LIGO-C950384-00-B

CBI

Chicago Bridge & Iron

Technical Services Company

1501 North Division Street
Plainfield, Illinois 60544-8929

815 439 6000
FAX: 815 439 6010

April 5, 1995

California Institute of Technology
Karen Dowd
Manager, Purchasing Department
Keith Spalding Building, Mail Code 309-6
1201 E. California
Pasadena, California 91125

Reference: Contract No. C146 for LIGO Beam Tube Modules

Subject: Qualification Test Review Data Package
CDRL #16 DRD#10 Items I & II
CDRL # 11 DRD #5

Attached please find the 24 copies of the Qualification Test Review Data Package for the Beam Tube Design and Qualification Test. The updated budgetary estimate for the Option effort will be presented at the Qualification Test Review meeting.

Regards, Marty Tellalian

M.L. Tellalian - PAE - CBI Technical Services
att.

cc: Larry Jones (Letter Only)
California Institute of Technology
LIGO Project
102-33 Bridge Laboratory
Pasadena, California 91125

CALIFORNIA INSTITUTE OF TECHNOLOGY
Laser Interferometer Gravitational Wave Observatory (LIGO) Project

To/Mail Code: Distribution/102-33
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Date: April 21, 1995

Subject: **DISTRIBUTION OF CDRL DOCUMENTATION**

Document #:	CBI-BTM010AA1X01	**DRD:**	010/005
Transmittal Date:	April 5, 1995	**Date Received:**	4/14/95

Title: Qualification Test Review Data Package of the Beam Tube Module, Items I & II

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LIGO PROJECT

BEAM TUBE MODULE DESIGN & QUALIFICATION TEST CALTECH CONTRACT C146

QUALIFICATION TEST REVIEW DATA PACKAGE CDRL #16 DRD #10 ITEMS #I & II

DESIGN QUALIFICATION TEST REPORT CDRL #11 DRD #5

PREPARED BY

CBI TECHNICAL SERVICES COMPANY
PLAINFIELD, ILLINOIS

APRIL 4, 1995

CBI CONTRACT 930212

LIGO PROJECT
BEAM TUBE DESIGN & QUALIFICATION TEST
QUALIFICATION TEST REVIEW DATA PACKAGE
INTRODUCTION
APRIL 17th & 18th, 1995

The LIGO Beam Tube Qualification Test Report describes the activities required to procure, fabricate, install, test a representative section of the LIGO Beam Tube Modules. The Design and Qualification Test were performed by employees of Chicago Bridge and Iron Company. The qualification test was conducted at CBI Technical Services Company's Research and Development Center in Plainfield, Illinois. Beam tube assemblies were inspected and stiffened at CBI's Corporate Weld Laboratory in Houston, Texas. Construction planning services were provided by CBI Services and CBI NaCon which are CBI's domestic operating companies.

The Qualification Test Report consists of the following sections:

Executive Summary
Provides a one page summary of the Qualification Test.

Acknowledgments

Table of Contents

Test Configuration
Provides a description of the Qualification Test configuration.

Test Activity Reports
The project procurement, processing, fabrication, installation, testing, and quality assurance have been broken down into a series of Test Activities. A report has been prepared for each test activity which consists of the following areas of discussion on the activity:

- Option Plans & Procedures
- Qualification Test Plans and Procedures
- Major Differences Between The Option & The Qualification Test
- Qualification Test Execution
- Discoveries & Conclusions
- Potential Risks & Additional Development

Lessons Learned & Proposed Changes
Presents the a summary of the lessons learned and the proposed changes from the Task Activity Reports

Major Risk Areas & Additional Development
Presents four major risk areas which could require a significant development effort.

Appendices
Provides supplemental information on some Test Activities.

LIGO PROJECT
BEAM TUBE DESIGN & QUALIFICATION TEST
QUALIFICATION TEST REVIEW DATA PACKAGE
EXECUTIVE SUMMARY
APRIL 17th & 18th, 1995

The LIGO Beam Tube Qualification Test consisted of a 49" diameter by 125 foot long tube section between fixed supports which is nearly identical to the repeating sections which make up the beam tube modules. An expansion joint and flexible support are located between the fixed supports. Component procurement, fabrication, installation, and testing were conducted over a 11 month period which was approximately 4 months longer than originally scheduled due to the additional work associated with the problems encountered. Component procurement and fabrication was conducted with procedures and by suppliers most likely to be used for the modules. Although many of the module construction procedures were used in the qualification test, conditions associated with field conditions were not represented in the test.

Many changes and modifications were developed through the execution of the qualification test. Most of the changes are attributed to the unique requirements of the LIGO project compared to typical industrial requirements. In addition, the repetitious nature associated with building nearly 10 miles of beam tubes requires careful cost consideration of tasks that must be repeated hundreds or thousands of times. A listing of the lessons learned through the installation and execution of the qualification test are contained in section entitled "Summary Lessons Learned".

At Caltech's request, outgas test data was taken for the full range of the Residual Gas Analyzer (RGA) for the duration of the test. Outgas data for an AMU range of 1 to 100 was recorded every 15 minutes and transmitted daily to Caltech when the QT assembly was at high vacuum pressures. The test produced accurate and reliable data on the system pumping and outgas characteristics. The measured hydrogen and water outgassing rates are as follows:

Pre-bake hydrogen: 3.0×10^{-14} torr liters per second cm^2
Pre-bake water: 2.2×10^{-11} torr liters per second cm^2
Post-bake hydrogen: 8.6×10^{-14} torr liters per second cm^2
Post-bake water: 6×10^{-18} torr liters per second cm^2

The lowest pressure achieved in the qualification test assembly following bake out was approximately 3×10^{-10} torr.

The Qualification Test identified a number of significant risk areas which will require additional development to accurately estimate the cost and likelihood of successful module performance. Although the spiral welded process is the most economical method of tube fabrication, the industry has limited capabilities to meet the unique requirements of the LIGO project. Further development of a tube mill and spiral weld procedure are required to ensure a reliable supply of economical tube sections suitable for use in the LIGO project. A specified cleanliness can not be achieved in light of the specified surface condition and the yet unknown site environment. Although the cleaning procedure developed and executed in the QT appears to be satisfactory, the effectiveness of the cleaning procedure and of the module cleanliness maintenance plans will not be known until module construction has begun. Conventional module and local leak test methods are economically unfeasible and will require the development of new and unproven methods. The failure of these unproven methods would require the use of costly conventional techniques. Information is contained in section entitled "Major Risks & Associated Development Required".

ACKNOWLEDGMENTS

CBI would like to acknowledge the support and assistance provided by the LIGO Project Team throughout the execution of the LIGO Beam Tube Design and Qualification Test. The project would not have been a success without the team work demonstrated by CBI and the LIGO Project Team. CBI especially thanks Professor Rainer Weiss, Larry Jones, and Gerry Stapfer for their input and counsel.

The authors would also like to thank the members of all the CBI companies involved in the LIGO Project who contributed to the safe and successful execution of the Design and Qualification Test. The success of the project is the result of the extraordinary effort and dedication of CBI's employees and the continuing support of the LIGO Project by CBI's management.

LIGO PROJECT
BEAM TUBE DESIGN & QUALIFICATION TEST
QUALIFICATION TEST REVIEW DATA PACKAGE

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SECTION 1

Qualification Test Pressure Boundary

Each beam tube module is composed of alternating fixed and flexible supports spaced 65 feet apart with an expansion joint located at the flexible supports. As such, the configuration of the beam tube module is repeated every 130'. The Qualification Test (QT) configuration is essentially a repeating section of the beam tube module between two fixed supports. The only significant difference between the QT configuration and a repeating module section are as follows:

- The length of the QT between fixed supports is approximately 125' instead of the 130' length used in the modules.
- The fixed supports in the module are not subjected to the pressure loads imposed by the heads used in the qualification test. The fixed support detail used in the QT is identical to the module details with the exception of the addition of thrust restraints added to carry the longitudinal pressure loads from the heads.

The QT pressure boundary is shown on CBI drawing #20, revision 4.

The QT sections on each side of the expansion joint are composed of two continuous lengths of spiral welded tube as shown on CBI drawing #21. The building columns in the test area limited the beam tube section length to 61'. The details of the pump port, expansion joint, and flexible support are identical to the details proposed for the modules. The end heads are stiffened flat plates which are fillet welded to the ends of the QT sections. The modules are attached to values at each end and do not have similar components. The stiffened heads are detailed on CBI drawing #24.

Qualification Test Outgas Test System

The QT pumping and outgas test facility is shown schematically on CBI drawings #1 & 2. The RGA utilized for all of the outgassing tests was a Balzers unit. The RGA head consisted of a Balzers QMA-125 head with a faraday cup and a 17 dynode, 90° secondary electron multiplier. The RGA head was also equipped with an ion counter option which was attached to the SEM. The RGA controller was a Balzers QMG 421C controller which was essentially a black box controller and was attached to a 486-50 PC. All RGA inputs and outputs were accomplished through the PC. The RGA software was designed such that an input parameters file had to be developed in order to operate the RGA in one of the many modes of operation available. A copy of an operating parameters file is included in the appendix.

The RGA was capable of the following modes of operation:

- Analog scan. The RGA would scan any range of the spectrum up to the full 100 AMU range with up to 64 divisions for each AMU. There are up to 64 channels so 64 different ranges could theoretically be scanned simultaneously.
- Bargraph scan. This mode provides a measurement of the peak value of each mass number in the scanned range. The range can be changed to any range desired up to the full 100 AMU

range of the unit. Again, the 64 channels allow up to 64 different bargraph scans simultaneously.

- Multiple Ion Detection (MID) mode. The MID mode of operation allows the user to scan one AMU in all or a portion of the 64 channels available. Each channel can be programmed to be analyzed using different ion detectors (faraday cup, SEM, or ion counting), different dwell times, different gains, different filters or any of the other settings which are changeable through the parameters files.
- The RGA can run any of the above modes of operation as a single scan, or can be run continuously for a specified number of scans or can be run a specified number of scans with a specified time span between each scan.
- The unit provides a file which is stored on the PC for each operation where saved data is requested. The file provides a digital record of the data.
- The unit will provide visual monitoring of the operation in progress on the PC's monitor.
- Review of a saved data file provides graphical representation of individual scans, trending of multiple scans, digital data for each scan, and statistics for multiple scans such as standard deviations, mean values, minimum and maximum values, etc.

Qualification Test Pumping System

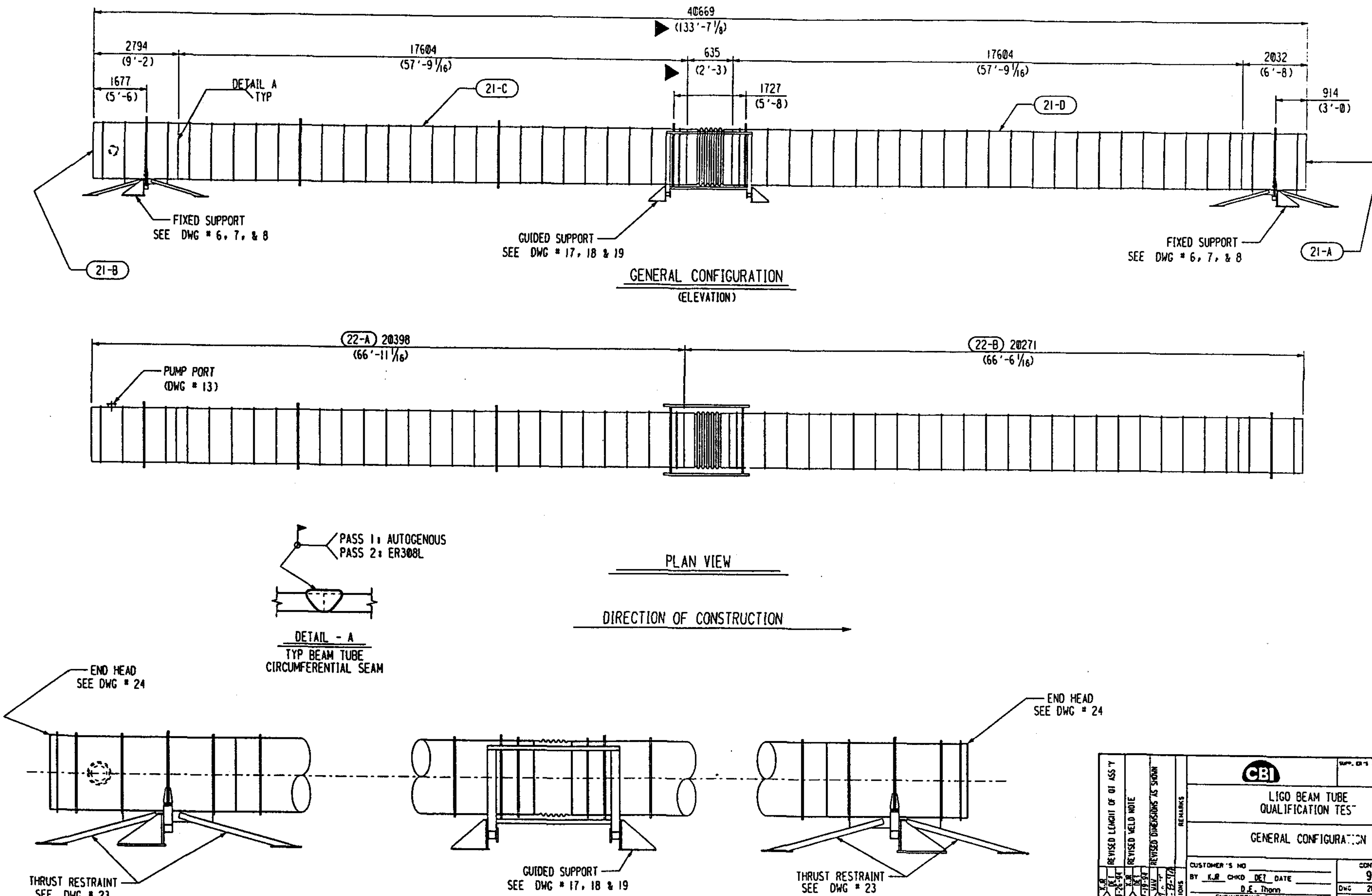
The pumping system consists of two pumping trains. The main pumping train for evacuation of the tube consists of an 8" ID liquid nitrogen trap, a 1100 L/S turbomolecular pump backed by a 35 L/S wide range turbomolecular pump, and finally backed by the DUO 250A roughing pump. This train was provided with a 4.70 inch orifice to maintain the water pumping speed below 600 L/S to simulate module pumping speeds. The LN2 trap was provided as both a water pump and as an oil back streaming protection device.

The secondary pumping system provided limited pumping for either the RGA, the calibrated leak manifold, or for the beam tube. The secondary pumping system consisted of a 35 L/S wide range turbomolecular pump and a 1.5 CMF roughing pump. The foreline of the turbomolecular pump was provided with an assimilation trap to prevent oil back streaming.

Both pumping systems were equipped with inbleed valves between the turbomolecular pump and the roughing pump. This was provided in order to bleed nitrogen into the roughing line to maintain the foreline in the viscous flow regime which also prevents the back streaming of oil vapor.

All components in the entire UHV portion of the pumping system from the beam tube to the turbomolecular pumps have metal seals to ensure bakeability and leak tightness of the system. All flanges in the UHV area were conflat type flanges. The roughing piping was sealed with the small ISO flanges.

The QT configuration drawings are contained on the following pages.



▶ INDICATES CHANGE FROM PREVIOUS ISSUE

REVISIONS	BY	CHKD	DATE	REMARKS
3	KJR	DET	9-26-94	REVISED LENGTH OF 01 ASS'Y
2	KJR	DET	7-19-94	REVISED WELD NOTE
4	VAV	"P"	7-13-94	REVISED DIMENSIONS AS SHOWN

CBI

SUPP. CB'S / PURCHASER'S NO

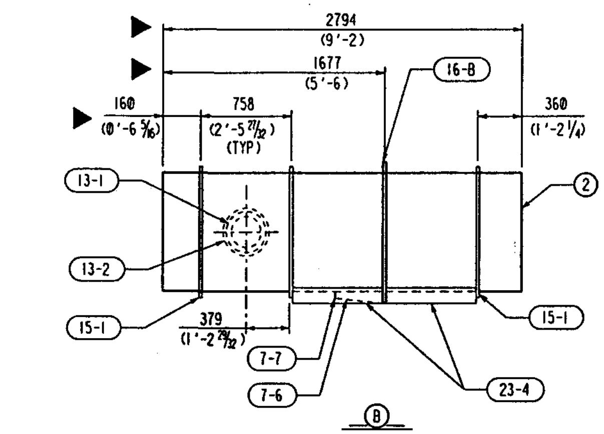
LIGO BEAM TUBE
QUALIFICATION TEST

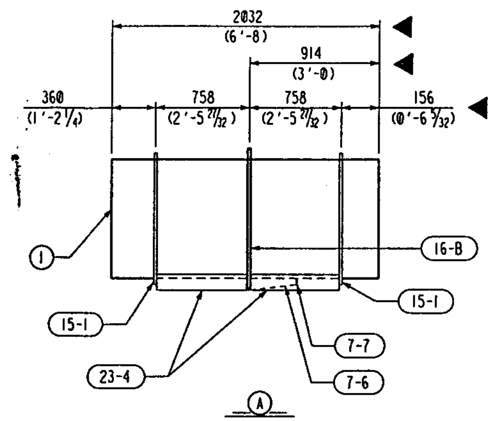
GENERAL CONFIGURATION

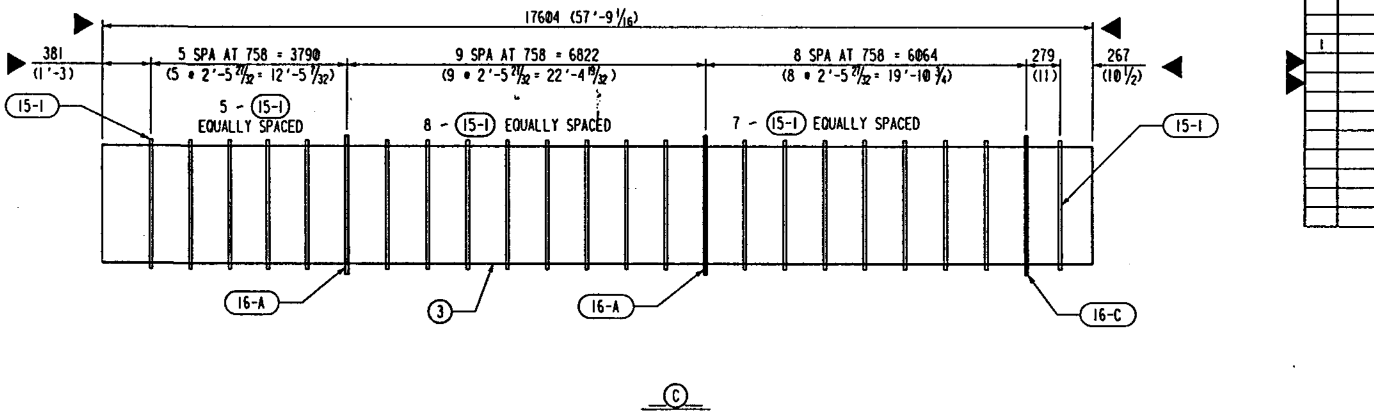
CUSTOMER'S NO
BY KJR CHKD DET DATE
D.E. Thonn
ENGINEERING SUPERVISOR

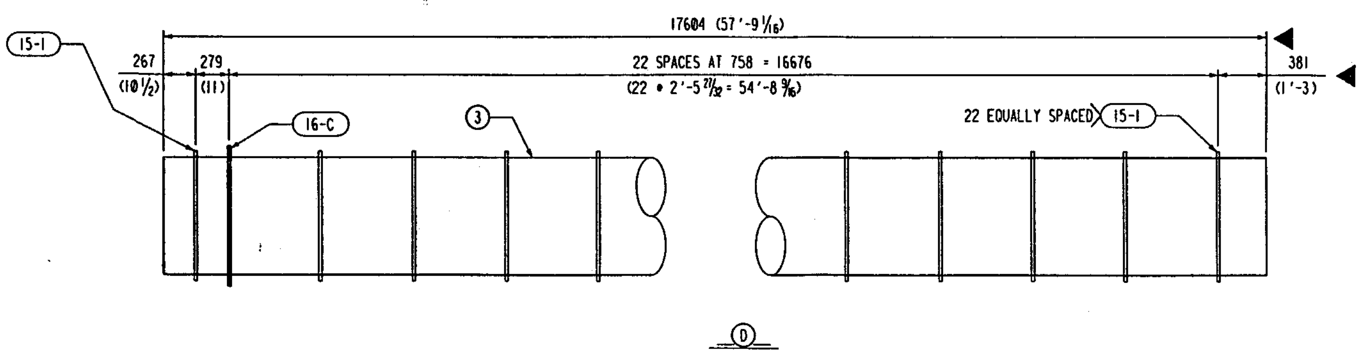
CONTRACT NO 930212
DWG 20
SHT
REV 4

3212A020









SHIP PC	MARK	ASSM PC	DESCRIPTION	LENGTH MM	SPEC
1	21-A		- BEAM ASSEMBLY -		
	21-1	1	BEAM TUBE 1245 x 3.2	2032	•
			(49.00 OD x 0.127" THK x 6'-8 LG)		
	15-1	2	VACUUM STIFFENERS		
	16-B	1	FIXED SUPPORT RING ASS'Y		
	7-6	1	PL SK X 10	457	
	7-7	1	PL 50 X 10	152	
	23-4	2	PL 127 X 9.5	762	
1	21-B		- BEAM ASSEMBLY -		
	21-2	1	BEAM TUBE 1245 x 3.2	2794	•
			(49.00 OD x 0.127" THK x 9'-2 LG)		
	15-1	3	VACUUM STIFFENERS		
	16-B	1	FIXED SUPPORT RING ASS'Y		
	7-6	1	PL SK X 10	457	
	7-7	1	PL 50 X 10	152	
	23-4	2	PL 127 X 9.5	762	
1	21-C		- BEAM ASSEMBLY -		
	21-3	1	BEAM TUBE 1245 x 3.2	17604	•
			(49.00 OD x 0.127" THK x 57'-9 1/16 LG)		
	15-1	22	VACUUM STIFFENERS		
	16-A	2	BAFFLE STIFFENER ASS'Y		
	16-C	1	GUIDED SUPPORT RING ASS'Y		
1	21-D		- BEAM ASSEMBLY -		
	21-3	1	BEAM TUBE 1245 x 3.2	17604	•
			(49.00 OD x 0.127" THK x 57'-9 1/16 LG)		
	15-1	24	VACUUM STIFFENERS		
	16-C	1	GUIDED SUPPORT RING ASS'Y		
			• = SA240 TP304L PER MAT'L SPEC		
			C-240-0186		

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

REV	BY	CHKD	DATE	REMARKS
3	KJR	DET	7-14-94	REVISED DIMENSION
2	KJR	DET	7-8-94	REVISED PC MKS.
4	KJR	[illegible]	9-26-94	REVISED DIMS & BILLING.

REVISIONS

CBI

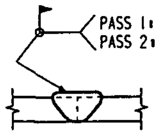
SUPPLIER'S / PURCHASER'S NO

LIGO BEAM TUBE
QUALIFICATION TEST

SUB-ASSEMBLIES
(A) (B) (C) & (D)

CUSTOMER'S NO
CONTRACT NO
BY KJR CHKD DATE
D.E. Thonn
ENGINEERING SUPERVISOR
DWG 21
SHT
REV 4

3212A021

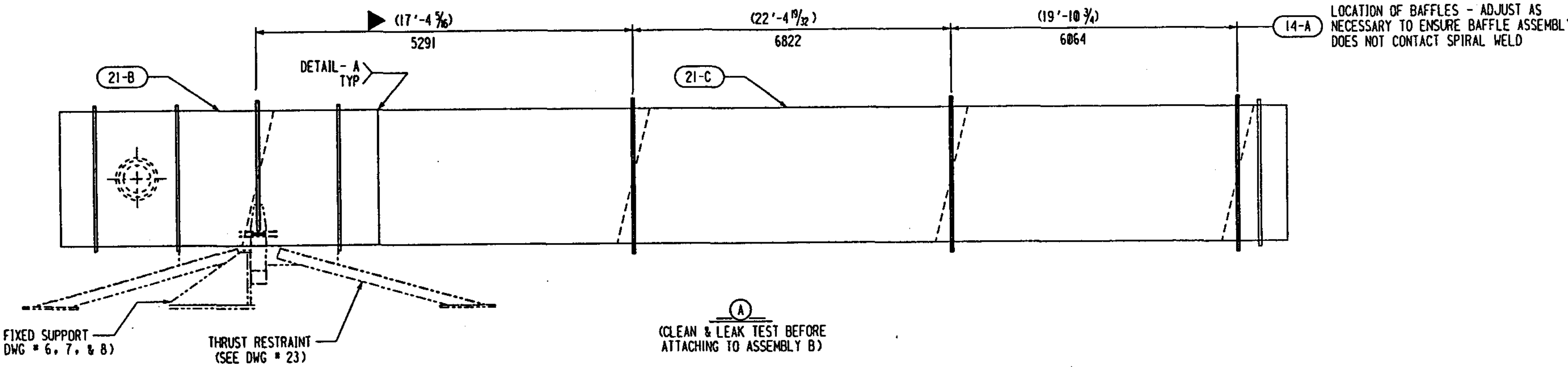


DETAIL - A

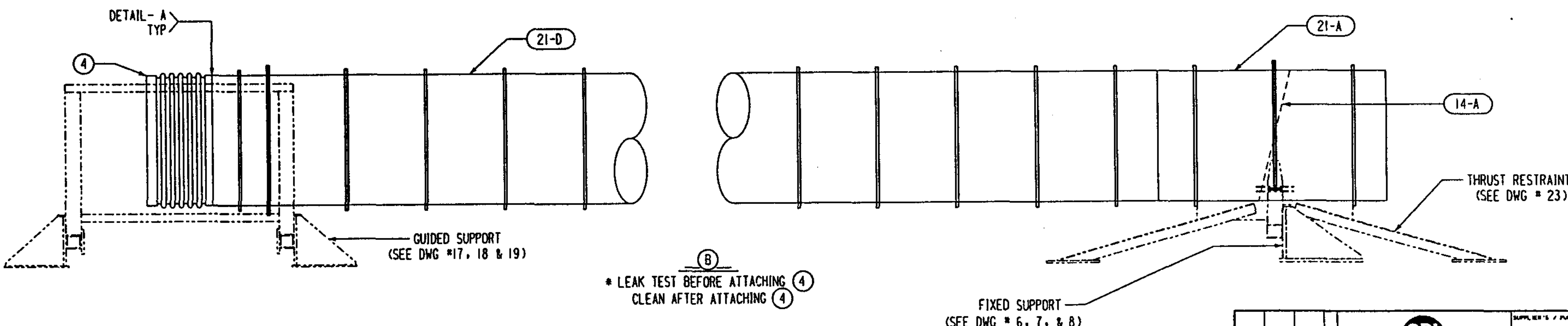
TYP BEAM TUBE CIRCUMFERENTIAL SEAM

SHIP PC	MARK	ASSM PC	DESCRIPTION	LENGTH MM	SPEC
1	22-A		- FIELD ASSEMBLY -		
	21-B	1	BEAM ASSEMBLY		
	21-C	1	BEAM ASSEMBLY		
	14-A	4	BAFFLES		
1	22-B		- FIELD ASSEMBLY -		
	21-A	1	BEAM ASSEMBLY		
	21-D	1	BEAM ASSEMBLY		
	22-4	1	EXPANSION JOINT		****
	14-A	1	BAFFLE		

**** = SA240 TP304L PER MAT'L SPEC C-240-0194



(A)
(CLEAN & LEAK TEST BEFORE ATTACHING TO ASSEMBLY B)



(B)
* LEAK TEST BEFORE ATTACHING (4)
CLEAN AFTER ATTACHING (4)

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

REV	BY	CHKD	DATE	REMARKS
3	KJR			REVISED DIMS.
2	KJR	DET	7-14-94	REVISED NOTES.
1	KJR	DET	7-8-94	REV'D AS NOTED.

CBI

SUPPLIER'S / PURCHASER'S NO

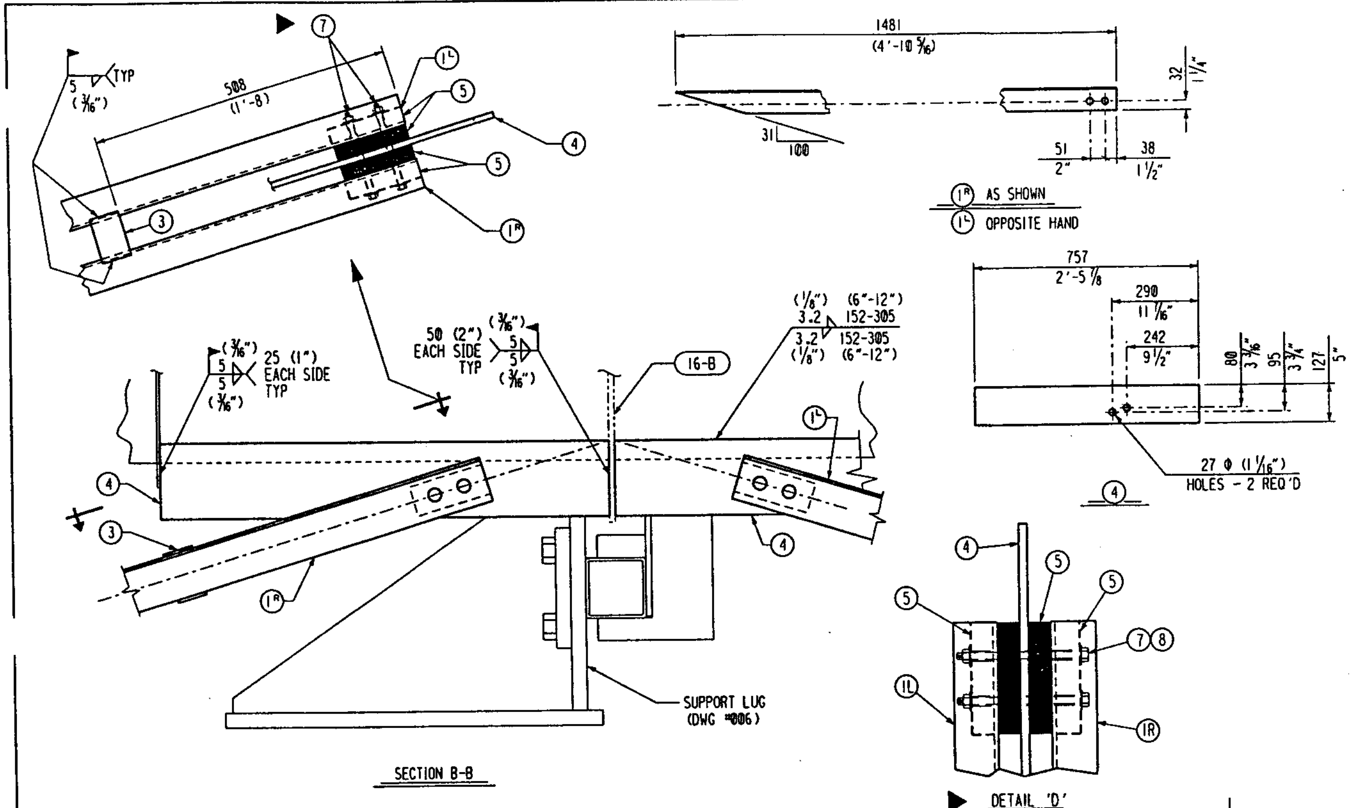
LIGO BEAM TUBE
QUALIFICATION TEST

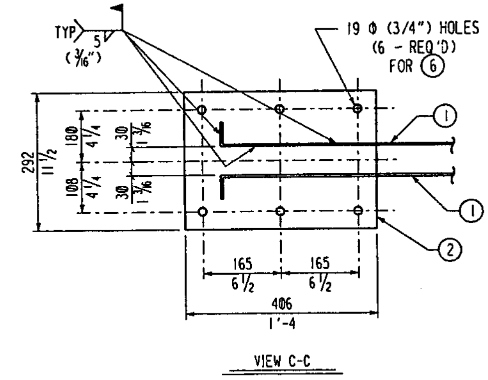
ASSEMBLIES
(A) & (B)

CUSTOMER'S NO
BY KJR CHKD DET DATE
D.E. Thonn
ENGINEERING SUPERVISOR

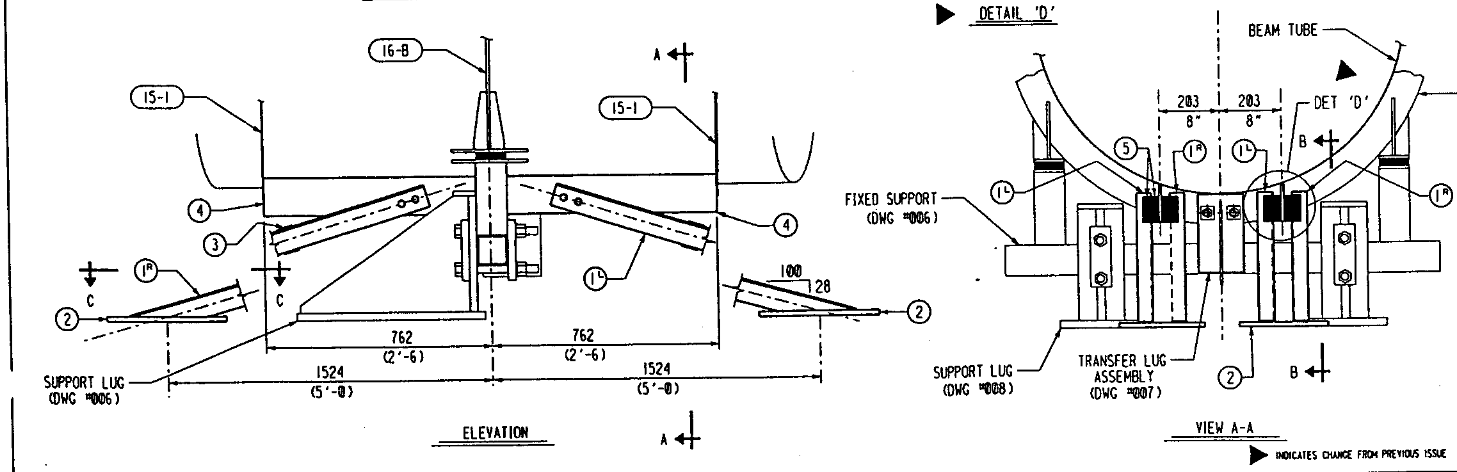
CONTRACT NO
DWG 22 REV 3
SHT

3212A022





SHIP PC	MARK	ASSM PC	DESCRIPTION	LENGTH MM	SPEC
8	23-1 RL		L 76 x 50 x 5	1481	A36
			(3 x 2 x 3/16 x 4'-10 5/16)		
4	23-2		PL 292 x 16	406	C.S.
			(11 1/2 x 5/8 x 1'-4)		
8	23-3		PL 50 x 4.7	76	C.S.
			(2 x 3/16 x 0'-3)		
4	23-4		PL 127 x 9.5	762	***
			(5 x 3/8 x 2'-6)		
16	23-5		MICARTA BLOCK 50 X 127 X 25 W/HOLES		
			(2 X 5 X 1) (GRADE G11)		
24	23-6		EXP ANCHORS 5/8" DIA HILTI KB 58-6		
			W/4" EMBED DEPTH (OR EQUAL)		
8	23-7		BOLT 1"(25) HVY HEX HD W/NUTS 1"	165	A307
			DIA HVY HEX	(6 1/2"	
8	23-8		MYLAR INSULATING SLEEVE 1" I.D.	102	MYLAR
			X 1/32 THK	(4)	
			(F.H.MALONEY)		
			*** = SA240 TP304L		



DETAILED AND BILLED FOR ONE SUPPORT - 2 REQ'D.

▶ INDICATES CHANGE FROM PREVIOUS ISSUE

REV	BY	CHKD	DATE	REMARKS
3	VAN	DET	2-8-94	REV QUANTITY OF PC MK 5 ADDED PC MK 8 AND REV PC MK 7
2	KJR	DET	7-15-94	ADDED NOTE, BOLTS, NUTS, HOLE SIZES, ANCHORS & WELDING.
1	KJR	DET	7-8-94	REV'D MAT'L SPEC & PC MKS.

CBI

SUPPLIER'S / PURCHASER'S NO

LIGO BEAM TUBE
QUALIFICATION TEST

FIXED SUPPORTS

CUSTOMER'S NO

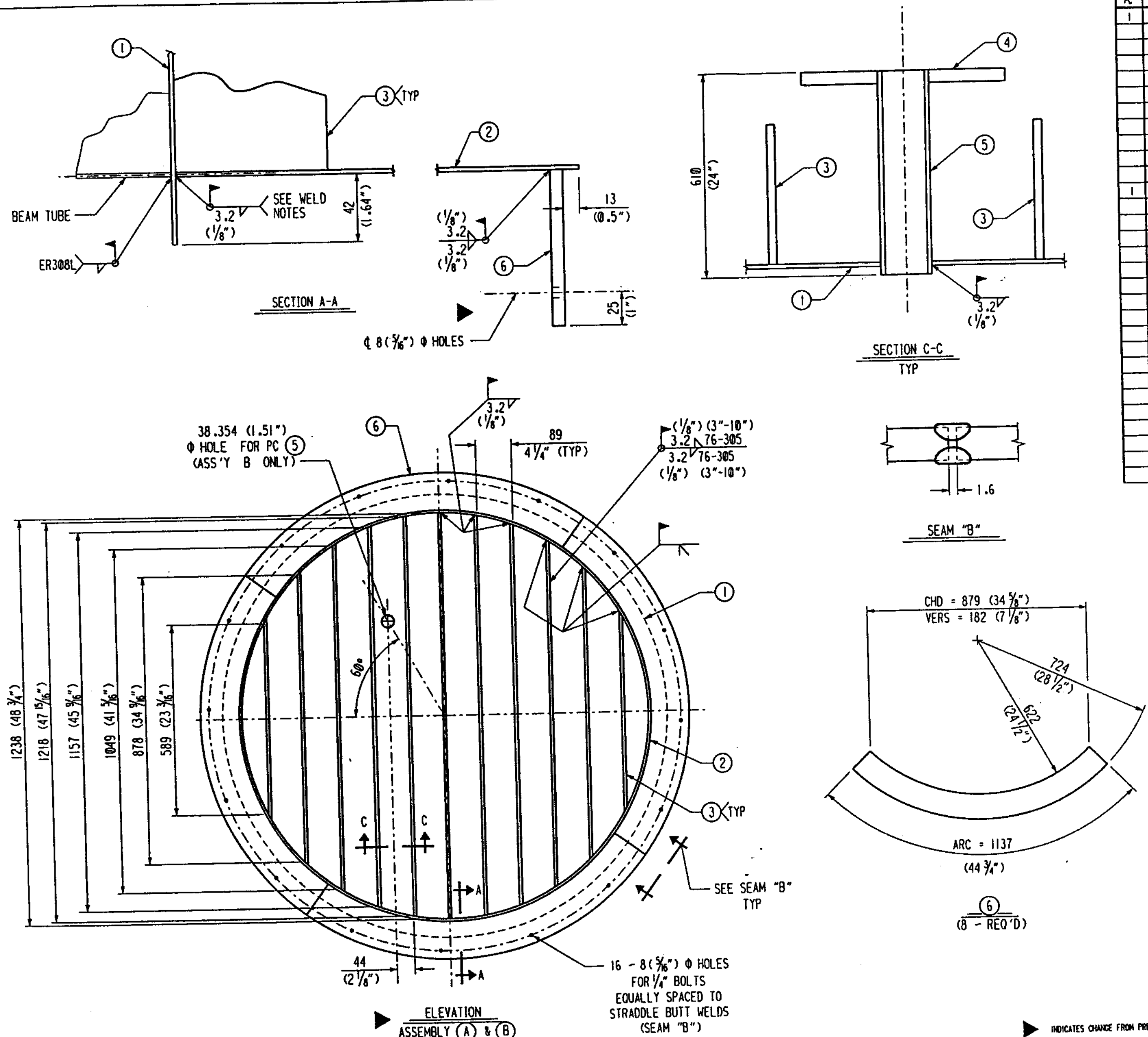
BY K.R CHKD DATE

D.E. Thorn
ENGINEERING SUPERVISOR

CONTRACT NO 930212

DWG 23 SHT REV 3

3212A023



▶ INDICATES CHANGE FROM PREVIOUS ISSUE

SHIP PC	MARK	ASSM PC	DESCRIPTION	LENGTH MM	SPEC
1	24-A		- END HEAD ASS'Y -		
	24-1	1	PL 1346 DIA X 2.7		***
			(53 DIA x 0.105" THK)		
	24-2	1	RING 1245 OD x 3.2	1219	***
			(49.00" OD x 0.127" x 4'-0 LG)		
	24-3	1	PL 114 x 9.5 X SK RUN	11020	***
			(4 1/2" x 3/8" x 35'-11 1/2)		
	24-6	4	PL SK X 9.5		***
			(C/F 725 X 9.5 X 1050 C/4)		
			(28 9/16" X 3/8" X 3'-5 5/16)		
1	24-B		- END HEAD ASS'Y -		
	24-1	1	PL 1346 DIA X 2.7		***
			(53 DIA x 0.105" THK)		
	24-2	1	RING 1245 OD x 3.2	1219	***
			(49.00" OD x 0.127" x 4'-0 LG)		
	24-3	1	PL 114 x 9.5 X SK RUN	11020	***
			(4 1/2" x 3/8" x 35'-11 1/2)		
	24-4	1	FLANGE NORCAL 275-150N		
	24-5	1	TUBING 1.5" OD X .120" THK	610	*
				(2'-0")	
	.24-6	4	PL SK X 9.5		***
			(C/F 725 X 9.5 X 1050 C/4)		
			(28 9/16" X 3/8" X 3'-5 5/16)		
			* = SA269 TP 304		
			*** = SA240 TP304L		

WELD NOTES:

1. FIRST TACK PLATE ASS'Y (A) TO END OF TUBE.
2. TACK OUTER RING IN PLACE.
3. TACK STIFFENERS IN PLACE.
4. WELD ASS'Y (A) TO TUBE.
5. WELD OUTER RING
6. WELD STIFFENERS.

BY	CHKD	DATE	REMARKS
KJR	DET	8-30-94	REV'D FITTINGS.
KJR	DET	10-?-94	ADDED BOLT HOLES.
KJR	DET	9-27-94	REVISED LENGHT OF PC (2).

REVISIONS

CBI

SUPPLIER'S / PURCHASER'S NO

LIGO BEAM TUBE
QUALIFICATION TEST

END HEAD ASSEMBLY

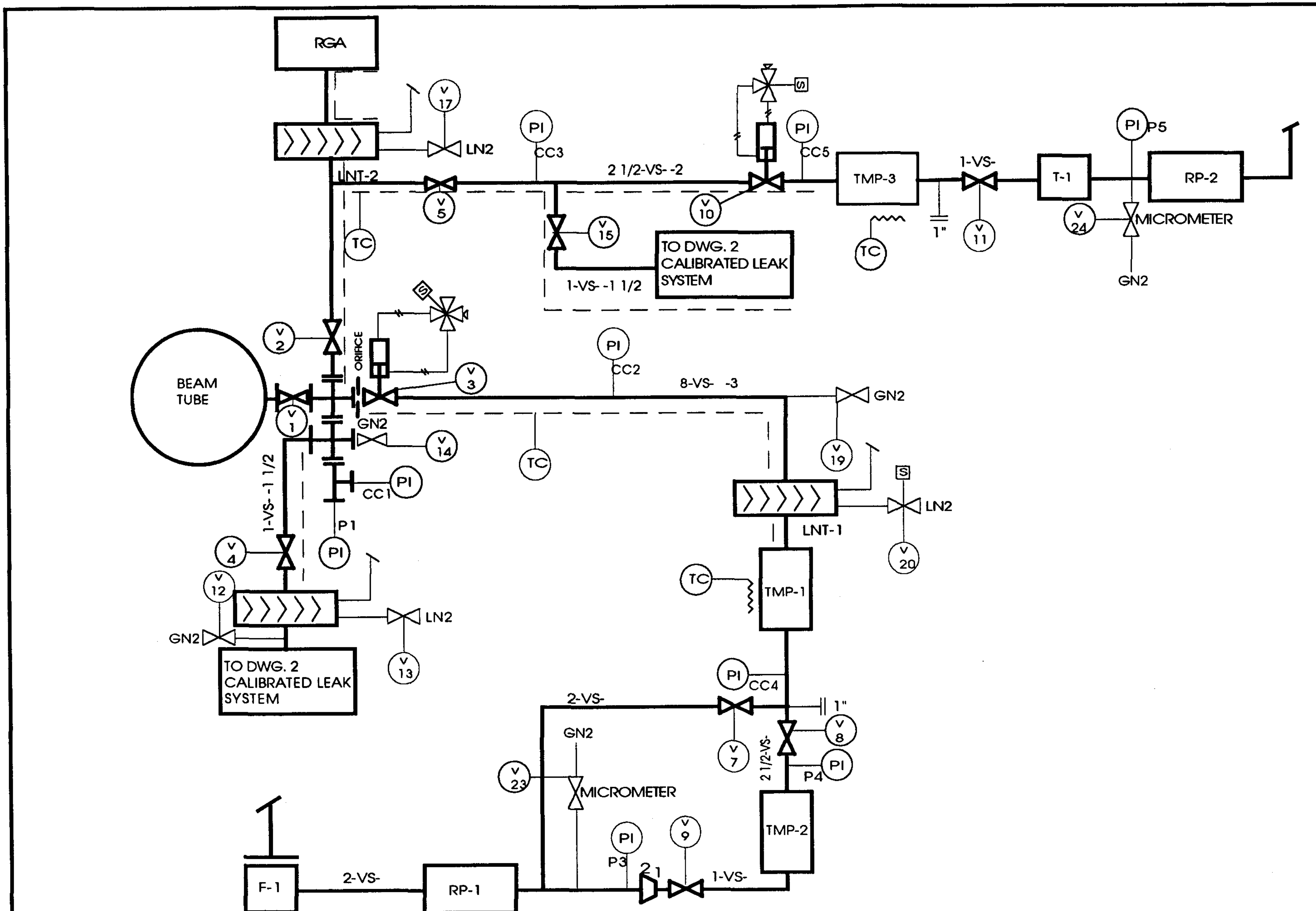
CUSTOMER'S NO ________

BY KJR CHKD DET DATE ________

D.E. Thom
ENGINEERING SUPERVISOR

CONTRACT NO 930212
DWG 24 REV 5
SHT

3212A024



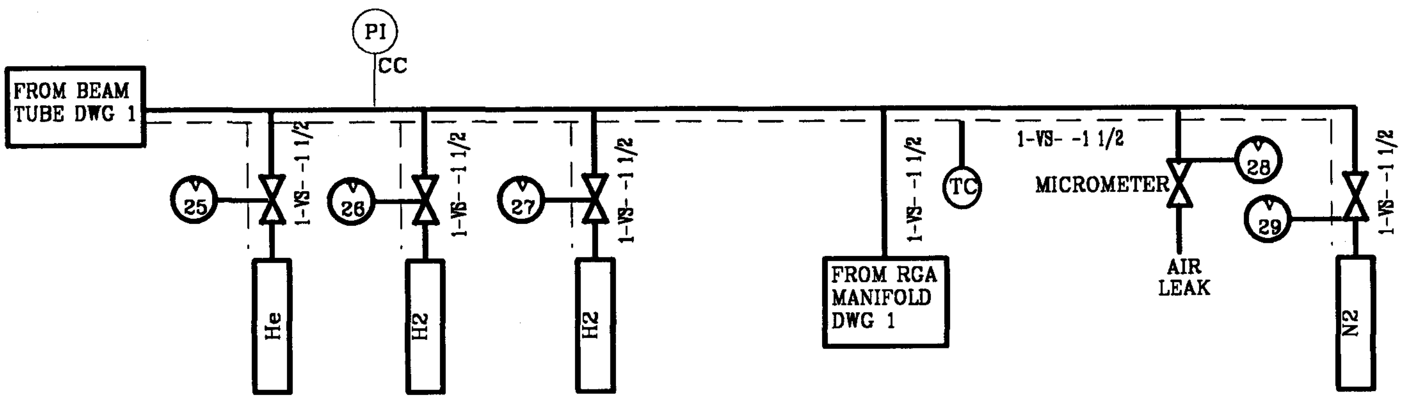
CBI

P & I DIAGRAM
VACUUM SYSTEMS
QUALIFICATION TEST
LIGO PROJECT
CALTECH

BY WAC CHKD ____ DATE 11/15/94
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO.
930212

DWG 1 REV 5
SHT 1



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

BY WAC CHKD ____ DATE 6/14/94
R. C. WEBER
ENGINEERING SUPERVISOR

CONTRACT NO. 930212

DWG 2 SHT 1 REV 4

SECTION 2

A.1 BEAM TUBE COIL MATERIAL

OPTION PLANS AND PROCEDURES:

C-240-0186, "Coil Material Specification"

QUALIFICATION TEST PLANS AND PROCEDURES:

Same as the Option

MAJOR DIFFERENCES BETWEEN THE QT AND OPTION:

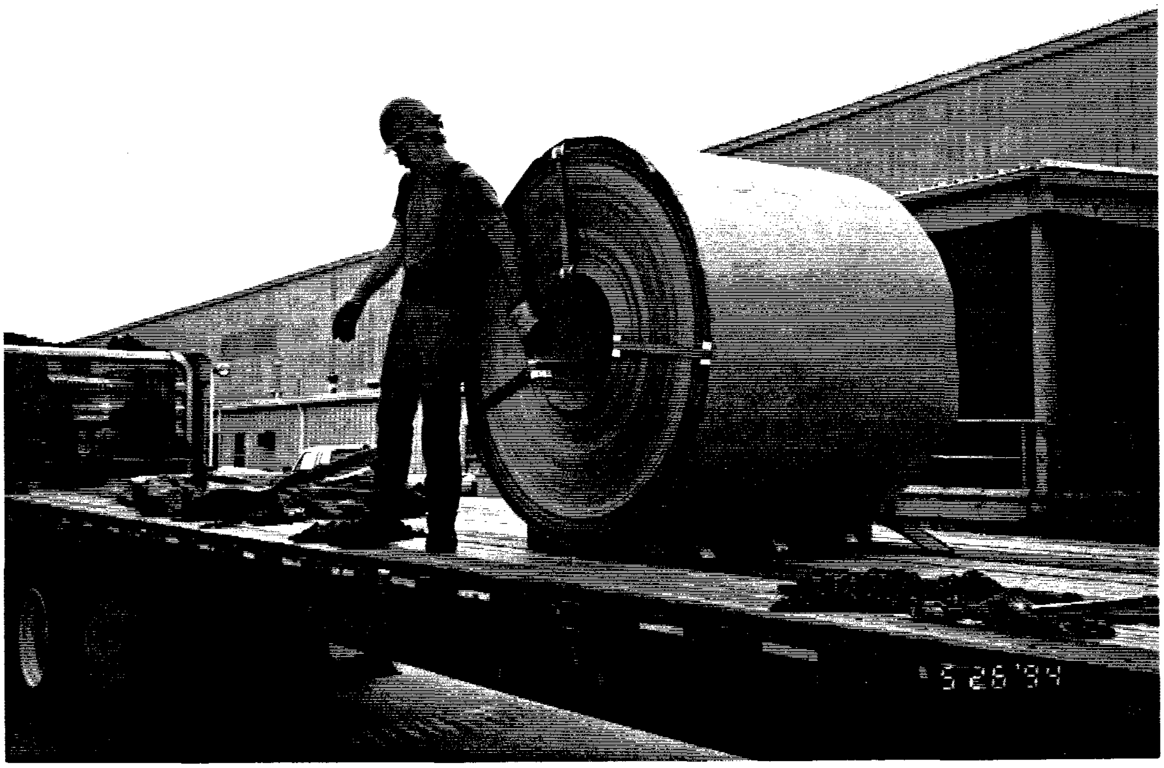
The steel supplier will manufacture the Option material specifically to meet the more stringent LIGO material specification. The more stringent carbon and sulfur limits specified for the Option material are not required for the QT material.

QUALIFICATION TEST EXECUTION:

A spiral forming and welding process which uses material in coil form has been selected to manufacture the beam tubes. The Caltech specified material for manufacturing the beam tubes is A240 Type 304L Hot Rolled Annealed and Pickled (HRAP) stainless steel with thicknesses not to exceed 0.130". A material specification has been written to define the technical requirements of the beam tube material. The main requirements are specified in LIGO Material Specification C-240-0186, "Coil Material Specification".

Material quotations were obtained for both the QT and Option beam tube material from ARMCO Advanced Materials Company, J&L Specialty Products Corporation, Washington Steel Corporation, and Avesta Sheffied Incorporated. ARMCO Advanced Materials Company was awarded the order to provide the coil material for the QT beam tube assembly based on both price and technical merit.

Caltech instructed CBI to purchase three full size coils. The three master coils (#115299B, #115300B & #115301B) were furnished by Armco Advanced Materials Company. These master coils were hot rolled at Armco Steel Company's plant in Middletown, OH. After hot rolling the master coils were annealed and pickled by North American Stainless (NAS) in Carrollton, KY. The master coils were furnished with a 49 inch wide mill edge and thickness of 0.125± 0.005 inch. The ±0.005 inch thickness tolerance is 1/2 the normal thickness tolerance specified by the ASME material specification. As shipped from NAS coil #115299B weighed 34,225#, coil #115300B weighed 33,540#, and coil #115301B weighed 33,860#.



Master Coil Before the Raw material Bake

The three coils of beam tube material purchased as part of the QT test had slightly higher carbon levels than the minimum specified by CBI in the LIGO coil material specification. Because the carbon level of these three coils was lower than the specified minimum for SA240 Type 304 the material and was accepted for use. Two of the coils (#115300b & 115301B) had 0.024% carbon and the third coil (#115299B) had 0.025% carbon. Although the carbon levels of the three coils are under the specified ASME minimum of 0.030% they are greater than the 0.020% minimum that is specified in the C-240-0186 LIGO material specification. The minimum carbon of 0.020% is specified to enhance the material's corrosion resistance without additional cost. The material manufacturers have offered this improved chemistry at no extra cost.

DISCOVERIES AND CONCLUSIONS:

- The manufacturer of the QT coil material was late in delivering the QT coil material. The amount of the coil material ordered for the QT was a relatively small order (102,00#) for the manufacturer. Also, the coil steel manufacturer only produced the SA240 Type 304L coil material every three to four weeks. The LIGO material was processed as part of a much larger order. The purchase order for the Option should include a firm delivery schedule. Both schedule and cost are effected by the size of the order processed. It is more economical for the coil steel manufacturer to produce the coil material in larger quantities. Armco can produce all the material needed for the LIGO beam tubes in a single day. Armco has offered a $0.02 per pound discount if the material is processed in 250 ton quantities and a $0.03 per pound discount if the coils are processed in 400 ton quantities.

- The coil material procurement specification should include the requirement to prohibit the use of materials that can contaminate the coil steel for use on LIGO, such as, cardboard edge protectors and painted or varnished carbon steel banding material that is normally used by the steel manufacturers to package the coil steel for shipping. During the QT North American Stainless used cardboard edge protectors and painted carbon steel banding material to package the coils for shipment. This resulted in the coil material being baked with the cardboard and painted banding material attached. After the bake it was learned that the cardboard and painted banding materials could have contaminated the surface of the LIGO coil steel as evidenced by the surface discoloration. The inner and outer wraps of material is to be discarded to avoid using potentially contaminated material. The circumference of the outer most wrap of the coils is 189" and the inner most wrap is 63". During the leveling process the coils were uncoiled and recoiled such that the outer wrap of the coils becomes the inner wrap. After leveling and before the material for the hydrogen outgas coupons was cut 65" of the coil material was remove from the outer wrap of all three coils.

- It was learned during the QT that the coil steel manufacturers resist changing their coil steel manufacturing process to provide for special contract requirements, such as, using special packaging materials. They feel that substituting the materials used for packaging and shipping the coils to be difficult to manage and control during the their manufacturing process. As an alternative in the Option, the coil steel material could be packaged and shipped by the selected steel manufacturer using their standard materials (cardboard edge protectors and painted banding material) and replaced with acceptable materials before baking at the bake facility. Specify the wrapping materials that are acceptable for use during the raw material bake, such as aluminum edge protectors and stainless steel banding material.

- After steam cleaning of the first QT beam tube unacceptable levels of hydrocarbon contamination were discovered on the surfaces of the beam tubes. A new cleaning process has been developed and was implemented during the QT to remove the hydrocarbon contamination to an acceptable level. The source(s) of the hydrocarbon contamination to the QT beam tube assemblies could not be determined. Therefore, during the Option all the coil manufacturing and preparation processes should be examined for potential sources of hydrocarbon contamination. Where possible the sources of hydrocarbon contamination should eliminate or minimized. Changes to the manufacturers and/or steel processors normal processes to eliminate potential may result higher costs. This must be negotiated before the order is awarded.

PROPOSED CHANGES:

- Include firm delivery dates as part of the coil steel purchase requirements.
- Specify the minimum quantities that the coil steel is to be processed. Select the quantity that will be most economical for the LIGO project.
- Prohibit the use of materials that can contaminate the coil steel during the bake.
- Examine the coil manufacturing processes for potential sources of hydrocarbon contamination.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The steel manufacturers and processors will not guarantee that the coil material will meet the specified hydrogen outgassing rate and/or the cleanliness for the LIGO beam tube. The steel manufacturers and processors are willing to produce and process the steel as currently specified in the LIGO specification.

A.2 EXPANSION JOINT /BAFFLE MATERIAL

OPTION PLANS AND PROCEDURES:

C-240-0194, "Expansion Joint Material Specification"
C-240-0187, "Baffle Material Specification"

QUALIFICATION TEST PLANS AND PROCEDURES:

Same as the Option

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

Same as the Option except the material may be SA240 Type 304L cold rolled sheet instead of hot rolled annealed & pickled. The cold rolled finish is acceptable for the QT.

QUALIFICATION TEST EXECUTION:

The specified material for the LIGO expansion joints and baffles is 0.105"±0.005" thick SA240 Type 304L Hot Rolled Annealed and Pickled (HRAP) stainless steel material in sheet form. For the Option, the expansion joint and baffle material will be produced and baked in coil form. The coils produced for the expansion joints are to be 61" wide instead of 49" wide to minimize the number of longitudinal weld joints in the expansion joint. The expansion joint material does not require stretcher leveling. Therefore, after the 61" wide coils are baked the material will be flattened and cut into 60" wide by 155.12" long flat sheets that are sized to manufacture the expansion joints.

In the Qualification Test (QT) the expansion joints and baffles were manufactured from SA240 Type 304 Cold Rolled (CR) material instead of the SA240 Type 304L (HARP) material that is specified for use in the Option. The SA240 Type 304L (HARP) material in 60" widths and 0.105" thickness was not readily available in the small quantity (10 sheets) needed for the QT. The SA240 Type 304 Cold Rolled (CR) material was available. The technical differences, the delivery and the cost of the two materials were assessed by CBI and Caltech before the decided to use the SA240 Type 304 (CR) sheet material for the expansion joints and baffles in the QT. The technical differences between the two material would not significantly change the QT and did not warrant the additional expense or time required to obtain the SA240 Type 304L (HARP) material.

A total of 10 sheets were purchased from Ryerson Steel. Four of the sheets came from coil # 114528. This material was used to manufacture the three Hyspan expansion joints, the 20 baffle segments, and the 160 coupons for hydrogen outgas testing by Caltech and CBI. Six of the sheets were cut from coil # 073524. This material was purchased to manufacture the end closure plates for the QT assembly, the 160 coupons for hydrogen outgas testing by Caltech and CBI, and possibly three additional expansion joints for testing. The material was purchased from Ryerson in Chicago and shipped directly to Metlab in Philadelphia. All ten sheets were baked at Metlab in Philadelphia with the three full size coils of beam tube material.

The following table compares the properties of the QT expansion joint and baffle materials those specified in the LIGO specification for the Option.

Spec./Mfg.	ASTM Spec.	LIGO Spec	NAS	UGINOX
Coil Number	--------	---------	114528	073524
Number of sheets	--------	---------	4	6
Carbon Content (%)	<0.030	< 0.20	0.046	0.038
Sulfur Content (%)	<0.030	0.010 to 0.020	0.003	0.001
Surface Finish	HARP	HARP	CR	CR

After the baked was completed all ten sheets of the expansion joint and bellows material were shipped to CBI Technical Services in Plainfield. Three of the four sheets from coil #114528 were shipped to Hyspan for fabricating the three expansion joints. The fourth sheet was cut in two pieces. One piece was used to manufacture the baffles and the 160 coupons for the hydrogen outgas tests were cut from the other piece. Two 53"Ø plates for the for the QT end closures were cut from one of the six sheets from coil # 073524 and 160 coupons for the hydrogen outgas tests from part of a second sheet. Four and one half sheets from coil #073524 have not been used and are currently packaged and stored at CBI Technical Services awaiting disposition from Caltech. These sheets were originally purchased to have manufacture three hydroformed expansion joints for comparison with the mechanically formed expansion joints.

DISCOVERIES AND CONCLUSIONS:

- The sheets of material that were purchased for the manufacture of the expansion joints, the baffles and the end closures in QT did not conform to the SA240 Type 304L material specification as specified when the order was placed. The material was purchased from a warehouse supplier because only a small amount of the material was needed and the material was needed quickly in order to have it baked with the coil material. The material test reports were not received and reviewed until after the material had been baked. The carbon content did not meet the 0.030% minimum for SA240 Type 304L material as specified by the ASME code. The carbon contents of the ten sheets of material as received were 0.038% and 0.046%. The material was accepted for use in the QT.

PROPOSED CHANGES:

- Review the material test reports before the material is processed.
- Void material specifications C-240-0187, "Baffle Material Specification". Revise material specification C-240-0194, "Expansion Joint Material Specification", to include the material used for the baffles. Except for length of the sheets these two specifications are the same.
- Include firm delivery dates as part of the coil steel purchase requirements.
- Prohibit the use of materials that can contaminate the coil steel during the bake.
- Examine the coil manufacturing processes for potential sources of hydrocarbon contamination.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The steel manufacturers and processors will not guarantee that the coil material will meet the specified hydrogen outgassing rate and/or the cleanliness for the LIGO beam tube. The steel manufacturers and processors are willing to produce and process the steel as currently specified in the LIGO specification.

B.1 RAW MATERIAL BAKE

OPTION PLANS AND PROCEDURES:

C-CMBS1, "Coil Material Bake Specification"

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

No major differences.

QUALIFICATION TEST EXECUTION:

The three master coils were baked at Metlab's facility in Philadelphia, PA. All three master coils were baked together along with the ten sheets of the 60 inch wide by 180 inch long by 0.105 inch thick material that was used to manufacture the QT expansion joints, baffles an end closure plates. The bake was performed in accordance with C-CMBS1, "Coil Material Bake Specification", except as noted in this report.

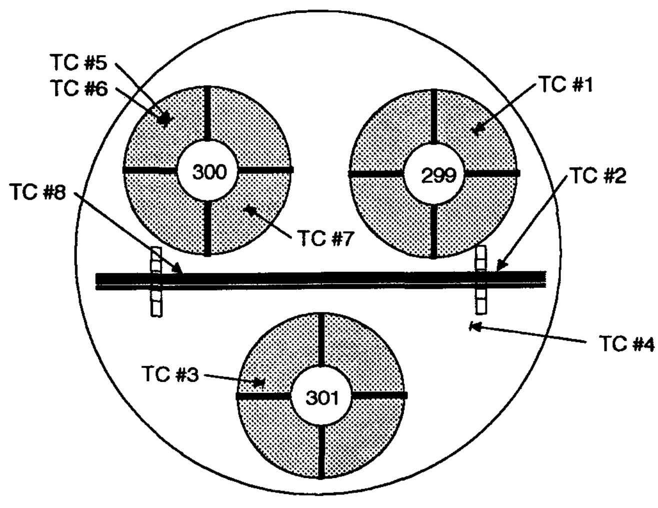
It is specified C-CMBS1, "Coil Material Bake Specification", that the surfaces of the material being baked must be vertical during the baking process to promote convection flow over the material surface. As such, the coil material must be baked with the "eye" of the coil vertical. Coils are manufactured with the eye of the coil horizontal and the coils are not normally turned during the coil manufacturing process. Neither NAS or Metlab had the equipment to turn the large 34,000# LIGO coils so that the eye of the coil are vertical. Also, Metlab did not have the capability of turning the coils. Because of this the coils were routed through CBI's facility in New Castle, DE. where they were turned for baking. Using a special turning device and two yard cranes the coils were turned by CBI. For the Option it is proposed that the equipment to turn the coils be purchased and installed at the facility performing the bake.

At NAS, a .075" thick by 1" wide by 48" long stainless steel bar was placed between coil wraps near the center of the coil to provide space for installing a thermocouple to monitor the inner temperature of the coil. Metlab installed two 1/16" diameter thermocouples along this bar to measure the temperature near the center of the coil. The temperatures measured by these two thermocouples established the time at which the coil material was at the 440°C bake temperature for the 36 hour hold time and the time the coil material had cooled to less than 150°C at which time the furnace cover was removed.

At Caltech's directive, a dry air purge system was purchased and installed to the furnace at Metlab to provide a clean dry air (air with a -20°C dewpoint) purge during the bake. The clean dry air purge was included to reduce the risk of contamination and hydrogen re-absorption. The flow rate of the dry purge system was to be 5 to 10 SCFM. The system as installed consisted of an 10 SCFM oilless air compressor, a 25 SCFM desiccant air dryer, and a 30 gallon air receiver. The dry air purge system did not perform as expected. The oilless air pump could not provide the minimum 5 SCFM flow rate at the 40 psig pressure required to run the desiccant air dryer. The highest flow rate that was obtained with dry air at or below the specified -20°C dewpoint was 3 SCFM. During the warm up cycle the dry air purge flow rate was 5 SCFM and the dry air dewpoint ranged from +1°C to -20°C. For the first six hours of the 36 hour hold cycle the dry air purge rate was 5 SCFM and the dry air dewpoint was -5°C. For the remainder of the 36 hour hold cycle the dry air purge flow was cut back to 3 SCFM and the dry air dewpoint was maintained at -20°C.

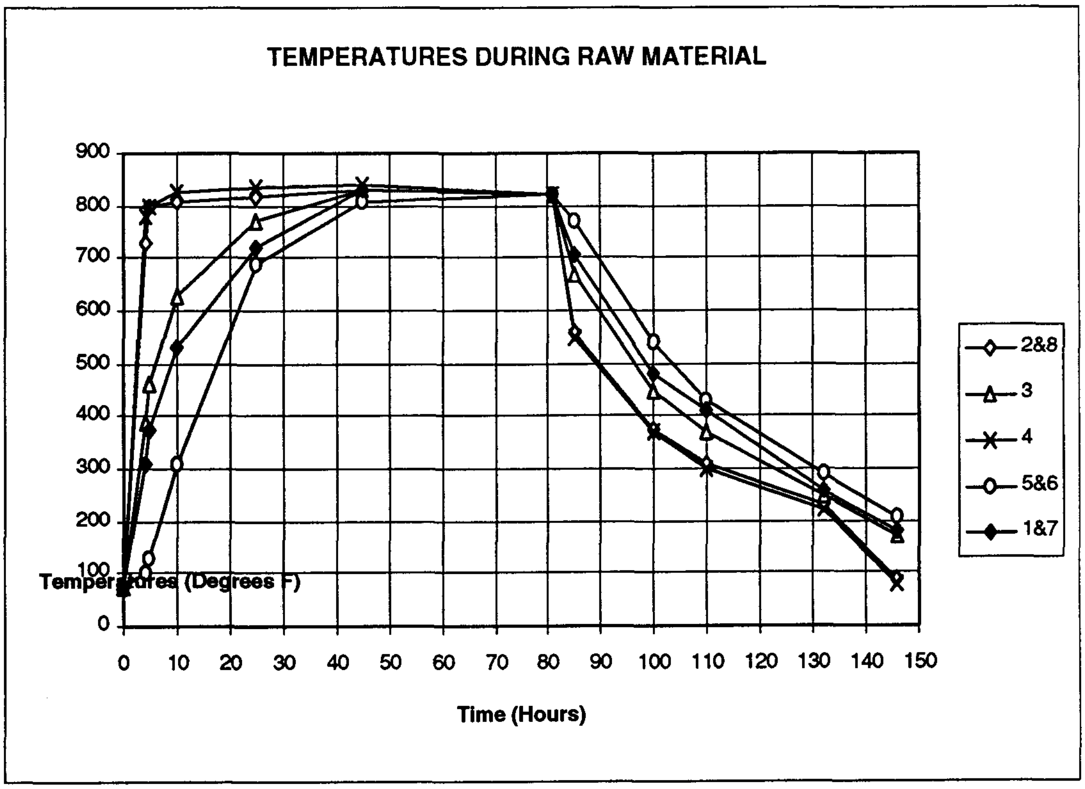
Eight thermocouples were installed to monitor the bake. The following is a list of the thermocouples along with a sketch showing the locations of the material and thermocouples inside the furnace:

Thermocouple	Location
1	Outside of coil #115299B
2	Top edge of sheet material
3	Outside of coil #115301B
4	Air inside furnace
5	Inside of coil #115300B
6	Inside of coil #115300B
7	Outside of coil #115300B
8	Top edge of sheet material



THERMOCOUPLE LOCATIONS
DURING THE RAW MATERIAL BAKE

During the cooldown cycle the furnace remained closed and was purged with clean and dry nitrogen gas at a flow rate of about 30 SCFM. The nitrogen gas purge was included to minimize the risk of contamination and hydrogen re-absorption during the cooldown period. To insure cleanliness the nitrogen gas used for the purge during the cooldown cycle came from a liquid nitrogen source. The coil material was kept closed and the nitrogen gas purge maintained until all of the thermocouples read less than 150°C. After cooling to 150°C the nitrogen purge was stopped and the lid of the furnace removed to permit the coils and furnace to cool in ambient air.



The coil material was baked with the banding and cardboard edge protectors that were installed by NAS. After the bake samples of the material in contact with the cardboard was test by MIT for contamination detrimental to the beam tube. Although tests performed by MIT on the material samples did not show any contaminants that would be detrimental to the beam tube that had been in direct contact with the banding material and cardboard , even so, Caltech decided not to use any of the coil material that had been in direct contact with the banding and/or cardboard edge protectors during the bake. A equivalent length to one wrap will be scrapped from the inside and outside of the coil. The inside wrap is 63" long and the outside wrap is 189" long.

Samples of the banding material and residue from the cardboard edge protectors were collected from the baked coils in case they were needed for analysis at some later date. Also, NAS furnished unbaked samples of the banding material and cardboard edge protectors that was used to band the LIGO coil material.

DISCOVERIES AND CONCLUSIONS:

- It was decided just prior to baking the coil material to perform bake the coils in a dry and clean air environment. The furnace at Metlab did not have the capability to provide clean dry air. Therefore, equipment was purchased and installed at Metlab to purge the furnace with clean dry air (-20°C dewpoint) at a minimum flow rate of 5 SCFM.

- During the bake it was discovered that the dry air purge equipment could not supply dry air at a flow rate of 5 SCFM. The air dryer did not provide dry air at -20°C dewpoint unless the system was operated at a minimum of 40 psig. The maximum flow delivered from the dry air system at 40 psig was about 3 SCFM. The clean dry air supply system for the Option must be designed to provide at least 5 SCFM. Also, it is recommended that a back up dry air purge system be installed in case the primary system fails during a bake.

- During the cooldown period to 300°C the furnace was kept closed and purged with dry nitrogen gas (gas boiled off liquid nitrogen source) at 30 SCFM instead of continuing the dry air purge.

- The bake facility must have the capability to handle the LIGO coil material as received from the steel mill.

PROPOSED CHANGES:

- Upgrade the air purge system to provide air with a dewpoint equal to or less than -20°C at minimum flow rate of 5 SCFM.

- Change the Bake Specification to include a dry nitrogen gas purge during cooldown.

- In the Option install equipment to turn the coils at the bake facility.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The company performing the raw material bake will not guarantee that the coil material will meet the specified hydrogen outgassing rate and/or the cleanliness for the LIGO beam tube. The steel manufacturers and processors are willing to bake the steel as currently specified in the LIGO Specification C-CMBS1, " Coil Material Bake Specification".

Only one of the steel suppliers, J&L, has agreed to perform the raw material bake for the Option. J&L's quote for the Option material was significantly higher (about 20%) than the lowest quote received for the Option coil material. Also, J&L took exception to the specified 440°C ± 8°C temperature range. They can only control the temperature to ± 20°C . Of the many other bake companies that were contacted only three were found who had the capability of performing the raw material bake and of these three only one, Metlab, was willing to quote the bakes for the Option. CBI has the" in house" capability of performing the bakes at higher estimated cost than Metlab. CBI cost would be higher because they would need to design, purchase and install the somewhat specialized bake equipment (insulated furnace, heaters and controllers). Presently, CBI plans to use Metlab to perform the Option bakes. However, if Metlab does not perform the bake and another outside source cannot be found to perform the bake at lower cost than CBI, CBI would perform the raw material bakes.

B.2 STRETCHER LEVELING

OPTION PLANS AND PROCEDURES:

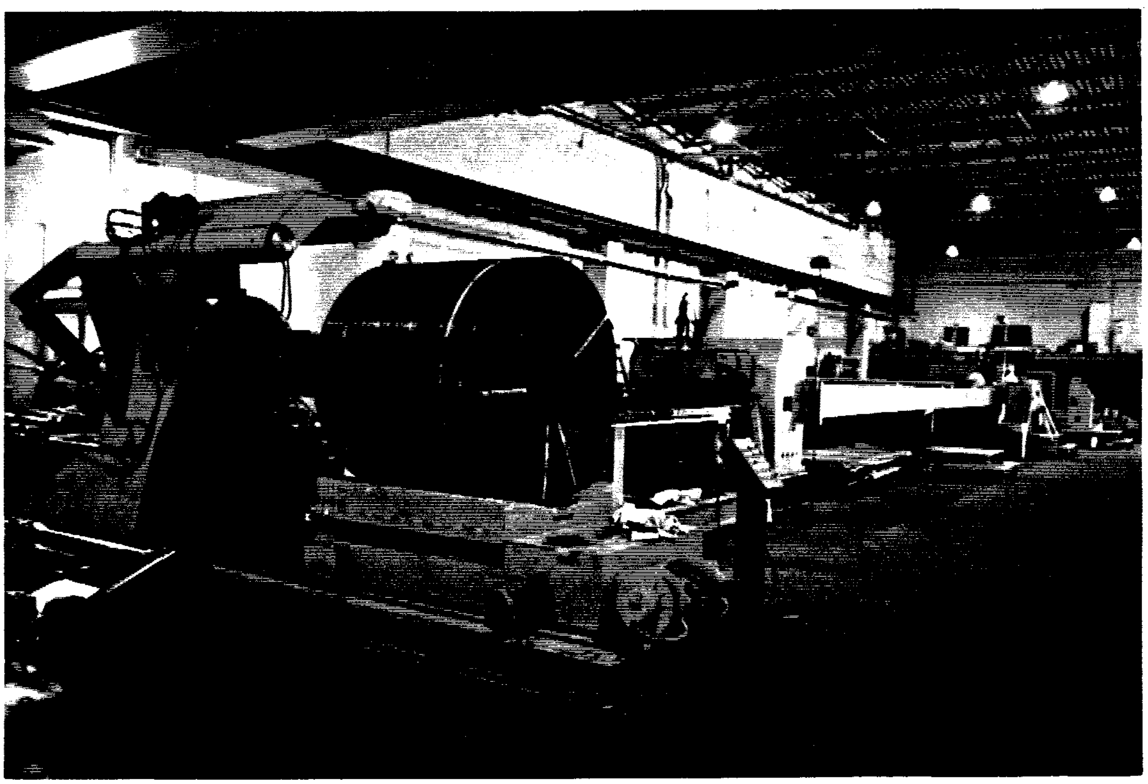
C-240-0186, "Coil Material Specification"

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

No major differences exist between the QT and the Option

QUALIFICATION TEST EXECUTION:

The coils were removed from the furnace and loaded directly onto trucks and shipped to Leveltek Inc. in Triadelphia, West Virginia. The coils were covered with tarps during shipment from Metlab to Leveltek. The coils were first shipped to CBI's facility in New Castle, Delaware where the coils were turned so that the eye of the coils were horizontal instead of vertical. LevelTek's leveling process requires that the eyes of the coils be horizontal and they did not have equipment to turn the coils.



Installing Coil into Stretcher Leveling Machine

The material was leveled to improve the flatness of the coil material. Using a hydraulic powered machine with gripper at 50' spacing and hydraulic cylinders at one end, the coil material was unrolled, gripped in 50' lengths, and stretched. During leveling process the coil material was stretched 12 inches per 50 foot length of coil. The coil material was permanently elongated 10.5 inches per each 50 foot length. This is equivalent to about 1.75% permanent elongation. As a result of the leveling process the width of the coil material was reduced by 3/8 inches and the thickness was reduced about 0.001 of an inch.

During the leveling process the coil material was unrolled and re-rolled. The inside and outside layers of the coil material were reversed.

DISCOVERIES AND CONCLUSIONS:

The leveling process permanently elongates the material 1.75% while reducing the 49" width by about 3/8". Also, the thickness is reduced about 0.0008".

PROPOSED CHANGES:

- Prohibit the use of materials that can contaminate the coil steel during the bake.
- Examine the coil manufacturing processes for hydrocarbon contamination's

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

No apparent risks have been identified from the QT and no additional development is needed.

B.3 REMOVAL OF COUPON MATERIAL AND SLITTING TO 16" WIDE COILS

OPTION PLANS AND PROCEDURES:

C-240-0186, "Coil Material Specification".
C-CMBS1, "Coupon Material Bake Specification".

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The plans and procedures that are planned for the Option were used in the QT.

QUALIFICATION TEST EXECUTION:

After the master coils were leveled they were shipped to MetalPro, Inc. in Carol Stream, Illinois. The coils were wrapped in waterproof paper and tarped during shipment from Leveltek to MetalPro.

At MetalPro the first 65 inches of material of each coil was remove and scrapped. This was the material that had been directly exposed to the cardboard edge protectors and painted banding material during the bake of the coil material. Next, two additional 72 inch long sheets were cut from each coil. The hydrogen outgas coupons were cut from one of these sheets. The other sheet was spare material. The coupon material was delivered to CBI Technical Services Company in Plainfield, IL. One of the sheets of material removed from each coil was sheared into coupons for hydrogen outgas testing by Caltech and CBI.

After the coupon material was removed two of the coils (#115300B and #115301B) were immediately banded and wrapped in waterproof paper for shipping and storage. These two coils were shipped to CBI Services Inc. near Kankakee, Illinois and placed into storage. The coils were covered with waterproof tarps and stored outside. Coil #115300B weighs about 33,175# and coil #115301B about 33,500

About 600 feet (nearly 1/3) of the third coil (#115299B) was slit into three 16" wide by 600 foot long coils. These 16" wide coils were used to manufacture the QT beam tube. The three coils were identified as coil #115299B-1L, #115299B-1M & #115299B-1R. Coil #115299B-1L was slit from the right side, coil #115299B-1M was slit from the middle, and coil #115299B-1R from the right side of the master coil. Coil #115299B-1L measured 15.995" inch wide, coil #115299B-1M measured 16.008" wide and coil #115299B-1R measured 15.997" wide. The total width variation was 0.013". This is much better than the specified variation of 0.031". The three coils 16" wide coils were shipped to TubeTek Inc. (the beam tube manufacturer) in Sanford, Florida.

