.1. Cleaning
 - 3.21.2. Security
- 3.22 Federal Notification

4.0 **SECURITY**

4.1 Fabrication Site:

Temporary fencing will be utilized to isolate critical areas for security purposes. Concret covers must be placed shortly after the tube and support installation is complete. This will prevent unauthorized access to the beam tube and will prevent projectile damage.

4.2 Erection Site: Clean Room and Positive air flow systems limit and constrain access to the installed tubes. These areas are locked out during off shift time periods. Monitoring is required to insure continued operation of equipment.

4.3 During second and third shift time periods, employees from the Leak Testing station are on site and will monitor security operations and operating equipment.

During off shift occasions such as weekends and holidays, locally hired professional security service will be employed for perform these functions.



5.0 MASTER PROCEDURES LIST / PLAN

5.1 Purpose:

The purpose of the Master Procedures Listing is to provide one single controlled source for all project procedures to insure that all parties are working under the same set of documents.

5.2 Contents:

The manual contains all procedures, plans and specifications utilized for construction the project.

5.3 Control:

During the Option, control of the Master Procedures List and Manual will be the responsibility of Project Management. Control will be accomplished in the same general manner as the QA Manual, to a predetermined list of Manual Holders, via revised indices accompanying each issuance.

6.0 MOBILIZATION PLAN

6.1 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. Initial mobilization is projected to be accomplished in three months. Office facilities for the on-site construction organization will be provided during the construction effort. After completion of work at the Hanford site, the same effort will be instituted at the Livingston, La. site.

*3 months
mobilization
period*

CBI has made complete site surveys. Local conditions, labor, permit requirements, local contractors, appear to be favorable for the project at both sites. One major outstanding item involves Caltech and their acquiring agreement to be a signee to the DOE Site Labor Agreement at Hanford. At present, the site is outside of the reservation fencing and is not a DOE project, thus it does not come under the agreement. Becoming a signee will bring about the application of Davis-Bacon wage rates at Hanford. This DOE Site Labor Agreement does not apply to the Livingston site. CBI will utilize its normal rates for Livingston.

*Permit
Bacon
Rates
Wash
not
L.A.*



LIGO PROJECT
WBS 300
CONSTRUCTION PLAN
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Manpower requirements have been developed with the estimate and schedule.

6.1.1 ERECTION DRAWINGS

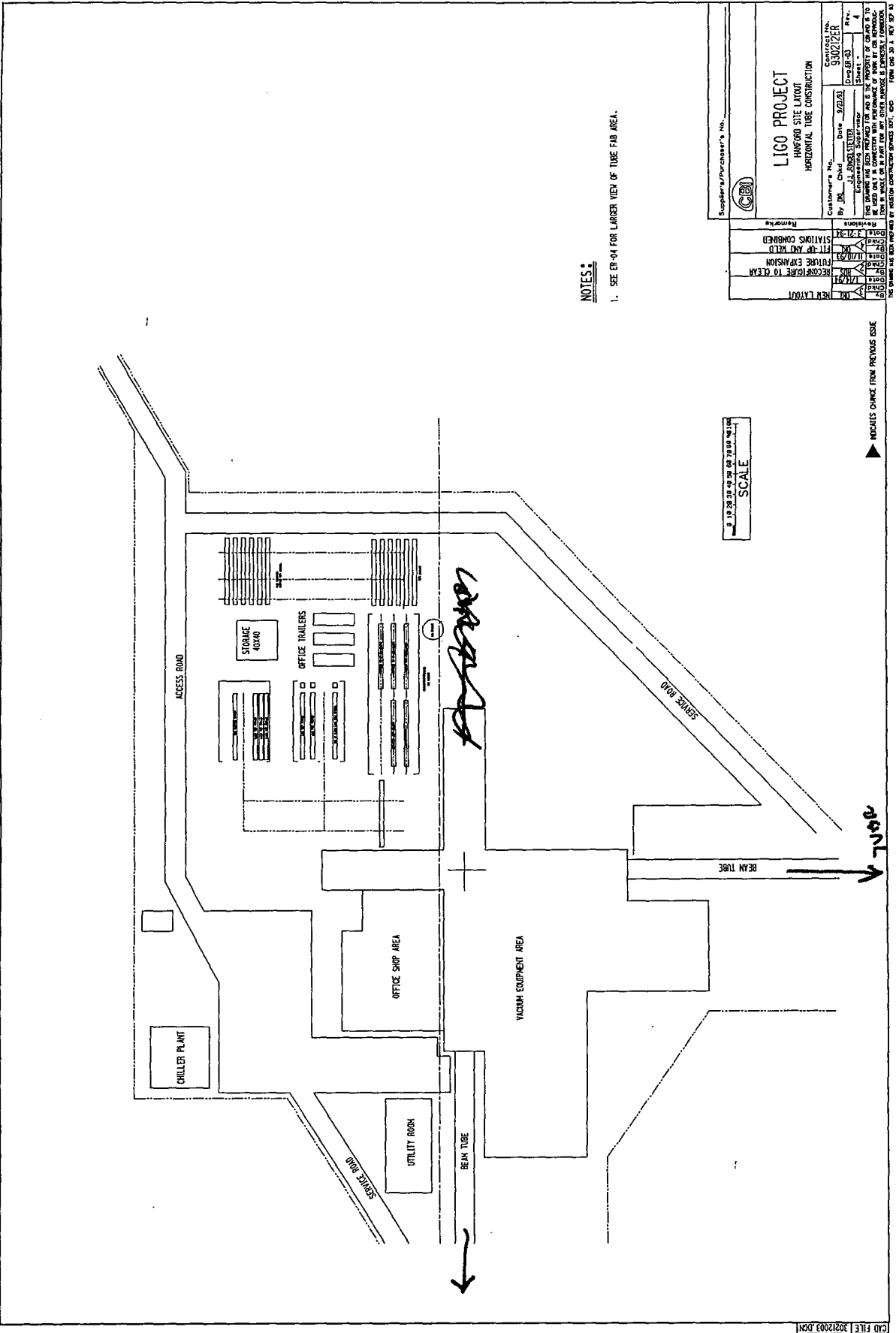
A full set of erections drawings and index is included in this plan. Specific references are made in the body of the plan explanations

6.2 FABRICATION FACILITY

The basic plan calls for a tube section fabrication facility to be erected, first at the Hanford site, then moved to the Livingston site. The fabrication facility is to be located near the corner station at each site. The shop sizes have been determined based on the most cost effective tube module lengths to use, the number of and size of the equipment, and the production rate. Drawings ER 03, 04, 05 & 06 show the planned 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 on-site complex has been designed to be a series of temporary portable type (e.g manufactured by Rubb) buildings with concrete floors. Some of the concrete slabs could be retained as part of the permanent installation. Rail mounted gantries running the full length of the fabrication shops are provided for handling the tubes during fit up, welding, leak testing and cleaning. Drawing ER 05 indicates a typical cross section of the main building showing the gantry crane system.

Alternative studies are being made for use of off-site leased facilities and the possible use of a more permanent type of building shell that might be left in place for use by Caltech. A preliminary report on this effort was presented to Caltech on March 17 1994 and is included as an attachment to this plan for information. See appendix B. Preliminary data indicate the on-site versus leased facilities will have about the same cost impact. The more permanent type of buildings on site may be a less expensive approach and will be explored further before final pricing.

Outside receiving and storage areas have been defined so as to provide a minimum two week supply of tube cans. These areas have a crushed stone sub-layer with an asphalt paving cover to minimize dusting and assist in maintaining cleanliness throughout the fabrication area.



NOTES:

1. SEE ER-04 FOR LARGER VIEW OF TUBE FAB AREA.

1" = 100' SCALE

Supplier/Purchaser's No.		Customer's No.	
930272R		930272R	
By J.L. CHUBB		Date 3/2/04	
Checked J.L. CHUBB		Drawn J.L. CHUBB	
Title PROJECT MANAGER		Title PROJECT MANAGER	
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6.3 ERECTION EQUIPMENT

Because of the relatively light weight of the tube sections the primary lifting equipment will be 15-18 ton hydraulic cranes. Spreader beams and nylon slings would be utilized for handling the tubes and subassemblies.

The tubes will be transported from the fabrication shop to the final installation area on small four-wheel trailers. Drawing ER 141 shows a typical load.

Standard CBI construction equipment lists have been developed for welding and general construction efforts.

6.4 SPECIAL EQUIPMENT / TOOLING

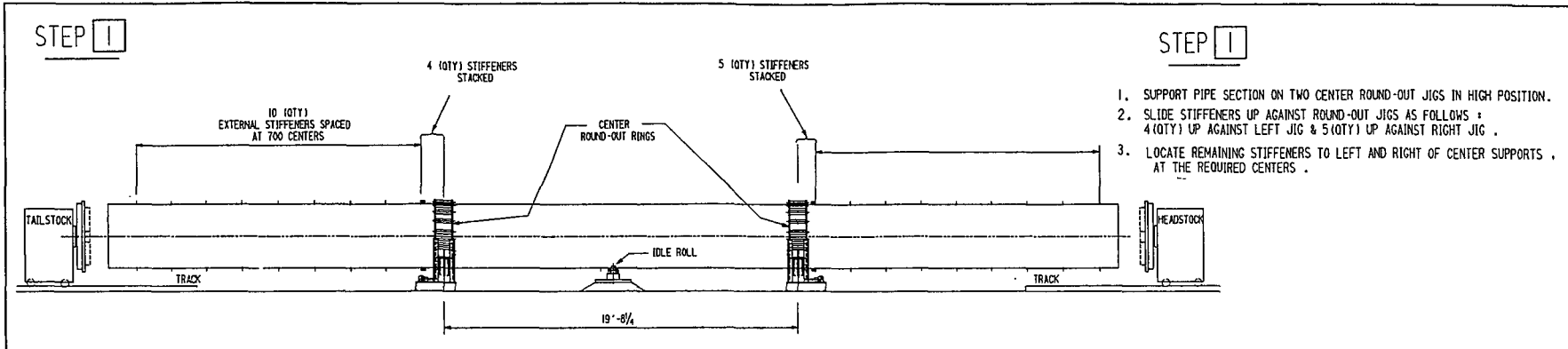
Because of the unique nature of this project, much of the equipment that will be used to fabricate, test, clean, and erect the cylinder sections has been designed specifically for each application.

6.4.1 FABRICATION

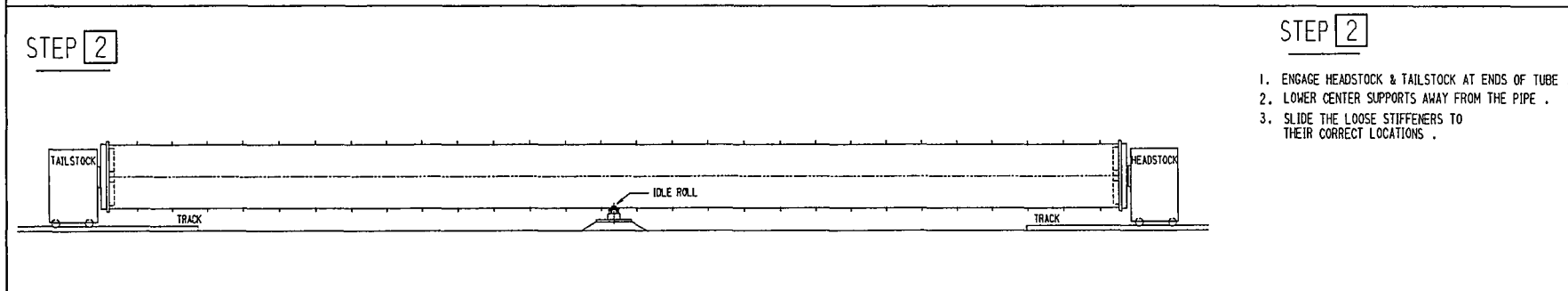
6.4.1.1 STIFFENER FIT-UP AND WELD STAND (Drawings ER 20-27)

The stiffener fit and weld stand is designed around installing stiffeners that use the concept of a single lapped joint as suggested by Caltech. This provides for the stiffener to be expanded oversize like a spring, positioned along the tube, the expansion released, the lapped connection is then utilized to pull the stiffener tight and in contact with the tube's outside circumferential surface. The lapped joints are then welded together and tack welded to the tube. Specific fitting and welding procedures have been developed for the installation of the stiffeners

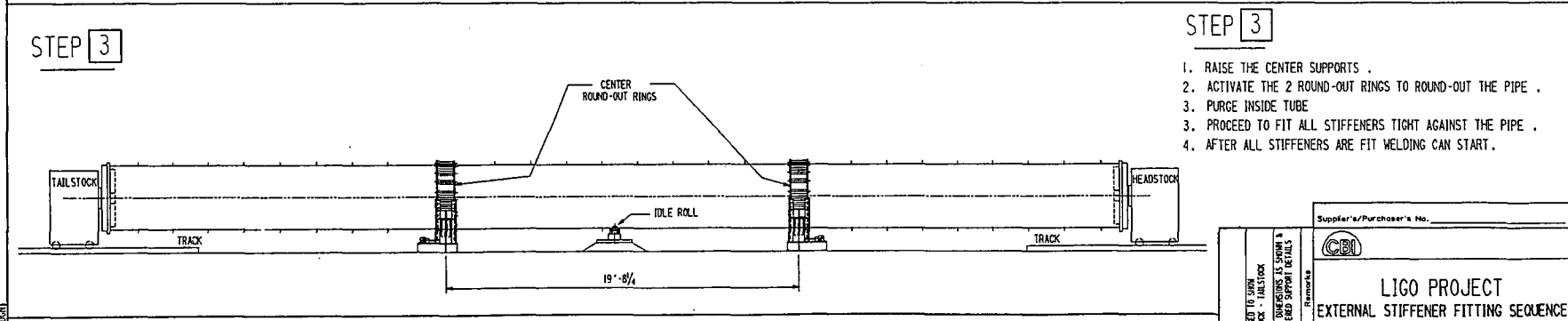
This station has four support saddles with round up clamps built in. Two of these are located near the tube ends and two at the third points. The unstiffened tube is set and rounded up on the saddle rings.



1. SUPPORT PIPE SECTION ON TWO CENTER ROUND-OUT JIGS IN HIGH POSITION.
2. SLIDE STIFFENERS UP AGAINST ROUND-OUT JIGS AS FOLLOWS :
4(0TY) UP AGAINST LEFT JIG & 5(0TY) UP AGAINST RIGHT JIG .
3. LOCATE REMAINING STIFFENERS TO LEFT AND RIGHT OF CENTER SUPPORTS , AT THE REQUIRED CENTERS .



1. ENGAGE HEADSTOCK & TAILSTOCK AT ENDS OF TUBE
2. LOWER CENTER SUPPORTS AWAY FROM THE PIPE .
3. SLIDE THE LOOSE STIFFENERS TO THEIR CORRECT LOCATIONS .

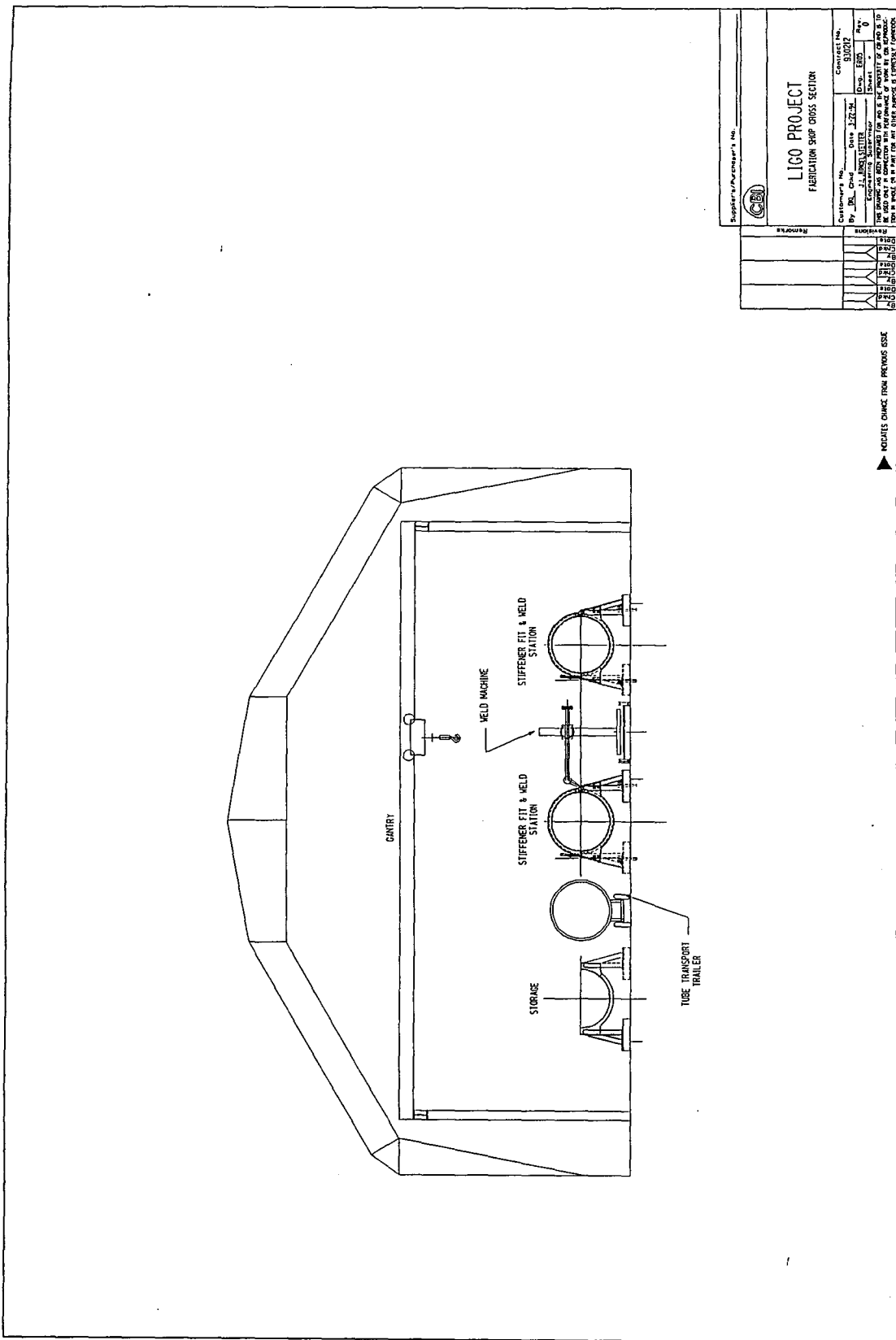


1. RAISE THE CENTER SUPPORTS .
2. ACTIVATE THE 2 ROUND-OUT RINGS TO ROUND-OUT THE PIPE .
3. PURGE INSIDE TUBE
3. PROCEED TO FIT ALL STIFFENERS TIGHT AGAINST THE PIPE .
4. AFTER ALL STIFFENERS ARE FIT WELDING CAN START .

CAD FILE: 3020202020202020

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. _____	
CGI	
LIGO PROJECT	
EXTERNAL STIFFENER FITTING SEQUENCE	
Customer's No. _____	Contract No. 930212ER
By: J.R. Chid Date: 04-NOV-93	Dwg: ER-20 Rev: 3
Engineering Supervisor: J.A. BINGEL/STETTER	Sheet: _____
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<small>THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES SEPT. 1992 FORM CHG 30-A REV SEP 93</small>	



INDICATE CHANGE FROM PREVIOUS ISSUE

Supplier's/Manufacturer's No.		Contract No.	
LIGO PROJECT		B10022	
FABRICATION SHOP CROSS SECTION			
Customer's No.	By	Date	Drawn
	J. J. WALKER	1/27/24	EBD
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6.4.1.2 STIFFENER WELDING (Drawings ER 30 - 36)

The stiffener fit-up and weld stand contains the welding and purging equipment to weld the stiffeners to the cylinder sections. The weld station has two weld heads, each mounted to move independently along the tube. The tube is mounted on a head-stock/tail stock system to accurately drive and control the rotation for welding. The drive system has integral purge and sealing systems for to protect the inside of the tube from oxidation during stiffener welding. Centralized rubber tired roll supports are used as a steady rest to minimize distortion from dead weight deflection of the tube.

6.4.1.3 EXPANSION BELLOWS FITTING & WELDING STAND (Drawings ER 40-46)

The second station in the fabrication shop is designed for fitting and welding the expansion joints to the tubes. This consists of a stationary frame with movable purge dam. The purge dam is inserted into the tube for purging. The welding process rotates around the tube to expansion bellows joint.

CBI developed a special fit up device that provides for the shell to shell alignment of the tubes together or the tubes to the expansion bellows.

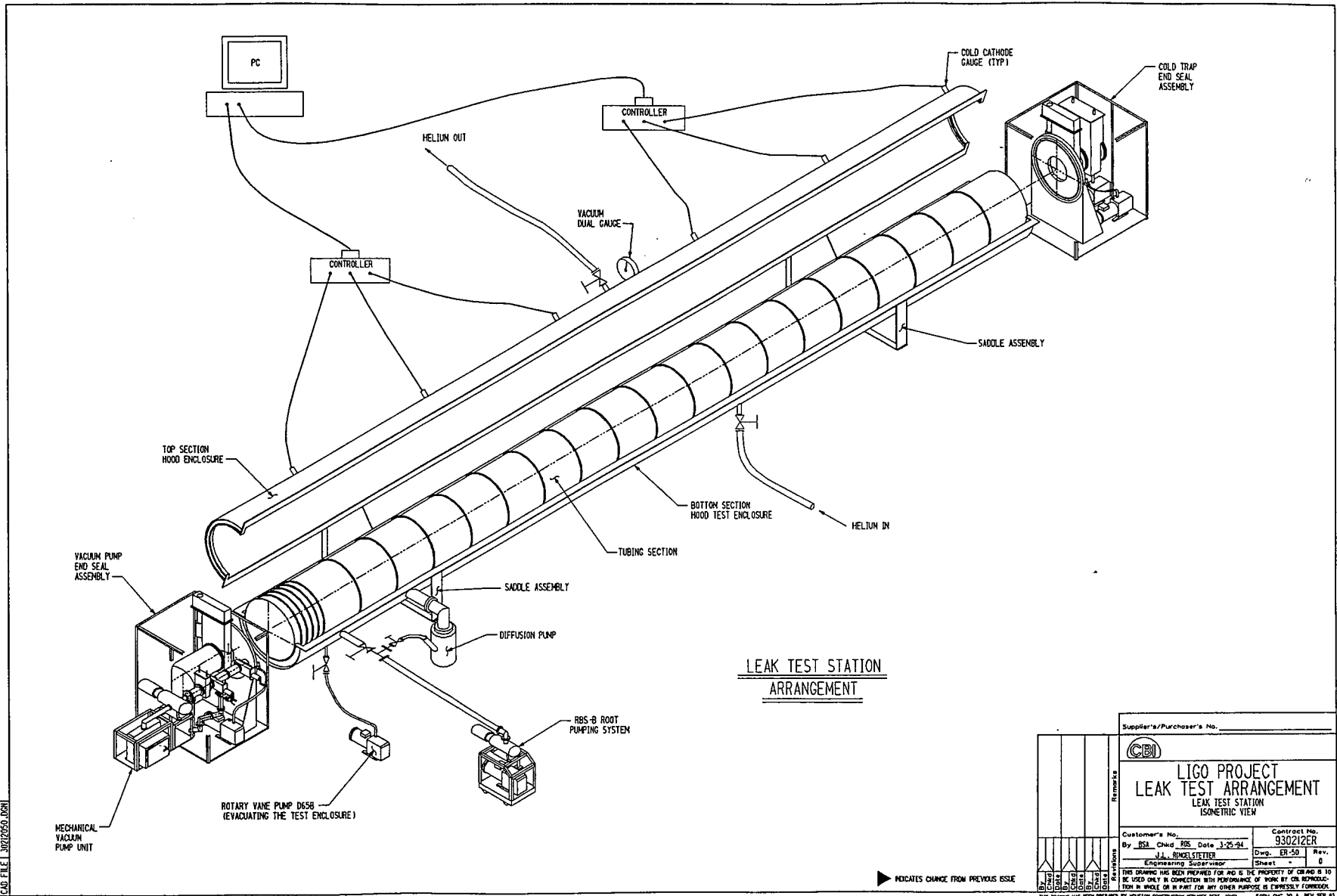
6.4.1.4 PUMP PORTS FITTING AND WELD STAND (Drawings ER 80-82)

The fit and weld station for the pump ports is located at the side of expansion joint fit and weld station for installation of the pump ports in the selected cylinder sections.

This involves the use of an internal box set up to allow for stiffening, fitting and welding in an inert environment. Manual TIG welding equipment is utilized in the tacking and welding process, utilizing proper shielding gases.

6.4.1.5 LEAK TESTING STAND (Drawings ER50-77)

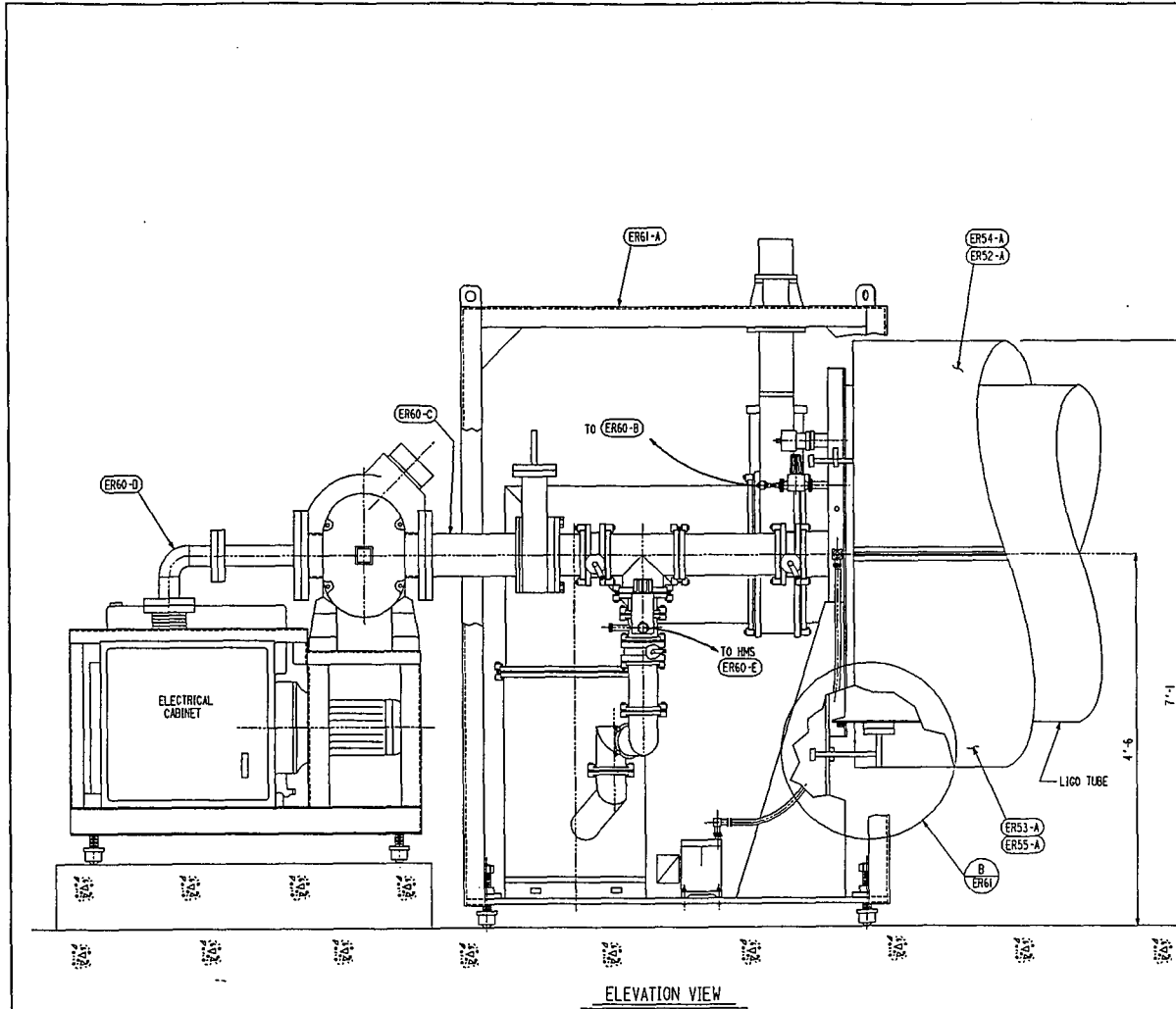
The next station in the shop is for leak testing the completed tube sections. In order to meet schedule, there are three stands, each with its own vacuum equipment, set up so that several tube assemblies can be pumped down and tested simultaneously. One of the three stands is equipped with a "time of flight" detection arrangement developed by CBI to help in the timely locating of any leaks.



CAD FILE: 3072050.DWG

► INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No.		Contract No.	
CBI		930212CR	
LIGO PROJECT LEAK TEST ARRANGEMENT LEAK TEST STATION ISOMETRIC VIEW			
Customer's No.		Contract No.	
By: RJA Chkd: RJS Date: 3-25-04		930212CR	
J.A. HINDELSTEIN		Dwg. ER-50	
Engineering Supervisor		Rev. 0	
Sheet		0	
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<small>THIS DRAWING HAS BEEN PREPARED BY HOUSTON CONSTRUCTION SERVICES, INC. FORM ENG 30-A REV SEP 03</small>			



SHP PC	MARK	ASSY PC	DESCRIPTION	LENGTH FT	INCHES	SPEC	EST WEIGHT
*	1	ER61-A	ROLLING VACUUM END SEAL ASSEMBLY				X
*	1	ER60-B	UHV MULTI-GAUGE 115 VAC/60 HZ "VARIAN" PART NO. L8321301				X
*	1	ER60-C	SPOOL ASSEMBLY				X
	1	ER60-1	FULL NIPPLE WITH 6 ASA ROTTABLE TWO GROOVED FLANGES "LESKER" PART NO. AFN1X0601 Q2R OR EQUAL			5TH STL	X
	2	ER60-2	O-RING & ASA SIZE "LESKER" PART NO. O-V265 OR EQUAL			VITON	X
	16	ER60-3	BOLT 3/4 DIA REG FIN HEX HEAD	0	2 1/2	A307B	X
	16	ER60-4	PLAIN WASHER 3/4 DIA NARROW			CARB STL	X
	16	ER60-5	NUT 3/4 DIA REG FIN HEX			A563A	X
*	1	ER60-D	MECHANICAL VACUUM PUMP UNIT				2300
	1	ER60-6	ASSEMBLY OF "LEYBOLD" RUHVAC MAU2001 SINGLE-STAGE ROTARY PUMP CAT. NO. 9175H AND DK200 ROTARY PISTON PUMP CAT. NO. 89503-1 MOUNTING ON 32-INCH WIDE FRAME "INDELCO"				X
	4	ER60-7	ACME ROD 1/4 DIA - STPI RIGHT-HAND THD "McMASTER-CARR" NO. 98935A131	0	6	CARB STL	X
	4	ER60-8	FLANGE MOUNTED UNIT - 1/2 DIA BALL TRANSFER HIGH CAP. "McMASTER-CARR" NO. 2415T64 ZINC PLATED			CARB STL	X
	4	ER60-9	ACME NUT 1/4 DIA - STPI RIGHT-HAND THD "McMASTER-CARR" NO. 94815A116			CARB STL	X
	4	ER60-10	ACME BRONZE ROUND NUT 1/4 DIA - STPI RIGHT-HAND THD "McMASTER-CARR" NO. 95072A118			BRONZE	X
	4	ER60-11	ACME MOUNTING FLANGE 1/4 DIA "McMASTER-CARR" NO. 95082A645			CARB STL	X
*	1	ER60-E	HELIUM MASS SPECTROMETER ULTRATEST UL400 HELIUM LEAK DETECTOR "LEYBOLD" CAT. NO. 89635-100 WITH OPTIONAL HIGH SENSITIVITY 2 X 10 ⁻⁹ atm cc/sec OR EQUAL				330

* BILLING FOR 1:3 REQUIRED.

