

ORIG SENT TO  
RAI BY MISTAKE  
SENT TO MARTY  
w/ MARKUPS

# LIGO PROJECT

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## FACSIMILE COVER SHEET

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My notes on the QT items tested vs. items by analysis. In general, we're looking for more statements of judgment: what needs to be tested and why; what needs to be analyzed and why; what needs neither and why not. The format you've got should work fine unless you have reason to change it.

In addition, many items have changed since this was originally written; see notes.



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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 .

**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.

*GENERAL - WHAT DO THESE DIFFERENCES MEAN? IF NOT TESTED, SHOULD THEY BE? WHY/WHY NOT?*



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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.

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.

NO -  
FIXED  
SUPPORTS  
ARE  
REINFORCED  
TO SERVE  
AS ANCHORS  
ACTUAL LOADS  
≠ OPTION  
DESIGN  
ARE NOT  
TESTED



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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.

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.

CURRENT PLAN IS TO DEMONSTRATE THERMAL PERFORMANCE AFTER QT IS COMPLETE & TUBE IS VENTED.

NO LONGER DESIGN IS NOT ACCEPTABLE

GENERALLY - EXCEPT - NO PAINT/ CARDBOARD IN BAKE BETTER DRY AIR PURGE

( IN PARALLEL WITH )

NEW PROCEDURES MAY BE NEEDED TO TRACK CONTAMINATION



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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. *NEEDS REWORK*

*NOT NECESSARILY  
- MAY BE CHANGED FOR THE OPTION  
WHAT ABOUT SHIPPING SUPPORT POLICY?*

### 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. *THE UNIFORMITY OF SPRING RATES.*

*PROJECT  
MENTION CONSIDERATION FOR FATIGUE TEST OF EXPANSION JOINT*



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**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.

MAYBE NOT -  
 TUBETEC MAY  
 USE NEWER,  
 WIDER MILL

**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.

DESIGN MAY  
 BE DIFFERENT

**- 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.

WHAT IS THE  
 METHOD? (S)  
 IS THERE A  
 PROCEDURE?

IS THERE A  
 DESIGN?

**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.

ISN'T THIS NOW CHANGED TO VERT?

**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.

WHAT ABOUT  
 NOSE CUTTING  
 TECHNIQUE?



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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.

THIS HAS BEEN  
 CHANGED  
 CUTOFF -> FROM  
 WHERE IS DISCUSSING  
 ON STRINGS?

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.

DID WE GET  
 THE DATA?

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.

IS THIS STILL  
 TRUE?

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.

DRAWINGS  
 OF  
 ENCLOSURES  
 WITH FIXTURES  
 & TUBE IN  
 SEQUENCED  
 POSITIONS

THIS MAY BE AN ITEM  
 CHECKED OUT PHYSICALLY  
 WITH A SLOW START MODE



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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.

WHAT WERE THESE?

**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:

ISN'T THE PROCEDURE SUBSTANTIALLY DIFFERENT?

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.

HOW WILL THE GPS BE DEMO'D/TESTED? WHAT IS THE GPS PLAN?

**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.

PA PROCEED - ENTRY/EXIT PAPERWORK

**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.

WILL TEMP AXIAL SUPPORTS BE DEMO'D? WHERE IS DWG?

**- 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.

CASKET CONCEPT  
IS NOT YET  
ACCEPTED

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.

THIS TOO  
IS CHANGED  
- MUST BE  
PROCESSED  
NOW?

#### 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.

VAC BOX  
WON'T WORK

#### 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  $1 \times 10^{-9}$  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.

THIS IS IMPORTANT  
↓  
BAG ALSO?  
PLAN TO DEM  
SIGNAL/NOISE  
IN SAME RATIO  
AS SURFACE  
AREAS

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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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.

EXCEPT FOR  
WATER  
PUMPING  
SPEED

- 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.

EXPAND  
FOR NEW  
PROCEDURE

WHAT WILL  
BE USED  
AS QA TEST  
FOR OPTION?

DELETED?

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 (I<sup>2</sup>R) 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 I<sup>2</sup>R bake out will ultimately be specified for the QT by Caltech..

END  
CONNECTIONS  
FOR  
CABLES?

The I<sup>2</sup>R 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. *CHANGED?*

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.

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. *AKIAL SIMPLEX*

If the I<sup>2</sup>R 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. *NOW REQUIRED*

### 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. *WAS THIS BEEN DONE?*

#### 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.

DEMO A  
COMPLIANCE  
MEETING  
SPECS?

## 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.