After the 600 feet of coil material for the QT was slit from the master coil another 72 inch long sheet of material was cut from the master for additional hydrogen outgas test coupons. The remainder of the coil (about # 21,500) was shipped to CBI Services Inc. near Kankakee, Illinois and place into storage with the other two master coils. The material in storage is available for use in the Option.

DISCOVERIES AND CONCLUSIONS:

The total width variation of the slit coils was ±0.013".

PROPOSED CHANGES:

- Examine the coil manufacturing processes for hydrocarbon contamination's
- Specify a maximum width variation of 0.010" for the slit coils.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

No apparent risks have been identified from the QT and no additional development is needed.

B.4 MATERIAL HANDLING AND TRANSPORTATION

OPTION PLANS AND PROCEDURES:

C-240-0186, "Coil Material Specification" specifies that the coil steel material shall be packaged and shipment as described

CBI Purchase Order #930212-0001, Rev. 0 to Armco Advanced Materials Co.

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

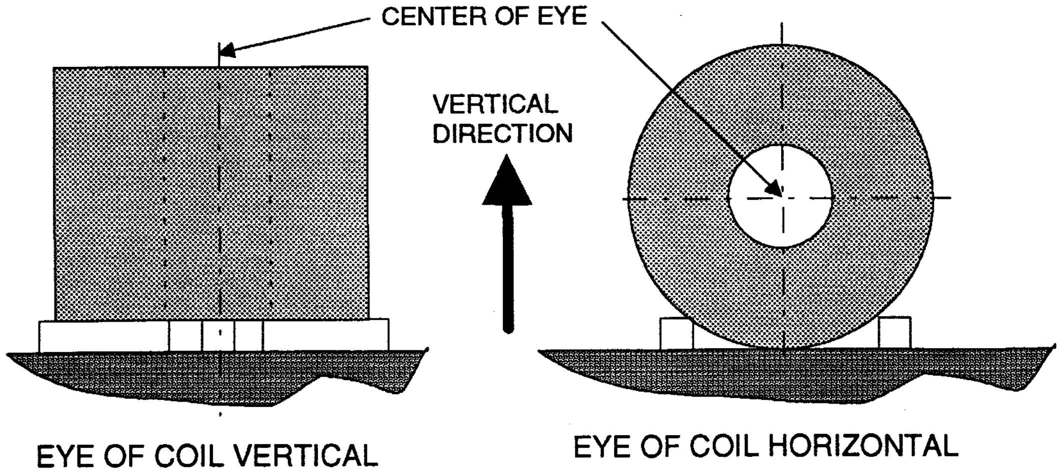
The Option coil material will be handled and transported the same as the QT coil material. No special equipment or processes have been developed for handling and transporting the coil material. The conventional equipment and processes used by the steel manufacturers and coil processors will be used for both the QT and the Option.

QUALIFICATION TEST EXECUTION:

In the QT it was specified that the coil steel be packaged in accordance with ASTM A-700 standard. This is the standard used by the steel manufacturers for packaging.

To ship from the steel manufacturer to the bake facility each coil was banded with painted carbon steel banding material and wrapped in heavy paper. Cardboard edge protectors were placed under the banding at edges of the coils to protect the edges. The coils were loaded on the truck with the eye of the coil horizontal. The coil was blocked front and back to keep it from rolling or sliding during shipment. The coil was covered with a tarp during shipment.

The coils were routed through CBI's facility in New Castle, Delaware on the way to the bake facility in Philadelphia, Pennsylvania. The coils were turned so that the eye of the coils were vertical. This is the position the coil must be in during the bake. The bake facility did not have the equipment and expertise to turn the coils. CBI used two yard cranes and a specially constructed turning device to turn the coils.



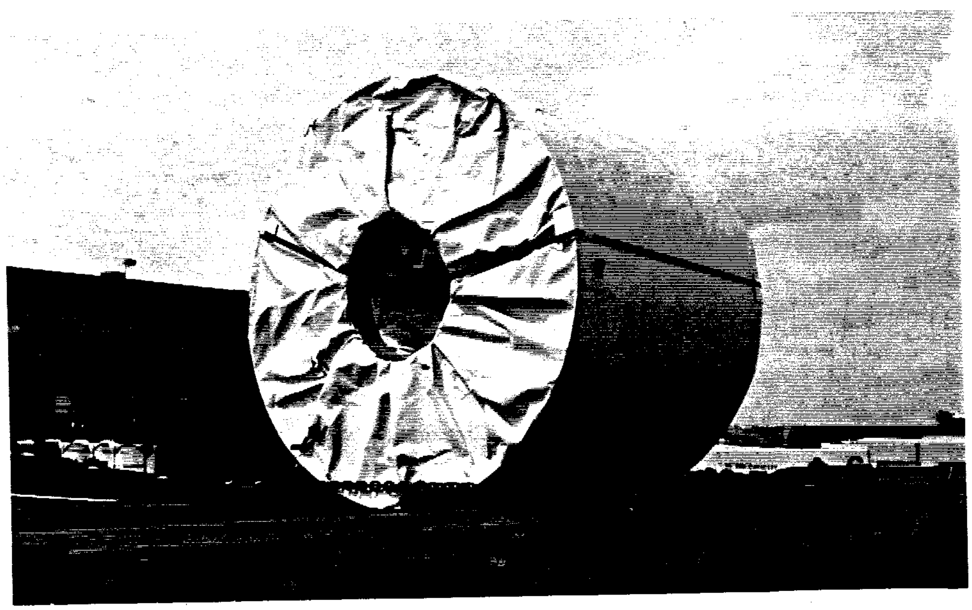
Turning a Coil from Eye Horizontal to Eye Vertical for the Bake

The coils were lifted into the furnace at Metlab using two 10 ton bridge cranes connected to a spreader bar. Short soft slings were purchased so that the coils could be lifted and removed from the truck and also clear top edge of the furnace. After the bake the coils were loaded onto the trucks with the eyes of the coils vertical.

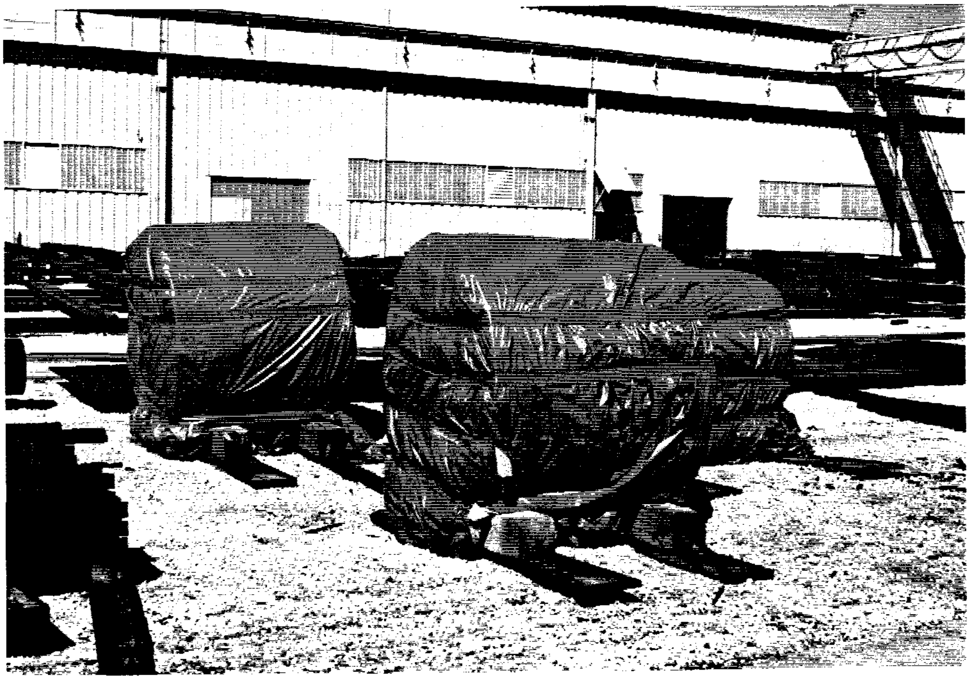
The coils were transported to CBI where they were turned so that the eyes of the coils were horizontal. This was done at CBI because the leveling facility did not have the equipment needed to turn the coils. The coils were shipped covered with a tarp.

No special handling equipment were needed to handle the material during the leveling process. The facility had the equipment and experience to lift and move the coils with the eyes of the coils horizontal. After leveling was completed at Leveltek in Triadelphia, West Virginia the coils were re-banded and wrapped in water resistant paper. Thick paper was installed between the painted carbon steel banding and the coil material. The coils were shipped directly to MetalPro in Carol Stream, Illinois.

No special handling equipment were needed to handle the material during the slitting process at MetalPro. The facility had the equipment and experience to lift and move the coils. This facility also had equipment to turn coils from eyes horizontal to eyes vertical. However, the material was processed with the eye vertical and did not require turning. After the coupon material was removed and the slitting completed, the coils were banded and wrapped in water resistant paper. Thick paper was installed between the painted carbon steel banding and the coil material. The tree slit coils were shipped to Tubetec in Florida to be used to manufacture the tubes for the QT. Upon arrival at Tubetec the material was stored until it was approved for use by Caltech. The other three coils (two full size coils and the remainder of the coil that was slit) were stored at MetalPro until the material was approved for use by Caltech.



Coils packaged for Shipment



Coil Material Stored for use on the Option

No special handling equipment were needed to handle the coil material during the tube manufacturing process at Tubetec. The facility had the equipment and experience to lift and move up to 12,000# coils.

DISCOVERIES AND CONCLUSIONS:

The steel manufacturer did not have the equipment to turn a 34,000# coil from eye vertical to eye to the side. Also, the bake facility could not turn the coils.

The steel manufacturer used painted carbon steel banding with cardboard edge protectors to package the LIGO coil. The paint on the banding and the cardboard are potential sources of contamination to the coil material.

PROPOSED CHANGES:

Install coil turning device at the bake facility to turn the coils before and after baking.

Have the bake facility remove the painted carbon steel banding and cardboard edge protectors and replace them with aluminum or stainless steel banding and edge protectors before performing the bake.

Specify that the coils are to wrapped in waterproof wrapping and tarped when they are being shipped.

Specify that the coil material be covered or wrapped at all times that the material is not being handled or processed.

Specify the right of the customer to witness some or all operations being performed.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

During the handling and transportation of the coil material the following potential risks have been identified.

During the handling, moving, processing and storing operations the coil material may become contaminated. This is of particular concern during and after the baking operation. Investigate the operations in processing the coil material to determine potential sources of contamination. Eliminate or minimize the potential sources of contamination. Hold meetings with the beam tube material vendors prior to awarding the order to identify and discuss the specific requirements the vendors must meet. Determine the vendors capability and willingness to comply with the specified requirements. Witness all first time operations and reserve the right to witness all operations as necessary to assure that the vendor is complying with the material requirements.

During the handling, moving, processing and storing operations the coil material may be damaged. This is of particular concern during the baking operation. Determine the vendors capability to safely lift and handle the coil material without damaging the material. Witness all first time lifting and handling operations and reserve the right to witness all operations as necessary to assure that the vendor can safely handle the coil material.

C.1.a COIL RECEIVING INSPECTION

OPTION PLANS AND PROCEDURES: **IR & C-240-186**

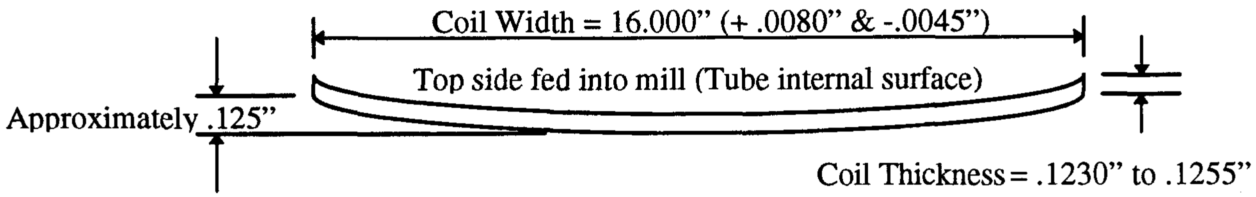
QUALIFICATION TEST PLANS AND PROCEDURES: **IR & C-240-186**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

Coil size.

QUALIFICATION TEST EXECUTION:

Three 16" wide coils were slit from a 48.5" wide coil. The three coils spliced together forms' continuos spiral tube production. The coil width of the three coils spliced during the QT was within .014" of each other. The coil had a concave cross section.



Sketch No. 1

The coil receiving inspection was continuos during mill operation as the surfaces became accessible. Refer to the Receiving Inspection Report (RIR) No. 001/003 in the appendix for additional details.

DISCOVERIES AND CONCLUSIONS:

The orientation of the coil worked with the natural tendency of the spiral weld shrinkage to scallop the tube wall. Coil orientation to minimize scallop and banding effects on tube shell would require special coil handling equipment. The finished spiral welded tube was within acceptable tolerances.

PROPOSED CHANGES:

There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk identified from the QT and additional development is unnecessary.

C.1.b TUBE SPIRAL WELD

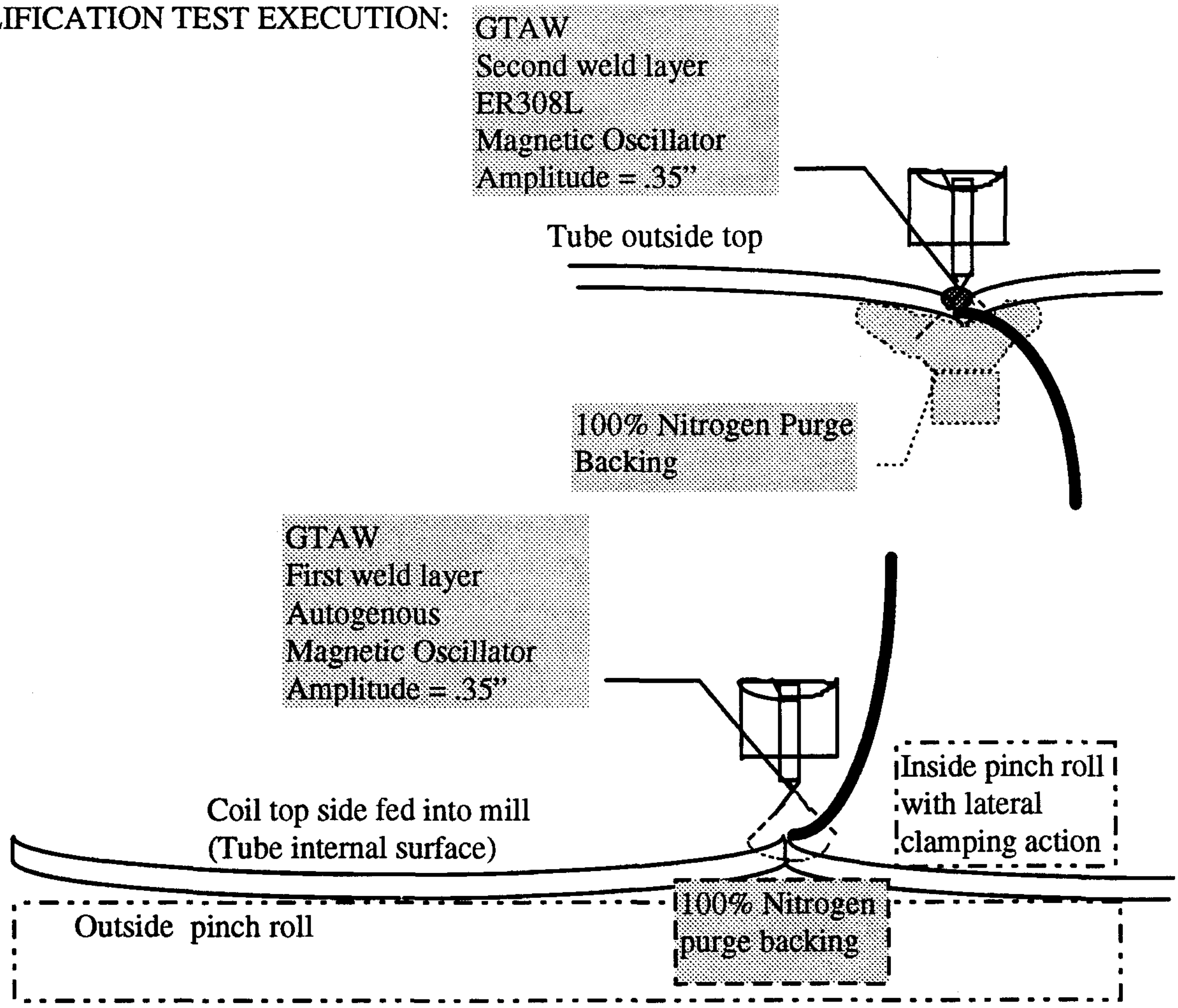
OPTION PLANS AND PROCEDURES: **WPS No. SPIRAL**

QUALIFICATION TEST PLANS AND PROCEDURES: **WPS No. SPIRAL**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

Length of continuos run of tube before mill is stopped.

QUALIFICATION TEST EXECUTION:



Sketch No. 2

The welding procedure specification establishes the requirements for the production of spiral welded tube. The tube mill pinch rolls forms the coil to the cylinder radius. The inside roll with lateral clamping action holds the aligned edges together and the mill power drive sets the travel speed for both inside and outside GTAW machine processes. The two welding processes must be started and stoped in harmony. The tube mill slows to a stop therefore, the welding current must be turned off first. There is a 2" length of spiral joint that has only one weld layer at the inside and outside stop & start location. A manual weld repair is required at both locations. The tube mill does not have a reverse capability.

The orientation of the coil worked with the natural tendency of the spiral weld shrinkage to scallop the tube wall. There was no change in the mill operation as the coil splices passed through the spiral tube mill. There were approximately 35 defects with an accumulative length of approximately 7 feet within the 1645 feet of QT spiral weld. The type defects produced were stops, starts, skips, pinholes, and undercut. Refer to the Assembly Check List for additional details. The appendix contains the assembly check list.

DISCOVERIES AND CONCLUSIONS:

- An oversized wire feed tip modified by crimping the end together caused pinholes and undercut. The wire would wander into the weld puddle. Vibration of the beam tube when touched by inspectors and operators caused the skips.
- The tube ends of each can section used for the QT had sections taken. The use of metallographic papers prepared the sections for etching to determine the weld layer overlap. The sections revealed that overlap of the weld layers did not occur even though the beam tube edges had achieved complete fusion. Unexpected conditions caused the lack of 100% weld penetration and inadequate overlap.
- The coil strip edges should be power brushed a distance of 1/4" ± 1/8" to limit reflectivity. Final QT cleaning made the polished area obvious.
- The process of the spiral welded tube mill involves more than what we expected.
- The ASME Section IX Welding Code does not list as essential or nonessential some ultra high vacuum welding technique variables. Clarifications of the Caltech specification applicable to the extent that welding techniques shall deviate from the ASME Code is important before supplementary development continues. The best high vacuum practice to eliminate any "virtual leaks" in the welds must have limits set. These limits must be routinely measurable. The Development of welding techniques that involve a change of mill travel speed will require a requalification of the welding procedure specification.

PROPOSED CHANGES:

- The ultra high vacuum welding technique variables needed to achieve and assure 100% weld fusion with approximately .050" overlap must be demonstrated on a production mock-up test to determine if changes are needed to the essential or nonessential variables listed in the ASME Section IX Welding Code. If necessary the Welding Procedure Specification WPS No. SPIRAL shall be requalified.
- Wire feed tip size shall be specified in WPS No. SPIRAL.
- The inside backing gas purge box for the second weld layer shall be improved.
- Coil strip edges shall be power brushed a distance of 1/4" ± 1/8" to limit reflectivity.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- The spiral welded tube manufacturing process shall be fully under the control of the beam tube contractor. The quality of spiral welds and repairs are critical to the leakage and outgas requirements. Additional development is needed to improve the spiral weld quality.
- The production rate and timely delivery is essential and critical to the schedule commitment of the beam tube contractor.
- Tubetec has plans to develop a new spiral welding mill. The new spiral welding mill may handle 30" to 48" coil strip widths. The beam tube contractor should participate in any additional development of the new tube mill.

C.1.c TUBE COIL SPLICE

OPTION PLANS AND PROCEDURES: **WPS No. SPLICE**

QUALIFICATION TEST PLANS AND PROCEDURES: **WPS No. SPLICE**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The three 16" wide coils were spliced together during a stop period of mill operation. Coil width set the sequence of coil selection. The 15.9955" wide left coil was fit and welded to the 15.9970" wide right coil. The 15.9970" wide right coil was fit and welded to the 16.0080" wide center coil. The top side was manual welded using GTAW procedure WPS No. SPLICE. The only side welded was the tube inside. No filler metal was used. The weld was ground flush and the ends were apparently taper ground to remove any offset. There was no change in the mill operation as the coil splice passed through the spiral tube mill. CBI completed the outside coil splice weld during stiffener welding operations while the beam tube section was under nitrogen purge.

DISCOVERIES AND CONCLUSIONS:

- The coil width of the three coils spliced during the QT was within .011" of each other.
- There was no noticeable change in the finished spiral weld at or near the coil splice or adjacent spiral welds.
- During the stiffener welding operations a stiffener crossed a coil splice. A 3 inch length of coil splice weld was completed before the stiffener was fit. The outside coil splice weld was completed after stiffener welding operations while the beam tube section was under nitrogen purge. Flat spots can develope if the shell is not stiffened during the final welding operation.

PROPOSED CHANGES:

Change WPS No. SPLICE to clearify side 1 to be the inside of the tube with only 1 pass autogenous and side 2 to be the outside of the tube with only 1 pass using ER308L.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- The quality of coil splice welds and repairs are critical to the leakage requirements.

C.1.d TUBE SECTION VISUAL INSPECTION

OPTION PLANS AND PROCEDURES: **MI, VI5, & VI8X**

QUALIFICATION TEST PLANS AND PROCEDURES: **MI, VI5, & VI8X**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

All beam tube sections were identified by an identification number painted on the outside surface of the beam tube at each end and at the coil splice. The unacceptable weld defect areas on the outside were marked with a black marker and recorded on an assembly check list. The unacceptable weld defect areas on the inside were recorded on an assembly check list. The type of unacceptable defects were stop/starts, skips, pinholes, and undercut over 1/32". The scalloping effect of the spiral weld on the tube wall measured approximately 3/32" (.093"). The beam tube straightness was measured during the layout of vacuum stiffeners at CBI Houston Corporate Welding.

DISCOVERIES AND CONCLUSIONS:

- The QT bake out determined the identification number paint is capable of withstanding 150°C bake temperatures.
- The ASME B31.3 acceptance standards for undercut is applicable for the spiral weld.
- The spiral weld shrinkage in conjunction with the coil skelp orientation contributed to a scalloping effect on the tube wall. The contribution to local deviation from theoretical cylinder form was significant. The spiral welded tube meet the straightness and cylindrical shape tolerances.

PROPOSED CHANGES:

- Include the ASME B31.3 acceptance standards for undercut into the visual inspection requirements procedure.
- Include the acceptance standards for dents into the visual inspection requirements procedure.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- Should a dent be present the accumilated local deviation may need corrective repair to become acceptable.

C.1.e TUBE SECTION HANDLING

OPTION PLANS AND PROCEDURES: **TT-H1N**

QUALIFICATION TEST PLANS AND PROCEDURES: **TT-H1N**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

Multiple tube section loads are planned for the option and a single tube section was a load for the QT.

QUALIFICATION TEST EXECUTION:

The tubes were completely covered by white tarp overlapped to make two layers at most locations that served as insulation. The ends were covered with two layers of plastic and sealed for transportation. The shipping restraints were fabricated oversized and had to be held in place with two layers of 1/2" rubber strips. The unstiffened beam tube sections arrived in Houston on July 18, 1994. The 61' tube section was placed outside covered with the white tarp. Surface temperature was taken on the covered tube and compared to the temperature on an uncovered auxiliary tube section placed in the sun. The maximum temperature on the top surface for the uncovered auxiliary tube was 156°F as compared to the covered tube of 115°F. The bottom surface of the uncovered auxiliary tube was ambient (98°F). The bottom surface of the covered tube could not be measured due to the tarp. The wind during measurement was approximately 5 to 10 mph.

DISCOVERIES AND CONCLUSIONS:

- The typical measured oval in the unstiffened tube was about 2".
- Lifting restraints were wood frames inserted into the tube. The inside restraints caused contamination that could not be removed during QT cleaning.

PROPOSED CHANGES:

- TT-H1N shall be revised so that only outside restraints are used during production handling for the option beam tube sections.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The beam tube contractor should participate in any additional development of handling spiral welded tube. The development will be undertaken during the preliminary stages of the option phase of the project.

- The handling of spiral welded tube is critical to the cleaning, leakage, and outgas requirements.
- Timely delivery is essential and critical to the schedule commitment of the beam tube contractor.

C.2 EXPANSION JOINT FABRICATION

OPTION PLANS AND PROCEDURES: Specification C-EJ-OP "LIGO Expansion Joints"

QT PLANS AND PROCEDURES: Specification C-EJ-QT

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:
The expansion joint configuration and fabrication method are identical to those proposed for the option. Material differences are described in section A.2.

QUALIFICATION TEST EXECUTION:
Three LIGO beam tube expansion joints were fabricated by Hyspan, Incorporated of Chula Vista, California. One expansion joint was fabricated for the QT and the other two were fabricated for future fatigue testing. Each expansion joint was fabricated from a single sheet of .105" thick X 60" X 160" SA-240 TY 304L stainless steel resulting in a single longitudinal seam. The material was trimmed to the required dimensions by the manufacturer. The expansion joint material used in the qualification test did not meet the LIGO specified minimum surface roughness due to the unavailability of thin hot rolled stainless steel sheets.

The expansion joints were made by forming a cylinder with a single longitudinal weld seam. Convolutions were formed individually with an expanding mandrel. The expansion joints are rolled between a series of discs to achieve the final shape. The joints were leak tested by welding an inner cylinder to the expansion joint to effectively form an annular vacuum chamber. As such, the expansion joints are not subjected to a significant longitudinal load during leak testing. After leak testing, the internal cylinder was removed and the ends of the expansion joint was machined on a horizontal bed lathe. After fabrication, the expansion joints were leak tested and a spring rate test was performed on the QT expansion joint.

DISCOVERIES AND CONCLUSIONS:
The mechanically formed expansion joint met most of the specified requirements and are suitable for use on the LIGO project. The overall dimensions of the expansion joint met the specified tolerances. Some dimensions of the expansion joint ends did not meet the specified tolerances required for butt welding the expansion joints to the tube sections. The weld procedures were modified to accommodate the as built dimensions. As is typical for expansion joint manufacturers, Hyspan does not currently have the equipment to perform a leak test to the specified helium sensitivity of 1 X 10-10 atm cc / second. Although no leaks were detected in the leak test, the helium leak test sensitivity was approximately 5×10^{-10} atm cc / second. The spring rate of the expansion joint used in the qualification test was measured by applying sufficient weight to the expansion joint to produce the full compressive stroke of 3.25". The measured spring rate was 5,800# versus the calculated spring rate of 8,021#. Hyspan misinterpreted the specification and cycled the expansion joint 20 times with the full weight. After 20 applications of

the full load, the expansion joint took a compressive set of 1.375". The expansion joint was re-rolled back to the original length. The following discoveries were made in the QT:

- The expansion joint configuration and selected fabrication method are well suited for the LIGO project.
- Expansion joint manufacturers currently do not have the capability to perform component leak tests with a helium leak sensitivity of 1×10^{-10} atm cc per second.
- The circumferential tolerance of the expansion joint ends can be increased slightly due to weld procedure modifications.
- All expansion joint ends may not meet the circumferential tolerance even though fabricators claims the ability to meet the tolerance.
- The flatness tolerance originally specified for the expansion joint ends can be increased due to weld procedure modifications. The expansion joints are too flexible to meet the original tolerance even though the ends are machined.
- The expansion joints must be carefully handled and packaged to prevent minor distortion of the machined ends.

PROPOSED CHANGES:
Minor changes are required in the specification to increase the end tolerances of the expansion joints. Expansion joint manufacturers must determine the most effective and economical method of packaging the expansion joints. Although the expansion joint is also leak tested as a part of the beam tube section before module installation, the selected manufacturer for the option should perform a leak test to the required sensitivity.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:
There are no significant risks or additional development associated with the expansion joint fabrication.

C.3 SUPPORT FABRICATION

OPTION PLANS AND PROCEDURES:

Specification C-SUPT-1 "Beam Tube Support Specification"
CBI Drawings #006, 007, 008, 017, 018, & 019

QT PLANS AND PROCEDURES: Same as those specified for the option.

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:
There are no differences in the fabrication of the QT supports and the option supports.

QUALIFICATION TEST EXECUTION:
Two fixed supports and one flexible support were fabricated for the Qualification Test. The QT supports were fabricated by Piping Accessories, Incorporated of Beaumont, Texas. The supports are composed primarily of galvanized carbon steel assemblies. The fixed and flexible supports attach to identical support lug assemblies which bolt to the beam tube slab. The support lugs as originally detailed did not provide access to allow the anchor bolts to be drilled and installed after the support lugs were placed in their final location. The support lugs were modified to provide this access. The modified support lugs were fabricated by CBI and were not galvanized.

DISCOVERIES AND CONCLUSIONS:
Piping Accessories built the supports to the drawings supplied by CBI and did not make any additional shop drawings. The hangers on the flexible supports were originally specified by CBI to be 2" X 3/16" bar stock composed of A572 Gr50 material. Piping Accessories stated that the hot dip galvanizing process would warp the bar hangers. As such, the bar hangers were not galvanized for the Qualification Test. A suitable corrosive resistant material must be selected for the modules. In addition to the support lug modification identified above, an interference was discovered between the tube and the support lug when the tube was at the lowest position. The following discoveries were made in the QT:

- The configurations of the fixed and flexible supports are well suited for the LIGO project.
- Support details were modified to provide jacking surfaces for tube alignment.
- Support frames were modified to facilitate access to drill and install the anchor bolts.
- Support details were modified to eliminate an interference for maximum alignment capability.
- Flexible support hangers should not be galvanized to prevent distortion of the relatively thin carbon steel hangers. Alternative corrosive resistant material should be used.

PROPOSED CHANGES:
The hanger material and support lug details must be revised as stated above.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:
There are no significant risks or additional development associated with the support fabrication.

C.4 BAFFLE FABRICATION

OPTION PLANS AND PROCEDURES:
Specification C-BAF-1 "Baffle Fabrication Specification"
CBI Drawing #014

QT PLANS AND PROCEDURES: Same as those specified for the option.

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:
There are no differences in the fabrication of the QT baffles and the option baffles.

QUALIFICATION TEST EXECUTION:
Five baffles were originally fabricated for the QT by Meyer Tool & Manufacturing , Incorporated of Oak Lawn, Illinois. The baffles were fabricated from .105" thick sheets of SA240 Type 304L stainless steel sheets. Baffles were fabricated from four equally sized sections. Sections were cut from the sheet by a water jet and welded together without filler wire by the Gas Tungsten Metal Arc (GTWA) process as specified.

DISCOVERIES AND CONCLUSIONS:
The LIGO specifications require that the baffle installation shall require no fastening and that the baffle thickness and unconstrained helix diameter shall provide sufficient friction and stability for secure positioning. Potential fabricators were unable to assist CBI in developing a configuration that would meet this specifications. The baffles were fabricated to a configuration developed by CBI. The baffles were correctly fabricated to the details specified. In particular, the water jet cutting method is capable of producing serrations to the tolerances specified.

PROPOSED CHANGES:
The fabrication procedure is acceptable but the LIGO specification prohibiting fastening results in a potentially unstable baffle as described in section F13.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:
The fabrication process does not present any risks and does not require additional development. However, a new baffle detail is required.

C.5 PUMP PORT

OPTION PLANS AND PROCEDURES: **RI & C-PORT-QT**

QUALIFICATION TEST PLANS AND PROCEDURES: **RI & C-PORT-QT**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

Two pump port assemblies (13-1-1 &2) supplied by Norcal Products, Inc. were incorrectly fabricated with a 23" cylinder radius. C-PORT-QT specifies a 24.5" cylinder radius. Assembly 21-B-1 has a 24.625" cylinder radius at the pump port location. There was approximately 1/4" gap between the beam tube shell and pump port neck. The radius was reworked to obtain adequate joint fit-up for the QT. This was accomplished by using a wrap around template and hand grinding the pump port neck to fit.

DISCOVERIES AND CONCLUSIONS:

The spiral welded tube production has a significant consequence because the outside diameter fluctuates at pump port locations. The current fit-up procedure and welding procedure does not accommodate more than .010" gap. The pump port location is stiffened with a reinforcing plate prior to hole cut out. The cylinder radius of the beam tube is fixed after the hole is cut out. The ammount of beam tube cold forming it takes to close the gap has not been determined. The clamping force to cold form the beam tube would be applied to the pump port conflat flange. Caution shall be taken not to deform the flange.

PROPOSED CHANGES:

Consider the use of clean ER308L filler metal for the first weld layer where the gap exceeds .010".

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Rework will affect the performance and schedule of the beam tube contractor. The pump port has to be fabricated to a known cylinder radius. The pump port supplier should demonstrate the ability to provide a pump port that meets the specification requirements before the option order is placed.

C.6 SUPPORT & BAFFLE STIFFENERS

OPTION PLANS AND PROCEDURES: **RI & C-SUPSTF-1**

QUALIFICATION TEST PLANS AND PROCEDURES: **RI & C-SUPSTF-1**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The type -1- baffle stiffener ring is made by bolting together with a 6 inch overlap two stiffener ring segements with two .5" holes & one No. 7 taper dowel hole at each end. The type -2- fixed support stiffener ring is made by bolting together with a 6 inch overlap one stiffener ring segement and one fixed support ring segement with matching holes and two 7/8" holes at the 180° centerline. The type -3- guided support stiffener ring is made by bolting together with a 6 inch overlap one stiffener ring segement and one guided support ring segement with matching holes and four 7/8" holes equally spaced below the 90° centerline and with four 7/8" holes equally spaced below the 270° centerline. The baffle stiffener ring, fixed support ring, and guided support ring is machined to obtain a 57.00" ± .010" outside diameter. The baffle stiffener ring, fixed support ring, and guided support ring is machined to obtain an inside diameter that exactly equals the outside diameter of the beam tube at the location where it will be attached with a tolerance of + .010" & - .000". The bolts shall not be removed until attachment fitting to make sure each stiffener ring is fitted to the place it was machined for.

The type -1- baffle stiffener, type -2- fixed support stiffeners, and type -3- guided support stiffeners supplied by Kentucky Metals, Inc. had inside diameters that appeared to be under size. A pie tape was used to make the measurement without adding the correction factor for the thickness of the tape (+0.022"). A trial fit to the beam tube indicated that the support stiffener was acceptable. The type -3- support stiffeners had holes drilled 1" from design location which caused installation modification to the guided support assembly.

DISCOVERIES AND CONCLUSIONS:

The correction factor for the thickness of the pie tape shall be considered if used to take measurements of inside diameters. The holes location should be checked during receiving inspection.

PROPOSED CHANGES:

There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Errors in manufacturing causes lost time. The rework, repair, or rejects will affect the performance and schedule of the beam tube module contractor. Communication and corporation with the support stiffeners supplier and beam tube contractor should be developed prior to option phase start. The variation in diameter of the beam tube must be known prior to final sizing. A fixed series of standard sizes of the support stiffeners will reduce the risk of errors and confusion.

C.7 VACUUM STIFFENERS

OPTION PLANS AND PROCEDURES: **RI & C-VAC-1**

QUALIFICATION TEST PLANS AND PROCEDURES: **RI & C-VAC-1**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The stiffeners are a single continuous 3/16" X 1¾" bar formed by rolling to a roll radius of 2' - 0½" +¼"/-0"; only the ends of the stiffener to be cut edges. The stiffener is to be installed over the tube from the ends and moved into place. The stiffener has a 4" +1"/- ½" overlap with a tight fit around the tube. Two different manufacturers of vacuum stiffeners were used on the QT beam tube sections. The 34 vacuum stiffener rings supplied by Meyer Tool & Mfg. Inc., had flat ends (approximately 6" on each end). These stiffeners did not have all the straight sections cut from the ends. The ends were reworked by CBI as needed to obtain adequate joint fit-up. The 34 vacuum stiffener rings supplied by Monarch Machine & Tool Co. were manufactured with an under size roll radius (approximately 2' - 0¼"). The vacuum stiffener rings were difficult to slid into position due to the small roll radius and a over sized beam tube diameter.

DISCOVERIES AND CONCLUSIONS:

Once in position, the stiffeners with small roll radius were fit with minimal effort. It is desirable to have stiffeners with a larger roll radius.

PROPOSED CHANGES:

The design roll radius should be changed to mate with the maximum beam tube outside diameter.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The rework, repair, or rejects will affect the performance and schedule of the beam tube module contractor. Communication and corporation with the vacuum stiffeners supplier and beam tube contractor should be developed prior to option phase start.

D.1.a PUMP PORT FIT-UP

OPTION PLANS AND PROCEDURES: **FPPUMPPORT**

QUALIFICATION TEST PLANS AND PROCEDURES: **FPPUMPPORT**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The pump port drilling per FFPUMPPORT did not function as planned and its use was discontinued during the qualification test. Plasma cutting was approved by Caltech after temperature measurements were taken. The temperature of the burned edge after plasma cutting was approximately 125°F. Before plasma cutting the inlet, a jack/purge device was placed inside the tube to isolate the work to only a 14" square around the pump port. This confined all grinding and cutting to the purge area. The cut out was made 1/2" smaller diameter. The plasma cut edge was cleaned for welding with a hand held power grinder to remove the 1/4" beam tube material to match the inside diameter of the pump port neck.

DISCOVERIES AND CONCLUSIONS:

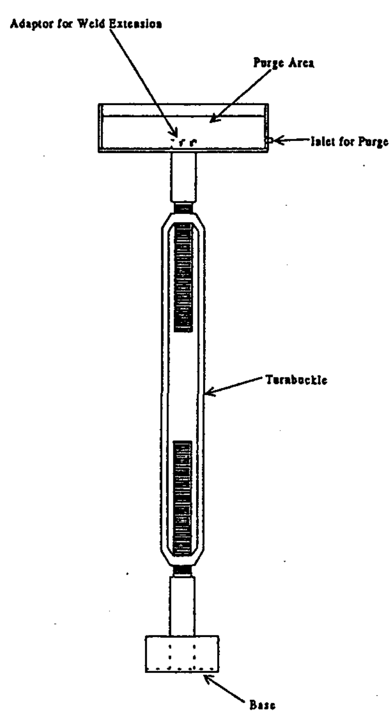
The quality of the welding improves if 1/8" of the beam tube edge is left. The 1/8" edge of material provides a heat sink to allow full penetration welding from the outside without suck backs.

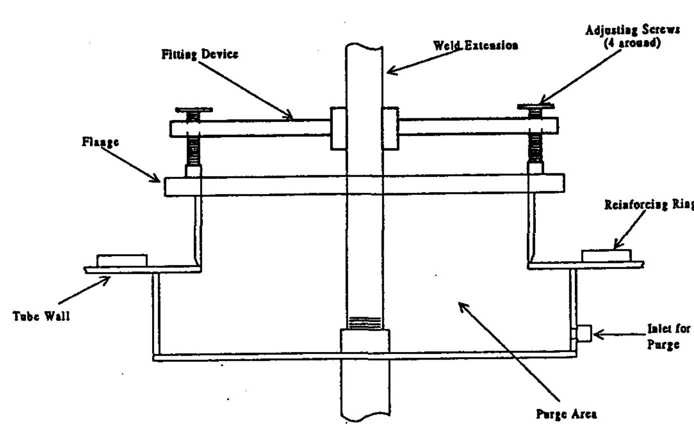
PROPOSED CHANGES:

- Change procedure to allow plasma cutting instead of drilling the pump port hole.
- Change procedure to eliminate or clarify mismatch criteria.
- Change procedure so that tacks are made from the outside.
- Change procedure so that sequence of purge, welding and inspection is in proper order.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Acceptable fit-up is dependant on the cylinder radius of the pump port neck matching the cylinder radius of the beam tube.





D.1.b PUMP PORT WELDING

OPTION PLANS AND PROCEDURES: **WPS ER308L/PORT**

QUALIFICATION TEST PLANS AND PROCEDURES: **WPS ER308L/PORT**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The modification to WPS ER308L/PORT consisted of welding the outside first. The extra edge on the inside surface allows better control of the heat input and a satisfactory full penetration weld pass may be deposited from the outside. A visual inspection of the inside of the pump port assures 100% penetration and fusion. Also, the inside may be viewed while welding is in progress. This weld layer is an autogenous GTAW.

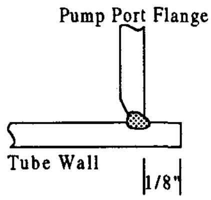


Figure 4: Pump Port Detail

After acceptable visual inspection, a second weld layer was deposited on the outside using ER308L to obtain the correct fillet weld size. After the outside passes were complete, the inside was washed using autogenous GTAW to smooth the inside surface. After all welding was complete, the inside edge was ground down flush with the pump port and a small radius applied to the corner.

DISCOVERIES AND CONCLUSIONS:

Acceptable fit-up is dependant on the cylinder radius of the pump port pipe matching the cylinder radius of the beam tube.

PROPOSED CHANGES:

Consider the use of clean ER308L filler metal for the first weld layer where the gap exceeds .010".

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Additional development to use filler metal where the gap exceeds .010" would be an alternate to reworking the pump port pipe cylinder radius.

D.2.a VACUUM STIFFENER ATTACHMENT FIT-UP

OPTION PLANS AND PROCEDURES: **FPSTIFFENER**

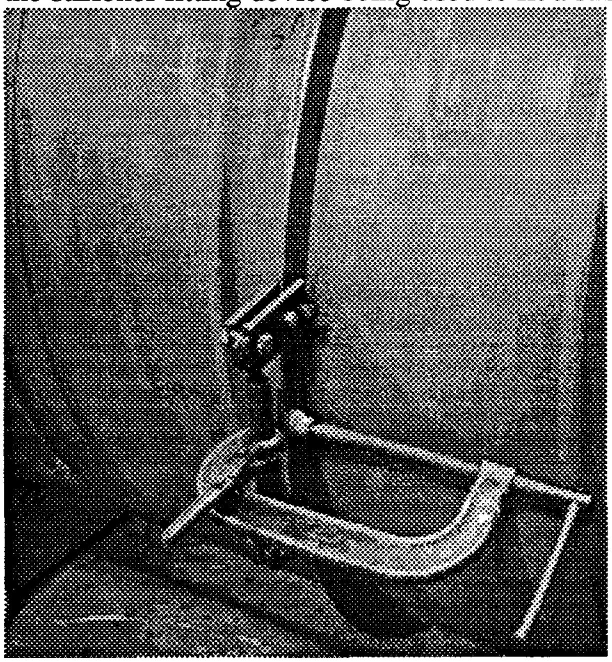
QUALIFICATION TEST PLANS AND PROCEDURES: **SAME**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The vacuum stiffener rings were difficult to slid into position due to the small roll radius and a over sized beam tube diameter. The stiffener is fit tight around the beam tube with the overlap crossing the sprial weld. The splice is carefully located with the lap on the right side to decrease the unwelded area. Small tacks are placed at 12" centers around the beam tube, then the splice lap is welded and the fitting device is removed. The photograph below shows the stiffener fitting device being used to fit a stiffener to the beam tube assembly.



DISCOVERIES AND CONCLUSIONS:

Attachment of the stiffener fitting device on each stiffener to move it into position is inefficient. It was found that welding the 4" hand pass at the stiffener laps should be done after the stiffener is welded in the machine set up. This eliminates some of the bend in the stiffener at the splices. Also, decreasing the tack spacing from 18" to 12" will result in a more straight stiffener.

PROPOSED CHANGES:

Change the procedure by deleting use of the stiffener fitting device to lock open the stiffener rings. The use of stiffener rings with a proper roll radius will eliminate the need to lock open the stiffener. Change the procedure tack spacing to 12".

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

D.2.b VACUUM STIFFENER ATTACHMENT PURGE

OPTION PLANS AND PROCEDURES: **FPSTIFFENER**

QUALIFICATION TEST PLANS AND PROCEDURES: **SAME**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The purging of the QT beam tube assemblies did not function as planned and was modified for the QT. On the first 60' beam tube section, it took nearly three (3) hours to obtain a purge level of 2.0% oxygen. Due to the length of time required, it was approved by Caltech to proceed with fitting and welding at a level of 2.0% or less. Fitting proceeded at a level of 2.0% and welding was completed at a purge level of 1.4% oxygen. Liquid nitrogen dewars without a high pressure gas outlet was used for purge gas supply. Improved methods were used for each beam tube can section purged. Upon stiffener attachment completion it was decided that improvement was needed to use liquid nitrogen as a purge gas source.

DISCOVERIES AND CONCLUSIONS:

During QT end closure installation nitrogen gas was used from liquid nitrogen dewars with high pressure outlets. The flow rate was increased by connecting three high pressure dewars to the pump port inlet. The outlet was sized so that pressure inside the beam tube did not blow out the seals. High forces at the open ends can be generated with very low pressures inside the beam tube. Safety clamps must be installed at each end cover.

PROPOSED CHANGES:

Change procedure so that power rolls and end covers are used instead of a headstock and tailstock.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

As improved methods are discovered, each phase of progress becomes more efficient.

D.2.c VACUUM STIFFENER ATTACHMENT WELDING

OPTION PLANS AND PROCEDURES: **WPS ER308L/STIFFENER**

QUALIFICATION TEST PLANS AND PROCEDURES: **SAME**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

During the stiffener attachment to beam tube welding operation the machine weld positioner advanced down the tube in a continious direction. The voltage sensor cable run out of length. The voltage sensor cable was moved from the end of the tube and placed on the ground terminal of the welding machine. Unstable welding occured. The wire feeder attempted to adjust the voltage of the circuit rather than the welding arc voltage. During attempts to stabilize the welding, the stickout was decreased to 3/8". The high voltage and short stickout caused the arc to establish across the contact tip. Copper was deposited into the weld. The copper tip made contact with the beam tube. The copper caused longitudinal and transverse cracks in the stiffener weld in three areas. Copper melts at a lower temperature than the stainless steel, so it is the last to solidify in the weld pool. As the weld metal cools and begins to solidify, solidification shrinkage stresses causes the weld to crack. The voltage sensor cable was placed onto the tube end and the stickout was adjusted back to 1/2". The welding operation was stabilized and the remaining stiffeners were completed with no problems.

DISCOVERIES AND CONCLUSIONS:

Vacuum stiffener rings tend to rotate due to shrinkage from the one-sided welding. The rotation is approximately 8 degrees.

The weld contact tip needs to be protected from making electrical contact with the beam tube. The welding tourch gas nozzle adjustment should cover the contact tip 1/8" minimum.

PROPOSED CHANGES:

Changes in the welding procedure have been made to prevent the recurrence of copper deposits into the weld. The revised welding procedure specifies that the gas nozzle shall cover the contact tip 1/8" minimum. The manual welds at the stiffener laps shall be made after machine welding is complete to reduce stiffener rotation. Vacuum stiffener design may require change to help control rotation.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Welding operators will be trained to watch for and prevent arcing at the contact tip.

D.2.d VACUUM STIFFENER ATTACHMENT WELDING REPAIR

OPTION PLANS AND PROCEDURES: **GR-8X & WPS ER308L/REPAIR**

QUALIFICATION TEST PLANS AND PROCEDURES: **SAME**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

Liquid penetrant procedures will not be used for inspection of option phase welds.

QUALIFICATION TEST EXECUTION:

A deep crater weld pick-up was made at a stiffener attachment weld stop where the tourch had been adjusted the opposite direction. The repair was found to leak when the assembly leak test was performed. There were 4 repairs required as a result of the copper tip making contact with the beam tube during the stiffener attachment to beam tube welding operation. The defects were removed before any welded repair was made. The copper deposits were removed until no areas could be seen from the etchant. Sections of the stiffener in these repair areas were removed in order to obtain PT exam. A process of PT exam followed by grinding/chipping was conducted until no detectable defects remained in the tube wall. In all three cases, the defect was removed by grinding/chipping into the tube wall 1/16" to 3/32". The largest repair area was 2" long by 1/2" wide with a depth of 3/32". Three jacks were made with a radius copper bar and placed on the inside of the tube wall pushing outwards at the three repair areas. The entire tube was purged with nitrogen to a level of 0.9% oxygen. Repairs were welded from the outside using GTAW process WPS ER308L/REPAIR. After the repairs were complete, the surface was PT examined and showed no detectable defects. An extra stiffener from Kentucky Metals was cut into the required lengths and re-fit to the tube wall. These stiffeners were welded using WPS ER308L/GMA allowing for a minimum of 1" lap at each end. Every stiffener weld on the last 60' beam tube section was visually inspected and any area that deviated from the normal contour of the stiffener weld was cleaned and PT examined. Fourteen (14) areas were examined and all of them showed no detectable defects.

DISCOVERIES AND CONCLUSIONS:

Copper deposits do not show completely when macro etched. A very smooth and polished surface is required to obtain a more detailed inspection. A liquid penetrant (PT) exam was conducted on this area and evaluated. It showed many transverse cracks. Welding operators will be trained to watch for and prevent arcing at the contact tip.

PROPOSED CHANGES:

There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The planned approach to leak testing established the strategy to discover defects. The QT has demonstrated an effective quality control system with repair procedures that remain active until the level of acceptable performance has been acheived. People will be encouraged to identify any inconsistency and will be recognized for their contribution to swift correction. Continuous development in leadership and management will imporve quality.

D.3 SUPPORT/BAFFLE RING ATTACHMENT FIT-UP, PURGE & WELDING

OPTION PLANS AND PROCEDURES: **FPSTIFFENER & WPS ER308L/STIFFENER**

QUALIFICATION TEST PLANS AND PROCEDURES: **SAME**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

A type -3- support stiffener ring installed on assembly 21-C-1 had the ends lapped opposite each other that caused installation interference for the support plat. The fit-up, purge and welding of the support/ baffle ring is comparable to the vacuum stiffeners activities.

DISCOVERIES AND CONCLUSIONS:

The clocking of the fixed support ring in relationship to a pump port or a guided support ring must be considered during fit-up. Assembly 21-C-1 was shipped by truck. The guided support ring was used as the forward bearing point and the last baffle stiffener ring was used as the aft bearing point. Fatigue cracks were found in the attachment welds during receiving inspection. The guided support ring is not intended to carry lateral loads and cannot be used to support the beam tube during shipment. The QT fixed support was installed on a short beam tube can section which experienced no unusual loading during shipment.

PROPOSED CHANGES:

There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

D.4 BEAM TUBE DIMENSIONAL INSPECTION BEFORE & AFTER STIFFENING

OPTION PLANS AND PROCEDURES: **DC**

QUALIFICATION TEST PLANS AND PROCEDURES: **DCQT**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The magnitude of dimensional inspection.

QUALIFICATION TEST EXECUTION:

A measurement record and checklist was completed for the QT beam tube assemblies. Outside diameters were measured at each end and at baffle/support ring locations using a pie tape. Straightness measurements were made between the beam tube wall and a music wire attached to standoff blocks at each end. Shims were added to make the music wire equal distance from the beam tube centerline. Reference marks were placed on the inside of the beam tube to monitor longitudinal shrinkage. The reference length was 61' - 2". The measurements were taken at the start of the shift with a constant temperature of 70° F. Assembly 21-C-1 and 21-D-1 having equal length and equal number of stiffeners produced measurements that were identical.

DISCOVERIES AND CONCLUSIONS:

After stiffening beam tube assembly 21-3-1 has a longitudinal straightness of .266" and varied outside diameters with a maximum difference of .279". After stiffening beam tube assembly 21-3-2 has longitudinal straightness of .078" and varied outside diameters with a maximum difference of .177". Varying outside diameters makes the most contribution to longitudinal straightness. The change in length (shrinkage) of the beam tube after welding the stiffeners was - 3/16" along the 0° and 180° reference lines and was - 1/4" along the 90° and 270° reference lines. The 1/16" difference in shrinkage along the 0°/180° Vs the 90°/270° reference lines may produce gaps that cannot be pulled together during fit-up if the ends are machined before stiffener attachment.

PROPOSED CHANGES:

Include clocking methods for dimension control in the procedure for the option phase.
Adjust the extent of dimensional inspection taking into consideration the straightness and roundness achieved for the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Constraints applicable to end machining activities should be considered. Improved methods are possible with additional development although the QT achieved acceptable results.

D.5 KICKER ATTACHMENT

OPTION PLANS AND PROCEDURES: **FPSTIFFENER & WPS-ER308L/GMA**

QUALIFICATION TEST PLANS AND PROCEDURES: **Same & WPS-E308L/STRUCT**

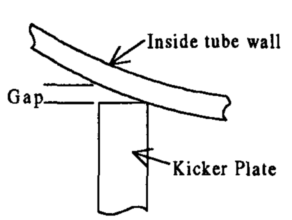
MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The kicker plate detail per Engineering drawing no. 23 is not applicable for the option.

QUALIFICATION TEST EXECUTION:

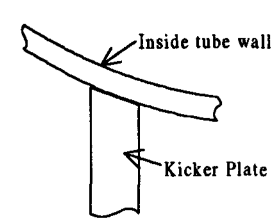
Two fixed support gusset assemblies supplied by Piping & Accessories were repaired using WPS-E308L/STRUCT to add 5/32" weld build up. The radius was hand reworked by grinding to obtain an acceptable joint fit up when attached to the beam tube in assembly 21-A & 21-B.

Piece 23-4 did not specify a mitered cut at the beam tube attachment edge. These kicker plates are longitudinal stiffeners unique to the QT only and are placed on the two short beam tube sections only. These plates do not extend perpendicular to the tube wall but extend downward at a slight angle. Special caution making the attachment fillet weld at the beam tube was used. In order to weld the side with a gap, excessive heat had to be applied to bridge the gap. This higher heat input resulted in melting through the inside of the tube shell. An inside repair was needed to fix the area of the beam tube shell in assembly 21-A. A visual inspection of these areas was determined to be acceptable and only the weld build up was removed by chipping for cosmetic purposes only. The kicker plates attached to assembly 21-B beam tube section were welded after a slight bevel was applied to the kicker plates.



The gap measured approx. 1/8" to 3/16". the inside tube

Figure 2: Kicker Support Plates



The gap was minimized and no melt though wall occurred.

Figure 3: Beveled Kicker Plates

DISCOVERIES AND CONCLUSIONS:

Engineering drawing no. 7 did not specify a radius on piece mark 7-7 at the beam tube attachment edge.

PROPOSED CHANGES:

Change Engineering drawing no. 7 to specify a radius on piece mark 7-7. Add details for fit-up, tacking and welding of fixed support gusset assemblies to procedure FFSTIFFENER.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

E.1 ASSEMBLY AREA

OPTION PLANS AND PROCEDURES:

INSTALLSEQ, "Beam Tube Can Section Installation Sequence For LIGO"
BFD-1, "Blower/Dryer/Filtration System for Beam Tube Positive Air Flow Specification and Procedure - Caltech"
CR1TSM, "Clean Room Transporting Storage and Maintenance Procedure - Caltech"
CRWA-1, "Clean Room Wearing Apparel for Beam Tube Access During Construction and Inspection Activities"

QUALIFICATION TEST PLANS AND PROCEDURES:

ISQT, "Beam Tube Can Section Installation Sequence For LIGO QT Addenda"
CRWAQT, "Clean Room Wearing Apparel for Beam Tube Access for LIGO Qualification Test Addenda"

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The QT beam tube assembly was installed inside the CBI Development Center located in Plainfield, Illinois. The beam tube installation plans and procedures used in the QT are not the same as those that will be used in the field conditions associated with the Option.

QUALIFICATION TEST EXECUTION:

The QT pumping system and the coupon outgas test system were built in a segregated vacuum laboratory. Prior to equipment installation, the vacuum laboratory was cleaned, painted, and hermetically sealed. The laboratory was kept at a slight positive air pressure through a filtered forced ventilation system during assembly of the QT pumping system, beam tube, and coupon system. The filters installed in the ventilation system were two, 2' X 2'X 1' HEPA filters with an efficiency of 90 to 95 %. All vacuum components were cleaned with acetone and alcohol prior to assembly. Open ends of the assembly were capped whenever possible to maintain cleanliness.

A temporary wall was installed in the vacuum lab prior to the completion of the beam tube installation. The temporary wall was fabricated from studs and polyethylene film. This allowed the clean atmosphere to be maintained for assembly of the pumping system while the beam tube assembly and installation was underway. After the beam tube was installed in the vacuum lab, the tube penetration through the laboratory wall was sealed, the tube area cleaned and the temporary wall removed. When the pump port or the south end of the tube was open, filtered clean air flowed into the tube from the vacuum lab.

The circumferential purge ring was placed in the north end of assembly 22A after cleaning. The ends of the QT beam tube assemblies 22A and 22B were covered with polyethylene and taped closed after cleaning. The south end of the 22A assembly was moved into the vacuum laboratory and sealed around the tube section to maintain the clean positive air pressure in the vacuum laboratory. Once the vacuum laboratory was sealed with a portion of the beam tube inside the lab, the polyethylene covering the beam tube end in the laboratory was removed and replaced with an aluminum end cap with a HEPA filter to permit air to flow from the vacuum room through the beam tube. The polyethylene at the north end of the 22A beam tube assembly outside the vacuum laboratory was slit to permit air to flow out from the positive pressure in the vacuum laboratory.

Beam tube assembly 22B was then positioned about 8" away from the assembly 22A. The polyethylene cover was removed from the north end of the 22A and the south end of the 22B at the circumferential joint. The two assemblies were positioned together and the polyethylene at the north end of the 22B was slit to permit the air to flow out. The combined assemblies were then entered from the north end place the circumferential purge dam for fitting and welding the circumferential seam. Proper clean room apparel was worn when the tube was entered for completion of the installation and inspection. The beam tube assembly was entered before the end heads were attached for the following purposes:

- Installation of the purge dam for tacking and welding the circumferential joint.
- Inspection of the first weld pass and repair of the circumferential weld joint.
- Removal of the circumferential purge dam after completion of welding.
- Cleanliness inspection of the beam tube
- Cleanliness inspection and an attempt to remove fluorescent area with solvents.
- Baffle installation and final inspection before attaching the north end closure.

The south end closure head was attached after completion of the circumferential seam and before the cleanliness inspection of the beam tube assembly. The north end closure was fit and welded to seal up the QT beam tube assembly after baffle installation and final inspection. The polyethylene was not removed until just before the end closure was fit to the beam tube.

DISCOVERIES AND CONCLUSIONS:
Tube access was not as difficult as anticipated but clean room clothing may cause personnel to overheat if the temperature in the tube is at or above room temperature. Carts should be used to move the purge dam inside the beam tube. The purge dam and associated hoses are difficult to carry and contacted the shell extensively during removal. Although an air flow was maintained in the tube from the vacuum laboratory, lint particles could be seen in the tube under black light inspection. The presence of these particles may be due to dirty filters or contamination in the vacuum laboratory. Clean room apparel was not worn in the vacuum laboratory.

PROPOSED CHANGES:
Carts should be used to transport materials inside the module during construction if the components can not be easily carried.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:
The qualification test did not represent the field conditions that will be encountered during module construction. The beam tube enclosure should be designed to maintain a tube interior temperature between approximately 40 and 80 degrees F. Unrelated construction activities and unknown environmental conditions will be encountered during the field construction of the modules. The effectiveness of the cleanliness maintenance procedures and equipment will not be

known until construction actually begins. The proposed plans and procedures may have to be modified in the field if the procedures are unable to sufficiently prevent contamination due to dust, dirt, insects, air borne spores and seeds, or other yet unknown sources of contamination.

Caltech and CBI have discussed the benefits of a qualification of the initial construction at Hanford and Livingston. Although a qualification of the initial construction may increase the effectiveness of the plans and procedures, the expenses and schedule delay could be significant. Construction qualification concepts should be considered which balance cost and schedule impacts with risks associated with presently unknown environmental conditions.

F.1 SHIPPING, RECEIVING, MOVING AND STORING

OPTION PLANS AND PROCEDURES:

CBI drawings ER014, ER015, ER016, ER140 and ER141

QUALIFICATION TEST PLANS AND PROCEDURES:

Standard CBI shipping, receiving, moving and storing practises were used in the QT.

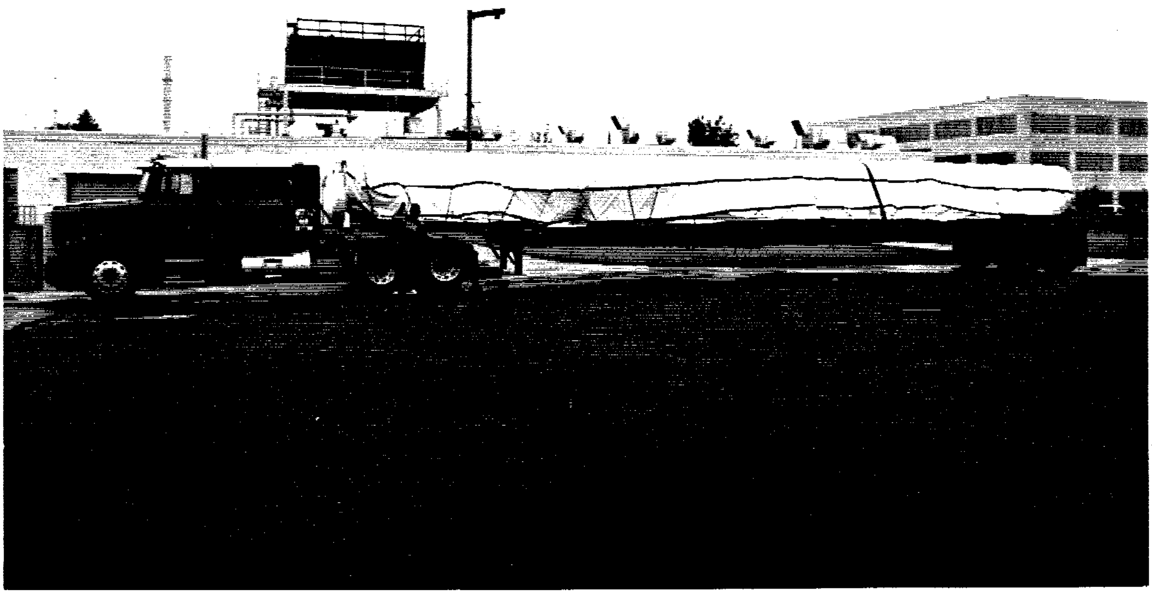
MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The shipping, moving and storing operations used in the QT are not the same as those planned for use in the Option. In the Option, the specialized equipment and processes will be used in the shipping, receiving, handling and storing operations. For instance, specially designed transport frames are to be used in the Option so that four full size beam tubes can be transported on a single truck. Option drawings ER014 through ER016 describe the beam tube transport equipment. For the QT CBI used standard equipment and practices to ship, receive, move and store the QT beam tube assemblies.

QUALIFICATION TEST EXECUTION:

The QT beam tube assemblies were transported from CBI's facility in Houston, Texas to CBI's facility in Plainfield, Illinois on extendible flat bed trailers. The 21A and 21B assemblies were shipped together on the same truck. The 21C and 21D assemblies were shipped on separate trucks. During shipment all four the assemblies were covered full length with white tarps to protect them road contamination and the sun's rays. All ends of the QT beam tube assemblies were covered with thick polyethylene that was sealed with tape.

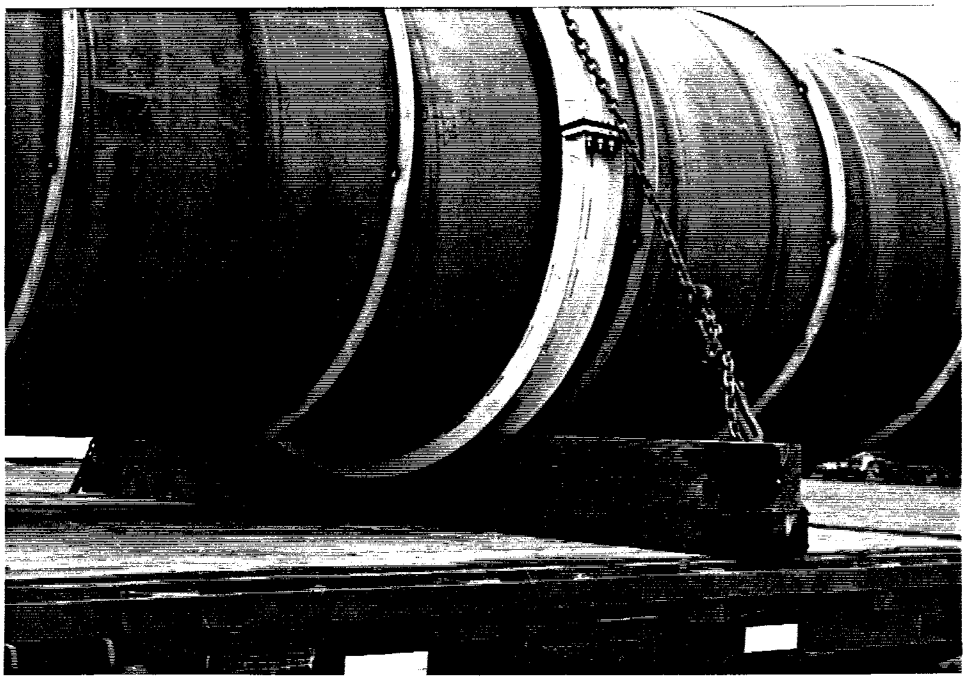
Upon arrival at Plainfield the truck hauling the 21C assembly was back down into the basement of the Plainfield facility. The trailer and the yard crane were positioned so that a monorail hoist could lifted one end and the beam while a yard crane lifted the other end. The 21A beam tube was lifted and the truck drove out from under the beam tube. As soon as the truck was out from under the beam tube it was lowered directly to the floor. The beam tube was then rolled to a storage area adjacent to the monorail hoist.



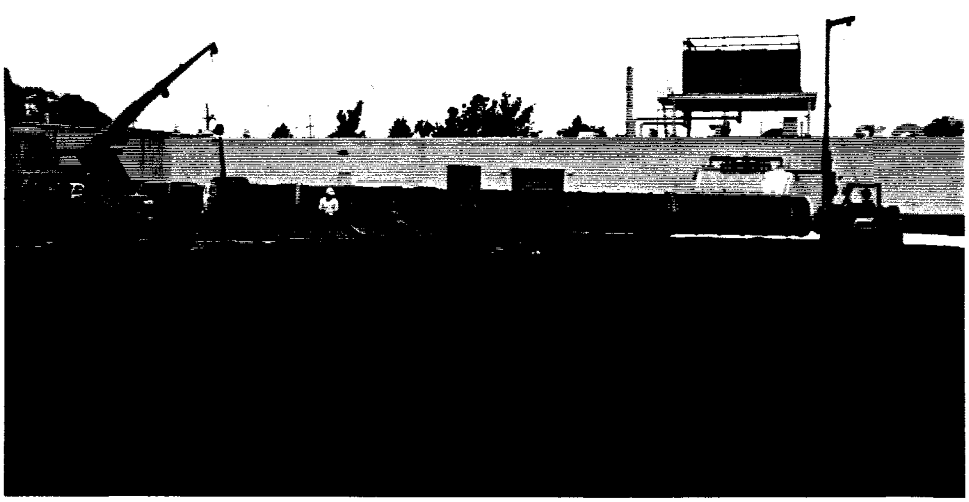
QT Beam Tube Assembly Arriving at Plainfield

During the receiving inspection of the 21A assembly cracks were discovered in the fillet welds at the guided support ring and one of the baffle rings. These were the two rings that were used to support the beam tube during the shipment from Houston. The cracks were created by the cyclic loadings imposed on the welds while traveling from Houston to Plainfield. The 21A beam tube assembly was support directly off the guided support and baffle rings during this shipment. The beam tube assemblies should be supported directly off the beam tube wall using a cradle instead of the support/baffle rings. This change was implemented during shipment of the 21D beam tube assembly.

Upon arrival at Plainfield the 21D assembly was unloaded and stored outside the facility. A small yard crane was used to lift one end of the beam tube assembly and a forklift the other end. The beam tube was lifted about a foot and the trailer driven out from under the beam tube assembly. The beam tube assembly was lowered until it was only a few inches off the ground. The yard crane and fork lift were used to move the beam tube assembly into a temporary storage area near the unloading area.



22D Beam Tube Assembly Shipping Supports



Moving 21D Beam Tube Assembly to Temporary Storage Area

21D Beam Tube Assembly in Temporary Storage at Plainfield

To provide a means of moving the 21C and 21D QT beam tube assemblies safely during the machining, testing, cleaning and final assembly operations dolly wheels were attached to both ends of the beam tube assemblies. With the wheels attached the beam tube assemblies could be easily and safely moved on the level by hand with the use of the forklift and yard crane. Each assemblies was moved several times during the machining, testing, cleaning and final assembly operations. The fork lift and yard crane were used when it was necessary to lift the beam tube assemblies.

Transporting 22D Beam Tube Assembly to QT Assembly Area

DISCOVERIES AND CONCLUSIONS:

Cracks developed in the support/baffle rings on the 21C QT beam tube assembly from cyclic loads imposed during shipment of the assembly from Houston, Texas to Plainfield, Illinois. During shipment the 21C assembly was support directly on the guided support ring and one of the baffle support rings.

PROPOSED CHANGES:

Do not support the beam tube assemblies on the directly on the support/baffle rings during shipment. Support a circumferential support ring that clamps directly onto the wall of the beam tube.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Due to the thinness of the beam tube wall the beam tubes are more susceptible to being damaged than thicker tubes of the same diameter. The equipment and procedures for moving and lifting the beam tubes in the Option has been planned and developed to safely handle the thin walled beam tube assemblies. Therefore, the risk to the beam tubes has be minimized and no additional development is needed at this time.

F.2 MACHINE THE ENDS OF THE BEAM TUBE ASSEMBLIES

OPTION PLANS AND PROCEDURES:

C-BT-CO, "LIGO Beam Tube Sections -Construction Option"
CBI Drawing #4 and #5

QUALIFICATION TEST PLANS AND PROCEDURES:

C-BT-QT, "Qualification Test Beam Tube Sections"
CBI Drawing #21

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The ends of the beam tube sections were not sized in the QT and the ends were machined by CBI instead of the beam tube manufacturer. The equipment used in the QT is not the same equipment as is planned for use in the Option. The equipment used in the QT was portable pipe cutoff equipment. The equipment and process used in the Option will be design to be more productive. The machining equipment and process used in the QT demonstrated that the ends of the beam tube can be prepared to the flatness and perpendicularity tolerances specified.

QUALIFICATION TEST EXECUTION:

The ends of the beam tube assemblies are machined flat in the QT and will also be machined in the Option for the following reasons:

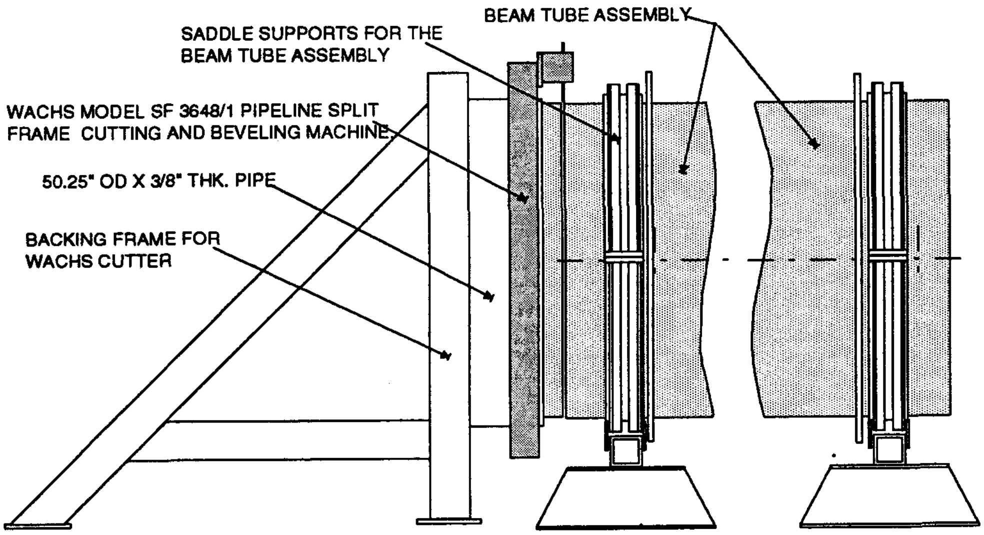
- The weld process qualification tests have established that the gaps in the weld joints must be less than 0.020" for welding. Which requires that the ends of the beam tube assemblies cannot be out of flat by more than 0.010.

- The out of straightness of the beam tube between the expansion joints (two beam tubes welded together) must be minimized to minimize the beam tube diameter and maintain the required clear aperture. A perpendicularity tolerance of 0.010" has been specified for the ends of the beam tube assemblies that weld together. Note that this perpendicularity tolerance is not a requirement for the ends of the beam tube assemblies that weld to the expansion joints. The perpendicularity tolerance for the end of the beam tube assemblies is established to minimize the out of straightness (dogleg) that can result from the fit up and welding of two adjacent beam tube assemblies. A maximum out of straightens of 0.159" can result from the ends of the beam tube being 0.010" from perpendicular to the longitudinal centerline of the beam tube assembly. The 0.159" out of straightness value has been used to calculated the current minimum beam tube diameter required to maintain the specified clear aperture.

- The ends of the beam tube assemblies must be flat and smooth to provide an adequate vacuum seal for leak testing.
- Machining the ends of the beam tube assemblies will provide better control over the length of the beam tube assemblies.

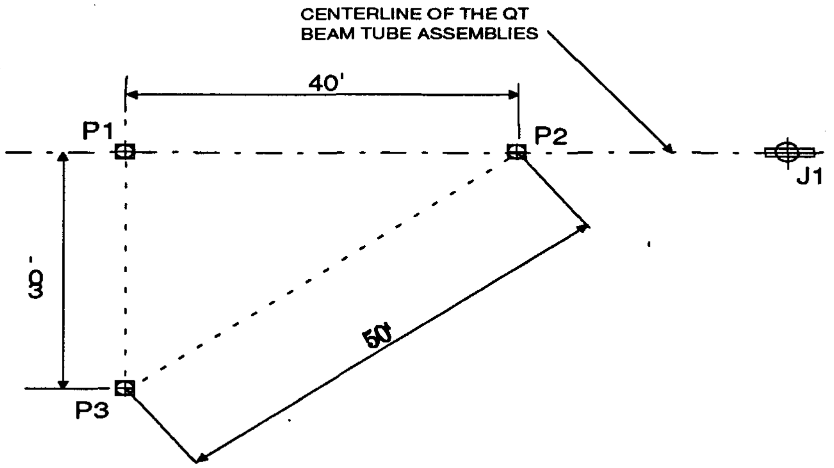
It was originally planned that the ends of the beam tubes would be machined by the beam tube supplier. However, none of the beam tube suppliers currently have the capability to machine 65' long beam tubes. For the QT it was decided to machine the ends beam tube assemblies after the stiffeners were welded since the stiffener welding could distort the machined surface. As part of the QT the amount shrinkage that occurred due to welding the stiffeners onto the 21-C and 21-D beam tube assemblies was measured and recorded. This was done to assess whether or not the beam tubes can be machined before welding the stiffeners.