NOTES:

1. WORK THIS DWG WITH DWG ER-41.
2. BALL TRANSFER UNIT DETAIL SEE DWG ER-63.

CAD FILE: 3072660.DWG

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No. _____

(CBI)

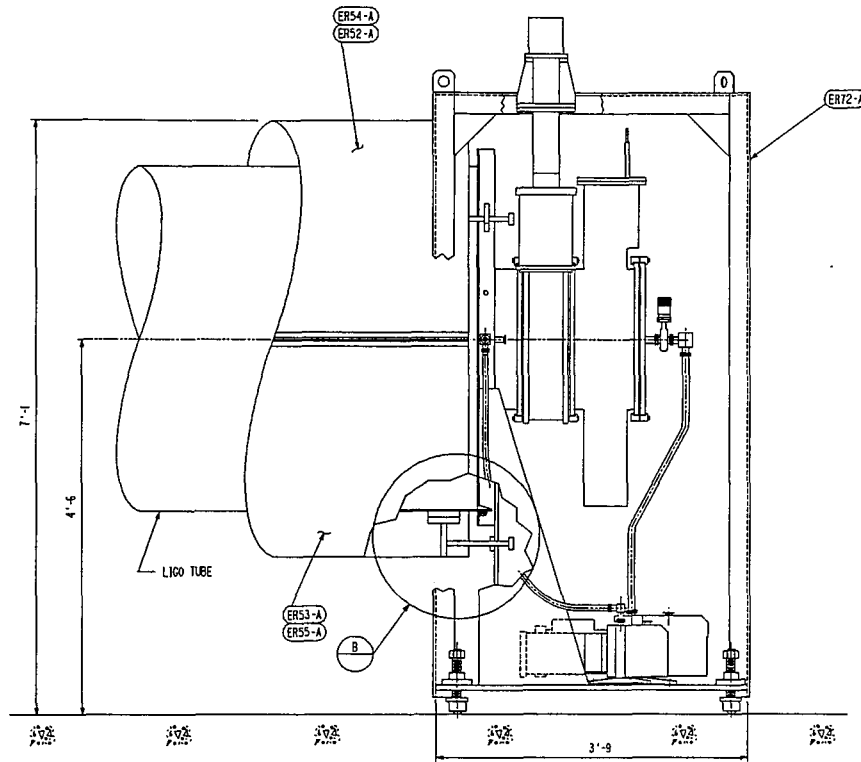
**LIGO PROJECT
LEAK TEST ARRANGEMENT
VACUUM PUMP END SEAL**

Customer's No. _____ Contract No. **93021ZER**

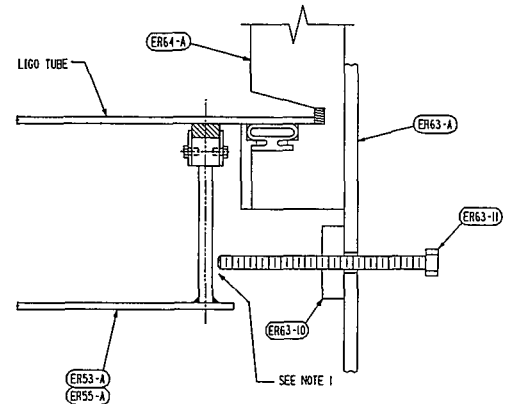
By **RS** Chkd **RS** Date **3-9-94** Dwg. **ER-60** Rev. _____
 J. J. BLOTTSTEIN
 Engineering Supervisor Sheet **1**

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ELEVATION VIEW



TYP DETAIL B
SEE NOTE 2

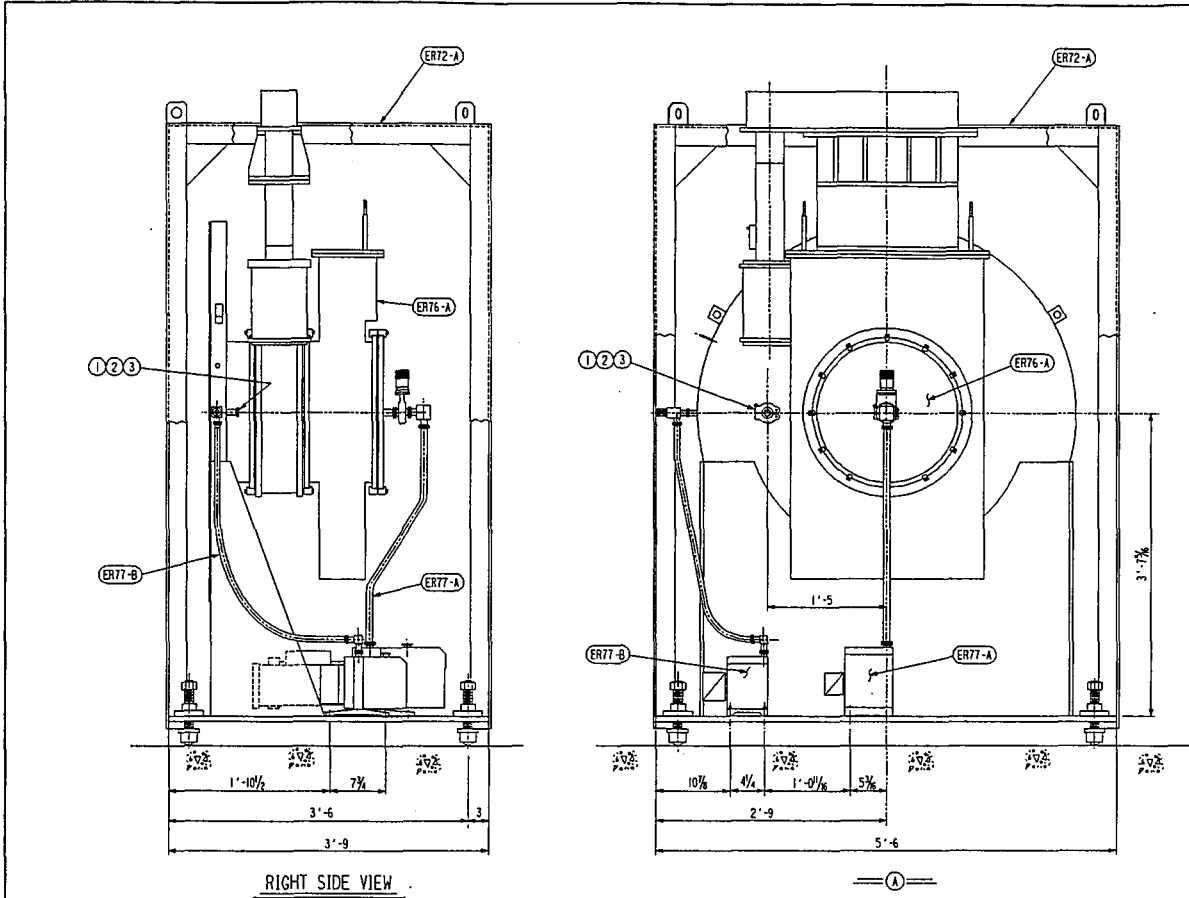
NOTES:

1. 1/4 GAP BEFORE VACUUM IN LIGO TUBE.
2. BOLT (ER63-11) BEARS AGAINST HELIUM HOOD DURING VACUUM.
3. TYP DETAIL AT 180° (BOTTOM). DETAIL SIMILAR AT 60° AND 300° EXCEPT PC (ER63-10) IS WELDED TO (ER64-A).
4. WORK THIS DWG WITH DWG ER-60 AND ER-61.

CAD FILE: 3020101.DWG

Supplier's/Purchaser's No.	
(CBI)	
LIGO PROJECT LEAK TEST ARRANGEMENT COLD TRAP END SEAL	
Customer's No.	Contract No.
By: <u>BSA</u> Chkd: <u>RJS</u> Date: <u>3-15-94</u>	<u>930212ER</u>
Engineering Supervisor	Dwg. <u>ER-70</u> Rev. <u>1</u>
Sheet <u>1</u>	
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▶ INDICATES CHANGE FROM PREVIOUS ISSUE



SHP PC	MARK	ASSY PC	DESCRIPTION	LENGTH		SPEC	EST WEIGHT
				FT	INCHES		
%	ERT1-A		COLD TRAP END SEAL ASSEMBLY				X
	ERT2-A		CARRIAGE SUBASSEMBLY				X
	ERT6-A		COLD TRAP LINE SUBASSEMBLY				X
	ERT7-A		COLD TRAP EVACUATION LINE SUBASSY				X
	ERT7-B		INTERSPACE VACUUM PUMP LINE				X
			PERMEATION HELIUM STANDARD LEAK CONNECTION				
	ERT1-1		CENTERING RING DN 16 KF "LEYBOLD"			STN/MTON	X
			CAT. NO. 88346 OR EQUAL				
	ERT1-2		BLANK FLANGE DN 16 KF "LEYBOLD"			STN STL	X
			CAT. NO. 88436 OR EQUAL				
	ERT1-3		CLAMP DN 16 KF "LEYBOLD" CAT. NO. 18341			ALUM	X
			OR EQUAL				

* BILLING FOR 1 + 3 REQUIRED.

CAD FILE: 3202011.DWG

Supplier's/Purchaser's No. _____

(CBI)

LIGO PROJECT
LEAK TEST ARRANGEMENT
 COLD TRAP END SEAL ASSEMBLY

Customer's No. _____ Contract No. **930212ER**
 By **ESA** Chid **RES** Date **3-4-94**
 J. J. ENGEL STEITZ
 Engineering Supervisor

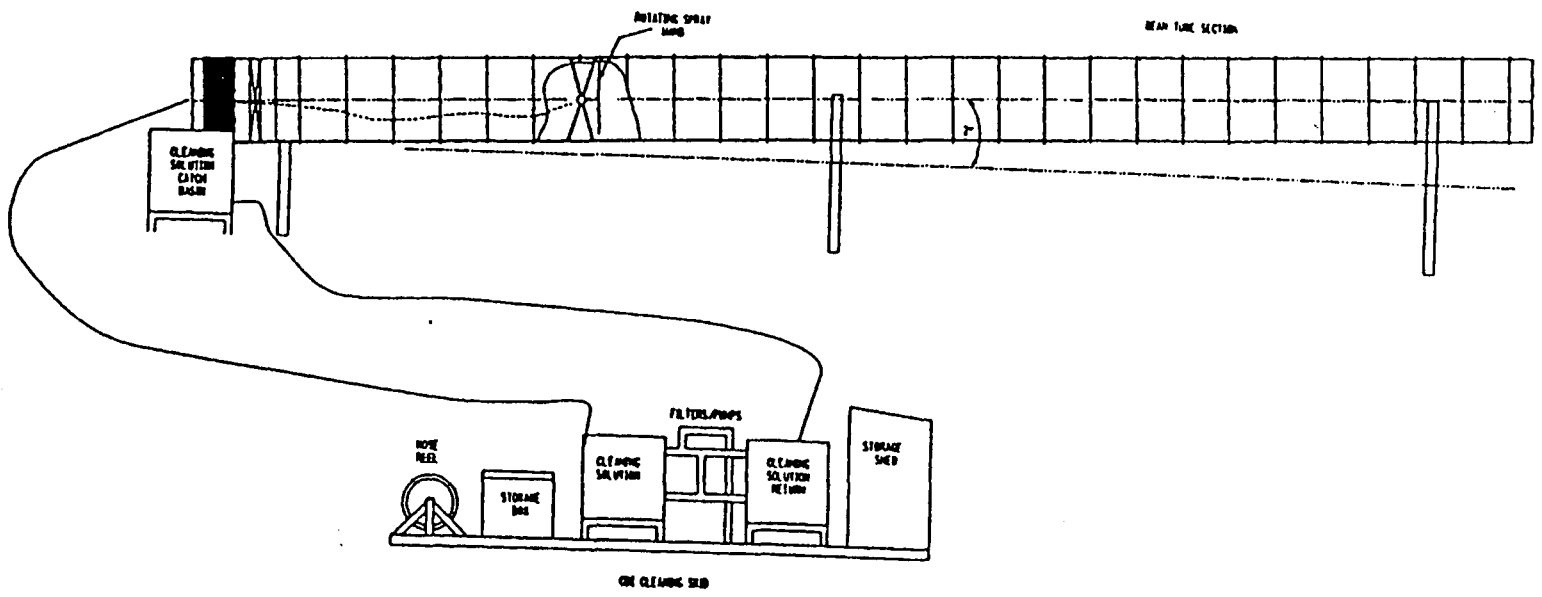
Dwg. **ER-71** Rev. **1**
 Sheet **-**

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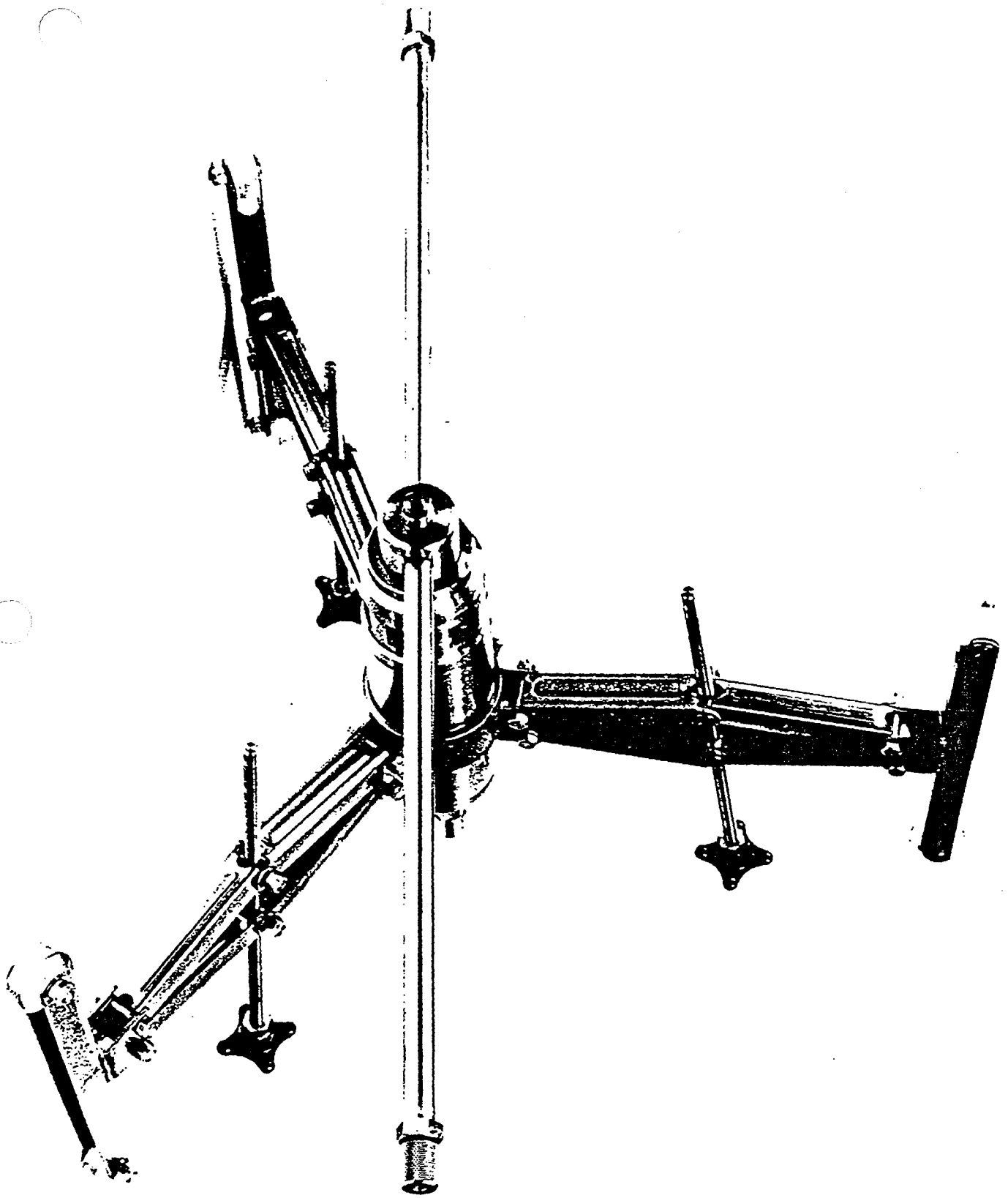
INDICATES CHANGE FROM PREVIOUS ISSUE

TITLE CLEANING OF COMPLETED
BEAM TUBE CAN SECTIONS
BEFORE LEAK TESTING AND
FINAL ASSEMBLY - CALTECH



CLEANING ARRANGEMENT

33





The leak test stations are designed by CBI at Houston. 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 is designed to accomplish the pressure level required to achieve system sensitivity in four hours.

CBI procedures list all of the equipment required for testing. Planning Procedure LIGOTP provides a guide for the requirements. Procedure 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 2×10^{-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.

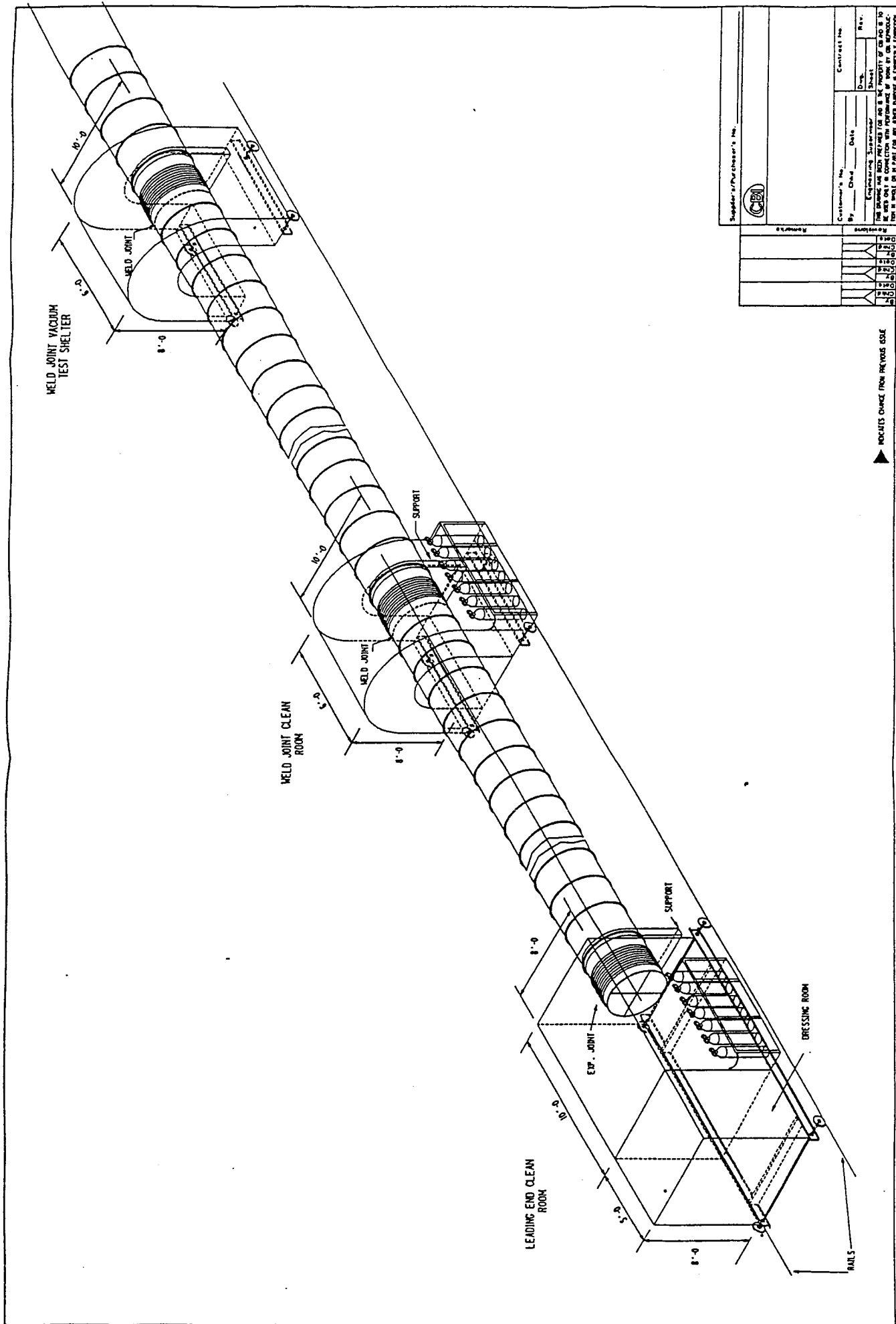
6.4.1.6 CLEANING STAND (Drawings ER-90-96)

The cleaning stand is a self contained system with provision for capture of the steam cleaning water. The set up utilizes a guided pipe spray cleaning head to provide heated cleaning to the full interior of the tube.

CBI will utilize it's standard cleaning solution storage and pumping system. A drawing of this equipment is attached.

6.4.2 ERECTION EQUIPMENT(Drawings ER 100-126)

The special erection equipment that is necessary to assemble the cylinder sections into the beam tube module is located on rails that are temporarily surface mounted on the concrete slab underneath the modules. The clean room facility will ride these rails. It contains a change room, transition room and work room with purge equipment and baffle storage which is positioned at the end of the module as the cylinder sections are being added. There is also an enclosure that rides the rails and provides cleanliness and weather



WELD JOINT VACUUM TEST SHELTER

WELD JOINT CLEAN ROOM

LEADING END CLEAN ROOM

DRESSING ROOM

Supplier's/Purchaser's No. **CEN**

Customer's No. _____ Date _____ Contract No. _____

By _____ Check _____

Engineering Supervisor _____

Sheet _____

Rev. _____

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FORM OCE 28 1 REV 3/7 63

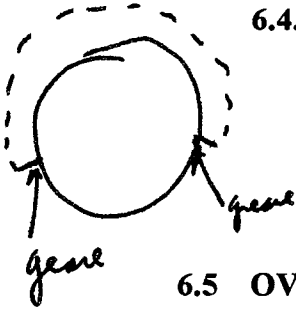
▲ INDICATES CHANGE FROM PREVIOUS ISSUE



protection for the cylinder joints as they are being fit and welded. A similar enclosure is used to house the vacuum test equipment that is required to leak test these seams after they are welded.

The rail is a simple angle mounted on base plates, these are "leap-frogged" ahead of the construction process.

6.4.3 TESTING - FIELD WELD JOINTS(Drawings ER-133 - 134)



This test requires a 190 degree external test box evacuation enclosure and the internal combination purge gas dam/tracer gas test hood along with associated equipment to leak test the cylinder sections of the field welded seams joining the tube assemblies together.

*How to avoid
 getting a leak
 by the seam*

6.5 OVERALL SITE COORDINATION

In order to maintain the schedule and adjust for any unexpected occurrences, site coordination during the installation of the tube assemblies is of utmost importance. Responsibility for overall site coordination should be determined by one contractor acting as the general contractor.

6.5.1 UTILITIES

Construction power is provided by Caltech from the permanent power substation located near the corner station at each site. Additionally construction power is provided at the end and mid point stations at Hanford and at the end stations at Livingston by CBI, utilizing portable generator units for the positive air flow units. Portable generator units are provided to supply power along the length of the beam tube modules as they are being assembled, this includes service to the clean rooms, welding and leak testing. Water is provided at the corner station on each site by Caltech. CBI will provide the necessary power panels to pick up and distribute construction power at 440 volts for use in the on-site shops.

6.5.2 ROAD ACCESS

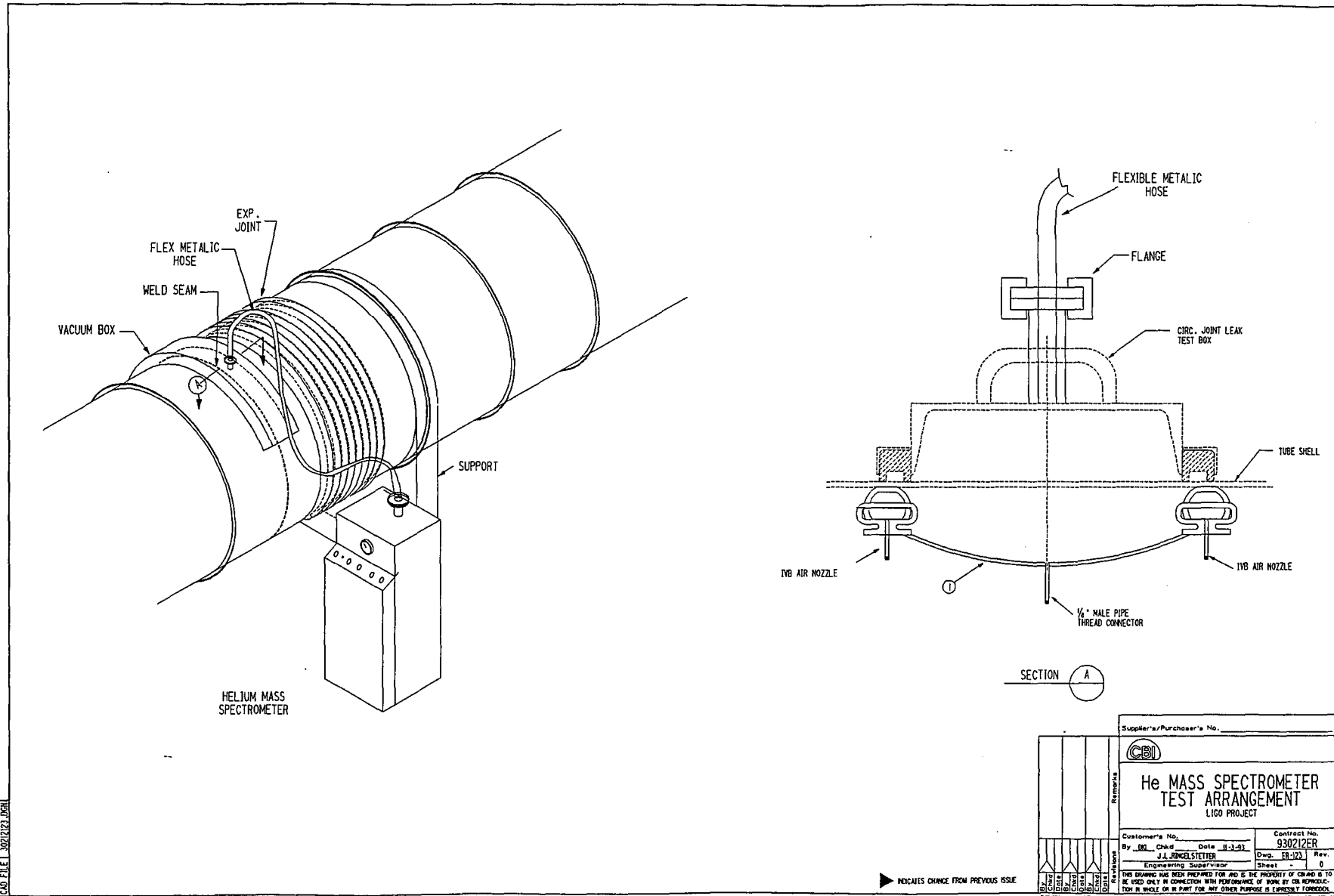
Road access is provided along the outside of the "L" shaped legs of the beam tube modules for moving the tube modules, lifting equipment, etc. into place. The welding and power generation equipment is trailer mounted and moves along the inside of the access road as the assembly progresses.



7.0 FABRICATION PLAN

7.1 General

The process flow for fabrication is in accordance with the procedure entitled "FABSEQ". Work is scheduled for 40 hours per week in all areas except the leak testing, where the operation will run around the clock to meet schedule. Present plans are to complete the fabrication of 10 tube subassemblies per week to support the installation schedule.

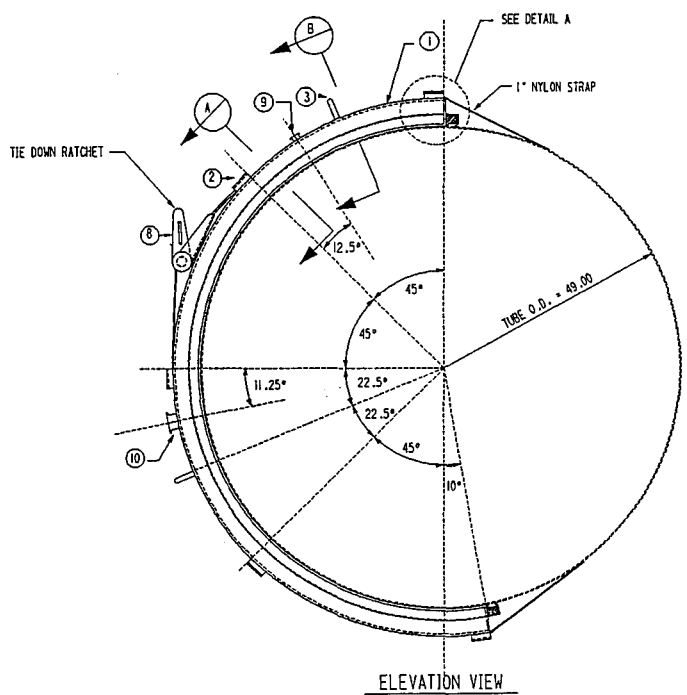


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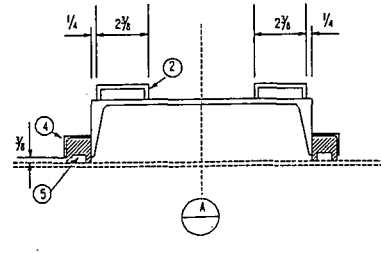
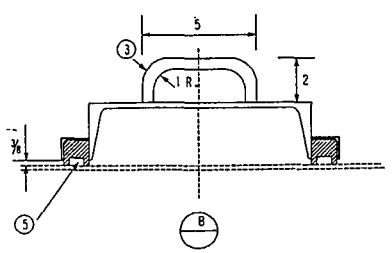
Supplier's/Purchaser's No.	
CEM	
He MASS SPECTROMETER TEST ARRANGEMENT	
LIGO PROJECT	
Customer's No.	Contract No.
By <u>DL</u> <u>CHAD</u> Date <u>11-1-91</u>	<u>930212R</u>
Engineering Supervisor	Dwg. <u>ER-123</u> Rev.
	Sheet <u>0</u>
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FORM CHG 30 1 REV SEP 83	

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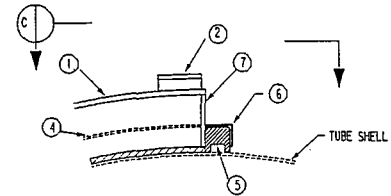
42



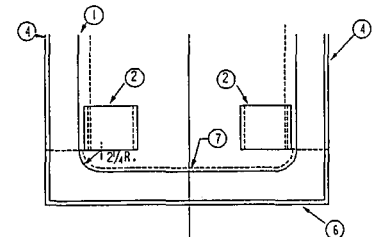
ELEVATION VIEW



SHF PC	MARK	ASST PC	DESCRIPTION	LENGTH FT	QUANTITY	SPCC	EST WEIGHT
			HELIUM LEAK TEST BOX				
	124-1	1	C 10 X 5.28 (ROLLED)			6061-T6	40
	124-2	8	PL. 3/8 X 2 (BENT)			6061-T6	-
	124-3	2	1/2 DIA. BAR (BENT)			6061-T6	-
	124-4	2	1 1/2 X 1 ANGLE (ROLLED)			6061-T6	-
	124-5	1	MOLDED RUBBER SEAL				
	124-6	2	2 1/2 X 1 ANGLE (BENT)			6061-T6	
	124-7	2	PL. 3/8 X 2 (BENT)			6061-T6	
	124-8	2	TIE DOWN RATCHET AND SLINGS				
	124-9	1	FLANGE - QF16-075-4A				KURT J ILESTKER
	124-10	1	FLANGE - QF40-150-4A				KURT J ILESTKER



DETAIL A



C

Supplier's/Purchaser's No. _____

(CBI)

LIGO PROJECT
CIRCUMFERENTIAL JOINT LEAK TEST BOX

Customer's No. _____ Contract No. 930212

By DKL Date 2-7-94

Engineering: J. ILESTKER Sheet 1 of 1

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8.0 TRANSPORT

8.1 General (drawings ER 14-16)

Transport of the tubes to the site from the manufacturer will be by truck. The optimum length has been determined through study to be 65 feet. This accommodates the specified baffle spacing, thus minimizing the diameter of the tube itself. Other items considered in the study included the original costing for the supports and expansion bellows along with the freight costs. Shipments over 65 feet will invoke state mandated escort requirements and substantially increase shipping costs. The "ER" drawings illustrate a typical trailer load and support saddles.

Transport and coordination of the tubes from the vendors is a very demanding and delicate matter as it impacts the production and installation schedule. CBI plans to have the vendor stock pile a two to three week supply. CBI is providing for the same at the site.

9.0 ERECTION PLAN

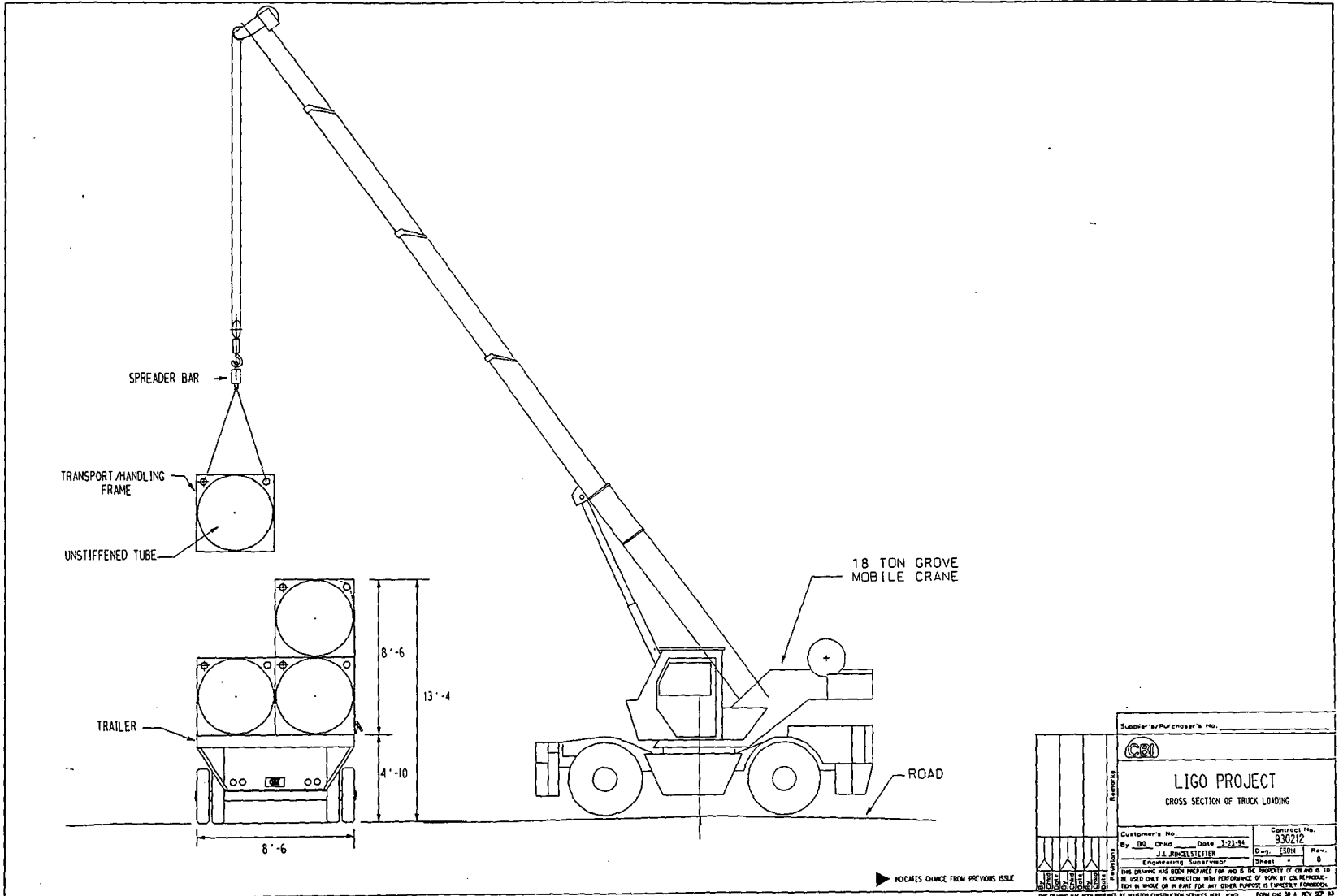
9.1 GENERAL

Installation of the subassemblies begins at a mid station and progress outward, working both legs simultaneously. The process flow for installation is to in accordance with the procedure entitled "INSTALLSEQ". 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.

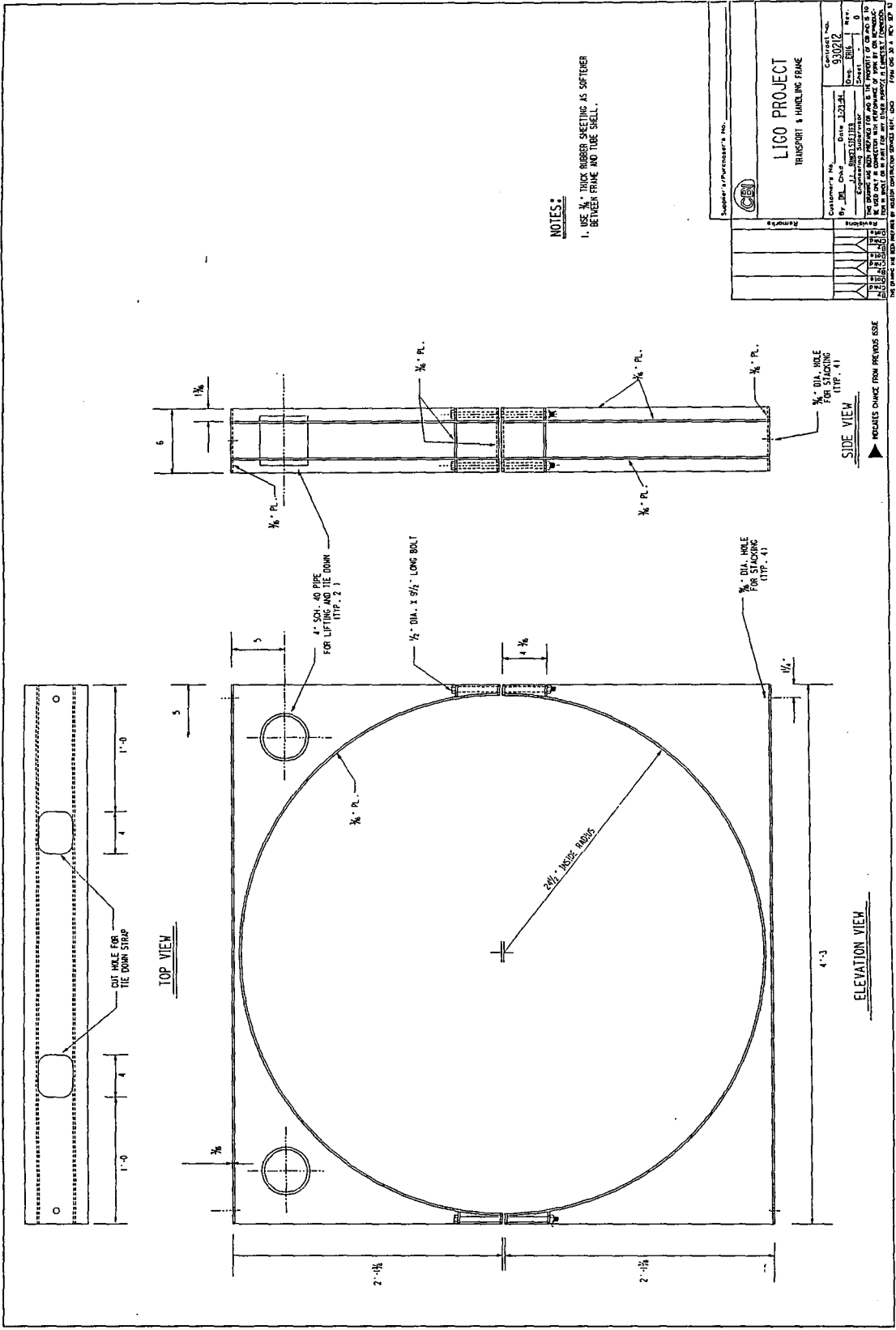
vertical bundles

9.2 PLACEMENT

The tube assemblies sections are cleaned and sealed before leaving the site fabrication facility. They are kept clean during all subsequent operations in the installation process. Sealed sections are hauled to the beam tube module on trailers and supported between the rails very near its final position. The leading end of the section is temporarily supported on the permanent support and the trailing end is on a temporary support or supported by a clamping device on the previous section. Handling utilizes a hydraulic crane and nylon slings with a spreader device to spread the load. There must be adequate room along the access road to manipulate the crane, the load, the portable power sources and the clean rooms. There is little room for other construction activities at this point.



Supplier's/Purchaser's No.	
CEI	
LIGO PROJECT	
CROSS SECTION OF TRUCK LOADING	
Customer's No.	Contract No.
By <u>DM, Chag</u> Date <u>3-23-94</u>	<u>930212</u>
<u>J.J. BRUCE STEEL</u>	Des. <u>ES01</u> Rev. <u>0</u>
Engineering Supervisor	Sheet <u>0</u>
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NOTES:
 1. USE 1/8" THICK RUBBER GASKETING AS SPACER BETWEEN FRAME AND TUBE SHELL.

Customer's/Manufacturer's No. **CEPI**

LIGO PROJECT
 TRANSPORT & HANDLING FRAME

Contract No. 930272

Customer No. 12024

By J.E. J. BINGELSEIJER

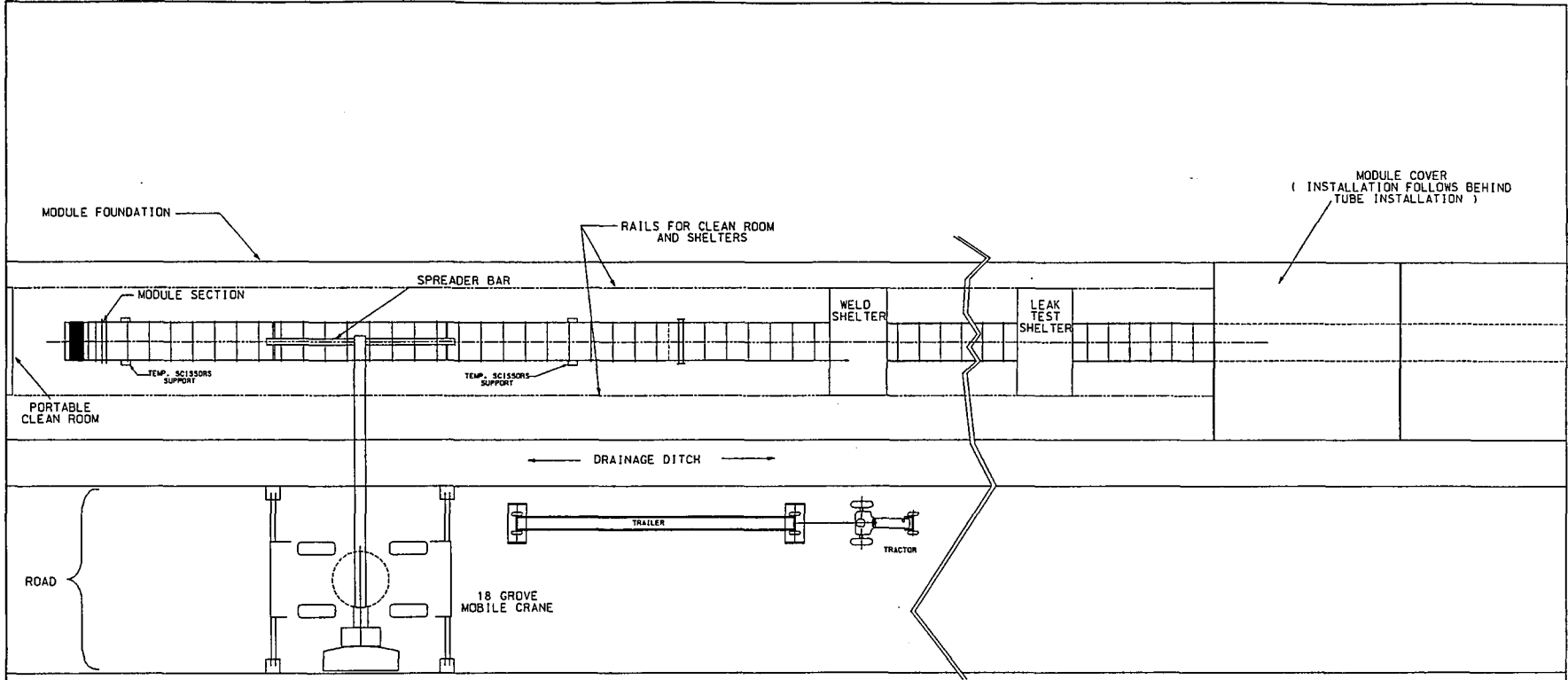
Engineering Supervisor

Drawn By

Checked By

Approved By

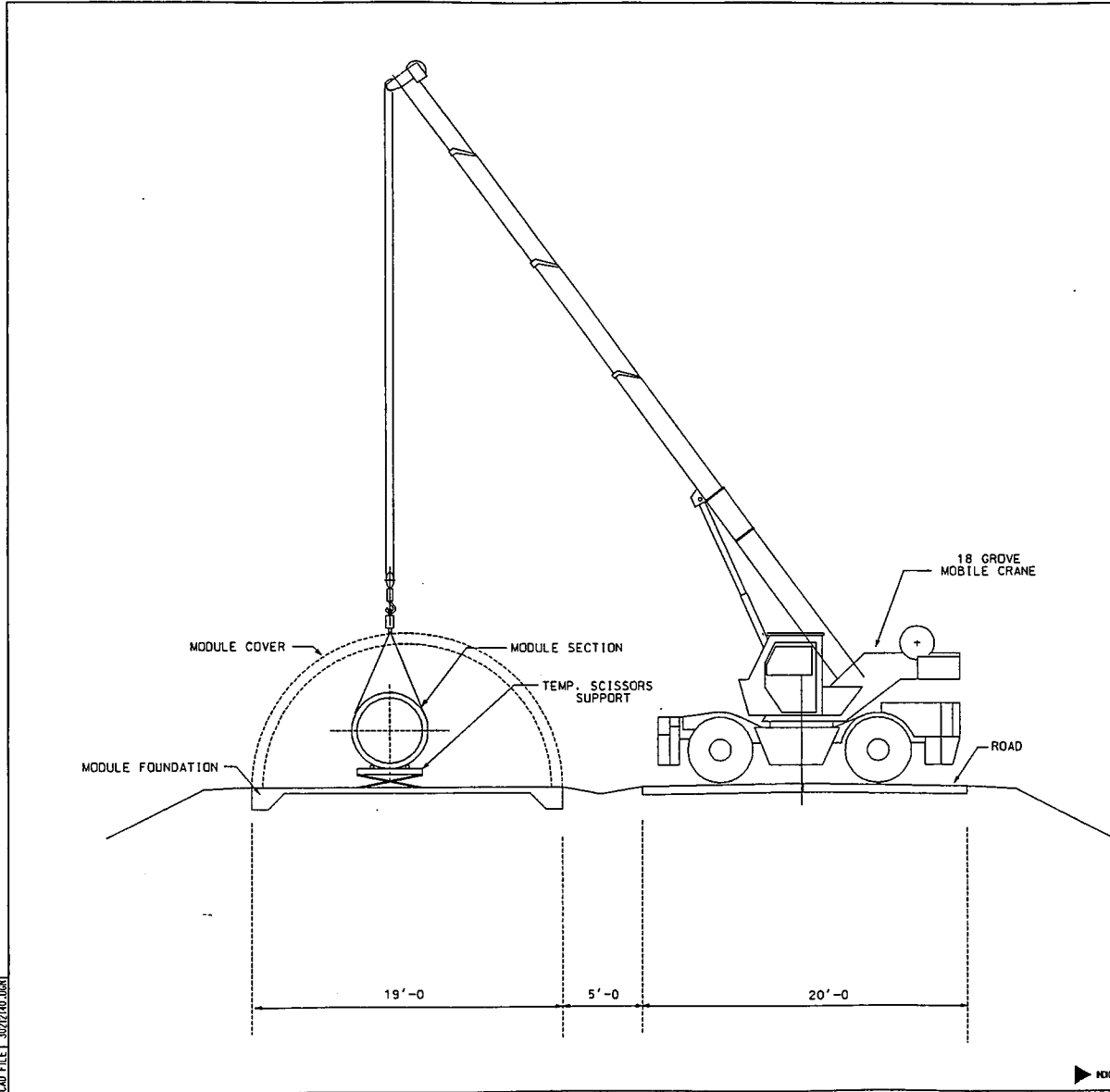
For a full and complete list of drawings, specifications, and other documents, refer to the LIGO Project Manual, Volume 1, Part 1, Section 1.1, Page 1.1.1.



CAD FILE: 302241.DWG

Supplier's/Purchaser's No.		Contract No. 930212ER	
		LIGO PROJECT PLAN VIEW OF TUBE INSTALLATION	
Customer's No.		Date 7-1-94	
By: J.J. RINGEL SLETTER		Dwg: ERH	
Engineering Supervisor		Sheet 1	
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NOTES:

1. CROSS SECTION OF ROAD/ TUBE & COVER IS SIMILAR FOR BOTH SITES

NON-DIMENSIONAL

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's/Purchaser's No.	
LIGO PROJECT ELEVATION VIEW OF TUBE INSTALLATION	
Customer's No.	Contract No.
By <u>DK</u> Chkd <u> </u> Date <u>2-4-94</u>	<u>930212ER</u>
Engineering Supervisor <u>J.J. RENZELSTETTER</u>	Dwg. <u>ER140</u> Rev. <u>0</u>
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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.

9.3 WEATHER PROTECTION

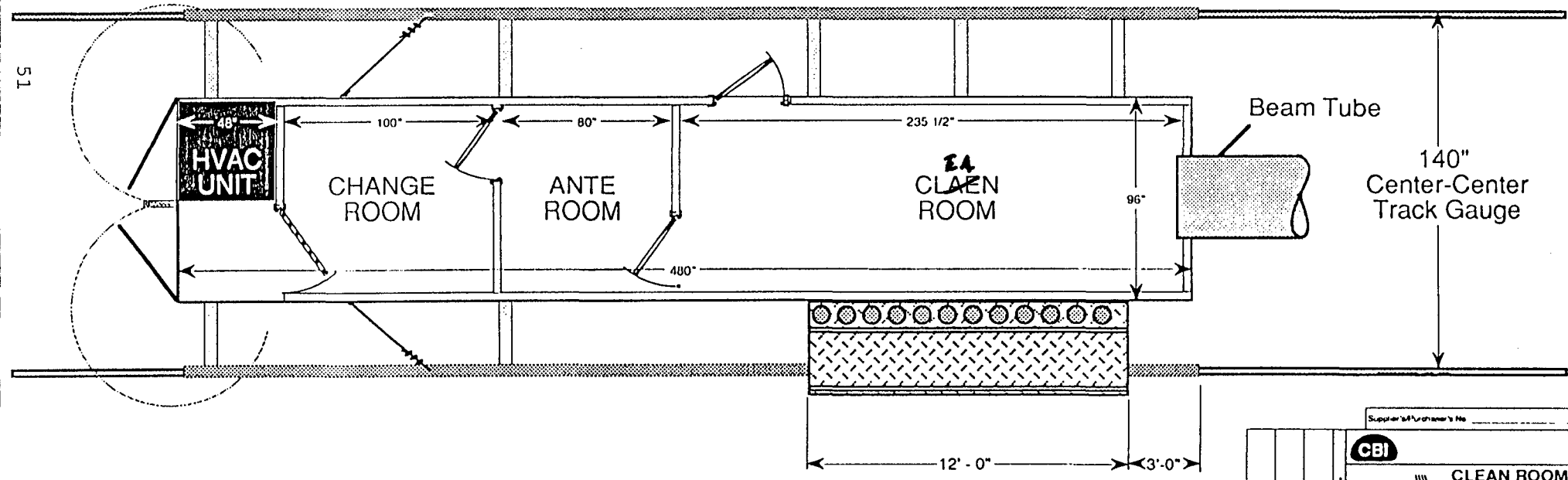
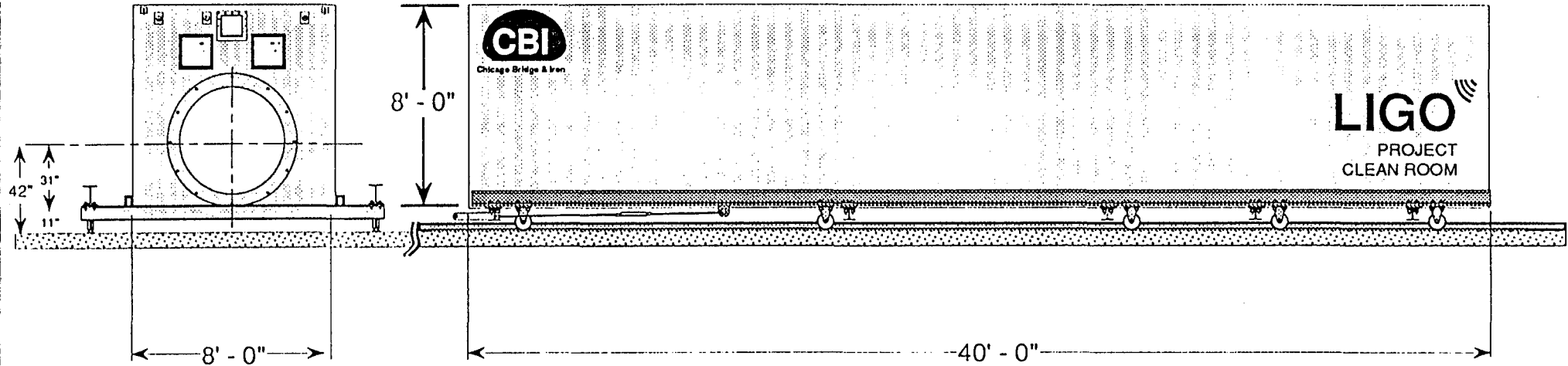
After the cylinder section is in position the clean room is rolled up to the leading end and sealed to it. The horseshoe shaped enclosure is rolled in position over the trailing end of the section to be installed and sealed to both it and the previously installed cylinder. After the cylinder section 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 are removed so that final alignment, fit up and welding of the new section can proceed.

9.4 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) are mounted on rails that are temporarily placed on the concrete slab beneath the beam tube module. The clean room is 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 contains 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 has a place for baffle storage, since the baffles will be installed after leak testing of the closure seams between cylinder sections. The workroom contains 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 egress and inert gas usage

There is a forced air system located at the beginning of the module at the mid-station. This provides filtered, dry air through the tube at all times and maintain a positive pressure to prevent infiltration. Back-up units and power supplies are in place to guarantee continued positive pressure during equipment maintenance and power disturbances.



Supplier's Reference No. _____

CBI

LIGO CLEAN ROOM
GENERAL Views
and Dimensions

Customer No. _____ Date _____

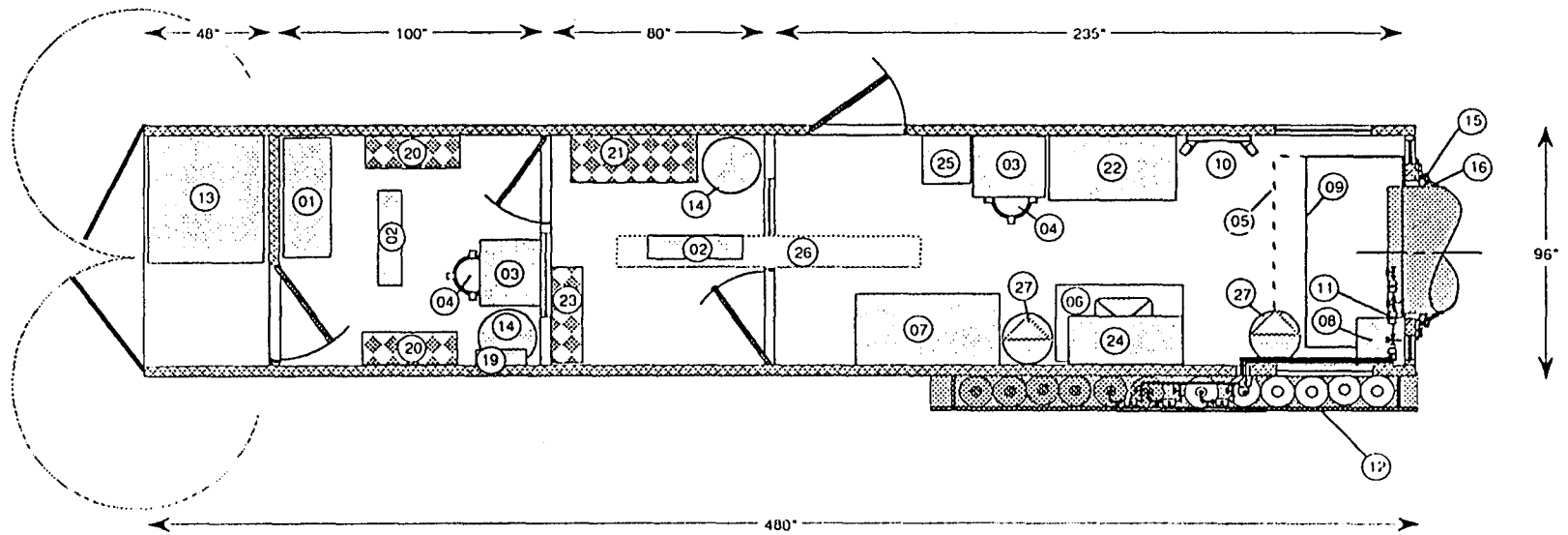
By _____ Dra. _____

Checked _____

Scale _____

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▶ INDICATE CHANGE FROM PREVIOUS ISSUE



EQUIPMENT LISTING

MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.	MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.
01	1	Hanging Lockers with Bar	4 comp		MMC4892T1	15	1	Inflatable Seal for Tube Penet.	48" Ø	See Seal Det	CRS-5-ISTP
02	2	Changing Bench	36"	Incls Pedistals	MMC4854T13	16	1	Secondary Gasket Seal	48" Ø	See Seal Det	CRS-6-SGF
03	2	Wall Attachment Desk	24x23"	Lift Top	MMC4894T36	17		Open			
04	2	Clean Room Stool	30" h		MMC5096T53	18	1	Screen Door Assembly	50" Ø	100 Mesh	CRS-7-SDA
05	1	Overhead Hood	48"x72"	See HVAC	HVAC EX04	19	1	First Aid Equipment Cabinet	18x24"	with Supplies	Mascon 53500M
06	1	Mobile Drain-off Workbench	48x28"	with Castners	MMC4785T24	20	6	Chrome Wire Mesh Shelving	36x12"	2units/3 shivs	MMC4717T22 & 17
07	1	Baffle Storage Cart	27x54"	with Castners	MMC2559T31	21	4	Chrome Wire Mesh Shelving	48x18"	1unit/4 shivs	MMC4717T25 & 44
08	1	Gas Hose Bin 18" Deep	18x18"	18ga.S.S	CRS-1-GHB	22	1	Inflatable Purge Dam Storage	48x24"	48" Height	MMC2559T21
09	1	Floor Tray Drain Mat	36"x72"	18ga.S.S	HVAC EX07	23	2	Chrome Wire Mesh Shelving	48x12"	1unit/2 shivs	MMC4717T23 & 15
10	2	Personnel/Equip Creepers	18"x36"	Tufflon Wheels	CRS-2-PEC	24	1	Flammable Mat'l Stge Cabinet	43x18"	Per OSHA	MMC4477T16
11	4	Purge Manifold Systems	N/A	S.S.Const	CRS-3-PMS	25	1	Tool Storage Cabinet	18x18"	66" Height	MMC4451T52
12	1	Gas Bottle Rack	Later	Per OSHA	CRS-4-GBR	26	1	S.S. Tube Storage Container	12x12"	114" Length	CRS-8-TSC
13	1	HVAC/Filter Unit	N/A	See HVAC	HVAC AHU-1	27	2	Oily Waste Cans	21" Ø	Per OSHA	MMC4070T8
14	2	Trash Container	N/A	Per NFPA	MMC4308T4	28	2	S.S. Dispensing Plunger Cans	1 qt	Not Shown	MMC40075T51
						29	2	Type II Safety Can with Spout	2 qt	Not Shown	MMC4200T7

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's Purchase No. _____

CBI

LIGO CLEAN ROOM EQUIPMENT PLAN VIEW

Customer No. _____ Date _____

Project No. _____

Scale _____

Drawn by _____

Checked by _____

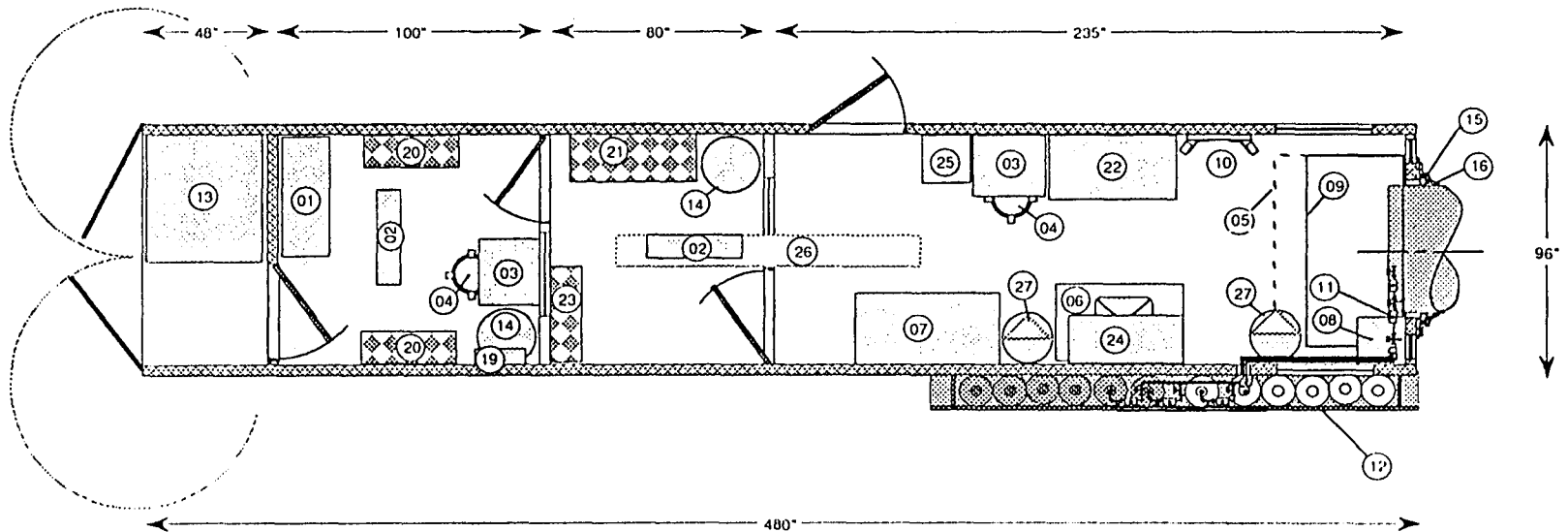
Approved by _____

Issue No. _____

Revision No. _____

Revision Description _____

Revision Date _____



EQUIPMENT LISTING

MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.	MARK	QTY	DESCRIPTION	SIZE	COMMENTS	REFERENCE NO.
01	1	Hanging Lockers with Bar	4 comp		MMC4692T1	15	1	Inflatable Seal for Tube Penet.	48" Ø	See Seal Det	CRS-5-ISTP
02	2	Changing Bench	36"	Incls Pedistals	MMC4854T13	16	1	Secondary Gasket Seal	48" Ø	See Seal Det	CRS-6-SGF
03	2	Wall Attachment Desk	24x23"	Lift Top	MMC4894T36	17		Open			
04	2	Clean Room Stool	30" h		MMC5096T53	18	1	Screen Door Assembly	50"Ø	100 Mesh	CRS-7-SDA
05	1	Overhead Hood	48"x72"	See HVAC	HVAC EX04	19	1	First Aid Equipment Cabinet	18x24"	with Supplies	Mascon 53500M
06	1	Mobile Drain-off Workbench	48x28"	with Castners	MMC4785T24	20	6	Chrome Wire Mesh Shelving	36x12"	2units/3 shlvs	MMC4717T22 & 17
07	1	Baffle Storage Cart	27x54"	with Castners	MMC2559T31	21	4	Chrome Wire Mesh Shelving	48x18"	1unit/4 shlvs	MMC4717T25 & 44
08	1	Gas Hose Bin 18" Deep	18x18"	18ga.S.S	CRS-1-GHB	22	1	Inflatable Purge Dam Storage	48x24"	48" Height	MMC2559T21
09	1	Floor Tray Drain Mat	36"x72"	10ga.S.S	HVAC EX07	23	2	Chrome Wire Mesh Shelving	48x12"	1unit/2 shlvs	MMC4717T23 & 15
10	2	Personnel/Equip Creepers	18"x36"	Teflon Wheels	CRS-2-PEC	24	1	Flammable Mat'l Storage Cabinet	43x18"	Per OSHA	MMC4477T16
11	4	Purge Manifold Systems	N/A	S.S.Constr	CRS-3-PMS	25	1	Tool Storage Cabinet	18x18"	66" Height	MMC4451T52
12	1	Gas Bottle Rack	Later	Per OSHA	CRS-4-GBR	26	1	S.S. Tube Storage Container	12x12"	114" Length	CRS-8-TSC
13	1	HVAC/Filter Unit	N/A	See HVAC	HVAC AHU-1	27	2	Oil Waste Cans	21"Ø	Per OSHA	MMC4070T8
14	2	Trash Container	N/A	Per NFPA	MMC4300T4	28	2	S.S. Dispensing Plunger Cans	1 qt	Not Shown	MMC40075T51
						29	2	Type II Safety Can with Spout	2 qt	Not Shown	MMC4200T7

▶ INDICATE CHANGE FROM PREVIOUS ISSUE

Supplier/Purchaser's No. _____

CBI

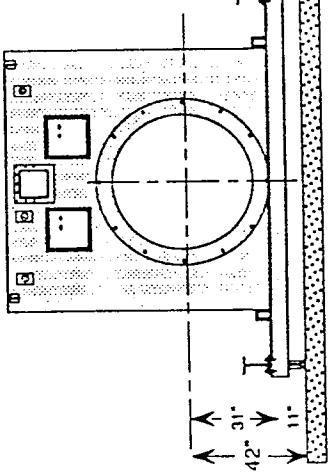
LIGO CLEAN ROOM EQUIPMENT PLAN VIEW

Revised by: _____ Date: _____

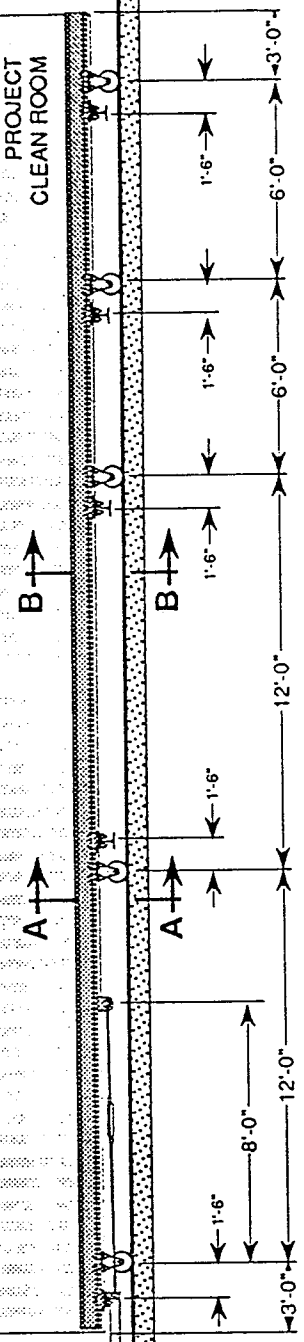
Drawn by: _____ Date: _____

Scale: _____

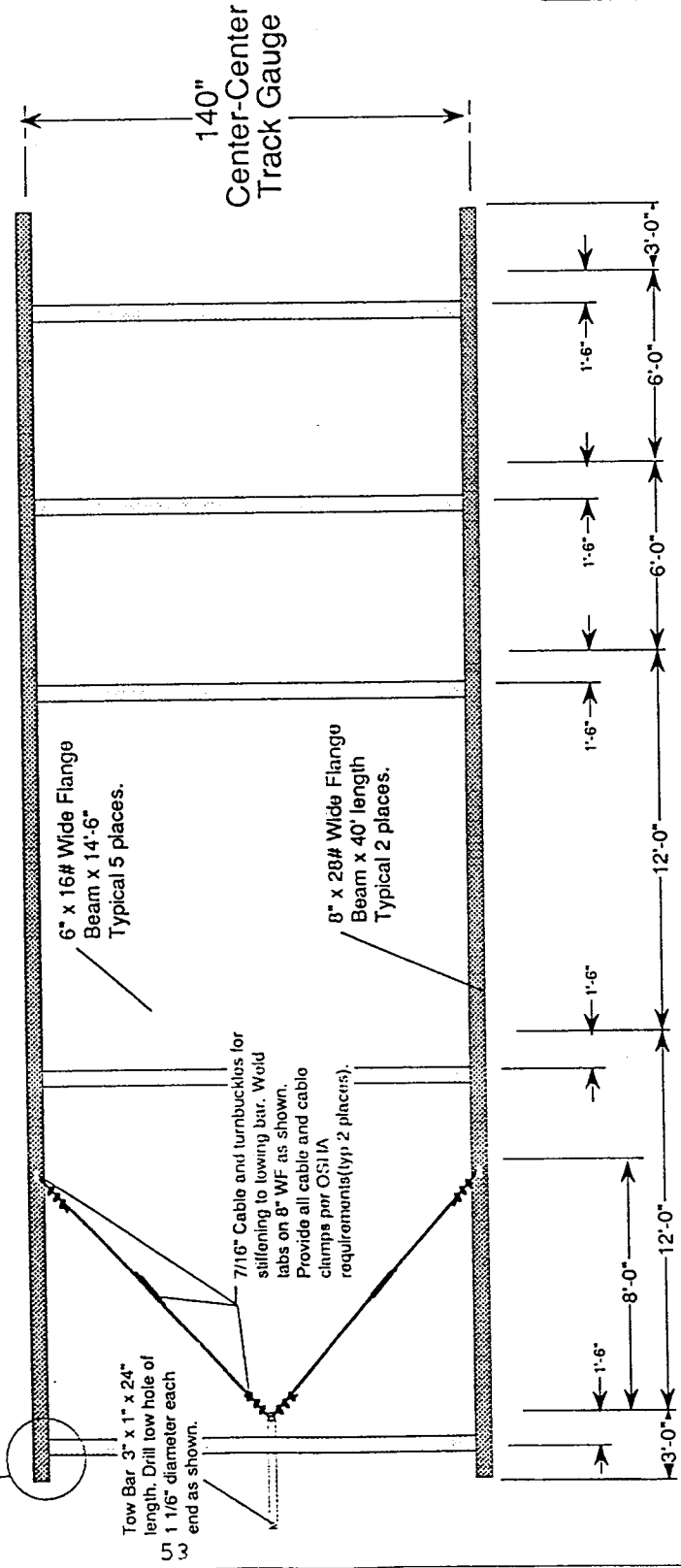
Notes: _____



LIGO
PROJECT
CLEAN ROOM



Connection is bolted: 3/4" -unc x
A325 material
Minimum of 4 bolts per connection.
Torque to bolts to proper tension
Typical at 10 connections



Tow Bar 3" x 1" x 24" length. Drill tow hole of 1 1/8" diameter each to end as shown.