The ends of the beam tube assemblies were machined at the QT assembly area at CBI's Plainfield facility. A portable pipe cut off machine was used to machine ten ends of the six beam tube assemblies (21A through 21D, 24A, and 24B). The portable pipe cut off machine was rented from E. H. WACHS Company. Only one end of 24A and 24B beam tube closure assemblies required machining. Normally this type of pipe cut off machine is mounted on the outside of the pipe or tube that is being cut. Because the LIGO beam tube tubes are so thin and the machined ends must be perpendicular to the beam tube centerline the cut off machine it was decided to mounted the machine on a rigid support frame



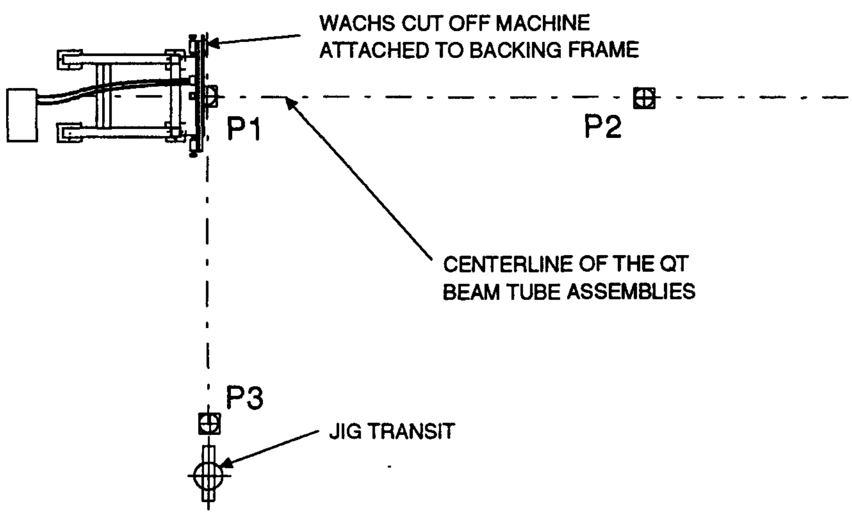
MACHINE SET UP TO CUT ENDS OF QT BEAM TUBE ASSEMBLIES

To provide the specified perpendicularity (0.010") the pipe cut off machine was accurately plumbed and aligned perpendicular to the centerline of the beam tube. Using a 50' tape, a jig transit and a stringline the three control points P1, P2 and P3 were accurately located and marked on the concrete floor. See the sketch below:



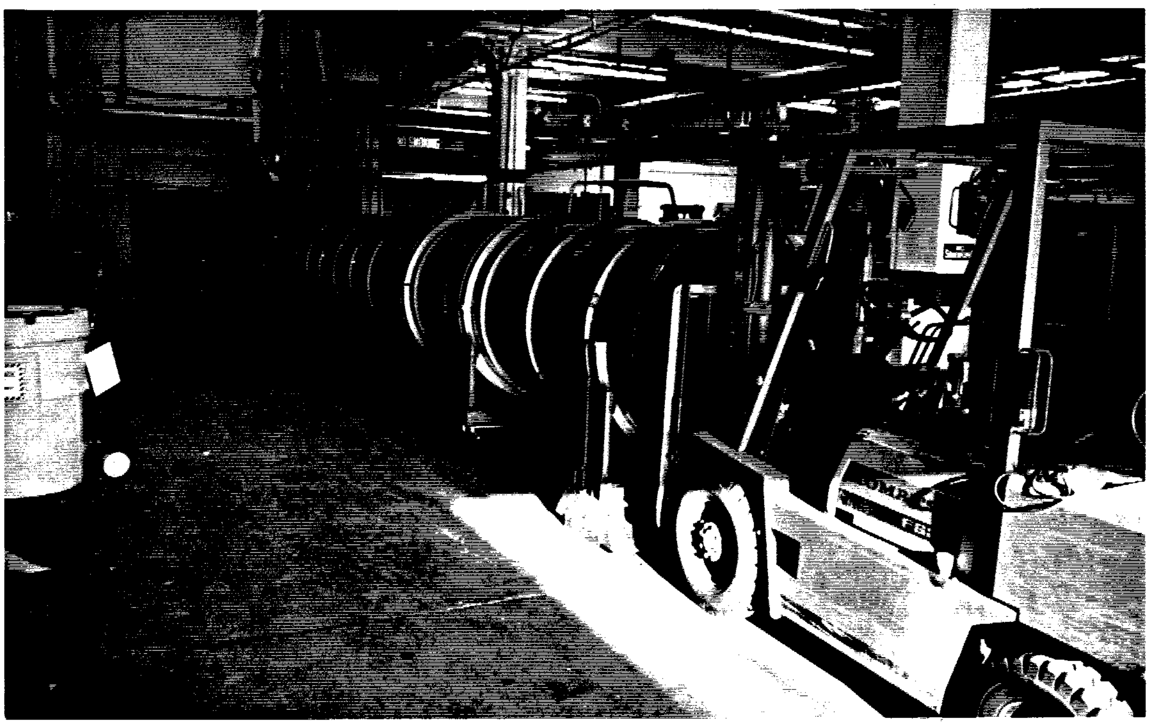
LAYOUT FOR MACHINING THE BEAM TUBE ENDS

Next the pipe cut off machine was mounted onto the support frame. The frame was accurately plumbed and aligned to be perpendicular to the centerline of the beam tube using a jig transit in line with line P1-P3 and centered to the beam tube center line using a plumb bob. See the sketch below:



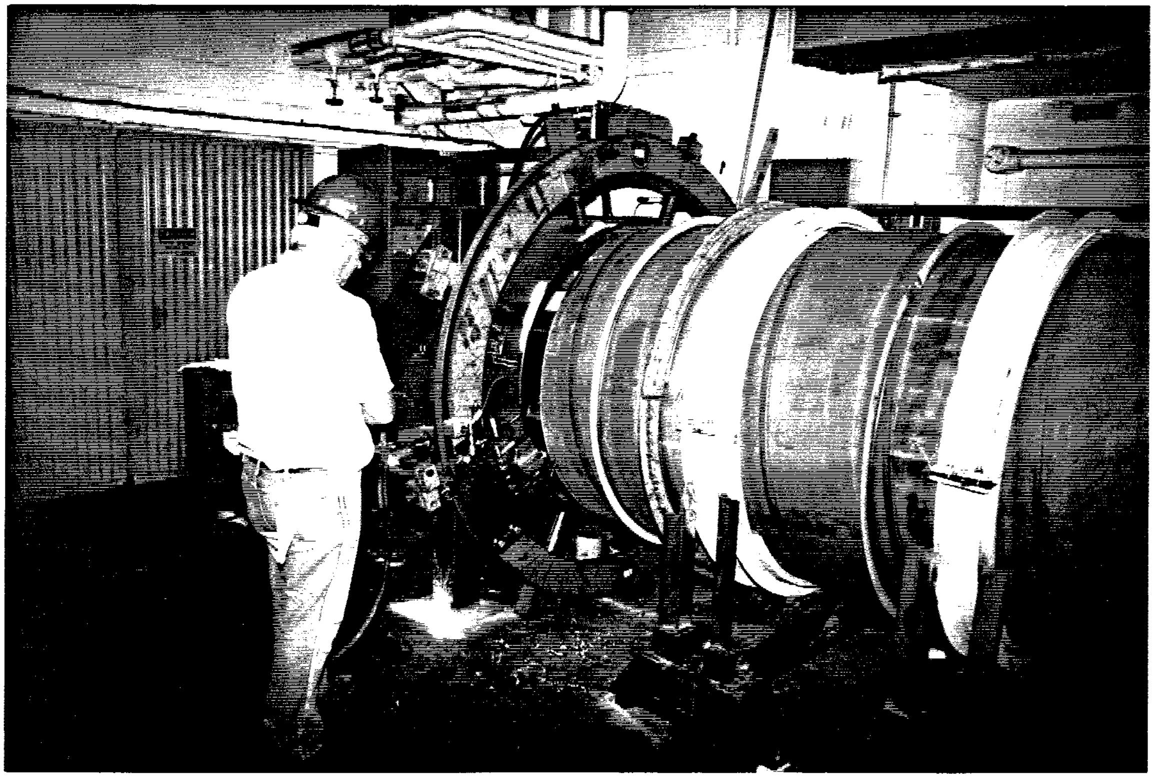
ALIGNMENT OF MACHINE FOR MACHINING THE BEAM TUBES

Saddle supports were positioned at the ends of the beam tube assembly that was being machined. During the QT these supports had to be re-positioned to accommodate the varying lengths of the QT beam tube assemblies. Since the beam tube assemblies in the Option will be nearly the same length, the supports for machining the beam tubes will remain at the same location throughout the Option. The saddle supports were centered over the beam tube centerline that was marked on the concrete floor and leveled so that the longitudinal centerline of the beam tube assembly being machined is parallel to the axis of rotation of the pipe cut off machine. Alignment at the ends of the beam tube assemblies was confirmed before the assembly was secured for machining. A tilt level and plumb bobs were used to confirm alignment.



21C Beam Tube Assembly Being Set Up to Machine

The tube sections were manufactured with a 4" cutoff length added to each end. The flexibility of the thin beam tube permitted the radial pressure from the tool to deflected the surface of the beam tube radially inward. After the tool broke through the inside surface of the beam tube, it would at times catch on the through cut and stall the machine. Eight equally spaced braces were added to the support frame of the cut off machine to provide support to the inner surface of the beam tube. A 4.00" long by 0.50" thick by 47.625" inside diameter stainless steel ring was installed inside the beam tubes assembly to stiffen the tube wall for machining. The end of the cylinder was located about 0.50" from the cut line to provide clearance for the parting tool. The bolts on the eight equally spaced braces inside the beam tube assembly were tightened against the inside surface of the split cylinder to provide radial support.



Machining the End of 21C Beam Tube Assembly

The machining process performed during the QT demonstrated that the ends of the beam tube assemblies can be cut to the 0.010" specified flatness and perpendicularity. However, the machining operation required more time than estimated. The equipment used was not designed and set up for productivity. On the average it took about approximately 8 hours to move, position, align and machine one end of a beam tube assembly. It is estimated that about 2/3 of this time was spent move, aligning and clamping down the assembly for the machining operation. Only about 1/3 of the time was spent actually machining the beam tube. Two of the beam tube end were machined in as little as one hour.

The machining equipment that was used to machine the QT beam tubes was rented from E. H. WACHS Company. During the machining process of the QT beam tube assemblies WACHS provided technical support and worked closely with CBI. At CBI's request WACHS has developed and proposed a machine that can be used to both expand and machine the ends of the beam tubes in one operation. The machine consist of an hydraulic powered tube expander/chuck with a pipe facing machine. See the WACHS drawing BSPG-055-00 that describes the combination expander/end prep machine. In the Option, the ends of approximately 800 beam tube assemblies (1600 beam tube ends) must be expanded and machined. The use of a machine of this type along with a significantly improved handling process and equipment should greatly improve productivity of the machining the ends of the beam tube assemblies.

DISCOVERIES AND CONCLUSIONS:

- The flexibility of the thin beam tube wall makes severing and squaring operations using radial feeding cutting more difficult than anticipated. It is proposed that the ends of the beam tubes be machined using a longitudinal feeding facing tool instead of radial feeding parting tool.

- A productive process and equipment is needed to machine the ends of the beam tubes. Expanding and machining the ends of the beam tubes are operations that will be performed approximately 1600 times during the Option. The capital investment in developing a more productive equipment and process could more than pay off in overall savings.

- The machining process, equipment and personnel must provide a square end to the specified tolerances.

PROPOSED CHANGES:

- Use a longitudinal feeding facing tool be used instead of radial feeding parting tool.

- Expand and machine the ends of the beam tubes at the same time using a custom machine that can both expand the ends of the beam tubes to a uniform size and also face the ends of the beam tubes.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- Develop a machine that will expanded and machine the ends of the beam tubes at the same time. E. H. WACHS Company has prepared a proposal for a custom machine that can both expand the ends of the beam tubes to a uniform size and also face the ends of the beam tubes. See the attached copy of the WACHS proposal.

- Develop the equipment and processes to productively move and set up the beam tube assemblies for machining.

F.3 SECTION LEAK TEST

OPTION PLANS AND PROCEDURES: HMST1N

QUALIFICATION TEST PLANS AND PROCEDURES: HMSTIQT

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The qualification test tube sections were bagged using polyethylene bags instead of a metal casket as proposed for the option. Polyethylene film was used due to the limited number of sections to be tested.

The polyethylene bagging was as expected, higher in man-hours than the estimated man-hours for a metal casket. The following problems are associated with the use of polyethylene bags:

- The first problem was the fragile nature of the polyethylene film. This did rip on at least one section leak test which resulted in an increased ambient helium background.
- Helium has a high permeation rate through the polyethylene. This also contributed to the high ambient helium background.
- The Polyethylene bag increased the difficulty of getting a high helium concentration in the bag due to the limited ability to evacuate the bag.
- Disposal of the polyethylene.

QUALIFICATION TEST EXECUTION:

The section leak tests were performed on the two long sections numbered 21C and 21A+D and the 8 foot long section with the pump port (21B). Each of the long sections of tube had one leak. The leak in section 21C was the result of shipping of the section without proper support. The section was shipped sitting on the large stiffeners and shipping forces caused a number of cracks to develop in the stiffener to tube welds. The cracks were discovered during the receiving inspection and were repaired. One of these weld repairs did leak. The other tube section had a leak in a stiffener weld repair made by CBI in Houston.. This leak was at a location where copper from the welding tip had imbedded in the weld and had caused a crack.

The tube sections were typically evacuated to the low 10^{-6} or high 10^{-7} torr range with a 10"∅, cold trapped diffusion pump backed by a roughing pump. The Helium Mass Spectrometer leak detector (HMS) was attached to the diffusion pump foreline. The helium background as measured with the HMS was typically in the low 10^{-9} ATM cc/S range and was nulled out in the HMS to the low 10^{-10} ATM cc/S range.

The bagging of the tube section was accomplished using two methods The first method used a sheet of polyethylene which was formed into a tube using a hand heat sealer. This sealer caused the seam to be melted in places and had to be taped with duct tape to seal the holes and to reinforce the seam for strength. The plastic tube was then slipped over one end of the beam tube and bunched up so the entire length fit between the end of the beam tube and the first support. The beam tube end was then lifted and the plastic tube slipped past the support. The other end of the beam tube was then lifted to get the plastic past the other support and the ends of the plastic tube were duct taped to the beam tube to complete the bag.

The other method of installing the bag was the traditional method of using a sheet of polyethylene and wrapping it around the tube and taping both the long seam and the ends of the plastic to the beam tube with duct tape to form a bag. The traditional method had the same problem with the beam tube support as the plastic tube method The bag was filled with helium during the leak test by using a shop vac to pull as much air out of the bag as possible and then backfilling the bag with helium. An oxygen meter was used to determine the concentration of helium in the bag.

The HMS was calibrated (peaked and zeroed) before each leak test using a 10^{-8} ATM cc/S range calibrated leak located on the HMS. The calibration was then confirmed after the actual leak test by using a 10^{-10} ATM cc/S range calibrated leak located on the end of the tube section which was remote from the pumping and HMS system. The typical response time for indication of the full signal was approximately one minute. The measurement of the small calibrated leak, on the far end of the tube, resulted in a HMS leak signal which was approximately the same as the calibrated leak rate so the HMS gain was about 1.0.

All of the leak tests exhibited a slow rise in the helium reading on the HMS. The rise typically started 6 to 10 minutes after the start of bag filling process. The final section was eventually tested with a bag around the mass spectrometer and a high flow rate nitrogen purge through the bag. This eliminated the helium rise on the mass spectrometer. The reasoning behind the slow rise is that the helium permeation and leakage out of the bag was entering the HMS roughing pump exhaust and migrating to the helium sensor.

Prior to the last leak test where the HMS was bagged and purged, several attempts were made to find other sources of leakage, such as the end head seals, various fittings on the vacuum system and the instrumentation on the end heads. All of these efforts failed to find another source of leakage. Pinhole type leakage through the tube was discounted due to the faster response time of the system. Long tortuous path leaks were discounted due to the repetition of the helium rise on each tube section tested.

DISCOVERIES AND CONCLUSIONS:

- The leak testing extended for a longer period of time than expected due to the search for the possible source of helium making the long slow rise in the HMS measurements. The test duration also was longer than predicted due to the two leaks which were detected. The option phase of the project will go much more smoothly due to the learning curve on this type of leak checking and the use of the caskets which will prevent most if not all of the increase in helium background levels. The benefits of the casket are as follows:
  - Steel casket is not helium permeable.
  - ease of installation over tube
  - can be opened to inspect or helium spray tube
  - can be evacuated (1 torr or less) to increase the helium concentration during leak testing
- The HMS must be located in a room or building separate from the area where the beam tubes are leak tested in order to eliminate the helium migration into the HMS. The HMS room or building must have a separate ventilation system from the beam tube test area and the room must be sealed to air migration from the tube test area.

- The Balzers DUO 60A roughing pump which was used for the evacuation of the tube sections and would have been used for the evacuation of the completed QT beam tube was inadequate for the intended use. This roughing pump was not designed to run continuously under high horsepower loads and therefore cannot evacuate large volumes. Extended pumping time at high horsepower conditions caused the pump to overheat and destroyed the bearings. A roughing / blower combination would not have helped and would have, in fact, maintained the roughing pump in a high horsepower condition for a longer period of time due to the compression through the blower. Balzers provided CBI with a Duo 250A as a replacement until Balzers completes the development of their improved roughing pumps. The high flow rate pump with the small roughing piping allowed the roughing pump to operate in a lower horsepower regime for most of the pumpdown. The Duo 250A was used for the entire time the QT was under vacuum with absolutely no problems.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- The use of a casket is still untried but the concept of the casket used as a rigid, non helium permeable bag with limited evacuation capability for helium purge only is a simple, low risk, economical application.

- The casket roughing system should be evaluated for the use of a blower to pump the helium from the casket to a holding tank. The development would include an economic evaluation to determine the savings in helium vs. the cost of the pumping and storage system. A helium storage system would not only save helium but would also reduce the amount of ambient background increase due to venting the helium to the atmosphere.

F.4 BEAM TUBE TO BEAM TUBE CIRCUMFERENTIAL FIT-UP

OPTION PLANS AND PROCEDURES: **FPCIRCUMFERENTIAL**

QUALIFICATION TEST PLANS AND PROCEDURES: **Same**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The beam tube end squareness and flatness was obtained by end machining. The ends were checked during circumferential joint fitting. Acceptable squareness and flatness was determined by a visual check. The ends were in contact at all locations after completion of the fitting and tacking operation.

DISCOVERIES AND CONCLUSIONS:

The purge ring was too small in size. The seal inflation pressure of 5 psig did not seal the outer seals against the inside of the beam tube. The optimum inflation pressure was 22 psig. The larger rubber envelope caused an increase in purge pressure as the heat accumulated during welding.

The MSA passport personal alarm was used to monitor the oxygen content of the purge gas for the first circumferential weld joint. The performance specification does not list accuracy below 2% oxygen. The recharge was used because the battery pack did not hold charge for the duration of fitting and welding. The recharge should not have been used during operation. The MSA model 360 was used for all other purge monitoring.

PROPOSED CHANGES:

Purge rings for the option will be purchased with a 48.75" outside diameter deflated outer seal.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F5 BEAM TUBE TO BEAM TUBE CIRCUMFERENTIAL WELDING

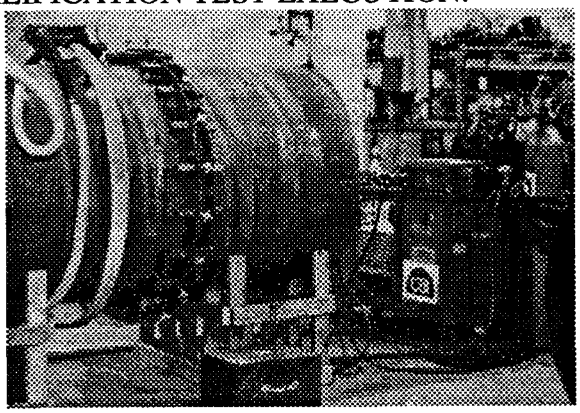
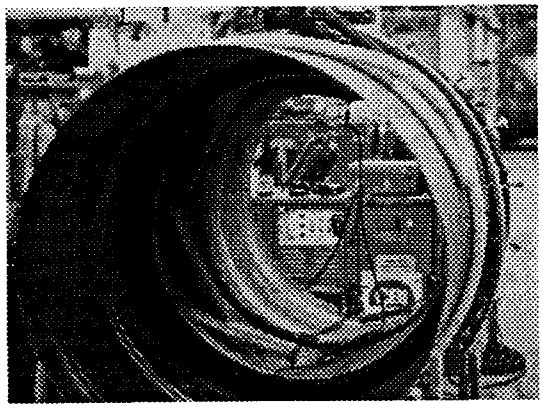
OPTION PLANS AND PROCEDURES: **WPS ER308L/CIRC**

QUALIFICATION TEST PLANS AND PROCEDURES: **SAME**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

CIRCUMFERENTIAL WELD JOINT MOCK-UP PHOTOGRAPHS


The first circumferential joint was between assembly 21-A and assembly 21-D. A weld repair was required before leak testing. The weld joint was leak tested using the helium mass spectrometer hood leak test procedure. The second circumferential joint was between assembly 21-B and assembly 21-C after they had passed leak test. The second circumferential joint was leak tested during beam tube module leak test after installation. There were no leaks detected for both circumferential weld joints.

DISCOVERIES AND CONCLUSIONS:

The welding heat build up did not damage the rubber purge ring. Temperature build up 1.5" from the weld was 222° F after four minutes. Temperature build up 3.5" from the weld was 124° F after nine minutes. The tourch travel speed was 4" per minute.

PROPOSED CHANGES: There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F.6 EXPANSION JOINT TO BEAM TUBE FIT-UP

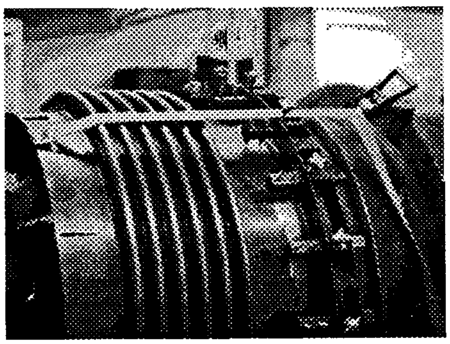
OPTION PLANS AND PROCEDURES: **FPCIRCUMFERENTIAL**

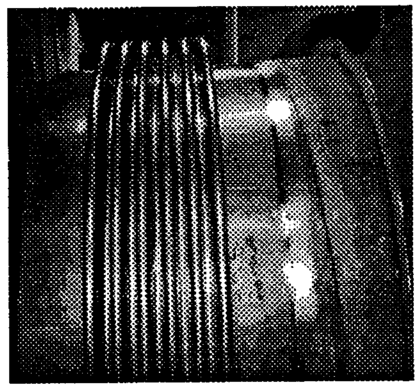
QUALIFICATION TEST PLANS AND PROCEDURES: **Same**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:





The third circumferential joint was between the expansion joint and assembly 21-D. The expansion joint has a 48.935" inside diameter. The beam tube has a 48.892" outside diameter. The inside offset of .021" and difference in thickness caused concern.

PROPOSED CHANGES:

The welding procedure was revised before the welding. No changes in the fit-up procedure was necessary.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F.7 EXPANSION JOINT TO BEAM TUBE CIRCUMFERENTIAL WELDING

OPTION PLANS AND PROCEDURES: **WPS ER308L/CIRC**

QUALIFICATION TEST PLANS AND PROCEDURES: **Same**

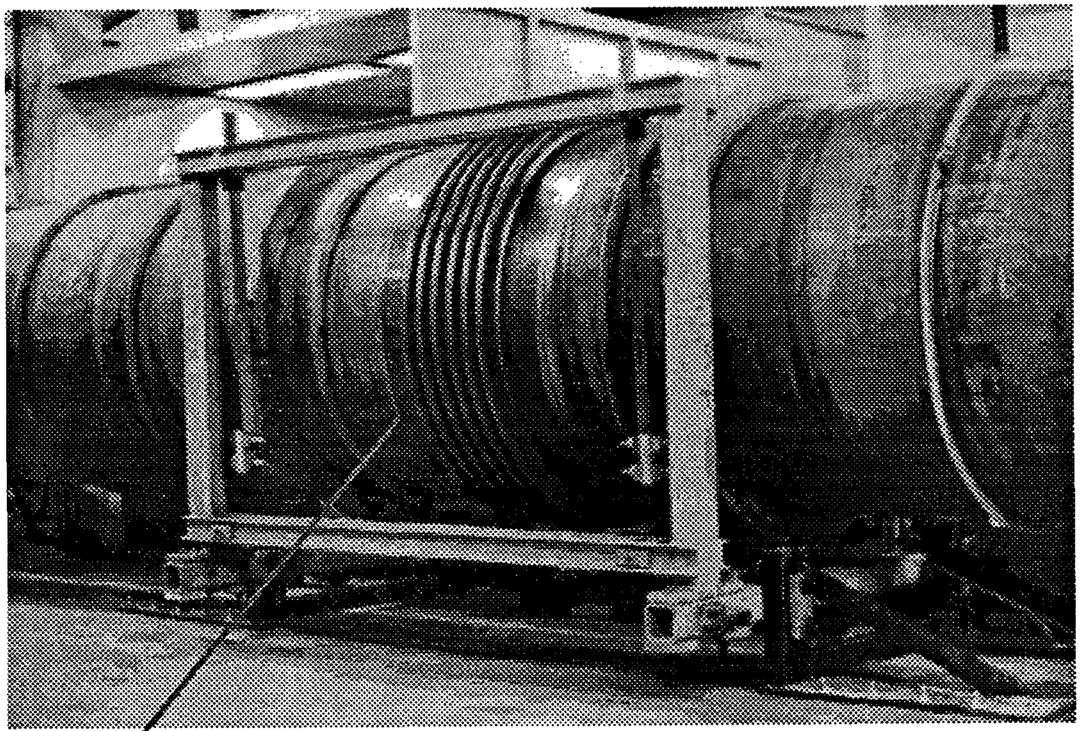
MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

There were no differences identified during the QT.

QUALIFICATION TEST EXECUTION:

The third circumferential joint was between the expansion joint and assembly 21-D. The offset and difference in thickness caused concern. A mock up circumferential joint was made using 0.05" oscillation amplitude which was not provided for in the current WPS ER308L/CIRC. Sample welds were made using the proposed welding parameters. An evaluation was made which resulted in a welding procedure revision that allowed oscillation amplitude for the first pass. There were no repairs required and the third circumferential joint was leak tested during beam tube module leak test after installation. No leaks were detected during leak testing.

The fourth and final circumferential joint was between the expansion joint and assembly 21-C. The automatic weld equipment was set up and the first weld pass was completed. There were segments of the weld where the arc would favor the expansion joint side more than the beam tube side. The purge ring was evacuated. Positive air flow and safe entry was verified. The purge ring was moved clear of the cicumferential weld joint. A visual inspection was performed. There were two segmental lengths (7.5" & 9.5") that needed repair. The two segmental lengths were repaired by chipping approximately .010" deep to remove incomplete penetration indications. The purge ring was installed. The purge ring outer seals were inflated to 22 psig. The argon backing purge gas valve was opened and the evacuation line was connected to an oxygen analyzer. 1.0% oxygen was established and the second weld pass was started. The welding operation was stopped to make an adjustment of the wire fed. A gas leak sound was detected by the welding operator. The second weld pass was approximately one half complete. The purge ring outer seal nitrogen flow meter indicated that a leak had developed in one of the inflatable seals. A calculation was made to estimate the time the nitrogen supply would last. There was enough time estimated to complete the second weld pass. The second weld pass was completed with four minutes of nitrogen flow remaining. The argon backing purge gas valve was closed and the purge ring was pulled out of the beam tube using the rubber gas hose. Entry of the workman was not necessary. The leak testing of the circumferential weld joint was postponed until module leak testing. A positive air flow and safe entry was verified. A visual inspection was performed. The circumferential weld joint was determined to be acceptable.



Fourth & Final Circumferential Weld

Note: The guided support was not installed when the joint was welded.

DISCOVERIES AND CONCLUSIONS:

The two segmental lengths with approximately .010" deep incomplete penetration indications was a result of the arc favoring the expansion joint side more than the beam tube side. The judgement of the operator was the likely source of substandard welding. The operator at the controls had not experienced the arc wandering condition. The operator had not performed machine welding using WPS ER308L/CIRC for a two mounth period.

The QT purge ring blew a hole in an outer seal during its final application and is not suitable for further use.

PROPOSED CHANGES:

Purge rings for the option will be purchased with a 48.75" outside diameter deflated outer seal. The outer seals will not be pressurized more than 5 psig as specified in the purge procedure.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F.8 BEAM TUBE SECTION CLEANING

OPTION PLANS AND PROCEDURES:

LIGOCP, "Planned Approach for Cleaning and Cleaning Maintenance for LIGO Project"
CL1N, "Cleaning of Completed Beam Tube Can Sections Before and After Leak Testing and Final assembly"
BI1N, "Blacklight Inspection Technique and Solvent Cleaning Procedure"

QUALIFICATION PLANS AND PROCEDURES:

LIGOCPQT, "Planned Approach for Cleaning Maintenance for LIGO Qualification Test Addenda"
CL1QT, "Cleaning of Completed Beam Tube Can Sections Before and After Leak Testing and Final assembly for LIGO Qualification Test Module Addenda"
BI1N, "Blacklight Inspection Technique and Solvent Cleaning Procedure"

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The beam tube assemblies were cleaned inside CBI's development center instead the cleaning facility as is proposed in the Option.

The steam cleaner apparatus was pulled through the beam tube by hand instead of using a variable speed winch.

The steam cleaner apparatus was pulled through the beam tube at 0.5 feet per minute instead of 2.0 feet per minute.

QUALIFICATION TEST EXECUTION:

Beam tube assembly 22A was cleaned per QT cleaning procedure CL1QT, "Cleaning of Completed Beam Tube Can Section before and after leak Testing and Final Assembly for LIGO QT Addenda". Numerous fluorescent indications were revealed by the blacklight inspection that was performed prior to the steam cleaning operation. Many of the fluorescent indications found during the blacklight inspection could not be removed by wiping with acetone and/or alcohol as directed in CL1QT. Several spots were successfully remove by vigorous sanding with emery paper. However, the sanding also removed the oxide coating on the beam tube and polished the surface. For the QT the decision was made by Caltech and CBI not to attempt to remove any fluorescent indications that could not be removed by wiping with acetone and/or alcohol.

At the end of the steam cleaning process the steam spray wand was not rotating. The wand was rotating at the beginning but had stopped sometime during the steam cleaning operation. The spray wand could not be seen during the steam cleaning due to the steam inside the beam tube. The pressure of the steam cleaner was increased to provide additional nozzle force so that the wand would not stop during the two hour long steam operation.

Steam Cleaning the 22A Beam Tube Assembly per CL1QT

Following the steam cleaning of the 22A beam tube assembly the inside of the beam tube was blacklight inspected to determine where the spray wand had stopped turning. This inspection was unsuccessful in establishing the location at which the spray wand had stopped turning. However, during the blacklight inspection a six to eight inch wide fluorescent band was observed at the bottom of the beam tube. The fluorescent band was visible the entire length of the beam tube. The tube did not have sufficient slope during the steam cleaning operation to sufficiently drain the water from the beam tube. Due to the shrinkage at the spiral welds, the water ponds between the welds. The slope of the tube was increased from 1:30 to 1:20 to minimize the amount of water ponding on the uphill side of the spiral welds.

A second blacklight inspection of the beam tube was made to assess the difficulty in removing the fluorescent band by wiping with acetone and/or alcohol. As part of this assessment portions the bottom beam tube wall were wiped with acetone and/or alcohol to remove the fluorescent band. During this cleaning assessment it was noticed that the areas adjacent to the fluorescent band showed fluorescent streaks when wetted with acetone and/or alcohol These streaks were not visible during the blacklight inspection of the unwetted surface. CBI informed Caltech of the fluorescent streaks that developed on the apparently clean material surface when the surface was using the newly developed "wet blacklight technique". In this technique the surface of the material is wetted with alcohol and the wetted surface inspected as specified in BI1N.

At this time Caltech directed CBI to study the occurrence, cause, effect, and source of the fluorescent contamination that were discovered by CBI using the wet blacklight technique. After further investigation and assessment the following were concluded:

- The "wet blacklight technique is an inspection process that can be used to qualitatively assess the presence of fluorescent contaminants on the LIGO material that are not visible using the normal dry blacklight inspection techniques.
- The contamination was wide spread and varied in intensity. Fluorescent indications were observed on all the LIGO QT beam tube assemblies using the wet blacklight technique.
- As the beam tube surface is wetted with alcohol fluorescent indications begin bleeding from minute spots to form fine fluorescent streaks as the bleeding continues. Isolated spots of contamination that were viewed under a microscope revealed that the contamination came from relatively deep local depressions in the steel surface.
- Repeated flushing of the surface with alcohol reduces the amount of fluorescence but does not entirely eliminate the fluorescence.
- Samples of the contaminated solvent taken from the alcohol use to wash the bleeders were analyzed to contain hydrocarbon type lubricants: silicone grease or oil, organic ester, and possibly a small amount of hydrocarbon oil or grease.
- The source(s) of the contaminant(s) could not be identified

Caltech decided that the current cleaning process, steam cleaning, was not adequate for the LIGO beam tube. The process must be improved or a new process developed that will effectively remove more of the hydrocarbons from the surface of the beam tube material. Therefore, the task of determining the best cleaning technique for Mirachem 500 and to compare the effectiveness of cleaning with Mirachem 500 only to the effectiveness of Mirachem 500 with a propanol rinse.

Representatives of Mirachem were consulted to determine how best to use Mirachem 500. Tests were conducted to determine the most effective concentrations of Mirachem 500 and to evaluate the benefits of applying the Mirachem 500 as a foam. Full strength Mirachem 500 was marginally more effective than solutions diluted with deionized water. After tests were performed to demonstrate the process of applying Mirachem 500 as foam, the foam did not provide any apparent benefits over using the full strength solution.

The best results were produced using the following cleaning process:

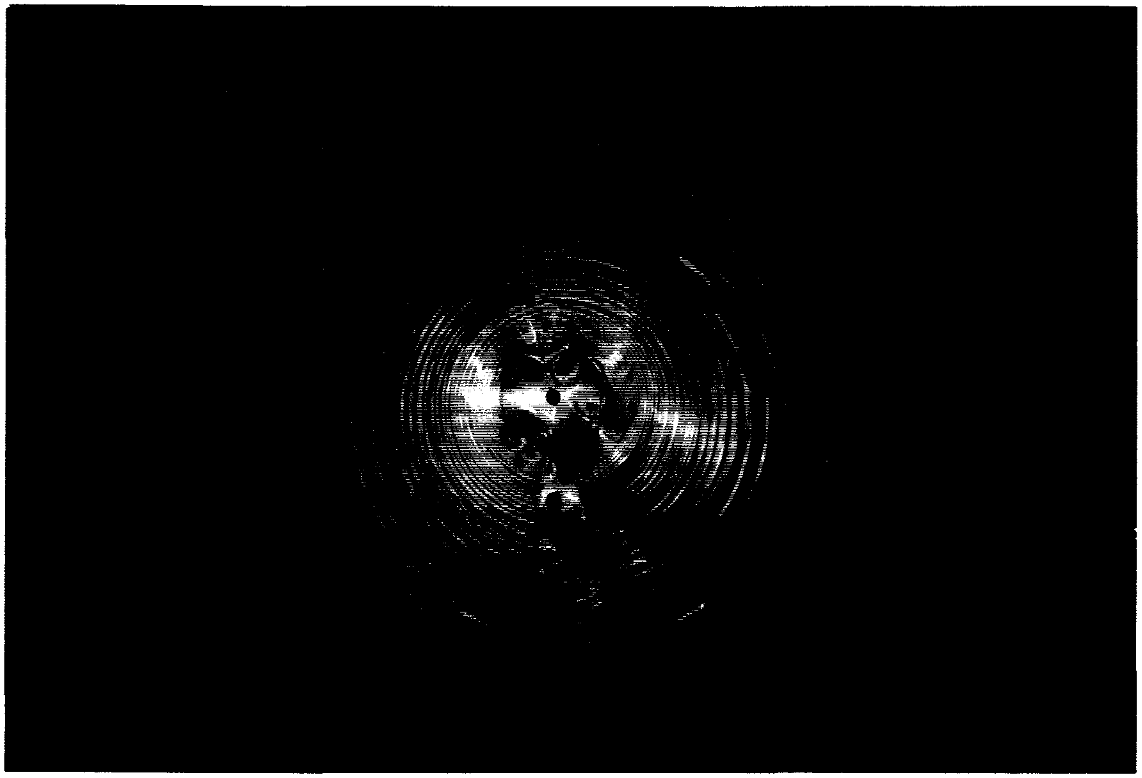
1. Level the beam tube assembly and wash the inside with full strength Mirachem 500 solution while rotating the beam tube assembly in the horizontal position.
2. Incline the beam tube assembly and pressure wash the inside surface with deionized water.
3. Steam clean the inside surface of the beam tube assembly while it is inclined.
4. Level the beam tube assembly and wash the inside with 2-propanol while rotating the beam tube assembly in the horizontal position.
5. Rinse the inside of the beam tube assembly while rotating the beam tube assembly in the horizontal position.

Testing of Mirachem 500 Solution and Foam

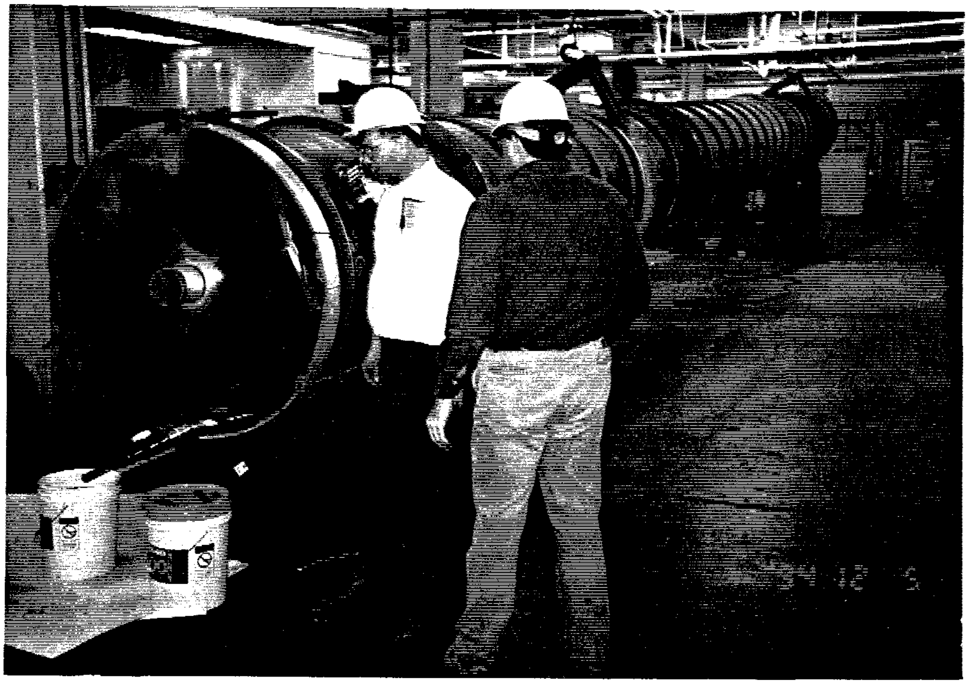
CBI developed and executed a QT cleaning procedure based on the cleaning process described above. The following cleaning procedures were developed to execute the QT cleaning process:

- CLTEST1, "Test to Assess the Effectiveness of Cleaning with Liquid Mirachem 500 and Isopropyl Alcohol".
- CL4QT, "QT assembly Cleaning Procedure".
- CL5QT, "QT Baffle Cleaning Procedure".
- CLSAMP1, "Procedure for Obtaining a Cleanliness Assessment Sample".
- CLBLEED1, "Bleeder Detection by Propanol Rinse with Blacklight Inspection".
- CLDROP1, "Water Break Test for Beam Tube Cleanliness Assessment".

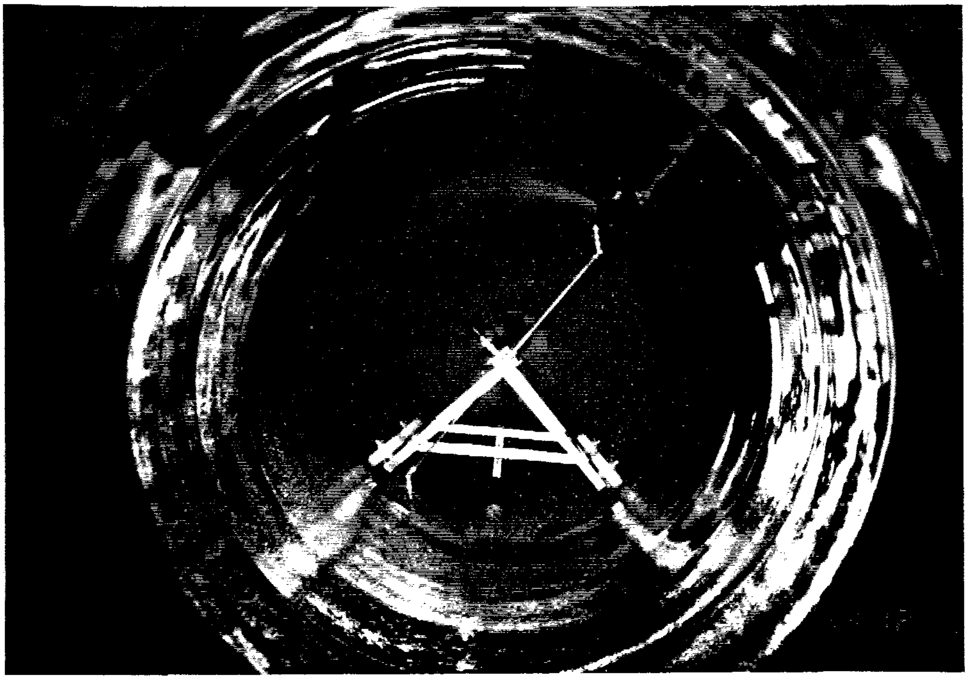
The QT beam tube assemblies 22A and 22B were cleaned per CL4QT, "QT assembly Cleaning Procedure". The QT baffles were cleaned per CL5QT, "QT Baffle Cleaning Procedure". A separate report, "Qualification Test Cleaning Report Task Orders #94-1, #94-1, and 94-1", was issued to document the work performed to assess the extent of the contamination, evaluate alternative cleaning methods and execute the selected cleaning process in the QT.



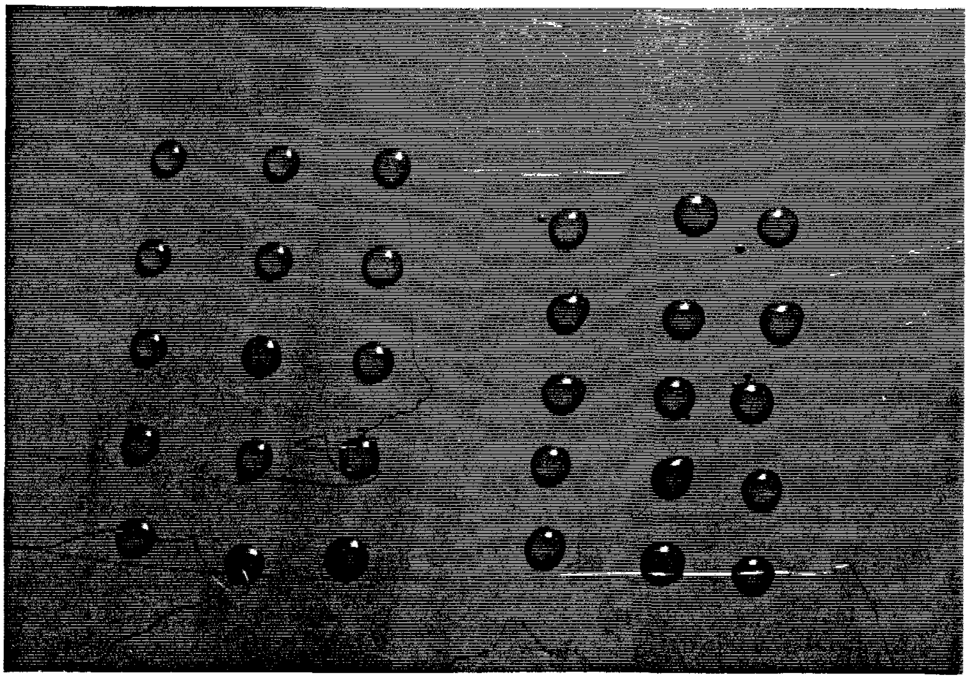
Washing 22A Beam Tube Assembly with Mirachem 500



Draining Mirachem 500 from 22A Beam Tube Assembly



Pressure Water Rinse of the 22A Beam Tube Assembly



Water Drop Test of 22A Beam Tube Assembly after Steam Cleaning

DISCOVERIES AND CONCLUSIONS:

Many of the fluorescent indications observed during blacklight inspection could not be removed by wiping with acetone and/or alcohol. The contaminants can be removed by sanding with emery paper. However, sanding also removes the oxide and polishes the surface of the beam tube. Removing the oxide and polishing the surface is not acceptable. The indications that could not be removed by wiping with acetone and/or alcohol were not removed in the QT.

The union that rotates the steam cleaner spray wand stopped during the steam cleaning of the 22A beam tube assembly. There was insufficient nozzle force throughout the steam cleaning operation to keep the wand rotating.

The cleaning procedure specified for use in the Option was not used in the QT. The steam cleaning process is not aggressive enough to remove hydrocarbon contaminants on the surface of the beam tube. A new procedure was developed and implemented as part of the QT.

F.9.A BEAM TUBE HANDLING

OPTION PLANS AND PROCEDURES:

See CBI Drawing #ER140 & #ER141

QUALIFICATION TEST PLANS AND PROCEDURES:

Standard shop lifting equipment was used to handle and assemble the QT beam tube. Attached dolly wheels to the beam tube assemblies to move by rolling.

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The beam tube handling operations used in the QT are not the same as those planned for use in the Option. Standard shop lifting equipment was used to handle the QT beam tube assemblies and dolly wheels were attached to the beam tube assemblies so they could be moved by rolling. The equipment and handling process shown in CBI drawing #ER140 and #ER141 will be acquired and used in the Option to handle and install the beam tubes assemblies.

QUALIFICATION TEST EXECUTION:

Fork lifts and a small yard crane were used to lift the beam tube assemblies during the QT machining, leak testing, subassembly, cleaning and final assembly operations. At all times soft nylon slings were used to move the assemblies.

Dolly wheels were attached to each end of the 21C and 21D beam tube assemblies to provide an easy and safe means of moving the assemblies inside the Plainfield development facility. Two people at each end of the beam tube assemblies could roll and turned the assemblies by pushing and pulling.

DISCOVERIES AND CONCLUSIONS:

No significant discoveries concerning handling were made during the QT.

PROPOSED CHANGES:

No changes proposed for the Option as the result of the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

No apparent risks uncovered during the QT and no additional development is required.

F.9.b FIT-UP & WELDING BEAM TUBE FIXED & GUIDED SUPPORTS

OPTION PLANS AND PROCEDURES: **INSTALLSEQ, WPS ER308L/GMA, WPS E308L / STRUCT, & WPS E7018/STRUCT**

QUALIFICATION TEST PLANS AND PROCEDURES: **ISQT, WPS ER308L/GMA, WPS E6010/STRUCT, & WPS ER70-S3/STRUCT**

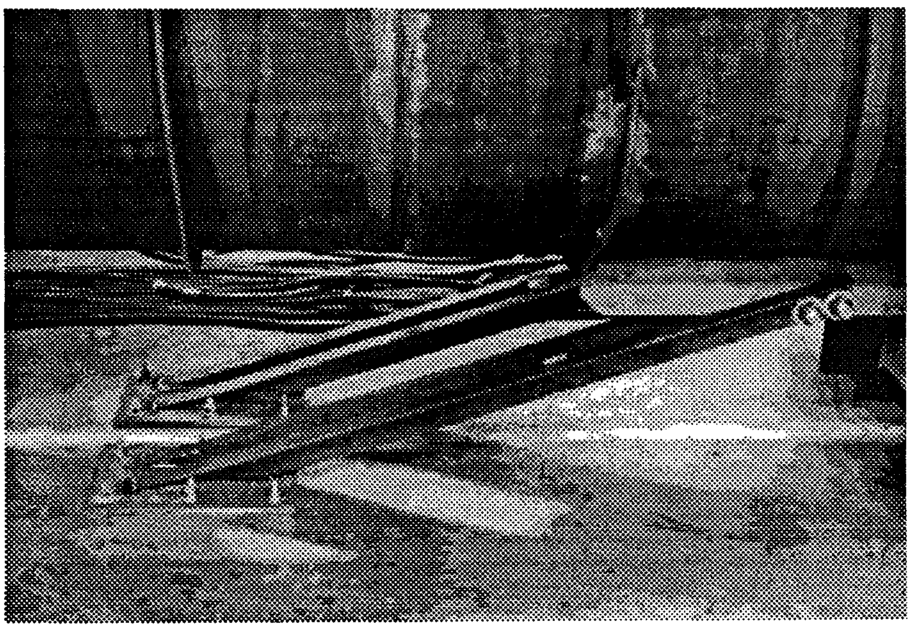
MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The structural support accessories will be assembled by the supplier for the option. Some of the support accessories were replaced because of design changes. The new assemblies were assembled and welded by CBITSC during the QT. The supplemental thrust restraint components are unique to the QT.

QUALIFICATION TEST EXECUTION:

The support lugs received from Piping Accessories, Inc. were not used. The expansion anchors would have had to be drilled before installation of the beam tube. The support lugs design was changed. CBITSC plainfield fit and welded the new support lug assemblies. The support lug assemblies were not galvanized.

The thrust restraint support was trial fit with the beam tube at the neutral elevation. There was a gap between the base plate and the kicker angle brace. One of the holes in the kicker angle brace was filled by welding and the hole was drilled at a new location. The kicker base plate location was determined and the expansion anchor holes were drilled in reference to the fixed support installation alignment marks on the basement floor.



QUALIFICATION TEST EXECUTION: (Continued)

The fixed supports were being installed while Caltech performed the reflectivity test. The supplemental thrust restraint components were not installed. The micarta blocks and mylar insulating sleeves required special installation sequence with related components. The following sequence was used to install the fixed support components:

1. The horizontal force transfer lug components were assembled and loosely attached to the stiffener ring (16-B) and to the tubular horizontal sub-assembly (7-2 & 6-1, etc.). The bolts and nuts were left loose.
2. The support lug (8-3) was loosely bolted to the tubular horizontal sub-assembly (6-1).
3. Sub-assembly (6-4,5,&6) was slid into position on the stiffener ring and the support components were assembled and loosely attached to the bearing plate on the tubular horizontal sub-assembly (6-3).
4. A visual check was made and bolts were tensioned.
5. Pieces 6-5 & 6-6 was welded to the support ring.
6. The temporary adjustable supports were removed at the fixed support areas.
7. The beam tube was moved and adjusted to the installation neutral position.
8. The horizontal dimension between the expansion joint circumferential weld joint centerlines was set at 2' - 3" (Normalized for 70° F temperature).
9. The beam tube installation alignment was verified.
10. The holes were drilled into the concrete basement floor using the support lug as a drilling template.
11. A plastic tube was used as a drill stop to obtain the embedment depth of the holes.
12. The expansion anchors were installed.
13. The torque was 75 ft. lbs.

QUALIFICATION TEST EXECUTION: (Continued)

The guided supports were being installed while Caltech performed the reflectivity test. The fixed supports were being installed at the same time so that similar task would be performed for continuity. The following sequence was used to install the guided support components:

1. The two tubular horizontal sub-assemblies (18-1) were adjusted to the neutral installation elevation and bolted to the four support lug sub-assemblies (8-3).
2. One hanger suspension sub-assembly (18-4) was trial attached to one side of the two tubular horizontal sub-assemblies (18-1).
3. The hole spacing error in the support stiffening ring was found.
4. The hanger plate (18-2) attachment welds were removed by air arc gouging.
5. The two hanger suspension sub-assemblies (18-4) were bolted to the two tubular horizontal sub-assemblies (18-1).
6. The guided support attachment plate was bolted to the support ring expansion joint side.
7. The four hanger bars, micarta blocks, mylar insulating sleeves, and bolts were assembled to the guided support attachment plates.
8. The top channel members of the hanger suspension sub-assemblies (18-3) were spread apart with shims and wedges allowing clearance and adjustment of the hanger plates.
9. The four hanger plates (18-2) were bolted to the four hanger bars (18-1).
10. The lateral restraint cable was insulated with high temperature electrical tape and loosely installed.
11. The beam tube clocking was adjusted.
12. The beam tube installation alignment and neutral elevation was checked and verified to be acceptable.
13. The wedges and shims were removed from between the channel members (18-3).
14. The hanger bars were checked for plumbness and the hanger plates (18-2) were welded to the channel members (18-3). The lateral restraint cables were tightened to remove slack.
15. The temporary adjustable supports were removed at the guided support area.
16. The beam tube was moved and adjusted to the installation neutral position.
17. The horizontal dimension between the expansion joint circumferential weld joint centerlines was set at 2' - 3" (A reference mark was made 4" from the centerlines during fit-up).
18. The beam tube installation alignment was verified.
19. The holes were drilled into the concrete basement floor using the support lug as a drilling template. Two holes at a floor drain was not drilled.
20. A plastic tube was used as a drill stop to obtain the embedment depth of the holes.
21. The expansion anchors were installed.
22. The torque was 75 ft. lbs.

QUALIFICATION TEST EXECUTION: (Continued)

The supplemental thrust restraint components were installed before the start of beam tube module leak testing pump down. The micarta blocks and mylar insulating sleeves required special installation sequence with related components. The following sequence was used to install the fixed support supplemental thrust restraint components:

1. The thrust restraint kicker angle (23-1LR) and components were assembled and loosely attached to the thrust plate (23-4). 1" X 8" long all thread rod was used as an alternate to bolts (23-7). The all thread rod and nuts were left loose.
2. The base plate was moved into position under the restraint kicker angles.
3. The expansion anchors were installed.
4. A two piece special fitting jig was bolted to the base plate that extended over the restraint kicker angles.
5. A pipe clamp, shims, and wedge was used to set the distance between the kicker angles.
6. Wedges were driven between the fitting jig and kicker angles to bring the kicker angle into contact with the base plate.
7. The fit-up was checked and adjusted as needed, then the fillet weld was completed using WPS ER70-S3/STRUT.
8. The fitting jig was removed and the spacer plate was welded to the two restraint kicker angles.
9. A visual check was made and the all thread rods and nuts were tensioned.
10. The expansion anchors torque was 75 ft. lbs.
11. The beam tube installation alignment was verified.

DISCOVERIES AND CONCLUSIONS:

The micarta blocks and mylar insulating sleeves required special installation sequence with related components.

PROPOSED CHANGES:

There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F.10 FIT-UP & WELD SOUTH END CLOSURE TO ASSEMBLY 22-A

OPTION PLANS AND PROCEDURES:

No end closure is planned for the option phase.

QUALIFICATION TEST PLANS AND PROCEDURES: **WPS ER308L/TEST HEAD**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The end closure is unique to the QT.

QUALIFICATION TEST EXECUTION:

Assembly 24-A leak test log and cleaning log was verified to be complete. The assembly sealed with clean polyethylene was moved into the vacuum room before the pump port assembly 22-A was installed. The assembly was set on a temporary adjustable support (wood frame work) at the neutral elevation. The pump port blind flange was removed and the opening was sealed with clean polyethylene with three copper tubes inserted as nitrogen gas purge supply lines. The 52" diameter aluminum end cover with a HEPA filter was removed from the beam tube end and the polyethylene was removed from the head plate. Assembly 24-A was moved into installation position and held in place with three pipe clamps. The weld joint was taped with special masking tape to contain the purge gas during fit-up and tacking. A 52" diameter aluminum cover with the 6" air vent nozzle and a 2" drain nozzle with shutoff valve used to cover the beam tube end during the cleaning operations was installed over the north (assembly 21-A-1) end using three pipe clamps and sealed with duct tape. Three liquid nitrogen dewars with high pressure gas outlets were connected to the three copper tubes. The 6" air vent was connected to a flexible duct tube that vented to the basement ventilation system. The valves were opened and the 133.5' beam tube module interior was filled with nitrogen gas until the oxygen level was less than 1.0%. The purge was obtained within approximately four hours. Two nitrogen flow valves were closed and one valve maintained the purge at less than 1.0% inside the beam tube module. The flexible duct tube was removed from the 6" air vent. The 6" vent nozzle was sealed with polyethylene and duct tape. The 2" drain nozzle was used to vent the beam tube during fitup tacking and welding. The beam tube end (21-2) was brought into alignment with the end closure spiral welded tube ring (24-2). Stainless steel wedges were driven between the beam tube shell and a stainless bar attached to the end closure head plate. The Fitting and tacking was completed.

QUALIFICATION TEST EXECUTION: (Continued)

The automatic weld equipment was set up and the first weld pass was completed. The second weld pass was approximately one half complete when the automatic weld equipment began to have the following problems: The heat build up in the end closure head plate caused distortion. The head plate would make contact with the automatic weld equipment and short out the control functions. The automatic weld equipment was removed from the joint. The joint was completed using the GMAW process WPS ER308L/GMA. An oversized weld (3/8" Vs 1/8" fillet) was applied to a 3 ft. segment of the end closure head ring (24-2) attachment to the head plate (24-1). The beam tube had 1/4" offset with the end closure head spiral ring between the 0° to 90° centerlines. A visual inspection was made on the outside welds. The welds were acceptable. The clean polyethylene and the three copper tubes were removed from the pump port. The opening was covered with the HEPA filter and sealed with duct tape. The 6" air vent was connected to a flexible duct tube that vented the inside of the beam tube to the basement ventilation system. A positive air flow and safe entry was verified. The HEPA filter and duct tape seal was removed and a visual inspection was made using a mirror and a flashlight through the pump port opening. The weld was acceptable. The HEPA filter was installed over the pump port and sealed with duct tape.

DISCOVERIES AND CONCLUSIONS:

Three liquid nitrogen dewars with high pressure gas outlets connected to an inlet manifold would be an improved purge method applicable to vacuum stiffener attachment. The 6" air vent connected to a flexible duct tube that vents to a ventilation system provides a safe and effective purge vent. A 65 foot beam tube can section interior can be filled with nitrogen gas so that the oxygen level is less than 1.0% within approximately two hours.

PROPOSED CHANGES:

The option phase "Fitting/Purge Procedure for Stiffener Attachment Welds for LIGO" Doc. ID No. FPSTIFFENER should be changed to incorporate the improved purge method.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F.11 FINAL ALIGNMENT OF THE QT BEAM TUBE ASSEMBLY

OPTION PLANS AND PROCEDURES:

ALI-1, "Initial & Final Alignment During Installation of the LIGO Beam Tube Modules Using GPS System - Caltech"

ALM-B, "Alignment Maintenance Using Global Positioning System (GPS) - Caltech"

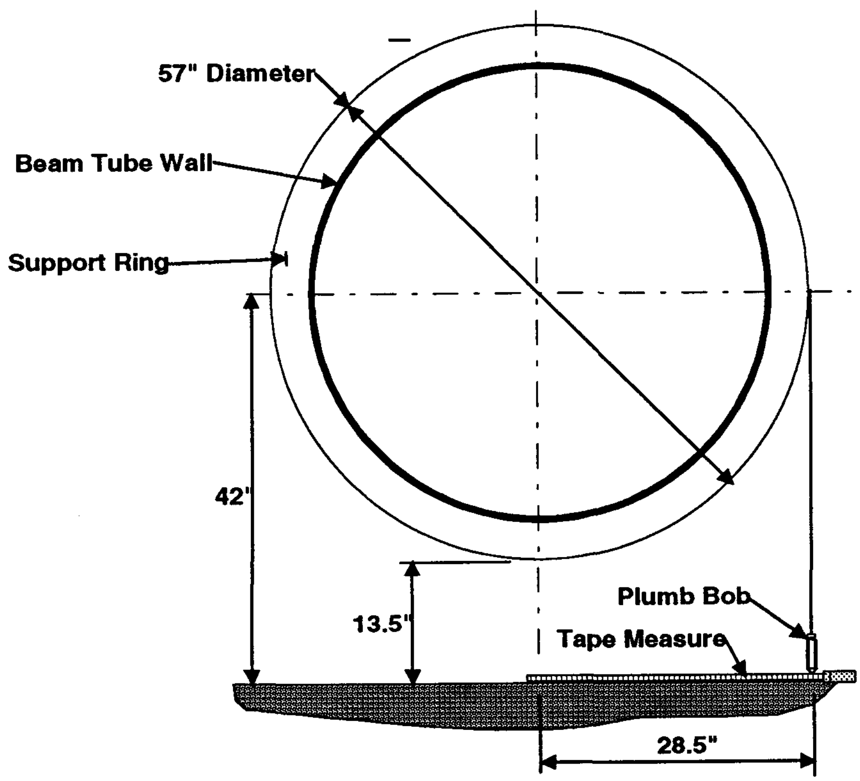
MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

The GPS System was not used during the alignment of the QT assembly. The GPS system has published accuracies that do not require verification as part of the QT. The beam tube centerline reference points on the floor were established using a jig transit and stringline. The elevations of the QT beam tube assembly were measured using a tilt level with and optical micrometer.

QUALIFICATION TEST EXECUTION:

The alignment of the beam tube assembly during the QT demonstrated that the alignment adjustment mechanism that are part of the supports will function as designed. Prior to installing the QT beam tube assembly the centerline reference points defining a straight line (the centerline of the QT beam tube assembly) were accurately located and marked on the concrete floor using the jig transit. A string line and a can of spray paint was used to establish the centerline between the reference points. These points were 25 to 30 feet apart. A stringline was stretched tightly between the adjacent reference points to define the centerline and the centerline projected onto the concrete slab by spraying paint directly over the stringline. The unpainted area under the stringline is the projected centerline. The beam tube centerline on the concrete slab was verified to be within ±0.030" of a straight line from end to end of the beam tube. A jig transit with an optical micrometer was used to perform the verification.

The 22A beam tube assembly was moved into position and aligned to the centerline using a plumb bob and a tape measure. The fixed and guided support rings at the ends of the 22A beam tube assembly were used to center and level. Accurate centering and leveling of the 22A was not attempted at this time.

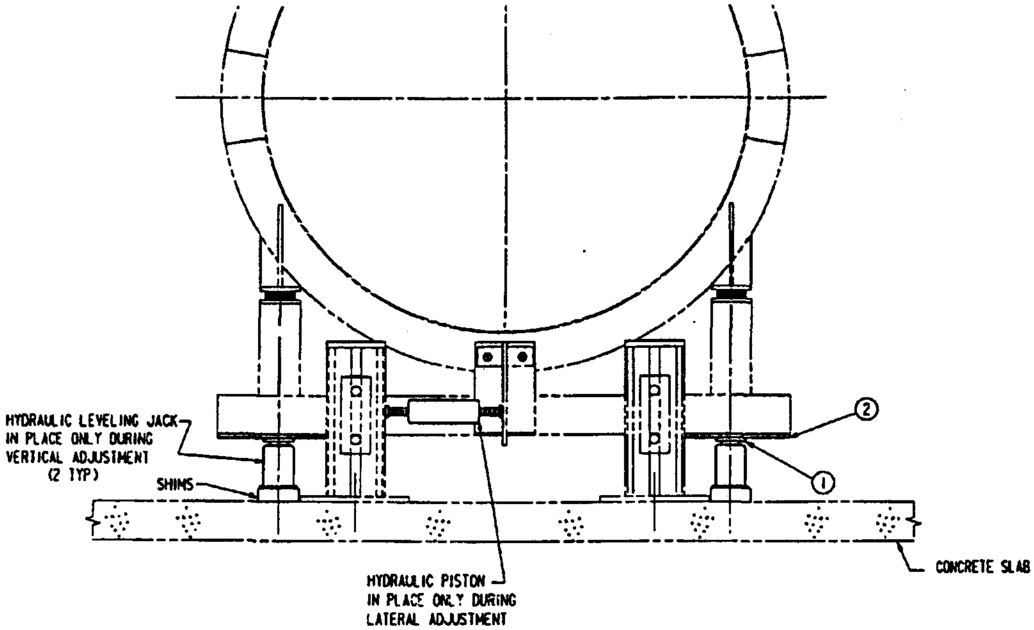


Next the 22B beam tube assembly was moved into position. The end of the 22B assembly (the expansion joint) was aligned and fit to the end of the 22A beam tube assembly. The guided support ring on the 22B assembly was rotated so that the holes in the support ring were clocked to match the holes in the guided support ring on the 22A assembly.

After the 22A and 22B beam tube assemblies were welded together and the supports installed the beam tube was final aligned. The pump port flange at the end of the beam tube was raised to align to the pump port flange of the QT vacuum pumping system. Next, the expansion joint was raised so that the 22A assembly was level and moved laterally to align with the centerline on the floor. Finally the end of the 22B assembly was leveled to the same elevation as the 22A assembly and moved laterally to align with the centerline on the concrete floor. A tilt level with an optical micrometer was used to verify the elevation readings. A plumb bob and tape measure were used to align the beam tube to the centerline on the concrete floor.

As part of the QT, dial indicators were installed to measure how accurately the beam tube movements could be controlled during the alignment process. It was established that the current supports and alignment process can control both the vertical and lateral movements to within

±0.030" without expending a lot of extra time. The QT alignment demonstrates that the procedures and equipment for moving the beam will function as designed



System to Move the Beam Tube During Alignment

DISCOVERIES AND CONCLUSIONS:

The current supports and alignment system can control the lateral and vertical movement to within ±0.030".

PROPOSED CHANGES:

Add brackets to the guided supports for the hydraulic cylinder to push against to facilitate moving in the lateral direction.

Make improvements in the procedure and equipment to make the system easier to operate and more productive.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Improve the method of installing and handling the jacking equipment to make the process of moving more efficient.

F.12 CLEANLINESS INSPECTION OF THE INSIDE SURFACE OF THE QT BEAM TUBE

OPTION PLANS AND PROCEDURES: **LIGOCP, CL3N, & BI1N**

QUALIFICATION TEST PLANS AND PROCEDURES: **LIGOCPQT, CL3QT, & BI1N**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The differences have not been determined.

QUALIFICATION TEST EXECUTION:

Prior to the installation of the north end test head closure (Assembly 24-B) a final cleaning inspection was performed. Fluorescent glow was on the beam tube surface. Additional cleaning would not remove the fluorescent glow without removing the oxide layer from the tube surface. A blacklight inspection report was completed with the results of the final cleanliness documented. Caltech gave direction to "Use-As-Is" per Nonconformance Report No. QT-16. Refer to the blacklight inspection report for a description of the fluorescent glow indications that were not removed from the QT beam tube module. The blacklight inspection report is included in appendix section F with the Beam Tube QT Module Cleaning Record & Check List "ID No." QT-P10.

DISCOVERIES AND CONCLUSIONS:

- The originally specified cleaning procedure was inadequate for the LIGO project.
- The discovery of minute bleeding spots of fluorescence under black light inspection led to a sizable program to improve the cleaning procedure.
- Areas of fluorescence can be seen under black light inspection before and after the cleaning process. Some of these areas can not be removed with solvents or detergents without removing the oxide layer from the tube surface.
- Outgas tests performed on the QT tube indicate that the presence of these fluorescent areas does not result in excessive hydrocarbon outgassing.

PROPOSED CHANGES:

- Cleaning procedures shall be changed to clearify criteria developed to produce and confirm suitable acceptance levels of cleanliness. Include the cleaning process developed to remove unacceptable fluorescent areas without removing the oxide layer from the tube surface.
- Change title of Blacklight Inspection Technique and Solvent Cleaning Procedure "BI1N" to Blacklight Inspection Technique and Acceptance Procedure "BI1X".
- Include the acceptance criteria for level of cleanliness to the Blacklight Inspection Acceptance Procedure.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- Additional development is required to incorporate the QT cleaning process into the option plans and procedures.

F.13 BAFFLE INSTALLATION

OPTION PLANS AND PROCEDURES:

CBI drawing 14, "Baffles"

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

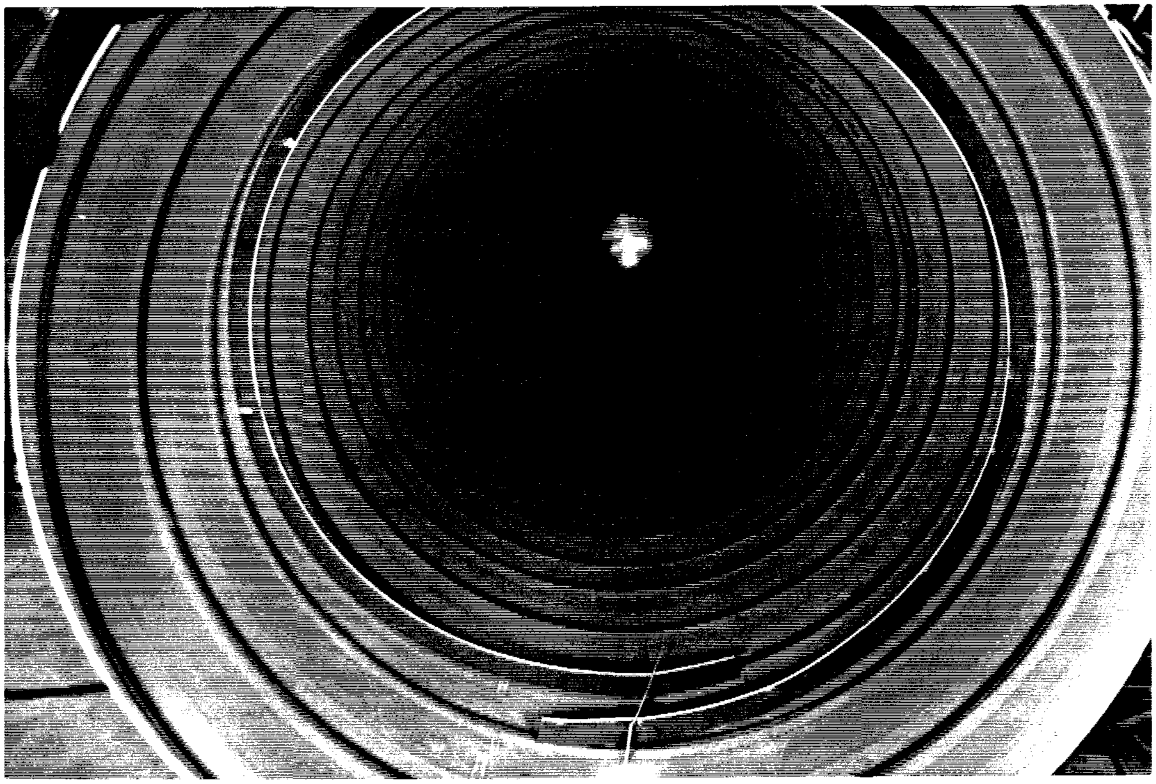
The baffles and baffle installation process used in the QT is essentially the same baffle and installation process currently planned for use in the Option. However, other baffle configurations are being investigate for use on the Option.

QUALIFICATION TEST EXECUTION:

Two baffles were installed inside the QT beam tube assembly. One baffle was installed at a guided support ring and the second baffle was installed at the north fix support ring. The ends of the baffle were overlapped about 30" to form a cone smaller than the inside diameter of the beam tube prior to installation. The first baffle was carried by one man approximately 60 feet down the beam tube to the location of the guided support. It took the person installing the baffle about 15 minutes to carry the baffle 60' down the beam tube, install the baffle at the guided support ring and return 60' to exit the beam tube. Only one person was needed to install the baffle inside the tube.

The baffles were formed to a slightly larger conical shape than the theoretical installed shape to provide the necessary force to hold the baffle in position after installation. The ends of the baffles did not conform as well as anticipated to the shape of the beam tube. However, with additional forming to the ends of the baffle the could be adjusted to conform to within 1/8" of the shape of the beam tube.

The stability of the installed baffle was not as good as expected. The baffles are easily moved after installation. There is much concern that the baffles will not remain in position during the life of the beam tube. The stability of the baffles must be improved for use in the LIGO beam tube.



Baffle Installed Inside the QT Beam Tube Assembly

DISCOVERIES AND CONCLUSIONS:

The baffles did not conform to the inside surface of the beam tube as expected. Additional forming at the ends of the baffle is required to produce a shape that will conform better to the surface of the beam tube.

The baffle was not as stable as expected. There is much concerned that after the baffles are installed they will move or fall over.

PROPOSED CHANGES:

Develop a shape at the end of the baffles that permits the baffles to conform to the shape of the beam tube after installation.

Also, add spacers and/or springs to the baffles to improve the stability of the baffles.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The current baffle configuration does not provide 100% guarantee that the baffles will not move or fall over inside the beam tube during the life of the beam tube. This may be an unacceptable risk. Additional development is needed to improve the current configuration to eliminate the risk of baffles moving or falling over. Caltech is considering replacing the current baffle configuration with a new configuration as well as re-assessing the feasibility of the design requirement that the baffles cannot be attached to the wall of the beam tube.

F.14 FIT-UP & WELD NORTH END CLOSURE TO ASSEMBLY 22-B

OPTION PLANS AND PROCEDURES:

No end closure is planned for the option phase.

QUALIFICATION TEST PLANS AND PROCEDURES: **WPS ER308L/TEST HEAD**

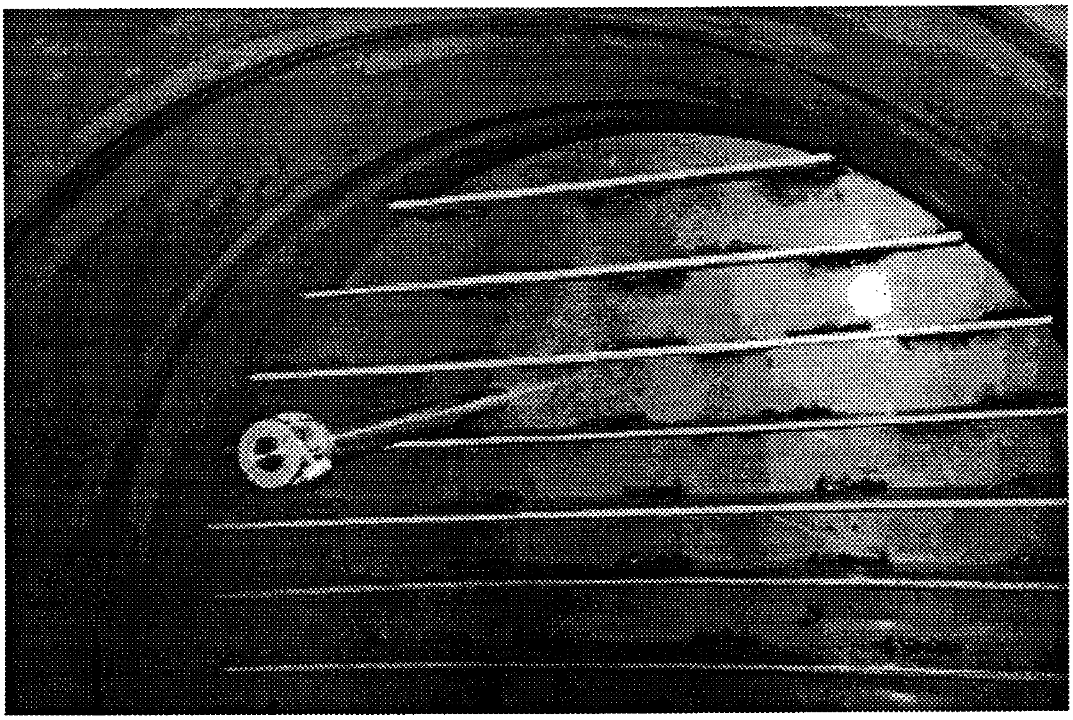
MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The end closure is unique to the QT.

QUALIFICATION TEST EXECUTION:

Assembly 24-B leak test log and cleaning log was verified to be complete. The assembly sealed with clean polyethylene was moved into position. The assembly was set on a temporary adjustable support (wood framework) at the neutral elevation. The black polyethylene end cover was removed from the beam tube end and the polyethylene was removed from the head plate. Assembly 24-B was moved into installation position and held in place with three pipe clamps. The weld joint was taped with special masking tape to contain the purge gas during fitup and tacking. One liquid nitrogen dewar with high pressure gas outlets was connected to a 3/8" valve fitting in the pumping system. The 1.5" helium leak nozzle was used to vent the beam tube during purge. The valves were opened and the 133.5' beam tube module interior was filled with nitrogen gas until the oxygen level was less than 1.0%. The purge was obtained after a third liquid nitrogen dewar with high pressure gas outlets was connected the following day. The 3/8" copper tube maintained the purge at less than 1.0% inside the beam tube module. The oxygen level was checked with an oxygen meter through the 1.5" nozzle. The beam tube end (21-1) was brought into alignment with the end closure spiral welded tube ring (24-2). Stainless steel wedges were driven between the beam tube shell and a stainless bar attached to the end closure head plate. The fitting and tacking was completed.

The automatic weld equipment was set up and the first weld pass was completed. The automatic weld equipment was removed from the joint. The second weld pass was completed using the GMAW process WPS ER308L/GMA. A visual inspection was made on the outside welds. The welds were acceptable. The inside weld was inaccessible; therefore, no visual inspection was possible. The nitrogen flow was stopped by closing the pumping system 3/8" valve. The nitrogen purge was maintained at less than 0.5% inside the beam tube module until the helium leak was installed. The dry nitrogen gas was held inside the beam tube module until pump down started for final leak testing. There were no leaks detected during final leak test.



**THE END
(CLOSURE ASSEMBLY 24-B)**

DISCOVERIES AND CONCLUSIONS:

The dry nitrogen gas held inside the beam tube module shortened the pump down time.
The high purity nitrogen gas preserved the beam tube interior from contamination.

PROPOSED CHANGES:

There were no changes identified in the QT.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no apparent risk and additional development is unnecessary.

F.15 QT PUMPING SYSTEM ASSEMBLY

OPTION PLANS AND PROCEDURES:
NONE - Outside of CBI's scope of work

QUALIFICATION TEST PLANS AND PROCEDURES:
P&I diagrams 1&2 as provided in the appendix
OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
The pumping system for the option phase of the project is currently outside of CBI's scope of work.

QUALIFICATION TEST EXECUTION:
The pumping system was designed during the engineering phase of the project prior to the FDR meeting. The most significant change from the FDR design was a shortening of the path from the large cross section main piping to the RGA. This was shortened in order to improve the performance of the RGA by reducing the conductance losses to the RGA.

The pumping system consisted of two pumping trains. The main pumping train for evacuation of the tube contained an 8" ID liquid nitrogen trap, 1100 L/S turbomolecular pump backed by a 35.L/S wide range turbomolecular pump and finally backed by the DUO 250A roughing pump. This train was provided with a 4.70 inch orifice to maintain the water pumping speed below 600 L/S. The LN2 trap was provided as both a water pump and as an oil back streaming protection device.

The secondary pumping system provided limited pumping for either the RGA, the calibrated leak manifold or for the tube. The secondary pumping system consisted of a 35 L/S wide range turbomolecular pump, a 1.5 CMF roughing pump. The foreline of the turbomolecular pump was provided with an assimilation trap to prevent oil back streaming.

Both pumping systems were also provided with inbleed valves between the turbomolecular pump and the roughing pump. This was provided in order to bleed nitrogen into the roughing line to maintain the foreline in the viscous flow regime which also prevents the back streaming of oil vapor.

The entire UHV portion of the pumping system from the beam tube to the turbomolecular pumps was purchased with metal seals to ensure bakeability and leak tightness of the system. All flanges in the UHV area were conflat type flanges. The roughing piping was sealed with the small ISO flanges.

The RGA utilized for all of the outgassing tests was a Balzers unit. The RGA head consisted of a Balzers QMA-125 head with a faraday cup and a 17 dynode, 90° secondary electron multipier (SEM). The RGA head was also equipped with an ion counter option which was attached to the SEM.

The RGA controller was a Balzers QMG 421C controller which was essentially a black box controller and was attached to a 486-50 PC. All RGA inputs and outputs were accomplished through the PC. The RGA software was designed such that an input parameters file had to be developed in order to operate the RGA in one of the many modes of operation available. A copy of two operating parameters file is included in the appendix.

The RGA was capable of doing the following modes of operation:

- Analog scan. The RGA would scan any range of the sepctrum up to the full 100 AMU range with up to 64 divisions for each AMU. There are up to 64 channels so 64 different ranges could theoretically be scanned simultaneously.
- Bargraph scan. This mode provides a measurement of the peak value of each mass number in the scanned range the range can be changed to any range desired up to the full 100 AMU range of the unit. Again, the 64 channels allow up to 64 different bargraph scans simultaneously.
- MID (multiple ion detection) mode. The MID mode of operation allows the user to scan one AMU in all or a portion of the 64 channels available. Each channel can be programmed to be analized using different ion detectors (faraday cup, SEM or ion counting), different dwell times, different gains, different filters or any of the other settings which are changeable through the parameters files.
- The RGA can run any of the above modes of operation as a single scan, or can be run continuously for a specified number of scans or can be run a specified number of scans with a specified time span between each scan.
- The unit provides a file which is stored on the PC for each operation wheresaved data is requested. The file provides a digital record of the data.
- The unit provides visual monitoring of the operation in progerss on the PC's monitor.
- Review of a saved data file provides graphical representation of individual scans, trending of multiple scans, digital data for each scan, statistics for multiple scans such as standard deviations, mean values, min. and max. values, etc.
- Graphical data can be presented with log or linear scales. The saved data can be manipulated to provide graphical data of the entire range of AMU magnitudes using logrithmic graphs or any portion of the graph can be displayed by changing the X or Y scale ranges using either logrithmic or linear scales.

Copies of screen prints some of the RGA's capabilities are included in the appendix.

Two hydrogen calibrated leaks, two nitrogen calibrated leaks, a helium calibrated leak and a precision variable air leak were provided for the pump system. All leaks except the helium leak were installed on the calibrated leak manifold of the pumping system. The helium leak was installed in the end head of the tube which is the farthest away from the pump port. in order to assure the ability to measure the specified sensitivity of the HMS and to confirm the response time of the system. The calibrated leak sizes are as follows:

- He — $4.7X10^{-10}$ ATM cc/S
- N2 — V25 — $4.9X10^{-10}$ ATM cc/S
- H2 — V26 — $2.15X10^{-7}$ ATM cc/S
- H2 — V27 — $6.5X10^{-6}$ ATM cc/S
- N2 — V29 — $6.3X10^{-8}$ ATM cc/S

The pumping system was installed on a framework so that the system could be assembled and tested before the beam tube was fabricated and installed in the final position. Care was taken to ensure that the framework was at the proper elevation and could be moved to the tube location after tube installation. The pumping system was completely assembled, started up and leak tested prior to the completion of the tube installation.