INDICATES CHANGE FROM PREVIOUS ISSUE

Supplier's Purchase Order No. _____

CBI CLEAN ROOM Rolling Frame & Track Assembly

LIGO

Customer No. _____

Project Name _____

Quantity _____

Unit Price _____

Total Price _____

Accepted by _____ Date _____

Approved by _____ Date _____

Notes: 1. This drawing shall be used only for the project and shall not be used for any other project. 2. All dimensions are in feet and inches unless otherwise specified. 3. All materials shall be as specified in the Bill of Materials. 4. All materials shall be of the highest quality available. 5. All materials shall be new unless otherwise specified. 6. All materials shall be of the same grade and type as specified in the Bill of Materials. 7. All materials shall be of the same manufacturer as specified in the Bill of Materials. 8. All materials shall be of the same size and specification as specified in the Bill of Materials. 9. All materials shall be of the same material as specified in the Bill of Materials. 10. All materials shall be of the same type as specified in the Bill of Materials.



DOC ID BDF-1
 REV. NO. 1
 CONTRACT 930212

TITLE: BLOWER/DRYER/FILTRATION SYSTEM PAGE NO. 1 OF 5
 FOR BEAM TUBE POSITIVE AIR FLOW
 SPECIFICATION AND PROCEDURE - CALTECH

	ENGR	WELD	Corp QA	Corp CONST	MFG	PREPARED	BY SDH	DATE 06-Nov-93
						REVISED	SDH	28-Mar-94
						<u>AUTHORIZED</u>		
						REFERENCE		
						STANDARD		REV. NO.

1.0 SCOPE:

This procedure covers the activities associated with the Blower/Dryer/Filtration System(BDF) located at the stationary beginning of the construction of the beam tube modules

The BDF System provides a positive air flow of clean, dry air through the tube during constructions activities.

Two(2) redundant units will be used. Controls shall be arranged to provide automatic start-up of one unit based on the condition or failure of the first. The second unit will provide back-up during servicing of the first and visa versa.

The following activities are described in this procedure:

- 1.1 General Arrangement and Specifications for the BDF Units.
- 1.2 Operating procedures for the BDF Units.
- 1.3 Maintenance Procedures for the BDF Units.
- 1.4 Storage and Shipping of BDF Units.

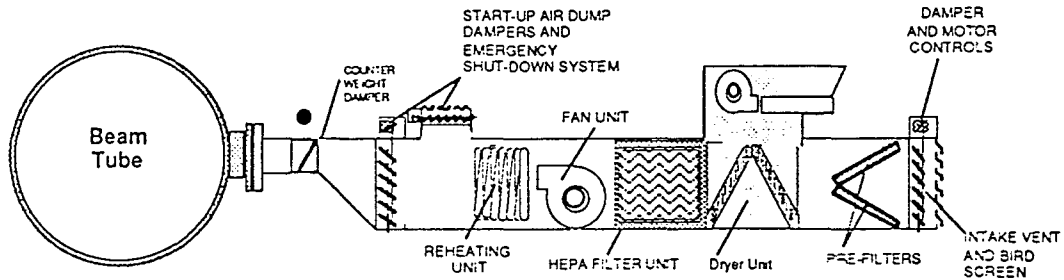
2.0 REFERENCES:

2.1 The procurement and operation of the BDF Units are 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



TITLE: BLOWER/DRYER/FILTRATION SYSTEM PAGE NO. 2 OF 5
 FOR BEAM TUBE POSITIVE AIR FLOW
 SPECIFICATION AND PROCEDURE - CALTECH



BDF SYSTEM UNIT

3.0 EQUIPMENT:

Equipment referenced in other CBI procedures will be incorporated into this procedure. For specific items, see applicable references.

- 3.1 1500 CFM System Fan and Motor
- 3.2 DX Pre-Cooling Coil
- 3.3 DX After Cooling Coil
- 3.4 Air Cooled Condensing Units
- 3.5 30% Efficient Pre-Filters
- 3.6 Outside Air Motorized Damper
- 3.7 HEPA Filter Sized at 100, rated >0.3 Microns
- 3.8 Spare HEPA Filter for one change
- 3.9 Motorized start-up and by-pass dampers
- 3.10 Electric Re-Heat Coils, SCR controlled
- 3.11 Fire/Smoke detectors
- 3.12 Control for Redundant Operation
- 3.13 Weatherproof/Outdoor Construction

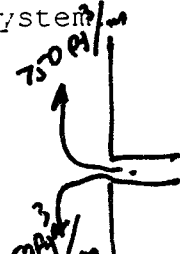
*25
1509
6p*

4.0 Operation of Units:

The BDF System shall produce the following output of air:

- 4.1.1 Air Flow volume of 1500 CFM to be divided equally in two directions. This provide a air flow velocity of 60 fpm.
- 4.1.2 Air quality shall maximum particle size of 0.3 microns using a HEPA 100 filter system

*chick
this #*

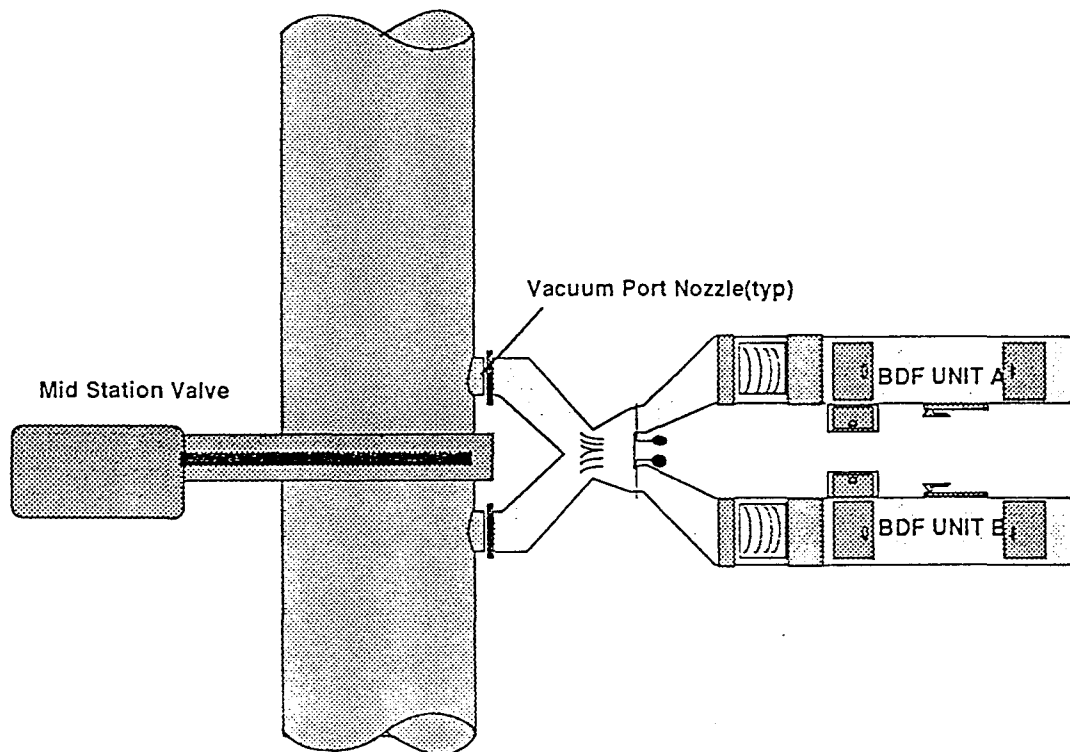


TITLE: BLOWER/DRYER/FILTRATION SYSTEM PAGE NO. 3 OF 5
FOR BEAM TUBE POSITIVE AIR FLOW
SPECIFICATION AND PROCEDURE - CALTECH

4.1.3 Moisture content shall equal 0° dew point at 75°F outlet temperature.

The BDF System shall be operated continuously during construction activities. The following event and response shall be controlled automatically.

- 4.2 Controls shall provide automatic unit start-up on the loss of the operating unit.
- 4.3 Controls shall shut down units and close all dampers upon detection of smoke or fire.
- 4.4 All dampers shall be provided with spring control to close upon loss of power to the unit.



BDF SYSTEM TUBE CONNECTION

4.4 Units shall be equipped with mercury filled, nitrogen purged contractors for motor and compressor operation.



9.5 ALIGNMENT

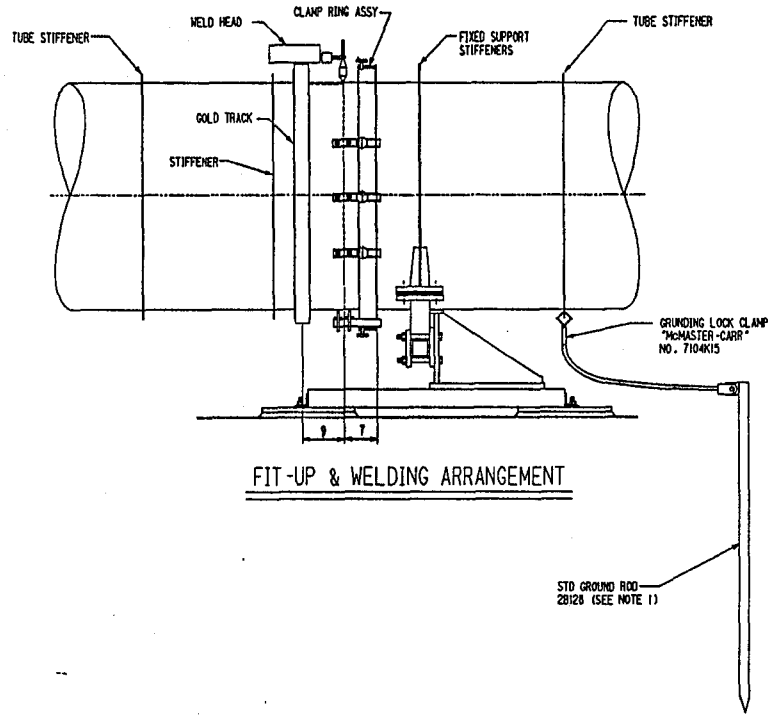
The current LIGO requirements include the alignment of the beam tube to provide a 1.07 meter clear aperture based on reference monuments supplied by Caltech spaced at 250 meter interval. The beam tube position is adjustable at all fixed and flexible supports which are spaced at just over 20 meters. Baffles are located at each support and thus support adjustments controls the clear aperture.

CBI has considered a number of options for the initial beam tube alignment and for the system alignment for facility operation. After review of the available techniques and systems, CBI proposes to utilize the GPS system as developed by Trimble Navigation. This system is utilized for setting the rough and final alignment for the tubes in accordance with approved procedures. CBI recommends the use of GPS as the base line system for the entire facility and follow-up alignment checking and adjusting. Procedures "ALI-B" and "ALM-B" have been developed to apply GPS to the beam tube module construction. Attached to the end of this section is a proposal for the use of the "Differential Global Positioning Methods for the LIGO Project". The use of the GPS system is proposed for the entire facility would replace the current monuments spaced at 250 meter intervals.

Basically, an initial tube layout is made on the foundations on embedded or attached plates. These initial layouts are used to initially set the tubes for welding utilizing conventional levels and plumb line techniques. After welding and leak testing, The GPS equipment is used to fine tune the tube in position. Adjustments are made to the structural support of make this alignment. A final alignment is made after the module is complete, to verify straightness and the aperture required.

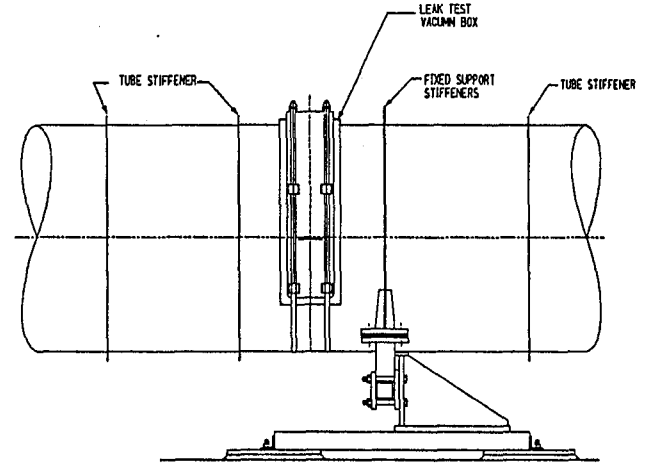
9.6 FIT & WELD PROCESS

When the alignment is complete, a purge collar is installed on the inside of the seam to be welded and the fitting and welding of the joint is accomplished from the outside using the tungsten inert gas process. When the welding is complete, the purge collar remains on the inside of the seam and the necessary inside leak test gas is provided. After leak testing and the removal of the inner purge collar, the leading end (clean room end) of the beam tube module is 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.



FIT-UP & WELDING ARRANGEMENT

STD GROUND ROD
28128 (SEE NOTE 1)



LEAK TEST ARRANGEMENT

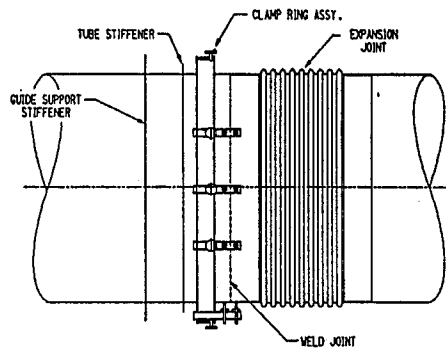
NOTES:

- 1. INSTALL GROUND ROD EVERY 250'-0."

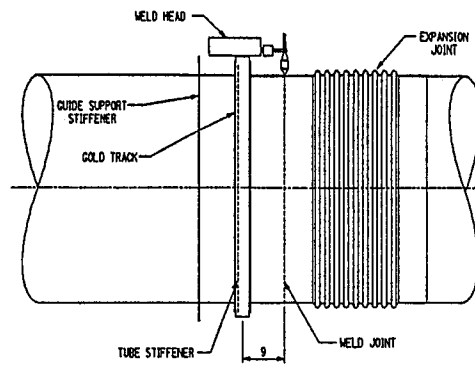
CAD FILE: 330212.DWG

Supplier's/Purchaser's No.	
CBI	
LIGO PROJECT	
FIT-UP WELDING AND LEAK TESTING CONFIGURATIONS AT FIXED SUPPORTS	
Customer's No.	Contract No.
By <u>JL</u> Date <u>J-10-04</u>	<u>930212</u>
<u>J.J. RUCKELSTEINER</u> Engineering Submanager	Drawn <u>EBM</u> Rev.
	Sheet <u>1</u>
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 OR FOR CBI. REPRODUCTION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN.	
<small>THIS DRAWING WAS PREPARED BY HOUSTON CONSTRUCTION SERVICES REPT. 1040 FORM ENG 20 4 REV 2/03</small>	

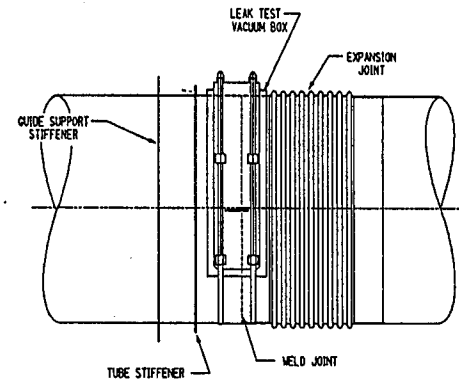
▶ INDICATES CHANGE FROM PREVIOUS ISSUE



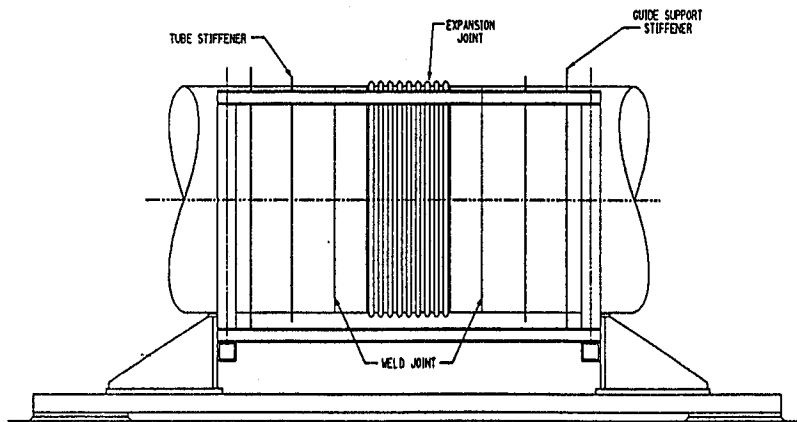
FIT-UP ARRANGEMENT



WELDING ARRANGEMENT



LEAK TEST ARRANGEMENT



FINAL POSITION GUIDED SUPPORT

NOTES:

1. GUIDE SUPPORTS ARE INSTALLED AFTER WELDING AND LEAK TESTING ARE COMPLETE

CAD FILE: 3022134.DWG

Supplier's/Purchaser's No.	
CBM	
LIGO PROJECT	
FIT-UP WELDING AND LEAK TESTING CONFIGURATIONS AT GUIDE SUPPORTS	
Customer's No.	Contract No.
By: J.J. ANGELSTETTER	Date: 2-11-24
Engineering Supervisor	Dwg. No. 930217
Sheet 1	Rev. 1
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▶ INDICATES CHANGE FROM PREVIOUS ISSUE



9.7 TESTING AND INSPECTION

Once the horseshoe shaped welding enclosure is out of the way the leak testing enclosure is rolled into place in preparation for leak testing.

Procedure HMST2N deals with the helium mass spectrometer hood testing of the closing weld joints between tube cans.

9.8 CLEANING

After the leak testing is complete and the inside equipment has been moved to the next seam to be tested, this cylinder section is carefully inspected for cleanliness, cleaned as necessary, and the baffle for this cylinder section is installed.

9.9 SEALING & SECURITY

There is a moveable seal that is installed at the leading edge of the section after it is cleaned. This seal progresses down the tube as it is assembled and serves notice that the area behind it has been completed and cleaned. The seal is 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 mid-station (starting point of beam tube module assembly) toward the clean room. A positive pressure is always be maintained inside the module with air flowing from the end completed toward the end being worked.

10.0 QUALITY MANUAL

The QA Manual is based on ANSI/ASQC Q91-1987 (ISO 9000). CBI has been using this quality system at overseas locations for several years. A full copy of this plan was submitted under separate cover. 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



LIGO PROJECT
WBS 300
CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

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. CBI has adapted this quality system manual into a contract specific manual for the LIGO project. The QA Manual meets 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) are 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.

11.0 SAFETY MANUAL

11.1 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.

The Safety Manual for the LIGO Project was submitted under separate cover. It addresses the following areas:

L. I. G. O. SAFETY MANUAL

1.0	-----	Safety Policy Statement
2.0	-----	Safety Responsibilities
3.0	-----	Safety Program
4.0	-----	Correcting Safety Violations
5.0	-----	Accident Reporting
6.0	-----	Subcontractors and Suppliers
7.0	-----	Regulatory Compliance
8.0	-----	Hazard Communication Program
9.0	-----	Occupational Disease
10.0	-----	Medical Facilities
11.0	-----	Housekeeping
12.0	-----	Sanitation
13.0	-----	Personal Protective Clothing & Equipment
14.0	-----	Material Handling and Storage
15.0	-----	Control of Ionizing Radiation
16.0	-----	Ventilation
17.0	-----	Lighting
18.0	-----	Fire Prevention
19.0	-----	Fire Protection
20.0	-----	Electrical Wiring and Apparatus
21.0	-----	Hand and Power Tools
22.0	-----	Equipment Maintenance



LIGO PROJECT
WBS 300
CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

23.0	-----	Motor Vehicles
24.0	-----	Lifting Equipment
25.0	-----	Scaffolds, Platforms, and Ladders
26.0	-----	Abrasive Blasting & Painting
27.0	-----	Earthmoving and Handling Equipment
28.0	-----	Excavations
29.0	-----	Trenching & Shoring
30.0	-----	Piping & Mechanical
31.0	-----	Pile Driving
32.0	-----	Unfired Pressure Vessels
33.0	-----	Welding and Cutting
34.0	-----	Steel Erection
35.0	-----	Concrete Construction
36.0	-----	Floor and Wall Openings

12.0 ENVIRONMENTAL PLAN

CBI has received Caltech's Environmental Assessment of the Hanford Site and has incorporated the necessary requirements into its Environmental Plan requirements. CB&I Corporate has produced the General Conditions of Environmental Plan which address the following issues:

- 12.1 Site Documentation/Contamination
- 12.2 Stormwater Permits
- 12.3 Hazardous Materials Handling
 - 12.3.1 Storage
 - 12.3.2 Disposal
 - 12.3.3 Manifest
- 12.4 Regulatory Inspections
- 12.5 Local/State Permits
- 12.6 Surface Drainage/Outfall Discharges
- 12.7 Sanitation
- 12.8 Training & Documentation
- 12.9 Emergency Communications
- 12.10 Spill Prevention
 - 12.10.1 Contamination
 - 12.10.2 Control
 - 12.10.3 Records
 - 12.10.4 Response Plan



- 12.11 Chemical Hygiene Plan
- 12.12 Fuel Storage/Handling

13.0. SCHEDULE & COST ENGINEERING

13.1 SCHEDULE, CPM SOFTWARE:

Caltech's schedule indicates starting erection of beam assemblies only after all assemblies have been fabricated. CBI plan shows the immediate placing of assemblies after fabrication. Space is a premium.

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:

- 13.2 Update Timing
- 13.3 Progress Reporting
 - 13.3.1 Format
- 13.4 Submittal Control
- 13.5 Weekly Schedule Meetings
- 13.6 Short Term Schedules
- 13.7 Earned Value/Progress Payment Evaluation
- 13.8 Dual Site Coordination

13.9 SCHEDULE & WORK BREAKDOWN STRUCTURE

A preliminary construction WBS description is attached for the Option. This WBS is based on the "FABSEQ", "INSTALLSEQ", & "MODSEQ" procedures with some of the detailed construction preparation activities required for mobilization and preparation to begin work. The schedule is an early start which will be extended for the actual start date. In addition, the schedule is not restrained by outside activities. Further refinement and incorporation into the LIGO project schedule will be required after the Beam Tube Module Design and Qualification Test.

The following schedules are attached as part of the FDR report:

- A. Hanford & Livingston Summary Bar Chart
- B. Hanford Mobilization Logic Diagram
- C. Detailed Flow Diagram for Tube Can Assembly & Erection
- D. Module Final Alignment & Testing Bar Chart
- E. Hanford WBS Chart
- F. Livingston WBS Chart



- G. Preliminary Early Date Tabular Report for Hanford Site
- H. Preliminary Early Date Tabular Report for Livingston

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.

13.9.1 WBS WORK LEVELS

13.9.1.1 WBS LEVEL ONE

The Beam Tube Fabrication and Installation work is item 1.1 for the Hanford site and 1.2 for the Livingston site. These are the first levels of the WBS.

13.9.1.2 WBS LEVEL TWO

The second level of the WBS indicates the major task groupings:

Hanford site:

- 1.1.1 Leg #1 Can Assembly & Erect
- 1.1.2 Leg #2 Can Assembly & Erect
- 1.1.3 Module Inspect & Test
- 1.1.4 Tube Cans
- 1.1.5 General
- 1.1.6 Mobilization
- 1.1.7 Expansion Bellows
- 1.1.8 Pump Ports
- 1.1.9 Stiffeners & Supports(incl. Baffles)

Livingston site:

- 1.2.1 Leg #1 Can Assembly & Erect
- 1.2.2 Leg #2 Can Assembly & Erect
- 1.2.3 Module Inspect & Test
- 1.2.4 Tube Cans
- 1.2.5 General
- 1.2.6 Mobilization
- 1.2.7 Expansion Bellows
- 1.2.8 Pump Ports
- 1.2.9 Stiffeners & Supports(incl. Baffles)

LIGO BEAM TUBE MODULE CONSTRUCTION

Chicago Bridge & Iron

March 15, 1994

1.1
Hanford Site
10/03/94.08:00A
02/05/96.02:00F

1
Leg 1 Can Assy
& Erect
01/09/95.04:00F
06/29/95.02:00F

2
Leg 2 Can Assy
& Erect
05/29/95.04:00F
11/01/95.03:00F

3
Module Inspect
& Test
06/29/95.02:00F
02/05/96.02:00F

4
Tube Cans
10/10/94.04:00F
10/09/95.05:00F

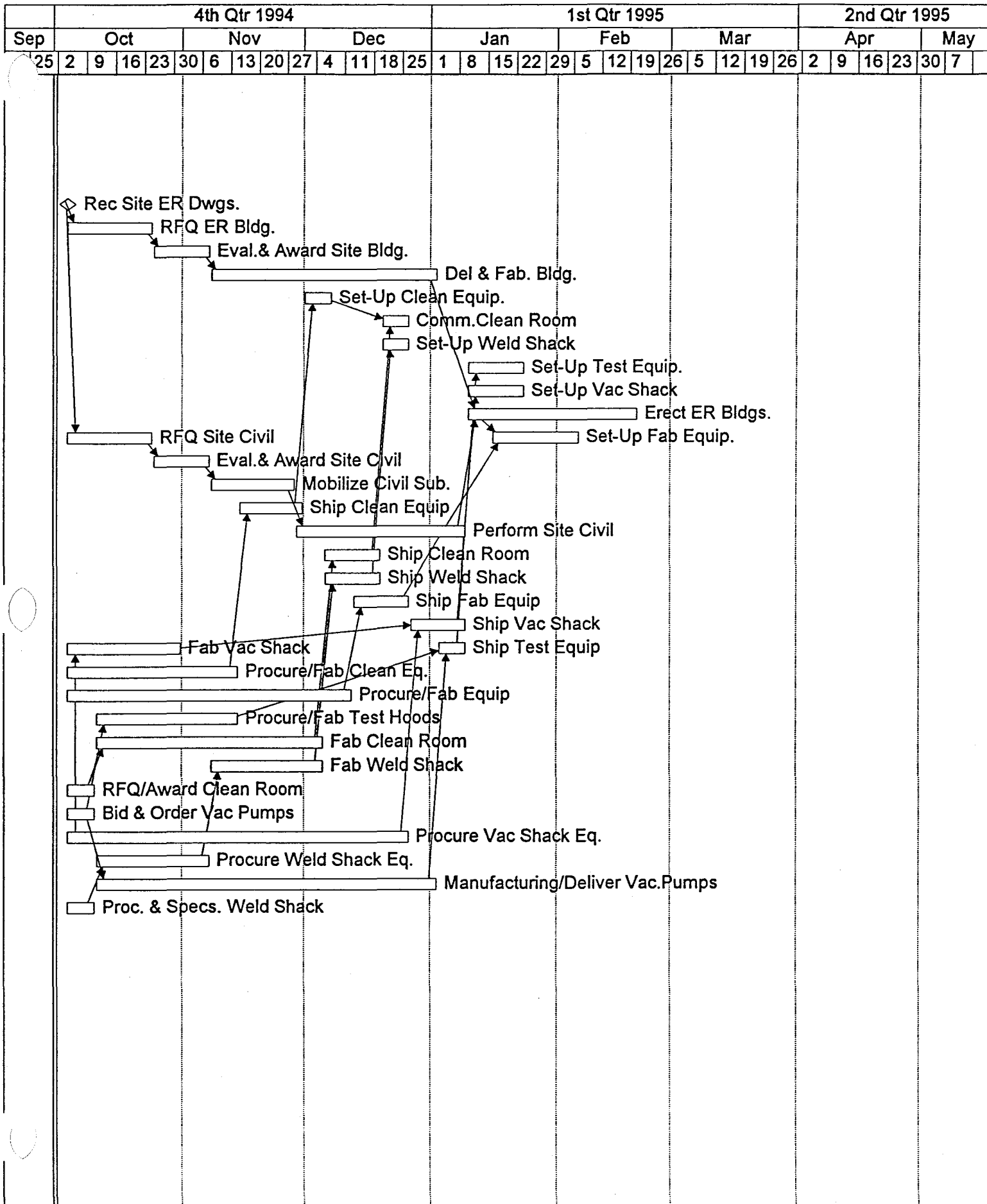
5
General
10/03/94.08:00A
02/05/96.02:00F

6
Mobilization
10/03/94.04:00F
02/20/95.05:00F

7
Expansion
Bellows
10/03/94.08:00A
07/14/95.05:00F

8
Pump Ports
10/10/94.04:00F
03/06/95.05:00F

9
Stiffeners &
Supports
10/10/94.04:00F
02/13/95.05:00F





13.9.1.3 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 Windows driven software program "Texim" is used to develop sub-project routines for 10 can schedule units (based on 10 tube cans per week production, assembly & erection). This program is then exported to the "Open Plan" database program and merged to produce the overall schedule.

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 Precommissioning
- 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

15.0 DEMOBILIZATION

15.1 EQUIPMENT

Upon the completion of CBI's work at the Hanford Site, all construction equipment is be removed transported and reassembled at the Livingston site. Following completion of the work at Livingston, all equipment is to be removed.



15.2 BUILDINGS

All temporary construction buildings are to 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.

15.3 PERSONNEL

CBI will maintain the necessary supervisory personnel at each job site until all CBI work has been completed and accepted by Caltech.

**PROPOSAL
FOR THE
USE OF
DIFFERENTIAL
GLOBAL POSITIONING METHODS
FOR
THE LIGO PROJECT**

Summary-

CBI proposes the use of Global Positioning System(GPS) technology for construction and maintenance of the LIGO facilities. Specifically, the "Differential" method of GPS(DGPS) positioning will provide accuracies within the LIGO requirements. Commercially available equipment will be used for all aspects facility construction and maintenance including civil, structural and beam tube positioning activities. Data collection and manipulation will be performed with total station¹ software creating a three dimensional rectangular coordinate system for each site. These coordinates will be referenced to the GPS ellipsoidal grid. Grid coordinate identification provides millimeter accuracy when determining relationships between LIGO facilities.

Facility and equipment design will allow for maximum use of GPS technology in an effort to reduce error inherent with radio transmission and reception of GPS signals. Designs for monument placement, antenna elevations, reduced horizon aspect² of structures, etc. are requirements for DGPS use. This proposal provides solutions for meeting these requirements.

Outline-

This is a listing of planned methods for achieving the required LIGO accuracies while making maximum use of GPS technology. The following is presented in increasing detail from the first paragraph of



¹ Total Station is a method of data collection and processing providing coordinate systems and measured points in three dimensions. This software is available from the GPS equipment manufacturer..

² GPS antenna require a minimum of +15° horizon view for maximum satellite coverage.

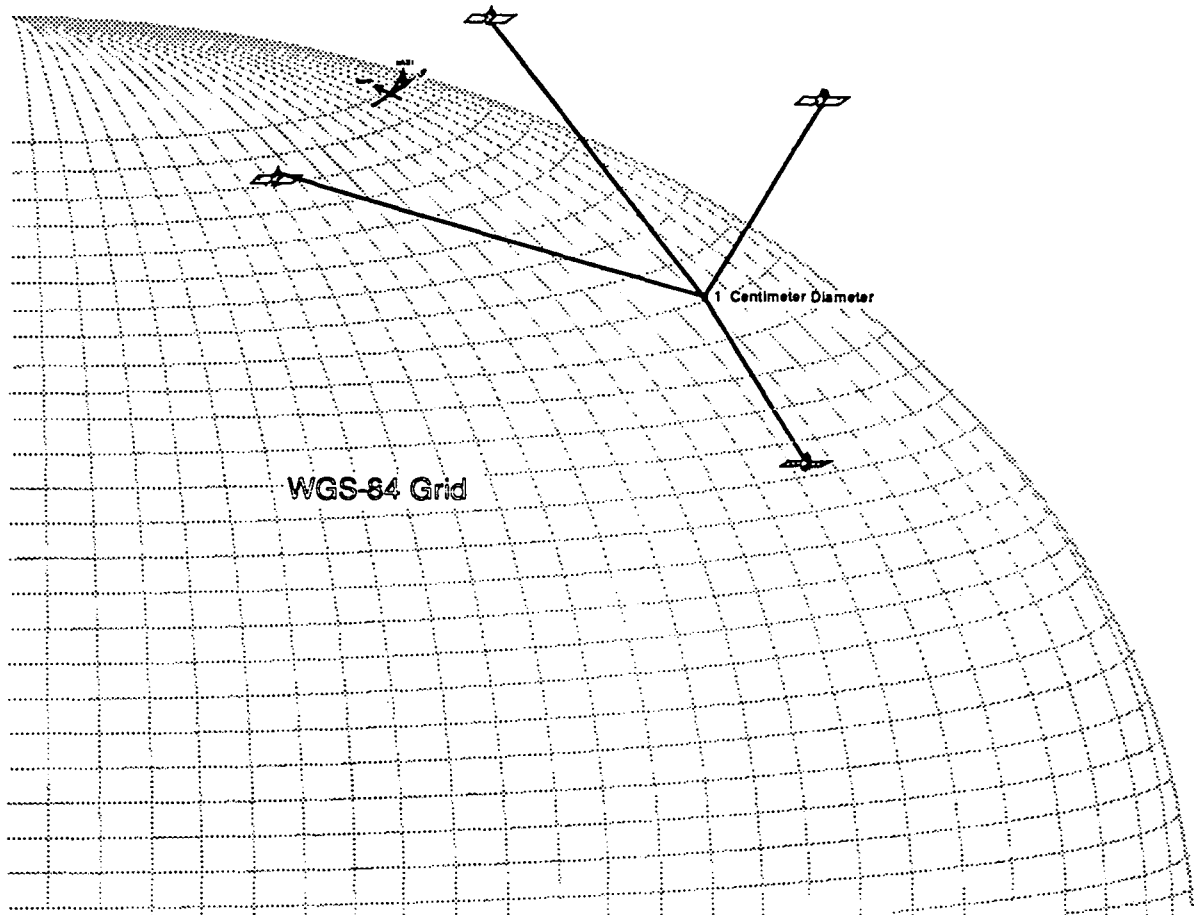
*Relative
align of
a site
is critical
Calculate
align of
points
between
sites
set a
range
current*

PROPOSAL

For The Use Of Differential Global Positioning Methods

For

The LIGO Project



each subject. Details presented in this proposal are conceptual in nature. Specific detail are included in Appendix A.

- 0.0 General GPS Information
- 1.0 Initial Site Survey and Listing of the GPS Scope of Work
- 2.0 Monument Design and Arrangement
- 3.0 DGPS Equipment Configurations
- 4.0 Beam Tube Alignment and Access Designs
- 5.0 Qualification of RTK Equipment

0.0 General GPS Information

The Global Positioning System(GPS) is a constellation of 24 satellites orbiting the earth. Each of these satellites is equipped with an atomic

PROPOSAL

For The Use Of Differential Global Positioning Methods
For
The LIGO Project

clock and has a precisely know orbit. Broadcasts from each satellite provide time and position information via radio waves. Commercially available GPS equipment will range from on-board ship computers to hand held receivers. This equipment can receive multiple satellite broadcasts and determine locations anywhere on earth within a few meters. Today, these systems are being used in many industries and through out the world. Parcel post companies can monitor their vehicles and locate which side of the street a truck is parked. Already, auto makers are developing monitoring systems that will pin-point a driver's position to a map reference. And in the near future, farmers will be able to plot out their fields and GPS controllers will drive their tractors to within centimeter accuracies.

Classical GPS-

The Global Positioning System "GPS" method uses four or more satellite broadcasts to determine position. A process similar to triangulation is used to locate a 'point of interest' position. The GPS equipment receives signals from the satellites and calculates position based on the known orbits and the distance from each satellite. This distance is determined by receiving a satellite signal that is coded with the time it left the satellite. The receiver divides this time by the speed of light and determines its distance from the point of interest. However, the speed of light is only constant in a vacuum and the distance the radio wave travels is filled with unknowns. Therefore, this form of autonomous³ GPS is restrained in its accuracies due to errors in satellite receptions. These errors consist of atmospheric conditions⁴, multipath errors (bouncing off obstacles like trees or buildings), and scrambling, known as "Selected Availability" error (the Department of Defence induces error to dilute accuracies for hostile forces). Luckily, the armed forces have allowed the commercial navigation industry to pursue another technique known as *Differential* GPS(DGPS).

³ Autonomous meaning a single receiver moving around the earth and within the collective error, monitoring its location.

⁴ Atmosphere is used to include the ionosphere and troposphere.

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**For The Use Of Differential Global Positioning Methods
For
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Differential GPS Methods-

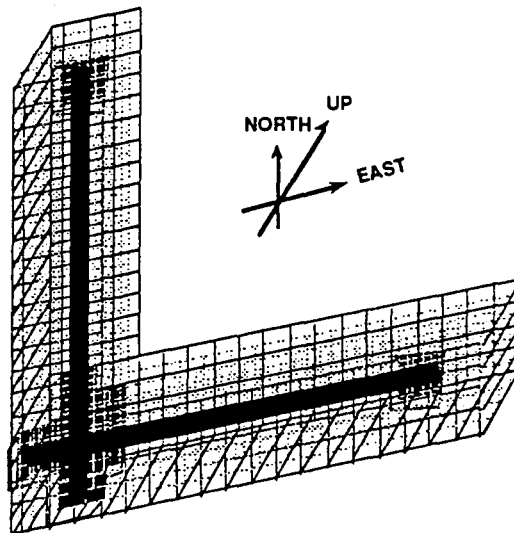
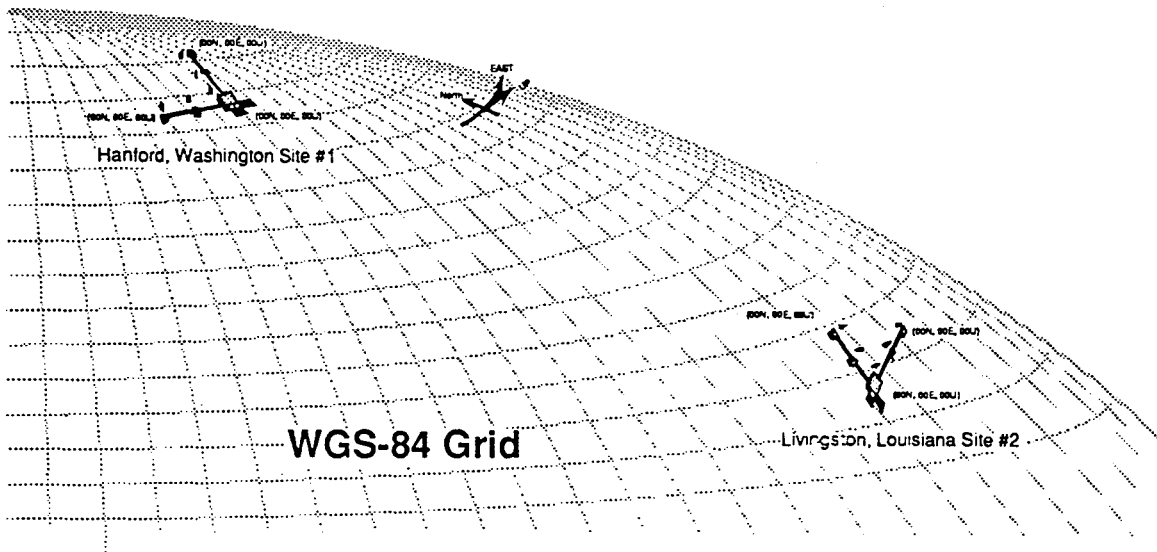
The few meters or even ten or twelve centimeters are not accurate enough for the proposed LIGO use. CBI proposes the use of the commercial method for DGPS for the LIGO project.

Differential GPS(DGPS) is a method of determining satellite transmission error with the result of increasing accuracies by magnitudes. This is accomplished by using two or more receivers that work together in a relatively small area of one-hundred kilometers or less. The satellites are high enough that the signals pass thru the same slice of atmosphere and therefore the errors are the same to each receiver. The first receiver is called the "Reference Receiver" and is located on a *known point*. The Reference Receiver monitors satellite signals in reverse. By knowing its position, and the satellite's position, the receiver calculates the distance and corrects for timing. These corrections are saved and processed later with the second receiver's data. These errors are constantly changing, so their corrections must be monitored continuously. The second receiver is known as the "Roving Receiver." As its name implies, it is moved over the area and positioned at points of interest. Data is collected from satellite transmissions and stored. Rover receiver data points are then post-processed with the reference receiver's correction data and millimeter accuracies are achieved within a few hours. This type of DGPS surveying is known as the "Static" method. This method of GPS, when used with "dual frequency" receivers achieves the greatest accuracies available in GPS technology. This Dual Frequency method will be used for determining monument locations, establishing the reference coordinate systems, and defining their locations to the WGS-84 ellipsoidal grid.

Real time data processing is required for GPS technology to become useful for construction and maintenance activities. This is possible when the reference receiver sends data over radio signals directly to the roving receivers. The roving receivers process corrections and achieve centimeter accuracies within 5 to 15 second time periods. This is known as the Real Time "Kinematic"(RTK) method and at this time, available from only one known manufacturer. The RTK trade off in accuracies do not compromise the LIGO requirements and its proposed use for daily construction and future maintenance will increase the efficiencies of layout and positioning activities at the LIGO facilities.

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**LIGO TYPICAL
COORDIANTE SYSTEI**

1.0 Initial Site Survey & GPS Scope of Work

GPS technology will be incorporated in all layout and surveying activities associated with the LIGO construction. The following is a general list of these planned activities.

Initial Site Survey-

Each site will receive a high accuracy DGPS "Static" survey that will determine monument positions within millimeter accuracies. This

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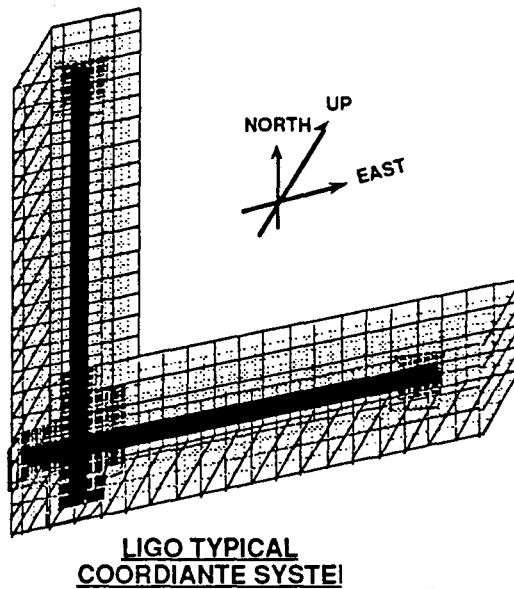
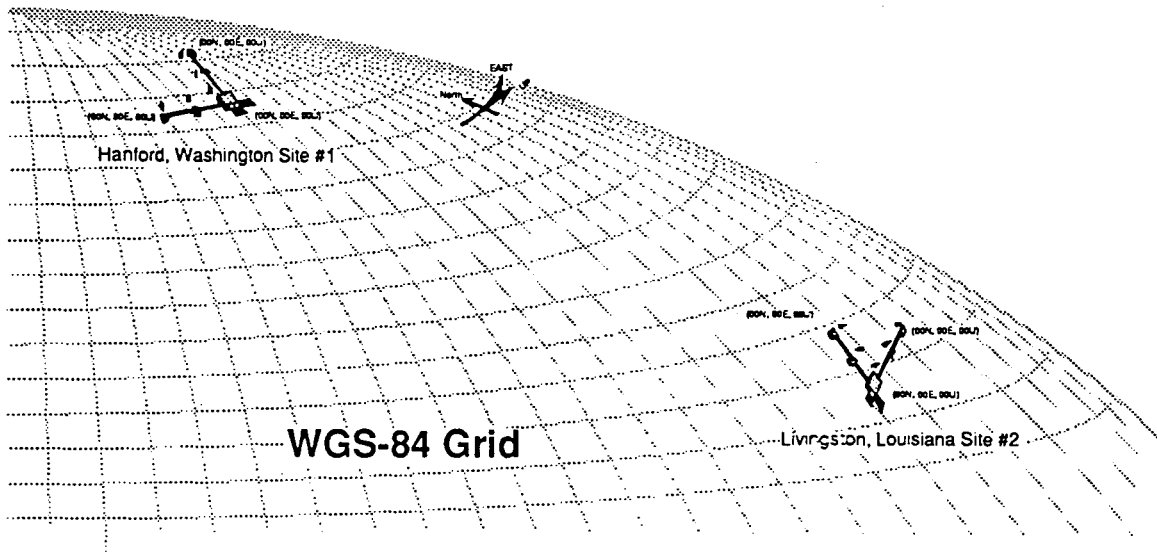
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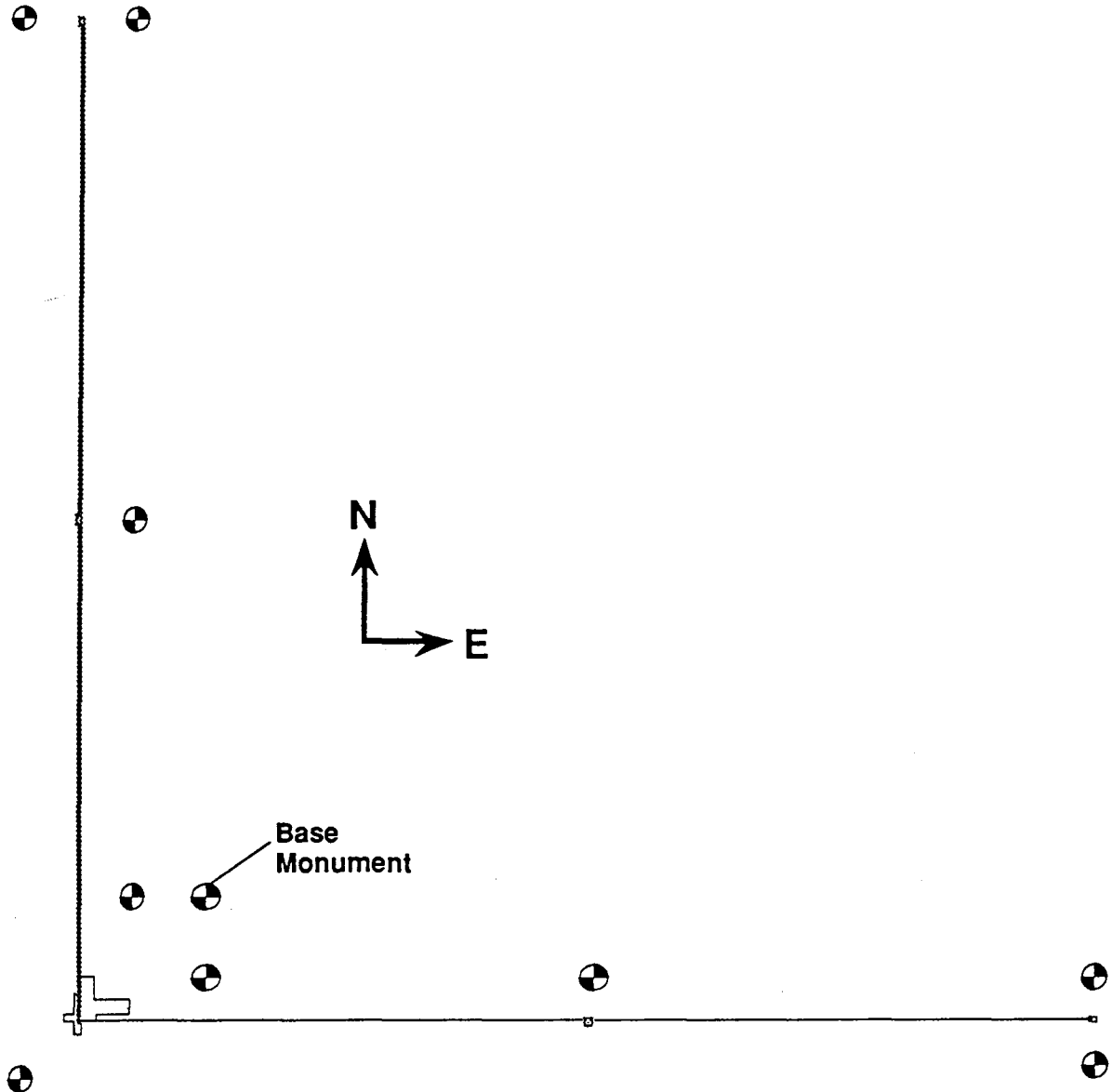
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survey will define a three dimensional rectangular coordinate system(North, East, Up). This coordinate system will be used for construction and maintenance activities at each LIGO facility. Periodic static surveys will be performed during the life of each facility to determine monument displacement and provide adjustments for the coordinate system.



The defined center of the coordinate system will be the point of intersection of the beam tubes at the corner station. Elevation will be set based on beam tube centerline at the four-way valve and references will be determined for each monument. An example of reference

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coordinates when based on a "theoretical" North/East site rotation is noted below:

Description	North	East	Up
Beam Tube Intersection	0.000m	0.000m	0.000m
Ref Monument "Base"	+50.000m	+50.000m	-1.000m
Ref Monument "A North"	+50.000m	+10.000m	-1.000m
Ref Monument "B North"	+2,000.000m	+10.000m	-1.000m
Ref Monument "C North"	+4,000.000m	+10.000m	-1.000m
Ref Monument "A East"	+10.000m	+50.000m	-1.000m
Ref Monument "B East"	+10.000m	+2,000.000m	-1.000m
Ref Monument "C East"	+10.000m	+4,000.000m	-1.000m
Ref Monument "S-W"	-25.000m	-25.000m	-1.000m
Ref Monument "N-W"	+4,000.000m	-10.000m	-1.000m
Ref Monument "S-E"	-10.000m	+4,000.000m	-1.000m

Each coordinate system will be referenced to the ellipsoidal grid known as the WGS-84⁵. This allows direct reference of one site coordinate system to another for determining beam tube relationships. The relationship to the WGS-84 will also reference legal monuments in the local area and provide established legal boundaries for the property.

A secondary monument system defining these boundaries will be set after the initial Static survey. These boundary monuments will meet local requirements for permanent markers and be installed using the RTK surveying method.

Listing of GPS Work Scope-

The GPS method of layout and alignment will be incorporated in job functions associated with construction activities including, but not limited to the following list. Real Time DGPS equipment and techniques will be the primary method of measurement unless otherwise noted.

- Initial Site Surveys for Construction
- Initial Layout and Installation of Monuments
- Layout and Monitoring of Civil Construction Activities
- Layout of Field and Shops Facilities
- Layout of Foundations and installation of form work
- Layout of Beam Tube Centerlines and Supports
- Alignment of Equipment, ie:, Roads, Rail systems, etc.

⁵ Grid defined by the National Geodetic Survey and used for GPS reference.

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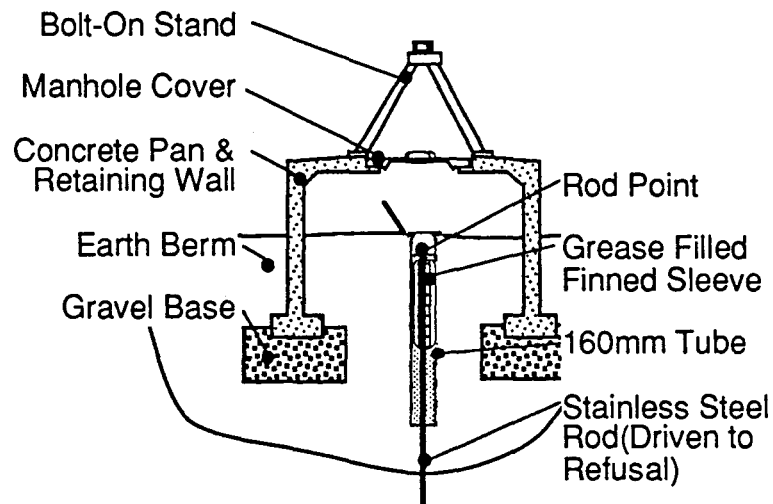
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- Layout and Construction of Structures and buildings
- Initial and Final Road Work
- Initial and Final Alignment of Beam Tubes

These items are a general planned use for RTK-GPS systems. The use of these methods will increase efficiencies over traditional surveying techniques and provide superior accuracy.

2.0 Monument Design and Arrangement

CBI proposes a monument system that will meet the long term requirements of each LIGO facility. The success of Differential GPS depends solely on firm, fixed reference points for the location of the Reference Receiver. Permanent Reference GPS monuments will consist of ten(10) rod marker systems with a protective earthen berm and foundation installed around the marker for tripod and/or fixture positioning.



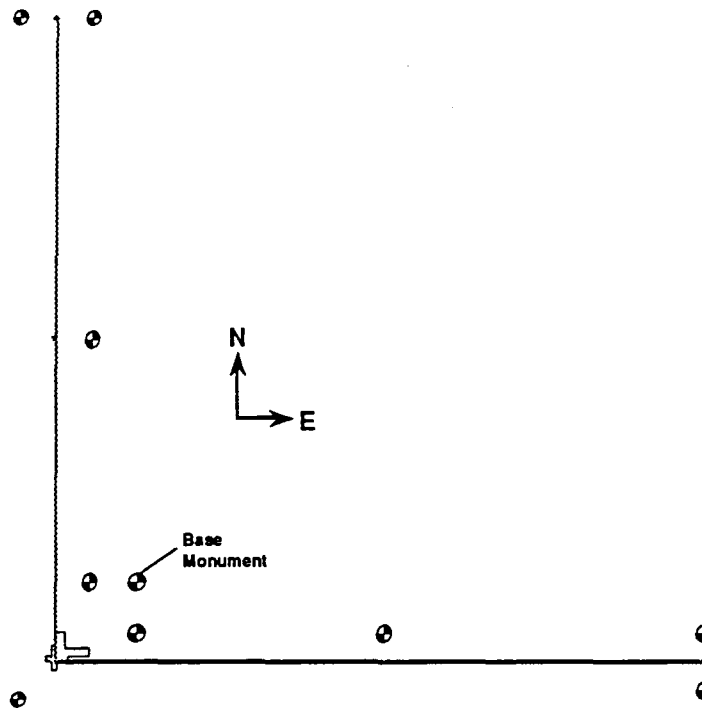
The rod marker system is provided by Berntsen International, Inc. of Madison, Wisconsin. These monuments are designed specifically for each LIGO application and will be subjected to testing during the DGPS qualification. Each monument location includes stainless steel rods with floating sleeves to compensate for frost heave and ground level shifts. Each sleeve includes a grease filled rod housing, finned sleeve and the rod point. This system is located in a 160 millimeter diameter, sand filled tube. Tests have been conducted by Geodetic Canada, the City of Winnipeg, Manitoba Canada and the National Geodetic Survey, Silver Springs, Maryland. These tests have concluded

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that the Berntsen Top Security Rod has sub-millimeter horizontal and vertical movement over test periods of five years and are measured to a 95% confidence level.

The monument foundation consists of a earthen berm, concrete pad and retaining wall. Drainage is provided away from the marker access area and a manhole and cover are provided for access to the marker system. An adjustable, ridged fixture will be bolted to the foundation pad for mounting the Reference Receiver with an all-weather cover attachment detail. The fixture will be removable and can be substitute with a standard surveying tripod when required.



Proposed monument arrangement requires positioning seven(7) monuments "within" the apex of the LIGO Beam Tube legs and three(3) monuments "outside" the apex. This arrangement allows for adequate radio reception between the Reference Receiver and the Roving Receivers with a minimum use of radio repeaters. The "Base Monument"(Reference Receiver Point) will be located beyond the LIGO *Phase C* expansion area at each facility. Expansion beyond the Corner Station Building will require movement of the reference Point. A static, dual frequency survey will be necessary to confirm any monument relocations or additions. Additional static, dual frequency geodetical surveys will be required in times of seismic or other ground disturbances and at periodic intervals during the facility life span.

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Based on the current monument reports, CBI suggests that a 5 year period be considered.

3.0 DGPS Equipment Configurations

Differential Global Positioning is an advancing technology that improves daily in what will soon be a five billion dollar industry. There appears to be three major suppliers of DGPS equipment suitable for Static Geodetical surveying equipment. These are Ashtech, Leica and Trimble Navigation. CBI proposes that the DGPS surveying contractor provide specifications on equipment to be used during the initial survey along with the proposed reporting format.

Static, Dual Frequency DGPS Equipment-

Initial Geodetical survey equipment will be comprised of dual frequency DGPS receivers and will utilize static techniques. This equipment will be supplied by the Surveying Contractor and approved by CALTECH prior to its use. Post-processing of data and error corrections will be required, and the Surveying Contractor will provide this equipment and service per a pre-approved format.

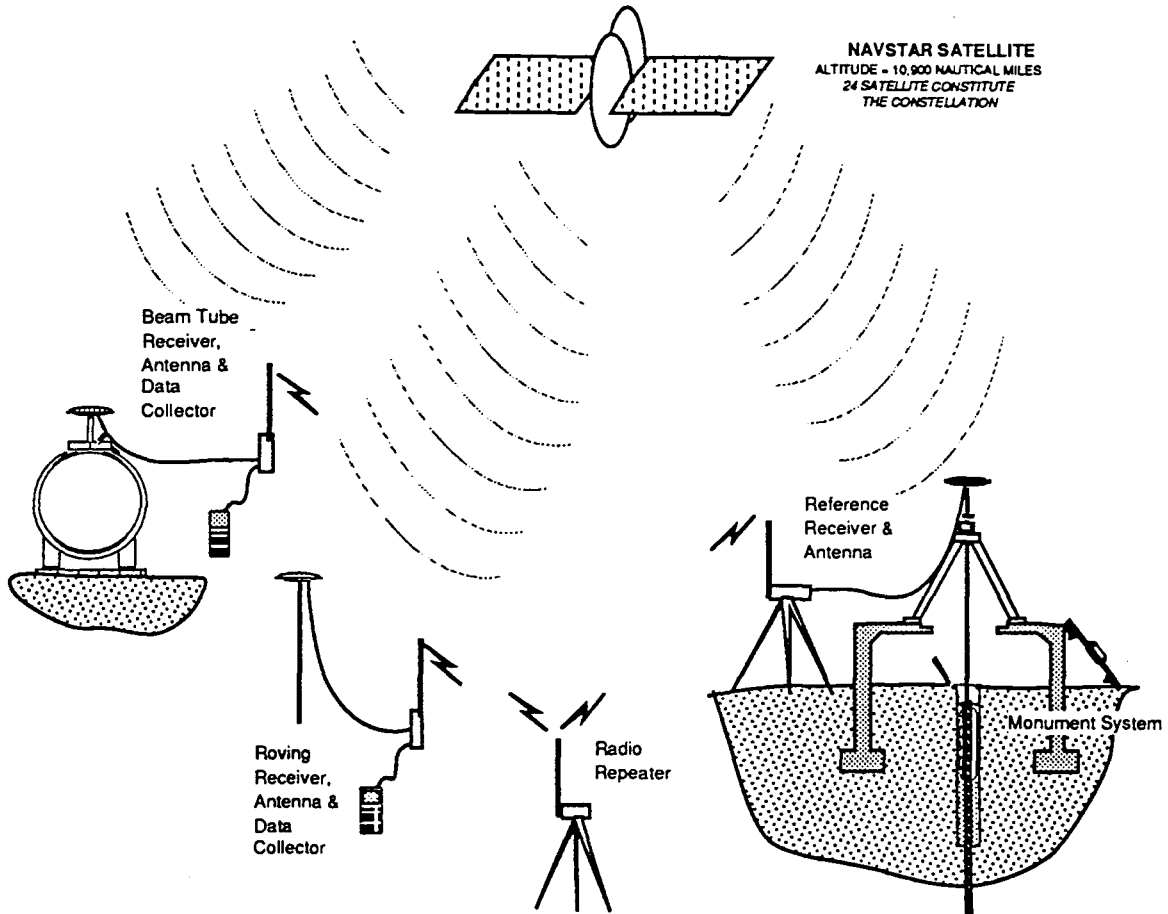
Real Time Kinematic DGPS Equipment-

CBI's proposed application of DGPS using real time kinematic methods requires a product with only one current manufacturer. This product is manufactured by Trimble Navigation of Sunnyvale, California, with product name: Site Surveyor II. This system has been demonstrated to perform within the required LIGO accuracies and provides useful programming features. The reason for the lack of current competitors seems to be the development of software within the data collector. The other major manufactures are developing similar systems, however introduction to the commercial market for these products is not yet scheduled.

CBI proposes to supply the Trimble Navigation Real Time Kinematic(RTK) Surveying equipment for the LIGO project. The RTK package will be pre-qualified by CBI and approved by CALTECH. This equipment will consist of receivers, antennas, radio repeaters, data collectors, computers, and computer software required to make full use of the GPS advantages.

SSC GPS
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copy
Paul Gilbert

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DGPS Equipment and Set-Up Configuration-

The basic package for DGPS surveys include the following equipment:

Qty	Description	Accessories
1	Reference Receiver	Stand or Mounting Bracket
1	Radio Antenna	Cabling as Required
1	Initializing Plate	Compass
1	Dome Antenna	Tripod & Optical Plummet
1+	Roving Receivers	Stands and/or Carriers
1	Radio Antenna	Cabling as Required
1	Dome Antenna	Cabling and Reference Pole
1	Roving Data Collector	Cabling to Receiver
Lot	Jigs and Fixtures for Adapting Dome Antenna	

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- 1+ Radio Repeaters Antenna and Stand
- 1 Software Package for Total Station and Mapping Programs
- 1 486 or Equal Computer with MS Windows® Software.
- 1 Printer, plotter, CD Rom and/or Disk Drive.

Civil, erection, and structural drawings shall include reference dimensions to the three-axis coordinates established during the initial static survey. These points will be located using the RTK feature of point locating so that layout and as-built conditions can be easily determined and documented.

CBI and Manufacturer trained technicians will use the equipment for civil and mechanical surveying and facility installations. Initial site layout and in-process excavation surveying will be performed by CBI. The RTK system will be able to determine construction progress in one-fourth the time of conventional optical surveying methods and provide immediate scaled drawings for accurate planning and payment schedule needs.

Structural/mechanical surveying needs will be provided by CBI using RTK equipment for layout, forming and as-built documentation. Beam tube installation and final alignment will be provided by CBI using the RTK equipment. Provisions for structures, valves, pumps, and similar obstructions that effect DGPS accuracies will be included in each area design.

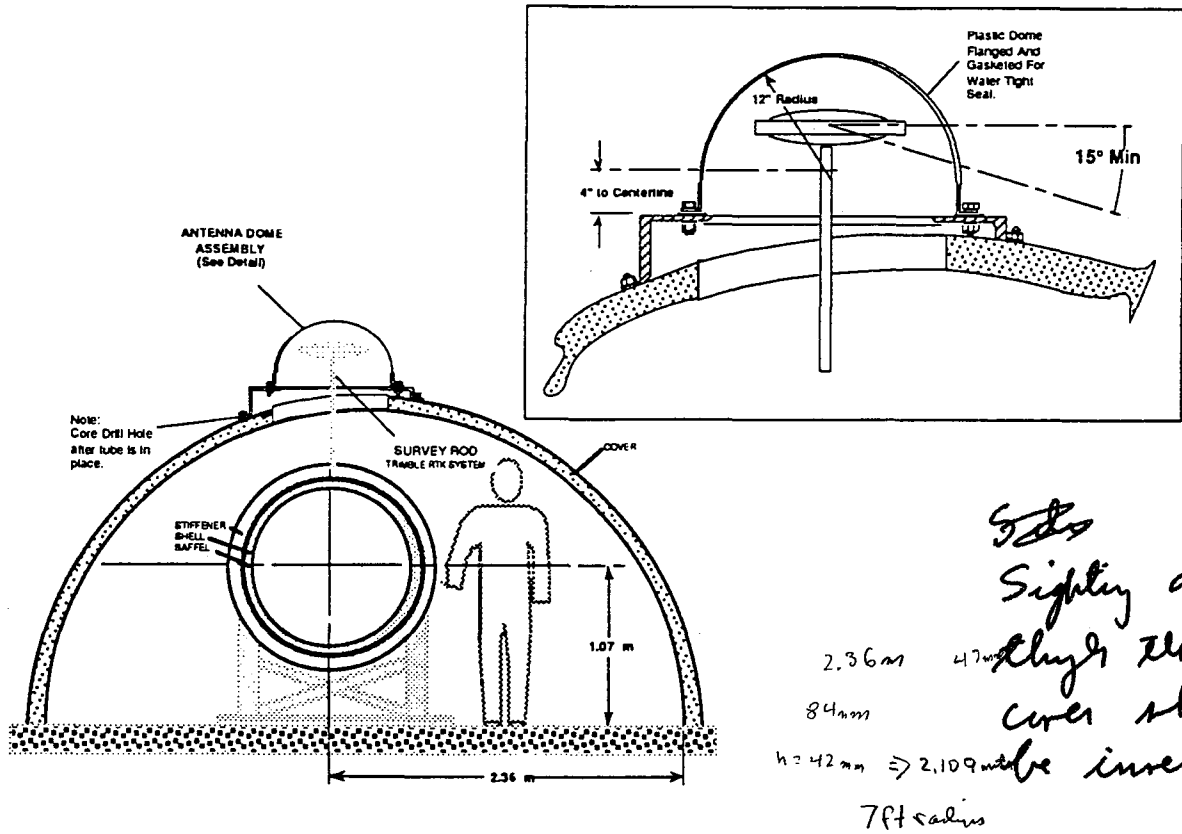
4.0 Beam Tube Alignment and Access Design-

The positioning of beam tube supports is considered a "millwright" trade with the appropriate procedures for alignment including level, soft foot, and positioning. The application of the GPS technology to this type of discipline is a new concept at CBI and will be for any other contractor in this field. Because of the newness of this technology, CBI will remain conservative to a point of providing procedures for existing optical/laser alignment technology. These procedures are in place and will become a permanent part of the LIGO Operation and Maintenance Manual. Their need is not expected and the promise of GPS and its advancing technology will continue to decrease the possibility for their need.

Special consideration is given to the center locating system at each beam tube support. Beam tube covers block GPS radio signals to the antenna, therefore a method of extending the antenna above the cover

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is required. CBI proposes a dome fixture. This dome will be fabricated from a plastic material that will not block radio waves and still provide a weather resistant cover for the lifetime of the facility. Acceptable materials for the dome are being studied and include cross-link polyethylene, co-extruded ABS® with a UV resistant coating, Lexan®, and acrylic. Each has good radio wave characteristics but polyethylene materials will best meet the 20 year facility life span requirements. The domes will be mounted to the concrete covers with fasteners and weather tight gaskets.

Beam Tube center reference points will be permanently marked on the support stiffener. This will be done with a centering fixture and verified by dimensions taken after each tube is welded into position. These as-built tube diameters will be keyed into the GPS software before alignment activities to plot DGPS data to the actual beam tube centerline. This allows for true aperture positioning in respect with tube best centers at the end connections. Axial views of the beam tube centerlines will identify high and low areas and generate a suggested alignment plan to position supports. This data will be valuable when

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ground or foundation shifts require centerline adjustments deviating from the original reference monument plan.

The antenna will be positioned to the beam tube support stiffener by means of a clamp-on fixture. This fixture centers to the permanent reference punch mark and has an adapter for the Rover RTK dome antenna. Also included is a level to verify rotation of the tube and can be used for re-adjustment.

Access to center points in buildings such as corner, mid and end stations are necessary for beam tube and equipment positioning after the buildings are erected. Two methods of accessing beam tube and related equipment are transfer points marked on steel plates embedded into the foundation beyond structures and overhead points accessed thru roof openings.