Leak testing was accomplished using V1, the beam tube isolation valve to seal the pumping system. This valve was tight enough that a blank flange was not required to evacuate the pumping system to a $1X10^{-10}$ ATM cc/S leak rate level. Prior to the bake out, leakage was discovered in a few of the O-ring seals on the roughing system and in elastomeric seals supplied in the vent valves of the turbomolecular pumps. The O-ring leaks were the result of installing the roughing system with totally dry new O-rings (no vacuum greases were applied to limit the hydrocarbon back streaming). The turbo pump vent valves were provided as an optional safety measure to properly repressurize the turbomolecular pump during a normal or emergency shutdown. However, these were removed when found to leak.

The pumping system was then moved to the pump port connection after beam tube installation. Heat tracing and insulation was applied to the connection to the pump port. Leak testing of the flange connections between V1 and the beam tube were accomplished with the final leak test of the completed beam tube.

A data acquisition system was developed to display and store desirable pressure and temperature data, and record a log book file. Temperature data included 17 thermocouples used for the coupon test system, 13 thermocouples for the beam tube pumping system and 20 thermocouples for the beam tube. Pressure data included two pressure gages for the coupon system and four pressure gages for the beam tube pumping system. The analog temperature and pressure data was measured on a Hewlett Packard HP3497 data acquisition system. A 486-50 PC was used to communicate with the HP and to store the generated data files. The files were stored on both the PC hard drive and on a network server hard drive such that the failure of one storage medium did not destroy the capability to recover the data.

The temperature and pressure software which was developed for this test had the ability to record the data at any time interval from continuous scan to as long as desired by the test director. The data was usually recorded every 15 minutes throughout the day. The software would automatically start a new file at midnight each day and save the previous days files.

The same computer used for the temperature and pressure data storage was also provided with a logbook file. The logbook was used to note operator actions, the state of all equipment and to indicate the periodical checks made to critical equipment. The logbook file was saved several times a day to both of the file storage locations.
A copy of the operating instructions for the data acquisition are attached in the appendix. The instructions also show the location of all thermocouples, samples of the logbook program and an example of a display screen for the temperature and pressure data program.

DISCOVERIES AND CONCLUSIONS:

- The installation of the pumping system on a moveable framework allowed the pumping system to be assembled prior the completion of the tube. This saved the project from a number of months of schedule delay.

- All of the turbomolecular pump vent valves were found to leak at a rate greater than the specified $1X10^{-10}$ ATM cc/S leak rate. The valves were located such that they vented the turbo pump from approximately the center stage of the pump. The small leakage resulting from the valves was not detrimental to the pumping system but it made sensitive leak testing impossible. These leaks and the leaks of the elastomer seals in the roughing piping made the leak testing difficult for the pump system.

F.16 I2R BAKEOUT SYSTEM INSTALLATION

OPTION PLANS AND PROCEDURES:
NONE - Not in Scope

QUALIFICATION TEST PLANS AND PROCEDURES:
BO-QT

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
The qualification test beam tube is much shorter than the heating lengths envisioned for the option modules. The heating length for the QT is approximately 141 ft. including the 4 foot extensions added to the ends of the tube. The option module will be heated every 250 m and will be heated at 8 consecutive 250M locations at one time. The length and total number of cables for the option will be much greater and will be a much larger effort to run the wires and to keep them organized for proper connection. Likewise the total number of thermocouples, welding machines and other instrumentation to control and monitor during the option bake out will be much greater and will require a significant increase in the capabilities of the control system.

QUALIFICATION TEST EXECUTION:
The installation of the weld machines, 480VAC power supply cables, DC power cables, thermocouple cables, PLC controls, and welder manual remote controls went smoothly. The PLC was commissioned prior to the bake out as it was also used to control the pumps and valves for the vacuum system. The PLC inputs from the tube thermocouples and the DC current shunts (for measuring current from each welder) were then confirmed and the bake out control logic in the PLC was tested. Prior to actually putting DC current through the tube a test was performed using a steel bar with the same overall resistance of the QT tube in order to confirm the performance of the weld machines in a heating application.

DISCOVERIES AND CONCLUSIONS:
None.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:
Care should be taken to keep all cabling neat and orderly with the proper separation between signal wiring and AC power wiring.

F.17 INSTALLATION OF THE THERMOCOUPLES TO MONITOR THE BAKE

OPTION PLANS AND PROCEDURES: None - Not in CBI's current scope of work

QUALIFICATION TEST PLANS AND PROCEDURES: None

QUALIFICATION TEST EXECUTION:

The beam tube was provided with 20 thermocouples to monitor the progress of the bake out and six thermocouples to control the bake out The twenty monitoring thermocouples were located as follows:

- One on the centerline of the north and south end head
- Five on each fixed support
  - Two located on the tube wall adjacent to opposite longitudinal support bars near the bolted attachment of the thrust restraints.
  - Two located on opposite thrust restraints below the bolted attachment to the longitudinal support bars.
  - One on the tube wall adjacent to the junction of a longitudinal support bar and the stiffener ring
  - One on the tube wall at the south support adjacent to the vertical support bars.
- Two in mid span of section 22A on the tube wall at the bottom of the tube. One is centered between support rings. The other is adjacent to one of the support ring.
- Two on the top of the expansion joint. One is on the top of one of the outside (convex) convolutes. The other is at the bottom of an adjacent inside (concave) convolute.
- One is located on the tube wall adjacent to the closest point, on the guided support. to one of the flexible hanger bar.
- Two at the bottom of the tube at mid span of tube section 22B. One is attached to the tube mid way between stiffener rings. The other is attached to the tube adjacent to the stiffener ring.

Six thermocouples were attached to the tube for control of the bake out. They were located mid span of sections 22A and 22B and also near the bellows. The thermocouples were located at the four tube quadrants and two thermocouples were located on 45° angles.

The thermocouples were attached to the tube and electrically isolated from the tube by using a RTV (silicone adhesive) / paper sandwich. A thin layer of RTV was applied to the surface of the tube and a layer of paper was imbedded into the RTV and another thin layer of RTV is applied over the paper. This sandwich was allowed to cure over night. Another thin layer of RTV was applied over the cured RTV / paper. The thermocouple was imbedded in the uncured RTV and the lead taped to the tube for support during curing. Paper is imbedded in the uncured RTV and another thin layer of RTV is applied over the paper. This procedure is shown in a sketch in the appendix. The thermocouple lead is then secured to the stiffener ring with a bar clamp in order to provide a strain relief for the thermocouple attachment.

In addition to the thermocouples located on the tube, there were 12 thermocouples located on the pumping system to provide control to the 12 individual heater control circuits. 18 thermocouples were installed on the pumping system to monitor the bake out of the pumping system. 12 of the monitoring thermocouples were located adjacent to the control thermocouples . The other six thermocouples were located on the RGA, TMP1 and TMP3 high vacuum flanges, and in the liquid nitrogen vessel of the three liquid nitrogen traps

DISCOVERIES AND CONCLUSIONS:

The thermocouple attachment method worked well with only one of the six tube temperature control thermocouples becoming disconnected. The thermocouple locations was generally very well selected, however, there never is enough thermocouples for every eventuality and a significant amount of temperature probing was required to get an overall picture of the temperature profile. The same was even more true for the pumping system. Due to the low thermal conductivity of stainless steel, each component was at a different temperature. Extensive temperature probing was also required on the pumping system.

PROPOSED CHANGES:

The layout of the thermocouples will change somewhat for the option phase of the project. The option phase supports do not have thrust restraints and will therefore require a different thermocouple layout. In addition , the tube will have no end heads.

Control thermocouples will also have to be supplied for each heating section of the module (8 per module). The location of the control thermocouples should be on each quadrant of the tube.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

There is no additional development work required except for the location of thermocouples for the option phase.

F.18 BEAM TUBE INSULATION

OPTION PLANS AND PROCEDURES: None

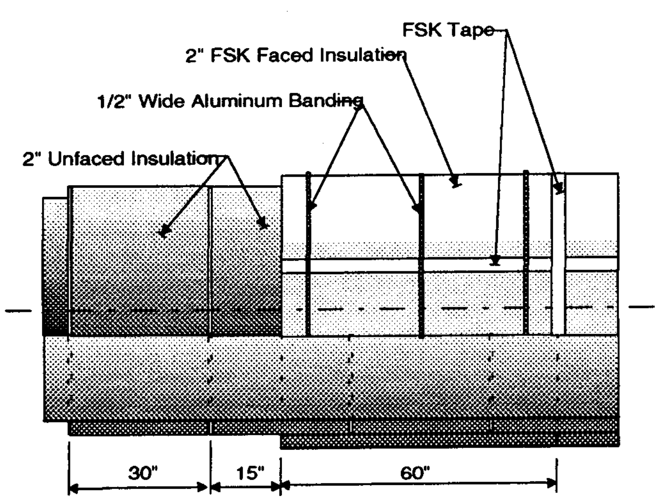
MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

During the Option eight beam tube modules will be insulated for baking. Each of the beam tube modules are 50 times longer than the QT.

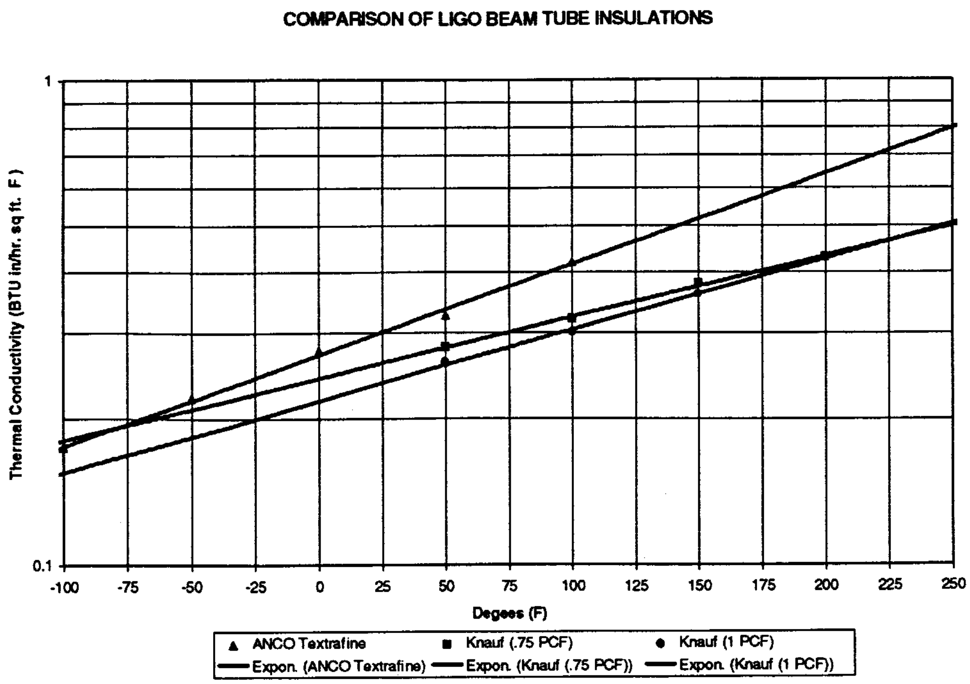
In the Option the beam tube modules will be inside the concrete beam tube cover at the time the insulation is installed. Space limitations may make it more difficult and time consuming to install the insulation.

QUALIFICATION TEST EXECUTION:

Except for the areas at the two fixed supports, the guided support, the two beam tube end extensions, and the intermediate baffle rings, the beam tube was wrapped with 2 layers of 2" thick fiberglass insulation, ANCO's textrafine. The outer layer of insulation was faced with a foil-skrim-kraft (FSK) covering and the inner layer was unfaced. The inner layer of insulation was manufactured to a 30 inches wide so that the layer could be installed between the beam tube stiffeners. The outer layer was manufactured 60" wide to overlap two consecutive beam tube stiffeners and the circumferential seams in the inner layers of insulation. FSK tape was used to hold the inner layers of insulation in place until the outer layers were wrapped over the inner layers. The outer layers of insulation were secured in place using 1/2" wide aluminum banding material. The longitudinal and circumferential joints in the outer insulation were taped closed with FSK tape.



Insulation on QT Beam Tube Assembly



Insulated QT Beam Tube Assembly

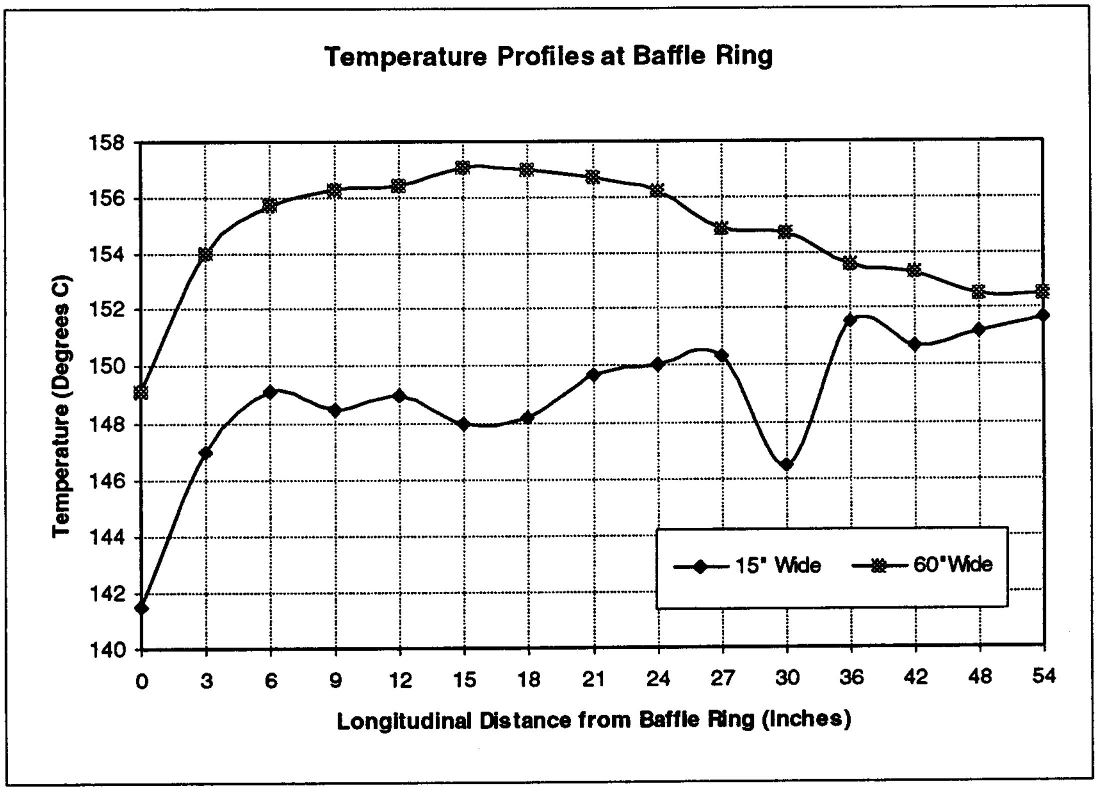
At the fixed supports additional insulation was added to minimize the heat loss and maintain a minimum temperature of 130°C at the coldest spot on the beam tube wall. An additional 60" wide layer of the 2" faced insulation was wrapped around the beam tube at the fixed supports to reduce the heat loss and increase the tube temperature at the supports. The vertical support brackets that attach directly to the beam tube, the vertical support members of the support frame, and the axial load kickers were all cover with additional layers of insulation to reduce the heat loss through the supports and maintain the beam tube cold spot temperatures above the 130°C minimum. Also, heat tape was installed around the axial load kickers to reduce the heat loss from the beam tube through the kickers.

Insulation at the Fixed Support

Initially the expansion joint was covered with a single layer of faced insulation. After a number of trials, the expansion joint was covered with a single layer of 1" thick FSK faced insulation. The insulation was reduced to permit more heat loss to compensate for the higher temperatures at the bellows due to the bellows geometry and thinner material. During the test it was determined that the temperature at the bottom of the bellows was about 45°C colder than the top. This was attributed to the convection of the air under the insulation and between the flutes of the bellows. An additional 24" wide 2" layer of faced insulation was added over the bottom quarter of the bellows to reduce the heat loss at the bottom of the bellows. Also, the seams in the insulation at the bellows were taped to reduce convective heat loss through the seams in the insulation. This reduced the temperature difference between the top and bottom to about 30°C. During the QT test the temperature at the top of the bellows was about 170°C while the temperature at the bottom was about 140°C.

An additional layer of 45" wide 2" thick insulation was added over the support rings on both sides of the expansion joint to reduce the heat leak to compensate for the heat leak through the guided supports. The hanger brackets and lower third of the hanger bar were cover with several layers of 2" insulation to reduce the heat loss from the brackets. Also, the middle third of the hanger bars were wrapped with a single layer of 2" thick insulation to minimize the heat leak from the bars.

An additional layer of the 60" wide 2" thick insulation was added over the baffle rings to reduce the heat loss to compensate for the added heat lost through the baffle rings. Temperature profiles were taken along the beam tube before and after adding the additional insulation to measure the change in the beam tube temperature due to the additional insulation.



The outside of the four foot long beam tube extensions were insulated similar to the beam tube as described above. In addition a 10" thick circular plug of insulation material was made and installed into the ends of the two beam tube extensions. An additional 2" layer of FSK faced insulation was added over the ends of the beam tube extensions and two feet from the end of the extensions. This additional insulation was needed to achieve the minimum temperature of 130°C at the center of the beam tube end closure plates.

DISCOVERIES AND CONCLUSIONS:

- The ANCO Textrafine insulation that was used to insulate the QT assembly did not have as low a thermal conductivity value as the Knauf insulation that was previously used by Caltech.
- The plan to use unfaced insulation for the inner layer of the two layer design makes it difficult to pull the inner layer tight during installation. Loose insulation around the beam tube provides larger convective heat leakage. Also, faced inner insulation will help maintain a more uniform temperature by reducing convection through the insulation.
- The circumferential joints in the QT insulation were taped closed to reduce convective heat losses. It is not certain that we can eliminate circumferential joint taping; this should be checked in the early stages of field operation.
- Insulating the expansion joint and the supports is not straightforward; this should be better designed and checked in the early stages of field operation.

PROPOSED CHANGES:

Use an insulation with lower thermal conductivity for the Option.

Use FSK faced insulation for the inner layer of insulation in the Option.

Tape the circumferential seams in the option

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Develop special insulation details for the fixed supports, guided supports, expansion joints, baffle rings and pump ports. Trial fit insulation on a mock up.

G.1 BEAM TUBE PUMPDOWN

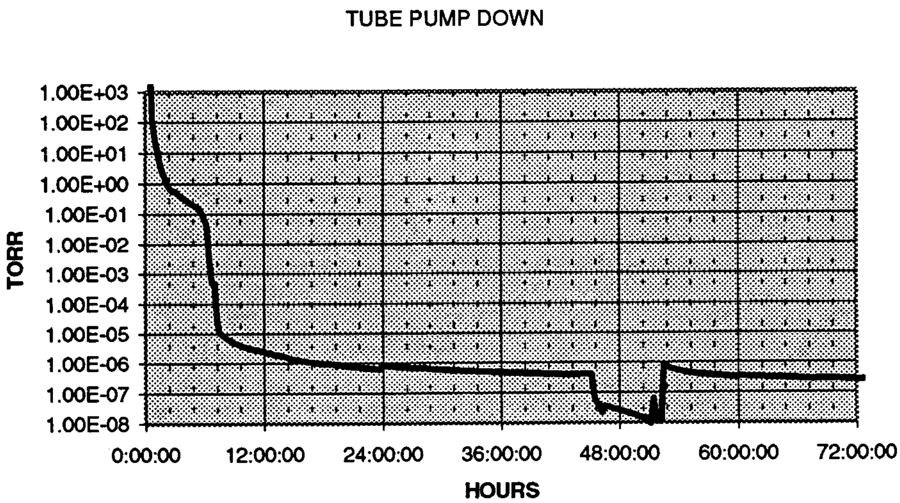
OPTION PLANS AND PROCEDURES:
None

QUALIFICATION TEST PLANS AND PROCEDURES:
OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
No procedures were developed for the option phase of the project because the development of the vacuum pumping system for the option phase is not in CBI's scope of work.

QUALIFICATION TEST EXECUTION:
The system was evacuated using the Balzers Duo 250A roughing pump until the lower pressure limit (lower viscous flow region) was reached on the roughing system. A blower / roughing pump package not selected due to increased cost vs. the one time pumpdown time savings.

The turbomolecular pump (TMP1) was then activated (0.15 torr). The turbo pump was started at a higher than normal pressure to ensure that the system remained in the viscous flow region to prevent back streaming of oil vapor. The high pressure combined with the large tube volume resulted in a very slow increase in the turbopump rotating speed. After approximately one hour, it was decided to throttle (but not completely close) the beam tube isolation valve (V1) in order to reduce the gas throughput of the pump and thus speed the increase in pump rotation speed. This worked well and after an additional half hour, the turbopump was up to the rated operating speed and the pressure was approximately 1×10^{-4} torr. V1 was then opened and the pressure on the pump side of the valve did not rise significantly (mid 10^{-4} torr range) which indicated that V1 was not significantly restricting the flow in the present flow regime. The pumpdown then resumed and the system was quickly evacuated to the high 10^{-7} torr range. The pumpdown curve is shown on the following page.



DISCOVERIES AND CONCLUSIONS:

The tube pumped down much quicker than expected from Caltech's BTD data. This was due to the nitrogen purge which was utilized to weld the end heads to the tube. This purge resulted in reduced water outgassing rates from the tube by well over a factor of 10 from normal stainless steels and from the outgassing rates exhibited by Caltech's BTD experiment.

Just prior to bake out, the beam tube conditions were as follows:

- Tube pressure: $5X10^{-8}$ torr
- RGA measurement of the four largest AMU values
  - AMU 2 $4.0X10^5$ counts per second (CPS)
  - AMU 18 $2.2X10^4$ CPS
  - AMU 28 $1.5X10^5$ CPS
  - AMU 44 $2.3X10^5$ CPS
  -

PROPOSED CHANGES:

The tube, during the option phase of the project, will be ventilated with dry air. The first tube module to be tested should be evacuated and the pumpdown curve or outgassing rate compared with the QT data. If the outgassing rate of the module is significantly higher, the LIGO team should consider a nitrogen purge of the remainder of the tube modules. A nitrogen purge is relatively inexpensive may be an economical alternative to an extended pumpdown. The safety concerns could be addressed without significant additional costs.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

Possible additional development work may include more investigation into the outgassing rates vs. the relative humidity of air in the tube. The goal of this additional work would be to reduce the size of the water pumping equipment provided for the project.

G.2 FINAL LEAK TEST OF THE QT ASSEMBLY

OPTION PLANS AND PROCEDURES: HMST4N & HMST5N

QUALIFICATION TEST PLANS AND PROCEDURES: HMST4QT

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The major difference between the qualification test and the option phase of the project is that there were portions of the QT beam tube which had not been leak tested by CBI prior to this final leak test. These portions of the tube were the expansion joint, the circumferential welds between the tube and the expansion joint, the two circumferential end cap welds and the circumferential weld between sections 22A and 22B.The expansion joint was leak tested by Hyspan prior to shipment to CBI. The portions of the tube which were untested by CBI were bagged and leak tested just prior to the start of the pre-bake outgassing tests. During the pre-bake outgas tests, the tube was subjected to an air signature evaluation for leakage as will the option phase of the project.

QUALIFICATION TEST EXECUTION:

The system was evacuated as discussed in section G.1 to a pressure of approximately 8 X 10^{-7} torr. The untested portions of the tube were then bagged and leak tested by attaching the HMS to the foreline of turbomolecular pump #1. During these tests, the individual bags covering the different untested weld seams were sequentially filled with helium. The beam tube was then, in the course of both pre-bake and post-bake outgassing tests, tested for leakage using the MIT air signature analysis. The QT pre-bake minimum measurable leak rate (due to limitations in the sensitivity of the air signature) is 1 x 10^{-7} TL/S. The QT post-bake air signature minimum measurable leak rate is 1 X10^{-11} TL/S. The above leak rates are the estimated minimum leak rates that can be measured with the air signature analysis. The water vapor prior to the bake out and other gasses such as carbon monoxide and hydrocarbon gasses limit the accuracy of the air signature to the above values. The option phase acceptable leak rates will be 2 decades higher than the QT acceptable leak rates.

DISCOVERIES AND CONCLUSIONS:

- There was no leakage discovered, but the same slow rise in helium background was experienced as in the section leak tests. Again this is attributed to back migration of helium from the HMS roughing pump exhaust to the helium detector.

- The pre-bake air signature analysis determined that the upper bound on an air leak was

1 X 10^{-9} TL/S. The post-bake air signature analysis has indicated a upper bound on an air leak of 1 X 10^{-11} TL/S and this may have improved by the QTR meeting date due to further analysis at MIT. The prebake minimum measurable leak rate decreased two decades from the minimum leak rate predicted prior to the QT. The low water outgassing rate experienced in the QT is probable the cause of the better than anticipated sensitivity prior to the bake. This means that if the water outgassing rate is as low on the option as the QT, the bake can be started with much less risk of finding a tube leak.

- The conclusion is that there is no leak in the tube which is above the specified leak rate and the slow rise in helium during the HMS leak testing was confirmed to be migration of helium instead of tube leakage. However, please note that a conflat flange leak did appear in the pumping system after the cool down. This could pose a problem for the leak testing effort in the option phase if conflat flange leakage is to be expected on each module.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- Based on the experiences of the qualification test, it is more likely to develop a leak in the conflat flanges associated with the pump ports than in the tube. This, while easily repaired if the leak is located behind the pump port valves, may require significant work in finding the leak(s). Costing for the option phase of the project may be jeopardized by leaks in conflat flanges, between the tube pump port and the pump port valve. The leaks on the tube side of the pump port valve will not be easy to repair because of the need to repressurize and rebake the tube. Additional development work may not be of assistance since the leaking flange found in the QT pump system did have two or three previous bake outs without exhibiting any leakage.

- The final leak test procedure during the option phase will begin with an air signature test. The air signature testing is a valuable tool in determining the air leak rate for the tube modules. The scaling factors are assumed to be known and the analysis should work on the tube modules, however, the technique is untried on a system as large as the beam tube module. This final test will have to wait until the first beam tube module is complete.

- The secondary feature of air signature analysis / RGA leak detection which makes the technique very valuable is the possibility of using the air signature to determine the approximate location of the leakage by using RGA's at each pump port along the length of the module. The air signature program may be able to localize a leak to within 50 to 100 ft if only one or two leaks are present. More leaks will reduce the localization capability of the air signature This is the feature of the air signature technique that can save the LIGO project a large sum during the leak testing of the modules. However, if the air signature technique fails to locate the leak(s), the entire module may have to be bagged in order to determine the leak location(s) and the leak detection costs will increase. A number of factors may be combined to limit the air signature technique's ability to find leaks. Some of these factors are listed below.

- Variations in the gage factors / ionization probabilities between units of the same model number.
- Variations in the calibration of individual RGA's
- The number of leaks present in the module.
- Variations in the conductance of each pump port or nozzle.
- Variations in the recording / control system connecting all RGA's together.

G.3 CIRCUMFERENTIAL WELD SEAM LEAK TESTING

OPTION PLANS AND PROCEDURES: HMST2N

QUALIFICATION TEST PLANS AND PROCEDURES: HMST2QT

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

Circumferential seam leak tests for the qualification test beam tube were bagged, as described in section G.2, instead of using the circumferential weld leak test box as proposed for the option phase of the project. The option phase leak test box concept was evaluated during the qualification test. The results of the evaluation are discussed below.

QUALIFICATION TEST EXECUTION:

All circumferential weld seams which were not checked in the section leak tests were bagged and leak tested after the qualification test beam tube was pumped down and ready for the start of the pre-bake outgassing studies. See section G.2 for a complete discussion of the leak test procedures used during the QT. No leakage was found in any of these circumferential seams.

Two leak test boxes were evaluated during the QT phase to confirm the use of the box concept during the option phase of the project. The second box eventually worked and provided the necessary sealing to achieve leak testing down to 1 X 10^{-10} ATM cc/sec. of helium.

The first box was fabricated from lexan and had problems sealing around the circumferential seam and also had problems with durability and background outgassing. CBI selected the worst locations on the tube for evaluation of the box. This location was near the junction of the spiral weld seam and the circumferential weld seam. The profile of the circumferential weld seam was that it had pulled in toward the center of the tube. The profile of the spiral weld seam was that the center of the weld was raised above the surface of the tube. The combination of the low profile of the circumferential seam with the high profile of the spiral seam created the sealing problem at the edges of the circumferential weld.

The second box was fabricated from aluminum with larger double o-rings (7/16"∅). This box had to be banded to the tube with the force necessary compress the O-ring over the spiral weld, which was the high spot on the sealing surface, enough to obtain a slight compression over the circumferential weld seam, which was the low spot in the surface profile.. This box eventually worked and provided the necessary sealing to achieve leak testing down to 1 X 10^{-10} ATM cc/sec. of helium. A complete report on the effort to test the two boxes is included in the appendix.

DISCOVERIES AND CONCLUSIONS:

- The tube surface finish is rough enough to make high vacuum sealing difficult.
- The first box was fabricated of lexan and was too fragile for production line testing.
- The first test box was difficult to seal and exhibited high residual outgassing.
- The problem encountered with the second box was that it was not a test method for a production line type of operation. The box was a 90° circular segment and the pumpdown and leak testing took between 2 and 3 hours. It would therefore take well over 8 hours to leak test a complete one circumferential weld seam.
- The aluminum box leak testing required the weld seam profiles to be ground to achieve the desired test sensitivity and leak tightness.
- Either leak test box could have easily been sealed to provide the desired sensitivity of $1X10^{-10}$ ATM cc / S if vacuum putty were allowed to assist in sealing the box. However, the concern for covering a leak in a weld joint prohibited the use of vacuum putty.

PROPOSED CHANGES:

CBI is currently reviewing options for improvement of the leak test box. These options include:

- Addition of a pumping system to the leak test box to reduce the pumpdown time. The prototype boxes used only the pumping system of the HMS.
- Use of a 360° box which will cover the entire weld area. This will allow the use of vacuum sealing putty to temporarily seal any leakage between the tube and the box because the putty would only be applied to areas of the tube which have already passed a leak test in procedure HMST1N.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The additional development of the leak test box is as described above. This development should be undertaken during the preliminary stages of the option phase of the project. The suggested development procedure would entail the development of a 360° box which would be used on some of the QT tube weld seams to determine the sealing capabilities of the new box. The new bow would also be provided with a pumping system to speed up the evacuation of the box and reduce the effect of any leakage.

G4 PRE-BAKE HYDROGEN OUTGAS TEST

OPTION PLANS AND PROCEDURES:
NONE

QUALIFICATION TEST PLANS AND PROCEDURES:
OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
The development of procedures for outgassing tests of the option phase of the project is not in CBI's scope of work.

QUALIFICATION TEST EXECUTION:
Hydrogen was measured by two methods during the outgas tests. the first method is to accumulate gas in the tube behind a closed isolation valve and measure the hydrogen partial pressure spike height on the RGA when the isolation valve is opened. The pressure spike is then ratioed to the spike height of a calibrated leak which is also accumulated. The equation for determining the hydrogen partial pressure also includes the ratio of the accumulation times and the size of the calibrated leak. The accumulation is typically the most accurate and foolproof method of outgas testing. Accumulation, however does not work as effectively on condensable gasses such as water or heavy hydrocarbons due to re-adsorption or condensation as the gas partial pressure rises within the closed space.

A variation of the accumulation method was also used during the outgas testing program. The accumulation with this variation is accomplished by closing V3 which is the isolation valve for the large pumping system. This variation isolated the RGA along with the beam tube and allows the RGA to measure the accumulation in real time so the rate of rises can be examined instead of only a final .pressure spike and pressure decay after the valve is opened to the pumping system.

The second method of measuring the hydrogen outgassing rate is to measure the difference between the steady state RGA value for the beam tube and pumping system, the value for the beam tube and pumping system with the calibrated leak open and the value of the pumping system only. The outgassing rate of the tube is then measured by subtracting the pumping system RGA measurement from the other measurements to get a ratio of the beam tube only measurement to the calibrated leak only measurement and multiplying by the calibrated leak size and dividing by the tube surface area.

DISCOVERIES AND CONCLUSIONS:
The hydrogen outgassing rate, as measured by the accumulation method is 3×10^{-14}

TL/S cm^2. The steady state method yields an outgassing rate of 1.6 X 10^{-14} TL/S cm^2. The accumulation method is the most accurate measure of the outgassing rate in these conditions and thus the outgassing rate which is most probable is $3.0X10^{-14}$ TL/S cm^2. Spread sheet calculation results are provided in the appendix as well as a copy of the RGA output.

G5 PRE-BAKE WATER OUTGASSING TESTS

OPTION PLANS AND PROCEDURES:
None

QUALIFICATION TEST PLANS AND PROCEDURES:
OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
There are no procedures developed for the option phase of the contract because this is out of CBI's scope of work.

QUALIFICATION TEST EXECUTION:
The water outgassing rate was one of the first tests performed on the tube after leak testing. due to the ease of the measurement. The partial pressure of water vapor is essentially the same as the total pressure measured with the cold cathode gage (CC1) because the concentration of the next highest component in the residual gas is at least 50 times less than the water vapor.

The key to the calculation of the water vapor outgassing rate is to accurately determine the net pumping speed of the system. The calculated pumping speed of LNT1 is 600 L/S. However, the pumping speed can be calculated for nitrogen through TMP1. This makes the water pumping speed by TMP1 equal to the square root of the ratio of molecular weights times the nitrogen pumping speed. The net water pumping speed for the trap can then be calculated by multiplying TMP1 water pumping speed by the ratio of CC1 gage readings before and after LNT1 is cooled.

After the water pumping speed is known, the outgassing rate can be determined by multiplying the water vapor partial pressure by the pump speed and dividing by the area of the tube surface.

DISCOVERIES AND CONCLUSIONS:
The above procedure yields a water vapor outgassing rate of from 1.9 to 2.2×10^{-11} TL/S cm^2 prior to the bake out of the tube. Variations in the outgassing rate are from using the two pumping speeds (calculated and measured). The Calculated pump speed for water was 600 L/S. The measured pump speed for water was 700 L/S. The most accurate outgassing rate is determined by measuring the pump speed for water and is therefore, the value of 2.2×10^{-11} TL/S cm^2.

G.6 PRE-BAKE AIR SIGNATURE ANALYSIS

OPTION PLANS AND PROCEDURES: HMST4N

QUALIFICATION TEST PLANS AND PROCEDURES: OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The only major difference in the procedures for the QT and option phases of the project is the use of only one RGA for the QT phase instead of an RGA on each port of the beam tube modules in the option phase. The use of multiple RGA's in the option allows for some degree of leak location as well as air signature leak detection.

The QT phase of the project will require air signature leak detection which is at least two decades better than the option phase to account for the difference in the beam tube length. The QT phase will, therefore, require air signature detection limits of $1X10^{-7}$ TL/S or better for the pre-bake measurements in order to achieve an option phase detection limit of $1X\ 10^{-5}$ TL/S or better.

QUALIFICATION TEST EXECUTION:

The QT execution consisted of running an air signature RGA steady state measurement of the tube. The RGA parameters program for the sir signature consists of the measurement of 41 mass numbers(1, 2, 12, 13, 14, 15, 16, 17, 18, 20, 24, 25, 26, 27, 28, 29, 30, 32, 34, 37, 38, 39, 40, 41, 42, 43, 44, 45, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 64, 65 and 66). The procedure also uses the RGA air signature program to measure the cracking patterns of known gasses such as room air and carbon monoxide. The cracking patterns of the known gasses are inserted into an air signature program written by Rainer Weiss. This program uses a Chi square analysis to determine the most probable mixture of gasses which make up the measured values in the RGA steady state tube measurement.

The air signature analysis developed by Rai Weiss is necessary in order to determine the tube air leak rate because multiple gasses inhabit the same AMU values. The most used AMU for air signature analysis is 28. The 28 peak shown on an RGA is made up of a mixture of gasses including diatomic nitrogen and carbon monoxide. The air signature program uses the published cracking patterns for many gasses that are typically found in a UHV system and the cracking patterns of gasses tested during the air signature testing of the tube (air and carbon monoxide for the prebake measurements). The program then varies the published cracking patterns in order to reduce the Chi squared values for the different gasses in the program. When the Chi squared values are minimized, the resulting gas mixture is statistically the most likely to be in the tube.

DISCOVERIES AND CONCLUSIONS:

Rainer Weiss' air signature analysis for the pre bake testing has determined that there is no leak which is detectable with a sensitivity of $1X10^{-9}$ TL/S. This is two orders of magnitude better sensitivity than expected based on the LIGO BTD experiment. The improvement in sensitivity is due to the lower water outgassing rate and may also be due to the extensive tube cleaning procedure which minimized the hydrocarbon outgassing. The increased sensitivity of the air signature means that the risk of discovery of weld leakage during or after the bake out of the beam tube module is has been lessened due to the very limited probability of a weld leak of less than $1X10^{-7}$ TL/S.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- Based on the reduction of the risk of a post bake weld leak discussed above, it may be worth the development costs to provide a nitrogen purge to the modules prior to the module pump down.

- The air signature analysis has shown much merit as a leak assessment tool. However, the concerns and risks discussed in section G2 are still valid.

G.7 BEAM TUBE I2R BAKEOUT

OPTION PLANS AND PROCEDURES: NONE - Not in Scope

QUALIFICATION TEST PLANS AND PROCEDURES: BO-QT

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The qualification test beam tube is much shorter than the heating lengths envisioned for the option module. The heating length for the QT is approximately 141 ft. including the 4 foot extensions added to the ends of the tube. The option module will be heated every 250 m. The voltage generated by the welding machines for the QT is only about 20% of that required for the modules. The higher DC voltage required for the option bake-out should increase the efficiency of the weld machines as power supplies.

The means with which the operator monitors and controls the welding machine currents and tube temperatures for the QT and option will be much different. Because of the small amount of welders and thermocouples needed for the QT, a simple PLC programming software package was used to monitor the bakeout from a CRT. For the option, a much more sophisticated operator interface software package will be required to monitor the status of the multiple PLC's, weld machines, and thermocouples from a centrally located CRT.

QUALIFICATION TEST EXECUTION:

The bakeout was started using 8 welding machines, each capable of supplying 300Amps of DC current. The I2R heating of the tube was interrupted initially due to the limited 480VAC power supply available at the start of the bakeout. This was caused by the less than expected efficiency of the welding machines used to supply the DC power to the beam tube. The efficiency of the weld machines for the QT was between 5 and 10 percent. This interruption lasted over a weekend and the system was restarted on Monday after additional 480VAC power was connected to the welder bank. The temperature of the tube was then run up manually using the 8 welding machines until a maximum temperature was reached. The maximum temperature reached using 8 welders was lower than 140°C. A ninth welding machine was added to the system to bring the temperature of the tube over 140°C. The additional welder was needed because of the additional DC current (ie additional heat) required to maintain the temperature in the tube over 140°C. This was caused by the less than anticipated "R" value for the insulation on the tube.

The start of the bakeout clock was also delayed by low temperatures at the fixed supports, where the vacuum load is transfered to the foundation, which are not part of the option phase support structure, the guided supports at the bellows and the tube end heads. These cold spots were corrected using heat tracing elements with local temperature controllers or additional insulation. The thirty day bakeout clock was started on Feb. 3, 1995. The 480VAC power supplied to the welding machines was approximately 160kVA.

Once the required equilibrium temperatures were reached using manual control, one of the welders was switched to automatic to provide a "trim" to maintain the desired setpoint temperature. This welder was controlled by a PID controller in the PLC which used 6 thermocouples along the tube to measure the tube temperature. The PID controller in the PLC used the lowest of the 6 thermocouple temperatures as its process variable. The setpoint was adjusted once during the bakeout.

The bakeout proceeded with improvements in the insulation of the tube, rewrapping the heat tracing, and reinsulating the pump system. The improvements in the tube insulation consisted of taping the longitudinal seams in the insulation cover to reduce convection from the tube bottom to the tube top and adjusting the insulation thickness over the bellows.

The steady state I2R bakeout was interrupted a couple of times during the month. The interruptions included repair of two weld machines. These operating anomalies did not seriously affect the bakeout and the bakeout was terminated on March 3, 1995.

DISCOVERIES AND CONCLUSIONS:

Overall the I2R heating system using CBI400 welders performed quite well over the long haul. Care should be taken to adequately size the 480VAC supply to the welder banks to account for the efficiency of the machines.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The potential for bakeout problems associated with the option phase of the project will be similar to the problems associated with the QT. It is recommended that spare welders be available during the option bakeout and that the welder banks be situated so that the changeout of a welder can be easily accomplished if a failure should occur.

G.8 PUMPING SYSTEM BAKE OUT

OPTION PLANS AND PROCEDURES: NONE - Not in Scope

QUALIFICATION TEST PLANS AND PROCEDURES: BO-QT

QUALIFICATION TEST EXECUTION:

The pumping system bake out was activated after the system heat tracing was rewrapped and expanded and after the pumping system was reinsulated. The rework of the system heating and insulation was caused by a bake test of the pumping system before the start of the QT test execution phase. The bake out test indicated that the heating was insufficient to maintain all components of the pumping system at 150°C. The system was also evaluated for components which could not be baked to the required 150°C. The evaluation led to the removal from the system of a Pirani, a Convectron gage and the removal of the RGA's ion counting electronics package which was attached directly to the SEM head of the RGA.

Other components of the system which were of concern were the RGA, the cold cathode gages and the calibrated leaks. The RGA heating control loop was controlled by using a controller which had its control thermocouple located directly on the RGA's faraday cup flange. The SEM flange of the RGA had a monitoring thermocouple installed so that the SEM temperature could monitored at all times. The Calibrated leaks were fabricated with a crimped and soft soldered seal on the opposite end of the leak from the piping connection. The outboard end of the calibrated leaks were left uninsulated to prevent solder melting.

The pumping system bake was activated after the heating and insulation were modified. The few days of the system bake out was devoted tuning up the insulation on the pumping system. More insulation was needed to maintain the RGA and the large Gate valves (V1 & 3).

DISCOVERIES AND CONCLUSIONS:

- It was difficult to maintain all components of the pumping system at the proper temperature. Many of the components were limited to temperatures of 150°C or less and had to be carefully controlled. These items included the RGA, the cold cathode gage heads and the calibrated leaks.
- It also appears that the cold traps were not bakeable as specified by CBI. A large quantity of hydrocarbon outgassing was traced to the cold trap LNT2 which was baked without any liquid in the trap. Discussions with Andonian Cryogenics indicated that the traps may contain G10 type composite material as a support for the liquid nitrogen vessel in the trap. The use of G10 cannot be confirmed until the system is disassembled.
- The liquid nitrogen traps required the most attention throughout the bake. The 180 liter dewars used for filling the traps were located on a scale to continuously monitor the

amount of liquid left in the dewar. This was a great assistance in monitoring the liquid remaining in the dewar and in predicting dewar replacement times. However, the piping loads from the system would change the weight of the dewar by as much as 20 lb. so care had to be taken to closely monitor the trap operation when the dewar was nearly empty. This was especially true when the bake out caused the heat transfer to the liquid and thus the liquid boiloff rate to increase by about 300%.

- LNT1 was accidentally allowed to warm up for approximately one hour during the bake and the pressure in the system spiked to the 10^{-4} torr range. The pressure in the beam tube rapidly recovered because the surfaces were hot and could not readsorb large quantities of water vapor. The bake out was set back for only about 12 hours.

- After cooldown, the following tube conditions were reached
  - The tube pressure reached a cold cathode gage measurement of $1.2X10^{-10}$ torr. However it was later determined that the gage was in error and the measured value was twice the indicated value so the minimum true pressure was approximately $2.4X10^{-10}$ torr.
  - The RGA measurements of the four largest AMU values was as follows:
    - AMU 2 $2.9X10^{5}$ CPS
    - AMU 12 $1.3X10^{3}$ CPS
    - AMU 28 $8.3X10^{3}$ CPS
    - AMU 40 $9.5X10^{2}$ CPS

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The potential for bake out problems associated with the option phase of the project will be similar to the problems associated with the QT. The main concern will be keeping the 8 to 10 cold traps operating for the duration on the bake without expending a large number of man-hours. The easiest and most economical method of storing and delivering liquid nitrogen to the traps should be investigated.

The long distances between pump ports prohibits the use of one large dewar with piping to all of the traps. The more economical solution may be to supply large dewars, such as 500 or 1000 gallon dewars at each cold trap with local piping only. Refill of the dewars, if required would be made by the liquid nitrogen supplier.

G.9 POST BAKE WATER OUTGAS TEST

OPTION PLANS AND PROCEDURES: NONE

QUALIFICATION TEST PLANS AND PROCEDURES: OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The development of outgassing procedures for the option phase of the project are not within CBI's scope of work

QUALIFICATION TEST EXECUTION:

The measurement of the post bake outgassing rate for water was the first activity after the bake because every operation after the bake has the possibility of increasing the water content in the tube. The water outgassing rate was measured by determining a difference in the steady state RGA measurements the system with the tube and the system without the tube. The RGA water differential can then be converted into a flow rate and outgassing rate by using the calculated RGA gage factor for nitrogen and assuming that the water gage factor is approximately equal to the nitrogen gage factor. Nitrogen is used instead of water vapor because there is no way to provide a water calibrated leak without saturating the surfaces of the tube with water. Nitrogen ionization factors are also very close to water ionization factors.

DISCOVERIES AND CONCLUSIONS:

The RGA measurement of the tube and pumping system was identical to the RGA measurement of the pumping system alone. The majority of the water vapor is being generated by the pumping system. The outgassing calculation of the tube and pumping system together yields an outgassing rate of 1.22×10^{-16} TL/S cm^2. It is possible to distinguish between RGA measurements which are 10% apart. The tube outgassing must therefore be less than 10 % of the combined measurement. The tube upper limit is therefore less than 1.22×10^{-17} TL/S cm^2.

A second method of trying to calculate the outgassing rate of water from the tube is to measure the pressure rise during an accumulation of the tube. This was done by closing off the isolation valves for each pump and allowing the RGA to measure the increase in water vapor as the tube accumulates. This method yielded an outgassing rate of 6.11×10^{-18} TL/S cm^2. This method may, however, not be as accurate due to the readsorption of water on the tube.

G.10 POST BAKE HYDROGEN OUTGASSING RATE.

OPTION PLANS AND PROCEDURES: None

QUALIFICATION TEST PLANS AND PROCEDURES: OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
The CBI scope of work does not require option phase outgassing test procedures.

QUALIFICATION TEST EXECUTION:
The post bake outgassing tests for hydrogen utilized two methods of outgassing calculations. The first method involved measuring the steady state differences between the beam tube partial pressure and the partial pressure when the calibrated leak is added to the system. The second method involves measuring the partial pressure difference between accumulations in the tube and in the calibrated leak. The outgassing tests for hydrogen were repeated many times due to a difference in the measurements between the pre-bake condition and the post bake condition.

DISCOVERIES AND CONCLUSIONS:
The outgassing rate for hydrogen jumped by approximately 300% during the bake out. The pre-bake measurements resulted in a hydrogen outgassing rate of 3.0 X 10-14 TL/S cm2. The post bake outgassing rate varied from 1.68 X 10^{-13} to 1.19 X 10^{-13} TL/S cm2 for the accumulation technique. The high calculated values of this technique are from short accumulations of the calibrated leak (3 minutes) with pressure spike levels which are only about 50% of the tube accumulation pressure spike. The longer accumulation times are more accurate due to the length of time it takes to open or close the tube isolation valve. The tube isolation valve is an 8" VAT UHV gate valve with a very fine thread on the handwheel. The valve handwheel must be rotated on the order of 50 complete revolutions to completely open the valve. The slow opening time with the fast accumulation allows a large error in the true accumulation time. The lower outgassing rates were all from longer accumulations. The lower outgassing values (longer accumulations which were 12 to 17 minutes)are less affected by the opening times of the valve and are therefore more accurate.

The outgassing rates calculated by the steady state approach range from 8.52 X 10^{-14} to 9.23 X 10^{-14} TL/S cm^2.

The most accurate measurements were made on March 9, 1995 where both LNT2 & 3 were at ambient temperature and were made with the cold cathode gages off. The calculated results from this day are 8.79 X 10^{-14} TL/S cm^2 for the steady state measurement and 1.24 X 10^{-13} TL/S cm^2 for the transient (accumulation) method with the long accumulation time. The post bake outgassing calculations indicated the most repeatable values for the outgassing of hydrogen were the steady state values. It is therefore suggested that the steady state values of the post bake outgassing rates should be used as the most valid post bake outgas rates for hydrogen. Sample RGA outputs and spread sheet calculations are provided in the appendix.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- The potential risk for the hydrogen outgassing is the increase in hydrogen during the bake out. this jump in hydrogen is acceptable if the option phase tube acts as the QT tube did. The hydrogen outgassing rate will be just below the maximum acceptable limit if the option phase tube behaves as the QT tube did. However, the outgassing rate will be over the allowable limit after the second bake out if the outgassing rate jumps every time the tube is baked.

- Additional development may be undertaken to repeat the bake out of the QT beam tube in order to determine if the hydrogen jump is repeated for subsequent bakes. If a significant hydrogen jump is measured, the bake may again be repeated to determine if there is a change in the rate of hydrogen jump for the subsequent bake outs.

G.11 POST BAKE AIR SIGNATURE ANALYSIS

OPTION PLANS AND PROCEDURES: HMST4N

QUALIFICATION TEST PLANS AND PROCEDURES: OUTGAS

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The only major difference in the procedures for the QT and option phases of the project is the use of only one RGA for the QT phase instead of an RGA on each port of the beam tube modules in the option phase. The use of multiple RGA's in the option allows for some degree of leak location as well as air signature leak detection.

The QT phase of the project will require air signature leak detection which is at least two decades better than the option phase to account for the difference in the beam tube length. The QT phase will, therefore, require air signature detection limits of $1X10^{-11}$ TL/S or better for the post bake measurements in order to achieve an option phase detection limit of $1X\ 10^{-9}$ TL/S or better.

QUALIFICATION TEST EXECUTION:

The QT execution consisted of running an RGA steady state measurement of the tube. The sir signature RGA parameters program (the same as that discussed for the pre bake air signature test) consists of the measurement of 41 mass numbers(1, 2, 12, 13, 14, 15, 16, 17, 18, 20, 24, 25, 26, 27, 28, 29, 30, 32, 34, 37, 38, 39, 40, 41, 42, 43, 44, 45, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 64, 65 and 66). The procedure also uses the RGA air signature parameter program to determine the cracking patterns of known gasses such as room air and carbon monoxide and carbon dioxide. The cracking patterns of the known gasses are inserted into an air signature program written by Rainer Weiss. This program uses a Chi square analysis to determine the most probable mixture of gasses which make up the measured values in the RGA steady state tube measurement.

DISCOVERIES AND CONCLUSIONS:

Rainer Weiss' post bake air signature analysis is being refined at the time of this writing. But, the work to date has provided an upper bound of the air leakage rate to be no more than $1\ X\ 10^{-11}$ TL/S. The air signature analysis is at least as sensitive as required to determine the leak rate of a tube module in the option phase of the project.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The same risks, benefits, concerns and development comments as discussed in sections G.2 and G.6 apply to this test.

G.12 ADDITIONAL INFORMATION

The following is a compilation of the information which was developed in the course of the outgassing studies. Some of this information was outside of CBI's scope of work and has been developed by Rainer Weiss. It is presented here to form a complete picture of the outgassing studies undertaken for this project.

Beam Tube Test Apparatus Parameters

Geometric	
Beam Tube Volume	$5.12 X 10^{4}$ liters
Area	$1.71 X 10^{6}$ cm^2
Vacuum Pumping System	
Hydrogen	570 ± 30 liters/sec
Nitrogen	246 ± 15 liters/sec
Water	690 ± 35 liters/sec
RGA Sensitivity In The Ion Counter Mode	
Hydrogen	$2.5 \pm 0.3 X 10^{-15}$ torr/count/sec
Nitrogen	$9.7 \pm 1.0 X 10^{-15}$ torr/count/sec
Water	$3.9 \pm 0.2 X 10^{-15}$ torr/count/sec

Pre Bake Outgassing Rates

Water	$1.2 X 10^{-8}$ / t(hours) TL/S cm^2
Hydrogen	$2.5 \pm 0.3 X 10^{-15}$ TL/S cm^2
Carbon Monoxide	$< 2 X 10^{-13}$ TL/S cm^2
Carbon Dioxide	$< 3 X 10^{-13}$ TL/S cm^2
Methane	$< 1 X 10^{-13}$ TL/S cm^2
Air Leak From Air Signature Tests	$< 1 X 10^{-9}$ TL/S

Post Bake Outgassing Results for a 140°C to 150°C Bake for 750 Hours

Hydrogen - absolute determination $8.6 \pm 0.2 \times 10^{-14}$ TL/S cm^2

AMU	External Accumulation	Internal Accumulation	Steady State
2	6.2 e-14 +- 1 e-15	< 1.0 e-13	8.8 e-14 +- 2 e-15
4		<	1.4 e-17 +- 2 e-18
12	4.7 e-16 +- 4 e-18	< 3.0 e-16	1.6 e-16 +- 2 e-17
13	4.1 e-17 +- 2 e-19	< 2.8 e-17	1.1 e-17 +- 4 e-18
14	5.3 e-17 +- 3 e-18	< 3.9 e-16	< 9.0 e-17
15	1.9 e-16 +- 2 e-18	< 1.8 e-16	4.7 e-17 +- 8 e-18
16	3.0 e-16 +- 3 e-18	< 2.8 e-16	2.8 e-16 +- 1 e-17
17	1.3 e-18 +- 2 e-18	< 4.8 e-18	< 8.0 e-18
18	< 2.4 e-18	< 1.3 e-17	< 8.6 e-18
20	< 1.2 e-18	< 7.8 e-17	< 4.4 e-18
24	6.7 e-19 +- 4 e-19	< 3.3 e-18	< 1.6 e-18
25	3.7 e-18 +- 7 e-19	< 1.0 e-18	< 5.0 e-18
26	1.7 e-17 +- 1 e-18	< 4.6 e-17	< 1.0 e-17
27	1.7 e-17 +- 2 e-18	< 5.1 e-17	1.5 e-17 +- 6 e-18
28	2.5 e-16 +- 1 e-17	< 2.0 e-15	3.6 e-16 +- 2 e-16
29	1.5 e-17 +- 1 e-18	< 3.0 e-17	< 4.0 e-17
30	4.0 e-18 +- 5 e-19	< 1.8 e-18	< 1.8 e-18
32	< 3.4 e-19	< 1.1 e-18	< 1.4 e-18
34	2.5 e-18 +- 5 e-19	< 1.7 e-18	< 1.0 e-18
37	3.0 e-18 +- 5 e-19	< 2.0 e-18	4.2 e-18 +- 2 e-18
38	4.0 e-18 +- 8 e-19	< 3.0 e-18	< 2.0 e-18
39	7.6 e-18 +- 2 e-18	< 1.3 e-17	1.5 e-17 +- 6 e-18
40	< 3.5 e-18	< 5.0 e-16	< 1.2 e-17
41	6.5 e-18 +- 2 e-18	< 1.6 e-17	1.2 e-17 +- 6 e-18
42	2.3 e-18 +- 1 e-18	< 6.3 e-18	< 4.2 e-18
43	3.1 e-18 +- 4 e-19	< 4.2 e-18	< 2.0 e-18
44	1.6 e-16 +- 3 e-18	< 6.1 e-17	1.5 e-16 +- 1 e-17
45	1.4 e-18 +- 3 e-19	< 8.3 e-19	< 2.1 e-18
48	< 1.3 e-19	< 4.4 e-20	< 5.0 e-19
49	3.5 e-19 +- 2 e-19	< 3.0 e-20	< 6.0 e-19
50	< 2.8 e-19	< 3.0 e-19	< 2.0 e-18
51	1.4 e-18 +- 3 e-19	< 1.2 e-18	2.7 e-18 +- 8 e-19

52	3.4 e-18 +- 2 e-19	< 4.2 e-19	< 7.0 e-19
53	< 1.7 e-19	< 3.9 e-19	< 7.0 e-19
54	< 1.5 e-19	< 1.3 e-19	< 8.0 e-19
55	5.2 e-19 +- 3 e-19	< 1.1 e-18	< 1.0 e-18
56	1.1 e-18 +- 3 e-19	< 1.4 e-18	< 8.0 e-19
57	< 1.9 e-19	< 4.8 e-20	< 5.0 e-19
58	< 1.9 e-19	< 5.0 e-20	< 6.0 e-19
64	4.3 e-19 +- 1 e-19	< 1.5 e-19	< 6.5 e-19
65	< 1.1 e-19	< 1.0 e-19	< 4.5 e-19
66	< 1.5 e-19	< 3.4 e-20	< 5.8 e-19

Air Leak Rate Using the Air Signature Program $<1X10^{-9}$ TL/S
refinement still continuing

Atmospheric Ratios

		After Bake RGA Untrapped	Before Bake RGA Trapped
GAS	AMU	Ratio	Ratio
N2	28	1.0 +- 6.2 e-3	1.0 +- 2.5 e-4
N2	14	0.1681 +- 1.0 e-3	0.1875 +- 3.4 e-4
A	40	0.0123 +- 1.0 e-4	0.0139 +- 5.2 e-5
N2	29	0.00743 +- 4.4 e-5	0.0096 +- 1.4 e-4
A	20	0.00182 +- 2.0 e-5	0.0019 +- 1.3 e-5
	27	0.00099 +- 8.6 e-6	0.0015 +- 2.4 e-5
O2	32	0.00098 +- 4.8 e-6	0.1708 +- 1.1 e-3
O2	16	0.00067 +- 2.5 e-5	0.0514 +- 1.2 e-3
CO2	44	0.00058 +- 3.4 e-5	0.0142 +- 9.0 e-3

Outgassing Rate Dependence On Temperature

Gas	AMU	Temp. Increase to Double Outgassing @ 300 K	Binding Energy in K
H_2	2	4.9 +- 0.7 K	1.3 +- 0.2 e4
H_2O	18	4.8 +-1.5 K	1.3 +- 0.4 e4
CO	28	analysis not completed	
CO_2	44	6.5 +- 3 K	9.6 +- 4 e3

H.1 COUPON OUTGAS TEST FACILITY INSTALLATION

OPTION PLANS AND PROCEDURES: COUP-01

QUALIFICATION TEST PLANS AND PROCEDURES: COUP-02

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

The major difference between the coupon testing during the QT and the testing during the option phase is that the test system has a different number of coupon test chambers. The coupon test system used for the QT had only one coupon chamber. The coupon test system to be used for the option phase will have the same number of chambers as the number of coils in one air bake cycle. This will allow the fastest testing of an entire air bake batch of tube material.

The current plans are for a coupon test system consisting of three coupon chambers. However, there is a possibility of an air bake cycle containing up to six coils. The coupon system will be increased to six chambers if the air bake increases to six coils per batch.

QUALIFICATION TEST EXECUTION:

The coupon system was designed, and procured in accordance with the FDR proposed system. The system consisted of two major pumping manifolds. The first manifold, called the dirty pump loop, is utilized to evacuate the coupon chamber and the coupons and is operated until the end of the coupon bake out. The second manifold is called the clean pumping system and is used only after the coupon bake out is completed.

Each manifold is provided with a Balzers TPU 062 H wide range turbomolecular pump and a Balzers DUO 1.5A two stage roughing pump. Each of the roughing pumps is provided with a variable leak valve to prevent back streaming of oil by limiting the pressure to the viscous flow range. The clean manifold is provide with a 4" ID cold trap and a Leybold Heraeus Transpector RGA. Each manifold is also provided with a cold cathode type vacuum gage.

The coupon chamber is fabricated from 6"Ø tubing with a wall thickness of 1/8". The initial chamber had Conflat blank flanges on both ends. However, in an effort to reduce the hydrogen background, one of the conflat flanged ends was cut off and a 1/8" plate welded to the tube for the end closure.

The coupon chamber and the entire clean pumping loop was baked, under vacuum, at over 400°C with the exception of the RGA and the cold cathode gages in an effort to minimize the hydrogen background. It was hoped that the hydrogen background would be low enough to utilize steady state outgassing techniques as well as accumulation techniques.

The coupon test system was leak tested using an Alcatel, turbomolecular pumped, helium mass spectrometer leak detector which was attached to the foreline of the turbomolecular pumps. The leak test was also repeated after the bake out. Three or four leaks were detected in the post bake leak test. These leaks were in conflat flanges. An effort was then made to ensure that all conflat flanges were tightened to a metal to metal condition.

H.2 COUPON OUTGAS TEST FACILITY VERIFICATION

OPTION PLANS AND PROCEDURES: COUP-01

QUALIFICATION TEST PLANS AND PROCEDURES: COUP-02

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
The option phase verification will be accomplished in the same fashion as the qualification test apparatus.

QUALIFICATION TEST EXECUTION:
The first step in the verification of the outgas test system was to bake out the empty coupon chamber and run a background outgassing test. Each time the chamber background is tested, the actual background measurement is repeated at least twice or until repeatable outgassing rates are measured. The background is measured by measuring the pressure spikes resulting from first an accumulation in the coupon chamber and then an accumulation in the hydrogen calibrated leak. The measurements were made using the Leybold Heraeus RGA. The calibrated leak accumulations are repeated until the pressure spike heights for the chamber and leak accumulations are of approximately the same height. This eliminated any errors due to non-linearity of the RGA.

The first series of background tests indicated a background which was higher than expected at approximately $8.5X10^{-10}$ TL/S. This rate is compared with the outgassing of a 110 piece set of coupons which would be $2.89X10^{-9}$ TL/S at the maximum desired outgassing rate of $1X10^{-13}$ TL/S cm^2 or $2.89X10^{-10}$ TL/S if the outgassing rate is a decade less than the maximum desired rate. It was then decided that the conflat flanges would be removed from one end of the coupon chamber and a thin plate closure welded in place of the conflats. The chamber was then rebaked at over 400°C.

The chamber background was then retested with no appreciable change in the results. It was then decided to use the chamber with the high background rate. The system as built would provide sufficient accuracy for the accumulation method but would not be sensitive enough for steady state measurements.

The system was then verified by testing four sets of coupons which Caltech had previously tested in their coupon testing apparatus. CBI's coupon chamber was twice the size of the Caltech chambers. Therefore, CBI tested two of Caltech's coupon sets each time the CBI system was operated. The Caltech coupons consisted of two sets of coupons which were near the upper acceptable limit for hydrogen outgassing and two sets of coupons which had lower outgassing rates. The following table lists the Caltech samples with the Caltech and CBI outgassing test results.

SAMPLE DESIGNATION	CIT OUTGASSING DATA - 1992	CIT OUTGASSING DATA - 1994	CBI OUTGASSING DATA - 1995
23-11C	$3.1X10^{-14}$	N/A	$6.5X10^{-14}$
75-11C	$1.8X10^{-14}$	$3.3X10^{-14}$	
23-11B	$8.4X10^{-14}$	N/A	$1.4X10^{-13}$
BLACK-1	$1.0X10^{-13}$	N/A	

DISCOVERIES AND CONCLUSIONS

The CBI hydrogen outgassing test facility is capable of measuring the outgassing rate of coupons using the accumulation method. It appears that CBI's measurements are somewhat higher than the measurements accomplished by Caltech. Some of the difference may be a caused by a recharging of the hydrogen in the baked out material and / or may be an offset caused by some slight difference in procedures.

PROPOSED CHANGES:

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- Additional development may consist of a determination of the relationship of the outgassing rate when the coupons are hot at the end of the bake and when the coupons have been allowed to cool down after the bake. If the temperature relationship can be determined, then the coupons could be tested while still hot and save at least two days during each test.

- A second development program may be undertaken during the option phase of the project. This development program would compare the outgassing rates of coils from the same bake cycle and manufactured from the same heat. If all of the coils which are from the same heat and which have been baked in the same bake cycle have similar outgassing results, Caltech may determine that only one coupon test is required for all coil made from the same heat and baked in the same bake cycle.

H.3 COUPON PREPARATION FOR HYDROGEN OUTGAS TESTING

OPTION PLANS AND PROCEDURES:

CLCOUP, "Cleaning of Outgas Coupons"
BI1N, "Blacklight Inspection Technique and Solvent Cleaning Procedure"

QUALIFICATION TEST PLANS AND PROCEDURES:

The QT plans and procedures are the same as the Option

MAJOR DIFFERENCES BETWEEN THE QT AND THE OPTION:

There are no major differences between the QT and the Option

QUALIFICATION TEST EXECUTION:

It is specified that all materials exposed to vacuum shall comply with LIGO Specification #1100007, "Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products". The material to be processed shall be conventional SA 240 Type 304L stainless steel, with thickness of .13 inch or less. All raw materials shall be air baked at 440°C ± 8°C for 36 hours. After the air bake, material samples (coupons) are to be taken from all baked materials and tested to confirm acceptable outgassing level for hydrogen.

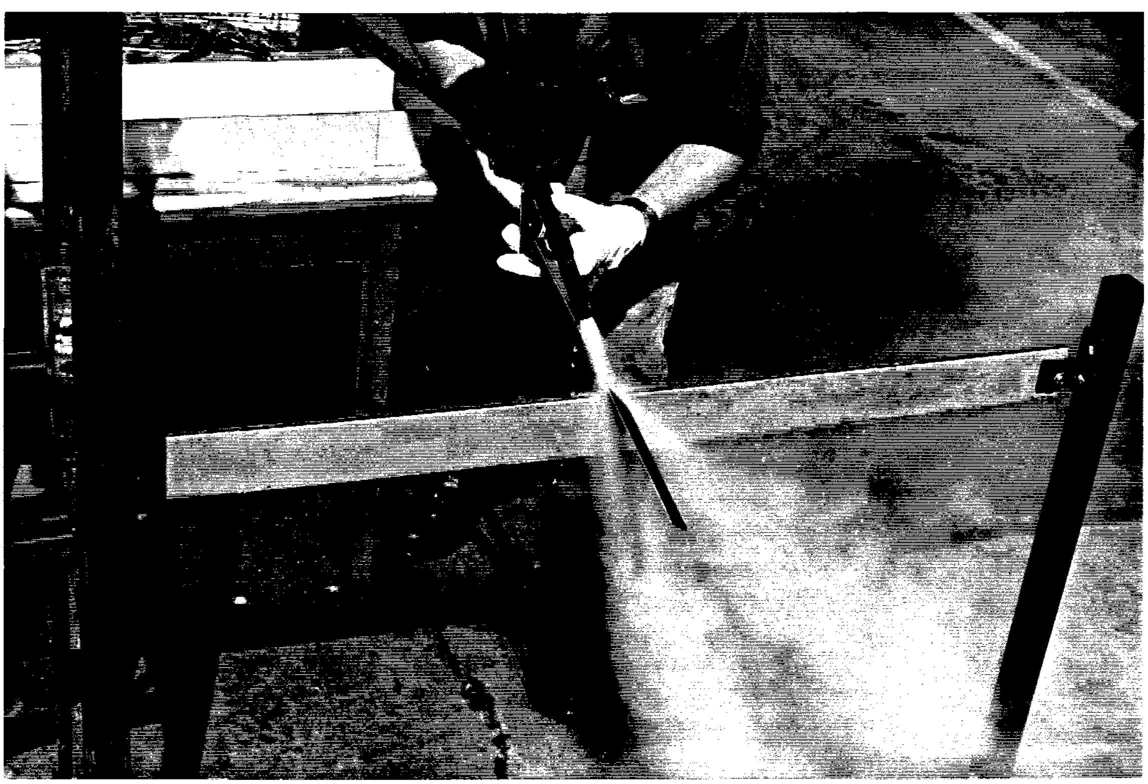
After the three coils of the beam tube material and the 10 sheets of expansion joint/baffle material were air baked a piece of material was removed from the outside of each of the three coils, from near the middle of coil #115299, and from one sheet of each of the two heat lots of the expansion/baffle material. The four pieces of material shear cut from the coils were approximately 75" long by 49" wide (mill edge). Hydrogen outgas coupons (192 @ 1" wide x 18" long) were sheared from each of these four sheets of coupon material. Also, two pieces of material 60" long by 54" wide were shear cut from a sheet from each heat lot of the expansion joint/baffle material. Hydrogen outgas coupons (180 @ 1" wide x 18" long) were shear cut from each of these two pieces.

The coupons were sheared at Lockport Fabricators and witnessed by CBI to insure that during the cutting process the materials tractability was maintained and that the coupons were not contaminated during the cutting process. The coupons from the six different material sources were shear cut and packaged separately.

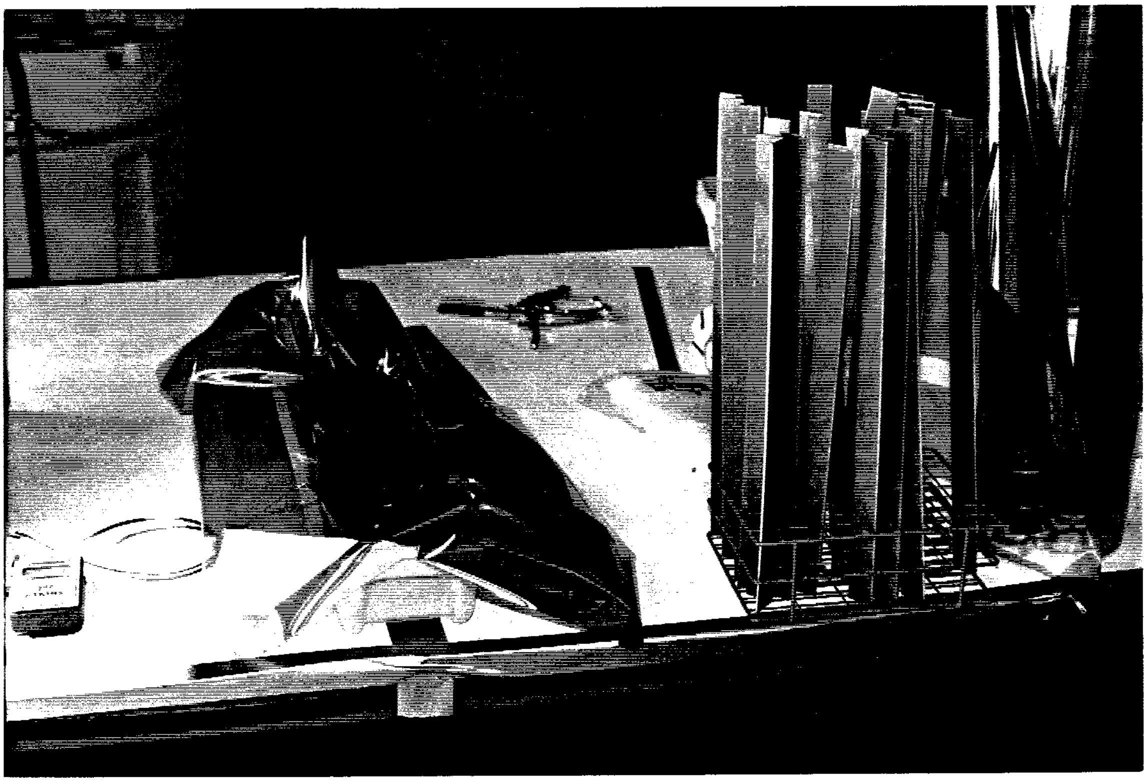
Every coupon was steel stamped with a heat serial coding (C1 through C6) to identify maintain tractability during the coupon cleaning, inspection, packaging and testing processes. Listed below are the Heat Serial codes and the corresponding material sources:

Heat Serial Coding	Material Source
C1	Coil #115299B (2nd wrap of coil)
C2	Sheet Heat #114528
C3	Sheet Heat #073524
C4	Coil #115300B (2nd wrap of coil)
C5	Coil #115301B (2nd wrap of coil)
C6	Coil #115299B (1/3 from outside of coil)

The coupons were cleaned, inspected and packaged per procedure CLCOUP, Rev 2, "Cleaning of Outgas Coupons" which consisted of a steam cleaning process only The sets of coupons having the same heat serial code were kept segregated and processed separately.



Cleaning Coupons for Hydrogen Outgas Testing



Hydrogen Outgas Coupons After Cleaning

During the blacklight inspection all coupons with indications were segregated from the clean coupons. About a dozen of the coupons from each of the coupon sets with heat serial codes C1, C4, C5 and C6 had unacceptable fluorescent indications. The contamination is most likely tape adhesives. At MetalPro, tape was used to attach the wrapping material to the coupon material during the wrapping process.

DISCOVERIES AND CONCLUSIONS:

In the QT the coupon material was not removed from the coils immediately after baking as was originally planned. The bake facility did not have equipment and expertise to remove the coupon material from the coils. The coupon material was removed from the coils by MetalPro before slitting.

The residue from tape adhesives is a contaminant. It produces unacceptable fluorescent indications during blacklight inspection.

PROPOSED CHANGES:

Revise the Option plan to remove the coupon material after leveling and before slitting. Plan to store the coil material at the slitting facility until approved for use. Slitting should not be performed until the material is approved for use.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The cost and time of shipping the coil material from the bake facility to the slitting facility would be lost if material had unacceptable level of hydrogen outgassing.

H.4 BEAM TUBE AND EXPANSION JOINT MATERIAL H2 OUTGAS TESTING

OPTION PLANS AND PROCEDURES: COUP-01

QUALIFICATION TEST PLANS AND PROCEDURES: COUP-02

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:
None.

QUALIFICATION TEST EXECUTION:
The beam tube material was the first QT material tested in CBI's hydrogen outgas test facility. The chamber was heated to 250°C for 36 hours and then allowed to cool with assistance of the chamber cooling water coils. The outgas tests were started at least 72 hours after the start of cool down. During the outgas tests, it was noted that a conflat flange was leaking. The leak was repaired and the outgas tests were restarted. The coupons were removed from the chamber after the completion of the outgas tests and the chamber was reevacuated and the chamber again tested for background.

The coupons from the expansion joint material were then loaded in to the chamber. The bake out and outgas tests were then repeated for the new material and the coupon testing was then complete for the QT phase of the project.

DISCOVERIES AND CONCLUSIONS:
The only discovery during the outgas testing was that the coupon chamber background outgas rate changed during the beam tube material outgas tests. The background outgassing increased to $1.5X10^{-9}$ TL/S. The results of the hydrogen outgas tests are as follows.

MATERIAL	MAT'L DESIGNATION	CIT OUTGAS RESULTS	CBI OUTGAS RESULTS
BEAM TUBE MATERIAL	115299B/C1	$2.5X10^{-14}$	$3.5X10^{-14}$
EXPANSION JOINT MATERIAL	073524(1D,C3)	$9.5X10^{-15}$	$3.2X10^{-14}$

The chamber background was not tested after the expansion joint material tests. The relatively high value for the expansion joint material may be due to another increase in the coupon chamber background.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

- It may be of value to determine if the high measurement of the expansion joint material is due to an increasing background and to determine the extent of the increase. Will the background keep increasing with each bake out or will the outgassing rate stabilize.
- The other possibility is a change in the operating procedures such that the background must be tested only if a set of coupons fails the acceptability test of $1X10^{-13}$ TL/S cm^2 and after set periods of time such as every month or two months.

I.1 NONCONFORMANCE AND CORRECTIVE ACTION SUMMARY

OPTION PLANS AND PROCEDURES: **QAP 13.1 & 14.1**

QUALIFICATION TEST PLANS AND PROCEDURES: **QAP**

MAJOR DIFFERENCES BETWEEN THE QUALIFICATION TEST AND THE OPTION:

ANSI/ASQC STANDARD Q91 Quality Assurance Manual is planned for the option and the ASME Section VIII Quality Control Manual was used for the QT.

QUALIFICATION TEST EXECUTION:

The nonconforming conditions found during receiving inspection were identified on the Stores Receiving Inspection Report. The nonconforming conditions were reworked, repaired or accepted for use-as-is with Caltech's agreement. The nonconforming conditions found during fabrication and installation were identified on the Nonconformance Report. The nonconforming conditions were resolved within the scope of the QT procedures. The repairs were controlled by check list. Adequate corrective action has been taken to rectify the nonconforming conditions and to prevent further recurrence. Refer to section I of the appendix for more details.

DISCOVERIES AND CONCLUSIONS:

The applicable activity report addresses discoveries and conclusions.

PROPOSED CHANGES:

The applicable activity report addresses proposed changes.

POTENTIAL RISKS & ADDITIONAL DEVELOPMENT:

The applicable activity report addresses potential risk and additional development.

SECTION 3

The following listing provides a brief description of the lessons learned during the execution of the qualification test and identifies proposed changes. Additional information is contained in the Task Activity Reports.

Material Procurement

- Steel mills are not well suited to economically meet special process or schedule requirements and as such, should not be used for these processes if possible.
- Special packaging is required to prevent potential contamination during the coil bake out.
- Material composition and performance requirements must be carefully reviewed to assure conformance.
- The steel manufacturing and processing may be introducing unknown contaminates to the steel surface.
- Specialized coil bake out facilities are not readily available to meet the LIGO bake process requirements. The conditions required for coil bake out must be determined. The furnace characteristics must then be developed to meet these requirements.
- The weld wire cleaning process must not adversely affect the spooling characteristics of the wire. Poorly spooled wire deteriorates weld performance.

Spiral Welded Tube Fabrication

- The spiral welded tube industry is not well suited to produce tube sections suitable for the LIGO project. Developments are required to improve the economy, reliability, and weld quality of the spiral tube sections for the LIGO project. The beam tube contractor and the LIGO Project Team must develop and control the tube fabrication.
- The Gas Tungsten Arc Welding (GTAW) process used for the spiral welds did not produce suitable welds due to the lack of penetration that developed during the weld process.
- The final inspection and associated minor weld repair is most economically performed during stiffener attachment.
- Coil slices were successfully made by stopping the mill and splicing the coils on the inside surface with a one pass weld without filler metal. The second pass on the outside with filler metal is best made during stiffener attachment.
- 100% argon should be used as the purge gas in the GTAW process to better maintain the tungsten tip profile.
- Axial straightness of the tube sections was .08" and .10" for the two 61' sections produced for the QT. Thus, the QT tubes met the specified straightness of .25".
- Tube manufacturing may be introducing unknown contaminates to the tube surface.

Beam Tube Stiffener and Pump Port Fabrication

- The stiffener and port details are well suited for the LIGO project.
- The dimensional tolerances of the vacuum stiffening rings must be closely controlled to facilitate fit-up and welding. The diameter of the vacuum stiffeners must be sized to equal or exceed the maximum tube diameter.

- The inside diameter of the support and baffle ring stiffeners exceeded the specified tolerances but were usable. The support and baffle ring stiffeners can be procured a group of five sizes to accommodate the anticipated tube diameter variation instead of machining each stiffener to a measured diameter.
- Pump port nozzle necks must be radiused to a close tolerance to facilitate attachment to the tube.

Support Fabrication

- The configurations of the fixed and flexible supports are well suited for the LIGO project.
- Support details were modified to provide jacking surfaces for tube alignment.
- Support frames were modified to facilitate access to drill and install the anchor bolts.
- Support details were modified to eliminate an interference for maximum alignment capability.
- Flexible support hangers should not be galvanized to prevent distortion of the relatively thin carbon steel hangers. Stainless steel hangers should be used.

Expansion Joint Fabrication

- The expansion joint configuration is well suited for the LIGO project.
- Expansion joint manufacturers currently do not have the capability to perform component leak tests with a helium leak sensitivity of 1×10^{-10} torr liters per second.
- The circumferential tolerance of the expansion joint ends can be increased slightly due to weld procedure modifications.
- All expansion joint ends may not meet the circumferential tolerance even though fabricators claims the ability to meet the tolerance.
- The flatness tolerance originally specified for the expansion joint ends can be increased due to weld procedure modifications. The expansion joints are too flexible to meet the original tolerance even though the ends are machined.
- The expansion joints must be carefully handled and packaged to prevent minor distortion of the machined ends.