Transfer points consist of one piece steel plates mounted to a foundation reference and cast in place to be flush with the foundation pad. This plate will consist of a 10 centimeter width carbon steel bar of two centimeter thickness. The bars will be an average of ten meters and have a reference point in the form of a five-eighths by eleven course thread. This threaded hole will be measured after foundation installation and before building construction. The CBI technician will use a tripod with an optical plummet(tribrac). This tribrac centers and levels to the target and positions the RTK antenna for an accurate reading. Long shots will be adjusted for earth curvature automatically by using the data logging features

Access through the roof shall be required for beam tube and equipment in the corner stations. Roof openings will be curb type, weather tight doors that are lockable from either side. These openings shall be located above beam tube supports and must be accessible from the roof. The CBI technician will use a tripod with an optical plummet(tribrac). This tribrac centers and levels to the target and positions the RTK antenna for an accurate reading. Vertical shots will be adjusted for earth curvature automatically by using the data logging features provided with the RTK data logger.

5.0 Qualification of RTK Equipment

The current accuracies published by the manufacturer run on the edge of LIGO needs in respect to Real Time methods. CBI will qualify the RTK system and if the accuracies are found beyond the requirements, then a Static, post-processing method will be used.

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CBI has developed a procedure for qualification for the Site Surveyor II equipment. The reason for this activity is to determine repeatability and techniques in which an expected accuracy can be gained. The positioning of beam tubes in a three dimensional area is an application of "Millwright" techniques to the DGPS technology. A great deal of information regarding the actual usability of this equipment will allow for accurate estimates of manpower and equipment needed for the installation and maintenance of the LIGO Beam Tube Centerlines.

Trimble Navigation will provide equipment and technicians in order to develop this "new" application of GPS. CBI proposes to conduct this qualification by setting-up an accurate test course, testing the equipment through many different conditions and using the computer software to develop coordinate systems and defining adjustment points.

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WBS 300
CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

Appendix B
Preliminary Study
On Site Fabrication Facilities vs. Leased Facilities

CBI stated in the Preliminary Design Review (PDR) that, in our experience, the costs of developing temporary on site fabrication facilities were about the same as leasing nearby facilities, when they are available.

At the request of Caltech, we have made some inquiries as to the availability of leasable facilities near the Hanford and Livingston LIGO sites.

Hanford Site:

We contacted Bullier & Bullier, commercial and industrial Realtors in the Portland, Oregon area who deal with properties in Oregon and Washington. They performed two searches, looking for properties that might meet our needs. The first search turned up properties more suitable for warehousing than fabrication, the second was more fruitful and turned up two possible sites, both in Portland, in the industrial area on Swan Island. There is no guarantee that either of these facilities will be available at the time they are required by the LIGO construction schedule.

With this information in hand and an estimate for using "Rubb" type temporary or "Pre-Engineered" type buildings at site, spread sheets were prepared comparing most of the variable costs between the optimum site in Portland and the field siting scenario. The optimum site has no outside storage area so additional inside area would have to be leased to accommodate out needs. The comparisons were made for 15 months leasing and 24 months leasing. The Realtor felt that it would be difficult to lease these types of facilities for anything less than two years. We felt that we would need that facility for 15 months as a minimum, to set up equipment, do the work, demobilize and leave a sufficiently clean environment to close out the lease.

Some added costs were considered, such as electrical power (furnished at no cost on site), double handling of the tubes, and extra shipping mileage. Others were not figured, such as extra project management staff to man separate sites along with the inefficiencies that would be incurred from this arrangement and salvage value of any on site buildings.

Livingston Site:

Our findings indicate that there is very little in the Livingston area that would be suitable for the type of fabrication required. We would have to go into Baton Rouge for heavy industrial plants. We ceased our search at this point and concentrated on available properties for the Hanford site. We have used the same data as developed for Hanford,

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WBS 300
CONSTRUCTION PLAN
FINAL DESIGN REVIEW DATA PACKAGE

assuming that such a facility could be found in Baton Rouge. The only difference is the assumption that outside storage would be available and at a lower rate per square foot.

Conclusion:

Attached are the following work sheets for the various options considered:

- "Rubb" Type Buildings @ Site vs. Lease Evaluation, 15 month Lease
- "Rubb" Type Buildings @ Site vs. Lease Evaluation, 24 month Lease
- "Pre-Engineered" Type Buildings @ Site vs. Lease Evaluation, 15 month Lease
- "Pre-Engineered" Type Buildings @ Site vs. Lease Evaluation, 24 month Lease

The results tabulate as follows for the two sites combined:

Lease at 15 months	\$850,212
Lease at 24 months	\$1, 297,255
"Rubb" Buildings	\$936,135
"Pre-Engineered" Buildings	\$945,707

The results of the study verifies the CBI statement concerning our experience in comparable costing of on site versus leased facilities.

The on site costs will also be impacted by the need for Caltech to retain one or all of the buildings for future use for storage, equipment development, and other users of the facility. If this becomes a real option, CBI will not use the temporary "Rubb" type buildings, but will go to a more commercially available "pre-engineered" structure such as those provided by "Butler Buildings" or equal.

KHF		LIGO PROJECT									
4/11/94		"RUBB" TYPE BUILDINGS @ SITE VS. LEASE EVALUATION									
24 MONTH LEASE @ COST TO CBI											
HANFORD SITE						LIVINGSTON SITE					
BUILDINGS						BUILDINGS					
BASE WORKING AREA		SF	20,000			BASE WORKING AREA		SF	20,000		
BASE RENTAL RATE		\$/SF/MO.	\$0.35			BASE RENTAL RATE		\$/SF/MO.	\$0.35		
NO. MONTHS RENTAL			24			NO. MONTHS RENTAL			24		
RENTAL COST					\$168,000	RENTAL COST					\$168,000
STORAGE YARD (must use inside bays)						STORAGE YARD					
AREA REQUIRED		SF	40,000			AREA REQUIRED		SF	45,476		
BASE RENTAL RATE		\$/SF/MO.	\$0.35			BASE RENTAL RATE		\$/SF/MO.	\$0.22		
NO. MONTHS RENTAL			24			NO. MONTHS RENTAL			24		
RENTAL COST					\$336,000	RENTAL COST					\$240,113
UTILITIES		\$/MO	5,000			UTILITIES		\$/MO	5,000		
NO. MONTHS RENTAL			24			NO. MONTHS RENTAL			24		
COST					\$120,000	COST					\$120,000
FREIGHT PORTLAND TO HANFORD					66,033	FREIGHT	BATON ROUGE TO LIVINGSTON				\$50,000
EXTRA HANDLING						EXTRA HANDLING					
WT/FT	NO. FT	MHRS/1000#	COST/MNHR	COST		WT/FT	NO. FT	MHRS/1000#	COST/MNHR	COST	
65	25,590	0.25	\$35	\$14,554	\$14,554	65	25,590	0.25	\$35	\$14,554	\$14,554
WEIGHT	1,663,350										
				TOTAL	\$704,587					TOTAL	\$592,668
											\$704,587
										GRAND TOTAL, LEASE	\$1,297,255
SITE:						SITE:					
	BLD 1	BLD 2	BLD 3	BLD 4			BLD 1	BLD 2	BLD 3	BLD 4	
FNDN	\$55,992	\$36,508	\$36,588	\$13,301		FNDN	\$55,992	\$36,508	\$36,588	\$13,301	
DEMOL.	\$9,852	\$5,388	\$5,388	\$1,970		DEMOL.	\$9,852	\$5,388	\$5,388	\$1,970	
ER/TD	\$26,775	\$20,230	\$16,600	\$2,975		ER/TD	\$26,775	\$20,230	\$16,600	\$2,975	
SHELL	\$44,686	\$36,956	\$27,137	\$5,715		SHELL	\$0	\$0	\$0	\$0	
HNDLG	\$81,702	\$40,891	\$40,891			HNDLG	\$8,170	\$4,089	\$4,089		
AIR	\$12,276					AIR	\$12,276				
POWER	\$5,000	\$2,500	\$2,500	\$500		POWER	\$500	\$250	\$250	\$50	
AC/HTG	\$1,000	\$4,215	\$500	\$200		AC/HTG	\$100	\$422	\$50	\$20	
	\$237,283	\$146,688	\$129,604	\$24,661			\$113,665	\$66,887	\$62,965	\$18,316	
				\$538,236						\$261,833	
YARD				\$68,033		YARD				\$68,033	
				\$606,269	\$606,269					\$329,866	\$329,866
											\$606,269
										GRAND TOTAL, TEMP @ SITE	\$936,135
RENTAL	\$1,297,255										
SITE	\$936,135										

KHF		LIGO PROJECT										
4/11/94		"PRE-ENGINEERED" BUILDINGS @ SITE VS. LEASE EVALUATION										
24 MONTH LEASE @ COST TO CBI												
HANFORD SITE					LIVINGSTON SITE							
BUILDINGS					BUILDINGS							
BASE WORKING AREA		SF		20,000		BASE WORKING AREA		SF		20,000		
BASE RENTAL RATE		\$/SF/MO.		\$0.35		BASE RENTAL RATE		\$/SF/MO.		\$0.35		
NO. MONTHS RENTAL				24		NO. MONTHS RENTAL				24		
RENTAL COST				\$168,000		RENTAL COST				\$168,000		
STORAGE YARD (must use inside bays)					STORAGE YARD							
AREA REQUIRED		SF		40,000		AREA REQUIRED		SF		45,476		
BASE RENTAL RATE		\$/SF/MO.		\$0.35		BASE RENTAL RATE		\$/SF/MO.		\$0.22		
NO. MONTHS RENTAL				24		NO. MONTHS RENTAL				24		
RENTAL COST				\$336,000		RENTAL COST				\$240,113		
UTILITIES		\$/MO		5,000		UTILITIES		\$/MO		5,000		
NO. MONTHS RENTAL				24		NO. MONTHS RENTAL				24		
COST				\$120,000		COST				\$120,000		
FREIGHT PORTLAND TO HANFORD					FREIGHT					UGE TO LIVINGSTON		
					66,033					\$50,000		
EXTRA HANDLING					EXTRA HANDLING							
WT/FT	NO. FT	MHRS/1000#	COST/MNHR	COST	WT/FT	NO. FT	MHRS/1000#	COST/MNHR	COST			
65	25,590	0.25	\$35	\$14,554	65	25,590	0.25	\$35	\$14,554	\$14,554	\$14,554	
WEIGHT	1,663,350											
				TOTAL					TOTAL	\$592,668		
										\$704,587		
										GRAND TOTAL, LEASE	\$1,297,255	
SITE:					SITE:							
	BLD 1	BLD 2	BLD 3	BLD 4		BLD 1	BLD 2	BLD 3	BLD 4			
FNDN	\$32,000	\$17,500	\$17,500	\$6,400	FNDN	\$32,000	\$17,500	\$17,500	\$6,400			
DEMOL.	\$0	\$0	\$0	\$0	DEMOL.	\$0	\$0	\$0	\$0			
ER/TD	\$0	\$0	\$0	\$0	ER/TD	\$0	\$0	\$0	\$0			
SHELL	\$96,000	\$52,500	\$52,500	\$19,200	SHELL	\$96,000	\$52,500	\$52,500	\$19,200			
HNDLG	\$81,702	\$40,891	\$40,891		HNDLG	\$8,170	\$4,089	\$4,089				
AIR	\$12,276				AIR	\$12,276						
POWER	\$5,000	\$2,500	\$2,500	\$500	POWER	\$500	\$250	\$250	\$50			
AC/HTG	\$1,000	\$4,215	\$500	\$200	AC/HTG	\$100	\$422	\$50	\$20			
	\$227,978	\$117,606	\$113,891	\$26,300		\$149,046	\$74,761	\$74,389	\$25,670			
				\$485,775					\$323,866			
YARD				\$68,033	YARD				\$68,033			
				\$553,808					\$391,899	\$391,899		
										\$553,808		
										GRAND TOTAL, TEMP @ SITE	\$945,707	
RENTAL	\$1,297,255											
SITE	\$945,707											



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WBS 350
COUPON OUTGAS TESTING
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WBS #350 - Coupon Outgassing Test Facility

A coupon test facility has been developed for both the qualification and option phases of the project. The contract calls for an outgassing test of the hydrogen for the material used in the qualification test and in the option phase of the project. CBI has interpreted this to mean that during the qualification test phase of the contract, one outgassing test will be accomplished for the beam tube material, the expansion joint material and the baffle material. These same materials will be tested in the option phase of the project. There will be only one coil used for the beam tube during the qualification test and only one batch of material used for the bellows and the baffles. However, many coils will be required for the option phase of the contract for each of the above components. Initially, one outgassing test will therefore be made for each coil of material during the option phase of the project. This may be reduced, at some time during the option phase, to each batch of material (ingot, heat and slab or continuous cast) or to each bakeout if more than one coil is baked at once, depending on the results of the initial outgassing tests which will be accomplished during the early stages of the option phase of the project.

The option phase facility consists of three coupon chambers (the number determined by the number of tests required every week), a clean pumping system, a dirty pumping system, an RGA system and a calibrated leak system. The coupon facility needed for the qualification portion of the project will only require one chamber and will, therefore, not require a dirty pumping system. The Piping and Instrumentation (P & I) Diagrams for the option phase of the facility are provided at the end of this section. The P & I Diagrams also indicate, which equipment will not be provided in the Qualification Test phase of the project (equipment which is dotted is not required for the qualification test facility).

The facility has the capability of testing the outgassing in a number of ways. The system will be capable of testing in a steady state mode and in an accumulation mode. The system will be utilized, at least initially, for accumulation type outgassing tests. This method will be used initially due to the initial ratio of system to coupon outgassing rate. As the system outgassing rate decays, the steady state outgassing measurement becomes more accurate. Initially, the system outgassing rate is predicted to be approximately 1×10^{-12} torr liters/sec cm^2 . This will provide a 10 to 1 ratio of coupon outgassing to system outgassing when the coupon chamber has accumulated for one hour and the pumping system is isolated for a maximum of 5 minutes. A shorter duration of pumping system isolation will increase this ratio and a longer accumulation time will also increase the ratio. The initial testing will utilize a one hour accumulation as a starting point.

Another method of accumulation testing is possible when the pumping system is operated throughout the testing process. This eliminates the need for accurate measurement of the system volume but degrades the pressure spike as the accumulated chamber is opened due to the continuous pumping.

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COUPON OUTGAS TESTING
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The system is provided with a pneumatic operated valve to isolate the pumping system in case of power or equipment failure. Back streaming of oil from the roughing pump is prevented with this valve as well as with a solenoid operated inbleed valve to keep the turbomolecular pump fore line in the viscous flow regime.

A cold trap is provided in the line to the RGA. This will reduce the false hydrogen signal from water and hydrocarbon fractionation. The cold trap will be operated whenever an RGA measurement is required. The cold trap is provided with a nitrogen inbleed valve to assist in warm up of the trap and to provide a viscous flow regime sweep of the water vapor to the pumping system when the trap is warming up.

A calibrated leak will be provided on the system. The leak is sized in the same range as the outgassing rate of the coupons. Calibration will be accomplished by allowing the calibrated leak to accumulate for a period of time to provide the same partial pressure as the calculated hydrogen outgassing rate from the coupons.

The system has been designed with a wide range turbomolecular pump which has a hydrogen compression ratio of 3×10^6 in order to ensure that the hydrogen background is as low as possible. This turbomolecular pump with a two stage roughing pump should allow hydrogen pumping into the 10^{-9} torr range.

A procedure has been developed for the outgassing of the coupons for the option phase of the project. The procedure is identified as "COUP-01" and is supplied in the detailed design package. A procedure has also been developed for the outgassing tests during the qualification test period. This procedure is identified as "COUP-02" and is also supplied in the detailed design package. The difference in the procedures is due to the reduced size of the system (only one coupon test chamber instead of three during the qualification test).



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LEAK TESTING
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WBS #360 - Leak Testing

From the initial review of the LIGO specification critical requirements of 1×10^{-10} atm cc/s total helium leakage rate and 10^{-9} - 10^{-10} torr operating absolute pressure level, CBI has proposed a positive step by step leak testing approach designed to achieve these required goals both economically and within the outlined construction schedule.

in this component module

This approach hinges on the requirement that before installation in the system, each component must be helium mass spectrometer (HMS) leak tested using a quantitative vacuum mode technique to prove that the total leakage rate for each component meets the specification requirements. This begins with the requirement that all vendor supplied items, such as expansion joints, be HMS hood tested by the vendor to provide a high degree of assurance that all such items have total leakage rates less than the allowable before being installed in a larger component assembled by CBI. This total leakage rate testing requirement is outlined in every CBI specification developed for vendor purchase items. To ensure they have not suffered any damage during transportation, these vendor supplied items are leak tested again by CBI as part of each can section assembly before being installed in a beam tube module

Such stringent leakage rates require the latest most sensitive state of the art helium mass spectrometer leak detectors for both the preliminary HMS quantitative leak tests of larger volume components, such as can sections, and for the final HMS leak testing of the even larger volume beam tube module.

The CBI Planned Approach to Leak Testing, identified as LIGOTP, focuses on the need to ensure that each and every item going into a beam tube module has a total leakage rate that is smaller than that allowed for the entire module. This straight forward approach which is intended to eliminate or minimize leakage problems during the final module test, has not changed dramatically since its original inception.

The planned approach scope lists the CBI procedures in order of their performance. The first is the HMS hood test of beam tube can sections, including vendor leak tested expansion joints and pump port nozzles when applicable. These can sections are quantitatively leak tested per procedure HMST1N after initial spot solvent cleaning but before final steam cleaning. CBI believes that the test stand with the metal hood enclosure approach used in this procedure is absolutely necessary to rapidly achieve the high sensitivity total leakage rate test required for each of the large 800 can sections and maintain the erection schedule for those can sections. To attain the test sensitivity required and meet the erection schedule means having a near 100% helium mixture in the hood and reaching a high vacuum level in each can section very quickly. To accomplish evacuation to a high vacuum level very quickly and use the same pump system to best advantage for leak testing requires a high speed throughput system such as either a



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LEAK TESTING
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turbomolecular pump or a diffusion pump. The Time of Flight system purposed by CBI in this same procedure will more quickly pinpoint the location of detected leaks than other more conventional techniques. Caltech has repeatedly asked CBI to demonstrate the need for the Time of Flight system on one of the test stand helium hoods. If 5% of the can sections at each job site ($400 \times .05 = 20$) had leakage of less than 10^{-5} atm. cc/s that had to be pinpointed and if one of every four (4) of these twenty leakers (5 total at each job site) had to be scrapped due to failure to rapidly locate the leak or leaks by conventional techniques, CBI estimates that using the Time of Flight system in lieu of conventional leak location techniques, would result in a saving of slightly in excess of \$100,000 at each job site. See the cost comparison estimate at the end of this leak testing discussion.

The major change in procedure HMST1N since the PDR has been to reduce costs by the change from a large turbomolecular pump to a much less expensive large diffusion pump in each of the test stand pumping systems used to perform the test of each of these can sections. This is one of the many accomplishments of the two day leak testing discussion held on 2/23 & 2/24/94 in Houston between Caltech, MIT and CBI.

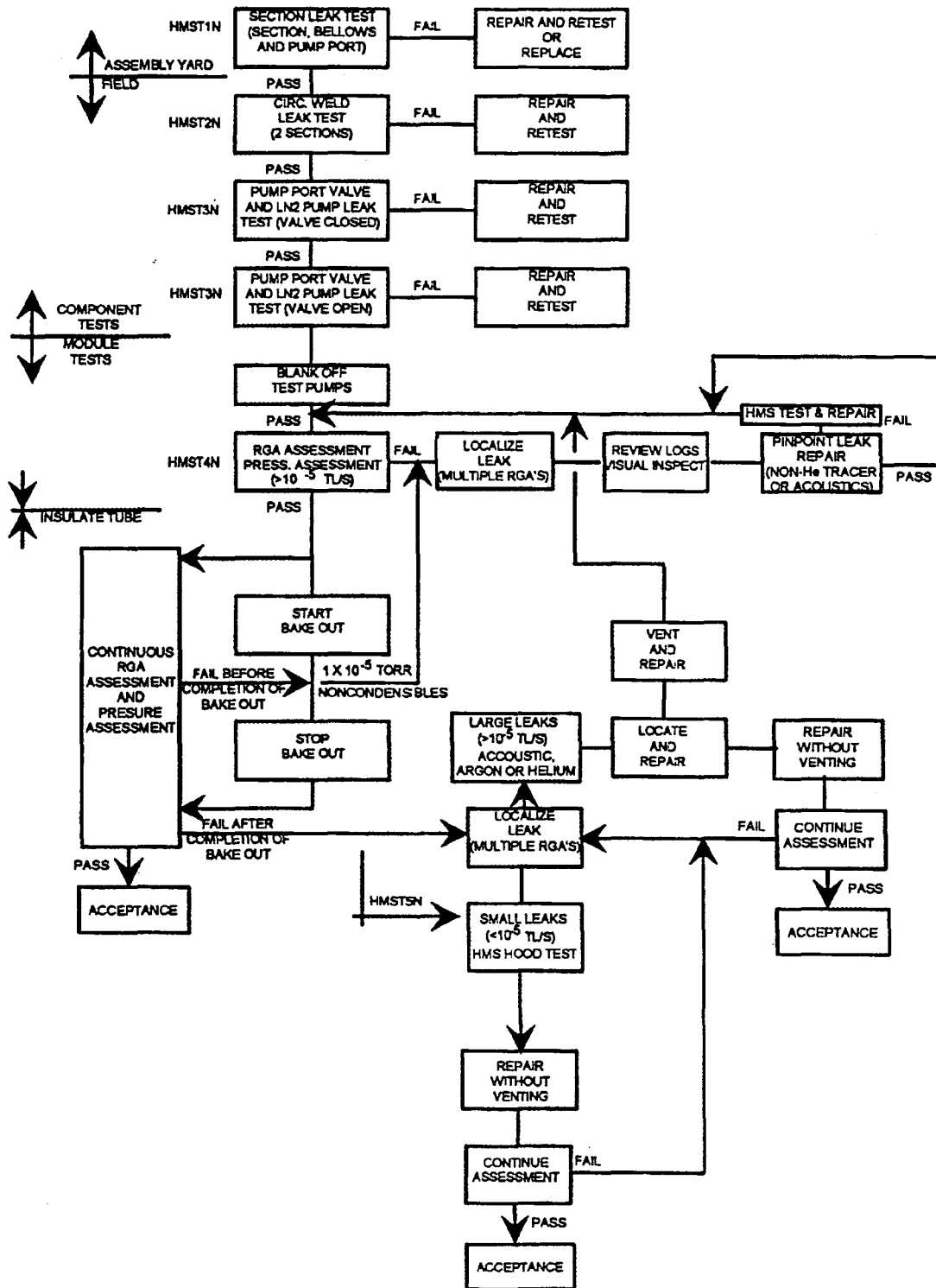
The second procedure outlines the HMS hood test of each of the circumferential weld joints between can sections. This local vacuum box hood test technique has been used successfully by CBI for well over 30 years. On one single contract for probably the largest high vacuum system ever constructed, CBI successfully performed this same procedure on some 450 penetrations plus box girder sections to the sensitivity limits of the HMS being used. Other than refinement of details, there has been little change in this HMST2N procedure since the PDR.

The third test procedure HMST3N of the pump ports has been revised since the PDR to include the LN₂ pump as well as the isolation valve on each of these pump port nozzles. Since the LN₂ pumps are needed to reduce pumping time during the module test phase to pump water vapor and other condensables, it became readily apparent that these cryogenic pumps needed to be installed and leak tested before the beam tube module final test. Following the step by step approach used for all other components, the logical time to accomplish this is when the can sections are being installed and there is still access to the inside of the beam tube. At this stage of installation, at each pump port the LN₂ pump and its internal tubes as well as the isolation valve seat and stem seals can be leakage rate tested very rapidly at or near a test sensitivity equal to that of the HMS instrument. It also eliminates these vendor tested LN₂ pumps as a potential source of leakage, particularly at the seals between each of the isolation valve flanges and the pump flanges. This change would have come about sooner except for the fact that these LN₂ pumps are not within the scope of work for the beam tube supplier. Thus, the two day joint leak testing meeting in Houston also resulted in this leak testing and time saving improvement.



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LEAK DETECTION DECISION TREE





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LEAK TESTING
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Time of Flight" Cost Study for
LIGO Contract 930212 for Caltech per
PDR Review Board "Request for Action"

Estimated "Time of Flight" Costs to Equip One Test Stand:

Description of Item	ENL	MHRS
Two (2) HPS Gauge Controllers @ \$1920.00 =	\$3840.00	
Six (6) HPS Cold Cathode Gauge Heads @ \$350.00 =	\$2100.00	
Six (6) 25 foot Cables @ \$105.00 =	\$ 630.00	
Tax plus shipping & handling =	\$ 553.00	
Six (6) KF40 fittings w1 1/2" weld stubs @ \$6.50 =	\$ 39.00	
DAS 1402 High Speed Board	\$ 699.00	
STC - 37 Das 1400 Terminal Interface	\$ 109.00	
Software (Labtech Notebook 7.2)	\$ 495.00	
Tax	\$ 20.00	
Elastometer test stand cover seals	\$ 200.00	
Labor to Install six (6) KF40 fittings		
16		
Labor to fabricate and install seals on ends of test stand lid and leak test and make seals operational		
40		
One 250 ISO K fitting	\$ 500.00	
One Balzar Model DIF 200 Diffusion Pump	\$ 6200.00	
Labor to install one 250 ISO K fitting		
4		
Labor to install TMP and make operational		
16		
Estimated cost required to pinpoint a 10^{-5} std. cc/sec or smaller size leak in a can section by "Time of Flight" - four people one shift per can for 20 cans (5%)= $32 \times 20 = 640$		640
<hr/>		
Time of Flight Total	\$15385.00	
716		



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LEAK TESTING
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Description of Item	ENL	MHRS
Estimated cost for conventional pinpointing methods		
Estimate requirements to pinpoint a 10^{-5} std. cc/sec. or smaller size leak by conventional means - four people three shifts per can for 20 cans (5%) = $96 \times 20 = 1920$		1920
Losses due to inefficiency caused by the disruption in the normal scheduled flow of one test can section per shift Three people per shift = $8 \times 3 =$ 24		
Scrap every fourth leaking can section out of twenty (five total) that leaks less than 10^{-5} std. cc/sec. - $\$15000 \times 5$	\$75000.00	
<hr/>		
Conventional Leak Pinpointing Method Total 1944	\$75000.00	
<hr/>		
Difference between higher cost conventional methods versus Time of Flight including equipment for T of F 1228	\$59615.00	
If \$45 is used for each manhour, the cost difference for each job site would be a total ENL of	\$114875.00	



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WBS 390
CLEANING AND CLEANING MAINTENANCE
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WBS #390 - Cleaning And Cleaning Maintenance

Economical and successful cleaning of the tube sections and maintaining the clean environment during the construction process are critical elements to the LIGO Beam Tube Module Design. Cleaning and cleaning maintenance are composed of four basic elements:

- Contamination Control and Inspection During Fabrication
- Cleaning Procedure Development
- Cleaning Procedure Execution
- Cleaning Maintenance During Installation and Construction

Contamination Control encompasses the entire fabrication and installation process from the manufacturing of the coil steel through component fabrication and handling and transportation. Contamination control requirements are contained in the component specifications to fabricators and in CBI's assembly and installation procedures. Beam tube and expansion joint manufacturers will steam clean and solvent wipe the equipment used for LIGO component fabrication. Carbon steel contamination will be limited to the extent possible total prevention of carbon steel contact is not feasible. All visual signs of carbon steel contamination and cutting splatter will be removed by scouring by the fabricator. Expansion joints and tube sections will be visually inspected for hydrocarbon contamination. Hydrocarbons will be removed by solvent wipe prior to sealing the components for shipment. Baffle sections will be final cleaned by the baffle fabricator and installed into the cleaned tube sections after inspection by CBI.

Upon receipt, CBI will visually inspect all expansion joints and tube sections for obvious visual damage and contamination which may have occurred during transport from the vendor.

After attaching all stiffeners and, where applicable, an expansion joint to the can section during fabrication of the can section assembly, the interior surfaces will be black light inspected for hydrocarbon contamination. All hydrocarbon indications will be removed by a solvent wipe using alcohol or acetone prior to leak testing each can section. The requirements for the solvent wipe and black light inspection are contained in the CBI Planned Approach to Cleaning identified as procedure CL1N.

The original Specification Number 1100007 outlined a "steam" cleaning process with Oakite 33 (a mild phosphoric acid) for final cleaning of the can sections of the beam tube modules after those can sections were helium mass spectrometer leak tested. The Caltech specified "steam" cleaning process with Oakite 33 (a mild phosphoric acid solution) consists of the following step.



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- Remove hydrocarbons with a solvent wipe.
- Spray rinse with hot water at 60°C (140°F).
- Spray at 60°C (140°F) with a 2% by volume Oakite 33 in water cleaning solution (or equivalent).
- Hold five (5) minutes.
- Spray at 60°C (140°F) with a 2% by volume Oakite 33 in water cleaning solution (or equivalent).
- Hold five (5) minutes again.
- Spray rinse with hot water at 60°C (140°F) to remove all traces of the Oakite 33 cleaning solution.

Based on CBI's past experience on ultra high vacuum facilities, Oakite 33 was judged to be costly due to disposal and handling requirements and not especially effective. CBI recommended alternative cleaning methods and with input from Caltech developed alternate coupon cleaning procedures in accordance with procedure CLALT for outgassing and surface analysis evaluation testing. At the suggestion of Caltech, each of these procedures included an identical oil (hydrocarbon) contamination section to put all the procedures on an equal footing for comparing their cleaning capabilities. These alternative cleaning procedures were identified as CLCOUPA for Oakite 33, COUPAO for steam and COUPA1 for Mirachem 500. Several other alternate procedures were written for other cleaning agents, but were not used. CBI prepared and cleaned a series of coupons each of the three procedures. These three sets of coupons were tested by both surface analysis and outgassing. Caltech evaluated these three cleaning procedures based on the test results which showed that the steam cleaning procedure was the most effective of the three. It is also the most economical, and does not influence the hydrogen outgassing characteristics of the material. As such, the specification cleaning process will be revised to steam cleaning from the originally specified Oakite 33 process. The procedure evaluation was based on the cleaning of relatively small samples using a hand held spray nozzle.

The beam tube can sections are cleaned just prior to installation to minimize the risk of contamination after final cleaning and to minimize the costs associated with cleaning maintenance. Final cleaning in place was determined to be problematic and disruptive to the installation process. Tube can sections are cleaned on site with equipment used for pipe cleaning modified as required to meet the requirements of the beam tube can section modules. The tube can sections are cleaned by a rotating jet cleaning head which is passed through an inclined can section. The equipment and procedure are described in CL1N. CBI has estimated the spray characteristics and will use these characteristics for the qualification test. Final cleaning spray parameters, such as speed, pressure, flow and jet rotation speed, will be based on the results of the qualification test since the evaluation of the coupon cleaning procedure was based on very small samples that are not very representative of the actual can section when it is being final cleaned.



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CLEANING AND CLEANING MAINTENANCE
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Maintenance of the beam tube sections during fabrication are accomplished by maintaining a continuous flow of dry filtered clean air in the beam tube under assembly with a portable clean room enclosure at the working end of the module. The blower, dryer, and filtration system is described in BDF-1. The portable clean room is described in CR1TSM. Beam tube module construction will begin at the beam tube termination's at the mid station. The filtered air system will be installed and the portable clean room will be placed over the working end of the termination. After checking the tube termination cleanliness, process of beam tube section attachment with the portable clean room will begin as described in CL2N.

The final cleaning of the beam tube in the field is limited to local cleaning of the circumferential weld joint between can sections and final inspection during the final exit of the locally cleaned beam tube. The personnel requirements for entry into a cleaned tube and the portable clean room are described in CRWA-1. Final local cleaning is described in CL3N.



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WBS 400
QUALIFICATION TEST
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WBS #410 - 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. The following are the specified requirements for the design qualification test:

- Demonstrate full conformance of LIGO Beam Tube Module detailed design with required performance parameters and constraints.
- Identify features that can be demonstrated through analysis and those that must be verified through testing.
- Utilize a physical configuration which permits testing of full scale LIGO Beam Tube components and validates the planned fabrication, field installation, and testing techniques.
- Accomplish Qualification Test in accordance with an approved/documented design qualification test plan and procedures.

WBS #420 - Qualification Test Plan

The qualification test plan consists of the list of items requiring verification testing and items verified by calculations; the test configuration and the procedures for fabrication, installation, and testing for that configuration; and the format for reporting the test results in the Design Qualification Test Report. This plan ensures that the Qualification Test demonstrates the critical features of the LIGO beam tube module design.

The overall test configuration, including procedures, controls the execution of the qualification test plan. The configuration has been assembled for submittal at this FDR by making conceptual plans, based on requirements, and preparing designs, drawings, and procedures on the basis of these plans. Beam tube component fabrication procedures/procurement specifications have been prepared and will be used to purchase these components for the QT. Fabrication by CBI will be accomplished in two locations, Houston Welding and Plainfield Research and Development. Houston Welding (HW) will receive the spiral welded tubes in the ordered QT lengths, the stiffeners, the baffle/support rings, and the pump port. CBI HW will perform the necessary receiving inspection including dimensional inspection and welding of stiffeners, support rings and pump port. Post welding dimensional checks of the stiffened beam tubes are also performed in Houston prior to shipment to CBI Plainfield Research and Development Center. CBI's Plainfield Research and Development (R&D) Center will receive the stiffened beam tubes



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QUALIFICATION TEST
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from HW and the expansion joints and supports from their respective manufacturers. The R&D center will perform the circumferential welds to create each beam tube can section (one aft (contains pump port) and one forward of the expansion joint). These can sections will be individually helium mass spectrometer hood tested. The expansion joint will be attached to the forward assembly and that circumferential weld will be HMS leak tested. The aft assembly will be installed including alignment as the starting piece of the QT Beam Tube Module, locating the pump port in the high vacuum lab. Final cleaning and baffle (~ 6 M spacing) installation of this aft assembly will occur at this time. The forward assembly (including expansion joint) will then be installed, including alignment, into the QT Beam Tube Module, including fitup, purge and welding of the circumferential seam joining the aft assembly to the forward assembly. This weld will be HMS leak tested. Final cleaning and baffle installation (~ 20M spacing) will occur at this time. The closure head will be installed including fitup, purge and welding. Installation alignment checks and support adjustments will be made. Vacuum thrust restraints will be added to the supports. The QT Beam Tube Module will be pumped down, air signature evaluated, and leak tested if necessary. The QT Beam Tube Module will be baked out while taking periodic RGA measurements. When the bakeout is complete, air signature will be evaluated and the QT Beam Tube Module will be leak tested if necessary. Final outgas test will then be performed .

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more than
1 baffle*

1. Listing of Test Items and Calculation Items

DRD No. 03 requires a listing of items requiring verification testing and items verified by calculations. This section provides this list.

The items that make up the list represent all of the most important issues that affect the design and production of complete beam tube modules. The first four sections of the list are ordered to chronologically follow the complete module sequence of operations, i.e. Design, Material Procurement, Fabrication, and Assembly. In addition, the key issues of Leak Testing, Cleaning/Outgas, and Dimensional Control are each addressed separately since they are affected by interrelated steps that are woven all through the option phase activities.

For each issue, a discussion is provided which covers not only whether the item is verified by test or not, but also any significant differences that exist between the Qualification Test (QT) and a Complete Module and the significance of these differences. Also, for those items that are not tested, the discussion covers how the verification is made that the plans for the Option meet specifications. This is in some cases by calculation, in other cases by analysis, by past experience etc.



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QUALIFICATION TEST
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- Design

Structural Performance of the Beam Tube Sections

Dimensions & Material: This area will be thoroughly and realistically tested during the QT. The differences between the QT and the complete module are very few and not significant. The beam tube material and thickness will be identical to option phase modules as will the stiffener material, sizes, spacing and attachment details. The only dimensional difference will be the length of tube sections (60' in QT instead of 65' and 62'-4"). However, the spacing of supports, which is the significant parameter from a structural standpoint, will be identical.

Loadings: The QT will include external pressure to the design level of full vacuum. The maximum axial compression load will also be applied during the QT bakeout.

Calculations: In addition to the above testing, calculations have also been prepared to demonstrate structural adequacy and conformance to specified codes.

Structural and Mechanical Performance of the Expansion Joints

Like the beam tubes, this area will be thoroughly and realistically tested during the QT. The expansion joints will be identical to the expansion joints used for the complete modules. Vacuum load and maximum axial deflection will be the same as applied to the complete modules. In addition, calculations have been made to demonstrate structural adequacy. The only difference in loading will be that the full number of cycles that the modules might experience will not be applied on the QT. The fatigue performance of the expansion joints is therefore addressed by calculation only.

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Structural, Mechanical and Thermal Performance of the Beam Tube Supports

Both the fixed supports and the guided supports will be tested during the QT in all of their most critical respects. The supports will be identical to those used for the complete modules. The range of movement required of the guided supports will be realistically tested during the QT bakeout.

Gravity loads applied to the supports will be somewhat different than design loads for the complete modules due to the fact that full length beam tube only extends in one direction from the QT fixed supports. This non critical element of design therefore relies on calculations. Likewise, no horizontal loads transverse to the tube will be applied. The design relies on calculations.

Height Constraints can
be managed



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QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE

Longitudinal loads will exist during the QT due to unbalanced pressure end loads and expansion joint reactions which are larger than will exist in the complete modules. However, these loads will, for the most part, be carried by supplemental bracing required to carry these larger loads rather than by the fixed supports. Therefore verification of the fixed supports' adequacy for design longitudinal loads relies on calculations.

The mechanical performance of the supports needed in order to accomplish final alignment of the tube will be fully demonstrated by test.

The thermal performance required to limit the local cool spot at supports during bakeout will be demonstrated by test as well as by analysis that has been completed.

Baffle Mechanical Performance

The baffles performance will be fully and realistically tested. The baffles will be identical to those to be used for the complete modules. The QT baffles will be placed in the tube as far as 70'+ from an open end and their fit to the inside surface and their stability without attachment to that surface will be verified by test.

- Materials Supplied To CBI

Coil Manufacture and Bakeout

The beam tube material manufacturing and bakeout process will be fully demonstrated during the Qualification Test. The processes for the Qualification Test will be the same as are planned for the Option.

Coupon Outgas Testing

The coupon outgas testing process will be fully demonstrated during the Qualification Test. The coupon testing done during the QT will use the same CBI coupon outgas test equipment and same methods as are planned for the Option with the exception that the Option test system will have more than one test chamber.

Confusion

Coupons will be outgas tested during the QT for all materials within the beam tube with the exception of the 10" pump port. Materials that will be tested include the tube material, bellows material and the baffle material. The limited area of the pump port negates the necessity for testing that material.



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Beam Tube Manufacturing

The spiral welded beam tube manufacturing process will be fully demonstrated during the Qualification Test. The manufacturing process for the Qualification Test will be the same as is planned for the Option.

Beam Tube Transportation

The beam tube transportation methods will be fully demonstrated during the Qualification Test. The transportation methods for the Qualification Test will be the same as is planned for the Option. In addition, the acceptability of these methods has been verified with respect to fatigue concerns by calculations.

Expansion Joint Manufacturing

The expansion joint manufacturing process will be fully demonstrated during the Qualification Test. The manufacturing process for the Qualification Test will be the same as is planned for the Option with the following exceptions:

- The expansion joints for the Qualification Test will be manufactured from flat sheets of SA 204 Type 304L cold rolled material. The material will be baked in the flat sheet form. For the Option the material will be purchased and baked in coil form.
- The expansion joints for the Option may be manufactured from Hot Rolled Annealed and Pickled (HRAP) Type 304L material instead of cold rolled 304L material. Although the HRAP material is less expensive than cold rolled material it is not economically available for the minimum quantities needed for the Qualification Test. Much larger quantities are required for the Option.
- The expansion joints in Qualification Test will be mechanically formed. In the Option the expansion joints may be hydroformed instead of mechanically formed. Only one of the expansion joint manufacturers has offered hydroformed bellows. Hydroforming the expansion joints should improve the shape of the expansion joints.

may be serious issue

Fatigue life may be a function of the forming

not hydroformed



**LIGO PROJECT
WBS 400
QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE**

Stiffener Manufacturing

The beam tube stiffener manufacturing process will be fully demonstrated during the Qualification Test. The manufacturing process for the Qualification Test will be the same as is planned for the Option.

Baffle Manufacturing

The baffle manufacturing process will be fully demonstrated during the Qualification Test. The manufacturing process for the Qualification Test will be the same as is planned for the Option.

- CBI Fabrication

Beam Tube Handling

The beam tube handling planned for use in the Option has been verified by calculations.

The beam tube handling methods and equipment used in the Qualification Test will not be the same methods and equipment planned for use in the Option. The handling equipment and methods used for the Option are specially designed and configured for repetitive lifting at the LIGO sites. Conventional handling methods and equipment will be employed during the Qualification Test to handle the beam tubes.

Stiffener Attachment: Fit up, Purge, Weld

The stiffener attachment process will be fully demonstrated during the Qualification Test. The welding procedure specifications (WPS) used in the Qualification Test (QT) will be the same as that planned for use in the Option. The welding equipment will be generic to (i.e. same type, possibly different brand name) that planned for use in the Option. The gas metal arc wire machine with down flat fixed torch and the internally purged beam tube can section turning on rollers are the general arrangement that will be used for the QT and for the Option.

Pumping Port: Repad Attach, Purge, Weld

The process of attaching the pump port repad will be fully demonstrated during the Qualification Test. The WPS, equipment, etc., used for the QT will be the same as or generic to that planned for use in the Option.



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QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE

Final Beam Tube End Preparation

The final beam tube end preparation process will be fully demonstrated during the Qualification Test. Procedures demonstrated will be the same as those which will be used for the Option.

During the QT, the beam tube end preparations will be performed before welding the stiffeners and related attachments. Measurements made during the QT of changes in tube end flatness will provide data which may justify having the beam tube supplier perform the final end preparations in the Option. If flatness is not maintained, final end preparations will be moved to after stiffener welding in both the QT and in the Option.

Pumping Port: Bore, Fit nozzle, Purge, and Weld

The pump port production process will be fully demonstrated during the Qualification Test. The WPS, equipment, etc., used for the QT will be the same as or generic to that planned for use in the Option.

Attach Expansion Joint: Fit, Purge, Weld

The expansion joint attachment process will be fully demonstrated during the Qualification Test. The WPS, equipment, etc., used for the QT will be the same as or generic to that planned for use in the Option.

Work Conditions

The procedures for beam tube can section fabrication will be tested during the QT under realistic work conditions. This fabrication for the qualification test will be performed indoors in an environment which will be very similar to the environment of the planned fabrication facility for the complete module.

- Assembly Of Beam Tube Modules

Use of Clean Room and Weld Enclosures

Use of Clean Room and Weld Enclosures is an item where the environment will be emulated during the QT while the actual equipment and operation planned for the Option will not be tested. The ability to provide a protected, access controlled, quality air enclosure, to exclude the outdoor environment from a critical work space, is an industry established construction activity. Past experience in providing these types of enclosures precludes the necessity to build and test their operation for the LIGO QT.



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WBS 400
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In order to emulate the Option phase work environment, special facility controls will be implemented in the CBI Research Center basement during the QT at times of critical installation events to prevent the final cleaned beam tube assemblies from being exposed to detrimental contaminated air flow.

Preliminary Alignment of the Beam Tube

Preliminary alignment of the beam tube assemblies in the Qualification Test will be demonstrated by test. The procedure will be similar to that planned for the Option with the following exception:

Conventional surveying and layout equipment will be used in the Qualification Test to establish the centerline reference points on the concrete slab rather than the Global Positioning System proposed for use on the Option.

Circumferential Welds: Fit, Purge, Weld

The procedures to be used for these circumferential welds will be fully demonstrated during the Qualification Test. The WPS, equipment, etc., used for the QT will be the same as or generic to that planned for use in the Option.

Sequence of Personnel Entrance into Beam Tube for Cleaning and for Installation/Removal of Purge Rings and Baffles

The sequence of personnel entrance into the Beam Tube will be fully demonstrated. The QT beam tube personnel entrance sequence will be the same as is planned for the Option.

Installation of Structural Supports

The installation of structural supports will be fully demonstrated during the Qualification Test. The procedure demonstrated will be the same as is planned for the Option.

- Leak Testing

Leak Testing of Can Assemblies

Leak testing of can assemblies will be demonstrated during the Qualification Test. However, the procedure demonstrated will differ in some ways from that which is planned for the Option.



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The major difference will be in the equipment used to supply Helium to the outside of the can section. For the Option, a high production method will be employed wherein the can section will be placed in a specially constructed casket which will contain the applied Helium. During the QT, helium will be applied in a fine spray or by isolating successive areas with plastic sheet and duct tape, and injecting these areas with helium.

*Bagging
 Rubber - like
 casket*

Differences in procedures will be small. Modifications between the QT and the Option phase are limited to small changes or adaptations to replicate the option phase of the LIGO project. Such changes are insignificant and may be examined in documents HMST1N and HMST1QT.

Leak Testing of Circumferential Beam Tube Welds

The leak testing of circumferential beam tube welds will be fully demonstrated during the Qualification Test. The procedure demonstrated will be the same as is planned for the Option.

Leak Testing of 10" Valve and Blind Flange Seals

The valve and blind flange mounted on the 10" pump port will be tested in the qualification test by bagging the exterior of the valve and port fittings. The inside of the tube will then be evacuated and a helium mass spectrometer hood test will be used to check for leakage. The difference between the test in the option phase and the qualification test is that CBI will use a vacuum box to evacuate the valve and fittings during the option phase. CBI has no concern about fabrication of a vacuum box for testing of the valve. CBI has used custom fabricated vacuum boxes on many projects. It is therefore not a test issue which must be modeled.

Leak Testing of Beam Tube Module

Leak testing of a beam tube module will be demonstrated during the Qualification Test. The leak test of the entire qualification test beam tube module, both before and after the bake out will be accomplished using an RGA to determine an air signature. If the pre bake out air signature indicates an air leak (the RGA has been calibrated with a known air leak), the techniques of leak test procedure HMST-4QT will be utilized to find the leak. If the post bake out air signature indicates that the air leakage is less than 1×10^{-9} atm cc/sec, the testing will be complete. If the air signature indicates a larger leak, the tube will be releak tested in accordance with HMST-4QT.

*These are
 sufficient
 in the early
 long term
 because this
 procedure
 is a part
 of the contract
 we need
 support.*

The Option leak location procedures discussed in HMST4N have been modified for the qualification test and are shown in HMST-4QT. The location technique used with the



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FINAL DESIGN REVIEW PACKAGE

qualification test will be spraying the seams and fittings with helium, as opposed to using multiple RGA's or vacuum gages as is proposed for the option phase leak location.

The qualification test procedure uses very similar procedures to that which will on the option phase of the project. The decision process used on the qualification test leak tests will be the same as the option phase, however, the equipment will be somewhat different. Pumping systems will not be accurately modeled in the qualification test.

- Cleaning / Outgas Performance

Can Assembly Cleaning

Can assembly cleaning will be demonstrated during the Qualification Test. The essential parameters of the Option Phase cleaning process will be replicated such as the temperature, pressure and flow rate of the steam, and the type of spray nozzle. However, the procedure demonstrated will differ in some ways from that which is planned for the Option. One difference will be the use of a small steam cleaning unit for the QT in lieu of a specially prepared cleaning skid for the Option. Another difference will be manual pulling of the jet cleaning apparatus through the can section in the QT in lieu of a power winch for the Option. Also, high flow input and output fans at the opposite ends of the can sections will be used for the Option but not for the QT and potable water will be used for the Option while softened water will be used for the QT.

Final Cleaning

The final cleaning procedure for the beam tube which is done in place after a can is final placed and welded will be fully demonstrated during the Qualification Test. The procedure demonstrated will be the same as is planned for the Option.

Bakeout

Based on the recommendations of the Preliminary Design Review Board, Caltech issued a Technical Directive Memorandum stating "Consider using direct current (I²R) heating for the tube sections and expansion joints (to be used during field bake out of the beam tube modules) during the qualification test. Due to the limited time available, Caltech has not yet processed this contract change request. However, the following is presented on the assumption that an I²R bake out will ultimately be specified for the QT by Caltech.

The I²R bake out of the qualification test beam tube will model the critical parameters of a full module bake out. These parameters are the electrical current, the insulation, the current injection details and the effect of the bake out on the outgassing rates. The current



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will be identical to the full scale module. The insulation will also be identical to the insulation used for the beam tube modules. This will allow an evaluation of the bellows heating, the tube cooling at the supports and the ease of insulation installation.

The current injection system will be identical to the beam tube modules. This will confirm the acceptability of current injection into a stiffener near the end of the tube instead of injecting the current into a copper bar clamped to the tube.

? Speedy
resistance
? cooling by
the leads

The pumping speed for water vapor during the QT will be set so that the pumping speed per unit of surface area during the QT will match that which will exist in the option phase. This accurate speed-per-area modeling will ensure that the water vapor outgassing rate will be realistically simulated in the qualification test.

~~outgassing rate~~
redesign

Parameters which will not be identical to a full module bake out will be the voltage, the percentage of tube which will have to be heated with auxiliary heaters due to end effects, and the control system. These parameters are not critical in the proof of the concept.

If the I²R bake out is not required, the qualification test will prove the insulation system, the temperature variations at the supports, and the effect of the bake out on the outgassing rates.

] X

Beam Tube Outgas Performance

One of the major purposes of the qualification test is the measure of the outgassing rate of the beam tube. The outgassing rates will, therefore, be measured during all phases of the qualification test. These outgassing tests will be utilized by Caltech as the final data required to confirm the pumping requirements of the full scale facilities.

- Dimensional Control

Control of Materials and Assemblies

The dimensional control of materials and assemblies will be fully demonstrated during the Qualification Test. The procedures demonstrated will be the same as are planned for the Option.

Final and Maintenance Alignment

The adequacy of Global Positioning System (GPS) for final and maintenance alignment of the beam tube modules is considered to be established by the equipment's proven track record. GPS will not be tested in the QT. The GPS is a tested and proven system with



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known accuracy. Further, significant improvements are anticipated in the GPS system before it is needed for the LIGO project.

Clear Aperture

Clear aperture through the beam tube and baffle system has been verified by calculation based on the stackup of the tolerances of the various components and the capabilities of the GPS alignment system. There will be no verification of clear aperture by test.

Handwritten note: [] *Legal showed a subhead into comment*

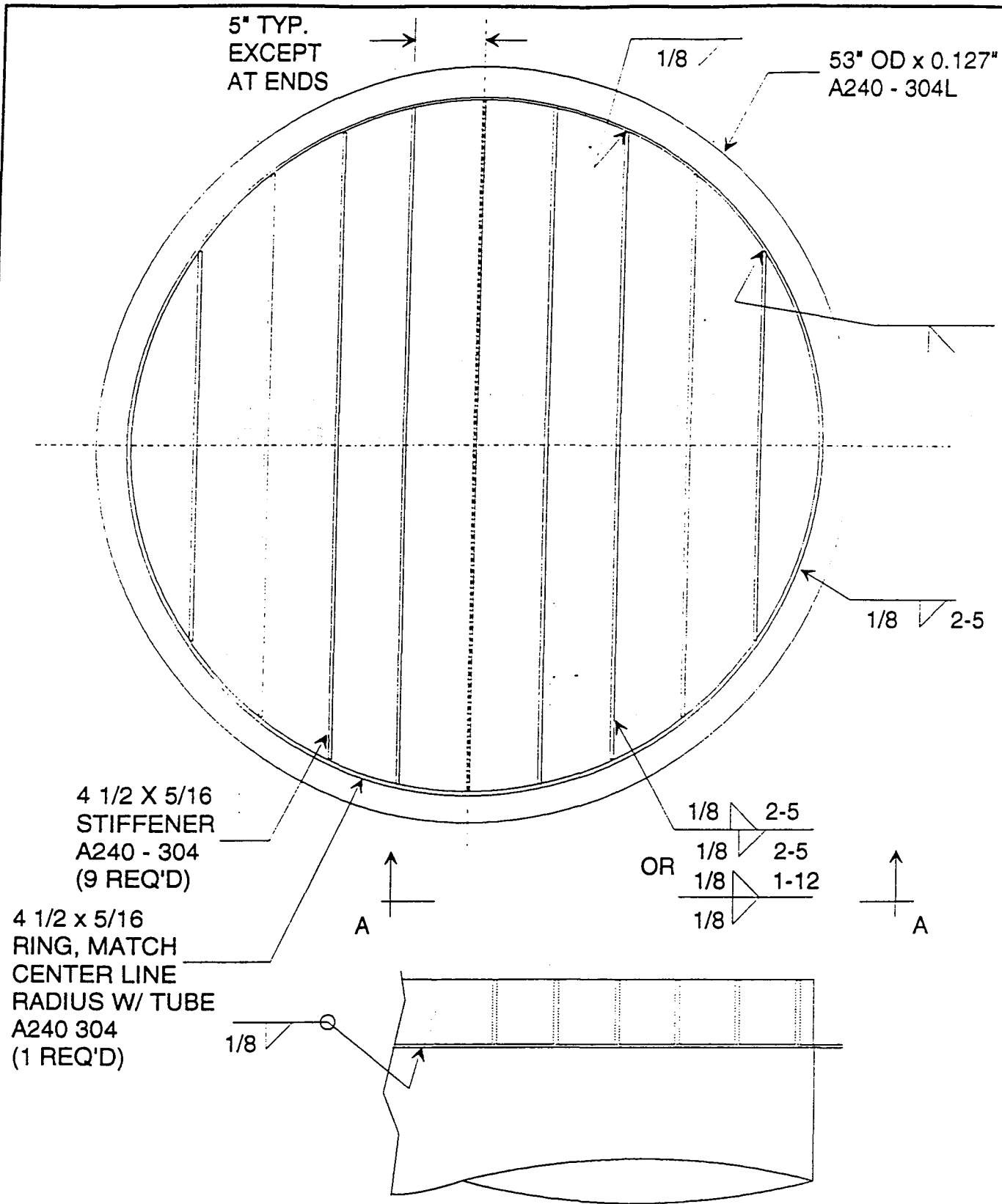
2. Test Configuration and Procedures for Fabrication, Installation, and Testing

- Qualification Test Beam Tube Module Physical Configuration

The qualification test beam tube module will be composed of primarily one subassembly and has an overall length of over 130' with support centerlines of 65'. This configuration represents a current design configuration which consists of repeating subassemblies with consistent distance between support centerlines of 65' throughout the Beam Tube Module length. As shown in Drawing 20, the general configuration for the Qualification Test consists of two sections of beam tube and one expansion joint. Additional representative design details include a pump port; size and spacing of vacuum stiffeners and baffle/support rings; fixed and guided support details and location; and baffle details and location for both the ~ 20 meter spacing and ~ 6 meter spacing.

Several items, shown on sketches at the end of this section, are specific to the Qualification Test and are not used in the Beam Tube Module Detailed Design. These items are the end test/closure heads and the thrust restraint supports. Both of these items provide closure, support and restraint for the vacuum end loads on the Qualification Test Beam Tube Module. Calculations for these items are included in the Qualification Test Plan Appendices.

The qualification test will be conducted in the basement of the Research and Development Center. The QT Beam Tube Module vacuum and outgassing system will be located in the LIGO Qualification Test Vacuum Lab. the vacuum and outgassing system will be connected to the QT Beam Tube Module at the pump port.



4 1/2 X 5/16
STIFFENER
A240 - 304
(9 REQ'D)

4 1/2 x 5/16
RING, MATCH
CENTER LINE
RADIUS W/ TUBE
A240 304
(1 REQ'D)

1/8

SECTION A

SUBJECT

QT STIFFENED END HEAD

CBI

OFFICE
NOE C

REVISION 1

REFERENCE NO.
930212

MADE BY
RJW

CHKD BY
TKH

MADE BY
RJW

CHKD BY
TKH

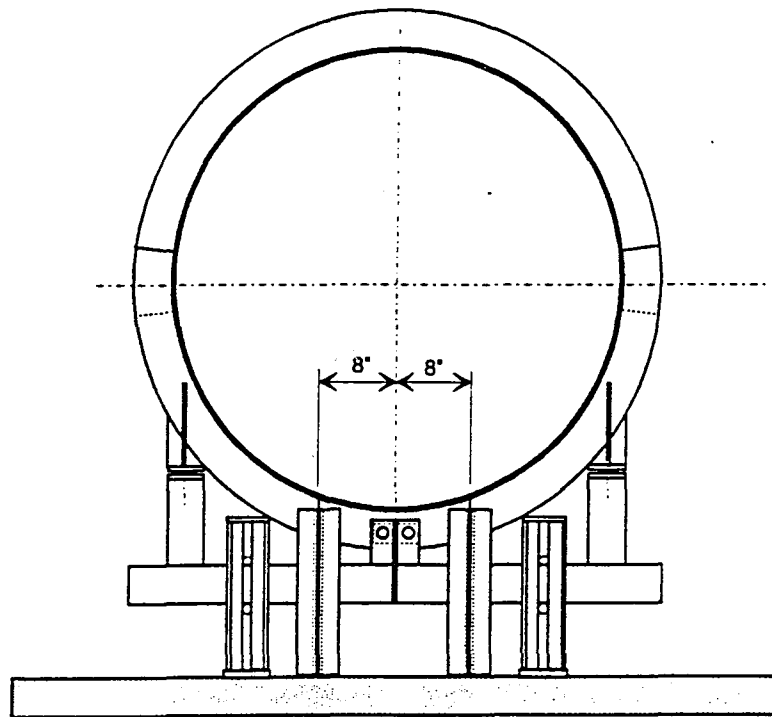
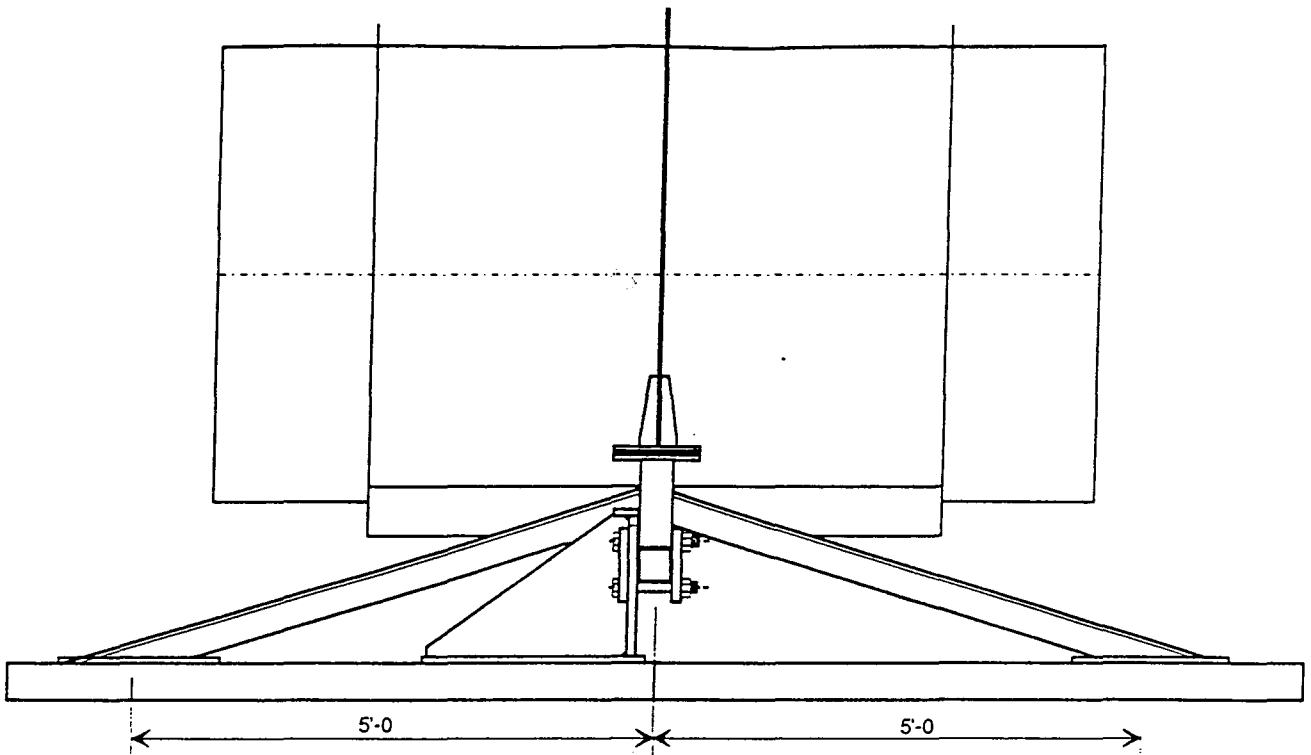
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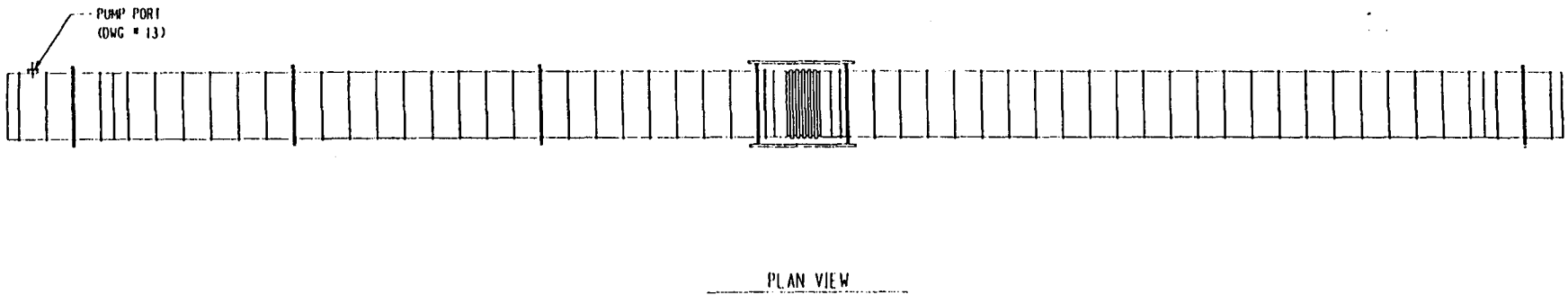
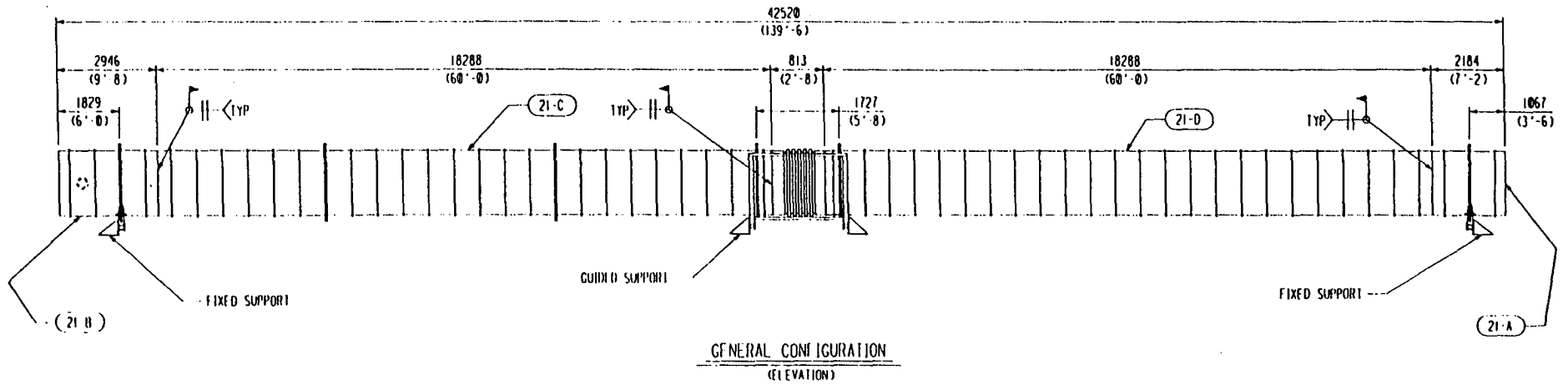
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29 March 94

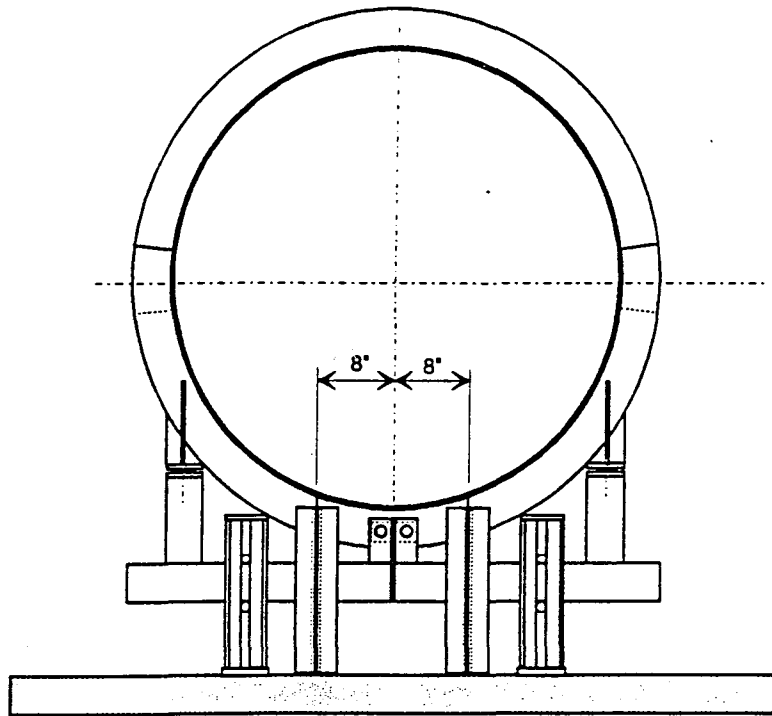
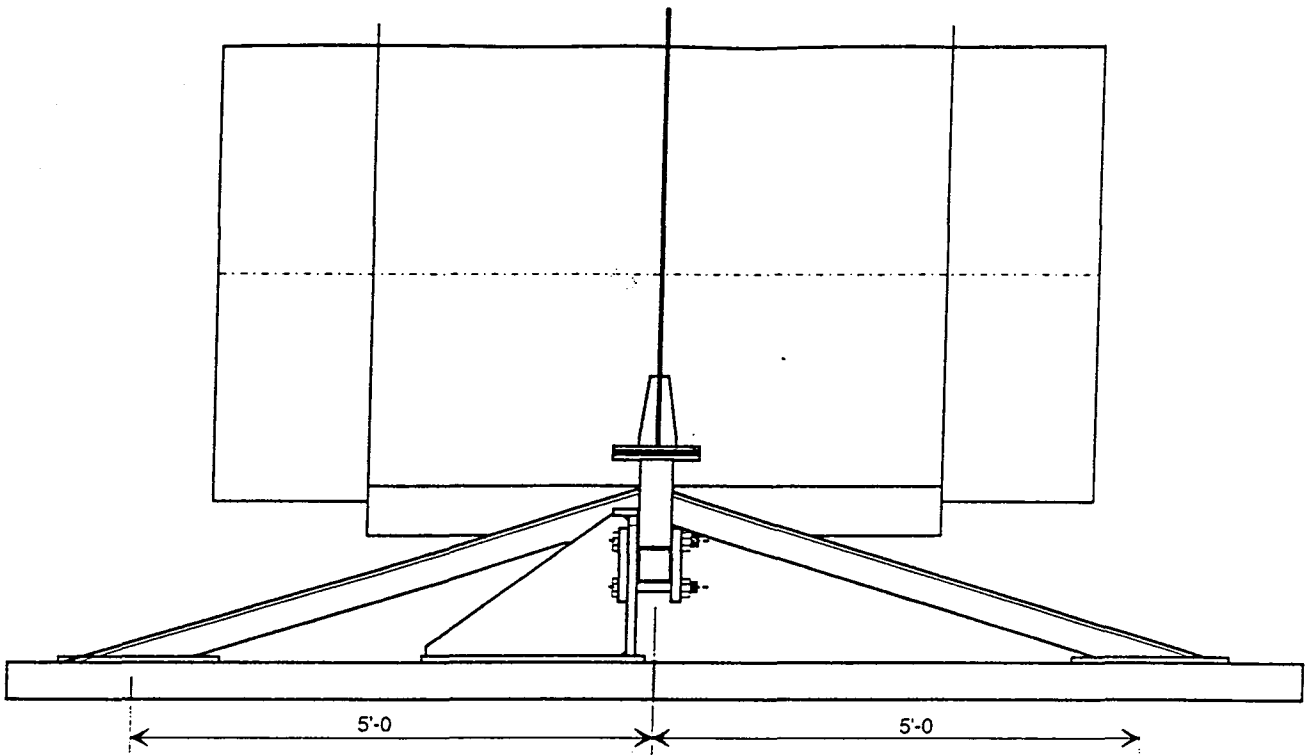