Stiffener and Pump Port Attachment

- Stiffener and pump port attachment procedures are well suitable for the LIGO project.
- Tack welds are required to hold the stiffener in place during welding. Tack welds should be spaced closer together to reduce weld distortion. Tack welds should be 1/2" long with a throat thickness approximately equal to the plate thickness.
- The weld procedure should be revised to require a minimum wire feed stick out dimension of 1/2" and to require a longer gas cup nozzle to prevent tip contact with the shell. The gas cup nozzle must cover the contact tip by at least 1/8" to protect the tip from arcing out on the tube surface.
- A large source of nitrogen gas is required to quickly produce the required purge environment in the tube prior to welding.
- The 4" hand pass at the stiffener lap should be welded after the automatic stiffener fillet weld.

- Grounding cables should be long enough to accommodate the full length of the tube section to prevent variations in the weld voltage when moving from one stiffener to the next.
- The beam tube section is too flexible to allow the use of a hole saw for the pump port opening. Plasma cutting is required.
- The tube straightness is not significantly affected by the weld shrinkage associated with stiffener attachment. Stiffener weld shrinkage reduces the overall tube length by approximately 1/4".
- The flatness of the end of the tube before and after stiffener attachment could not be measured accurately enough to determine if tube facing can be executed prior to stiffener attachment. Tube sections can probably be machined prior to stiffener attachment but confirmation is required.
- The QT beam tube sections contained two leaks at unrelated fillet weld repair locations. One leak occurred at a fillet weld repaired to remove cracks caused by copper deposits from the welding contact tip. The other leak occurred at the repair of a fatigue crack caused by improper support of the tube during shipment.

Tube Assembly End Preparation

- Spiral welded tube manufacturers do not currently have the ability to machine and expand the tube ends to the circumferential and flatness tolerances required.
- The relative flexibility of the thin tube makes end facing a very difficult operation. End preparation should be executed with a end facing tool rather than a radial cut off tool.
- The end of the tube must be round and well supported during the end preparation.

Tube Shipping & Handling

- The tube shipping supports must distribute the load evenly to the tube wall during transportation.
- Tube stiffeners should not be used to support the tube during shipping and handling due to the inherent weakness of single sided fillet welds.
- Tube sections must be covered when exposed to the sun to prevent distortions due to the thermal gradients that are caused by solar radiation.

Baffles

- The current baffle specification and design may not be suitable for use in the LIGO project due to the potential lack of stability.
- The beam tube diameter must be increased slightly to accommodate the poorer than anticipated fit provided by the current baffle design.
- The spring force of the baffle may not provide sufficient long term stability of the baffle. Repeated bake outs or seismic events may cause the baffle to become unstable and impinge on the clear aperture. The specification prohibiting baffle attachment to the tube wall should be removed.

Circumferential Weld Seams

- The machine Gas Tungsten Arc Welding (GTAW) process executed with the automatic features of the Dimetrics Gold Track II power source produced excellent circumferential welds.
- The purge dam must be fabricated to the specified diameter to provide the required fit up.
- The maximum temperature rise in the tube shell 3.5" away from the circumferential seam is 65 degrees F. Standard elastomeric material such as butyl rubber can be used for the weld purge dam.
- Close edge alignment of the circumferential seam is required to provide a suitable weld seam. The maximum gap is .010" and the maximum plate offset is 1/4 of the thickness or 1/32".
- The purge pressure must be kept to a minimum and constant during the circumferential weld. The weld seam must be taped during the weld process to help maintain a constant gas flow and pressure as the first pass closes the circumferential seam.
- Circumferential welds seams are difficult to perform and must be executed with close attention to the approved procedures.
- Mechanical oscillation of the weld arc allows a greater degree of plate offset and greater degree of weld gap and should be included in the first and second circumferential pass.

Beam Tube Section Leak Tests

- Section leak tests were successfully executed to the required sensitivity. The double seal configuration provides a suitable seal for sensitive leak testing to a helium rate of 1 X 10-10 torr liter per second.
- Back migration of helium through the helium mass spectrometer causes a gradual rise in the helium background measured in the tube. The mass spectrometer must be bagged and purged with nitrogen or otherwise separated from the atmosphere around the tube being tested.
- Bagging the tube section with polyethylene plastic requires a large quantity of helium to produce a 75% helium environment around the tube. Helium is lost through the seams and permeates through the bag which contributes to helium back migration.
- The tube section pumping system should contain metal seals to limit helium permeation through the pumping system flanges.
- Pre-made bags reduce the effort required to bag the tube sections but are still difficult to install.
- The two leaks discovered during the QT were at through thickness weld repairs. These repairs were located at stiffener attachment fillet welds that had been repaired due to unusual events.

Circumferential Leak Testing

- The circumferential seams can be leak tested with an external box to the required helium leak rate sensitivity of 1 X 10-10 torr liter per second.
- It is difficult to adequately seal the external box without vacuum putty such as Apeizon Q due to the shell profile at the weld and due to the roughness of the weld and tube.

- Leak testing with a short segmental box is time consuming due to the need to vent the purge ring of helium and reseal and evacuate the vacuum box each time it is moved.
- Additional development is required to reduce the time required to perform the circumferential leak test. The development should attempt to produce an external leak test ring which tests the entire seam at one time.

Tube Cleaning

- The originally specified cleaning procedure was inadequate for the LIGO project. The discovery of minute bleeding spots of fluorescence under black light inspection led to a sizable program to improve the cleaning procedure. A detergent bath and high pressure water rinse now proceed the previously specified steam cleaning process. In addition, the steam cleaning process is now followed by a solvent wash and solvent rinse.
- The rotating union used for steam cleaning requires a minimum pressure of 130 psi to maintain rotation. The steam cleaning unit pressure and flow capacity do not provide a sufficient margin over that required by the rotating union to assure continuous operation.
- Additional development is required to incorporate the QT cleaning process into the option plans and procedures.
- Areas of fluorescence can be seen under black light inspection before and after the cleaning process. Some of these areas can not be removed with solvents or detergents without removing the oxide layer from the tube surface. Outgas tests performed on the tube indicate that the presence of these fluorescent areas does not result in excessive hydrocarbon outgassing. Cleaning procedures and acceptance criteria must be developed to produce and confirm a suitable level of cleanliness.
- Additional development is required to incorporate the QT cleaning process into the module plans and procedures.

Tube Bake Out

- The I^2R heating method performed well even though the welding machines were very inefficient at the low voltage required for the Qualification Test.
- The QT bakeout required approximately 2200 amps at 7 volts which was supplied with 9 welding machines. Two welding machines malfunctioned during the 28 day bake out and were repaired or replaced.
- Fiberglass insulation is a suitable low cost insulation for the beam tube modules. One 2" thick unfaced layer of fiberglass insulation covered by an additional 2" layer of fiberglass insulation with facing were used in the QT. The Foil Skrim Kraft (FSK) facing prevents convection through the insulation and reduces radiation losses. Both layers of insulation should be faced to reduce convection through the insulation and provide a more uniform temperature.
- Insulation should overlap on the ends and fit snug to the tube to prevent convection currents in the voids present in loose fitting insulation. In addition, outer seams in the insulation should be taped to limit convection losses and the resulting temperature variation at the seams.

- Commercially available fiber glass insulation products have widely varying conductivities for similar configurations. The quality of the insulation selected must be balanced with the associated insulation costs and the power requirements to maintain the tube temperature.
- Expansion joints are difficult to maintain at the tube temperature due to the additional heat generated by the higher resistance of the joint, the higher local surface area, and the convection cells formed by convolutions. The expansion joint was insulated with a single layer of 1" thick FSK faced insulation around the entire circumference and an additional 2" layer of unfaced insulation on the bottom 180 degrees.
- The flexible supports do not require auxiliary heat sources if insulated for the bake out.
- The heat loss at the fixed supports must be reduced by reducing the area of the insulation blocks to prevent the need for an auxiliary heat source at the fixed supports.

QT Pumping System

- The Balzers RGA used in the QT is well suited for the LIGO project. The Balzers turbomolecular pump also performed well.
- The original Balzers roughing pump purchased for the QT was not capable of the sustained, high load pumping required to rough pump the beam tube sections or QT assembly without over heating. The larger replacement pump provided by Balzers performed adequately.
- The pressure measured by cold cathode gauges in the 10^{-10} torr range may be off by a factor of 2 or 3.
- A flange leak developed in a 6" conflat flange during a 150 degrees C bake out even though the flange had been baked a number of times earlier without producing a leak. Similar occurrences during the module leak test would greatly increase the module leak test difficulty.
- Spacers used in the cold traps may be a source of hydrocarbon outgassing during bake out of the cold traps.
- Cold traps quickly warm and release condensables when the cold trap exterior is being baked and the supply of LN2 is disrupted. A reliable continuous source of LN2 must be developed for the module cold traps.

Outgas Test Results

- The outgas tests were completely successful and produced accurate, reliable outgas test data.
- The outgassing rates of the beam tube QT assembly are as follows;
  - Pre-bake hydrogen: 3.0×10^{-14} torr liters per second cm^2
  - Pre-bake water: 2.2×10^{-11} torr liters per second cm^2
  - Post-bake hydrogen: 8.6×10^{-14} torr liters per second cm^2
  - Post-bake water: 2×10^{-17} torr liters per second cm^2
- Air signature analysis can detect an air leak in the qualification test assembly prior to bake out as small as 1×10^{-9} torr liters per second
- Although the analysis of the post bake outgas data continues to be refined, the air signature analysis method is able to detect an air leak in the QT assembly after bake out as small as 1×10^{-11} torr liters per second.

Coupon Hydrogen Outgas Testing

- The coupon outgas tests were successful and produced accurate, reliable hydrogen outgas test data.
- Although the coupon outgas test facility was designed to make steady state hydrogen outgas test measurements, the hydrogen outgas background of the system was too high to allow steady state measurements.
- CBI's measured hydrogen outgassing rate of coupons taken from LIGO material before component fabrication is as follows:

    Beam tube material: 3.5×10^{-14} torr liters per second cm^2
    Expansion joint material: 3.2×10^{-14} torr liters per second cm^2

- Caltech tested qualification test material and confirmed CBI's test results. CBI also tested material previously tested by Caltech and confirmed Caltech's test results. All of CBI's tests were conducted after Caltech's tests. CBI always reported higher hydrogen outgassing rates than Caltech.

SECTION 4

The qualification test identified many proposed changes and additional development requirements associated with the LIGO beam tube modules. The following areas represent the greatest risks to the beam tube module performance and /or cost:

- Tube Section Fabrication
- Spiral Weld Procedure
- Module Leak Testing
- Cleanliness & Cleanliness Maintenance

A detailed discussion of each of these areas is presented below.

TUBE SECTION FABRICATION

The most economical method of producing tube sections for LIGO is the spiral welded method. However, the spiral welded tube industry currently has neither the equipment nor the procedures in place to reliably produce tube sections of the quality required for the LIGO project. Further development is required to ensure the supply of spiral welded tube section suitable for the LIGO project.

After a literature survey to determine the industry capabilities, CBI toured the four most promising manufacturers of spiral welded pipe and tube. Tubetec, Incorporated of Sanford, Florida and Northwest Pipe Company of Portland, Oregon, were selected for the supply of pre-qualification tube sections for evaluation during the developmental design prior to the Final Design Review. Tubetec was selected for the Qualification Test tube sections due to their superior technology, quality, and economy compared to other spiral welded tube manufacturers. Although the tube sections supplied by Tubetec for the Qualification Test served their intended function, they do not meet the requirements for the LIGO modules. The supply of the unstiffened beam tube sections for the LIGO project is an area of significant cost and reliability risk as described below. Unless an alternative source can be developed, CBI believes that the best course of action for the LIGO project is to have a spiral welded tube mill produced by Tubetec specifically for the LIGO project. Without the use of Tubetec, the direct cost of the unstiffened tube sections will likely increase by at least $2,500,000.00 and significant additional development costs will be required. The uncertainties associated with the supply of the tube sections prevent the development of a reasonable updated budgetary estimate for the spiral welded fabrication.

Most large diameter tube fabricators are engaged in the fabrication of relatively thick wall, carbon steel pipe. Tubetec is the only fabricator experienced in the Gas Tungsten Metal Arc (GTMA) process engaged in the fabrication of large diameter, thin wall, spiral welded, stainless steel tubes which are similar to the tubes required for LIGO. Tubetec has developed a spiral welded pipe mill specifically for the production of thin wall stainless steel pipe. The pipe is sold primarily for low pressure transmission of liquids and represents approximately 30% of their annual sales. Although currently Tubetec is the best suited manufacturer in the industry for LIGO, CBI is concerned that that the supply of the tube sections from Tubetec could be jeopardized for the following reasons:

- Tubetec is a small family owned business with a total annual sales of $7,500,000. The LIGO beam tubes would approximately double the value of spiral welded tube produced by Tubetec for the duration of the LIGO production.
- Tubetec's existing markets are currently strong.
- Tubetec's limited resources and capacity using their existing mill could prevent Tubetec from meeting the LIGO schedule requirements while maintaining the required quality.
- Tubetec's current spiral welded tube mill was developed primarily for relatively small diameter pipe. As such, the maximum coil width that can be accommodated is 16 inches. The use of 16 inch coil for the LIGO beam tube modules would result in approximately 94 miles of spiral butt weld which limits daily production and could increase the risk of leaks. An increase in the coil width will decrease the length of weld by the ratio of the widths.

In addition, the weld procedure used by Tubetec for the Qualification Test sections did not meet the required 100% weld penetration over the entire length of the spiral weld. Spiral weld procedure development is required as described later in this section.

At present, CBI believes that Tubetec is best suited to supply a mill dedicated to the LIGO project due to their expertise in the design, fabrication, and start-up of a spiral welded tube mill. CBI recommends the development of a dedicated LIGO mill to ensure the uninterrupted supply of economical tube sections which are suitable for the LIGO project. The goal of the development effort would be to determine the coil width and other mill characteristics best suited for the LIGO project. A qualification test would be conducted on tubes manufactured from the LIGO mill prior to placing the mill into LIGO module production. CBI has approached Tubetec for the supply of a mill for the LIGO project. Although their initial response was favorable, Tubetec will not make any commitments for the project until the beam tube contractor is selected.

Alternatively, other potential sources of the spiral welded tube mill or spiral welded tube sections must be developed. The development would focus on modifying mills typically used for relatively thick wall fabrication to provide the fit up and forming characteristics required for thin wall fabrication.

SPIRAL WELD PROCEDURE

The most economical method of producing tube sections for LIGO is the spiral welded method. However, the spiral welded tube industry has limited abilities in producing spiral welds suitable for the LIGO project. Evaluations of the Qualification Test tube sections has revealed that a lack of complete penetration in the spiral welds developed sometime during the production process. Additional information is contained in Appendix C.1.

The quality of the spiral weld is primarily dependent on the fit up provided by the tube mill and on the procedures and parameters used to perform the welding. Northwest Pipe Company and Tubetec produced trial tube sections for evaluation during the developmental design prior to the qualification test. The trial section produced by Northwest Pipe contained relatively large holes due to the poor fit up provided by their mill which is typically used for thick wall, large diameter, carbon steel pipe. The trial tube section provided by Tubetec appeared to have adequate weld quality but an evaluation of the weld cross section has revealed insufficient weld penetration.

CBI selected Tubetec for the Qualification Test and worked with Tubetec to develop the weld procedure and parameters. CBI specified 70% penetration from each side to ensure that the spiral weld would meet the required 100% penetration. Weld parameters were established prior to production of the QT section through trial welds on flat plates. Weld sections taken at start of the QT tube production showed complete penetration. The QT tube sections were then produced using the established and tested weld parameters. Following production of the qualification test sections, CBI evaluated weld cross sections at each end of the tube sections used in the qualification test. At the start of LIGO QT fabrication, the weld procedure produced approximately 70% penetration on the inside pass and 40% penetration on the outside pass resulting in full penetration. However, the depth of penetration decreased during the tube fabrication to the point that most of the spiral weld in the qualification test did not have 100% penetration. Although this condition does not affect the qualification test, this condition is unacceptable in tube sections for the modules. The cause of the lack of penetration must be determined to enable the production of tube sections that meet the project requirements. To achieve this end, the following spiral weld development is recommended:

- An evaluation of additional weld sections in unused QT tube sections to determine the characteristics of the welding throughout the production of approximately 180' of LIGO beam tube. Sections should be evaluated in an attempt to correlate the changes in the weld cross section to any changes in the procedure.
- An evaluation by Tubetec of the cross sections prepared by CBI and a comparison of the weld procedure used for the QT with procedures used by Tubetec in other similar applications.
- An investigation of welds made in other similar tube sections produced by Tubetec.
- Additional tube sections could be manufactured by Tubetec from material which has been procured by CBI for Caltech and is currently in storage. Welds would be made with different parameters and then studied to determine resulting weld characteristics.

MODULE LEAK TESTING

Based in part on information developed during the Qualification Test, the following activities will have a significant influence on the level of effort, time, and materials required to produce beam tube modules with a demonstrated leak rate:

to re-pressurize the tube after bake out is difficult to predict. The cost and time required to re-pressurize with a dry gas or to perform additional bake outs are significant and the likelihood of these activities is difficult to predict.

Beam tube section leak tests and circumferential weld leak tests should produce a leak free module. However, the untried nature of the module leak rate procedure and the impact of module assembly and bake out presents uncertainties and risks which prevent an accurate estimate of the resources required to produce and demonstrate a leak free module. Although the Qualification Test has provided insight into the ultimate leak tightness of the module, the costs associated with producing and demonstrating the module leak tightness will not be known until a module has been completed. Additional study is required to determine the feasibility of new and previously untried leak test methods. In addition, commercial agreements must be developed which recognize the potential level of effort required to demonstrate module leak tightness.

CLEANING & CLEANLINESS MAINTENANCE

The qualification test identified the inadequacy of the originally specified cleaning procedure. Minute spots of contaminant were left on the surface after the single step steam cleaning procedure. A three step cleaning process was developed during the QT which consists of a Mirachem 500 wash, a water rinse, a steam rinse, a solvent wash, and a solvent rinse. Even after this process, some contaminants, that could be seen only when viewed under ultra-violet light, remained on the tube surface. The Qualification Test demonstrated that the beam tube surface can not be cleaned sufficiently to produce "no visible contaminant material" as currently specified.

The qualification test did not represent the field conditions that will be encountered during module construction. Unrelated construction activities and unknown environmental conditions will be encountered during the field construction of the modules. The effectiveness of the cleanliness maintenance procedures and equipment will not be known until construction actually begins. The proposed plans and procedures may have to be modified in the field if the procedures are unable to sufficiently prevent contamination due to dust, dirt, insects, air borne spores and seeds, or other yet unknown sources of contamination.

The hydrocarbon outgassing rates measured in the Qualification Test were within the current project requirement. However, the hydrocarbon outgassing rates of the actual modules is difficult to predict in light of the unknown conditions that will exist during module construction. No absolute level of cleanliness can be predicted for the beam tube modules. Caltech and CBI have discussed the benefits of qualifying procedures during the initial construction at Hanford and Livingston. Although a qualification of the initial construction may increase the effectiveness of the plans and procedures, the expenses and schedule delay could be significant. Construction qualification concepts which balance cost and schedule impacts with the risks associated with presently unknown environmental conditions should be considered.

APPENDICES

SECTION 2.A APPENDICES

CBI

DATE 04/19/94

CBI Technical Services
1501 NORTH DIVISION STREET
PLAINFIELD, IL 60544-8929
(815) 439-6340
FAX: (815) 439-6010

PURCHASE ORDER NUMBER
930212-0001 Rev. 0

CONTRACT
930212

SHEET NO. 1 OF 6

SHIP PREPAID TO:

SEE BELOW

TO:
ARMCO ADVANCED MATLS CO. 01402
1129 CANDLENUT DRIVE
NAPERVILLE, IL 60540

Attn: DEBBIE JUNK
(708)983-3004 FAX: (708)983-3006

BUYER	REQUISITION BY	SHIP VIA	STATE TAX		CONFIRMING	NON-CONFIRMING
WAYNE J. MEYER	C-240-0186	COMMERCIAL CARRIER	APPLIES			YES
F.O.B SEE BELOW	TERMS NET 30 DAYS		EXEMPT	YES	SHIP BY DATE 04/29/94	

PLEASE ENTER OUR ORDER FOR THE FOLLOWING, SUBJECT TO THE TERMS & CONDITIONS ON REVERSE SIDE HEREOF

ITEM NO.	QUANTITY	DESCRIPTION	ID	PRICE	INTERNAL US
		This Purchase Order is being faxed; the original and all attachments will be overnite mailed. Do not duplicate. Reference our formal Request for Quotation R-930212-002 dated 02/04/94 and Armco Advanced Material Company's faxed response dated 02/22/94. This is our formal order for the following:			
1	3	COILS 16" WIDE (FINISHED) X 0.125; 9000# MIN. WEIGHT, SA240 TYPE 304L 11000# MAX. WEIGHT, in strict accordance with Coil Material Specification C-240-0186, revision 0 dated 03/03/94 (with the exception of paragraph 2.6 which does not apply to the qualification test). The above unit price per coil is based on a coil weighing the minimum of 9000# at the rate of $103.13/cwt. This includes a $5.00/cwt charge for tension leveling. Final invoicing will occur at the rate of $103.13/cwt times the actual final shipping weight of each coil.			
2	2	COILS 48" WIDE (MILL EDGE) 27,035.1000/Per X 0.125; 27000# MIN. WEIGHT, SA240 TYPE 304L 34000# MAX. WEIGHT, in strict accordance with Coil Material Specification C-240-0186, revision 0			

LIGO File 930212-0001

[X] ACKNOWLEDGMENT COPY ATTACHED – PLEASE RETURN AT ONCE AND INDICATE F

[ ] NO ACKNOWLEDGMENT NECESSARY

M. Tellalian - NOE C
Steve Peters - RCE
Ken Flessas/CBICL - Houston
Wayne J. Meyer /File

SPECIAL CONDITIONS

Furnish all invoices and bills of lading in duplicate to us at
01 NORTH DIVISION STREET

We reserve the right to refuse all invoices unless bills of lading, express receipts or prepaid bills are attached to the invoices.

PURCHASE ORDER NO. & CONTRACT NO. TO APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

BY Wayne J. Meyer
AUTHORIZED PURCHASING SIGNATURE
ADDRESS ALL CORRESPONDENCE TO SIGNEE

WAYNE J. MEYER

CBI

CBI Technical Services Co.
1501 NORTH DIVISION STREET
PLAINFIELD, IL 60544-8929
(815) 439-6340
FAX: (815) 439-6010

930212-0001 Rev. 0

CONTRACT 930212

DATE 04/19/94

SHEET NO. 2 OF 6

TO: ARMCO ADVANCED MATLS CO.
1129 CANDLENUT DRIVE
NAPERVILLE, IL 60540

01402

SHIP PREPAID TO:

SEE BELOW

Attn: DEBBIE JUNK
(708)983-3004 FAX: (708)983-3006

BUYER	REQUISITION BY	SHIP VIA	STATE TAX		CONFIRMING	NON-CONFIRMING
WAYNE J. MEYER	C-240-0186	COMMERCIAL CARRIER	APPLIES			YES
FOB: SEE BELOW	TERMS: NET 30 DAYS		EXEMPT	YES	SHIP BY DATE: 04/29/94	

PLEASE ENTER OUR ORDER FOR THE FOLLOWING, SUBJECT TO THE TERMS & CONDITIONS ON REVERSE SIDE HEREOF

ITEM NO.	QUANTITY	DESCRIPTION	ID	PRICE	INTERNAL USE
		dated 03/03/94 (with the exception of paragragh 2.6 which does not apply to the qualification test). The above unit price per coil is based on a coil weighing the minimum of 27000# at the rate of $100.13/cwt. This includes a $5.00/cwt charge for tension leveling. Final invoicing shall occur at the rate of $100.13/cwt at the actual final shipping weight of each coil.			
		NOTES:			
		A) The following value added activities will be performed on the above material. Costs for these activities is included in the unit rates.			
		1. Three coils (NAS 050, 0.125 x 49.5) will be produced by NAS. One of the coils will be designated as the Qualification Test (QT) Coil to be used for producing the three 16" wide finished coils and should be marked as such. This QT Coil only will have a bar (approximately .075" X 1" X full width) placed in the center of the coil to create an opening across the width to be used to place a thermocouple in during the bakeout. This bar will be provided to NAS by the Purchaser.			

[XX] ACKNOWLEDGMENT COPY ATTACHED – PLEASE RETURN AT ONCE AND INDICATE FIRM SHIPPING DATE.

[ ] NO ACKNOWLEDGMENT NECESSARY

SPECIAL CONDITIONS

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PURCHASE ORDER NO. & CONTRACT NO. TO APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

BY Wayne J Meyer
AUTHORIZED PURCHASING SIGNATURE
ADDRESS ALL CORRESPONDENCE TO SIGNEE

WAYNE J. MEYER

PURCHASE ORDER

CBI

CBI Technical Services Co
1501 NORTH DIVISION STREET
PLAINFIELD, IL 60544-8929
(815) 439-6340
FAX: (815) 439-6010

PURCHASE ORDER NUMBER
930212-0001 Rev. 0
CONTRACT
930212

SHEET NO. 3 OF 6

SHIP PREPAID TO:

SEE BELOW

DATE 04/19/94

ARMCO ADVANCED MATLS CO. 01402
1129 CANDLENUT DRIVE
NAPERVILLE, IL 60540

Attn: DEBBIE JUNK
(708)983-3004 FAX: (708)983-3006

BUYER	REQUISITION BY	SHIP VIA	STATE TAX		CONFIRMING	NON-CONFIRMING
WAYNE J. MEYER	C-240-0186	COMMERCIAL CARRIER	APPLIES			YES
FOB	TERMS		EXEMPT	YES	SHIP BY DATE 04/29/94	
SEE BELOW	NET 30 DAYS					

PLEASE ENTER OUR ORDER FOR THE FOLLOWING, SUBJECT TO THE TERMS & CONDITIONS ON REVERSE SIDE HEREOF

ITEM NO	QUANTITY	DESCRIPTION	ID	PRICE	INTERNAL USE
		2. The three NAS 050, 0.125 X 49.5 coils are to be shipped to Metlab in Philadelphia, Pennsylvania on or before 04/29/94. Full shipping consignment and shipping details are indicated on the attached Customer Specification Questionaire for Metlab shipment. Note that this material must be shipped to Metlab with the eye of the coils vertical (eye to the sky). The coils shall be packaged for shipment to Metlab as described in ASTM A700-90, Section 12.4.5.1, except as illustrated in Figure 64 versus Figure 63. Note that the coils will be baked as packaged. Do not use flammable materials. Use only metal banding protectors and load on a truck using blocking which allows the insertion of slings for unloading. Material to be covered for weather protection during shipment. 3. Metlab will perform a material bakeout on the three coils and return the coils to Leveltek in Pittsburgh, Pennsylvania. This material will be shipped from Metlab "eye to the sky". 4. NAS will arrange for Leveltek to stretcher level all three coils. Once stretcher leveling is complete, Leveltek will ship the three coils to a location to be determined by Armco for the following:			

[X] ACKNOWLEDGMENT COPY ATTACHED - PLEASE RETURN AT ONCE AND INDICATE FIRM SHIPPING DATE.

[ ] NO ACKNOWLEDGMENT NECESSARY

SPECIAL CONDITIONS

...a invoices and bills of lading in duplicate to us at:

1501 NORTH DIVISION STREET

We reserve the right to refuse all invoices unless bills of lading, express receipts or prepaid bills are attached to the invoices.

BY Wayne J Meyer
AUTHORIZED PURCHASING SIGNATURE
ADDRESS ALL CORRESPONDENCE TO SIGNEE

PURCHASE ORDER NO. & CONTRACT NO. TO APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

WAYNE J. MEYER

PURCHASE ORDER NUMBER 930212-0001 Rev. 0

CONTRACT 930212

SHEET NO. 4 OF 6

SHIP PREPAID TO:

SEE BELOW

CBI

CBI Technical Services Co
1501 NORTH DIVISION STREE.
PLAINFIELD, IL 60544-8929
(815) 439-6340
FAX: (815) 439-6010

DATE 04/19/94

ARMCO ADVANCED MATLS CO.
1129 CANDLENUT DRIVE
NAPERVILLE, IL 60540

01402

Attn: DEBBIE JUNK
(708)983-3004 FAX: (708)983-3006

BUYER	REQUISITION BY	SHIP VIA	STATE TAX		CONFIRMING	NON-CONFIRMING
WAYNE J. MEYER	C-240-0186	COMMERCIAL CARRIER	APPLIES			YES
FOB: SEE BELOW	TERMS: NET 30 DAYS		EXEMPT	YES	SHIP BY DATE 04/29/94	

PLEASE ENTER OUR ORDER FOR THE FOLLOWING, SUBJECT TO THE TERMS & CONDITIONS ON REVERSE SIDE HEREOF

ITEM NO.	QUANTITY	DESCRIPTION	ID	PRICE	INTERNAL USE
		- For the QT Coil that has been marked for slitting to 16", six (6) total sheets 72" X full width will be cut from the end prior to slitting, marked as being cut from this master coil, and shipped regular commercial freight to CBI's Plainfield office at the address that appears in the heading of this purchase order. This QT Coil will then be finished slit into three (3) coils 16" wide. Each 16" finished coil will be marked right, center, or left. These three 16" coils are to be shipped to Tubetec, Inc. in Sanford, Florida. Full shipping consignment and shipping details are indicated on the attached Customer Specification Questionnaire for Tubetec Shipment.			
		- One sheets each 72" X full width is to be cut from the end of each of the remaining two coils. These two sheets are to be shipped with the other six sheets cut from the master coil to the Plainfield, Illinois address. The two coils are then to be shipped to CBI's Kankakee, Illinois facility. Full shipping consignment and shipping details are indicated on the attached Customer Specification Questionnaire for Kankakee Shipment.			
		B) Armco may invoice for freight costs for the			

[X] ACKNOWLEDGMENT COPY ATTACHED – PLEASE RETURN AT ONCE AND INDICATE FIRM SHIPPING DATE.

[ ] NO ACKNOWLEDGMENT NECESSARY

SPECIAL CONDITIONS

...sh all invoices and bills of lading in duplicate to us at:
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PURCHASE ORDER NO. & CONTRACT NO. TO APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

BY Wayne J. Meyer
AUTHORIZED PURCHASING SIGNATURE
ADDRESS ALL CORRESPONDENCE TO SIGNEE

WAYNE J. MEYER

PD 706 REV SEP 9?

CBI

DATE 04/19/94

CBI Technical Services Co
1501 NORTH DIVISION STREET
PLAINFIELD, IL 60544-8929
(815) 439-6340
FAX: (815) 439-6010

930212-0001 Rev. 0

CONTRACT

930212

SHEET NO. 5 OF 6

SHIP PREPAID TO:

SEE BELOW

TO:
ARMCO ADVANCED MATLS CO.
1129 CANDLENUT DRIVE
NAPERVILLE, IL 60540

01402

Attn: DEBBIE JUNK
(708)983-3004 FAX: (708)983-3006

BUYER	REQUISITION BY	SHIP VIA	STATE TAX		CONFIRMING	NON-CONFIRMING
WAYNE J. MEYER	C-240-0186	COMMERCIAL CARRIER	APPLIES			YES
F.O.B. SEE BELOW	TERMS NET 30 DAYS		EXEMPT	YES	SHIP BY DATE 04/29/94	

PLEASE ENTER OUR ORDER FOR THE FOLLOWING, SUBJECT TO THE TERMS & CONDITIONS ON REVERSE SIDE HEREOF

ITEM NO.	QUANTITY	DESCRIPTION	ID	PRICE	INTERNAL USE
		final quantities of material shipped to Tubetec and to CBI's facilities in Kankakee and Plainfield on an equalized basis of freight costs from Carrolton, Kentucky to each of those locations. The Purchaser will be responsible for arranging for shipment and for paying the freight costs from Metlab's facility to Leveltek's facility. All other shipments and freight costs are the responsibility of Armco and are included as part of the equalized freight costs from Carrolton, Kentucky to the final destination. C) This purchase order is being issued in full accordance with the attached "Purchase Order & Subcontract Provisions", any Federal Acquisition Regulation (FAR) contained or referenced therein, and the Terms and Conditions listed on the reverse side of this form. You are required to fill out, certify, and return the following Federal Certifications: - Certification of Nonsegregated Facilities, Clean Air and Water and Anti-Kickback Compliance. - Certification regarding Lobbying. - Certification Regarding Debarment, Suspension, Ineligibility and Voluntary Exclusion - Lower Tier Covered Transaction.			

[X] ACKNOWLEDGMENT COPY ATTACHED - PLEASE RETURN AT ONCE AND INDICATE FIRM SHIPPING DATE.

[ ] NO ACKNOWLEDGMENT NECESSARY

SPECIAL CONDITIONS

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PURCHASE ORDER NO. & CONTRACT NO. TO APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

BY Wayne J Meyer
AUTHORIZED PURCHASING SIGNATURE

ADDRESS ALL CORRESPONDENCE TO SIGNEE

WAYNE J. MEYER

PD 306 REV SEP 9

PURCHASE ORDER

CBI

CBI Technical Services Co.
1501 NORTH DIVISION STREET
PLAINFIELD, IL 60544-8929
(815) 439-6340
FAX: (815) 439-6010

PURCHASE ORDER NUMBER: 930212-0001 Rev. 0

CONTRACT: 930212

DATE: 04/19/94

01402

SHEET NO. 6 OF 6

SHIP PREPAID TO: SEE BELOW

TO: ARMCO ADVANCED MATLS CO.
1129 CANDLENUT DRIVE
NAPERVILLE, IL 60540

Attn: DEBBIE JUNK
(708)983-3004 FAX: (708)983-3006

BUYER	REQUISITION BY	SHIP VIA	STATE TAX		CONFIRMING	NON-CONFIRMING
WAYNE J. MEYER	C-240-0186	COMMERCIAL CARRIER	APPLIES			YES
F.O.B.: SEE BELOW	TERMS: NET 30 DAYS		EXEMPT	YES	SHIP BY DATE: 04/29/94	

PLEASE ENTER OUR ORDER FOR THE FOLLOWING, SUBJECT TO THE TERMS & CONDITIONS ON REVERSE SIDE HEREOF

ITEM NO.	QUANTITY	DESCRIPTION	ID	PRICE	INTERNAL USE
		- Assurance of Compliance with National Science Foundation Regulation Under Title VI of the Civil Rights Act of 1964.			
		D) All correspondence to should be directed to Wayne J. Meyer at the address and phone/fax numbers that appear in the heading of this Purchase Order.			
		E) Attachments			
		1. Coil Material Specification C-240-0186, Revision 0, dated 03/02/94.			
		2. Coil Material Bake Specification C-CMBS1, Revision 1, dated 02/02/94.			
		3. LIGO Beam Tube Specification 1100007, Revision C, dated 03/26/92.			
		4. Purchase Order & Subcontract Provisions.			
		5. NAS Customer Specification Questionnaire for Shipment to Metlab.			
		6. NAS Customer Specification Questionnaire for Shipmemt to Tubetec, Inc.			
		7. NAS Customer Specificatgion Questionnaire for Shipment to CBI Services, Inc.			
		--			

[XX] ACKNOWLEDGMENT COPY ATTACHED - PLEASE RETURN AT ONCE AND INDICATE FIRM SHIPPING DATE.

[ ] NO ACKNOWLEDGMENT NECESSARY

SPECIAL CONDITIONS

...n all invoices and bills of lading in duplicate to us at:

1501 NORTH DIVISION STREET

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PURCHASE ORDER NO. & CONTRACT NO. TO APPEAR ON ALL ...

BY Wayne J. Meyer
AUTHORIZED PURCHASING SIGNATURE
ADDRESS ALL CORRESPONDENCE TO SIGNEE

WAYNE J. MEYER

NORTH AMERICAN STAINLESS

Route 2, Box 436
Ghent, KY 41045-9615

Phone: (502) 347-6000
Fax: (502) 347-6001

Date: May 23rd 94

To: Bill Martins

Company Name: Armco

Fax Number: (708) 983 3006

From: Anil Yadav

Subject: CBI, chemistries.

No. of Pages(including this page): 1

Ladle analyses for coil numbers 115299B 115300B and 115301B applied to CBI orders is listed.

Heat No.	C	Cr	Mn	Mo	N	Ni	P	S	Si
5299	0.025	18.120	1.670	0.250	0.056	8.470	0.026	0.017	0.290
5300/5301	0.024	18.230	1.710	0.230	0.058	8.530	0.026	0.020	0.390

Stainless steel bar supplied by CBI has been inserted in coil number 115300B.

NAS NORTH AMERICAN STAINLESS

METALLURGICAL TEST REPORT

Route 2, Box 136
Ghent, KY 41045-9615
(502) 347-6000

JUN 01 '94 05:07PM RYERSON BRITE LINE

Certificate: 006625 01
Customer: 0007 006
NAS Order: AN 02763 06
Your Order: 33-A-2968

Mail To: JOSEPH T. RYERSON/CENTRAL
720 EAST 111TH STREET
CHICAGO IL 60680

Ship To: JOSEPH T. RYERSON/CENTRAL
720 EAST 111TH STREET
CHICAGO IL 60680

Date: 5/31/94
Page: 1
Steel: TP 304. X Not per P.O.
Finish: 2B
Corrosion: ASTM A262/92 PRAC E

PRODUCT DESCRIPTION:

STAINLESS STEEL COIL, COLD ROLLED, ANNEALED AND PICKLED.
ASTM A167/92B,A240/92B,A480/92C,ASME SA240/92,SA480/92,QQS766D,
COND A,X MG PERM,AMS5513F X MRK,MIL5059D,AMD3,X CRWN MEAS,F/B SMP

REMARKS:

Material free of mercury contamination. No weld repairs.

Product ID#	Coil #	Thickness	Width	Weight	Length	Mark	Pieces	COMMODITY CODE NO.
114528 B	114528 B	.1054	60.0000	16,625	COIL	00081	1	740240
114528 C	114528 C	.1054	60.0000	17,610	COIL	00082	1	740240

CHEMICAL ANALYSIS

HEAT	C	CR	CU	MN	MO	N	NI	P	S	SI
4528	.046	18.387	.221	1.458	.244	.058	8.056	.032	.003	.392
	X ** *	✓		✓		✓	✓	✓	X *	✓

No limits specified

* Not per C-240-186
** Not per SA240 Type 304L

MECHANICAL PROPERTIES

Product ID #	Coil #	loc / dir	Strength. KSI	Y. S.(0.2%). KSI	ELONG. (2") %	Hardness RB	Bend 180 deg 1t
114528 B	114528 B	B	98.47	48.50	49.72	89.00	OK
114528 B	114528 B	F	94.31	43.03	55.33	85.50	OK
114528 C	114528 C	B	98.47	48.50	49.72	89.00	OK
114528 C	114528 C	F	94.31	43.03	55.33	85.50	OK

RICOH FAXLINK 6100. JUN 08 '94 11:56AM P.1

QC ENGINEER [signature] 5/31/94

...54106 — From Ryerson Steel

CERTIFICAT DE RECEPTION NF EN 102[redacted] .1 .B

N - [redacted] 12682-01/1

UGINE[redacted]
USINE DE GUEUGNON
71130 GUEUGNON
FRANCE 1
BOBINES A FROID 2

X Not per P.O.

SIGLE DE L'USINE PRODUCTRICE / herstellerzeichen / trade mark		
UGINOX 3	T 304 ASTM A 240-93 ASME SA 240-92 DUPONT SW300-N/ MIL-S-5059-D/AMS 5513-D (LAST EDITIONS) EMBRITTLEMENT TEST PER ASTM A 262-91 PR F (ANNEAL TEMPERATURE 1900 DEGREES F MIN) OK IN PRODUCTION OR TESTING OF MATERIAL NO DIRECT CONNECTED MERCURY CONTAINING INSTRUMENTS HAVE BEEN USED NOR IN SUCH PRODUCTION OR, TESTING HAS MERCURY BEEN HANDLED IN THE IMMEDIATE VICINITY OF THE PRODUCT. MATERIAL IS ALSO FREE OF LOW MELTING ALLOY CONTAMINATION. 6	A : HYPERTREMPE (1) losungsgel + abgeschreckt solution treated R : RECUIT geglüht annealed E : ECROUI kaltverfestigt work hardened T.E : TREMPE vergütet hardened tempered 7

USC 774508

Nom et/ou service contrôle / vermachungs - organisation inspection	CLIENT ET / OU DESTINATAIRE / besteller und / oder empfänger / purchaser and / or consignee	N. DE COMMANDE CLIENT / kundebestell nummer / purchaser order number	N. DE COMMANDE USINE / werksbestell nummer / works order number	NUANCE ET SPECIFICATIONS TECHNIQUES / stahlsorte und prüfbedingungen / quality and specifications	ETAT DE LIVRAISON / lieferzustand / as delivered (1)
SERVICE METALLURGIQUE 8	JOSEPH T RYERSON & SON INC 9	33A2988 10	54747 11	AISI304 /2B ASTM A 240 /93 AISI304 7508 J / 12	A 13

IDENTIFICATION DU PRODUIT erzeugnis benennung product identification: N. BOBINE band nr coil n.	N. COULEE schmelze n. heat n.	N. DE POSTE post nr item n.	NOMBRE stück - zahl pieces nbr	DIMENSIONS abmessungen - dimensions: EPAISSEUR dicke thickness	LARGEUR breite width	LONGUEUR länge length	POIDS NET neto gewicht net weight	EMPLA-CEMENT (2)	TRACTION - ZUGVERSUCH - TENSILE TEST: SENS (3)	Rp 0.2 PSI	Rp 1 PSI	Rm PSI	A % 80MM	A % 2 ''		DURETE härte hardness HRB	ESSAIS COMPLEMENTAIRES zusätzliche probe additional tests
									MINI	30015		74965		45			
									MAXI			100050				92	
343968	073523	1	1	2,500	1524,00		7220		T	45385		91060	52	56		85	
343970	073524	1	1	2,500	1524,00		7035		T	44805		92220	52	56		85	
15	16	17	18	19	20	21	22	23	24	25	26	27	28	28	29	30	37

ANALYSE CHIMIQUE - CHEMISCHE ZUSAMMENSETZUNG - CHEMICAL ANALYSIS

PROCEDE D'ELABORATION schmelzungsart steel making process	N. BOBINE band nr coil n.	N. COULEE schmelze nr heat n.	TYPE D'ANALYSE (4)	C	Si	Mn	Ni	Cr	Mo	Ti	N	S	P	CU			
			MINI				8,00	18,00									
			MAXI	0,080	0,750	2,000	10,50	20,00	0,750		0,100	0,030	0,045	0,750			
	343968	073523	C	0,033	0,366	1,410	8,73	18,34	0,029		0,037	0,001	0,018	0,051			
FE + AOD + CC	343970	073524	C	0,038	0,364	1,399	8,71	18,39	0,203		0,034	0,001	0,022	0,164			
				X* **	✓	✓	✓	✓			✓	X**	✓		no limits specified		
38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55

* Not per SA240 304L
** Not per C-240-1/86

SERVICE METALLURGIQUE
LE : 13/04/94
LE RESPONSABLE
DER WERKSSACHVERSTANDIGE
THE INSPECTOR

UGINE S.A. M. GODARD CONTROLE RECEPTION

L'AGENT RECEPTEUR

BEND TEST : OK

* HRB:E>=1,0MM / 30T:0,50<=E<1,0MM / 15T:E<0,50MM 56

ROBELAGE - LOCATION (2)
1 : debut - anfang - front
2 : fin - ende - back
3 : milieu - mitte - middle 57

RICHTUNG - DIRECTION (3)
l : long - langs - longitudinal
t : travers - quer - transverse 58

ANALYSE - ANALYSIS (4)
c : coulee - schmelze - heat
p : produit - stuck - product 60

LES ESSAIS DE PLIAGE SONT SATISFAISANTS
die ergebnisse der faltversuchen entsprechen den vorschriften
bend test results are satisfactory

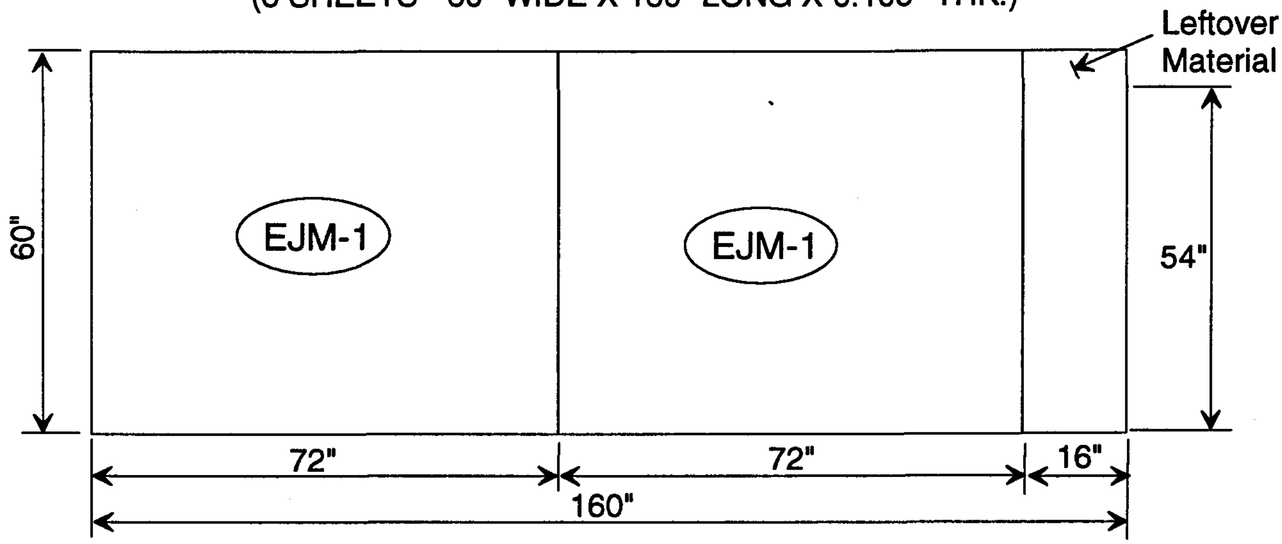
CONTROLE DE MARQUAGE D'ASPECT ET DE DIMENSIONS : SATISFAISANTS
bezeichnung, besichtigung und ausmessung : ohne beanstandung
marking, inspection and measurement : without objection 62

63

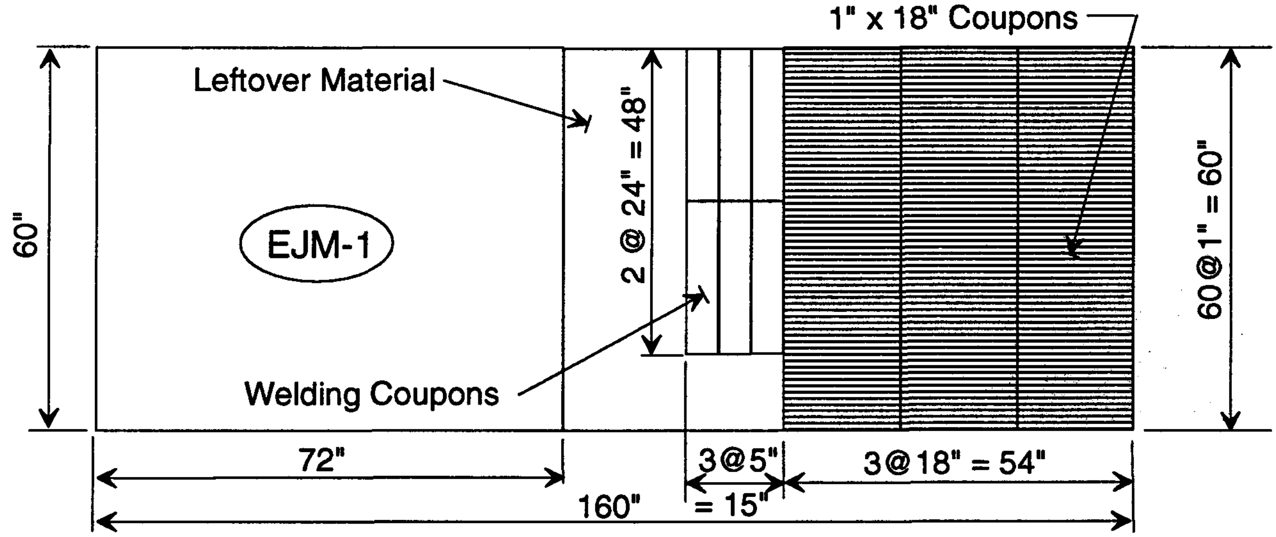
NOUS CERTIFIONS QUE LES PRODUITS ENUMERES CI-DESSUS SONT CONFORMES AUX PRESCRIPTIONS DE LA COMMANDE
wir bestatigen hiermit dass die obengenannten erzeugnisse den bestellung vorschriften entsprechen
we certify hereby that the above mentioned products are consistent with the order prescriptions

CUTTING SKETCHES FOR MATERIAL WITH HEAT NUMBER 73524

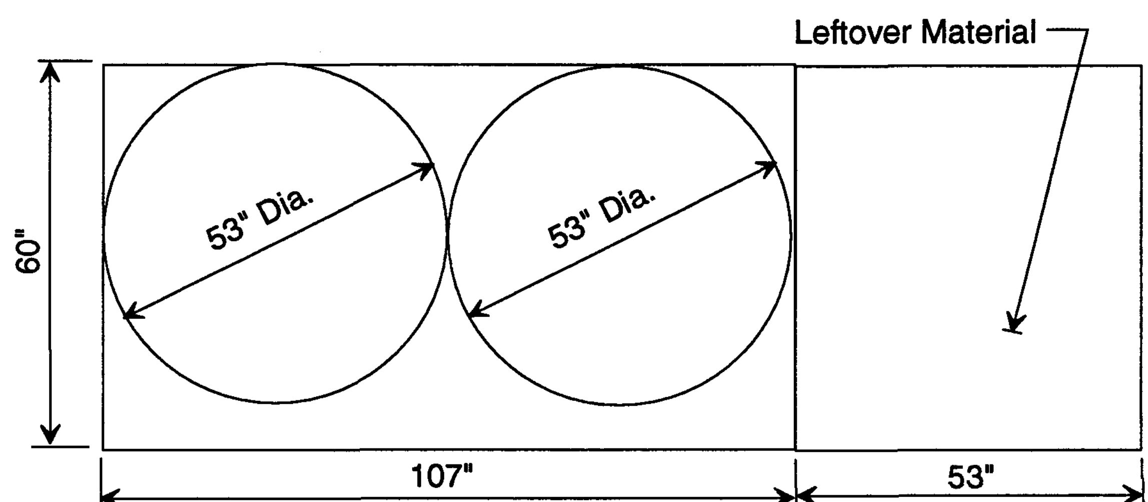
(6 SHEETS - 60" WIDE X 160" LONG X 0.105" THK.)



PATHWAY EXPANSION JOINT MATERIAL (Four Required)

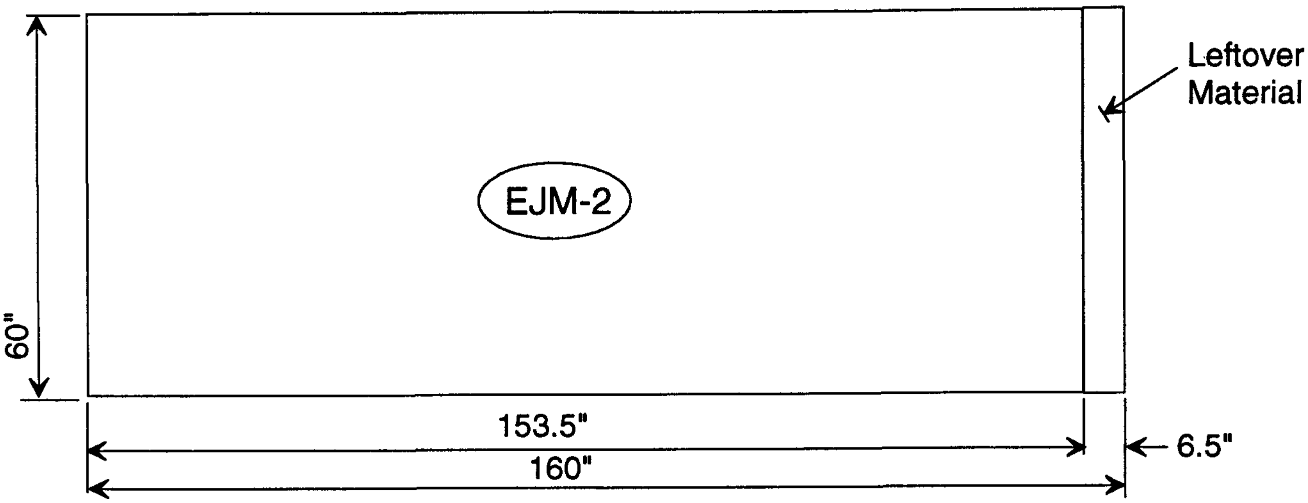


MATERIAL FOR PATHWAY EXPANSION JOINT AND COUPONS (One Required)

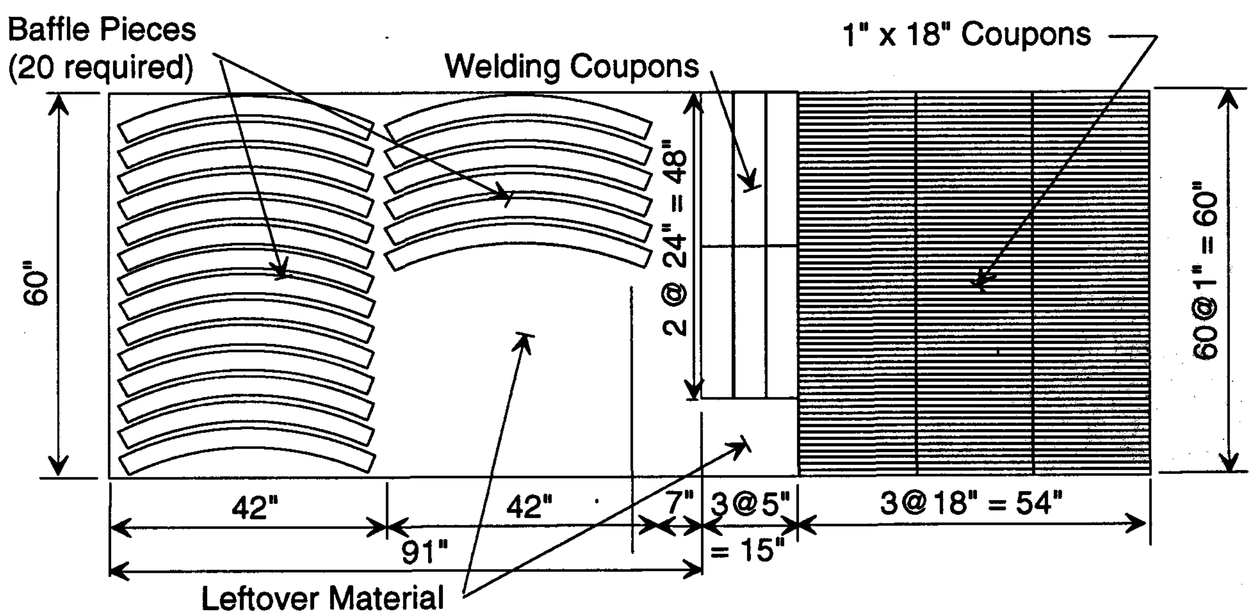


MATERIAL FOR QT END CLOSURES (One Required)

DRAWN BY: SWP
DATE: 6/2/94
REVISED BY: SWP
REV. DATE: 7/19/94



HYSPAN EXPANSION JOINT MATERIAL (Three Required)



MATERIAL FOR BAFFLES AND COUPONS (One Required)

CUTTING SKETCHES FOR MATERIAL WITH HEAT NUMBER 4528

(4 SHEETS - 60" WIDE X 160" LONG X 0.105" THK.)

DRAWN BY: SWP
DATE: 6/2/94
REVISED BY: SWP
REV. DATE: 7/19/94

SECTION 2.C APPENDICES

March 7, 1995

TUBETEC SPIRAL WELD SECTION REPORT

Six (6) spiral weld sections were taken from tube segments adjacent to each QT beam tube assembly at CBITSC Plainfield. The segments were produced during the end machining operation and are approximately within six inches of the QT beam tube ends. The attached diagram "Tubetec Spiral Welded Tube Production Layout" describes the locations and other related data.

A band saw was used to remove the coupons from the segments. The coupons were marked with identification numbers. The coupons were shipped to CBI Houston Corporate Welding. The sections were saw cut, mounted, polished with metallographic papers and etched. The sections were placed under 4X and 100X magnifying lens and photographed. The photographs were identified by number, labeled and copied. The copies are attached to this report. The photographed sections were evaluated to determine the minimum depth of penetration and overlap for the inside and outside welds.

RESULTS :

1. The 70% minimum depth of penetration and overlap of approximately .050" for the inside and outside weld was not achieved.

RECOMMENDED DISPOSITION :

1. Accept as is for the QT.

CORRECTIVE ACTION :

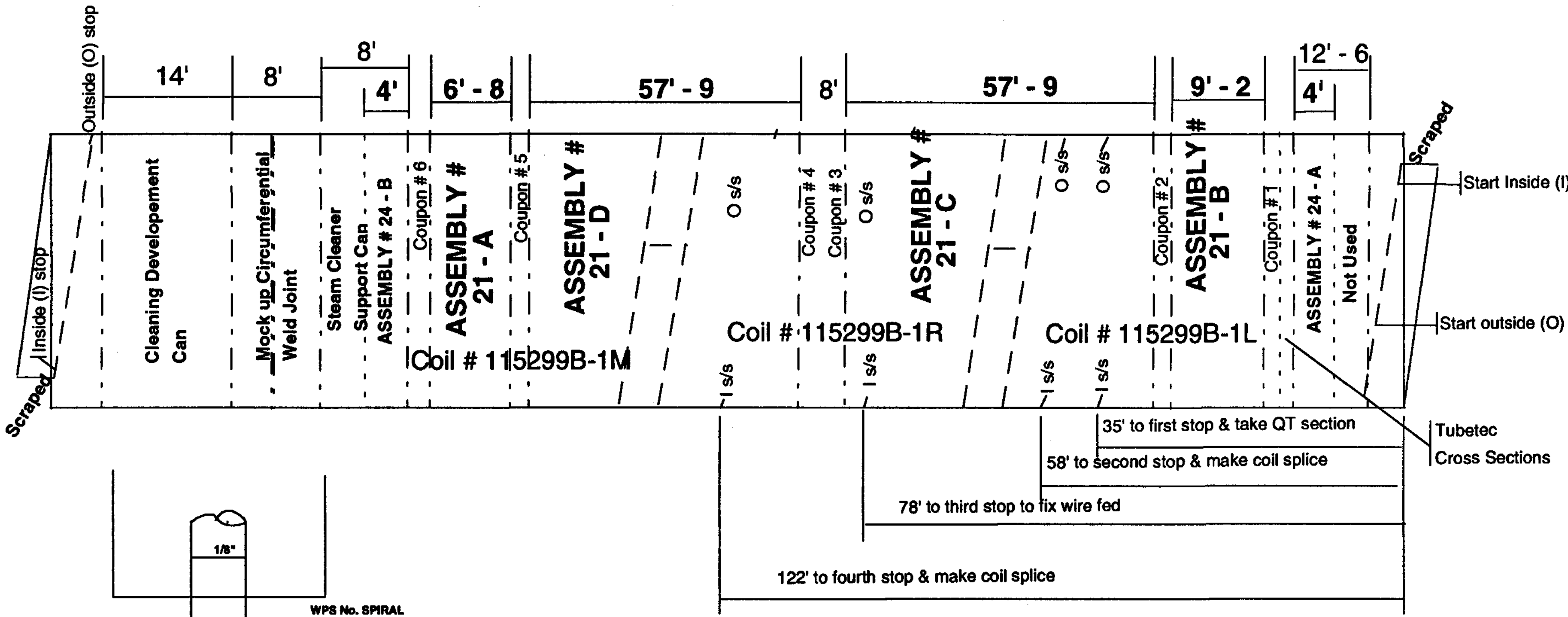
1. Accept as is for the QT.
2. Build data for use in lessons learned from the QT.

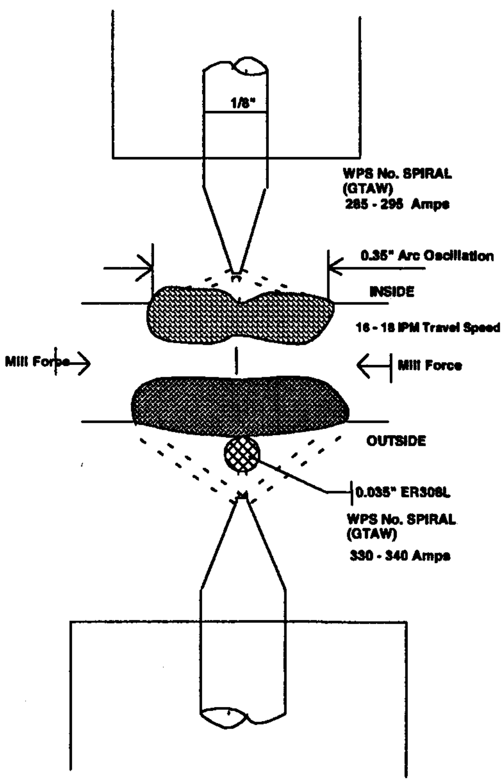
LESSONS LEARNED :

1. The ends of each can section when smoothed by filing, machining, or grinding and etched do not produce the desired contrast and does not show the overlap clearly when a hand held magnifying lens is used.
2. The 100X magnification photograph shows three zones. The first zone is the inside GTAW autogenous weld layer. The second zone is a unique bonding process that is not addressed by the WPS used by Tubetec. The third zone is the outside GTAW ER308L weld layer.

AUXILIARY DATA :

1. Special transverse side bend specimens were made from segment identification number 5. The guided-bend radius was .25". There were no detectable indications shown by a 10X magnifying lens. The attached 100X magnification photographs showed no detectable indications.
2. The unique bonding process occured after the left side coil #115299B-1L had been spliced to the right side coil # 115299B-1R. The sulfur content of the coils were .017% as measured by heat and product analysis.
3. The unique bonding process as shown in sections 3, 4, 5, & 6 occurred after the third period (stop/start) of mill operation and continued for the remainder of the QT production.
4. The welding parameter monitoring was of general nature; and there were no detailed records made during the production welding.
5. The tungsten shape and condition was not monitored during the QT production by CBI. The method used by Tubetec during the WPS qualification test was acceptable. The tungsten electrode wear was not measured during the QT production.
6. The travel speed was not monitored during the QT production by CBI. Any change in the travel speed was negligible. The travel speed was set at the start of production and no changes were perceived by CBI during the QT production.
7. The voltage was controlled by automatic voltage control. Automatic voltage control is documented by the performance qualification test record.
8. The magnetic oscillator parameters were not monitored during the QT production by CBI. The parameters were established by Tubetec during the WPS qualification test.

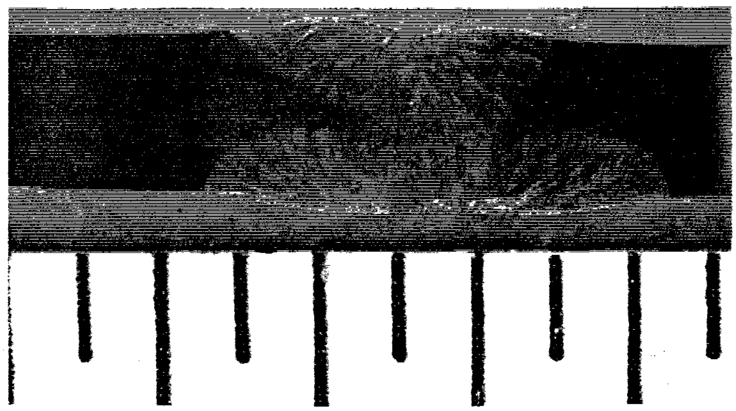




TUBETEC SPIRAL WELDED TUBE PRODUCTION LAYOUT

March 7, 1995

H12341 #1 Inside



Measure Units = 1/16"

Transparent metalographic polishing artifact →

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Transparent metalographic polishing artifact →

CL

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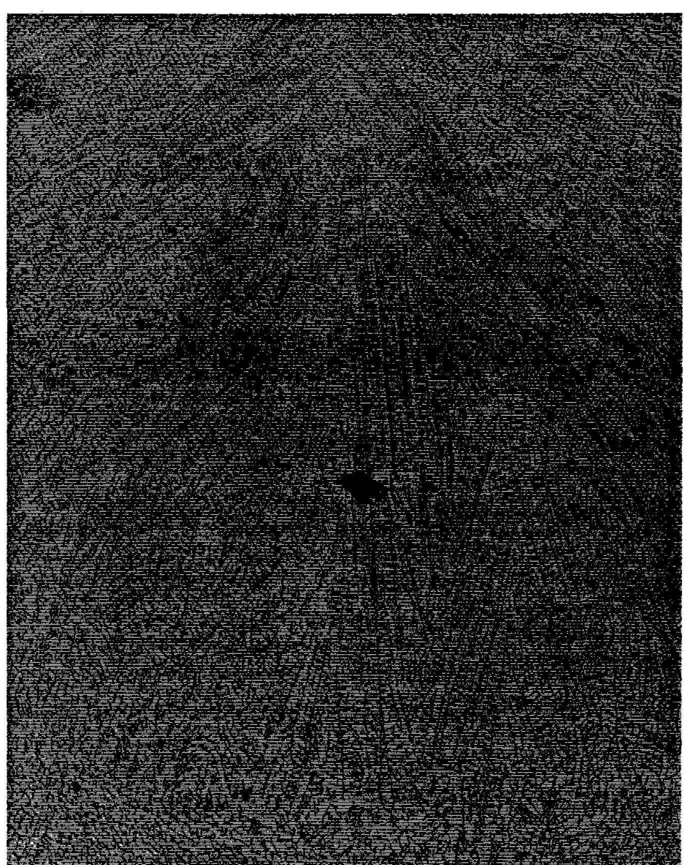
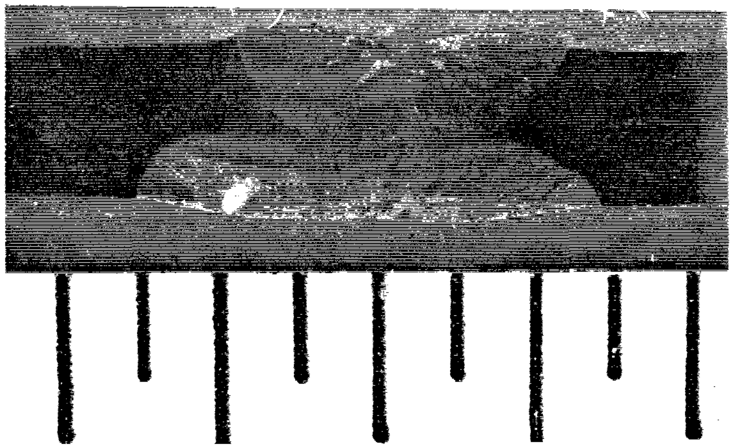
E



H12341 # 1 100X

H12341 #2 Inside

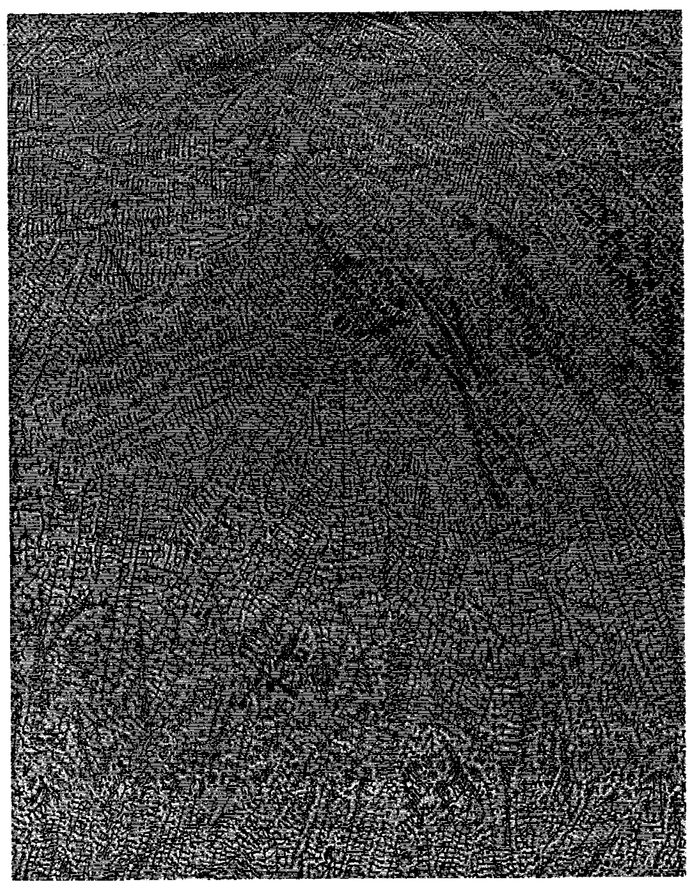


Measure Units = 1/16"

INSIDE

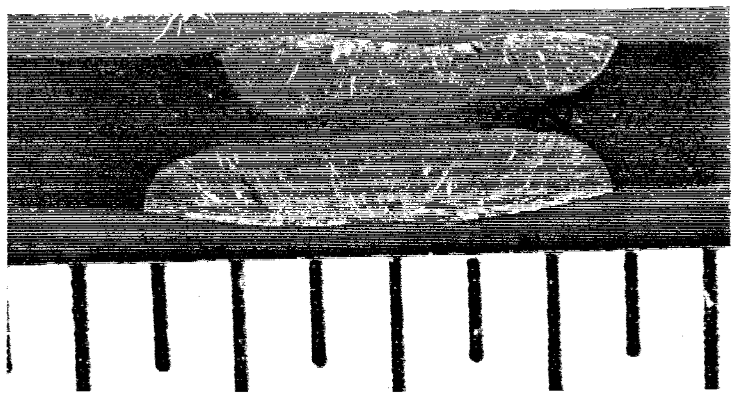
CL

OUTSIDE



H12341 #2 100X

H12341 #3 Inside



Measure Units = 1/16"

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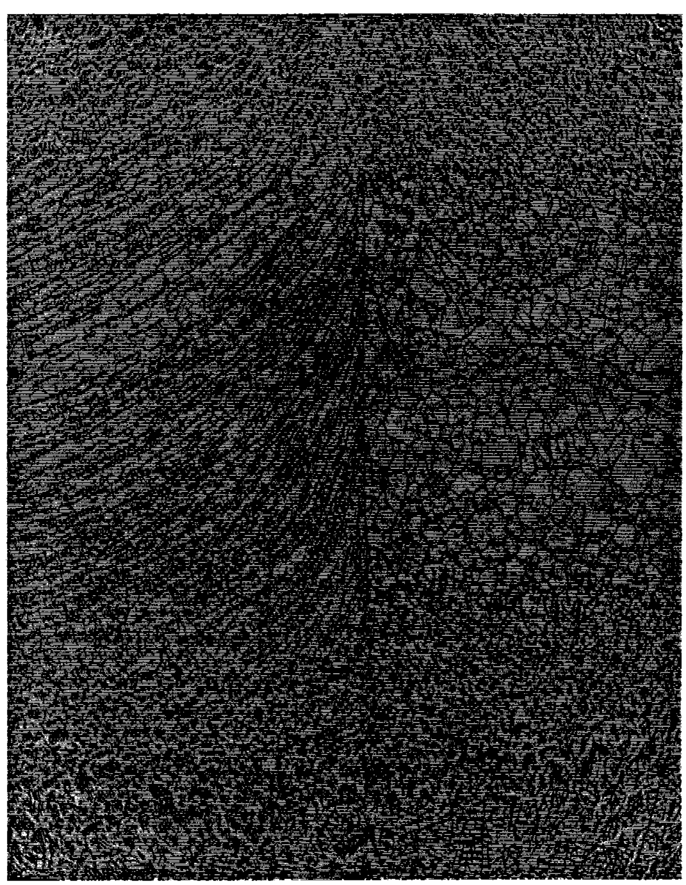
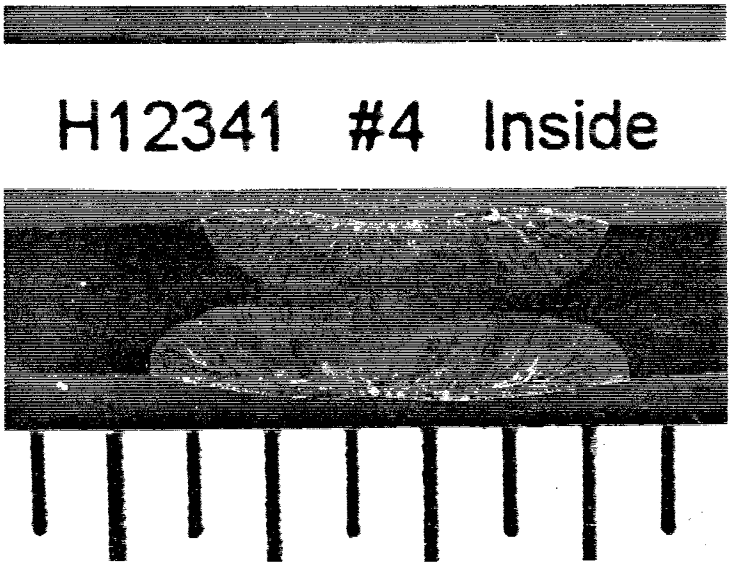


H12341 # 3 100X

H12341 #4 Inside

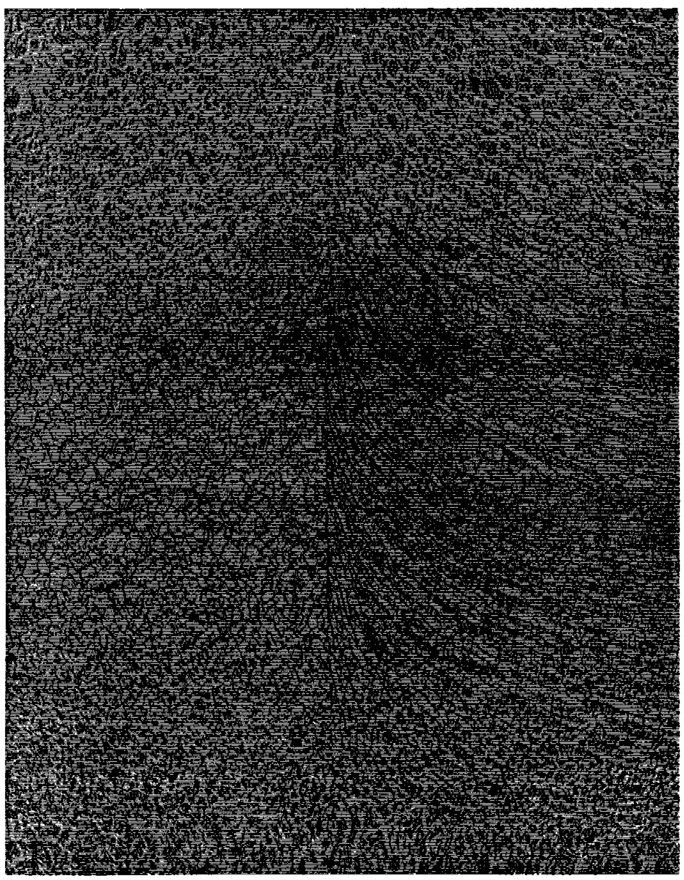


Measure Units = 1/16"

INSIDE

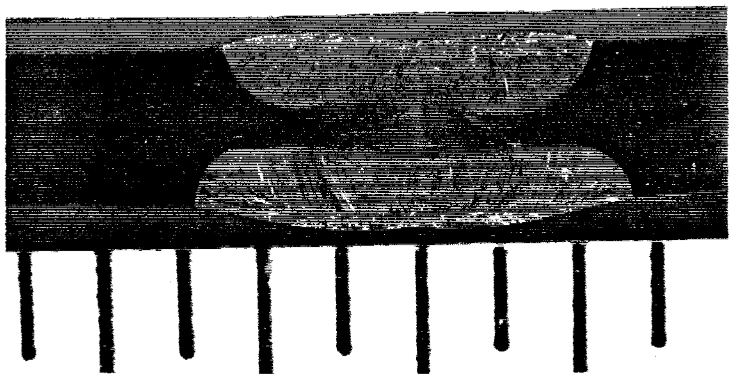
CL

OUTSIDE



H12341 # 4 100X

H12341 #5 Inside



Measure Units = 1/16"

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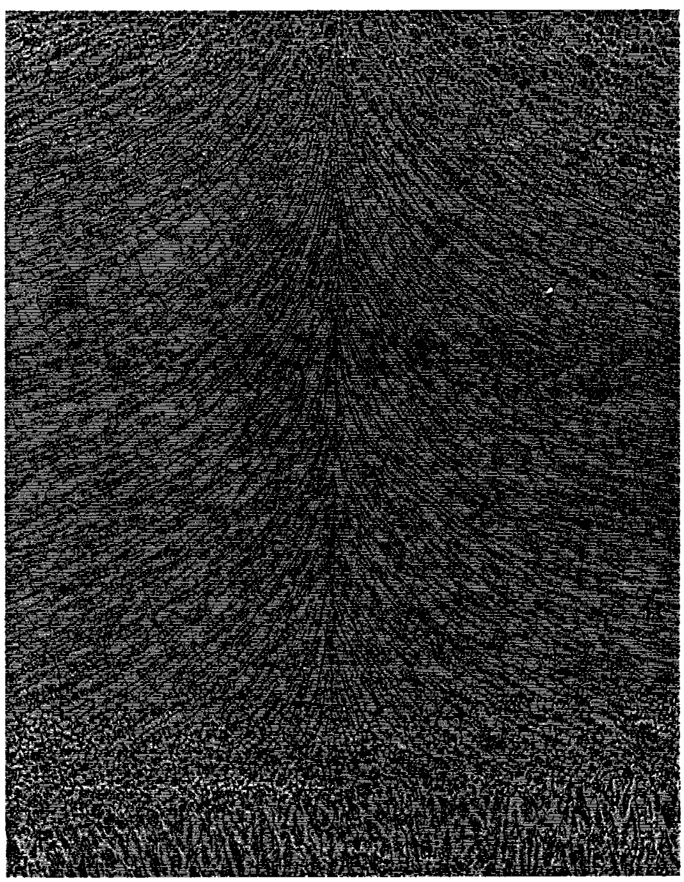
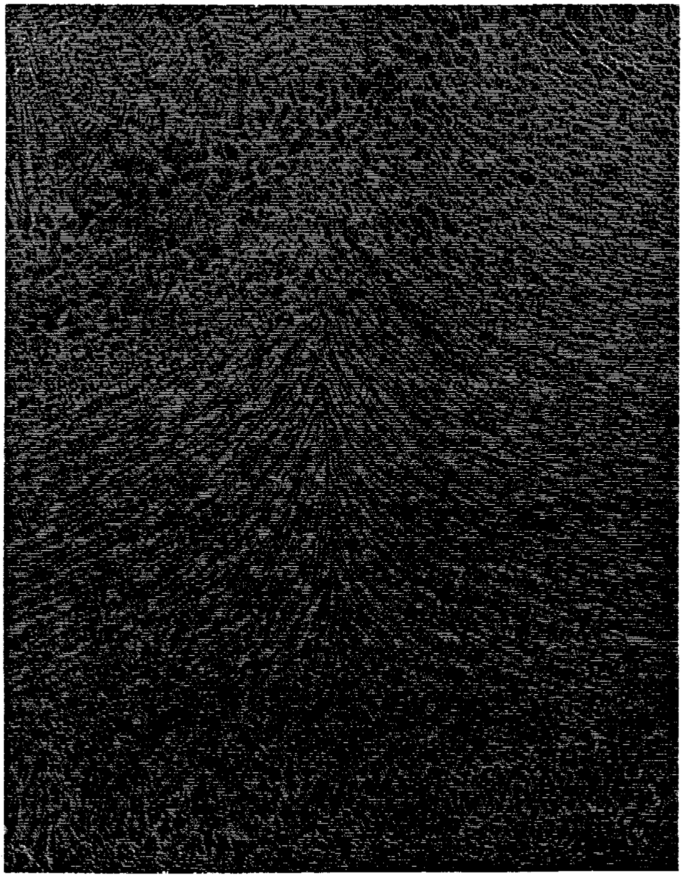


H12341 # 5 100X

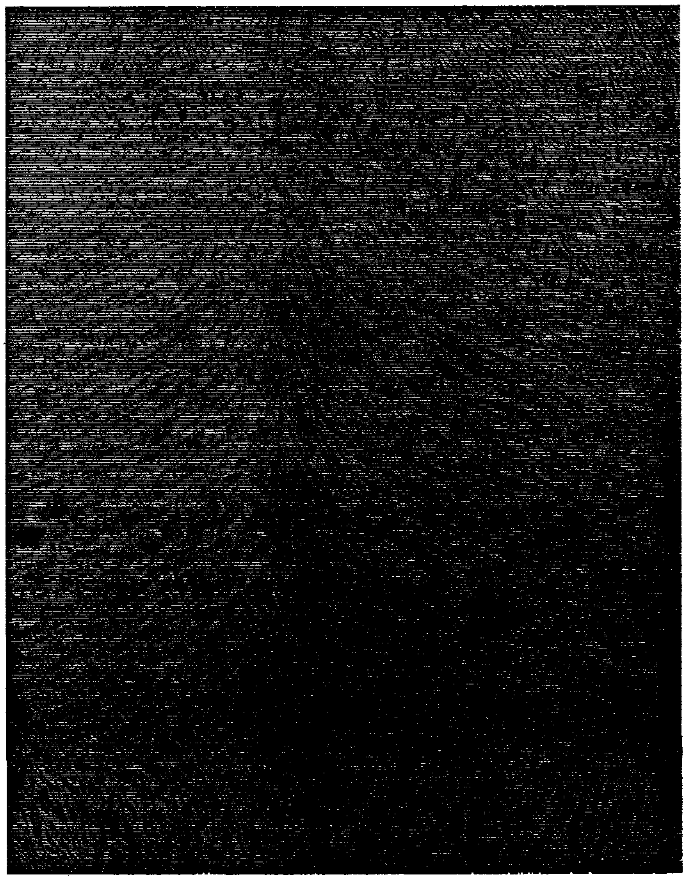


INSIDE

CL

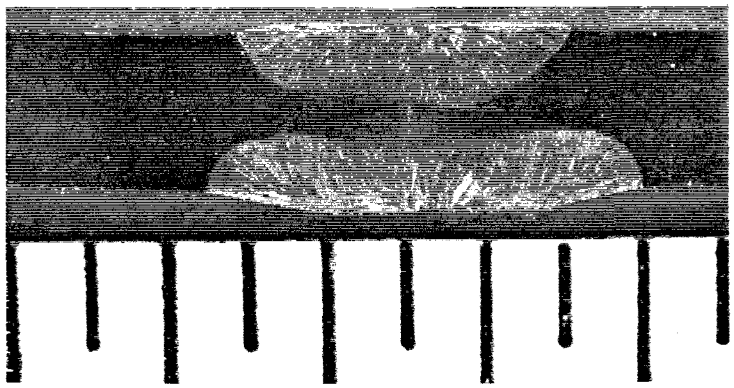
OUTSIDE

H12350 #5, SIDE BEND 1 100X



H12350 #5, SIDE BEND 2 100X

H12341 #6 Inside

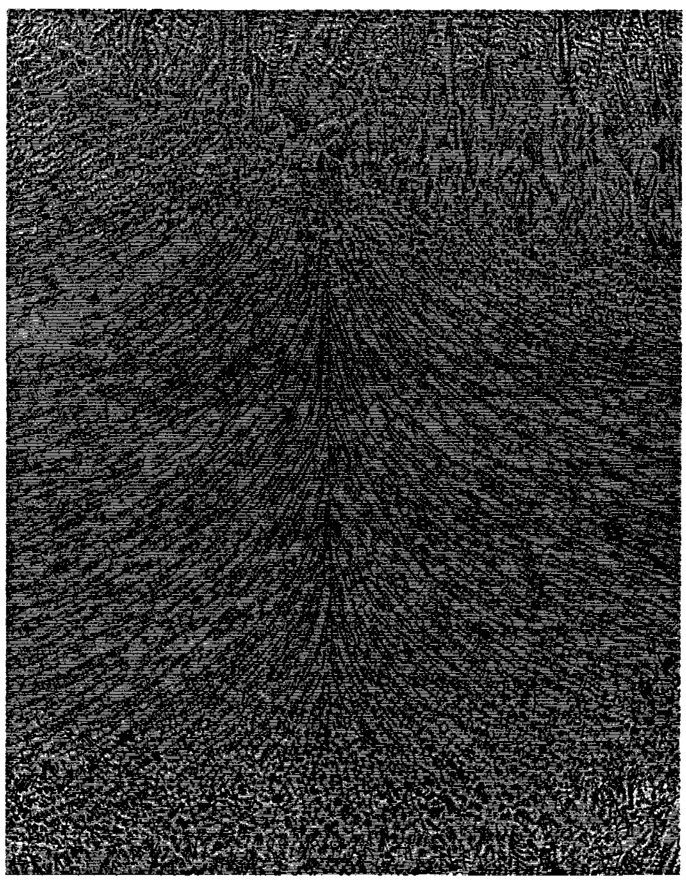


Measure Units = 1/16"

INSIDE

CL

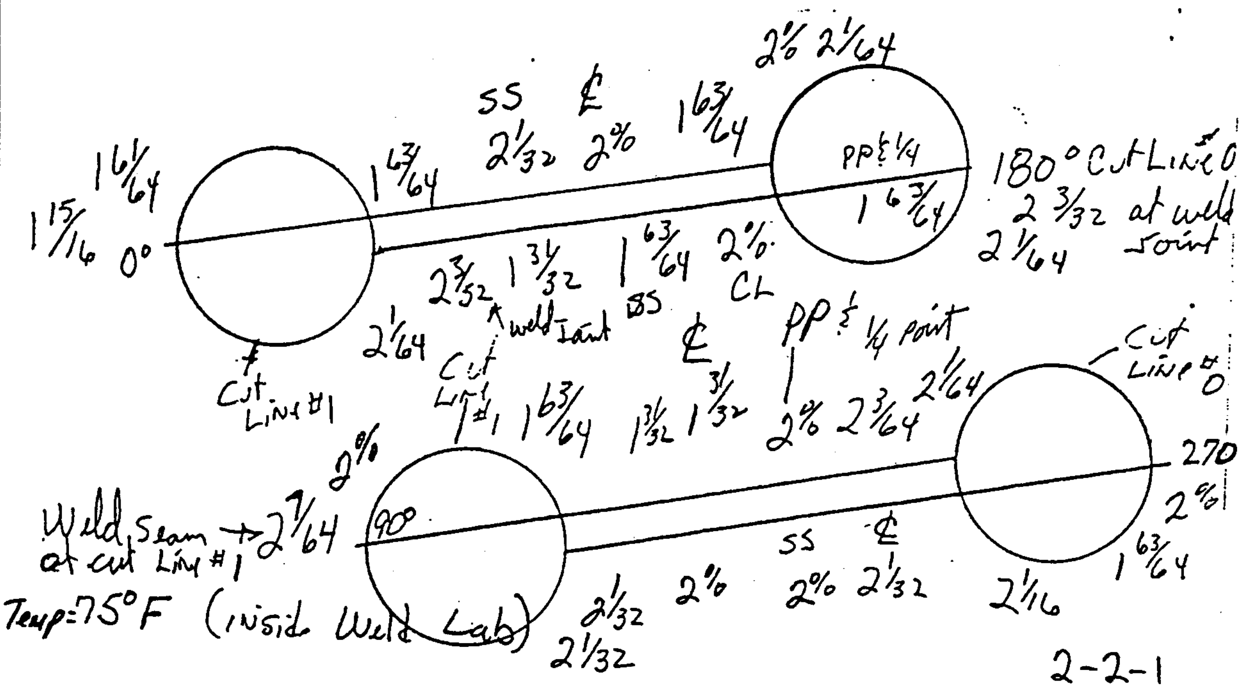
OUTSIDE



H12341 # 6 100X

SECTION 2.D.4 APPENDICES

MEASUREMENT RECORD & CHECK LIST



Seq. No.	Description: Operation, Inspection, or Examination to be completed	Applicable Procedure or Instruction	Init. Req'd "X"	CBI Operation Insp. or Exam Accepted: Initial	Date	REMARKS:
1	Take Measurements					
2	before Welding Stiffeners		x	WLR	7/18/94	
3						
4						
5						
6						
7						
8						
9						
10						

Made By	Chk'd By	Rev.					Contract Number	
WLR			By				930212	No. QT - H5
Date 7/19/94	Date		Chk'd					Sheet 1 of 1
			Date					

DC8.1 REV MAR 94

CBI MEASUREMENT RECORD & CHECK LIST

See Procedure "Doc. ID No." DCQT

Seq. No.	Description: Operation, Inspection, or Examination to be completed	Applicable Procedure or Instruction	Init. Req'd "X"	CBI Operation Insp. or Exam Accepted: Initial	Date	REMARKS:
	Take before Welding Measurements			WLR	7/22/94	
	Take After Welding Measurements			WLR	8/8/94	

Made By	Chk'd By	Rev.		Contract Number	
WLR		By		930212	No. QT-H6
Date 8/22/94	Date	Chk'd / Date			Sheet 1 of 7

DC.1 REV MAR 94

QT Beam Tube Section: 21-3-1 (Before welding)

Location	Spiral No.	0°	180°	Location	Difference	Diameter
End	0	2 2/64	2 2/64	End	0	49.44
19°	1	2 3/64	1 62/64		5/64	49.49
	2	2 4/64	2		4/64	49.44
	3	2 6/64	1 63/64		7/64	49.43
	4	2 6/64	1 61/64		9/64	49.46
	5	2 4/64	1 59/64		9/64	49.52
	6	2 4/64	1 59/64		9/64	49.52
	7	2 4/64	1 60/64		8/64	49.50
	8	2 5/64	1 59/64		10/64	49.50
	9	2 4/64	1 58/64		10/64	49.54
	10	2 2/64	1 58/64		8/64	49.57
	11	2	1 57/64	Rolls	7/64	49.61
Rolls	12	1 63/64	1 54/64	Rolls	9/64	49.68
	13	1 63/64	1 55/64		8/64	49.66
	14	2	1 55/64		9/64	49.64
	15	2	1 56/64		8/64	49.63
	16	2 2/64	1 59/64		7/64	49.55
	17	2 5/64	1 59/64		10/64	49.50
Splice	18	2 5/64	1 59/64		10/64	49.50
	19	2 4/64	1 58/64		10/64	49.54
	20	2 3/64	1 59/64		8/64	49.54
	21	2 5/64	1 60/64		9/64	49.49
	22	2 6/64	1 60/64		10/64	49.47
	23	2 6/64	1 61/64		9/64	49.46
	24	2 6/64	1 62/64		8/64	49.44
	25	2 6/64	1 63/64		7/64	49.43
	26	2 7/64	1 63/64		8/64	49.41
	27	2 8/64	1 62/64		10/64	49.41
	28	2 8/64	1 62/64		10/64	49.41
	29	2 8/64	1 60/64		12/64	49.44
	30	2 8/64	1 61/64		11/64	49.43
	31	2 8/64	1 61/64		11/64	49.43
	32	2 6/64	1 59/64		11/64	49.49
	33	2 4/64	1 60/64		8/64	49.50
	34	2 4/64	1 59/64		9/64	49.52
	35	2 2/64	1 59/64		7/64	49.55
	36	2 2/64	1 58/64		8/64	49.57
Rolls	37	2 4/64	1 59/64	Rolls	9/64	49.52
	38	2 3/64	1 60/64		7/64	49.52
	39	2 5/64	1 60/64		9/64	49.49
	40	2 5/64	1 59/64		10/64	49.50
	41	2 5/64	1 60/64		9/64	49.49
	42	2 4/64	1 60/64		8/64	49.50
	43	2 4/64	1 60/64		8/64	49.50
	44	2 2/64	1 62/64		4/64	49.50
14°	45	2 3/64	2 1/64	7°	2/64	49.44
End	46	2	2	End	0	49.50

Location	Spiral No.	90°	270°	Location	Difference	Diameter
End	0	2	2	End	0	49.41
15°	1	2	1 63/64		1/64	49.42
	2	2 2/64	2		2/64	49.37
	3	2 4/64	2 2/64		2/64	49.31
	4	2 6/64	2 2/64		4/64	49.28
	5	2 6/64	2		6/64	49.31
	6	2 5/64	1 62/64		7/64	49.36
	7	2 3/64	1 61/64		6/64	49.41
	8	2 2/64	1 61/64		5/64	49.42
	9	2 2/64	1 61/64		5/64	49.42
	10	2 1/64	1 59/64		6/64	49.47
	11	2	1 57/64		7/64	49.52
	12	2	1 56/64		8/64	49.53
Rolls	13	2	1 56/64	Rolls	8/64	49.53
	14	1 63/64	1 55/64		8/64	49.56
	15	1 61/64	1 56/64		5/64	49.58
	16	1 62/64	1 57/64		5/64	49.55
	17	2	1 58/64		6/64	49.50
Splice	18	2 1/64	1 58/64		7/64	49.48
	19	2 1/64	1 59/64		6/64	49.47
	20	2 2/64	1 58/64		8/64	49.47
	21	2	1 59/64		5/64	49.48
	22	2 2/64	1 60/64		6/64	49.44
	23	2 2/64	1 62/64		4/64	49.41
	24	2 4/64	1 62/64		6/64	49.37
	25	2 4/64	1 62/64		6/64	49.37
	26	2 4/64	2		4/64	49.34
	27	2 5/64	2 2/64		3/64	49.30
	28	2 4/64	2 1/64		3/64	49.33
	29	2 4/64	2 2/64		2/64	49.31
	30	2 2/64	2 1/64		1/64	49.36
	31	2 2/64	2 1/64		1/64	49.36
	32	2 1/64	2		1/64	49.39
	33	2	2		0	49.41
	34	2	1 62/64		2/64	49.44
	35	2	1 62/64		2/64	49.44
	36	2 1/64	1 62/64		3/64	49.42
Rolls	37	2	1 61/64	Rolls	3/64	49.45
	38	2 1/64	1 61/64		4/64	49.44
	39	2 3/64	1 62/64		5/64	49.39
	40	2 2/64	1 62/64		4/64	49.41
	41	2 3/64	1 62/64		5/64	49.39
	42	2 3/64	1 62/64		5/64	49.39
	43	2	1 61/64		3/64	49.45
	44	2 1/64	1 62/64		3/64	49.42
18°	45	2 2/64	2	9°	2/64	49.37
End	46	2 3/64	2 3/64	End	0	49.31

Average Deviation: 8/64
Largest Deviation: 12/64

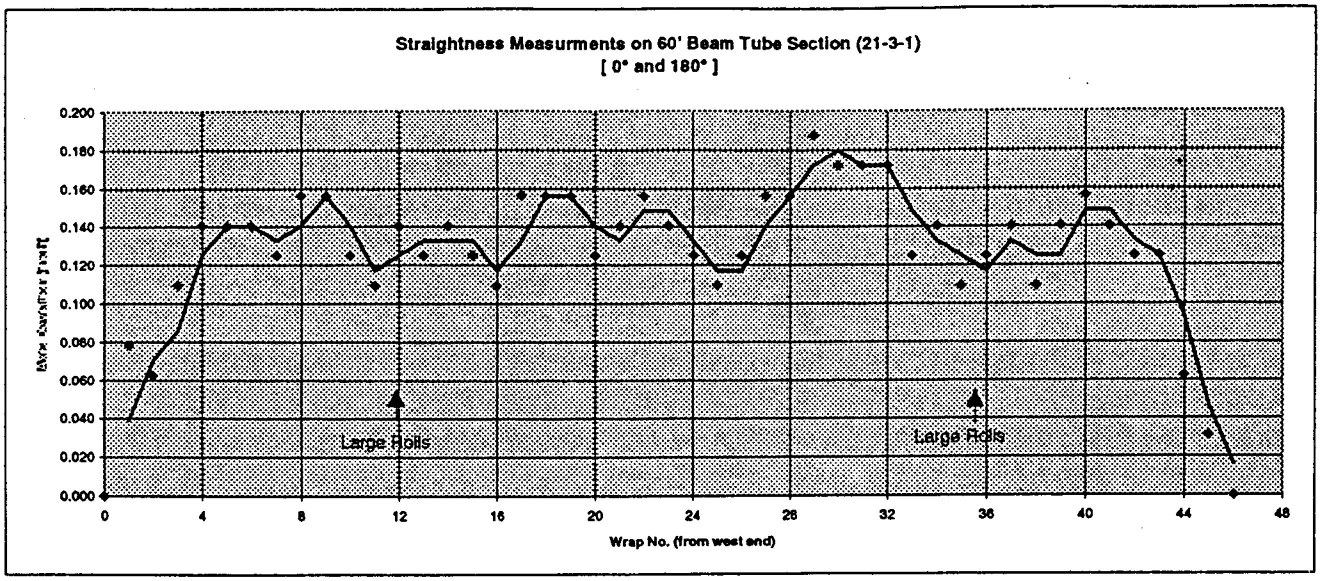
Average Diameter: 49.50
Largest Diameter: 49.68
Smallest Diameter: 49.41

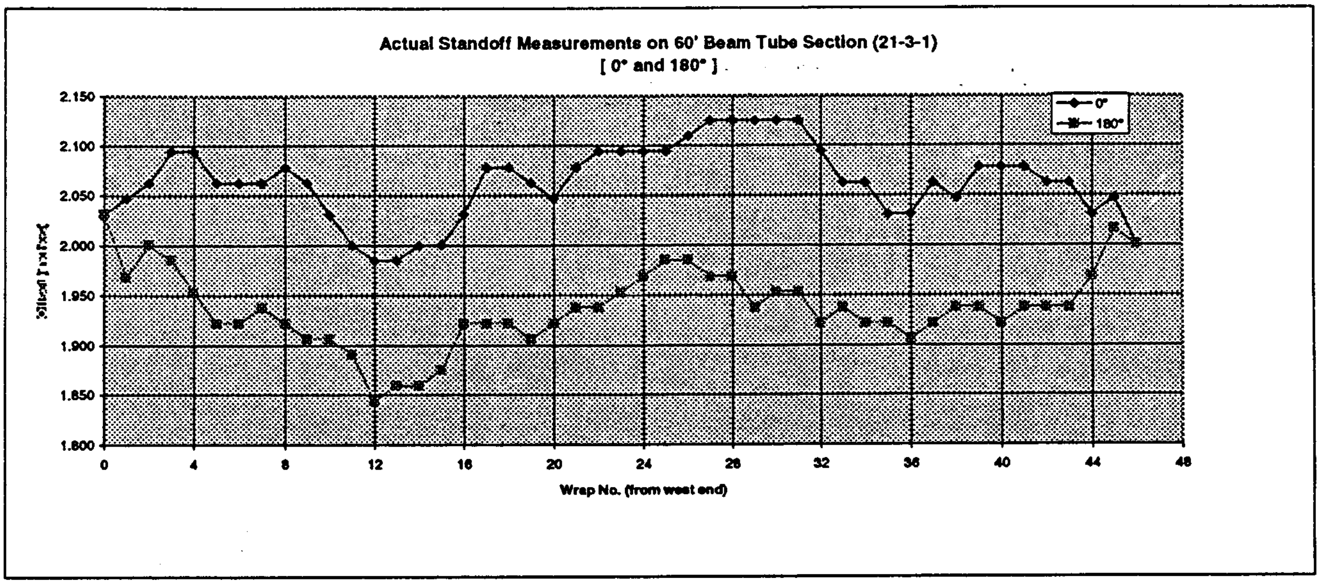
Average Deviation: 4/64
Largest Deviation: 8/64

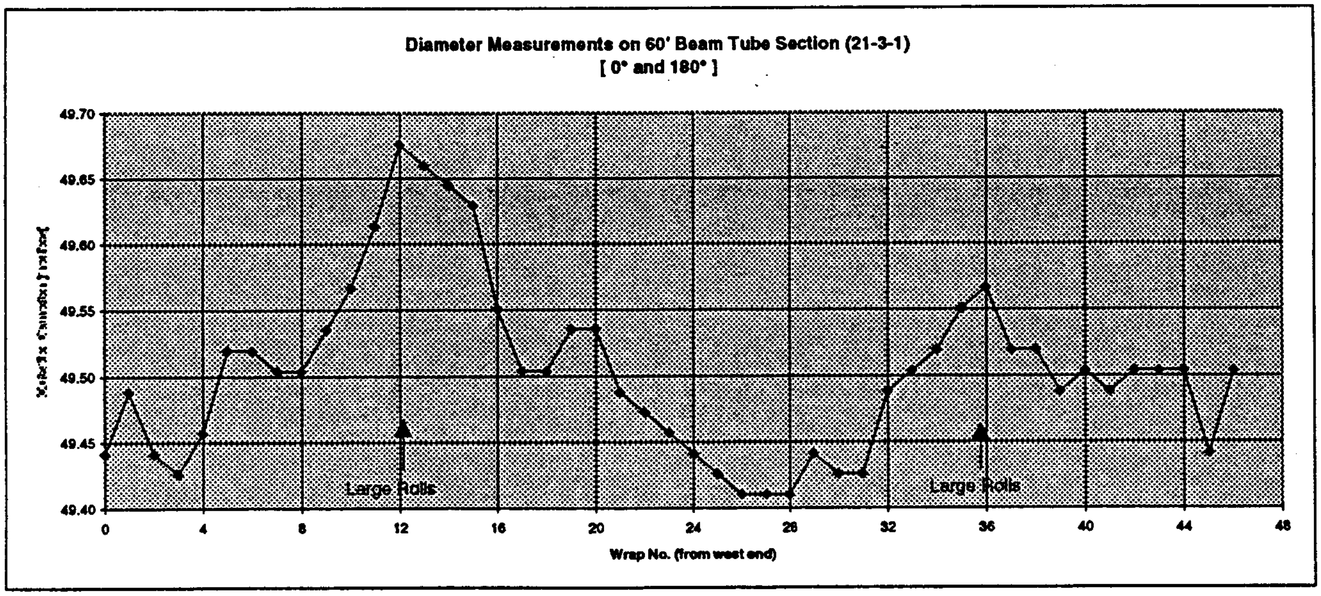
Average Diameter: 49.42
Largest Diameter: 49.58
Smallest Diameter: 49.28

Outside diameter (pi-tape)

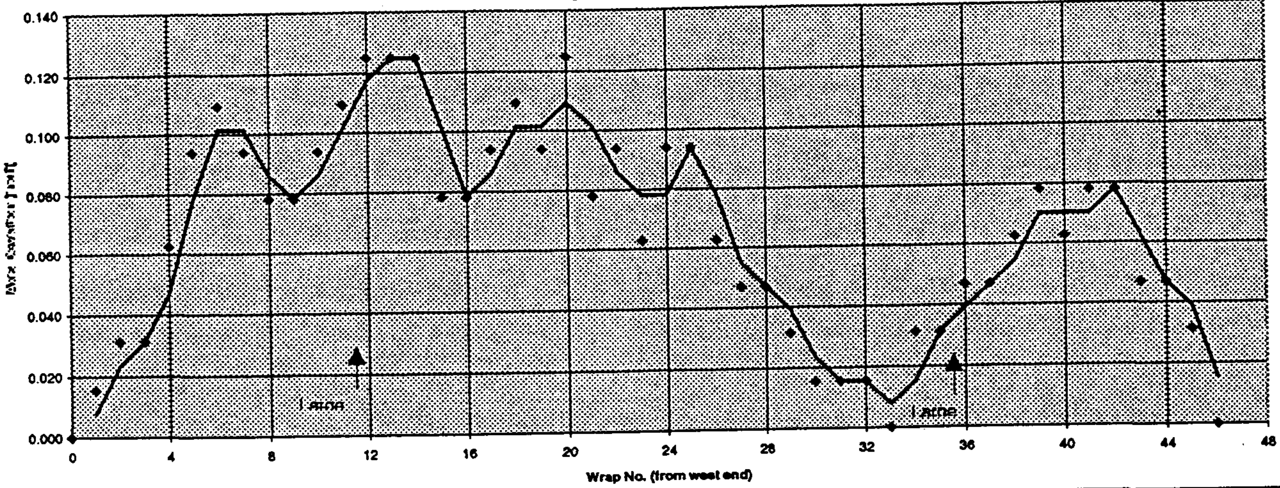
4th wrap: 49.018 85°F
14th wrap: 49.164
27th wrap: 49.035
37th wrap: 49.033


Straightness Measurments on 60' Beam Tube Section (21-3-1)
[0° and 180°]
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0
4
8
12
16
20
24
28
32
36
40
44
48
Wrap No. (from west end)
Large Rolls
Large Rolls

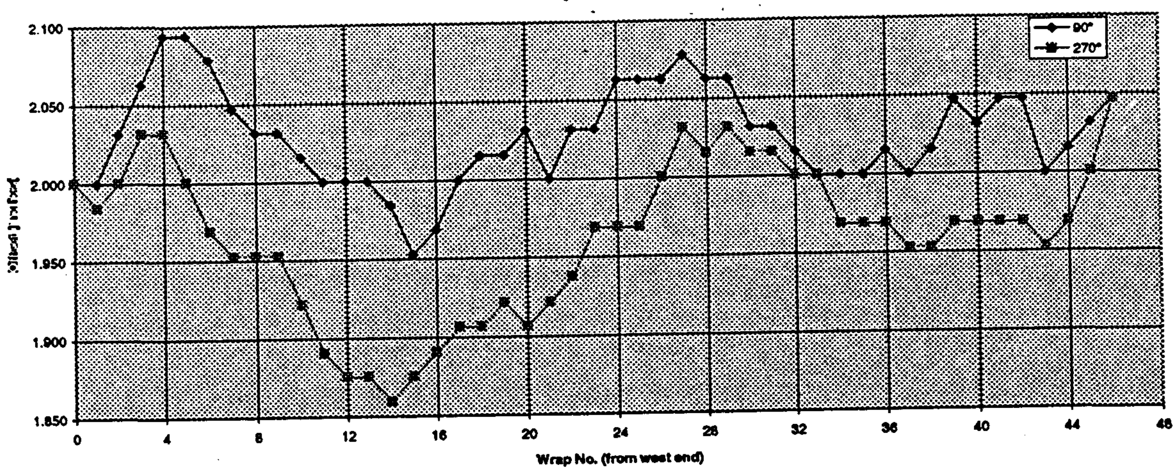

Actual Standoff Measurements on 60' Beam Tube Section (21-3-1)
[0° and 180°]
2.150
2.100
2.050
2.000
1.950
1.900
1.850
1.800
0
4
8
12
16
20
24
28
32
36
40
44
48
Wrap No. (from west end)
0°
180°


Diameter Measurements on 60' Beam Tube Section (21-3-1)
[0° and 180°]
49.70
49.65
49.60
49.55
49.50
49.45
49.40
0
4
8
12
16
20
24
28
32
36
40
44
48
Wrap No. (from west end)
Large Rolls
Large Rolls

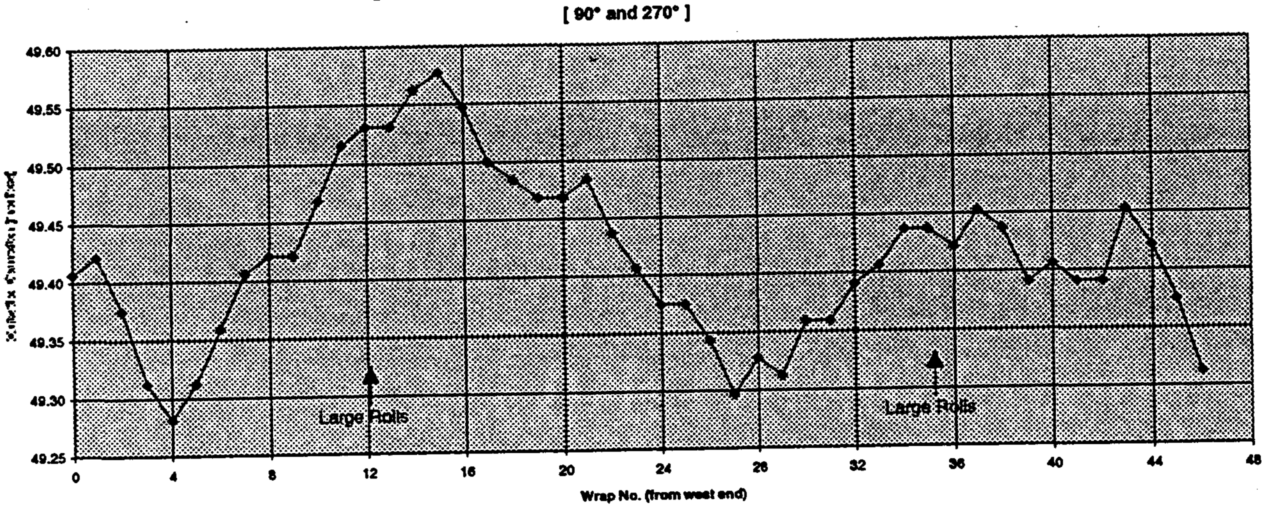
Straightness Measurements on 60' Beam Tube Section (21-3-1)
[90° and 270°]



Standoff Measurements on 60' Beam Tube Section (21-3-1)
[90° and 270°]



Diameter Measurements on 60' Beam Tube Section (21-3-1)
[90° and 270°]



QT Beam Tube Section: 21-3-1 (After welding)

Location	Spiral No.	0°	180°	Location	Difference	Diameter
End	0	4 38/64	4 38/64	End	0	49.00
19° VS	1	4 38/64	4 31/64		7/64	49.11
	2	4 42/64	4 31/64		11/64	49.05
	3	4 42/64	4 32/64		10/64	49.03
	4	4 41/64	4 32/64	VS	9/64	49.05
	5	4 39/64	4 27/64		12/64	49.16
	6	4 39/64	4 27/64	VS	12/64	49.16
	7	4 41/64	4 24/64		17/64	49.17
	8	4 41/64	4 26/64		15/64	49.14
VS	9	4 41/64	4 26/64		15/64	49.14
Rolls	10	4 39/64	4 25/64	Rolls	14/64	49.19
Rolls VS	11	4 41/64	4 25/64	Rolls	16/64	49.16
	12	4 36/64	4 25/64		11/64	49.23
VS	13	4 36/64	4 23/64		13/64	49.27
	14	4 37/64	4 23/64		14/64	49.25
	15	4 36/64	4 24/64		12/64	49.25
	16	4 37/64	4 24/64		13/64	49.23
	17	4 39/64	4 28/64	BS	11/64	49.14
Splice	18	4 42/64	4 27/64		15/64	49.11
	19	4 41/64	4 29/64	VS	12/64	49.09
	20	4 36/64	4 25/64		11/64	49.23
	21	4 39/64	4 28/64		11/64	49.14
	22	4 40/64	4 27/64		13/64	49.14
	23	4 37/64	4 26/64		11/64	49.20
VS	24	4 41/64	4 27/64		14/64	49.13
	25	4 40/64	4 28/64		12/64	49.13
VS	26	4 41/64	4 29/64		12/64	49.09
	27	4 41/64	4 31/64		10/64	49.06
	28	4 42/64	4 31/64		11/64	49.05
	29	4 43/64	4 33/64		10/64	49.00
	30	4 43/64	4 33/64		10/64	49.00
	31	4 44/64	4 35/64		9/64	48.95
	32	4 44/64	4 36/64	Rolls VS	8/64	48.94
Rolls	33	4 43/64	4 34/64	Rolls	9/64	48.98
	34	4 43/64	4 33/64	BS	10/64	49.00
	35	4 41/64	4 32/64		9/64	49.05
	36	4 42/64	4 32/64		10/64	49.03
VS	37	4 42/64	4 31/64		11/64	49.05
	38	4 41/64	4 31/64		10/64	49.06
VS	39	4 44/64	4 31/64		13/64	49.02
	40	4 42/64	4 33/64		9/64	49.02
	41	4 41/64	4 31/64		10/64	49.06
	42	4 40/64	4 31/64		9/64	49.08
	43	4 39/64	4 30/64		9/64	49.11
	44	4 37/64	4 29/64		8/64	49.16
	45	4 40/64	4 33/64	VS	7/64	49.05
End	46	4 33/64	4 33/64	End	0	49.16

Average Deviation: 11/64
Largest Deviation: 17/64

Average Diameter: 49.10
Largest Diameter: 49.27
Smallest Diameter: 48.94

Location	Spiral No.	90°	270°	Location	Difference	Diameter
End	0	4 31/64	4 31/64	End	0	49.22
15°	1	4 34/64	4 31/64	8°	3/64	49.17
BS	2	4 38/64	4 33/64		5/64	49.08
	3	4 39/64	4 36/64		3/64	49.02
VS	4	4 41/64	4 35/64		6/64	49.00
	5	4 39/64	4 33/64		6/64	49.06
	6	4 39/64	4 33/64		6/64	49.06
	7	4 40/64	4 32/64		8/64	49.06
	8	4 40/64	4 33/64	VS	7/64	49.05
	9	4 40/64	4 33/64		7/64	49.05
Rolls	10	4 39/64	4 31/64	Rolls VS	8/64	49.09
Rolls	11	4 38/64	4 30/64	Rolls	8/64	49.13
	12	4 37/64	4 28/64		9/64	49.17
VS	13	4 37/64	4 28/64		9/64	49.17
	14	4 35/64	4 27/64		8/64	49.22
	15	4 37/64	4 28/64		9/64	49.17
	16	4 36/64	4 29/64		7/64	49.17
	17	4 37/64	4 29/64		8/64	49.16
	18	4 36/64	4 28/64		8/64	49.19
	19	4 35/64	4 28/64		7/64	49.20
	20	4 34/64	4 26/64		8/64	49.25
	21	4 35/64	4 28/64	VS	7/64	49.20
	22	4 36/64	4 29/64		7/64	49.17
	23	4 37/64	4 30/64	VS	7/64	49.14
	24	4 38/64	4 30/64		8/64	49.13
	25	4 39/64	4 31/64		8/64	49.09
	26	4 39/64	4 33/64		6/64	49.06
	27	4 39/64	4 33/64		6/64	49.06
VS	28	4 40/64	4 33/64		7/64	49.05
	29	4 39/64	4 34/64		5/64	49.05
VS	30	4 40/64	4 34/64		6/64	49.03
	31	4 39/64	4 35/64		4/64	49.03
Rolls	32	4 39/64	4 35/64	Rolls	4/64	49.03
Rolls	33	4 39/64	4 35/64	Rolls	4/64	49.03
	34	4 38/64	4 35/64	BS	3/64	49.05
	35	4 39/64	4 33/64		6/64	49.06
	36	4 38/64	4 35/64	VS	3/64	49.05
	37	4 39/64	4 34/64		5/64	49.05
	38	4 37/64	4 34/64		3/64	49.08
VS	39	4 38/64	4 33/64		5/64	49.08
	40	4 38/64	4 32/64		6/64	49.09
VS	41	4 39/64	4 32/64		7/64	49.08
	42	4 39/64	4 31/64		8/64	49.09
VS	43	4 35/64	4 31/64		4/64	49.16
	44	4 34/64	4 30/64		4/64	49.19
VS	45	4 34/64	4 31/64		3/64	49.17
End	46	4 36/64	4 34/64	End	2/64	49.09

Average Deviation: 6/64
Largest Deviation: 9/64

Average Diameter: 49.11
Largest Diameter: 49.25
Smallest Diameter: 49.00

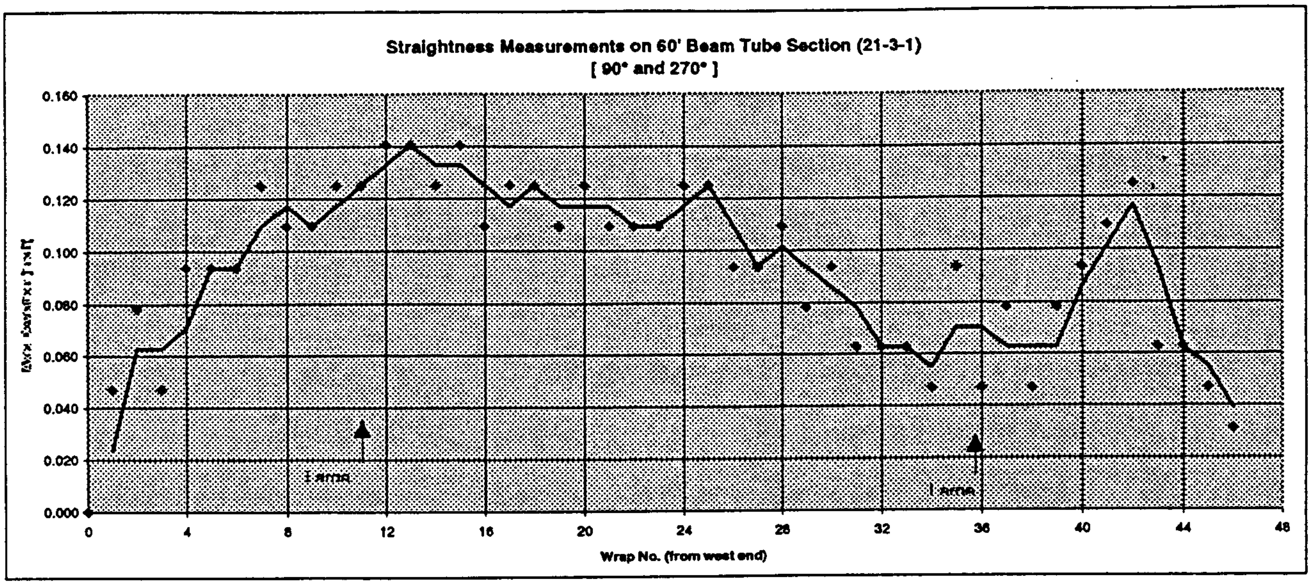
Outside diameter (pi-tape)

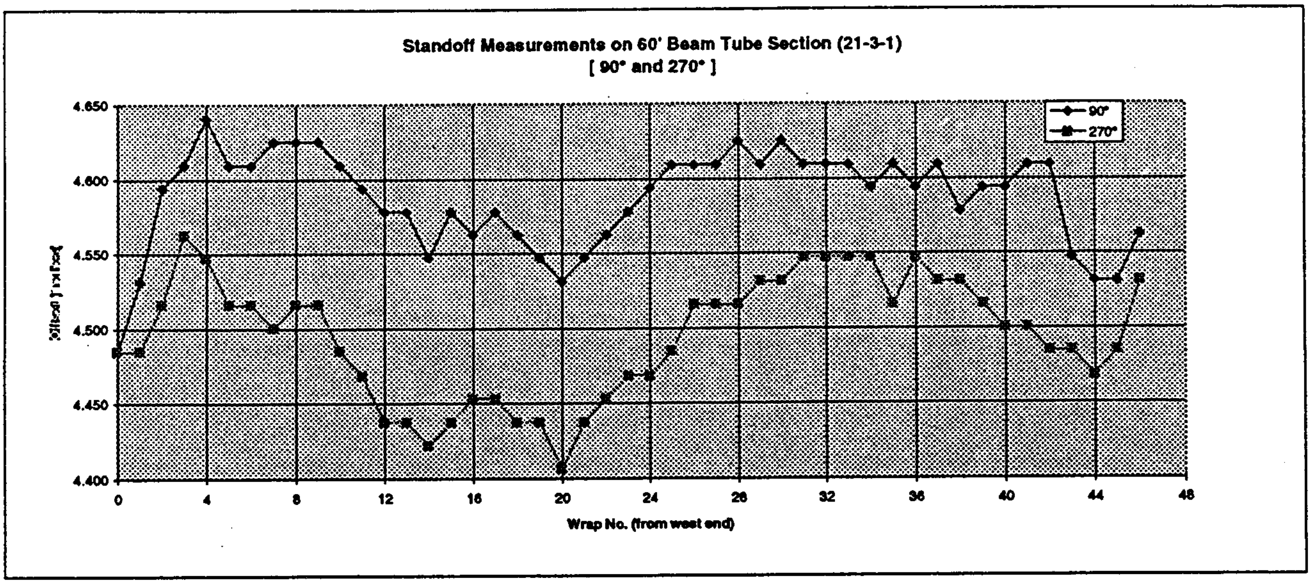
West cut-line: 49.115
West reference: 49.120
16-C-1: 49.045
4th wrap: 49.037
West rolls: 49.039

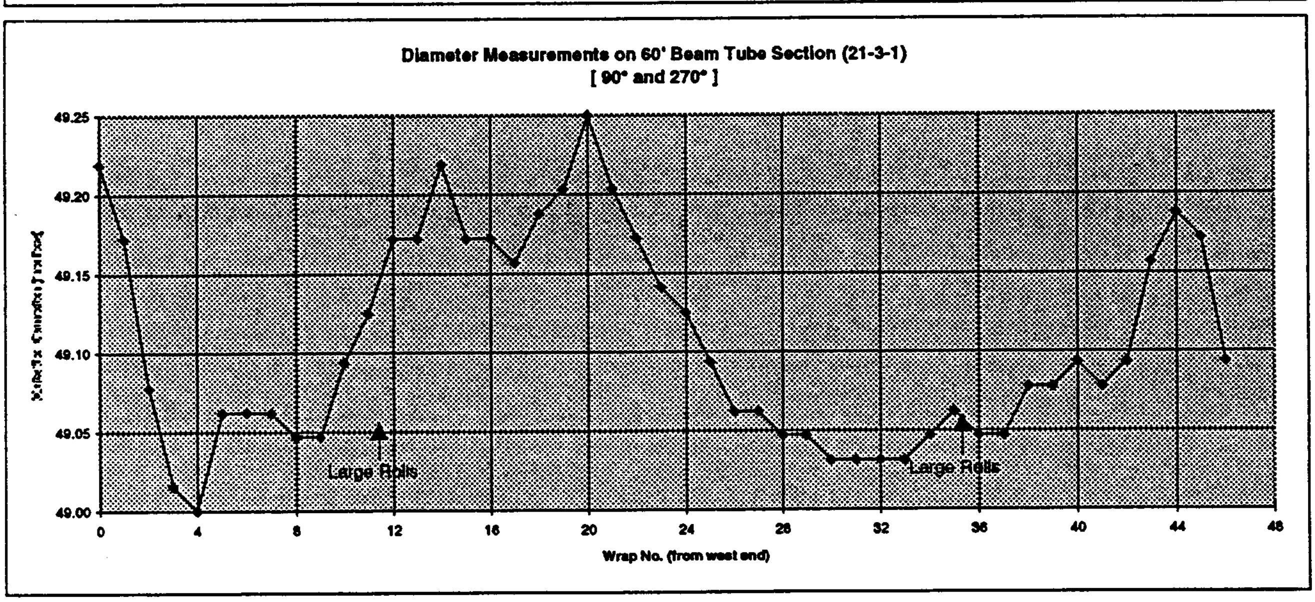
16-A-1: 48.988
14th wrap: 49.167
16-A-2: 49.110
Centerline: 49.100
27th wrap: 49.045

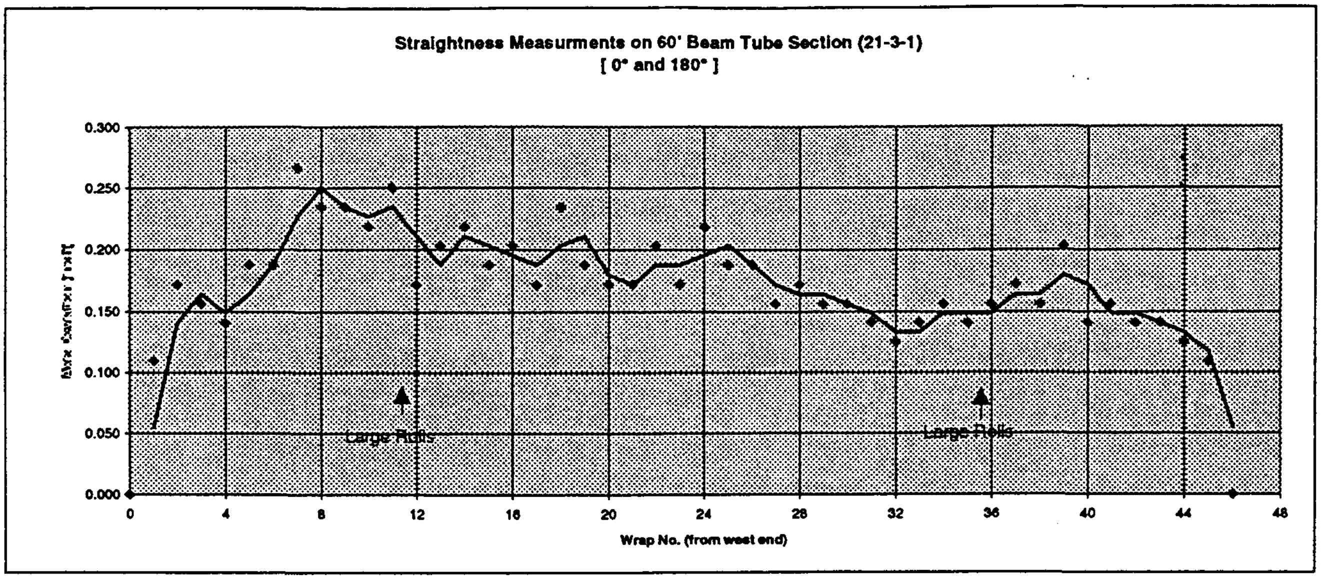
37th wrap: 49.025
East reference: 49.110
East cut-line: 49.120

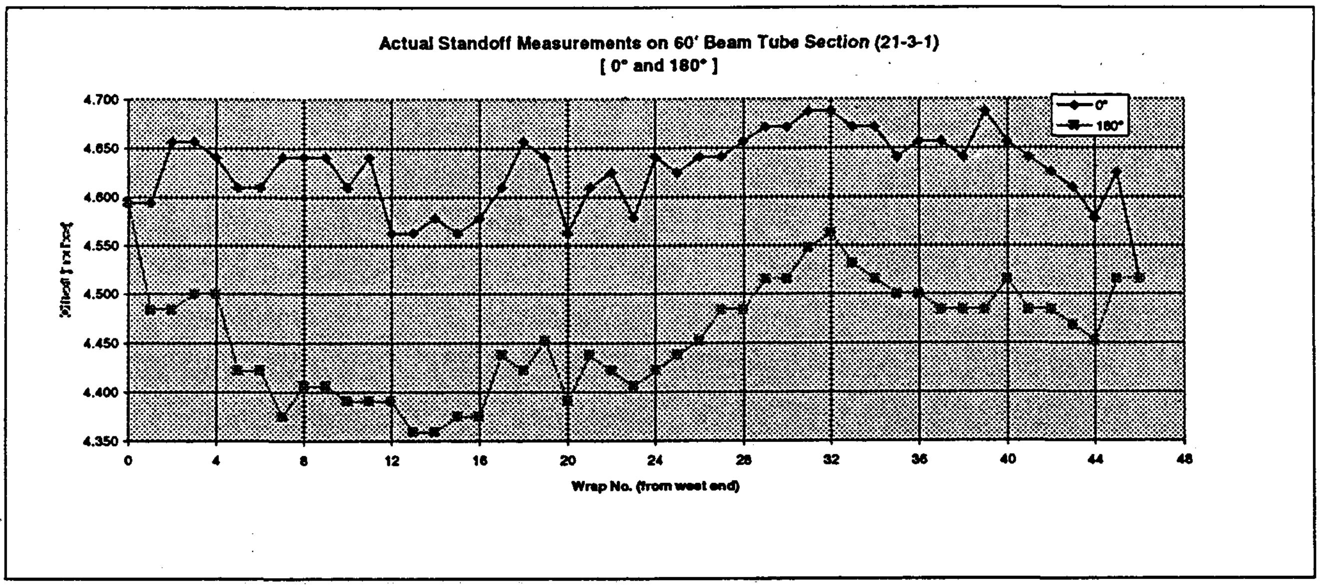
67°F

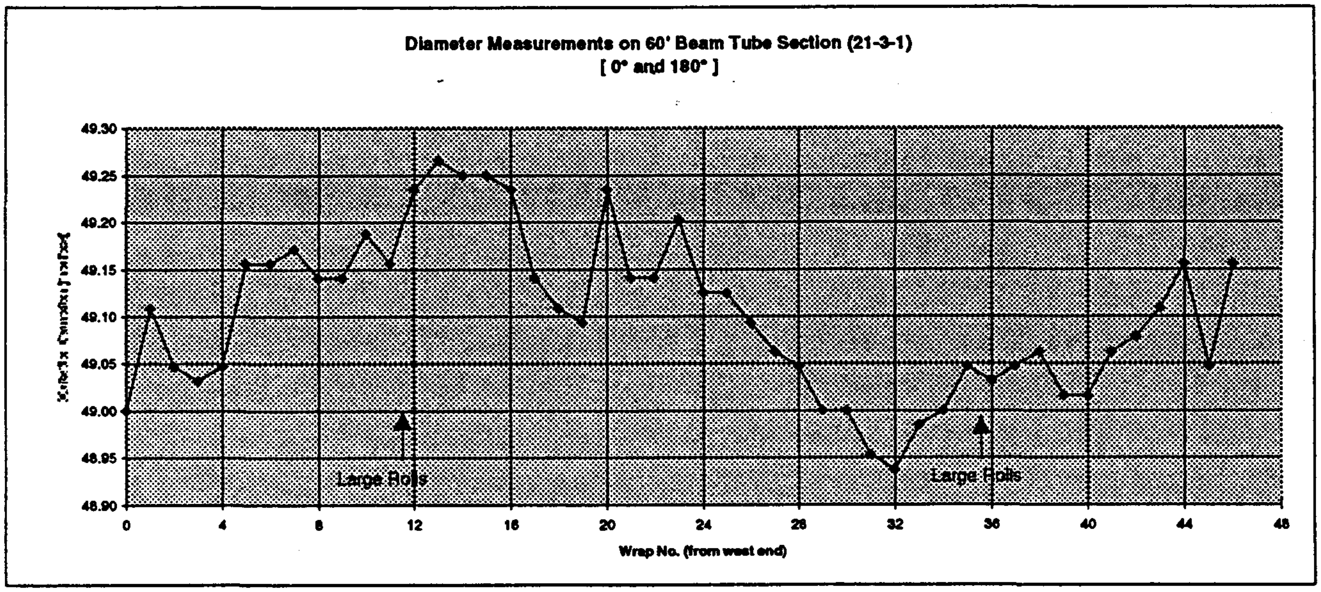

Straightness Measurements on 60' Beam Tube Section (21-3-1)
[90° and 270°]
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0 4 8 12 16 20 24 28 32 36 40 44 48
Wrap No. (from west end)


Standoff Measurements on 60' Beam Tube Section (21-3-1)
[90° and 270°]
90°
270°
4.650
4.600
4.550
4.500
4.450
4.400
0 4 8 12 16 20 24 28 32 36 40 44 48
Wrap No. (from west end)

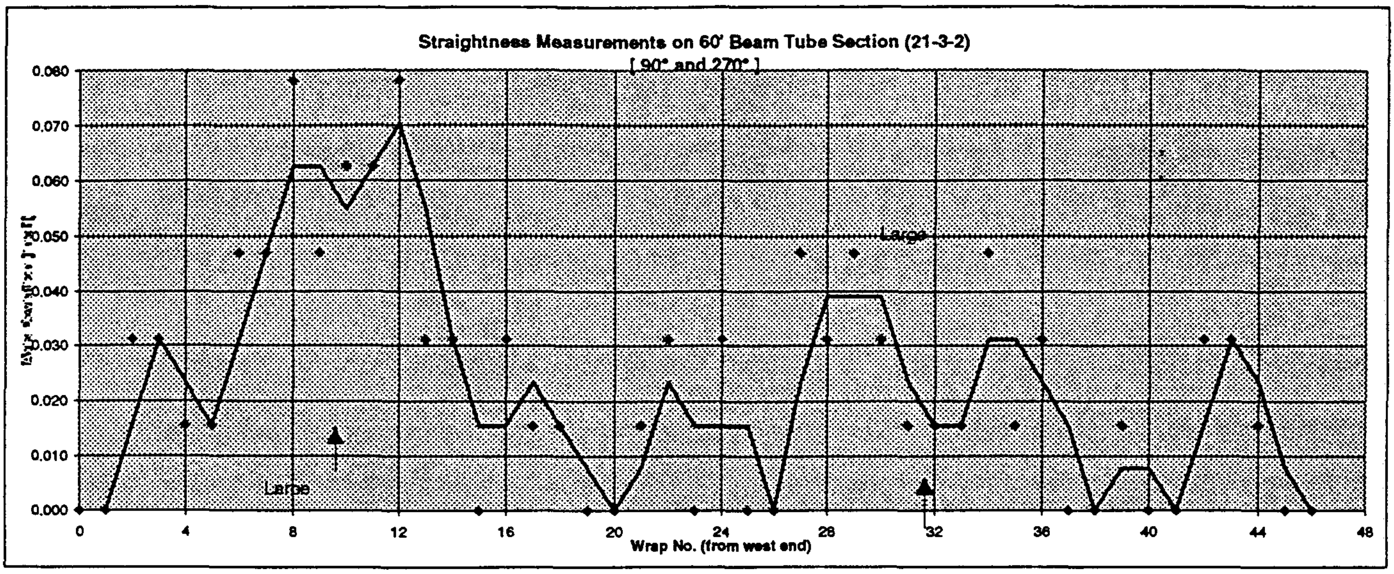

Diameter Measurements on 60' Beam Tube Section (21-3-1)
[90° and 270°]
49.25
49.20
49.15
49.10
49.05
49.00
Large Rolls
Large Rolls
0 4 8 12 16 20 24 28 32 36 40 44 48
Wrap No. (from west end)

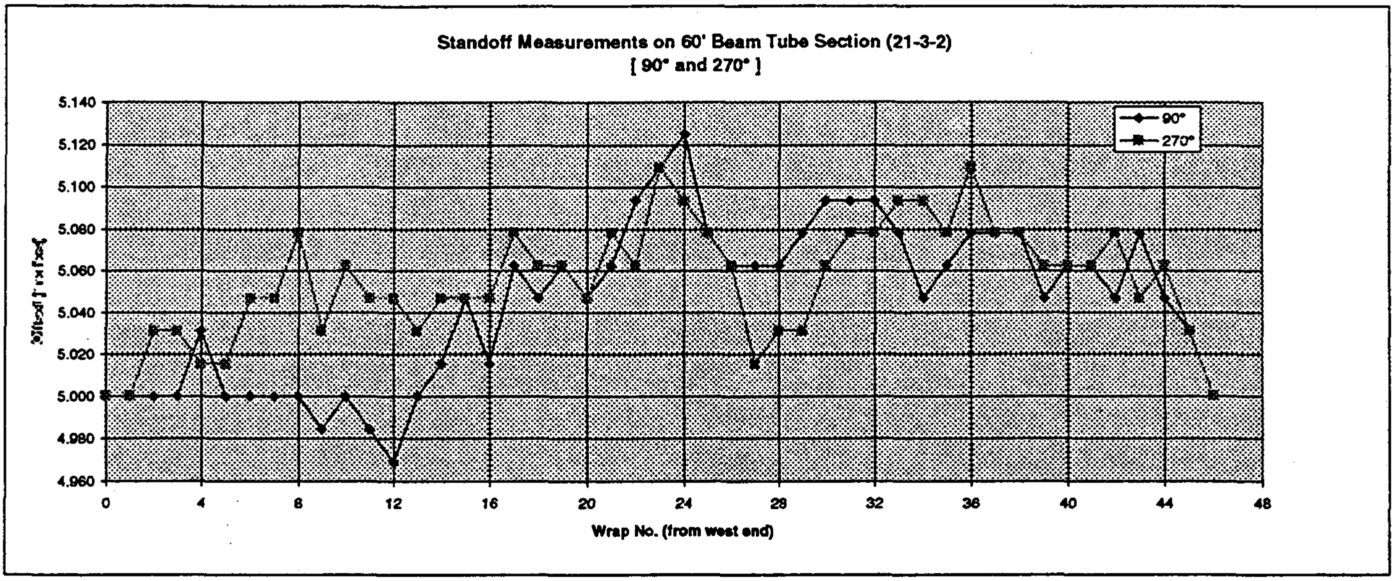

Straightness Measurments on 60' Beam Tube Section (21-3-1)
[0° and 180°]
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0
4
8
12
16
20
24
28
32
36
40
44
48
Large Rolls
Large Rolls
Wrap No. (from west end)

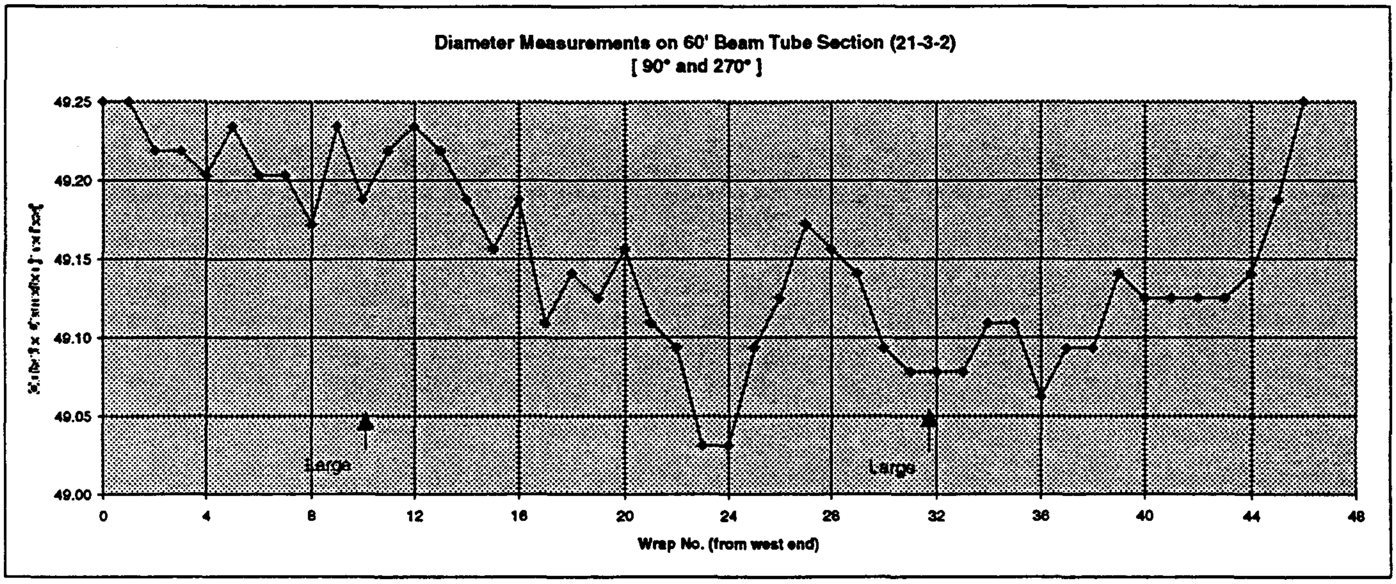

Actual Standoff Measurements on 60' Beam Tube Section (21-3-1)
[0° and 180°]
0°
180°
4.700
4.650
4.600
4.550
4.500
4.450
4.400
4.350
0
4
8
12
16
20
24
28
32
36
40
44
48
Wrap No. (from west end)


Diameter Measurements on 60' Beam Tube Section (21-3-1)
[0° and 180°]
49.30
49.25
49.20
49.15
49.10
49.05
49.00
48.95
48.90
0
4
8
12
16
20
24
28
32
36
40
44
48
Large Rolls
Large Rolls
Wrap No. (from west end)

Beam Tube Section 21-3-2 (After Welding)







CB&I MEASUREMENT RECORD & CHECK LIST

See Procedure "Doc. ID No." DCQT

Description				CBI		REMARKS:
Seq. No.	Operation, Inspection, or Examination to be completed	Applicable Procedure or Instruction	Init. Req'd "X"	Operation Insp. or Exam Accepted Initial	Date	
	TAKE before MEASUREMENTS			W/R	8/8/94	
	TAKE AFTER MEASUREMENTS			W/R	8/10/94	

Made By	Chk'd By	Rev.	By				Contract Number	No. QT-H7
8/8/94			Chk'd				930212	Sheet 1 of 7
Date W/R	Date		Date					

DC.1 REV MAR 94

QT Beam Tube Section: 21-3-2 (Before welding)

Location	Spiral No.	0°	180°	Location	Difference	Diameter
End	0	5	5	End	0	49.31
19°	1	4 61/64	4 63/64		2/64	49.38
	2	4 62/64	5		2/64	49.34
	3	4 63/64	5		1/64	49.33
	4	4 62/64	4 63/64		1/64	49.36
	5	4 62/64	4 63/64		1/64	49.36
	6	4 62/64	4 62/64		0	49.38
	7	4 61/64	4 62/64		1/64	49.39
	8	4 59/64	4 60/64		1/64	49.45
	9	4 58/64	4 60/64		2/64	49.47
Rolls	10	4 58/64	4 60/64	Rolls	2/64	49.47
Rolls	11	4 58/64	4 60/64	Rolls	2/64	49.47
	12	4 58/64	4 61/64		3/64	49.45
	13	4 59/64	4 61/64		2/64	49.44
	14	4 60/64	5		4/64	49.38
	15	4 61/64	5		3/64	49.36
	16	4 61/64	5		3/64	49.36
	17	4 61/64	5		3/64	49.36
	18	4 62/64	5		2/64	49.34
	19	4 63/64	4 61/64		2/64	49.38
	20	5	5		0	49.31
	21	4 63/64	5		1/64	49.33
	22	4 63/64	4 61/64		2/64	49.38
	23	4 63/64	4 61/64		2/64	49.38
	24	5	5		0	49.31
	25	5	4 63/64		1/64	49.33
	26	4 60/64	4 62/64		2/64	49.41
	27	4 60/64	4 62/64		2/64	49.41
	28	4 61/64	4 62/64		1/64	49.39
Splice	29	4 60/64	5	Splice	4/64	49.38
	30	4 58/64	5		6/64	49.41
	31	4 60/64	4 62/64		2/64	49.41
Rolls	32	4 58/64	4 62/64	Rolls	4/64	49.44
	33	4 59/64	4 62/64		3/64	49.42
	34	4 58/64	4 62/64		4/64	49.44
	35	4 59/64	4 62/64		3/64	49.42
	36	4 60/64	4 63/64		3/64	49.39
	37	4 61/64	5 1/64		4/64	49.34
	38	4 63/64	5 1/64		2/64	49.31
	39	4 63/64	5 2/64		3/64	49.30
	40	5	5 2/64		2/64	49.28
	41	5	5 3/64		3/64	49.27
	42	5	5 3/64		3/64	49.27
	43	5 1/64	5 3/64		2/64	49.25
	44	4 63/64	5 4/64		5/64	49.27
14°	45	5	5 2/64		2/64	49.28
End	46	5 4/64	5 4/64	End	0	49.19

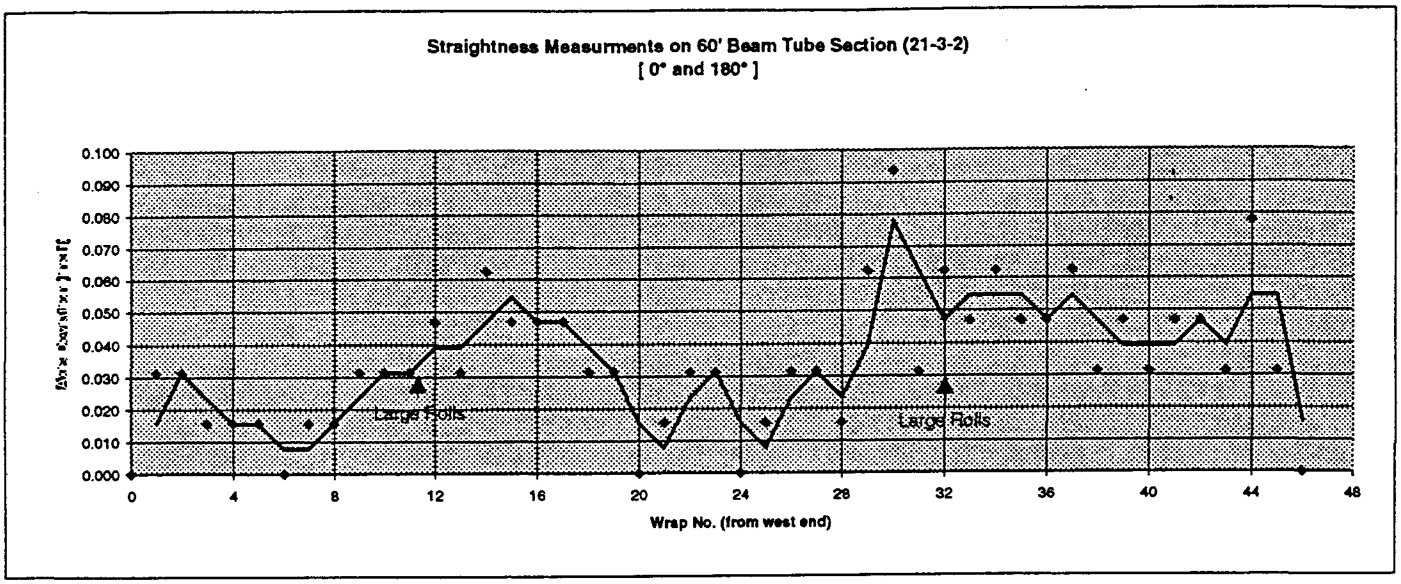
Average Deviation: 2/64
Largest Deviation: 6/64

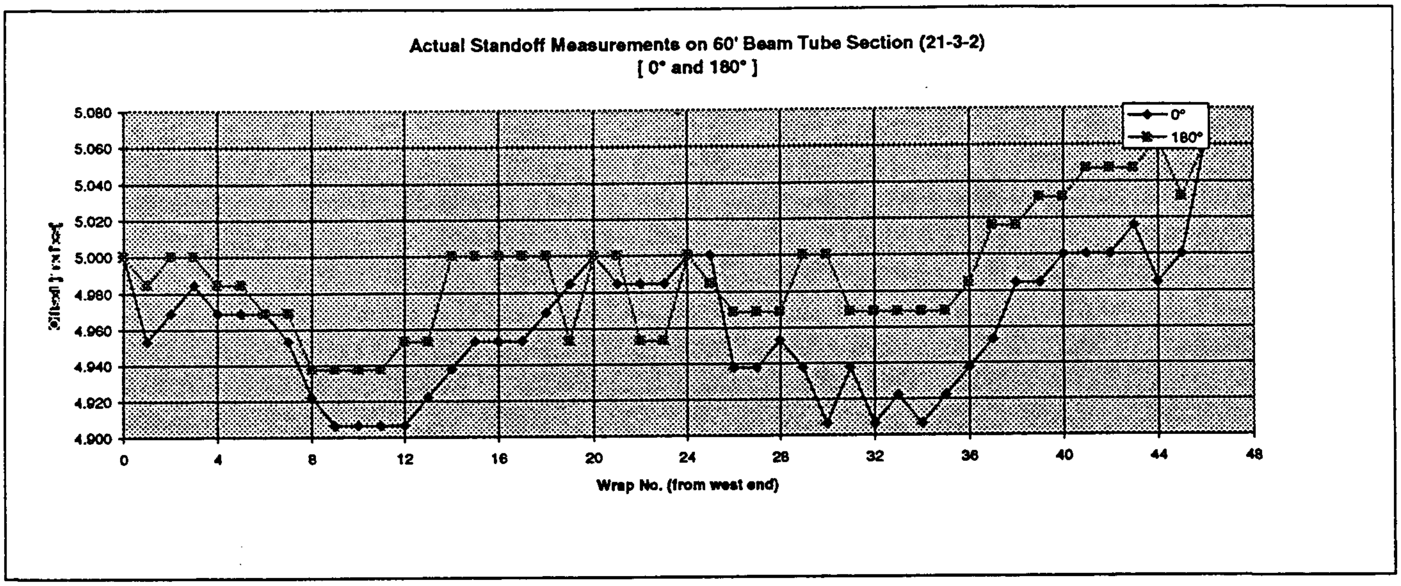
Average Diameter: 49.36
Largest Diameter: 49.47
Smallest Diameter: 49.19

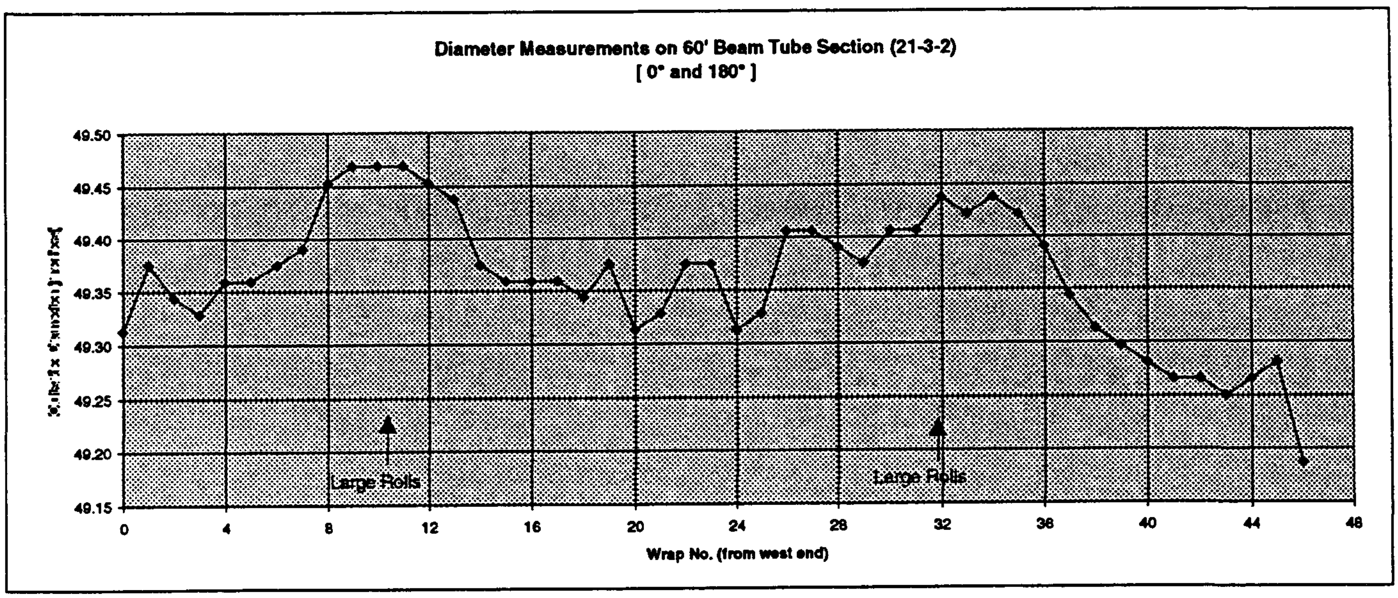
Location	Spiral No.	90°	270°	Location	Difference	Diameter
End	0	5	5	End	0	49.25
15°	1	5	5		0	49.25
	2	5	5		0	49.25
	3	5	5		0	49.25
	4	5	5		0	49.25
	5	4 63/64	4 62/64		1/64	49.30
	6	4 61/64	5		3/64	49.30
	7	4 61/64	4 62/64		1/64	49.33
	8	4 60/64	5		4/64	49.31
	9	4 58/64	4 59/64		1/64	49.42
Rolls	10	4 58/64	4 60/64	Rolls	2/64	49.41
Rolls	11	4 58/64	4 60/64	Rolls	2/64	49.41
	12	4 59/64	4 61/64		2/64	49.38
	13	4 59/64	4 60/64		1/64	49.39
	14	4 62/64	4 62/64		0	49.31
	15	4 61/64	4 62/64		1/64	49.33
	16	4 62/64	4 62/64		0	49.31
	17	4 61/64	5		3/64	49.30
	18	4 63/64	5		1/64	49.27
	19	4 63/64	5		1/64	49.27
	20	5	5		0	49.25
	21	4 62/64	5		2/64	49.28
	22	4 62/64	5		2/64	49.28
	23	4 62/64	5		2/64	49.28
	24	4 62/64	5		2/64	49.28
	25	4 61/64	5		3/64	49.30
	26	4 58/64	4 61/64		3/64	49.39
	27	4 59/64	4 61/64		2/64	49.38
	28	4 59/64	4 60/64		1/64	49.39
Splice	29	4 60/64	4 61/64	Splice	1/64	49.36
	30	4 61/64	4 60/64		1/64	49.36
	31	4 60/64	4 61/64		1/64	49.36
Rolls	32	4 60/64	4 60/64	Rolls	0	49.38
	33	4 59/64	4 61/64		2/64	49.38
	34	4 61/64	4 60/64		1/64	49.36
	35	4 60/64	4 60/64		0	49.38
	36	4 61/64	4 61/64		0	49.34
	37	4 61/64	4 61/64		0	49.34
	38	4 63/64	5		1/64	49.27
	39	5	4 62/64		2/64	49.28
	40	5 1/64	5		1/64	49.23
	41	5 1/64	5		1/64	49.23
	42	5 1/64	5		1/64	49.23
	43	5 2/64	5 2/64		0	49.19
	44	5 2/64	5 1/64		1/64	49.20
18°	45	5 3/64	5 2/64		1/64	49.17
End	46	5 2/64	5 2/64	End	0	49.19

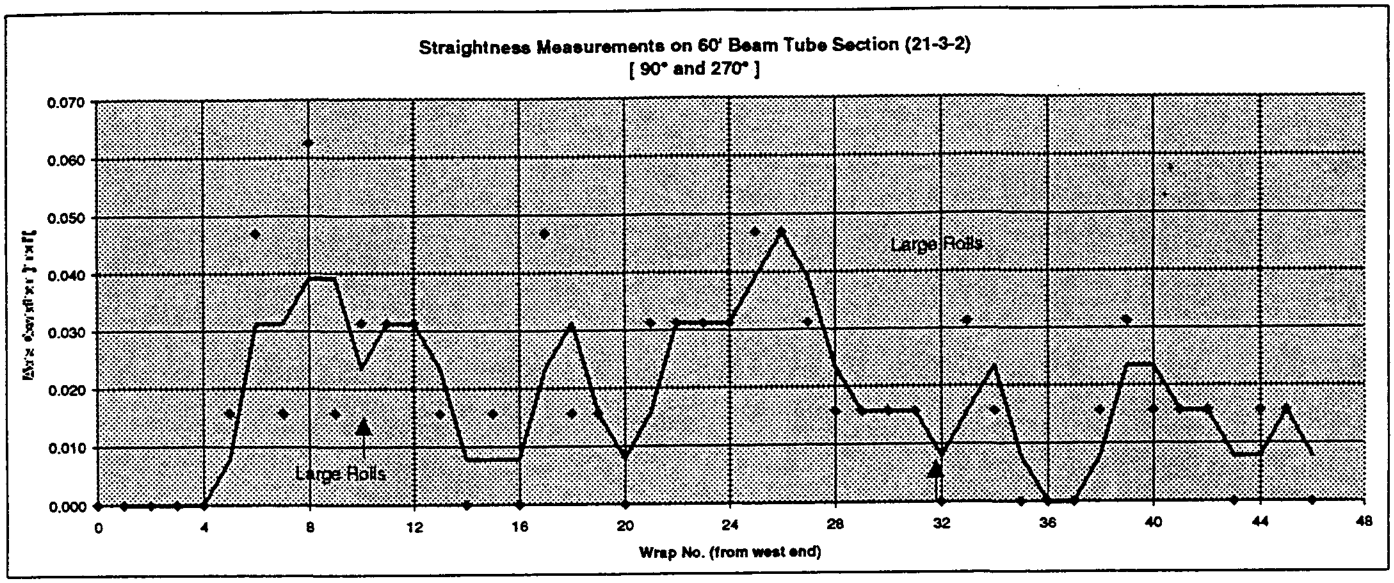
Average Deviation: 1/64 68°F
Largest Deviation: 4/64

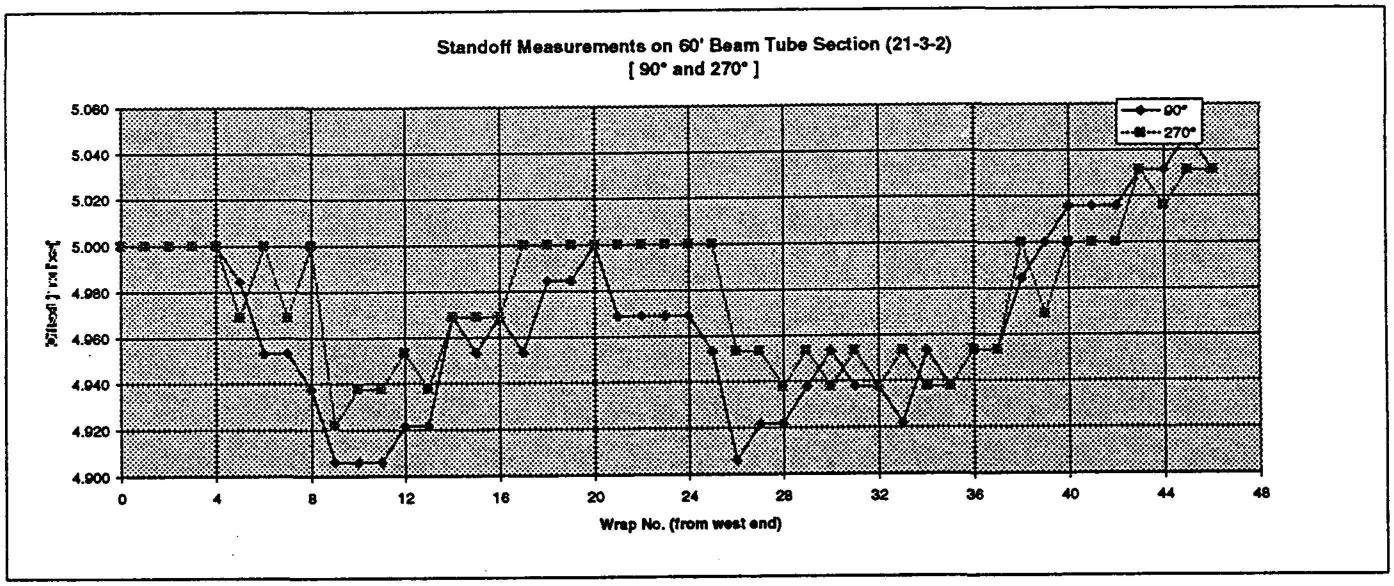
Average Diameter: 49.31
Largest Diameter: 49.42
Smallest Diameter: 49.17