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	DATE 4/1/94	DATE 4/6/94	DATE	DATE	SK-QT1

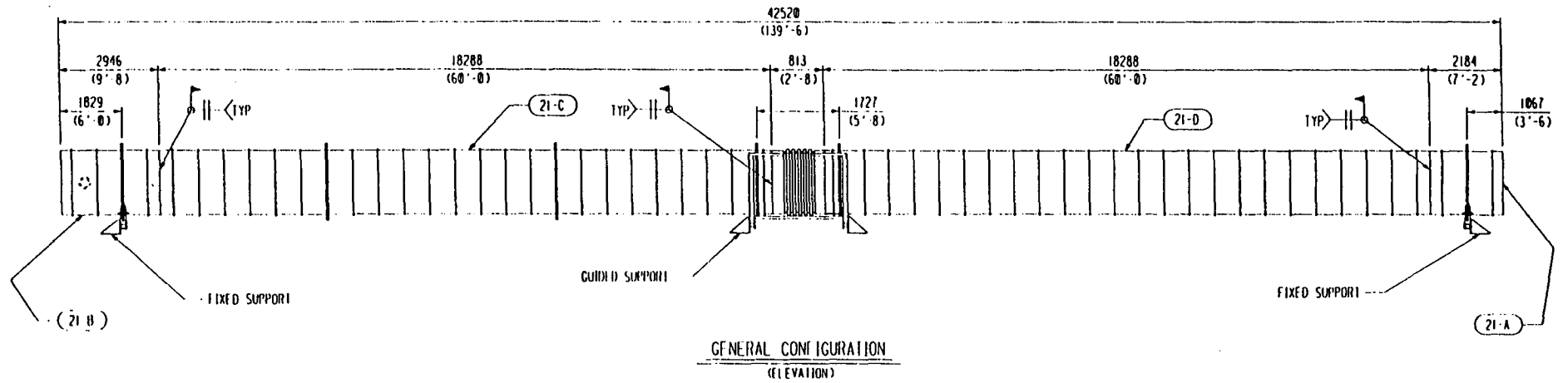


		LIGO BEAM TUBE QUALIFICATION TEST	
		GENERAL CONFIGURATION	
CUSTOMER'S NO	DATE	CONTRACT NO	REV
BY <u>A.R. OWG</u>		<u>930212</u>	0
ENGINEERING SUPERVISOR		DWG NO	REV
		0	0
<small>THIS DRAWING AND INFO PREPARED FOR AND IS THE PROPERTY OF CBI AND IS TO BE USED ONLY IN CONNECTION WITH PERFORMANCE OF WORK BY CBI. REPRODUCTION IN WHOLE OR IN PART FOR ANY OTHER PURPOSE IS EXPRESSLY FORBIDDEN.</small>			

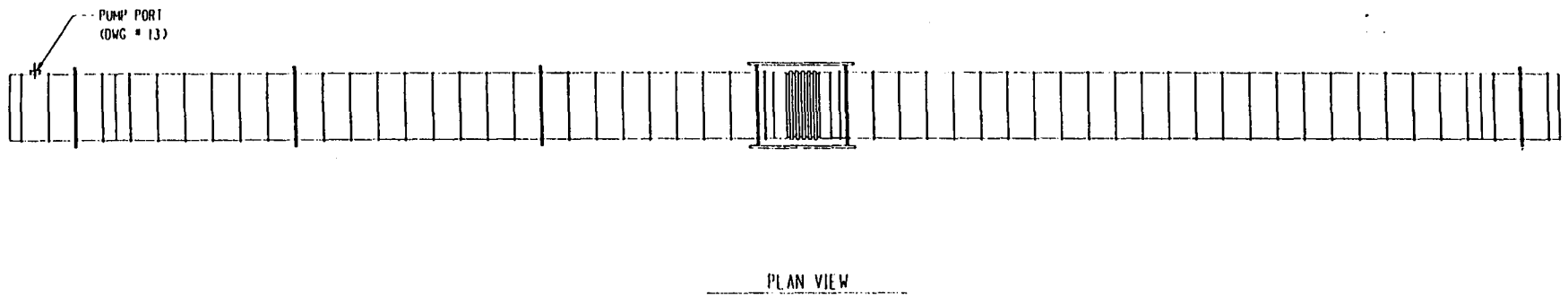
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SUBJECT THRUST RESTRAINT QUALIFICATION TEST LIGO	GBI OFFICE		REVISION:		REFERENCE NO.
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	DATE 4/1/94	DATE 4/6/94	DATE	DATE	SK-QT1



DIRECTION OF CONSTRUCTION →



15

		LIGO BEAM TUBE QUALIFICATION TEST	
		GENERAL CONFIGURATION	
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BY J.R. CHOD	DATE	DWG	REV
D.J. THOMPSON		20	0
ENGINEERING SUPERVISOR		SET	0
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▶ INDICATES CHANGE FROM PREVIOUS ISSUE



LIGO PROJECT
WBS 400
QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE

- Qualification Test Pumping and Outgassing System

The pumping and outgassing system for the Qualification test is shown in the P & I Diagrams which are located at the end of this section. The system will utilize a 1100 L/S turbomolecular pump backed by a smaller wide range turbomolecular pump and again backed by a mechanical pump. The two turbomolecular pumps in series are provided to effectively evacuate the chamber and provide the hydrogen compression ratio necessary to minimize the hydrogen background in the system. The large turbomolecular pump has a hydrogen compression ratio of 2200. The small, wide range turbomolecular pump used to back the large pump has a hydrogen compression ratio of 3×10^6 . The combination, along with the roughing pump which will be operated at approximately 200 micron, in order to maintain the flow in the viscous regime, will provide a compression ratio in the range of 10^{12} . This will allow the system to be evacuated into the 10^{-9} torr range.

Caltech has required a maximum water vapor speed of 600 L/s in order to simulate the water pumping speed which will be present in the full size modules. CBI will therefore provide an orifice in the pumping system piping in order to limit the speed to the specified 600 L/s.

The pumping system is provided with a cold trap to prevent back streaming and to provide a known water vapor pump speed for the water vapor outgassing test. The pumping systems are also provided with a pneumatically operated valve which will shut upon equipment or electrical failure. These two features along with a viscous flow inleed in the roughing line will prevent any hydrocarbon back streaming into the beam tube.

The outgassing test will be accomplished using a steady state outgassing technique. The partial pressure of hydrogen in the system should be in the 10^{-9} torr range and the water vapor should be in the 10^{-12} torr range, if the outgassing rates are as experienced by Caltech. The Qualification test will utilize a Balzers RGA with a detection limit in the 10^{-15} torr range. The hydrogen outgassing rate for the pumping and outgassing test system will be an order of magnitude less than the outgassing from the beam tube so the test accuracy should be sufficient for the test purposes. Spurious hydrogen from fractionation of water and hydrocarbons will be minimized because of the cold trap located in front of the RGA. The line length between the cold trap and the RGA will be minimized to minimize contamination.

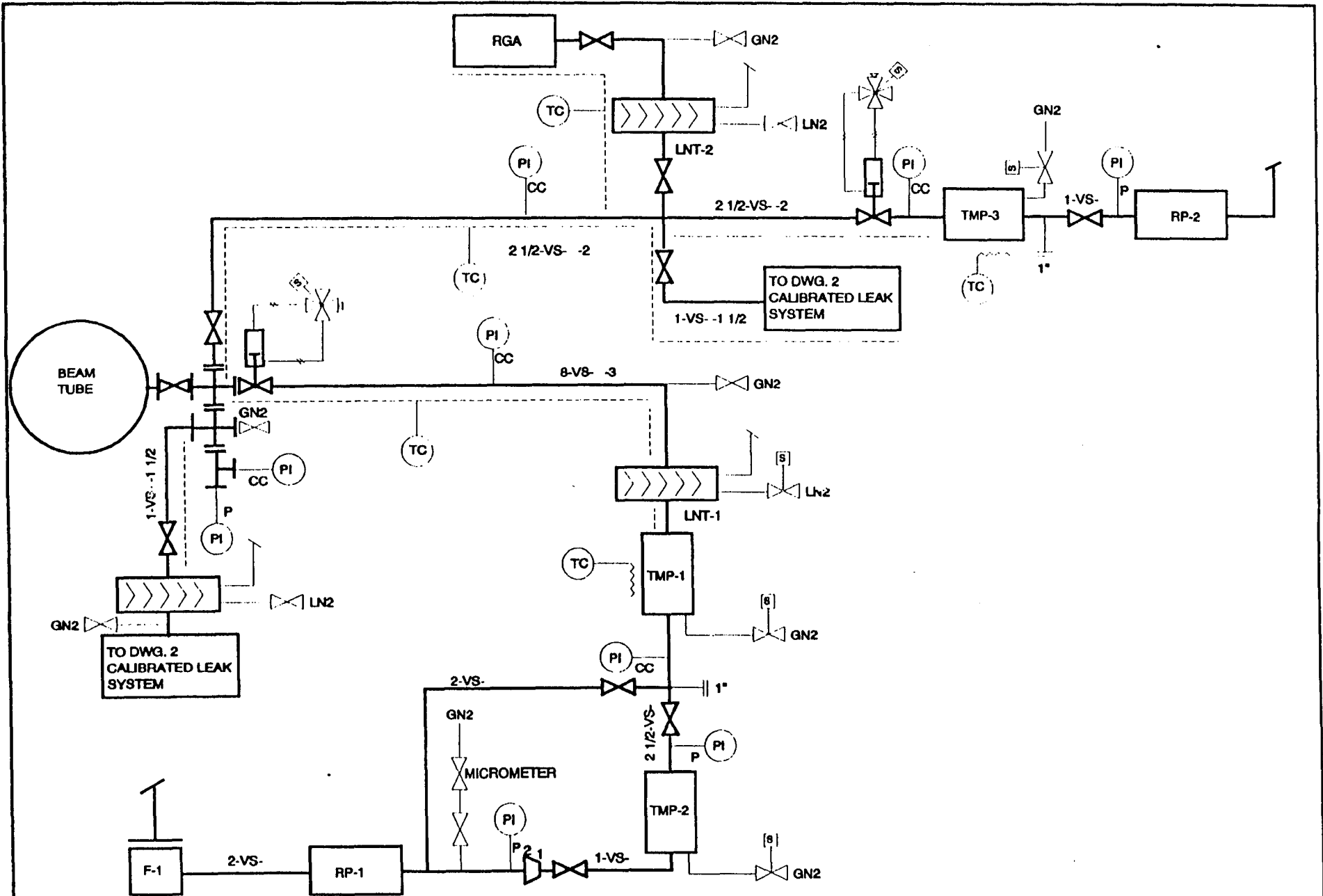
The entire pumping and outgas test system will be heat traced and insulated in order to bake out the equipment up to the maximum temperature limitations provided by the equipment manufacturers. The pumping and outgas test systems are predicted to have an initial outgassing rate of approximately 1×10^{-12} torr liter/sec cm^2 after bake out.

H₂
N₂
H₂O
~ H_nC_mO_q



**LIGO PROJECT
WBS 400
QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE**

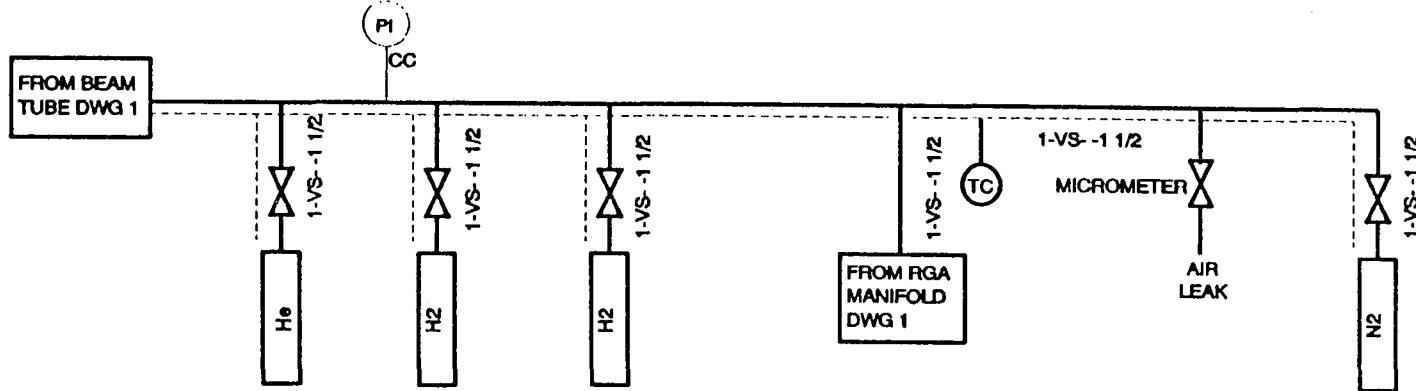
Calibrated leaks will be provided for nitrogen, hydrogen, helium and air leakage. These leaks will be provided in the proper ranges to accommodate calibration of the RGA and the Helium Mass Spectrometer.



P & I DIAGRAM
 VACUUM SYSTEMS
 QUALIFICATION TEST
 LIGO PROJECT
 CALTECH

BY WAC CHKD _____ DATE 3/11/94
 R. C. WEBER
 ENGINEERING SUPERVISOR

CONTRACT NO. 930212	
DWG 1	REV 6
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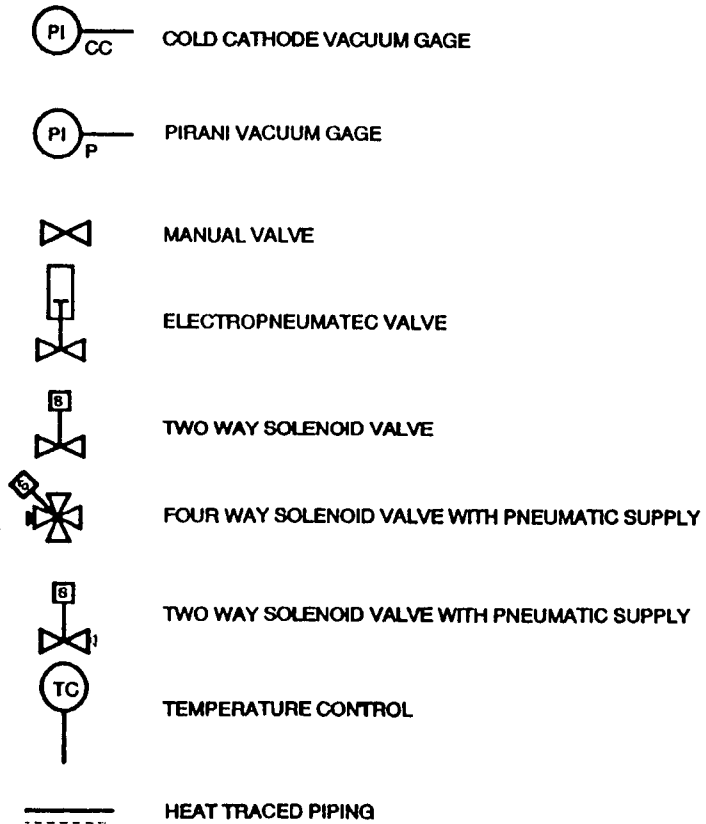


P & I DIAGRAM
 CALIBRATED LEAK SYSTEM
 QUALIFICATION TEST
 LIGO PROJECT
 CALTECH

BY WAC CHKD _____ DATE 11/0/00
 R. C. WEBER
 ENGINEERING SUPERVISOR

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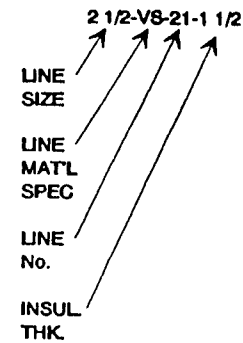
P & I SYMBOLS



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



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

BY WAC CHKD DATE 11/10/83
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
830212

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QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE**

- Qualification Test Procedures - WBS 440

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 at the end of this section. This procedure list identifies each procedure as to its authored origination: (1) directly from the detailed design; (2) QT addenda to the detailed design; or (3) QT specific. The addenda approach was adapted for some of the QT procedures so that the correlation and replication of the detailed design procedure could be maintained and monitored during the specific operation. This approach can be more cumbersome from a process performance standpoint but it will allow both Caltech and CBI a better opportunity to make the necessary comparisons between the detailed design and the Qualification Test.

(a) QT Coupon Outgas Test Procedure - COUP-02

This procedure specifies the outgas test required for the QT material coupons. The QT outgas test system utilizes a single chamber configuration and provides for an ambient temperature outgassing test. This procedure mirrors the Option Coupon Outgas Test Procedure with the exception that the Option Procedure COUP-01 uses a 3-chamber configuration.

(b) Construction Plan

Fabrication and installation operations of the QT Beam Tube Module are sequenced and specified in the procedures identified as FSQT and ISQT, respectively. These procedures/sequences outline the sequential operations including dimensional control, leak testing, and cleaning that have to occur to fabricate the assemblies and install/construct the QT Beam Tube Module. Ongoing critical operations such as cleaning and leak testing have separate procedures for the different methods used at different points in the sequences. Planned approach procedures for cleaning (LIGOCPQT) and leak testing (LIGOTPQT) describe general requirements common to all the separate procedures and describe how and when each procedure is used.

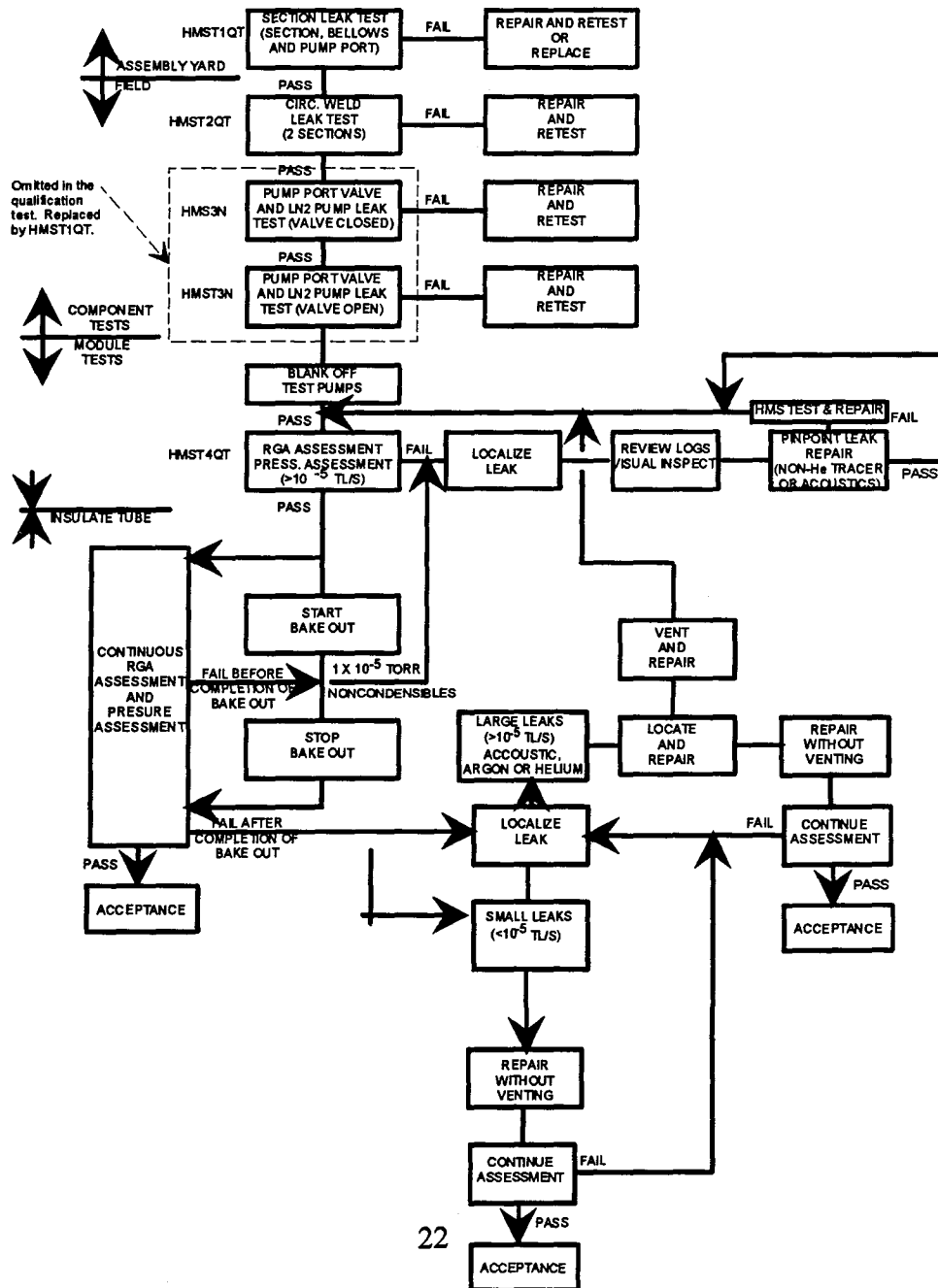


**LIGO PROJECT
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QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE**

(c) Leak Testing Procedures

The leak testing procedures are developed and used to meet the planned approach to leak testing specified in LIGOTPQT which provides for leak testing of each beam tube can section (HMST1QT), each closing weld joint between beam tube can sections (HMST2QT) and leak testing of the entire QT beam tube module (HMST4QT). The decision tree for the Qualification Test is essentially the same as that for the complete module and is included here to show the QT approach to leak testing.

**LEAK DETECTION DECISION TREE
QUALIFICATION TEST**





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QUALIFICATION TEST
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3. Qualification Test Report

The Qualification Test Report will follow the outline/index shown at the end of this section. Data will be reported in the same format as it is specified to be recorded in the Qualification Test Procedures. This data will range from initial coupon outgas test results; through fabrication/installation data which includes dimensional, cleaning, and leak testing data; to final acceptance testing data. Documentation will be recorded and reported for each operation performed to identify anomalies, changes, improvements, or identity to the procedure as written. Computerized data will be formatted and reported as required by the QT Data Acquisition Procedure.

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

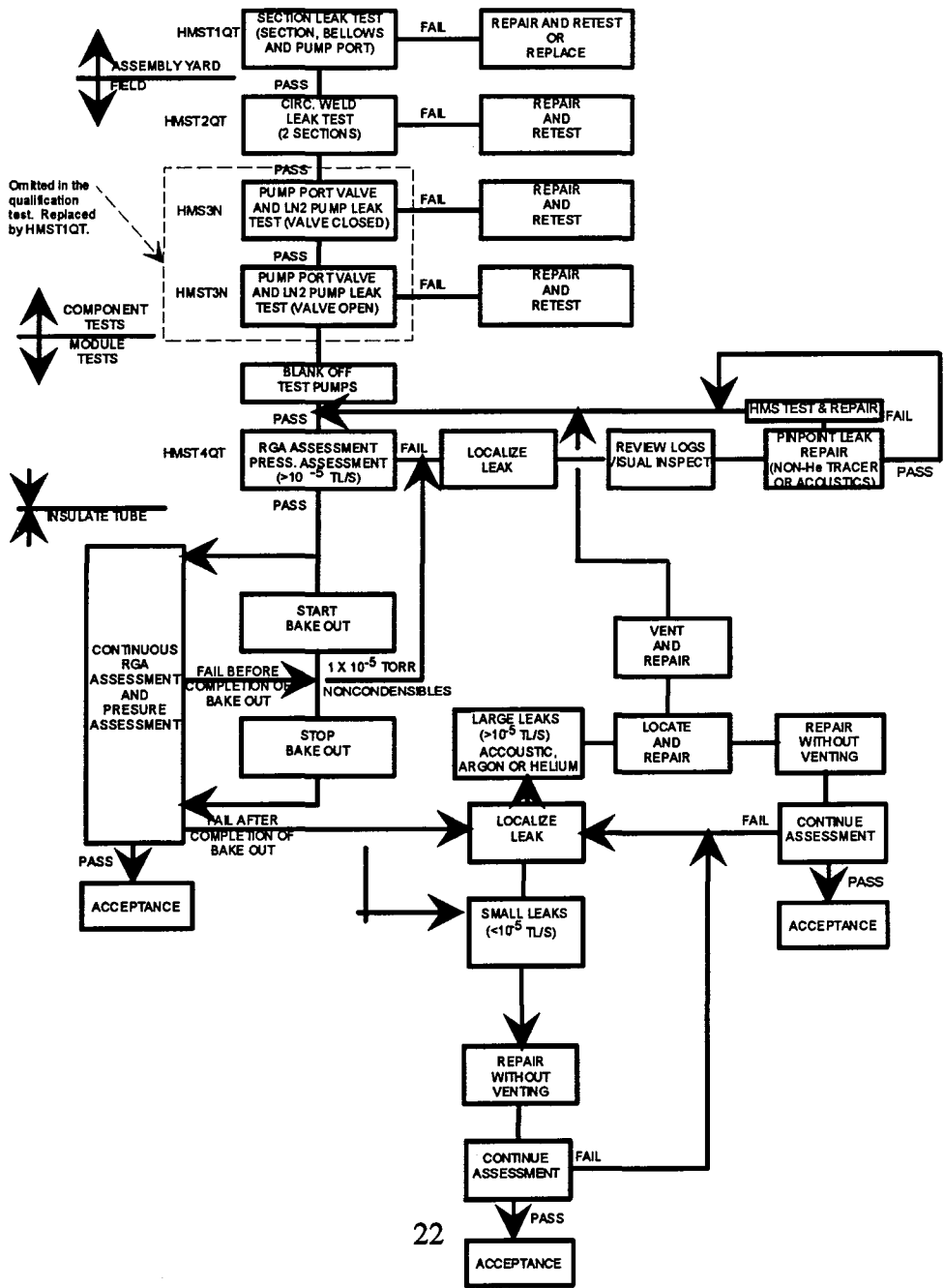


LIGO PROJECT
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QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE

(c) Leak Testing Procedures

The leak testing procedures are developed and used to meet the planned approach to leak testing specified in LIGOTPQT which provides for leak testing of each beam tube can section (HMST1QT), each closing weld joint between beam tube can sections (HMST2QT) and leak testing of the entire QT beam tube module (HMST4QT). The decision tree for the Qualification Test is essentially the same as that for the complete module and is included here to show the QT approach to leak testing.

LEAK DETECTION DECISION TREE
QUALIFICATION TEST





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QUALIFICATION TEST
FINAL DESIGN REVIEW PACKAGE**

(d) Qualification Test Pumpdown and Outgassing Test Procedure - WBS 444

A procedure has been developed for the pump down and outgassing test of the beam tube during the Qualification Test. The procedure, which is identified as "OUTGAS", is provided in the Qualification Test Plan package. The procedure covers the pump down procedure and the outgassing test program which will be accomplished during the qualification test.

The contract calls for the outgassing test of the qualification test tube sections. This is interpreted to include an outgassing test which measures the hydrogen and water vapor (the only two materials specified in specification 1100007) outgassing rates after the tube has been baked out and returned to ambient temperature. CBI does however, understand that the qualification test tube section represents an additional, very large scale, outgassing test specimen and further study of the outgassing characteristics of the material, before, during and after the bake out is of interest to the LIGO project team. This procedure has, therefore, been written to include intermittent RGA measurements for outgassing studies and for air signature leak test studies. The RGA measurements will be accomplished as follows:

- before the bake out for outgassing and air signature testing
- every 30°C during the heat up portion of the bake out for outgassing
- every day during the steady state portion of the bake out for outgassing
- after the bakeout for outgassing and air signature testing *and hydrocarbons*

(e) Bakeout Procedure

The QT bakeout procedure specifies the equipment and procedure required to emulate the complete Beam Tube Module field bakeout parameters that affect the level of post bake outgassing. This procedure specifies electric resistance heating cable to heat up and maintain the necessary bake temperature.

CBI has prepared a basic design of the module bakeout and QT bakeout based on the I²R method. On the basis of this preliminary design CBI has submitted a request for change to perform a basic I²R bakeout of the QT and will provide a proposal for CBI to include a module I²R bakeout in the design and perform the bakeout in the Option.

(f) Data Acquisition Procedure

The Data Acquisition Procedure describes the written documentation and computerized data acquisition that is required throughout the Design Qualification Test. Hardware and software used to record analog instrument data is described in addition to the hardware and software dedicated solely to RGA output data. Text files for computerizing lab notes which correlate to instrument state and output is also described. Daily transmission via modem is specified for tests run on the QT Beam Tube Module for outgassing, etc., when in an evacuated state.



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Qualification Test Procedures

ID	Title	Directly from Detailed Design	QT Addenda to Detailed Design	QT Specific
Material Specifications				
C-240-0186	Coil Material Specification	X		
C-CMBS1	Coil Material Bake Specification	X		
WMS-ER308L	Cleaning and Bakeout Procedure of ER 308L Weld Wire	X		
C-240-0187	Baffle Material Specification	X		
C-CMBS1	Baffle Material Bake Specification	X		
C-240-0194	Expansion Joint Material Specification	X		
Purchasing Specifications				
C-BT-QT	Qualification Test Beam Tube Sections			X
C-EJ-QT	LIGO Beam tube Expansion Joints Qualification Test			X
C-SUPT-1	Beam Tube Support Specification	X		
CBAF-1	Baffle Fabrication Specification	X		
C-PORT-QT	Pump Port Specification			X
C-PORTPAD-1	Pump Port Reinforcing Pad Specification	X		
C-VAC-1	Vacuum Stiffener Specification	X		
C-SUPSTF-1	Support Ring/Baffle Ring Fabrication Specification	X		
Fabrication/Installation Procedures				
FSQT	Beam Tube Can Section Fabrication Sequence for LIGO Qualification Test Addenda		X	
ISQT	Beam Tube Can Section Installation Sequence for LIGO Qualification Test Addenda		X	
FPCircumferential	Fitting/Purge Procedure for Circumferential Butt Welds for LIGO	X		
FPStiffener	Fitting/Purge Procedure for Stiffener Attachment Welds for LIGO	X		
FPPumpPort	Fitting/Purge Procedure for Pump Port Attachment Welds for LIGO	X		
MI	Material Traceability	X		
IR	Receiving Inspection	X		
DCQT	Dimensional Control		X	
Welding Procedures				
WPS-INDEX	Weld Procedure Index	X		
WPS-ER308S/GMA (w/PQR 4858)	Weld Procedure, GMA Welding for 304L Materials	X		
WPS-ER308L/Repair (w/PQRs 10029 & 4858)	Weld procedure, GMA for Repair Welding for 304L Materials	X		



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ID	Title	Directly from Detailed Design	QT Addenda to Detailed Design	QT Specific
GR-8X	General Repair Procedure for Materials and Welds for LIGO Beam Tube Modules	X		
CUP-8X	Plate Clean-Up Procedure for LIGO Beam Tube Modules	X		
WPS-E7018/STRUCT (w/PQR 8903)	Welding Procedure for Structural (Carbon to Carbon)	X		
WPS-E308-STRUCT (w/PQR 9168)	Welding Procedure for Structural (Stainless to Stainless)	X		
WPS-E309-STRUCT (w/PQR 6190)	Welding Procedure for Structural (Carbon to Stainless)	X		
WPS-ER308L-Circ (w/PQR 10029)	Welding Procedure for Expansion Joint to Beam Tube Can Assemblies	X		
WPS-ER308L/Port (w/PQR 10029)	Welding Procedure for 10"Ø Vacuum Port Nozzle to Beam Can Assemblies	X		
WPS-ER308L/Stiffener (w/PQR 4858)	Welding Procedure for Stiffener to Beam Tube Cans	X		
GWPS-SMAW	General Welding Procedure Specification for the Shielded Metal Arc Process	X		
GWPS-GTAW	General Welding Procedure Specification for the Gas Tungsten Arc Process	X		
GWPS-GMAW & FCAW	General Welding Procedure Specification for the Gas Metal Arc and Flux Cored Arc Processes	X		
NDE Procedures				
VI5	Visual Inspection Technique Procedure Standard Procedure	X		
VI8	Visual Inspection Requirements for ASME Section VIII Code - Division 1 & 2 Pressure Vessels	X		
Cleaning Procedures				
CLCOUP	Steam Cleaning of Coupons for Outgassing Test	X		
LIGOCPQT	Planned Approach for Cleaning Maintenance for LIGO Qualification Test Addenda		X	
CL1QT	Cleaning Of Completed Beam Tube Can Sections Before And After Leak Testing And Final Assembly For Ligo Qualification Test Module Addenda		X	
CL2QT	Maintenance Of Partially Completed Beam Can Sections For Ligo Qualification Test Module Addenda		X	



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ID	Title	Directly from Detailed Design	QT Addenda to Detailed Design	QT Specific
CL3QT	Final Cleaning and Inspection of LIGO Beam Tube Inner Surfaces Including Baffles for LIGO Qualification Test Addenda		X	
CRWAQT	Clean Room Wearing Apparel for Beam Tube Access for LIGO Qualification Test Addenda		X	
Leak Testing Procedures				
LIGOTPQT	Planned Approach to Leak Testing for LIGO Qualification Test Addenda		X	
HMST1QT	Helium Mass Spectrometer Hood Test of Beam Tube Can Sections for LIGO Qualification Test Addenda		X	
HMST2QT	Helium Mass Spectrometer Hood Test of Closing Weld Joints Between Beam Tube Cans for LIGO Qualification Test Addenda		X	
HMST4QT	Helium Mass Spectrometer/Performance Test of Beam Tube Modules for LIGO Qualification Test Addenda		X	
Outgas Testing Procedures				
Coup-02	Coupon Outgassing Test Procedure Qualification Test			X
OUTGAS	Pump Down and Outgassing Test Procedure			X
Alignment Procedures				
AQT	Installation Alignment and Support Adjustment Procedure for LIGO Qualification Test			X
Bakeout Procedures				
BO-QT	Preliminary Procedure for Bakeout of Qualification Test Beam Tube			X
Data Acquisition Procedures				
DAQT	Data Acquisition Procedure			X