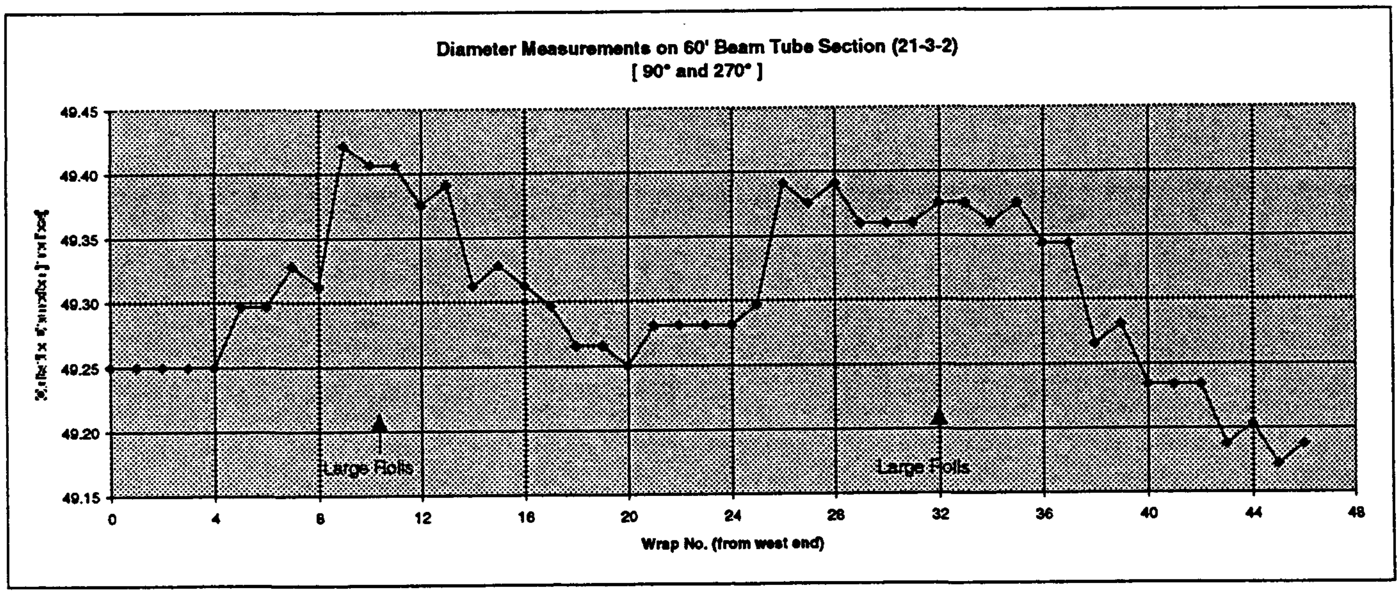

Straightness Measurments on 60' Beam Tube Section (21-3-2)
[0° and 180°]
Large Rolls
Large Rolls
Wrap No. (from west end)


Actual Standoff Measurements on 60' Beam Tube Section (21-3-2)
[0° and 180°]
0°
180°
Wrap No. (from west end)


Diameter Measurements on 60' Beam Tube Section (21-3-2)
[0° and 180°]
Large Rolls
Large Rolls
Wrap No. (from west end)


Straightness Measurements on 60' Beam Tube Section (21-3-2)
[90° and 270°]
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
0
4
8
12
16
20
24
28
32
36
40
44
48
Large Rolls
Large Rolls
Wrap No. (from west end)


Standoff Measurements on 60' Beam Tube Section (21-3-2)
[90° and 270°]
90°
270°
5.060
5.040
5.020
5.000
4.980
4.960
4.940
4.920
4.900
0
4
8
12
16
20
24
28
32
36
40
44
48
Wrap No. (from west end)


Diameter Measurements on 60' Beam Tube Section (21-3-2)
[90° and 270°]
49.45
49.40
49.35
49.30
49.25
49.20
49.15
0
4
8
12
16
20
24
28
32
36
40
44
48
Large Rolls
Large Rolls
Wrap No. (from west end)

QT Beam Tube Section: 21-3-2 (After welding)

Location	Spiral No.	0°	180°	Location	Difference	Diameter
End	0	5	5	End	0	49.31
14"	1	5 4/64	5	8"	4/64	49.25
	2	5 4/64	5		4/64	49.25
	3	5 4/64	5 1/64		3/64	49.23
	4	5 4/64	5 3/64		1/64	49.20
	5	5 5/64	5 3/64		2/64	49.19
	6	5 6/64	5 4/64	VS	2/64	49.16
	7	5 5/64	5 3/64		2/64	49.19
	8	5 3/64	5 4/64	VS	1/64	49.20
Rolls	9	5 2/64	5 2/64	Rolls	0	49.25
Rolls	10	5 1/64	5 1/64	Rolls	0	49.28
VS	11	5 6/64	5 2/64		4/64	49.19
	12	5 4/64	5 2/64		2/64	49.22
VS	13	5 6/64	5 2/64		4/64	49.19
	14	5 6/64	5 3/64		3/64	49.17
	15	5 6/64	5 3/64		3/64	49.17
	16	5 6/64	5 5/64		1/64	49.14
	17	5 6/64	5 5/64		1/64	49.14
	18	5 6/64	5 6/64	VS	0	49.13
	19	5 6/64	5 5/64		1/64	49.14
	20	5 5/64	5 6/64	VS	1/64	49.14
	21	5 5/64	5 3/64		2/64	49.19
	22	5 5/64	5 4/64		1/64	49.17
	23	5 6/64	5 3/64		3/64	49.17
VS	24	5 6/64	5 3/64		3/64	49.17
	25	5 3/64	5		3/64	49.27
VS	26	5 5/64	5 2/64		3/64	49.20
	27	5 4/64	5 2/64		2/64	49.22
	28	5 5/64	5 4/64		1/64	49.17
	29	5 8/64	5 6/64		2/64	49.09
	30	5 10/64	5 6/64		4/64	49.06
	31	5 8/64	5 9/64	VS	1/64	49.05
Rolls	32	5 8/64	5 6/64	Rolls	2/64	49.09
Rolls	33	5 9/64	5 9/64	Rolls	0	49.03
	34	5 8/64	5 6/64		2/64	49.09
	35	5 9/64	5 7/64		2/64	49.06
	36	5 9/64	5 8/64		1/64	49.05
VS	37	5 11/64	5 8/64		3/64	49.02
	38	5 9/64	5 9/64		0	49.03
VS	39	5 11/64	5 8/64		3/64	49.02
	40	5 10/64	5 8/64		2/64	49.03
	41	5 10/64	5 6/64		4/64	49.06
	42	5 10/64	5 7/64		3/64	49.05
	43	5 10/64	5 8/64	VS	2/64	49.03
	44	5 9/64	5 6/64		3/64	49.08
5"	45	5 9/64	5 8/64	9"	1/64	49.05
End	46	5 10/64	5 10/64	End	0	49.00

Average Deviation: 2/64
Largest Deviation: 4/64

Average Diameter: 49.14
Largest Diameter: 49.31
Smallest Diameter: 49.00

Location	Spiral No.	90°	270°	Location	Difference	Diameter
End	0	5	5	End	0	49.25
10"	1	5	5	6"	0	49.25
BS	2	5	5 2/64		2/64	49.22
	3	5	5 2/64		2/64	49.22
VS	4	5 2/64	5 1/64		1/64	49.20
	5	5	5 1/64		1/64	49.23
	6	5	5 3/64		3/64	49.20
	7	5	5 3/64		3/64	49.20
	8	5	5 5/64	VS	5/64	49.17
	9	4 63/64	5 2/64		3/64	49.23
Rolls	10	5	5 4/64	Rolls VS	4/64	49.19
Rolls	11	4 63/64	5 3/64	Rolls	4/64	49.22
	12	4 62/64	5 3/64	VS	5/64	49.23
	13	5	5 2/64		2/64	49.22
	14	5 1/64	5 3/64		2/64	49.19
VS	15	5 3/64	5 3/64		0	49.16
	16	5 1/64	5 3/64		2/64	49.19
VS	17	5 4/64	5 5/64		1/64	49.11
	18	5 3/64	5 4/64		1/64	49.14
	19	5 4/64	5 4/64		0	49.13
	20	5 3/64	5 3/64		0	49.16
	21	5 4/64	5 5/64	VS	1/64	49.11
	22	5 6/64	5 4/64		2/64	49.09
	23	5 7/64	5 7/64	VS	0	49.03
	24	5 8/64	5 6/64		2/64	49.03
	25	5 5/64	5 5/64	VS	0	49.09
REP	26	5 4/64	5 4/64		0	49.13
	27	5 4/64	5 1/64		3/64	49.17
VS	28	5 4/64	5 2/64		2/64	49.16
	29	5 5/64	5 2/64		3/64	49.14
VS	30	5 6/64	5 4/64		2/64	49.09
	31	5 6/64	5 5/64		1/64	49.08
Rolls	32	5 6/64	5 5/64		1/64	49.08
Rolls	33	5 5/64	5 6/64	VS	1/64	49.08
	34	5 3/64	5 6/64		3/64	49.11
	35	5 4/64	5 5/64	VS	1/64	49.11
	36	5 5/64	5 7/64		2/64	49.06
	37	5 5/64	5 5/64		0	49.09
	38	5 5/64	5 5/64		0	49.09
	39	5 3/64	5 4/64		1/64	49.14
	40	5 4/64	5 4/64		0	49.13
VS	41	5 4/64	5 4/64		0	49.13
	42	5 3/64	5 5/64		2/64	49.13
VS	43	5 5/64	5 3/64		2/64	49.13
	44	5 3/64	5 4/64		1/64	49.14
8"	45	5 2/64	5 2/64	12"	0	49.19
End	46	5	5	End	0	49.25

Average Deviation: 2/64
Largest Deviation: 5/64 90°F

Average Diameter: 49.15
Largest Diameter: 49.25
Smallest Diameter: 49.03

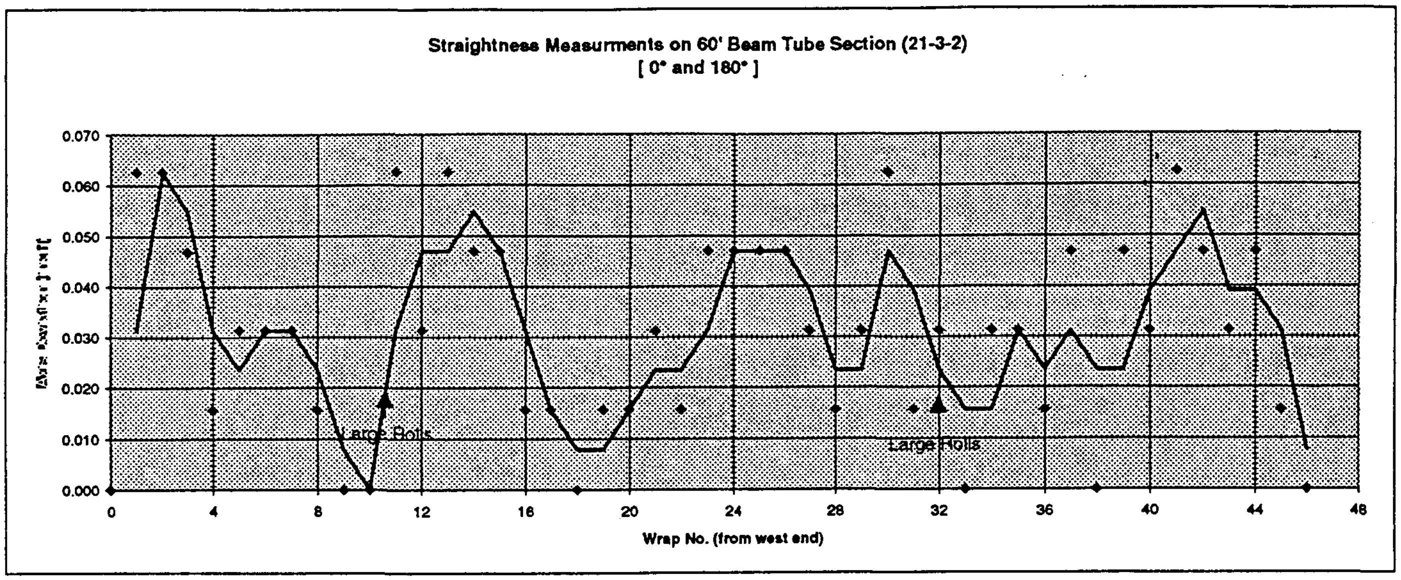
Outside diameter (pi-tape):

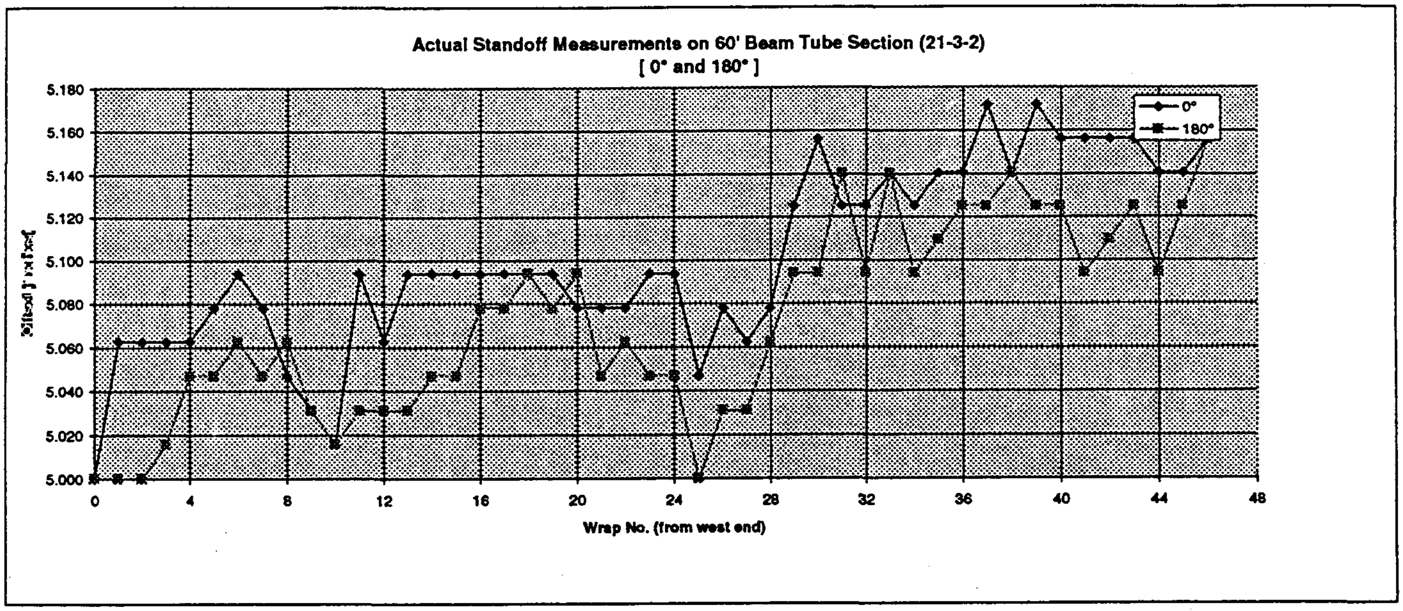
West end: 49.118
West cut-line: 49.139
1/8 L: 49.073
2/8 L: 49.092
West rolls: 49.096

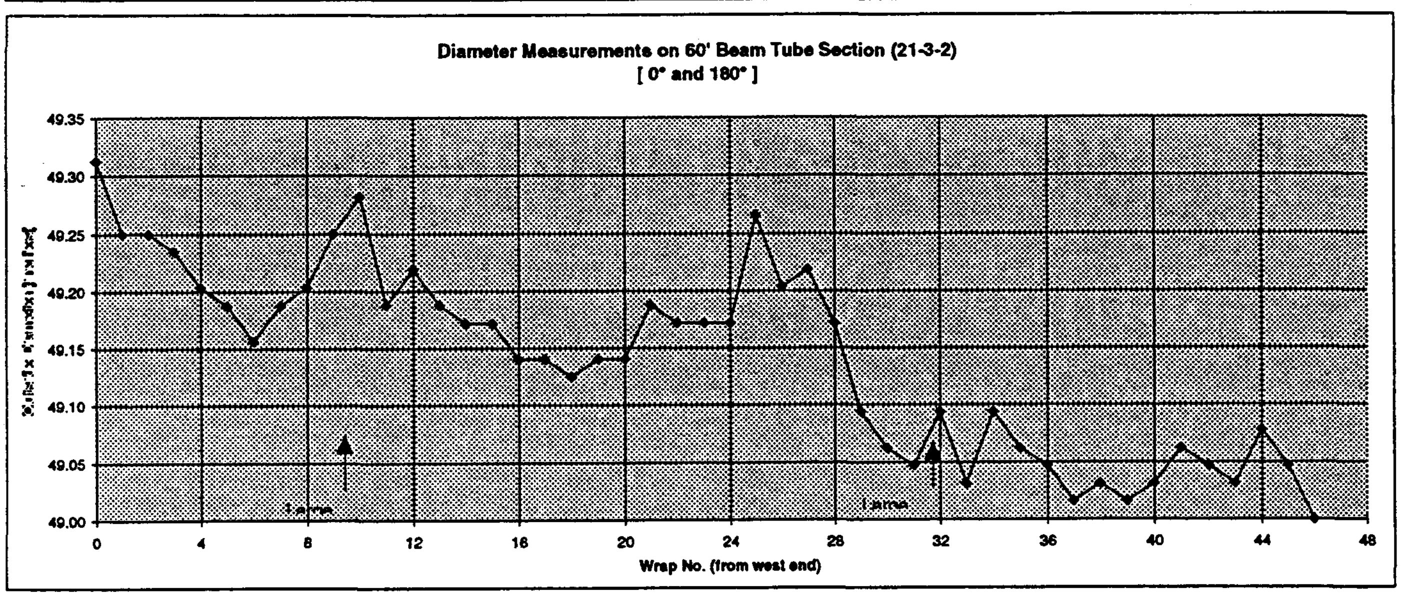
3/8 L: 49.065
4/8 L: 49.050
5/8 L: 49.010
East rolls: 49.096
6/8 L: 48.976

7/8 L: 49.002
East cut-line: 49.020
East end: 49.010

68°F

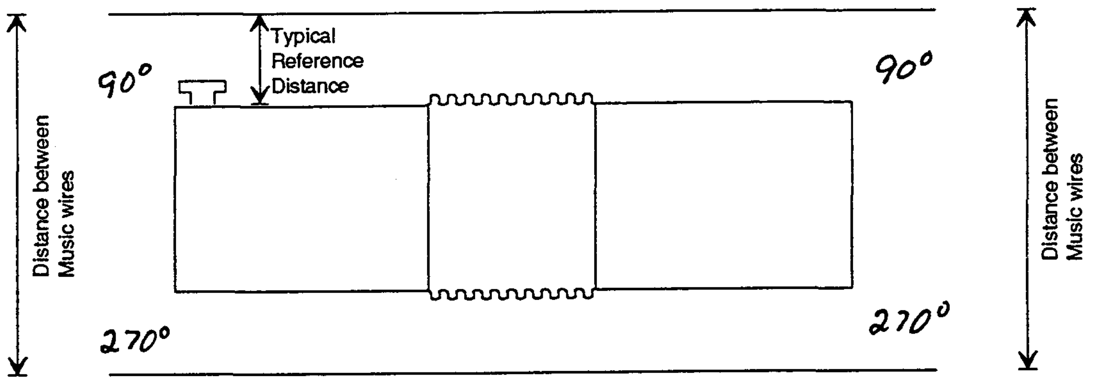

Straightness Measurments on 60' Beam Tube Section (21-3-2)
[0° and 180°]
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Large Rolls
Large Rolls
0 4 8 12 16 20 24 28 32 36 40 44 48
Wrap No. (from west end)


Actual Standoff Measurements on 60' Beam Tube Section (21-3-2)
[0° and 180°]
5.180
5.160
5.140
5.120
5.100
5.080
5.060
5.040
5.020
5.000
0°
180°
0 4 8 12 16 20 24 28 32 36 40 44 48
Wrap No. (from west end)


Diameter Measurements on 60' Beam Tube Section (21-3-2)
[0° and 180°]
49.35
49.30
49.25
49.20
49.15
49.10
49.05
49.00
0 4 8 12 16 20 24 28 32 36 40 44 48
Wrap No. (from west end)

SECTION 2.F.1 APPENDICES

MEASUREMENT RECORD & CHECK LIST



- Plan View -

Description				CBI		
Seq. No.	Operation, Inspection, or Examination to be completed	Applicable Procedure or Instruction	Init. Req'd "X"	Operation Insp. or Exam Accepted Initial	Date	REMARKS:
1	Make Measurements Before Welding			WLR	10/11/94	
2	Make Measurements After Welding			WLR	10/13/94	
3	Record Measurements			WLR	10/13/94	
4						
5						
6						
7						
8						
9						
10						

Made By	Chk'd By	Rev.	By				Contract Number	No. QT-9P
WLR			Chk'd				930212	Sheet 1 of 4
Date 10/19/94	Date		Date					

DC8.1 REV MAR 94

QT Beam Tube Module 20-A (before welding)

Beam Tube Module Before and After Welding

Location	Sta. No.	90°	270°	Location	Difference	Diameter
End 0	0	0.000	0.000	End 0	0	49.24
15-1-30	1	0.063	0.000	15-1-30	4/64	49.31
pp	2	0.000	0.078	pp	5/64	49.30
15-1-31	3	0.094	0.000	15-1-31	6/64	49.28
8"-16-B	4	0.063	-0.063	8"-16-B	8/64	49.38
16-B-1	5	0.063	-0.016	16-B-1	5/64	49.33
15-1-32	6	0.063	-0.031	15-1-32	6/64	49.34
B1	7	0.000	0.000	4"-B1	0	49.16
B1+4"	8	0.125	-0.016	B1+4"	9/64	49.27
15-1-20	9	0.031	0.016	15-1-20	1/64	49.33
15-1-22	10	0.219	0.063	15-1-22	10/64	49.09
15-1-24	11	0.281	0.078	15-1-24	13/64	49.02
15-1-23	12	0.281	0.078	15-1-23	13/64	49.02
15-1-21	13	0.250	0.094	15-1-21	10/64	49.03
16-A-1	14	0.219	0.125	16-A-1	6/64	49.03
15-1-26	15	0.313	0.156	15-1-26	10/64	48.91
15-1-25	16	0.234	0.141	15-1-25	6/64	49.00
15-1-27	17	0.234	0.156	15-1-27	5/64	48.98
15-1-28	18	0.219	0.172	15-1-28	3/64	48.98
15-1-29	19	0.219	0.156	15-1-29	4/64	49.00
15-1-18	20	0.188	0.141	15-1-18	3/64	49.05
15-1-17	21	0.125	0.141	15-1-17	1/64	49.11
15-1-15	22	0.109	0.109	15-1-15	0	49.16
8"-16-A	23	0.078	0.078	8"-16-A	0	49.22
16-A-2	24	0.125	0.109	16-A-2	1/64	49.14
15-1-14	25	0.172	0.125	15-1-14	3/64	49.08
15-1-16	26	0.094	0.125	15-1-16	2/64	49.16
15-1-10	27	0.094	0.094	15-1-10	0	49.19
15-1-11	28	0.063	0.156	15-1-11	6/64	49.16
15-1-12	29	0.109	0.156	15-1-12	3/64	49.11
15-1-13	30	0.141	0.188	15-1-13	3/64	49.05
15-1-8	31	0.125	0.188	15-1-8	4/64	49.06
8"-16-C	32	0.109	0.141	8"-16-C	2/64	49.13
16-C-1	33	0.141	0.141	16-C-1	0	49.09
15-1-9	34	0.063	0.125	15-1-9	4/64	49.19
B2	35	0.000	0.000	B2	0	49.12
22-4-1	36	0.000	0.000	22-4-1	0	49.10
22-4-1	37	0.000	0.000	22-4-1	0	54.84
22-4-1	38	0.000	0.000	22-4-1	0	49.13
22-4-1	39	0.000	0.000	22-4-1	0	54.84
22-4-1	40	0.000	0.000	22-4-1	0	49.17
B3	41	0.000	0.000	B3	0	49.14
15-1-58	42	0.031	0.031	15-1-58	0	49.31
16-C-2	43	0.031	0.031	16-C-2	0	49.31
8"-6-C-2	44	0.063	0.000	8"-6-C-2	4/64	49.31
15-1-57	45	0.125	0.016	15-1-57	7/64	49.23
15-1-56	46	0.078	0.047	15-1-56	2/64	49.25
15-1-55	47	0.047	0.016	15-1-55	2/64	49.31
15-1-54	48	0.078	0.000	15-1-54	5/64	49.30
15-1-53	49	0.031	0.000	15-1-53	2/64	49.34
15-1-52	50	0.078	0.000	15-1-52	5/64	49.30
15-1-51	51	0.094	0.016	15-1-51	5/64	49.27
15-1-50	52	0.063	0.000	15-1-50	4/64	49.31
15-1-49	53	0.125	0.000	15-1-49	8/64	49.25
15-1-48	54	0.125	0.000	15-1-48	8/64	49.25
15-1-47	55	0.125	0.000	15-1-47	8/64	49.25
15-1-46	56	0.125	0.031	15-1-46	6/64	49.22
15-1-45	57	0.078	0.000	15-1-45	5/64	49.30
15-1-44	58	0.078	0.031	15-1-44	3/64	49.27
15-1-43	59	0.094	0.031	15-1-43	4/64	49.25
15-1-42	60	0.063	0.063	15-1-42	0	49.25
15-1-41	61	0.047	0.063	15-1-41	1/64	49.27
15-1-40	62	0.031	0.063	15-1-40	2/64	49.28
15-1-39	63	0.031	0.063	15-1-39	2/64	49.28
15-1-38	64	0.000	0.063	15-1-38	4/64	49.31
15-1-37	65	0.000	0.094	15-1-37	6/64	49.28
15-1-36	66	0.016	0.125	15-1-36	7/64	49.23
3"-B4	67	0.000	0.000	B4	0	49.02
15-1-34	68	-0.031	0.078	15-1-34	7/64	49.33
16-B-2	69	0.000	0.016	16-B-2	1/64	49.36
15-1-33	70	0.016	0.016	15-1-33	0	49.34
End 00	71	0.000	0.000	End 00	0	49.05

Location	Sta. No.	90°	270°	Location	Difference	Diameter
End 0	0	0.000	0.000	End 0	0	49.24
15-1-30	1	0.063	0.000	15-1-30	4/64	49.31
pp	2	0.000	0.078	pp	5/64	49.30
15-1-31	3	0.094	0.000	15-1-31	6/64	49.28
8"-16-B	4	0.063	-0.063	8"-16-B	8/64	49.38
16-B-1	5	0.078	-0.047	16-B-1	8/64	49.34
15-1-32	6	0.094	-0.063	15-1-32	10/64	49.34
B1	7	0.000	0.000	B1	0	49.16
B1+4"	8	0.141	0.000	B1+4"	9/64	49.23
15-1-20	9	0.063	0.031	15-1-20	2/64	49.28
15-1-22	10	0.250	0.063	15-1-22	12/64	49.06
15-1-24	11	0.266	0.078	15-1-24	12/64	49.03
15-1-23	12	0.281	0.078	15-1-23	13/64	49.02
15-1-21	13	0.250	0.109	15-1-21	9/64	49.02
16-A-1	14	0.234	0.125	16-A-1	7/64	49.02
15-1-26	15	0.281	0.156	15-1-26	8/64	48.94
15-1-25	16	0.250	0.141	15-1-25	7/64	48.98
15-1-27	17	0.250	0.156	15-1-27	6/64	48.97
15-1-28	18	0.234	0.156	15-1-28	5/64	48.98
15-1-29	19	0.234	0.172	15-1-29	4/64	48.97
15-1-18	20	0.203	0.156	15-1-18	3/64	49.02
15-1-17	21	0.156	0.141	15-1-17	1/64	49.08
15-1-15	22	0.125	0.094	15-1-15	2/64	49.16
8"-16-A	23	0.078	0.125	8"-16-A	3/64	49.17
16-A-2	24	0.125	0.141	16-A-2	1/64	49.11
15-1-14	25	0.188	0.156	15-1-14	2/64	49.03
15-1-16	26	0.109	0.125	15-1-16	1/64	49.14
15-1-10	27	0.109	0.156	15-1-10	3/64	49.11
15-1-11	28	0.094	0.172	15-1-11	5/64	49.11
15-1-12	29	0.125	0.188	15-1-12	4/64	49.06
15-1-13	30	0.156	0.219	15-1-13	4/64	49.00
15-1-8	31	0.156	0.156	15-1-8	0	49.06
8"-16-C	32	0.125	0.172	8"-16-C	3/64	49.08
16-C-1	33	0.156	0.156	16-C-1	0	49.06
15-1-9	34	0.078	0.078	15-1-9	0	49.22
B2	35	0.000	0.000	B2	0	49.12
22-4-1	36	0.000	0.000	22-4-1	0	49.10
22-4-1	37	0.000	0.000	22-4-1	0	54.84
22-4-1	38	0.000	0.000	22-4-1	0	49.13
22-4-1	39	0.000	0.000	22-4-1	0	54.84
22-4-1	40	0.000	0.000	22-4-1	0	49.17
B3	41	0.000	0.000	B3	0	49.14
15-1-58	42	0.047	0.063	15-1-58	1/64	49.27
16-C-2	43	0.063	0.094	16-C-2	2/64	49.22
8"-6-C-2	44	0.078	0.063	8"-6-C-2	1/64	49.23
15-1-57	45	0.063	0.078	15-1-57	1/64	49.23
15-1-56	46	0.125	0.094	15-1-56	2/64	49.16
15-1-55	47	0.078	0.094	15-1-55	1/64	49.20
15-1-54	48	0.094	0.078	15-1-54	1/64	49.20
15-1-53	49	0.078	0.063	15-1-53	1/64	49.23
15-1-52	50	0.125	0.063	15-1-52	4/64	49.19
15-1-51	51	0.094	0.063	15-1-51	2/64	49.22
15-1-50	52	0.094	0.063	15-1-50	2/64	49.22
15-1-49	53	0.125	0.047	15-1-49	5/64	49.20
15-1-48	54	0.141	0.063	15-1-48	5/64	49.17
15-1-47	55	0.172	0.063	15-1-47	7/64	49.14
15-1-46	56	0.125	0.063	15-1-46	4/64	49.19
15-1-45	57	0.125	0.047	15-1-45	5/64	49.20
15-1-44	58	0.094	0.078	15-1-44	1/64	49.20
15-1-43	59	0.125	0.094	15-1-43	2/64	49.16
15-1-42	60	0.125	0.094	15-1-42	2/64	49.16
15-1-41	61	0.109	0.094	15-1-41	1/64	49.17
15-1-40	62	0.094	0.094	15-1-40	0	49.19
15-1-39	63	0.094	0.094	15-1-39	0	49.19
15-1-38	64	0.063	0.109	15-1-38	3/64	49.20
15-1-37	65	0.094	0.125	15-1-37	2/64	49.16
15-1-36	66	0.094	0.141	15-1-36	3/64	49.14
B4	67	0.000	0.141	B4	9/64	48.88
15-1-34	68	0.047	0.141	15-1-34	6/64	49.19
16-B-2	69	0.031	0.016	16-B-2	1/64	49.33
15-1-33	70	0.016	0.031	15-1-33	1/64	49.33
End 00	71	0.000	0.000	End 00	0	49.05

Average Deviation: 4/64
Largest Deviation: 13/64

Average Diameter: 49.35
Largest Diameter: 54.84
Smallest Diameter: 48.91

Average Deviation: 3/64
Largest Deviation: 13/64

Average Diameter: 49.31
Largest Diameter: 54.84
Smallest Diameter: 48.88

70°F

Outside diameter (pi-tape)

End 0: 49.244
Pump Port: 49.266
16-B-1: 49.255

21-B@B1: 49.162
21-C@B1: 49.116
16-A-1: 49.005

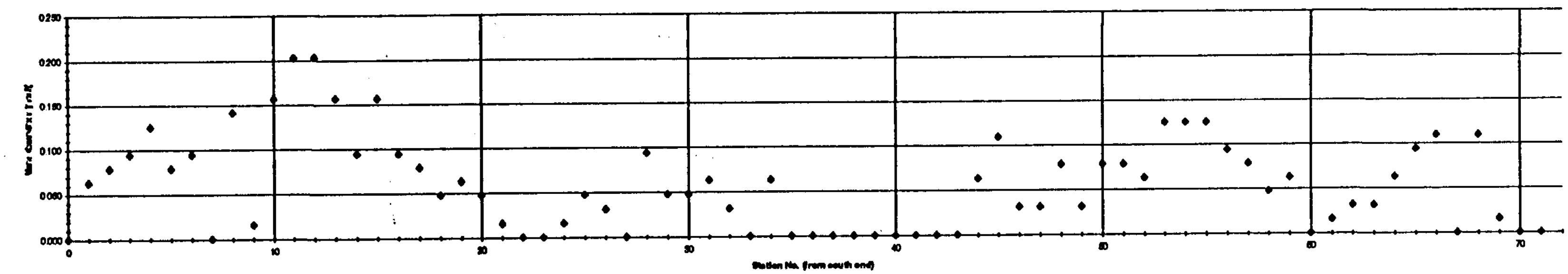
16-A-2: 49.115
16-C-1: 49.055
21-C@B2: 49.122

21-D@B3: 49.142
16-B-2: 49.121
21-D@B4: 49.022

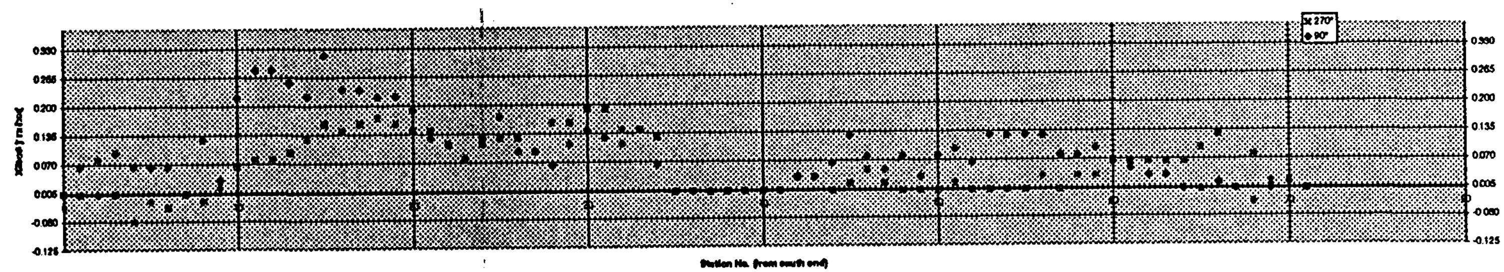
21-A@B4: 49.025
16-B-2: 49.038
End00: 49.054

QT-9P
Sheet 2 of 4

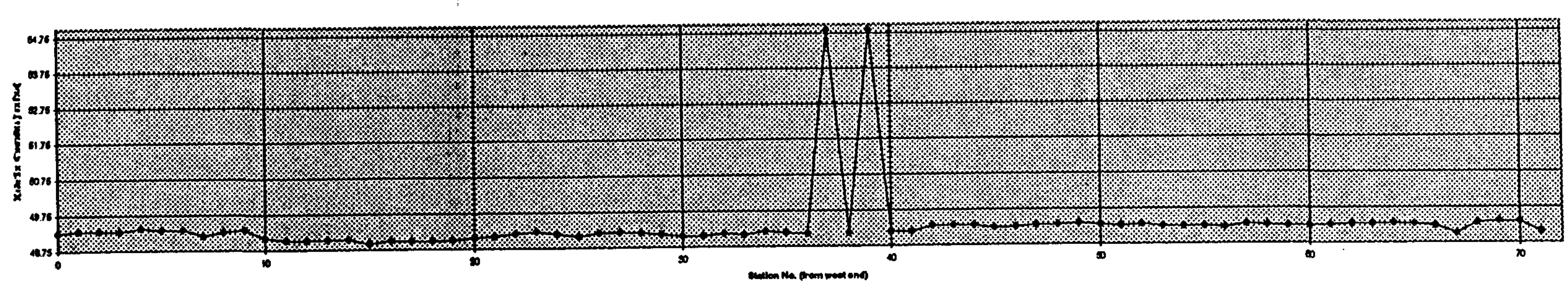
Straightness Measurements on QT Beam Tube Module
Before Welding (90° and 270°)



Actual Standoff Measurements on QT Beam Tube Module
Before Welding (90° and 270°)



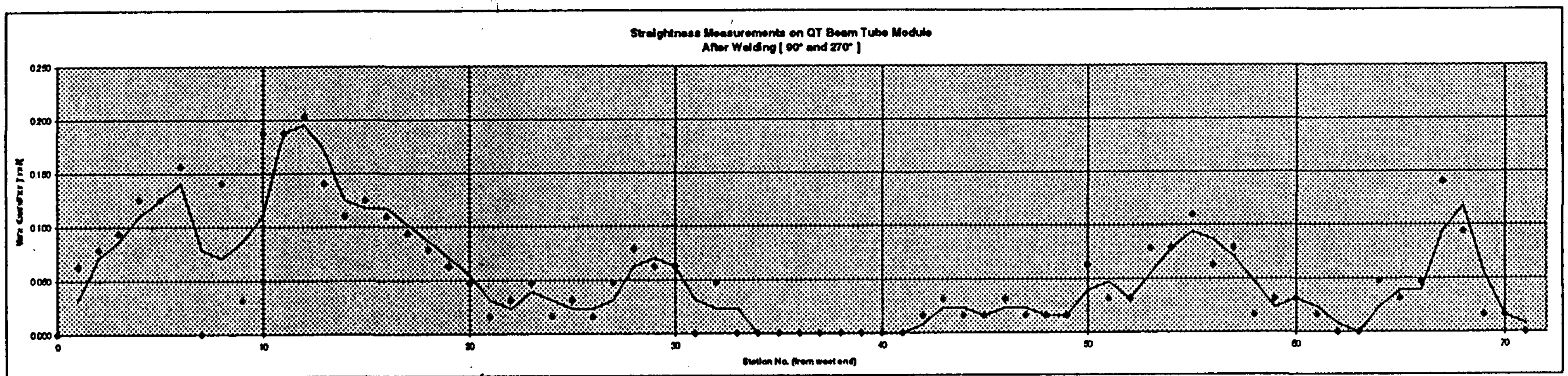
Diameter Measurements on QT Beam Tube Module
Before Welding (90° and 270°)

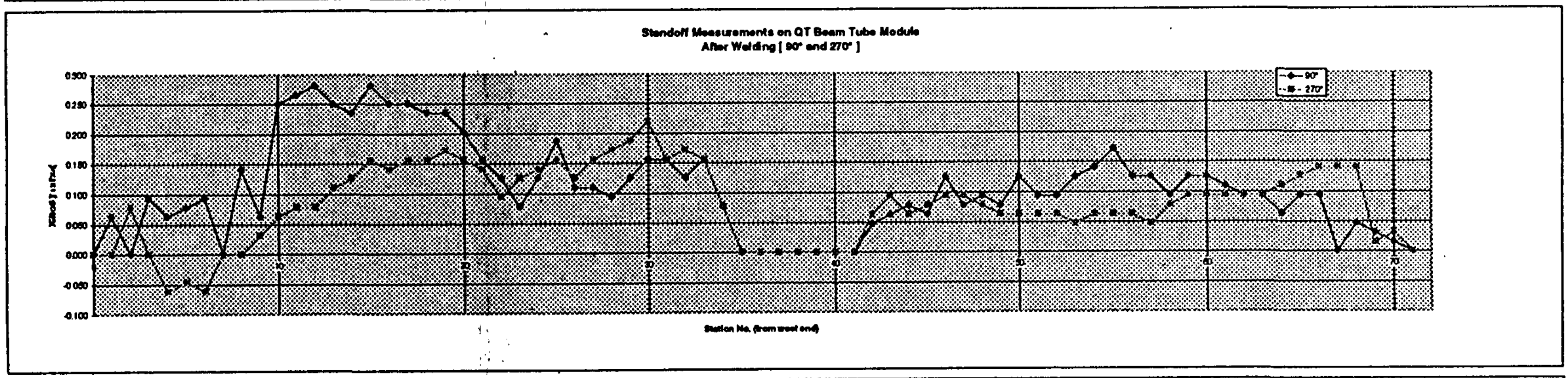


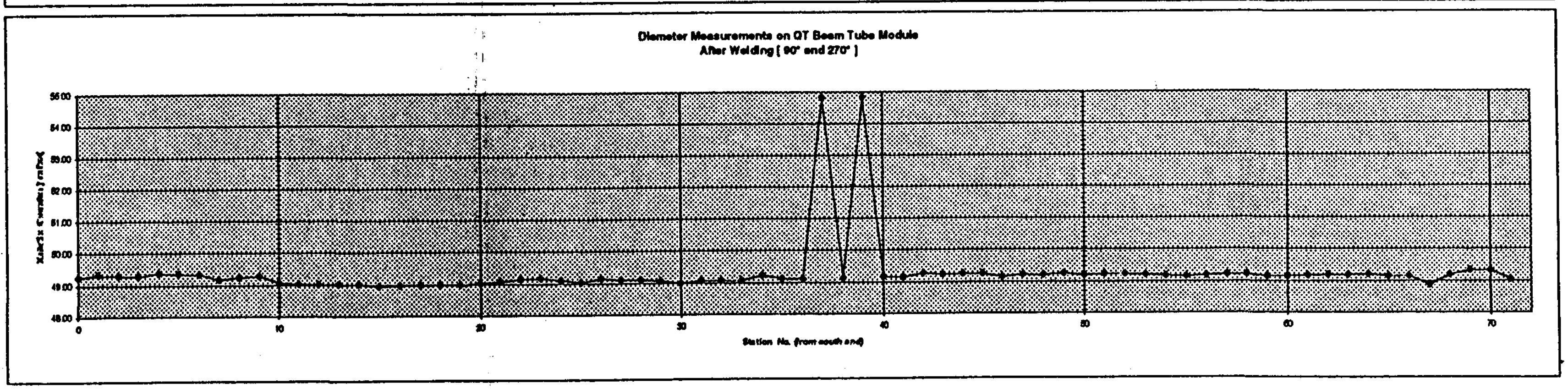
QT-9P

Sheet 3 of 4

Beam Tube Modul[illegible] and After Welding

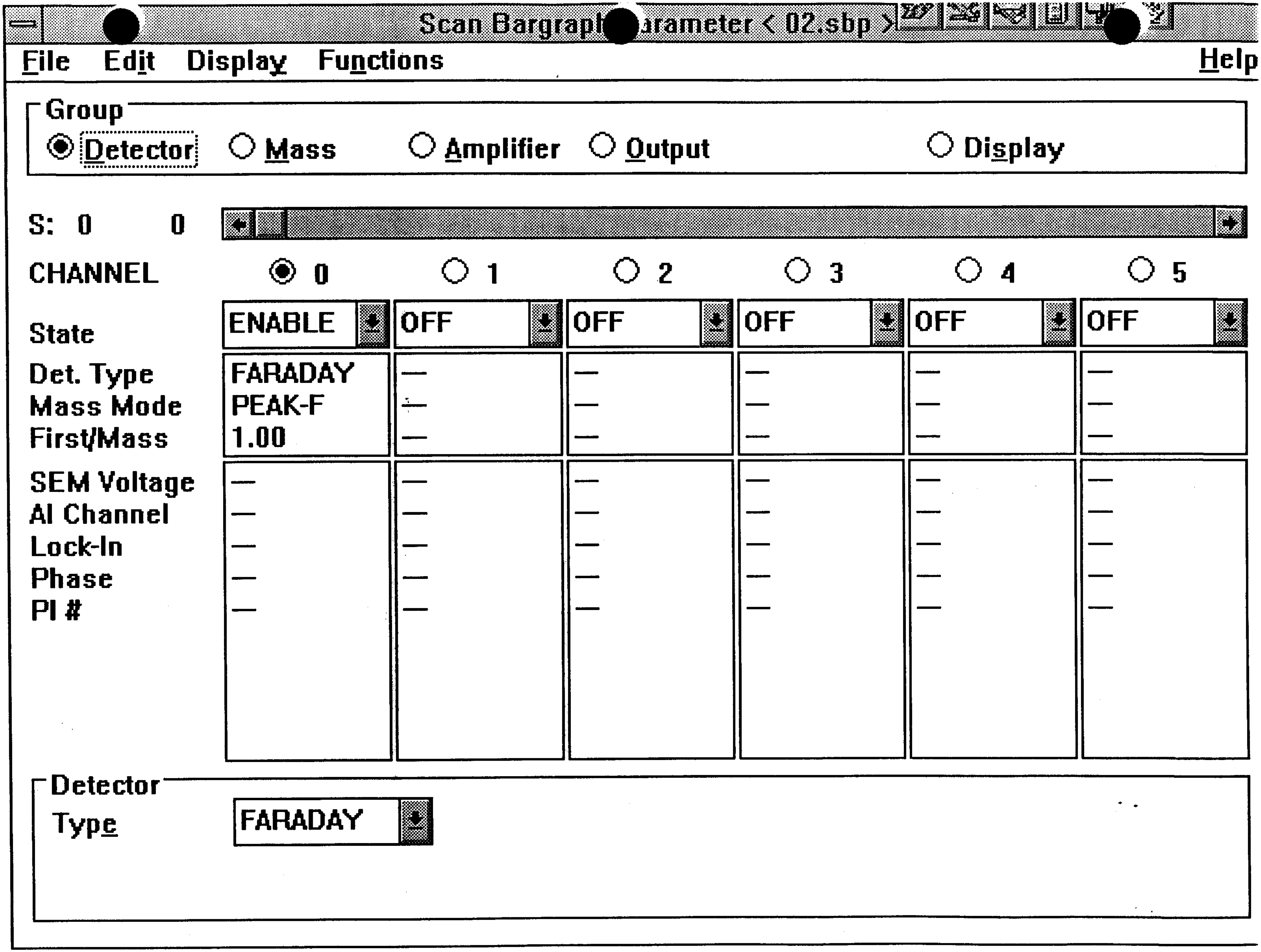






Sheet 4 of 4
QT-5P

SECTION 2.F.15 APPENDICES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Edit
Display
Functions
Help
Group
Detector
Mass
Amplifier
Output
Display
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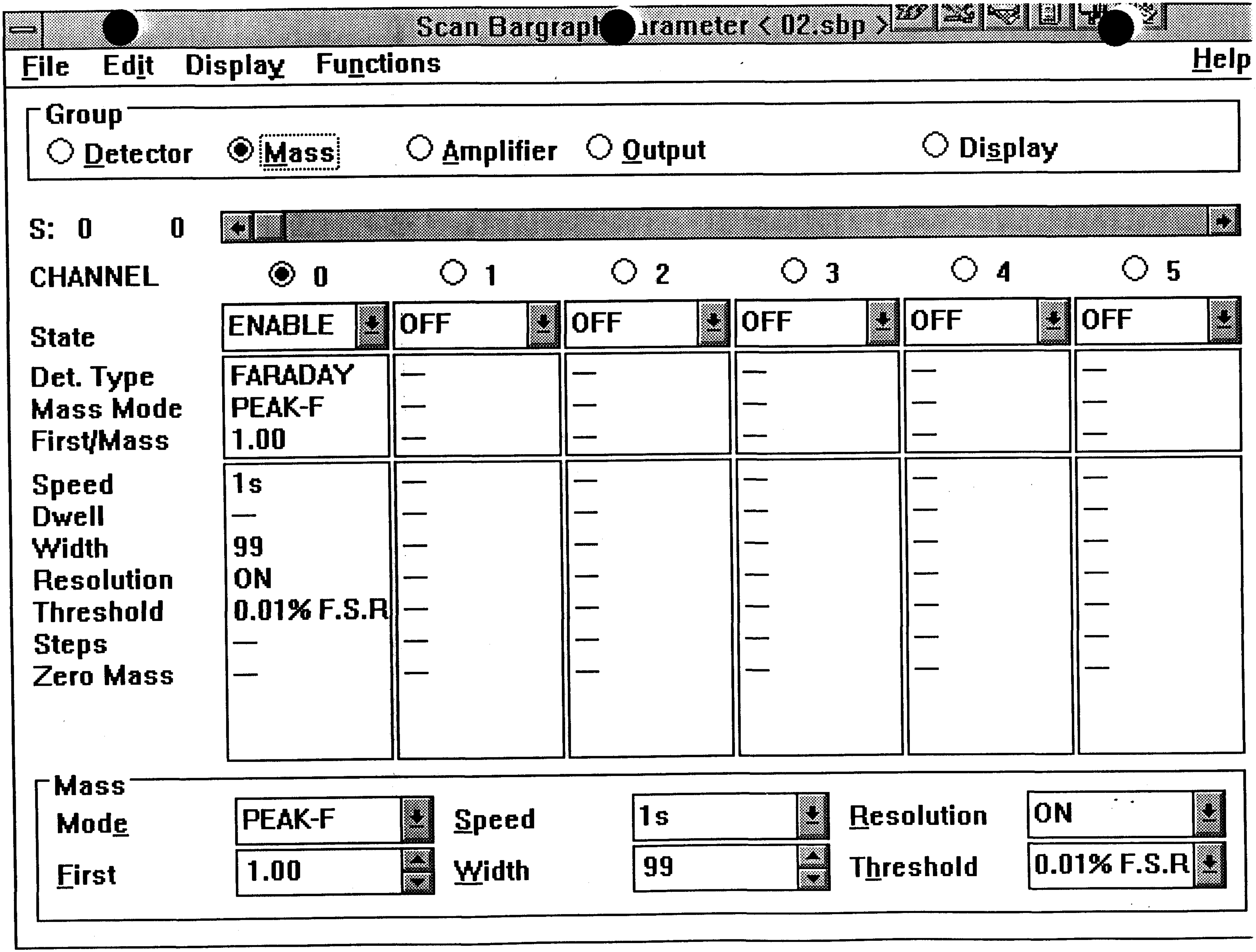
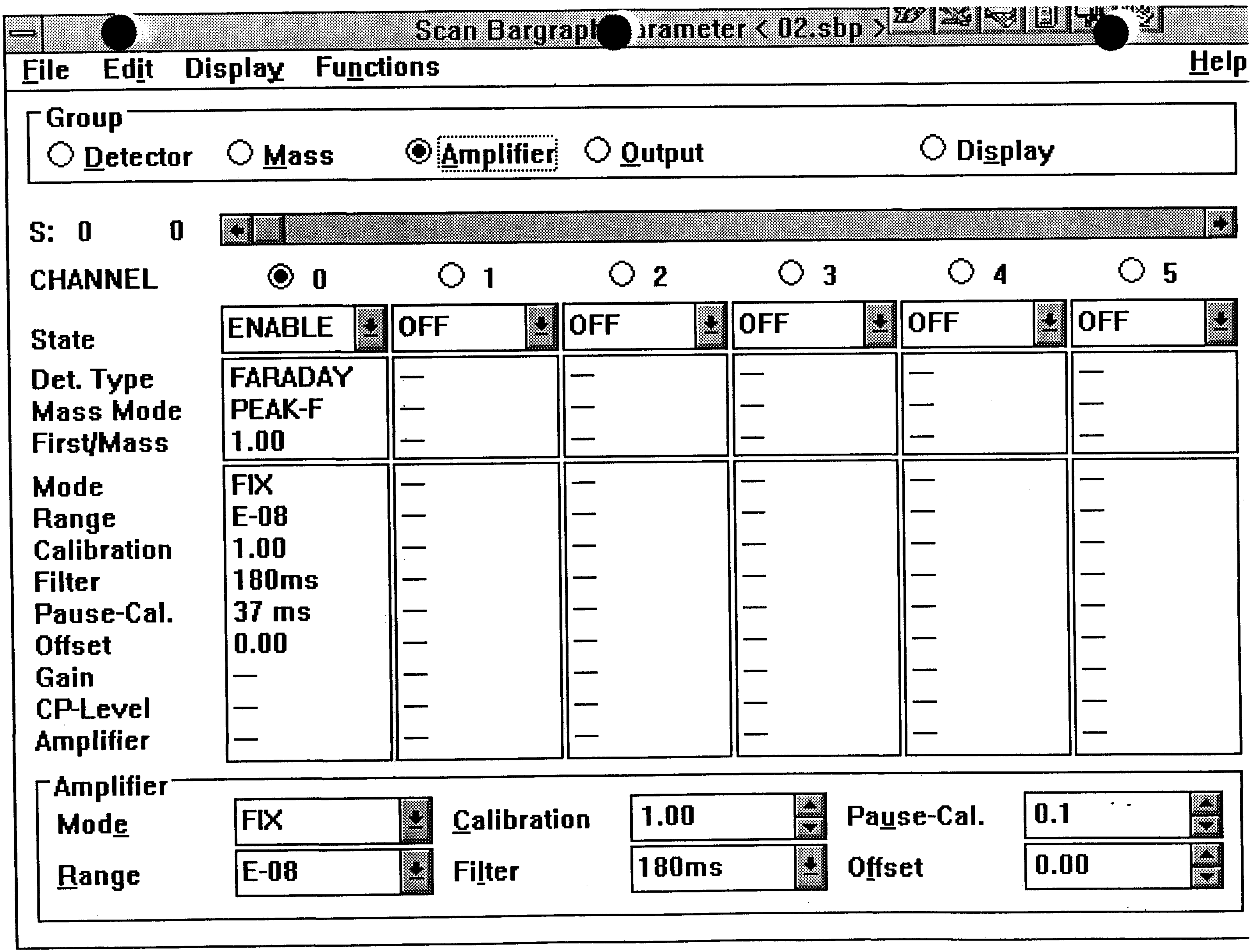
CHANNEL
0
1
2
3
4
5
State
ENABLE
OFF
OFF
OFF
OFF
OFF
Det. Type
Mass Mode
First/Mass
FARADAY
PEAK-F
1.00
SEM Voltage
AI Channel
Lock-In
Phase
PI #
Detector
Type
FARADAY


Scan Bargrap rameter < 02.sbp >
File Edit Display Functions Help
Group
Detector Mass Amplifier Output Display
S: 0 0
CHANNEL 0 1 2 3 4 5
State ENABLE OFF OFF OFF OFF OFF
Det. Type FARADAY
Mass Mode PEAK-F
First/Mass 1.00
Speed 1s
Dwell
Width 99
Resolution ON
Threshold 0.01% F.S.R
Steps
Zero Mass
Mass
Mode PEAK-F
First 1.00
Speed 1s
Width 99
Resolution ON
Threshold 0.01% F.S.R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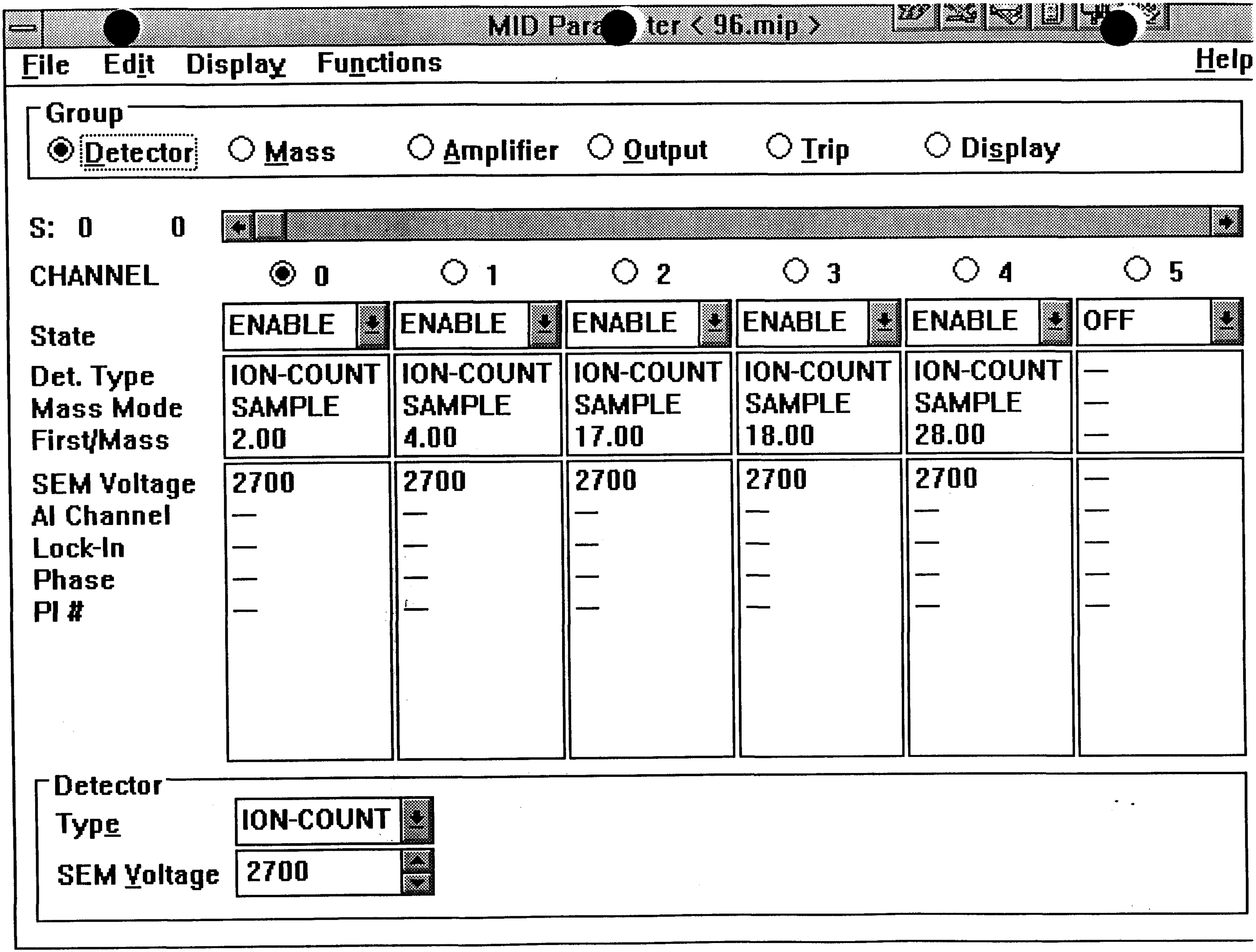
File
Edit
Display
Functions
Help
Group
Detector
Mass
Amplifier
Output
Display
S: 0 0
CHANNEL
0
1
2
3
4
5
State
ENABLE
OFF
OFF
OFF
OFF
OFF
Det. Type
Mass Mode
First/Mass
FARADAY
PEAK-F
1.00
Mode
Range
Calibration
Filter
Pause-Cal.
Offset
Gain
CP-Level
Amplifier
FIX
E-08
1.00
180ms
37 ms
0.00
Amplifier
Mode
FIX
Range
E-08
Calibration
1.00
Filter
180ms
Pause-Cal.
0.1
Offset
0.00


MID Para ter < 96.mip >
File Edit Display Functions Help
Group
Detector Mass Amplifier Output Trip Display
S: 0 0
CHANNEL 0 1 2 3 4 5
State ENABLE ENABLE ENABLE ENABLE ENABLE OFF
Det. Type ION-COUNT ION-COUNT ION-COUNT ION-COUNT ION-COUNT —
Mass Mode SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE —
First/Mass 2.00 4.00 17.00 18.00 28.00 —
SEM Voltage 2700 2700 2700 2700 2700 —
AI Channel
Lock-In
Phase
PI #
Detector
Type ION-COUNT
SEM Voltage 2700

MID Parameter < 96.mip >

File Edit Display Functions Help

Group

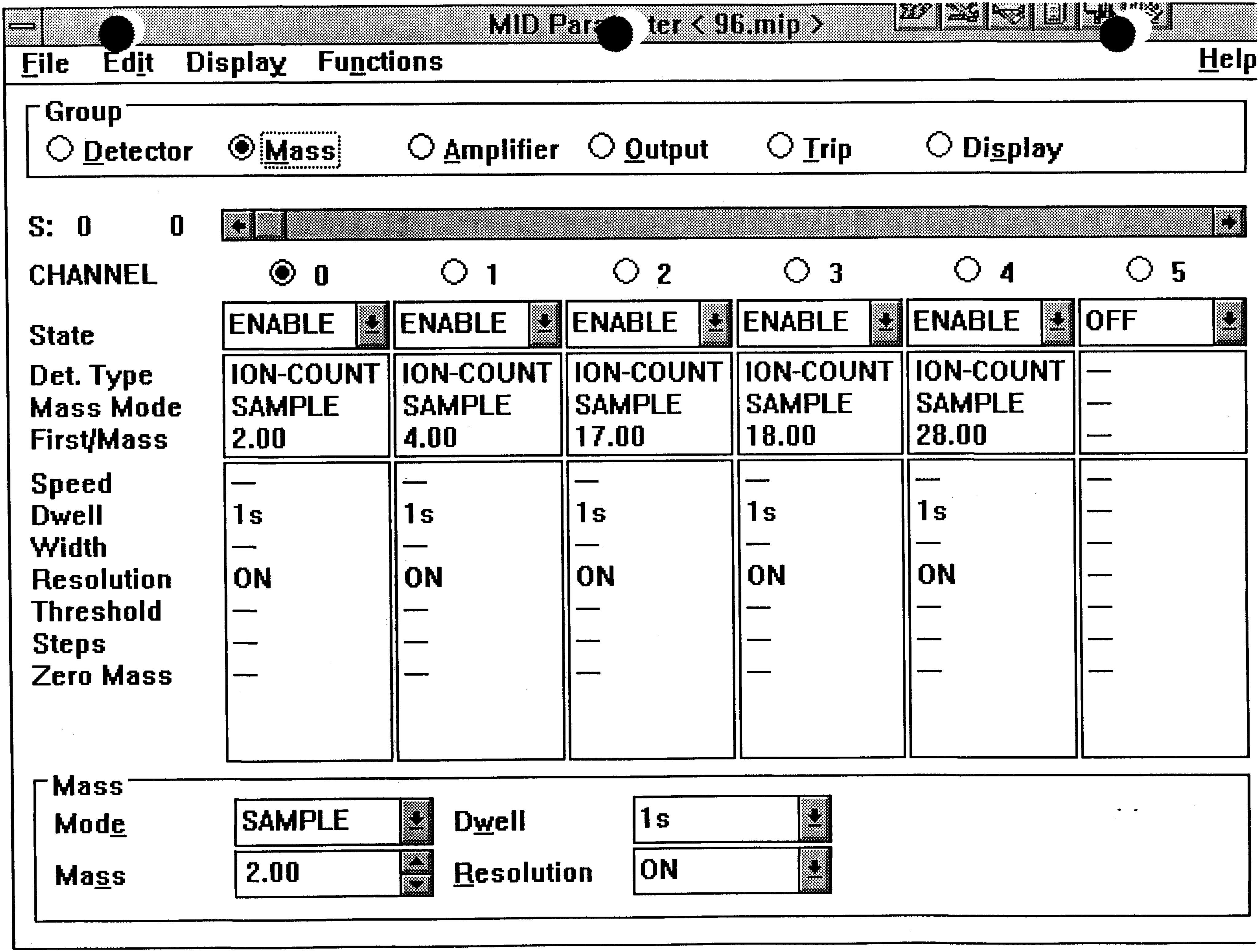
○ Detector ◉ Mass ○ Amplifier ○ Output ○ Trip ○ Display

S: 0 0

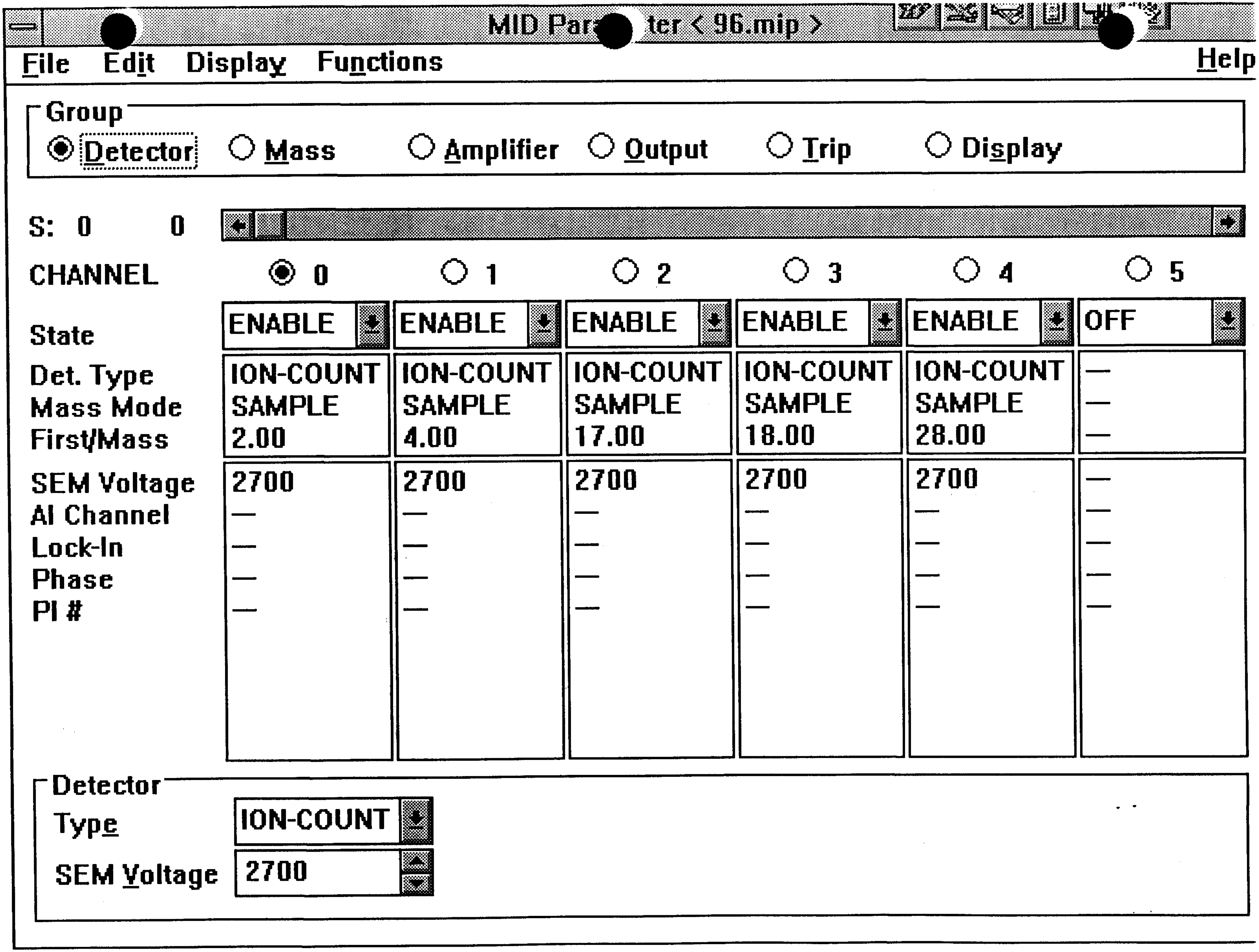
CHANNEL	◉ 0	○ 1	○ 2	○ 3	○ 4	○ 5
State	ENABLE	ENABLE	ENABLE	ENABLE	ENABLE	OFF
Det. Type	ION-COUNT	ION-COUNT	ION-COUNT	ION-COUNT	ION-COUNT	—
Mass Mode	SAMPLE	SAMPLE	SAMPLE	SAMPLE	SAMPLE	—
First/Mass	2.00	4.00	17.00	18.00	28.00	—
Speed	—	—	—	—	—	—
Dwell	1s	1s	1s	1s	1s	—
Width	—	—	—	—	—	—
Resolution	ON	ON	ON	ON	ON	—
Threshold	—	—	—	—	—	—
Steps	—	—	—	—	—	—
Zero Mass	—	—	—	—	—	—

Mass

Mode	SAMPLE	Dwell	1s
Mass	2.00	Resolution	ON



MID Par ter < 96.mip >
File Edit Display Functions Help
Group
Detector Mass Amplifier Output Trip Display
S: 0 0
CHANNEL 0 1 2 3 4 5
State ENABLE ENABLE ENABLE ENABLE ENABLE OFF
Det. Type ION-COUNT ION-COUNT ION-COUNT ION-COUNT ION-COUNT —
Mass Mode SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE —
First/Mass 2.00 4.00 17.00 18.00 28.00 —
Speed — — — — — —
Dwell 1s 1s 1s 1s 1s —
Width — — — — — —
Resolution ON ON ON ON ON —
Threshold — — — — — —
Steps — — — — — —
Zero Mass — — — — — —
Mass
Mode SAMPLE
Dwell 1s
Mass 2.00
Resolution ON



MID Par ter < 96.mip >
File
Edit
Display
Functions
Help
Group
Detector
Mass
Amplifier
Output
Trip
Display
S: 0 0
CHANNEL 0 1 2 3 4 5
State
ENABLE ENABLE ENABLE ENABLE ENABLE OFF
Det. Type
Mass Mode
First/Mass
ION-COUNT SAMPLE 2.00
ION-COUNT SAMPLE 4.00
ION-COUNT SAMPLE 17.00
ION-COUNT SAMPLE 18.00
ION-COUNT SAMPLE 28.00
SEM Voltage
Al Channel
Lock-In
Phase
PI #
2700 2700 2700 2700 2700
Detector
Type
ION-COUNT
SEM Voltage
2700

MID Par[illegible]ter < 96.mip >

File Edit Display Functions Help

Group

○ Detector ○ Mass ◉ Amplifier ○ Output ○ Trip ○ Display

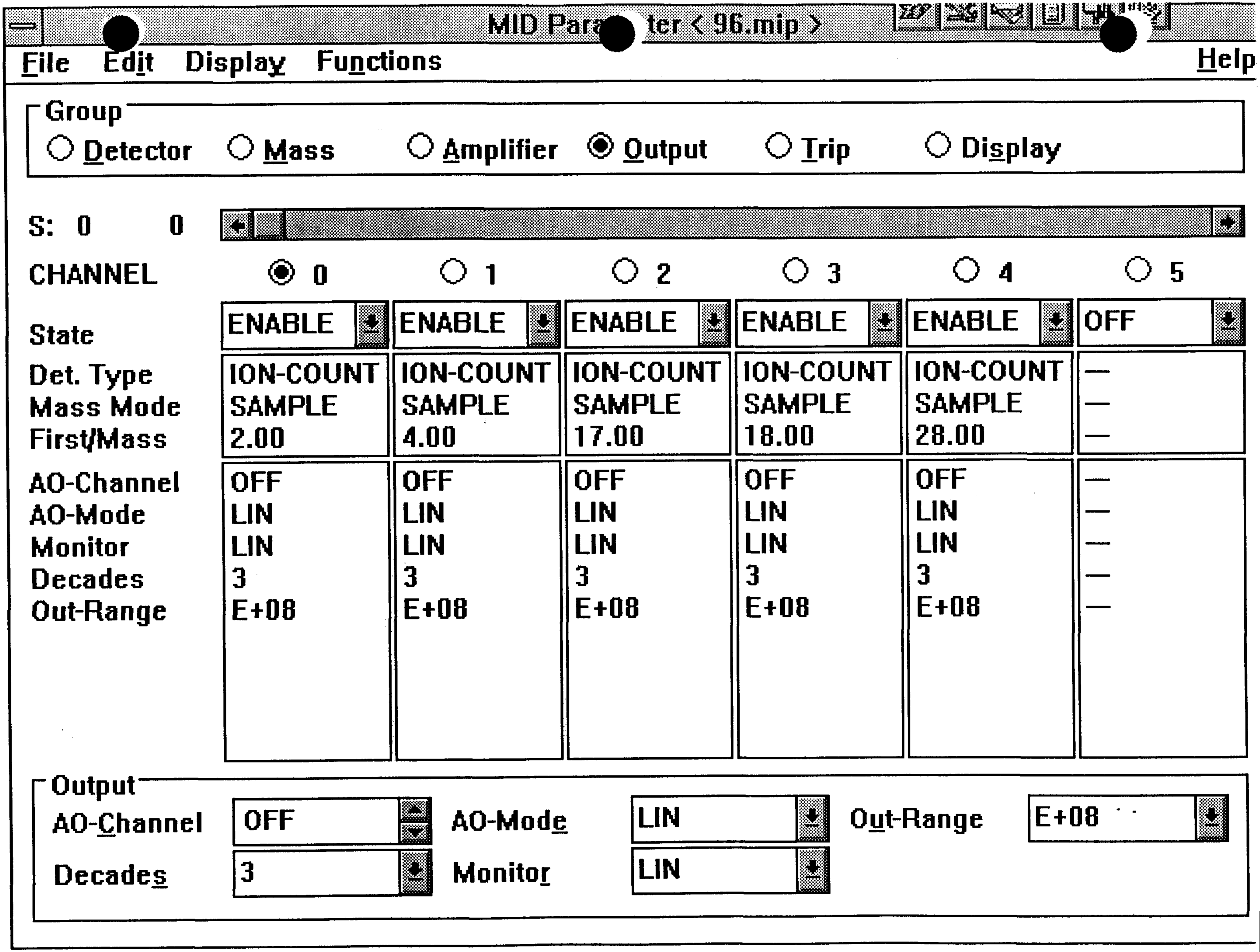
S: 0 0

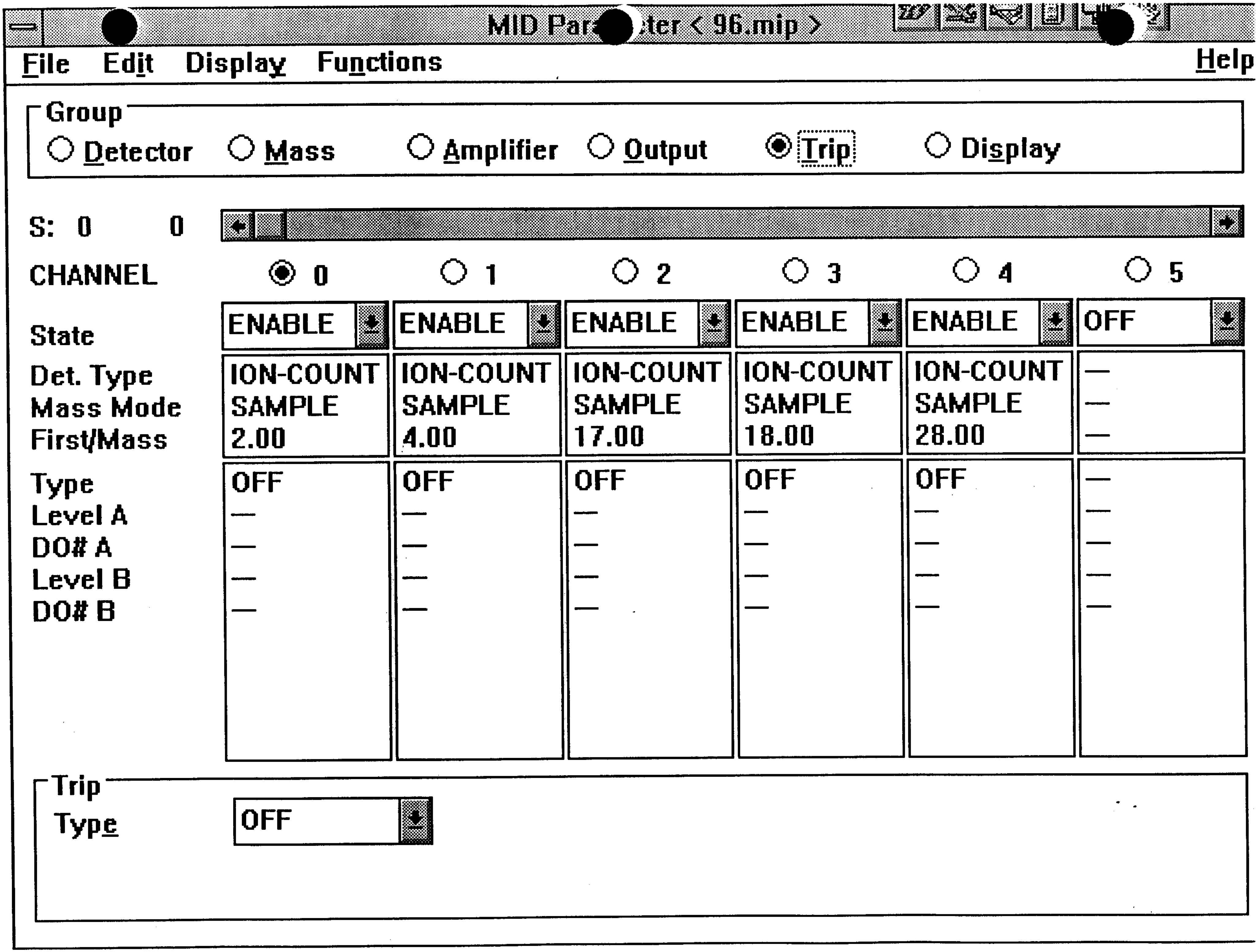
CHANNEL	◉ 0	○ 1	○ 2	○ 3	○ 4	○ 5
State	ENABLE	ENABLE	ENABLE	ENABLE	ENABLE	OFF
Det. Type	ION-COUNT	ION-COUNT	ION-COUNT	ION-COUNT	ION-COUNT	—
Mass Mode	SAMPLE	SAMPLE	SAMPLE	SAMPLE	SAMPLE	—
First/Mass	2.00	4.00	17.00	18.00	28.00	—
Mode	—	—	—	—	—	—
Range	—	—	—	—	—	—
Calibration	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	—
Filter	—	—	—	—	—	—
Pause-Cal.	6 ms	6 ms	6 ms	6 ms	6 ms	—
Offset	—	—	—	—	—	—
Gain	—	—	—	—	—	—
CP-Level	0.10	0.00	0.00	0.00	0.00	—
Amplifier	—	—	—	—	—	—

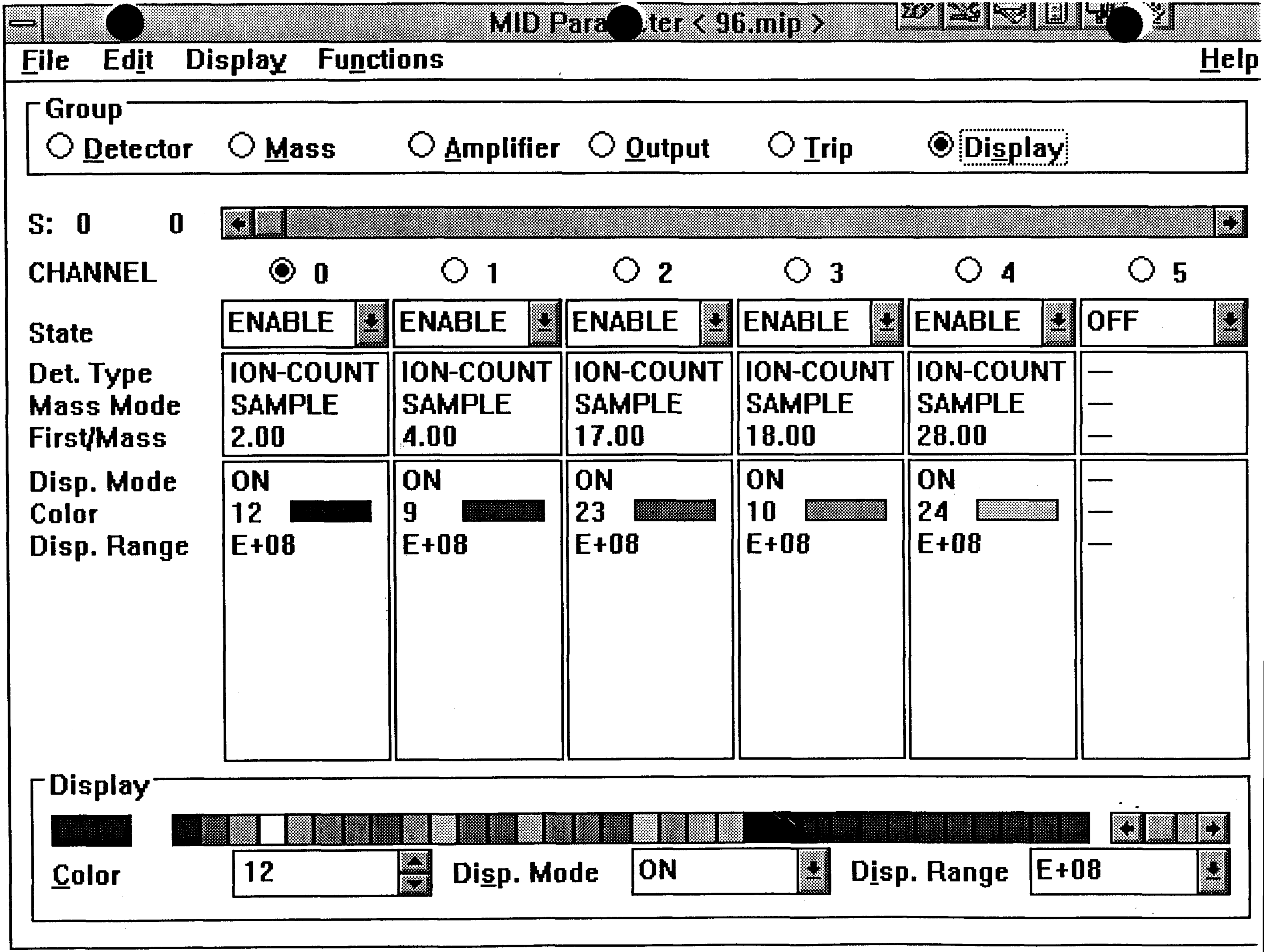
Amplifier

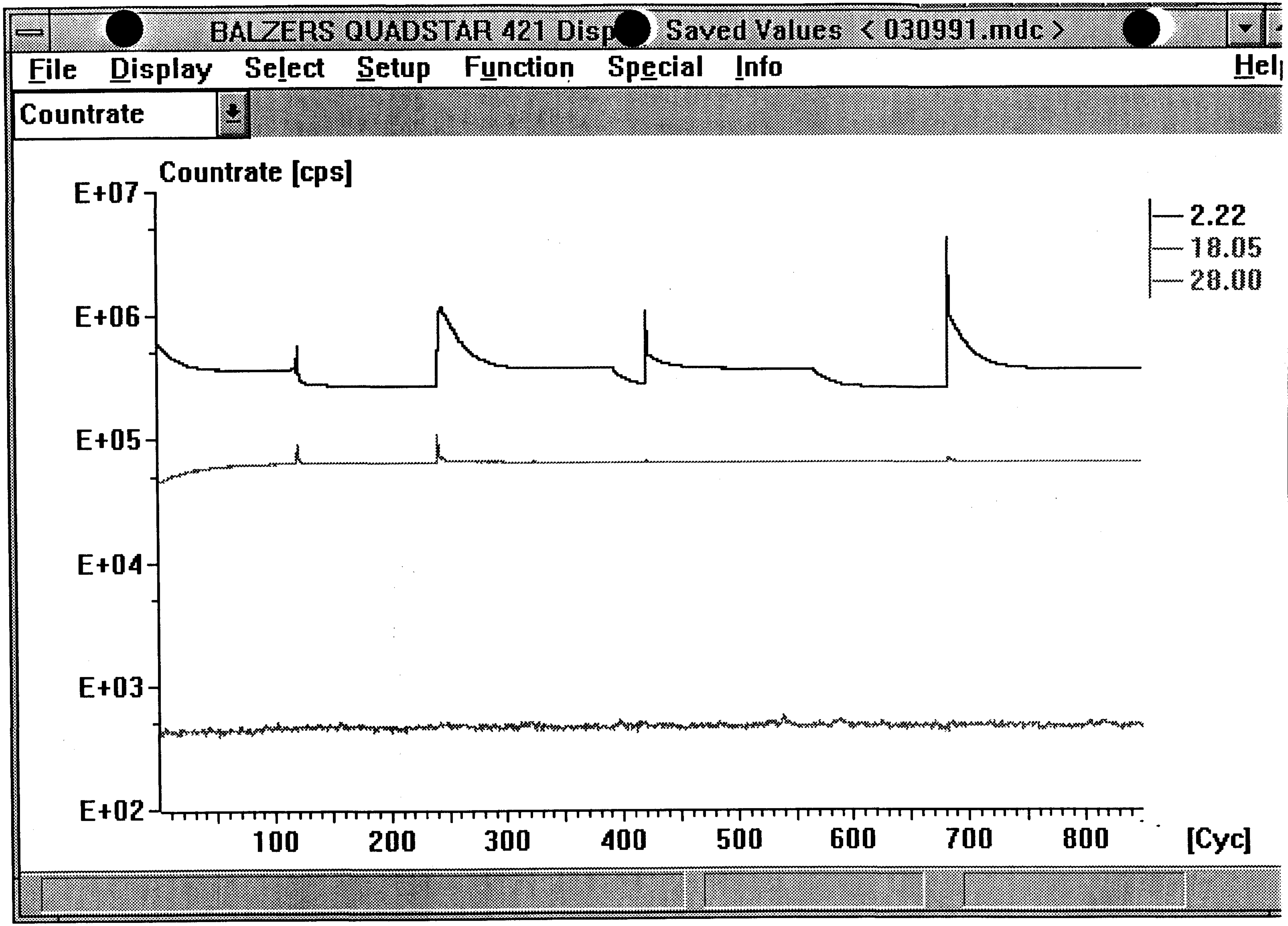
Calibration 1.00E+00 CP-Level 0.10

Pause-Cal. 1.0


MID Para ter < 96.mip >
File
Edit
Display
Functions
Help
Group
Detector
Mass
Amplifier
Output
Trip
Display
S: 0 0
CHANNEL
0
1
2
3
4
5
State
ENABLE
ENABLE
ENABLE
ENABLE
ENABLE
OFF
Det. Type
Mass Mode
First/Mass
ION-COUNT
SAMPLE
2.00
ION-COUNT
SAMPLE
4.00
ION-COUNT
SAMPLE
17.00
ION-COUNT
SAMPLE
18.00
ION-COUNT
SAMPLE
28.00
AO-Channel
AO-Mode
Monitor
Decades
Out-Range
OFF
LIN
LIN
3
E+08
Output
AO-Channel
OFF
AO-Mode
LIN
Out-Range
E+08
Decades
3
Monitor
LIN


MID Par ter < 96.mip >
File Edit Display Functions Help
Group
Detector Mass Amplifier Output Trip Display
S: 0 0
CHANNEL 0 1 2 3 4 5
State ENABLE ENABLE ENABLE ENABLE ENABLE OFF
Det. Type ION-COUNT ION-COUNT ION-COUNT ION-COUNT ION-COUNT —
Mass Mode SAMPLE SAMPLE SAMPLE SAMPLE SAMPLE —
First/Mass 2.00 4.00 17.00 18.00 28.00 —
Type OFF OFF OFF OFF OFF —
Level A — — — — — —
DO# A — — — — — —
Level B — — — — — —
DO# B — — — — — —
Trip
Type OFF


MID Para ter < 96.mip >
File
Edit
Display
Functions
Help
Group
Detector
Mass
Amplifier
Output
Trip
Display
S: 0 0
CHANNEL
0
1
2
3
4
5
State
ENABLE
ENABLE
ENABLE
ENABLE
ENABLE
OFF
Det. Type
Mass Mode
First/Mass
ION-COUNT SAMPLE 2.00
ION-COUNT SAMPLE 4.00
ION-COUNT SAMPLE 17.00
ION-COUNT SAMPLE 18.00
ION-COUNT SAMPLE 28.00
Disp. Mode
Color
Disp. Range
ON 12 E+08
ON 9 E+08
ON 23 E+08
ON 10 E+08
ON 24 E+08
Display
Color
12
Disp. Mode
ON
Disp. Range
E+08



BALZERS QUADSTAR 421 Disp Saved Values < 030991.mdc >
File
Display
Select
Setup
Function
Special
Info
Hel
Countrate
Countrate [cps]
E+07
E+06
E+05
E+04
E+03
E+02
2.22
18.05
28.00
100
200
300
400
500
600
700
800
[Cyc]

Statistical Values < 030991.mdc >

Previous | Next | Title : Countrate | Unit : cps

Comment :

Start Cycle : 1 | End Cycle : 849 | Cycles : 849

Name	Minimum	Maximum	Mean	STD ABS	STD REL
2.22	2.545E+05	4.098E+06	3.699E+05	1.738E+05	4.698E-01
18.05	3.775E+02	5.635E+02	4.534E+02	2.048E+01	4.518E-02
28.00	4.444E+04	1.071E+05	6.301E+04	3.437E+03	5.455E-02

OK

Integral Valu[e] < 030991.mdc >

Previous | Next

Title : Countrate | Unit : cps

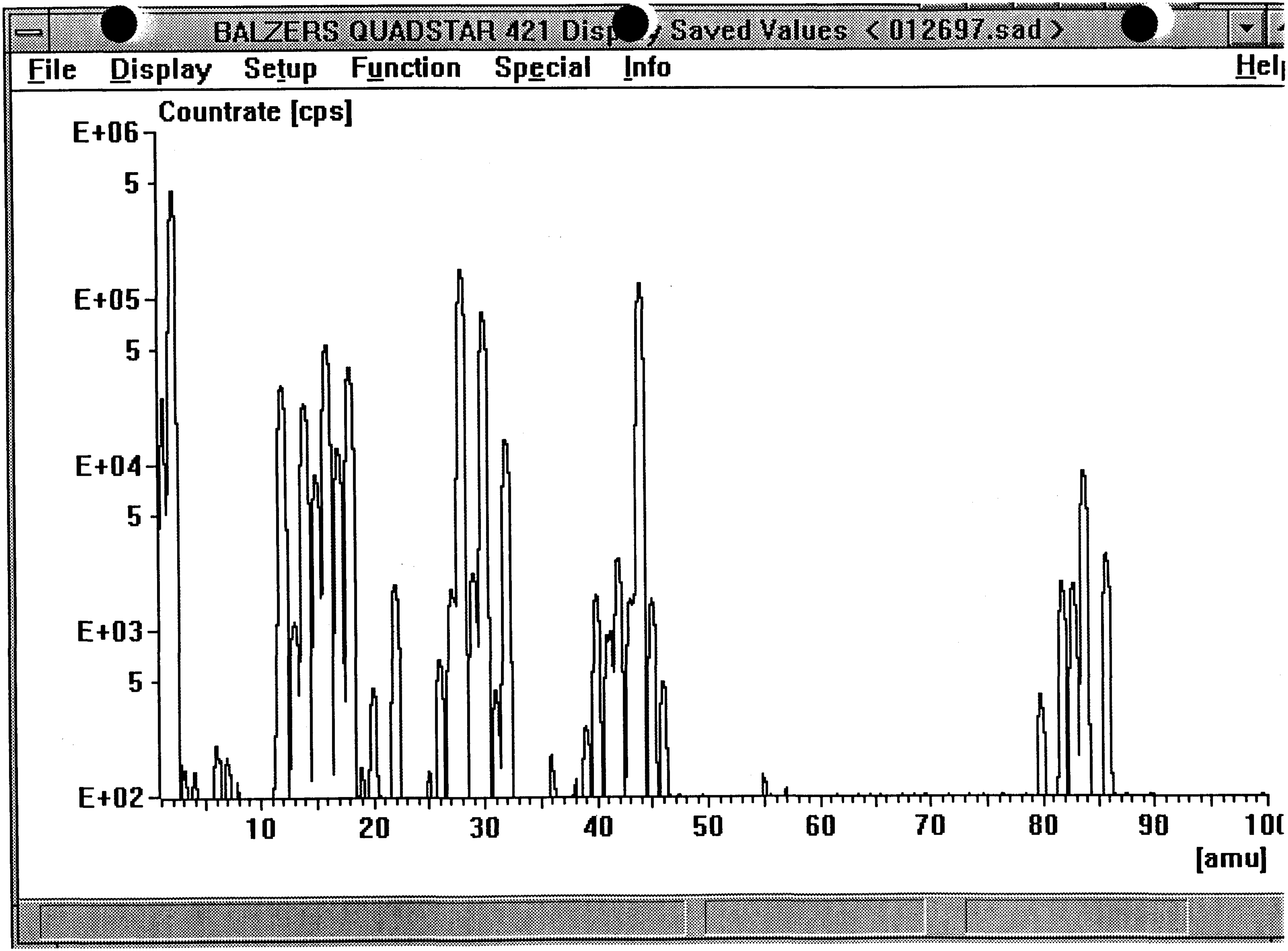
Comment :

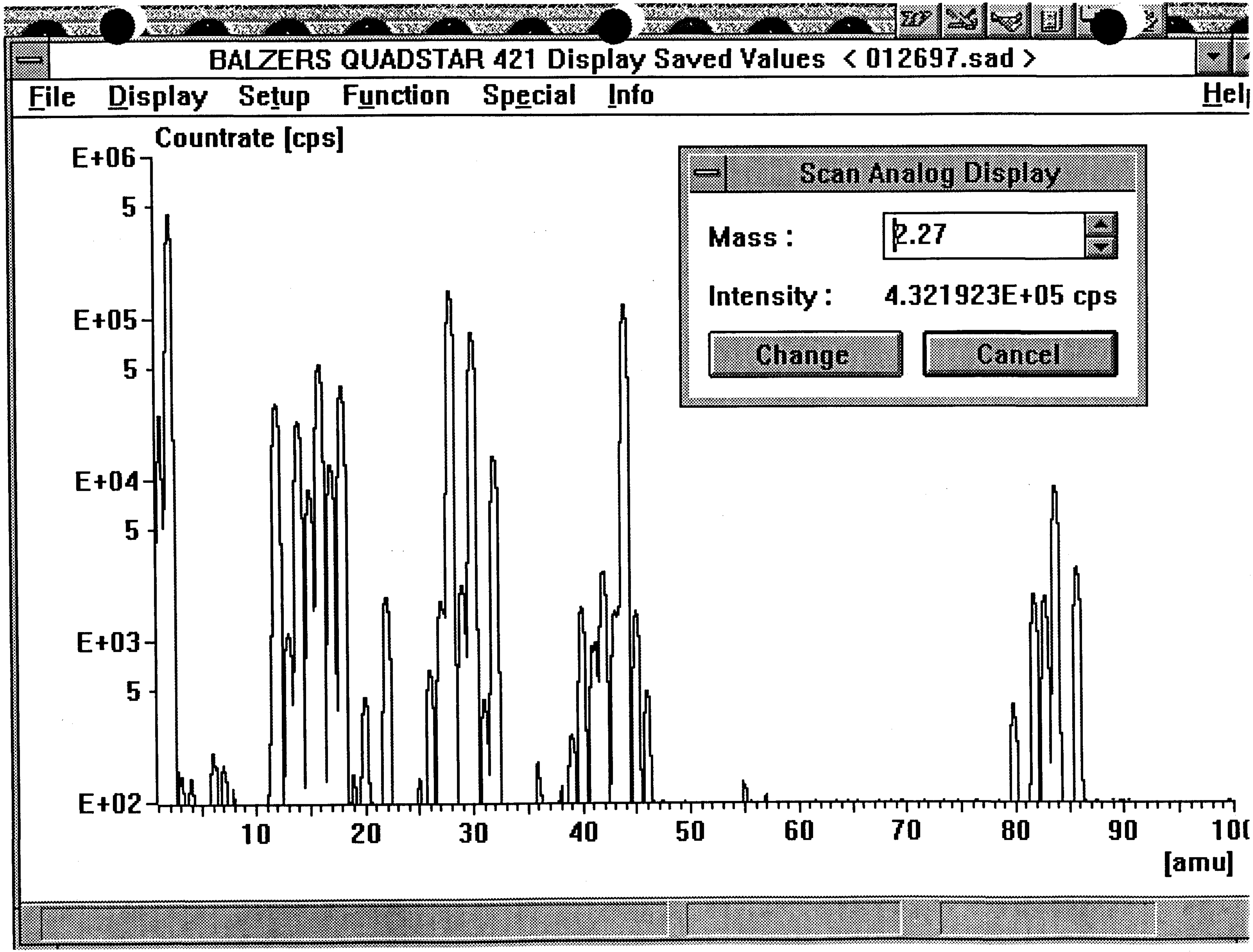
Start Cycle : 1 | End Cycle : 849 | Cycles : 849

Start Time : 30.32s | End Time : 5270.65s | Time : 5240.33s

Name	Integral
2.22	1.938E+09 cpss
18.05	2.376E+06 cpss
28.00	3.302E+08 cpss

OK


BALZERS QUADSTAR 421 Disp
Saved Values < 012697.sad >
File
Display
Setup
Function
Special
Info
Countrate [cps]
E+06
5
E+05
5
E+04
5
E+03
5
E+02
10
20
30
40
50
60
70
80
90
[amu]


BALZERS QUADSTAR 421 Display Saved Values < 012697.sad >
File Display Setup Function Special Info
Countrate [cps]
E+06
5
E+05
5
E+04
5
E+03
5
E+02
10 20 30 40 50 60 70 80 90
[amu]
Scan Analog Display
Mass : 2.27
Intensity : 4.321923E+05 cps
Change
Cancel

Number of stored cycles	113
Printed start cycle	1
Printed end cycle	113
Number of stored datablocks	1

Datablock 0,	Ion Current,	[A],			
0/0	16.00	min:	2.893E-13	max:	4.077E-13
0/1	17.00	min:	2.064E-12	max:	2.770E-12
0/2	18.00	min:	7.292E-12	max:	9.796E-12

MID[illegible]CLES : 012322.mdc PAGE : 1/

DATE : 1/23/95 **TIME :** 5:08:57 PM **Cycles :** 11

Number Title Name Unit	 Date	 Time	0/0 Ion Current 16.00 A	0/1 Ion Current 17.00 A	0/2 Ion Current 18.00 A
1	1/23/95	5:08:57 PM:33	3.942E-13	2.769E-12	9.793E-12
2	1/23/95	5:09:14 PM:91	4.077E-13	2.765E-12	9.787E-12
3	1/23/95	5:09:32 PM:48	3.927E-13	2.766E-12	9.796E-12
4	1/23/95	5:09:50 PM:17	3.931E-13	2.765E-12	9.787E-12
5	1/23/95	5:10:07 PM:75	3.928E-13	2.766E-12	9.788E-12
6	1/23/95	5:10:25 PM:38	3.918E-13	2.765E-12	9.791E-12
7	1/23/95	5:10:42 PM:95	3.914E-13	2.768E-12	9.793E-12
8	1/23/95	5:11:00 PM:64	3.955E-13	2.770E-12	9.789E-12
9	1/23/95	5:11:18 PM:22	3.923E-13	2.761E-12	9.779E-12
10	1/23/95	5:11:35 PM:85	3.896E-13	2.761E-12	9.776E-12
11	1/23/95	5:11:53 PM:48	3.911E-13	2.761E-12	9.783E-12
12	1/23/95	5:12:11 PM:11	3.934E-13	2.765E-12	9.784E-12
13	1/23/95	5:12:28 PM:69	3.925E-13	2.763E-12	9.780E-12
14	1/23/95	5:12:46 PM:32	3.941E-13	2.764E-12	9.783E-12
15	1/23/95	5:13:03 PM:95	3.964E-13	2.766E-12	9.780E-12
16	1/23/95	5:13:21 PM:52	3.895E-13	2.764E-12	9.784E-12
17	1/23/95	5:13:39 PM:16	3.969E-13	2.769E-12	9.785E-12
18	1/23/95	5:13:56 PM:79	3.976E-13	2.758E-12	9.776E-12
19	1/23/95	5:14:14 PM:47	3.953E-13	2.759E-12	9.770E-12
20	1/23/95	5:14:32 PM:50	3.915E-13	2.760E-12	9.770E-12
21	1/23/95	5:14:49 PM:62	3.914E-13	2.761E-12	9.773E-12
22	1/23/95	5:15:07 PM:31	3.913E-13	2.762E-12	9.765E-12
23	1/23/95	5:15:24 PM:89	4.026E-13	2.762E-12	9.777E-12
24	1/23/95	5:15:42 PM:52	3.939E-13	2.759E-12	9.775E-12
25	1/23/95	5:16:00 PM:15	3.934E-13	2.765E-12	9.776E-12
26	1/23/95	5:16:17 PM:72	3.964E-13	2.764E-12	9.778E-12
27	1/23/95	5:16:35 PM:36	3.939E-13	2.763E-12	9.775E-12
28	1/23/95	5:16:52 PM:93	3.957E-13	2.767E-12	9.776E-12
29	1/23/95	5:17:10 PM:62	3.959E-13	2.763E-12	9.775E-12
30	1/23/95	5:17:28 PM:25	3.942E-13	2.762E-12	9.773E-12
31	1/23/95	5:17:45 PM:77	3.935E-13	2.763E-12	9.778E-12
32	1/23/95	5:18:03 PM:51	3.935E-13	2.764E-12	9.780E-12
33	1/23/95	5:18:21 PM:30	3.954E-13	2.764E-12	9.772E-12
34	1/23/95	5:18:38 PM:72	3.923E-13	2.761E-12	9.779E-12
35	1/23/95	5:18:56 PM:24	3.923E-13	2.761E-12	9.761E-12

MID[illegible]LES : 012322.mdc

DATE : 1/23/95 **TIME** : 5:08:57 PM **Cycles** : 11

Number Title Name Unit	Date	Time	0/0 Ion Current 16.00 A	0/1 Ion Current 17.00 A	0/2 Ion Current 18.00 A
36	1/23/95	5:19:13 PM:98	3.906E-13	2.757E-12	9.740E-12
37	1/23/95	5:19:31 PM:61	3.896E-13	2.748E-12	9.691E-12
38	1/23/95	5:19:49 PM:19	3.782E-13	2.685E-12	9.404E-12
39	1/23/95	5:20:07 PM:90	3.715E-13	2.594E-12	9.089E-12
40	1/23/95	5:20:24 PM:62	3.658E-13	2.529E-12	8.894E-12
41	1/23/95	5:20:42 PM:41	3.543E-13	2.480E-12	8.746E-12
42	1/23/95	5:21:00 PM:26	3.483E-13	2.440E-12	8.616E-12
43	1/23/95	5:21:17 PM:84	3.342E-13	2.402E-12	8.515E-12
44	1/23/95	5:21:35 PM:52	3.362E-13	2.385E-12	8.449E-12
45	1/23/95	5:21:53 PM:50	3.364E-13	2.373E-12	8.390E-12
46	1/23/95	5:22:10 PM:79	3.341E-13	2.361E-12	8.329E-12
47	1/23/95	5:22:28 PM:36	3.317E-13	2.337E-12	8.274E-12
48	1/23/95	5:22:45 PM:94	3.304E-13	2.325E-12	8.216E-12
49	1/23/95	5:23:03 PM:62	3.221E-13	2.299E-12	8.157E-12
50	1/23/95	5:23:21 PM:20	3.164E-13	2.289E-12	8.092E-12
51	1/23/95	5:23:38 PM:83	3.227E-13	2.270E-12	8.024E-12
52	1/23/95	5:23:56 PM:41	3.221E-13	2.247E-12	7.968E-12
53	1/23/95	5:24:14 PM:90	3.173E-13	2.240E-12	7.939E-12
54	1/23/95	5:24:31 PM:67	3.196E-13	2.239E-12	7.910E-12
55	1/23/95	5:24:49 PM:30	3.104E-13	2.228E-12	7.891E-12
56	1/23/95	5:25:06 PM:93	3.138E-13	2.224E-12	7.870E-12
57	1/23/95	5:25:24 PM:51	3.167E-13	2.221E-12	7.851E-12
58	1/23/95	5:25:42 PM:19	3.139E-13	2.219E-12	7.845E-12
59	1/23/95	5:25:59 PM:83	3.158E-13	2.209E-12	7.823E-12
60	1/23/95	5:26:17 PM:35	3.138E-13	2.207E-12	7.812E-12
61	1/23/95	5:26:35 PM:90	3.150E-13	2.204E-12	7.790E-12
62	1/23/95	5:26:52 PM:61	3.145E-13	2.193E-12	7.774E-12
63	1/23/95	5:27:10 PM:24	3.162E-13	2.192E-12	7.759E-12
64	1/23/95	5:27:27 PM:93	3.083E-13	2.191E-12	7.749E-12
65	1/23/95	5:27:45 PM:45	3.127E-13	2.190E-12	7.734E-12
66	1/23/95	5:28:03 PM:13	3.113E-13	2.182E-12	7.719E-12
67	1/23/95	5:28:20 PM:71	3.097E-13	2.179E-12	7.700E-12
68	1/23/95	5:28:38 PM:40	3.101E-13	2.177E-12	7.686E-12
69	1/23/95	5:28:55 PM:92	3.114E-13	2.175E-12	7.678E-12
70	1/23/95	5:29:13 PM:66	3.115E-13	2.173E-12	7.664E-12

Number Title Name Unit	Date	Time	0/0 Ion Current 16.00 A	0/1 Ion Current 17.00 A	0/2 Ion Current 18.00 A
71	1/23/95	5:29:31 PM:23	3.148E-13	2.164E-12	7.654E-12
72	1/23/95	5:29:48 PM:81	3.012E-13	2.155E-12	7.649E-12
73	1/23/95	5:30:06 PM:44	3.070E-13	2.158E-12	7.636E-12
74	1/23/95	5:30:23 PM:96	3.041E-13	2.156E-12	7.624E-12
75	1/23/95	5:30:41 PM:70	3.056E-13	2.151E-12	7.607E-12
76	1/23/95	5:30:59 PM:28	3.039E-13	2.156E-12	7.595E-12
77	1/23/95	5:31:16 PM:86	2.964E-13	2.148E-12	7.602E-12
78	1/23/95	5:31:34 PM:60	3.052E-13	2.143E-12	7.576E-12
79	1/23/95	5:31:52 PM:34	3.039E-13	2.140E-12	7.570E-12
80	1/23/95	5:32:10 PM:20	3.036E-13	2.138E-12	7.566E-12
81	1/23/95	5:32:27 PM:71	3.036E-13	2.136E-12	7.554E-12
82	1/23/95	5:32:45 PM:40	2.973E-13	2.136E-12	7.544E-12
83	1/23/95	5:33:03 PM:80	3.070E-13	2.133E-12	7.530E-12
84	1/23/95	5:33:20 PM:66	3.020E-13	2.125E-12	7.516E-12
85	1/23/95	5:33:38 PM:34	3.015E-13	2.128E-12	7.508E-12
86	1/23/95	5:33:55 PM:92	3.013E-13	2.126E-12	7.502E-12
87	1/23/95	5:34:13 PM:61	3.013E-13	2.119E-12	7.498E-12
88	1/23/95	5:34:31 PM:24	3.002E-13	2.116E-12	7.490E-12
89	1/23/95	5:34:48 PM:76	3.022E-13	2.112E-12	7.481E-12
90	1/23/95	5:35:06 PM:50	2.990E-13	2.116E-12	7.469E-12
91	1/23/95	5:35:24 PM:20	3.002E-13	2.110E-12	7.464E-12
92	1/23/95	5:35:41 PM:65	2.969E-13	2.108E-12	7.445E-12
93	1/23/95	5:35:59 PM:28	2.926E-13	2.105E-12	7.446E-12
94	1/23/95	5:36:16 PM:86	3.027E-13	2.105E-12	7.437E-12
95	1/23/95	5:36:34 PM:54	3.007E-13	2.100E-12	7.433E-12
96	1/23/95	5:36:52 PM:12	2.967E-13	2.102E-12	7.420E-12
97	1/23/95	5:37:09 PM:81	2.993E-13	2.098E-12	7.412E-12
98	1/23/95	5:37:27 PM:38	2.986E-13	2.094E-12	7.395E-12
99	1/23/95	5:37:44 PM:96	2.951E-13	2.093E-12	7.392E-12
100	1/23/95	5:38:02 PM:64	2.968E-13	2.090E-12	7.383E-12
101	1/23/95	5:38:20 PM:22	2.940E-13	2.084E-12	7.377E-12
102	1/23/95	5:38:37 PM:85	2.930E-13	2.085E-12	7.367E-12
103	1/23/95	5:38:55 PM:37	2.917E-13	2.080E-12	7.371E-12
104	1/23/95	5:39:13 PM:11	2.949E-13	2.082E-12	7.363E-12
105	1/23/95	5:39:30 PM:69	2.959E-13	2.078E-12	7.347E-12

MID [illegible]CLES : 012322.mdc

DATE : 1/23/95 TIME : 5:08:57 PM Cycles : 11

Number			0/0	0/1	0/2
Title			Ion Current	Ion Current	Ion Current
Name			16.00	17.00	18.00
Unit	Date	Time	A	A	A
106	1/23/95	5:39:48 PM:27	2.893E-13	2.073E-12	7.337E-12
107	1/23/95	5:40:05 PM:95	2.904E-13	2.072E-12	7.339E-12
108	1/23/95	5:40:23 PM:53	2.932E-13	2.074E-12	7.325E-12
109	1/23/95	5:40:41 PM:16	2.928E-13	2.069E-12	7.316E-12
110	1/23/95	5:40:58 PM:79	2.909E-13	2.067E-12	7.310E-12
111	1/23/95	5:41:16 PM:37	2.900E-13	2.064E-12	7.304E-12
112	1/23/95	5:41:34 PM:50	2.906E-13	2.064E-12	7.297E-12
113	1/23/95	5:41:51 PM:63	2.955E-13	2.067E-12	7.292E-12

LIGO DATA ACQUISITION SOFTWARE MANUAL

prepared by
William S. Schoerner

January 17 1995

Operating the Data Acquisition Program

Hardware Requirements

All temperature measurements will be made with Type-K (Chromel-Constantan) thermocouples using a Hewlett Packard HP3497 Data Acquisition and control unit with HP44422A thermocouple multiplexer card. A Gateway-2000 486-DX2 50 MHz personal computer using MS-DOS Version 6.2 and running custom data acquisition software named "LIGOTEMP" will be used to collect, display and record all the data. The HP3497 is interfaced to the computer through a National Instruments AT-GPIB adapter. The data acquisition system will also monitor other analog data signals such as vacuum gauges

Software Requirements

In order to run "LIGOTEMP", the config.sys file must contain the entry "device = c:\at-gpib\gpib.com" to install the AT-GPIB adapter. In addition, the "Universal Language Interface" driver "ULI.COM" should be included in the **autoexec.bat** which is executed when the computer is first turned on. While the program may be run directly from DOS, it is preferably started within Microsoft Windows 3.1 which also allows maintaining a separate text window to serve a laboratory notebook for recording comments and observations. The program and supporting configuration files are stored on the C drive in the directory path C:\LIGO\DATA.

Data is stored in this directory and is copied to the L:\PUBLIC\LIGO\DATA directory on the RSE network file server. A new data file is created every 24 hours starting at midnight. The file name is constructed from characters representing month, day and year followed by the character "L" (example: APR0494L.CSV). The file name includes the ".CSV" extension which is a data format recognized by spreadsheet software such as "EXCEL". The Data file will contain a single line with a title describing the file and the date. The second line contains a brief identifier for each of the transducers. There are a total of 50 thermocouples identified as TE-1, through TE-1 and six vacuum gages. "VAC-1" and "VAC2" are the cold cathode and the pirani on the coupon test chamber vacuum system. "CC1", "CC2", "CC3", and "PP1" are the cold cathode and pirani gages on the beam tube vacuum chamber.

Running LIGOTEMP

It is preferred that the software be run after first logging on to the file server as a LIGO project user. This assures that the data files will be copied to the L:\PUBLIC\LIGO directory on the network file server. However the program will auto-start under DOS but data will be stored only to the local hard drive. Therefore, the program will recover from a temporary power interruption without any loss of data, but the user should exit the program and log onto the file server when convenient.

The program will continuously display the data to the screen but store data to disk at intervals determined by the current saved configuration. The following function keys are active and may be pressed to modify the program as needed:

F1. ***Store Data.*** Allows an immediate storage of a single scan to the hard drive. This will over ride the selected interval in the configuration file. After a single scan store, the program will revert to the default interval.

F3. ***Sleep Mode Toggle.*** By pressing this key the scanning will toggle sleep mode on and off. The screen will always display the current mode. In sleep mode, the default store interval is still in effect, but the screen display will be refreshed only once per interval rather than continuously. There are two reasons why sleep mode might be chosen:

1. Sleep mode significantly reduces the amount of activity that the CPU must handle and thus frees up system resources when running concurrently with Windows. This is especially important when using the logbook editor in a separate window.
2. Sleep mode extents the life of the relay multiplexer on the HP3497.

F6. ***Quit program.*** This is the only recommended way to exit or terminate the program. If selected, the user will be given a second chance to verify this or continue the program.

F10. ***Change Setup.*** The configuration menu allows the user to select the number of thermocouples to be read, the interval for storing data, and the descriptive text in the header on the display screen. After the selections are made, the user must decide if these changes are temporary or to be saved to the configuration file. If the changes are saved, they will become the default settings on subsequent startups of the program.

Other Files Required

LIGO.CFG

This file is a text file containing limited configuration parameters. Some of the parameters do not apply to the current program, but must contain the same structure and order. A typical LIGO.CFG file would appear as follows:

- 900 | The number of seconds between stored data saves
- 120 | not used
- 0 | not used
- 55 | number of transducers- not used
- Plainfield Development - LIGO | screen header text
- 2400 | modem baud rate - not used

PARMDATA

This file contains coefficients for three kinds of thermocouples

- type 1 = T (copper-constantan)
- type 2 = K (chromel-alumel)
- type 3 = J (iron-constantan)

CHANLIST.TXT
This file contains a list of channel assignments and descriptions for each input measurement. The descriptions are those that appear on the during operation. The list also contains the actual input card channel assignment for the HP3497A Data Acquisition system. The first three columns of the attached table, **LIGO Channel List** are essentially the same as this file. This file may be edited with a text editor such as Notepad, but care should be taken not to add extra lines and to preserve the spacing and the length of text in the descriptions.

Running A Word Logbook Document at the Same Time

Windows, has been configured so that both LIGOTEMP and WORD are both in the "Startup-Window". LIGOTEMP has also been configured to multitask with WORD, in fact both programs can be displayed at the same time in two separate windows. However, Windows can become quite slow and unresponsive if the data acquisition system in a scanning operation. During extended periods of text entry in the logbook, LIGOTEMP should be placed in "sleep" mode by pressing F3. This way scanning will only be done at save intervals instead of continuously. In sleep mode, only the last saved data is displaced on the screen, and this might be several minutes old depending on the selected save interval. Remember to turn off sleep mode to update the screen when monitoring temperatures.

Press the Alt-Tab key combination to cycle between LIGOTEMP, WORD and the Windows Program Manager. To display LIGOTEMP in a "window", first enter LIGOTEMP then press the Alt-Enter key combination at it will become an active "window". This window will share screen space with other applications and it can be moved or resized.

EXAMPLE OF LOGBOOK ENTRY

01/13/95 14:16: This is a test of the LIGO logbook file editor. The **Edit Vector** macro has been modified and improved and should speed up the process of scrolling through the document. The new Toolbar "button" for the Edit Vector macro is the "V" button. This will load a vector editing program on the screen. In order to change the vector status, press the arrow keys to move the cursor. When the cursor covers the vector component, press the space bar to toggle the vector between 0 and 1. The "RGA" component is different in that it allows entry of values from 0 to 99. The space bar is used to increment the value in single increments and the * key is used to increase the value in increments of 10. When the value is increased past 99, it will roll over to 0.

When any changes are made, and you wish to update the vector status file, the return key should be pressed. The current vector file will be updated and the vector status file will be appended to indicate the changes made as well as the time when this happened. The vector status file is named "STATUS.CSV" in the directory "C:\LIGO\LOGBOOK\MACRO". This file is log file that pertains only to changes in the status of the system vector.

In the following example, all elements of the status vector are changed to the value of zero (0).

01/13/95 14:43

V1= 0	V2= 0	V3= 0	V4= 0	V5= 0	V7= 0
V8= 0	V9= 0	V10= 0	V11= 0	V12= 0	V14= 0
V15= 0	V19= 0	V25= 0	V26= 0	V27= 0	V28= 0
V29= 0	RGA= 0	TMP1= 0	TMP2= 0	TMP3= 0	RP1= 0
RP2= 0	LNT1= 0	LNT2= 0	LNT3= 0	CC1= 0	CC2= 0
CC3= 0	CC4= 0	CC5= 0	CC6= 0		

01/13/95 14:46: V1, V2, V7 are opened

01/13/95 14:47

V1= 1	V2= 1	V3= 0	V4= 0	V5= 0	V7= 1
V8= 0	V9= 0	V10= 0	V11= 0	V12= 0	V14= 0
V15= 0	V19= 0	V25= 0	V26= 0	V27= 0	V28= 0
V29= 0	RGA= 0	TMP1= 0	TMP2= 0	TMP3= 0	RP1= 0
RP2= 0	LNT1= 0	LNT2= 0	LNT3= 0	CC1= 0	CC2= 0
CC3= 0	CC4= 0	CC5= 0	CC6= 0		

01/13/95 14:47: RGA is set to status 33.

01/13/95 14:48

V1= 1	V2= 1	V3= 0	V4= 0	V5= 0	V7= 1
V8= 0	V9= 0	V10= 0	V11= 0	V12= 0	V14= 0
V15= 0	V19= 0	V25= 0	V26= 0	V27= 0	V28= 0
V29= 0	RGA= 33	TMP1= 0	TMP2= 0	TMP3= 0	RP1= 0
RP2= 0	LNT1= 0	LNT2= 0	LNT3= 0	CC1= 0	CC2= 0

01/13/95 14:52: In order to have the proper appearance of the LOGTEXT.DOC file on the screen, the following settings are suggested.

Font:Times New Roman - 12 Point
Zoom:(View Menu) Custom 85%
Tabs: 0.9 in.
Margins: One inch for top, bottom left and right
Indentation:0.9" from left, -0.9 first line

These values have been assigned to the *Page Style* named "LIGO".

01/13/95 15:10: The time stamp shown at the beginning of this line is produced by clicking on the "**clock**" button on the toolbar. This should precede and logbook entries. When entering comments, it is not necessary to press the <enter> key at the end of each line. The word wrap feature of Microsoft Word will automatically feed the text to the next line. It should also be noticed that after the first line in a paragraph, the text is indented. The <enter> key should be pressed to signify the end of a paragraph and the cursor will return to the far left margin.

01/13/95 15:21: After each entry, it is a good practice to save the document. At certain intervals the logbook file should be converted to an **ASCII** file. From **the FILE** Menu, select **SAVE AS**. Next select **SAVE FILE AS TYPE** and select "**DOS Text with Layout** (*.asc)". In the File Name entry box, enter the name of the file you wish to save it as. Use a new different name or else the new file will replace ant file with the same name.

01/13/95 16:32

V1= 1	V2= 1	V3= 0	V4= 0	V5= 0	V7= 1
V8= 0	V9= 0	V10= 1	V11= 0	V12= 0	V14= 0
V15= 0	V19= 1	V25= 0	V26= 0	V27= 0	V28= 0
V29= 0	RGA= 41	TMP1= 0	TMP2= 0	TMP3= 0	RP1= 0
RP2= 0	LNT1= 0	LNT2= 0	LNT3= 0	CC1= 0	CC2= 0
CC3= 0	CC4= 0	CC5= 0	CC6= 0		

How to insert a *System Vector* into the LogbookFile

1. Place the cursor on the place in the document where you want to insert the *system vector.*

2. Click on the "V" tool button. This activates the **Edit Vector** macro.

3. A screen will appear showing the name of each element of the *system vector* and its current status. The value zero (0) signifies the elment is closed or off. The value one (1) indicates that it is open or on. One element, indicated as "RGA" can contain a value ranging from 0 to 99.of the *system vector* will appear as a Table of 2 columns. Refer to the table of RGA status to determine the correct value.

4. Use the arrow keys to move the cursor on the *system vector* screen and use the space bar to change the value of the vector element. The "RGA" component will accept values between 0 and 99. The "*" key will advance the value by tens and the space bar by ones. If the value is advanced past 99 it will return to 0. If you decide that no changes are to be made, or you wish to undo any entry errors, press "Control-X" to exit without any changes. When Word asks if you wish to paste the *system vector* into the document, click on the "cancel" box.

5. When you have finished editing the vector, press the enter key to save the new vector and return to the logbook document. Word will also ask you if you wish to paste the current vector into the document. Click on the "yes" box or press enter to confirm or click on "cancel" if you do not want to paste the vector into the document.

6. The edited vector is copied and pasted into the LOGBOOK document at the previously selected cursor location. The copied vector is preceded with a time stamp.

7. Each time the *system vector* is recalled for editing, it will contain the most recent values in the template. Only the devices that have changed will require editing.

Example of Display Screen

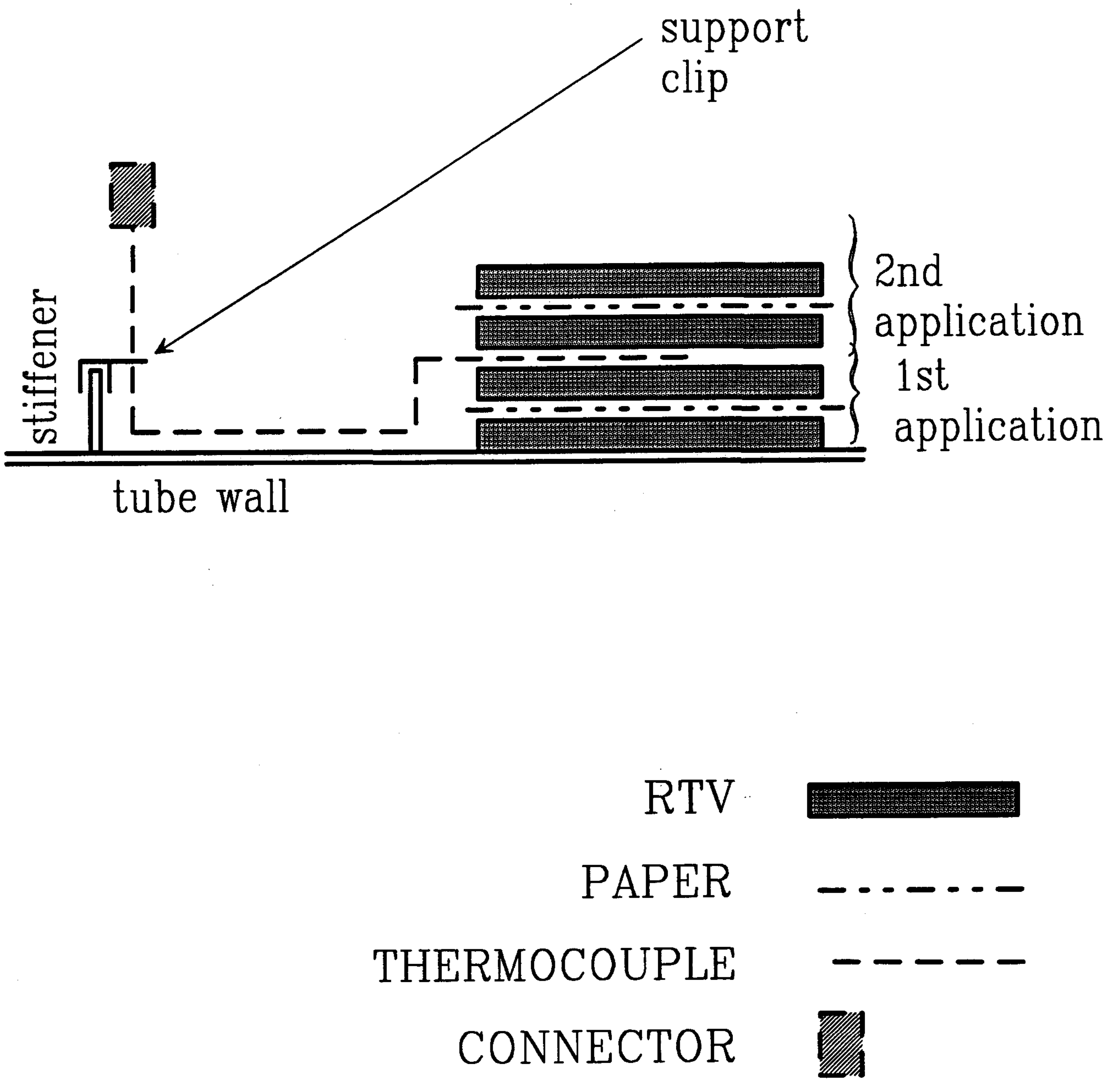
```
Chicago Bridge and Iron Technical Services Company
         Test Location : Plainfield Development - LIGO
         Date: 01-16-1995   Time: 14:41:41
     Temperature                                HPS 937 Vacuum Gauge Controller
-------------------------------------------------------------------------------
  1. Chamber Repress. Valve..  24.7 °C     1. Cold Cathode.....    4.72E+04 Torr
  2. Chamber Isolation Valve.  24.8 °C     2. Pirani...........    2.15E+04 Torr
  3. Cross - Chamber inlet...  25.1 °C     3. CC1..............    2.16E-12 Torr
  4. Tee at H2 Leak Valve....  24.7 °C     4. CC2..............    4.59E+04 Torr
  5. H2 Leak Isolation Valve.  24.8 °C     5. P1...............    2.13E-12 Torr
  6. Pneumatic Valve - Turbo.  24.7 °C     6. CC3..............    1.41E-08 Torr
  7. Turbo Pump.............   24.6 °C
  8. Cold Trap..............   24.6 °C
  9. Cross at RGA...........   24.6 °C
 10. Cold Trap Vent Valve....  24.6 °C
 11. RGA Isolation Valve.....  24.5 °C    31. N End Head Center Line..   -.- °C
 12. RGA Spool..............   24.7 °C    32. N Support - NE Stiffener   -.- °C
 13. Coupon Chamber - Top....  25.3 °C    33. N Support - N Plate.....   -.- °C
 14. Coupon Chamber - Center.  25.2 °C    34. N Support - SW Kicker...   -.- °C
 15. Coupon Chamber - Bottom.  25.1 °C    35. N Support - S. Plate....   -.- °C
 16. Inside Coupon Chamber...  25.2 °C    36. N Support - SE Kicker...   -.- °C
 17. Liquid Nitrogen Trap....  24.8 °C    37. 22B Top Center..........   -.- °C
 18. LNT-1..................   86.0 °C    38. 22B Top Stiffener.......   -.- °C
 19. 8 in. Tee..............   67.6 °C    39. Flex. Supp.- Stiffener..   -.- °C
 20. V-3.................... 108.1 °C    40. Bellows ins conv - Top..   -.- °C
 21. 8 in. Cross............ 102.6 °C    41. Bellows outs conv - Top.   -.- °C
 22. V-1....................   88.4 °C    42. 22A Bottom Center.......   -.- °C
 23. V-2....................   90.3 °C    43. 22A Bottom Stiffener....   -.- °C
 24. V-10...................   52.5 °C    44. S Support - NW Stiffener   -.- °C
 25. RGA....................   77.9 °C    45. S Support - NW Plate....   -.- °C
 26. V-15...................   26.6 °C    46. S Support - NW Kicker...   -.- °C
 27. Calib. Leaks...........   86.2 °C    47. S Support - SE Plate....   -.- °C
 28. LNT 1 Internal..........   -.- °C    48. S Support - SE Kicker...   -.- °C
 29. LNT 2 Internal..........   -.- °C    49. S.Support - W Beam......   -.- °C
 30. LNT 3 Internal..........   -.- °C    50. S End Head Center Line..   -.- °C


                                          Press <F1> to store scan once
                                          Press <F2> to clear screen
                                          Press <F3> to toggle sleep mode.
                                          Press <F6> to quit
                                          Press <F10> to change setup

                                          Current save interval is 15  min.
                                          Sleep Mode on
```

LIGO Channel List

Transducer Number	H.P. Channel Number	Description	H.P. Card Num.	Input Terminal
1	0	1. Chamber Repress. Valve..	0	0
2	1	2. Chamber Isolation Valve.	0	1
3	2	3. Cross - Chamber inlet...	0	2
4	3	4. Tee at H2 Leak Valve....	0	3
5	4	5. H2 Leak Isolation Valve.	0	4
6	5	6. Pneumatic Valve - Turbo.	0	5
7	6	7. Turbo Pump.............	0	6
8	7	8. Cold Trap..............	0	7
9	8	9. Cross at RGA...........	0	8
10	9	10. Cold Trap Vent Valve....	0	9
11	10	11. RGA Isolation Valve.....	0	10
12	11	12. RGA Spool...............	0	11
13	12	13. Coupon Chamber - Top....	0	12
14	13	14. Coupon Chamber - Center.	0	13
15	14	15. Coupon Chamber - Bottom.	0	14
16	15	16. Inside Coupon Chamber...	0	15
17	16	17. Liquid Nitrogen Trap....	0	16
18	26	18. LNT-1..................	1	6
19	27	19. 8 in. Tee..............	1	7
20	28	20. V-3....................	1	8
21	29	21. 8 in. Cross............	1	9
22	30	22. V-1....................	1	10
23	31	23. V-2....................	1	11
24	32	24. V-10...................	1	12
25	33	25. RGA....................	1	13
26	34	26. V-15...................	1	14
27	35	27. Calib. Leaks...........	1	15
28	40	28. LNT 1 Internal..........	2	0
29	41	29. LNT 2 Internal..........	2	1
30	42	30. LNT 3 Internal..........	2	2
31	43	31. N End Head Center Line..	2	3
32	44	32. N Support - NE Stiffener	2	4
33	45	33. N Support - N Plate.....	2	5
34	46	34. N Support - SW Kicker...	2	6
35	47	35. N Support - S. Plate....	2	7
36	48	36. N Support - SE Kicker...	2	8
37	49	37. 22B Top Center..........	2	9
38	50	38. 22B Top Stiffener.......	2	10
39	51	39. Flex. Supp.- Stiffener..	2	11
40	52	40. Bellows ins conv - Top..	2	12
41	53	41. Bellows outs conv - Top.	2	13
42	54	42. 22A Bottom Center.......	2	14
43	55	43. 22A Bottom Stiffener....	2	15
44	56	44. S Support - NW Stiffener	2	16
45	57	45. S Support - NW Plate....	2	17
46	58	46. S Support - NW Kicker...	2	18
47	17	47. S Support - SE Plate....	0	17
48	18	48. S Support - SE Kicker...	0	18
49	21	49. S.Support - W Beam......	1	1
50	22	50. S End Head Center Line..	1	2
51	23	1. Cold Cathode.....	1	3
52	24	2. Pirani..........	1	4
53	36	3. CC1.............	1	16
54	37	4. CC2.............	1	17
55	38	5. P1..............	1	18
56	20	6. CC3.............	1	0

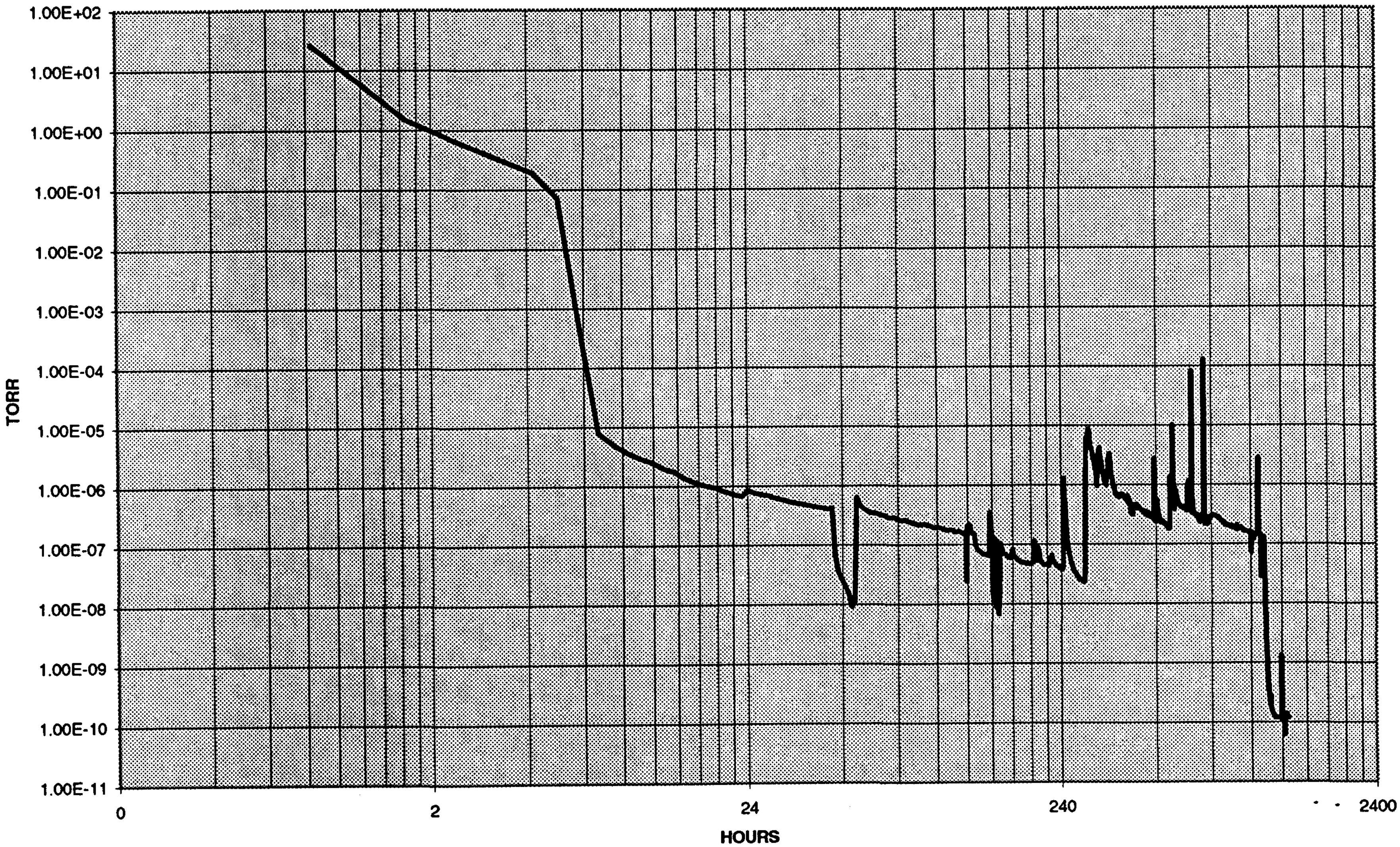
SECTION 2.F.17 APPENDICES

THERMOCOUPLE ATTACHMENT DETAIL



SECTION 2.G.1 APPENDICES

TUBE PUMP DOWN



SECTION 2.G.3 APPENDICES

CIRCUMFERENTIAL WELD JOINT LEAK TEST VACUUM BOX PERFORMANCE EVALUATION FOR LIGO QUALIFICATION TEST

PERFORMANCE REQUIREMENTS

The vacuum box used to create the pressure differential for the Local Hood Test Procedure must be evacuated within a reasonable time to a sufficiently low vacuum (absolute test pressure) to enable the test operator to unambiguously detect a total helium leakage rate of 1 x 10^{-10} atm cc/sec.

PLASTIC VACUUM BOX EVALUATION

Beam Tube Section for Evaluation

Trial HMS tested a circumferential weld joint that joined two of the qualification beam tube sections. The weld had typical reinforcement and peaking.

Plastic Vacuum Box

Overall Box Dimensions - 1/2" x 12" wide x 35" long with built in "O" ring grooves
Dimensions of evacuated space - 1/16" deep x 8" wide x 31" long (Volume ≈ 0.25 liters)
Perimeter seals - two 0.375" diameter 50 duromter Buna N rubber "O" rings
Connections - pump port; 40 KF (1-1/2" Ø), He calibrated leak port; 40 KF (1-1/2" Ø), & between seals port; 16 KF (3/4" Ø)

Procedure Related Equipment:

1. Helium Mass Spectrometer - Alcatel Model ASM 110 TCL
   a. Turbomolecular pump speed (net) ≈ 3 liters/sec.
   b. Roughing pump speed @ inlet port = 1 liter/sec
   b. Instrument sensitivity = 2 X 10^{-11} atm cc/sec. of helium per division
2. Calibrated Helium Standard Leak with a leak rate of 2.1 x 10^{-8} atm cc/sec. of helium connected to the box KF reducer listed as item 6..
3. Six (6) feet of flexible stainless steel hose with 25 KF (1" Ø) connectors on the ends.
4. One butterfly valve 40 KF (1-1/2" Ø)
5. One in-line valve 25 KF (1" Ø)
6. Reducer 40 KF to 25 KF (1" Ø)
7. Heavy Duty Ratchet Tie Down Straps
8. Auxiliary Duo Seal Mechanical Vacuum Pump (Displacement ≈ 1 l/s)

Sequence

Installed the assembled vacuum box over a segment of the circumferential weld joint with no special preparation. Cleaned the test area by wiping the outside of the can with clothes soaked with alcohol. Held the vacuum box against the beam tube outer shell by two ratchet straps. Used wood and metal wedges to tighten the vacuum box against the shell at each location where spiral or circumferential welds were crossed by the box seals. Connected the HMS leak detector to the box.

Evacuated the box with the auxiliary vacuum pump. Partially throttled the HMS into the box. Obvious seal leakage was observed. The box would not evacuate low enough to allow the HMS throttle valve to be completely opened. Stopped test.

After grinding the circumferential weld and spiral weld reasonably smooth in the areas where the box seals crossed these welds, the reseated box evacuated low enough to get the HMS throttle valve about 3/4 open. The HMS manifold gauge indicated an absolute pressure of about 10^{-2} torr. The HMS high vacuum section gauge indicated an absolute pressure of about 2 x 10^{-5} torr . The background signal was in the middle of the 3 x 10^{-9} atm. cc/sec. range scale. Nulled the background signal to 1.0 in the
10 x 10^{-10} atm. cc/sec. range scale. Calibrated the test system using the standard leak on the box. The response signal increased above background to a reading of 1.69 on the 3 x 10^{-8} atm. cc/sec. range scale. The response time had been calculated to be approximately 25 to 30 seconds. The actual response time was about 50 seconds.

For an allowable leakage rate of 1 x 10^{-10} atm. cc/sec., this system calibration resulted in an allowable signal increase during test of 0.8 on the 10 x 10^{-10} atm. cc/sec. range scale in about one minute of elapsed test time for this test set up.

Though it was proven that the required test sensitivity was achievable with the plastic box, it was obvious that plastic would not be sufficiently durable for this repeat type of leak testing. Thus, it was decided to try an aluminum box with slightly larger diameter "O" rings

ALUMINUM VACUUM BOX EVALUATION

Beam Tube Section for Evaluation

Trial HMS tested a circumferential weld joint between two four (4) foot long sections of beam tube. These beam tube sections had vacuum stiffeners tack welded at each end to keep the beam tube round. The weld had offset, peaking, reinforcement and roughness that was close to the maximum allowable per the visual inspection procedure VI8X.

Aluminum Vacuum Box

Overall Box Dimensions - 3/8" thick x 16" wide x 48" long
Dimensions of evacuated space - 1/8" deep X 8" wide 39" long (Volume ≈ 0.64 liters)
Perimeter seals - two 0.4375" diameter 50 durometer Buna N rubber "O" rings
Connections - pump port; 40 KF (1-1/2" Ø), He calibrated leak port; 25 KF (1" Ø), & between seals
port; 25 KF (1" Ø)

Procedure Related Equipment:

1. Helium Mass Spectrometer - Alcatel Model ASM 110 TCL
   a. Turbomolecular pump speed (net) ≈ 3 liters/sec.
   b. Roughing pump speed @ inlet port = 1 liter/sec
   b. Instrument sensitivity = 2×10^{-11} atm cc/sec. of helium per division
2. Calibrated Helium Standard Leak with a leak rate of 2.1×10^{-8} atm cc/sec. of helium
3. Six (6) feet of flexible stainless steel hose with 25 KF (1" Ø) connectors on the ends.
4. Three butterfly valves 40 KF (1-1/2" Ø)
5. Two inline valves 25 KF (1" Ø)
6. Cross & Tees 16 KF (3/4" Ø)
7. Reducers 40 KF to 25 KF (1" Ø) & 25 KF to 16 KF (3/4" Ø)
8. Heavy Duty Ratchet Tie Down Straps (15 ft. min. 10 kips)
9. Duo Seal Auxiliary Mechanical Vacuum Pump (Displacement = 30 CFM). This pump could have been much smaller.

Auxiliary Equipment used to Analyze Aluminum Vacuum Box Results

1. Two Convection Gauge Tubes with controller 16KF (3/4" Ø
2. Two ionization gauge tubes with controller

First Aluminum Vacuum Box Evaluation

Sequence

Installed the vacuum box over a segment of the circumferential weld joint with no special preparation or cleaning. Held the assembled vacuum box against the beam tube outer shell with three ratchet straps. Used wood and metal wedges to tighten the vacuum box against the shell at each location where spiral or circumferential welds were covered by the seals.

The preliminary pump down of the vacuum box was done with a redundant convection gauge installed at a cross 16KF (3/4" Ø) with the calibrated helium leak and a blank flange. The second redundant convection gauge was installed at a tee 16KF (3/4" Ø) with a butterfly valve 40 KF (1-1/2" Ø) and the duo seal vacuum pump hardware to measure the absolute pressure in the space between the seals. The vacuum box chamber pressure measured by the first convection gauge was 10^{-3} torr. The pressure between the seals measured by the second convection gauge was 2.6×10^{-2} torr. The leak detector high vacuum absolute pressure reading was at 1.0×10^{-5} mbar. The system calibration was performed with the helium standard leak attached at the leak detector. The pump down of the box was done over a ten hour period. This indicated excessive seal leakage. Detailed data was not recorded in the log.

The vacuum box was moved one inch from its original location in an attempt to keep the weld reinforcement from making contact with the metal seal restraint plate. An ion gauge tube was installed at the cross with the convection gauge and calibrated helium standard leak. The vacuum box was pumped down for testing. The data was recorded in the leak testing log notebook.

Minimum absolute pressure achieved in the vacuum box chamber was 1.5×10^{-4} torr. Pump down time to this ultimate absolute pressure was 7 hours. This long pump down indicated excessive seal leakage.

The lowest background helium signal without nulling was 2.0 on the 10^{-9} atm.cc/sec. range scale. By nulling the background, the leak detector was readily capable of unambiguously detecting leakage of 1.0×10^{-10} atm. cc/sec. of helium within the established response time.

Inner seal leakage was observed. The typical inner seal width was 11/32". At the circumferential weld joint, the inner seal width was less than 1/16". The vacuum box needs a minor modification to allow better contact at the circumferential weld joint. The seal rings had exhibited particles of paint and concrete that came loose from the outside of the beam tube during the test. Special cleaning is required for the outside of the beam tube where the vacuum box seals come in contact with the can.

Second Aluminum Vacuum Box Evaluation

Sequence

A 1/2" wide X 1/8" deep groove was made across the seal retainer bars on the ends at the center line of the vacuum box. The vacuum box was installed over a segment of the circumferential weld joint that had been cleaned with stainless pads and Proponal soaked lint free rags. The vacuum box was moved four inches from the previous location. The vacuum box was held against the beam tube outer shell by three ratchet straps. Wood and metal wedges were used to tighten the vacuum box against the shell at each location where spiral or circumferential welds were covered by the seals. An ion gauge was installed at the cross with the convection gauge and the calibrated helium standard leak. It was to be used for analyzing the results.

Minimum absolute pressure achieved in the vacuum box in four hours was 2.4 X 10^{-4} torr.

The lowest background signal without nulling was 3.6 divisions on the 10^{-9} atm.cc/sec. range scale. By nulling the background, the leak detector was readily capable of unambiguously detecting leakage of
1.0 x 10^{-10} atm. cc/sec. of helium within the established response time.

The inner seal did not make contact at the circumferential weld joint. There was a 7/8" long non-contact area where offset + reinforcement + banding was greater than 1/8".

Third Aluminum Vacuum Box Evaluation

Sequence

The vacuum box was installed over a segment of the circumferential weld joint one inch from the previous location. The vacuum box was held against the beam tube outer shell by three ratchet straps. Wood and metal wedges were used to tighten the vacuum box against the shell at each location where spiral or circumferential welds were covered by the seals. The helium mass spectrometer and connection hardware were installed as before. Polyethylene sheeting was taped around the outer edge of the vacuum box and filled with nitrogen to lower the helium background.

Minimum absolute pressures achieved in the vacuum box were: 3.0 X 10^{-4} torr in 30 minutes;
2.0 X 10^{-4} torr in 1 hour;
1.0 X 10^{-4} torr in 7 hours

The lowest background signal without nulling was 1.6 divisions on the 10^{-9} atm.cc/sec. range scale. By nulling the background, the leak detector was readily capable of unambiguously detecting leakage of
1.0 x 10^{-10} atm. cc/sec. of helium within the established response time.

The inner seal did not make contact at the circumferential weld joint. There was a 3/32" long non-contact area where offset + reinforcement + banding is greater than 1/8". To further reduce leakage, the circumferential weld joint must be ground and polished where the seals make contact with the weld.

Fourth Aluminum Vacuum Box Evaluation

Sequence

A segment of the circumferential weld joint was measured and marked to fit the vacuum box. Four (4") inches at each end the circumferential weld was contoured and polished with a 80 grit 2" sanding wheel. The area under the vacuum box was cleaned with Merichem 500, rinsed with warm water, then rinsed with Proponal and allowed to dry. The vacuum box was cleaned and installed over the segment of the circumferential weld joint. The vacuum box was held against the beam tube outer shell by three ratchet straps. An ion gauge was installed at the cross with the convection gauge and the calibrated helium leak. The leak detector and connection hardware were installed. The preliminary pump down of the vacuum box was done with the leak detector. The vacuum box absolute pressure convection gauge reading was 4.7×10^{-2} torr in 10 minutes and the pressure between the seals was at 760 Torr. A 5 psig nitrogen purge was injected between the seals. In 10 minutes the vacuum box absolute pressure convection gauge reading was 8.0×10^{-3} torr and the pressure between the seals was at 1013 Torr. A redundant ionization gauge and a second redundant convection gauge were installed to two 16KF (3/4" Ø) tees with a butterfly valve 40 KF (1-1/2" Ø) with the duo seal vacuum pump connected to the space between the seals.

Based on prior helium background signals at this absolute pressure level for this system, after nulling the background, the leak detector would have been readily capable of unambiguously detecting leakage
of 1.0×10^{-10} atm. cc/sec. of helium.

The ultimate absolute pressure obtained in the box after evacuating it for another 6 days was shown on the auxiliary ionization gauge as 3.3×10^{-5} torr. The absolute pressure between the seals was $3.3 \times {}^{-4}$ torr.

CONCLUSIONS

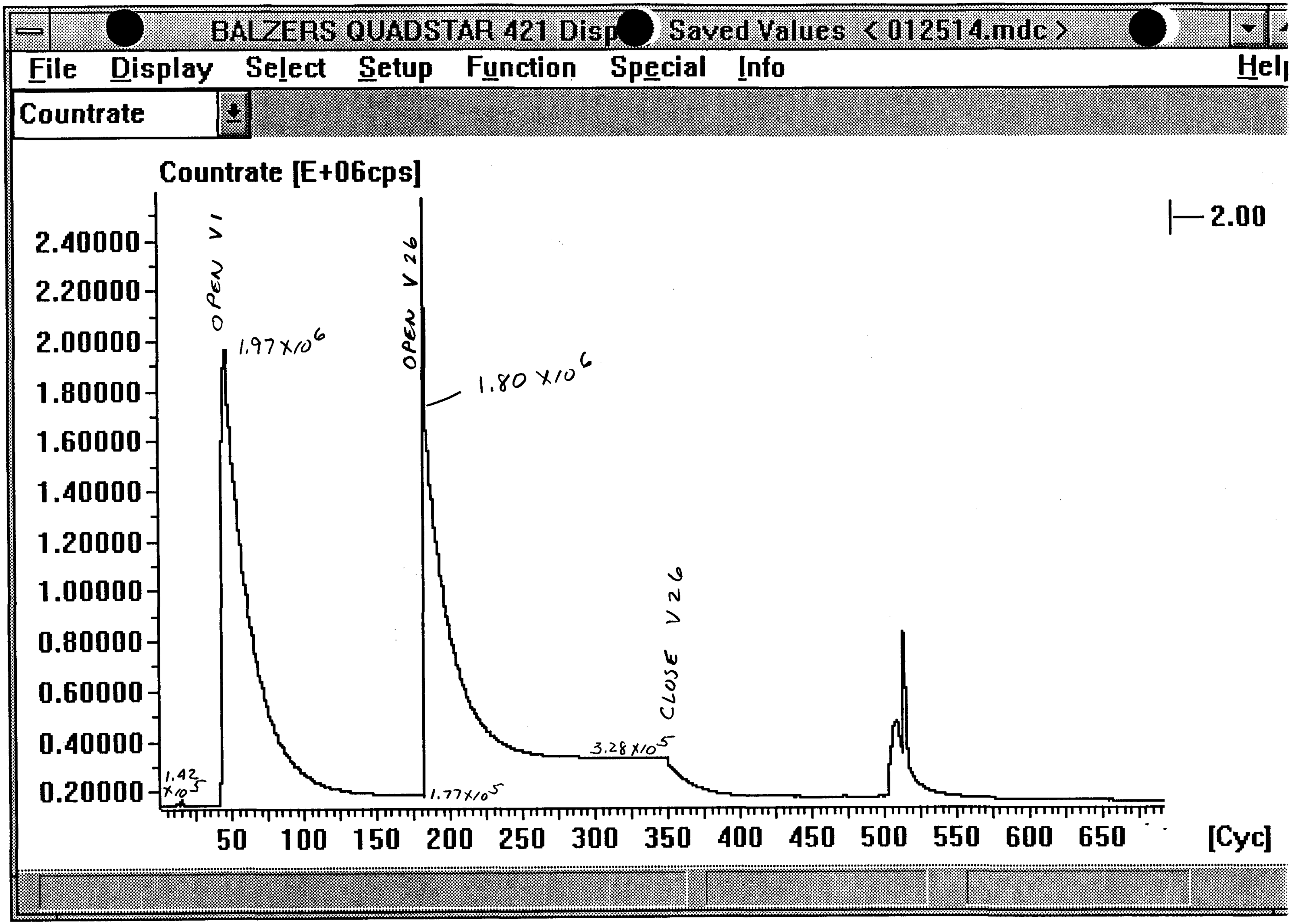
This type of local aluminum vacuum box is capable of achieving the required test sensitivity of 1×10^{-10} atm. cc/sec. with some amount of grinding and preparation of the weld surfaces where they will be crossed by the vacuum box "O" ring seals. However, the degree of leak tightness that can be obtained where the box seals cross the welds is too inconsistent and sometimes more time consuming than the erection schedule would allow. This result would dictate that a 360 degree vacuum box would be the realistic choice for the full scale LIGO.

SECTION 2.G.4 APPENDICES

OUTGASSING RATE CALCULATION

GAS TO BE INVESTIGATED =	H2 PRE-BAKE	
RGA FILE FOR TUBE ACCUMULATION =	012514.ASC	
RGA FILE FOR LEAK ACCUMULATION =	012514.ASC	
TUBE ACCUMULATION SPIKE HEIGHT =	1.97E+06	CPS OR AMPS
TUBE ACCUMULATION TIME =	6.60E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	1.80E+06	CPS OR AMPS
LEAK ACCUMULATION TIME =	1.70E+01	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	1.69E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.28E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.42E+05	CPS OR AMPS
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**3.01E-14**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**1.61E-14**	**TL/S CM2**	**STEADY STATE APPROACH**



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1.77 X10^5

SECTION 2.G.5 APPENDICES

PREBAKE H_2O OUTGAS TESTS

CALCULATED H_2O PUMPING SPEED = 600 L/s

$$Q = PS_{H_2O} = 5.5\times10^{-8}\ \text{TORR}\ (600\ \text{L/s}) = 3.3\times10^{-5}\ \text{TL/s}$$

$$q = \frac{3.3\times10^{-5}\ \text{TL/s}}{1.71\times10^{6}\ \text{cm}^2} = \underline{\underline{1.93\times10^{-11}\ \text{TL/s cm}^2}}$$

N2 PUMPING SPEED = 260 L/s

H_2O PUMPING SPEED (TURBO) = $260\left(\sqrt{\frac{28}{18}}\right) = 324$ L/s

CCI PRIOR TO TRAP COOLDOWN = 1.51×10^{-7} TORR

CCI AFTER LNT1 COOLDOWN = 7.0×10^{-8} TORR

$$P_1 S_1 = P_2 S_2 = Q$$

$$S_2 = \frac{P_1 S_1}{P_2} = \frac{1.51\times10^{-7}\ (324)}{7\times10^{-8}} = 700\ \text{L/s TRAPPED}$$

$$Q = PS = 5.5\times10^{-8}\ \text{T}\ (700) = 3.85\times10^{-5}\ \text{TL/s}$$

$$q = \frac{3.85\times10^{-5}\ \text{TL/s}}{1.71\times10^{6}} = \underline{\underline{2.25\times10^{-11}\ \text{TL/s cm}^2}}$$

SUBJECT	CBI OFFICE		REVISION		REFERENCE NO. 930212
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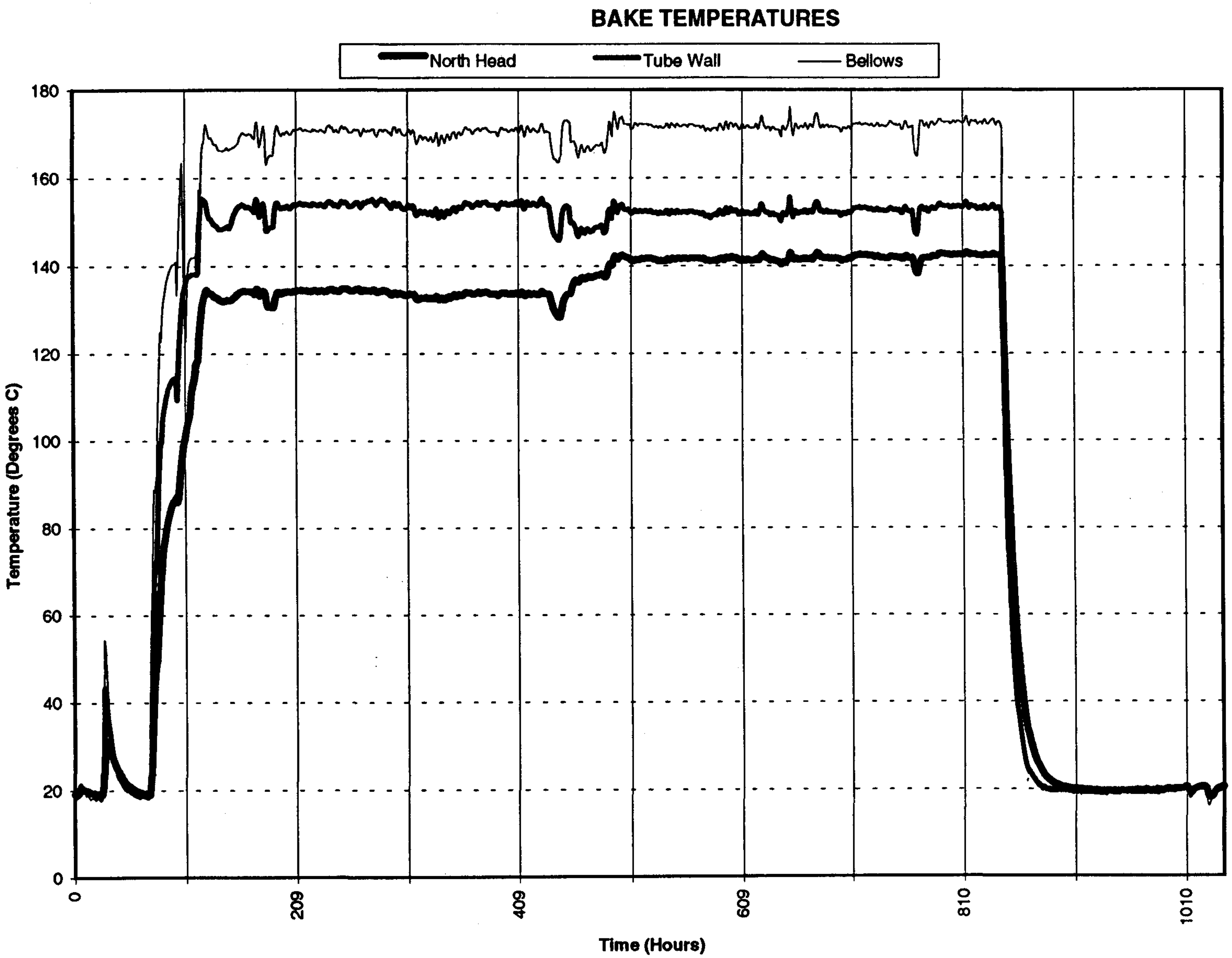
	DATE 3/24/95	DATE	DATE	DATE	

SECTION 2.G.7 APPENDICES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1010
Time (Hours)

SECTION 2.G.9 APPENDICES

WATER OUTGASSING RATE - POST BAKE

FILE 031043 USES V3 CLOSURE TO ISOLATE THE RGA WITH THE TUBE TO WATCH THE ACCUMULATION OF GASSES IN THE TUBE

THE RATE OF PRESSURE RISE IS PROPORTIONAL TO THE OUTGASSING RATE

$$q = \frac{\Delta P \, V}{t \, A}$$

FROM THE FILE, THE H_2O COUNT RATE WENT FROM 309 CPS TO 473 CPS IN 2953 SEC

ASSUME THE GAGE FACTOR FOR H_2O IS THE SAME AS N_2 = 9.174×10^{-15} TORR/CPS

309 CPS PRESSURE = $309 (9.174 \times 10^{-15}) = 2.83 \times 10^{-12}$

473 " " = $473 (9.174 \times 10^{-15}) = 4.34 \times 10^{-12}$

$\Delta P = (4.34 - 2.83) \times 10^{-12} = 1.51 \times 10^{-12}$

$$q = \frac{1.51 \times 10^{-12} \, T \, (5.12 \times 10^{4}) \, L}{2953 \, \text{sec} \;\; 1.71 \times 10^{6} \, cm^2} = 1.53 \times 10^{-17} \, TL/s\,cm^2$$

TUBE + RGA SYSTEM

SUBJECT	CBI OFFICE		REVISION		REFERENCE NO. 930212
	MADE BY WAC	CHKD BY	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 3/27/93	DATE	DATE	DATE	

FIND THE OUTGASSING RATE OF :

THE RGA SYSTEM ONLY 031045

640 CPS $(9.174 \times 10^{-15}) = 5.87 \times 10^{-12}$ T

775 CPS $(9.179 \times 10^{-15}) = 7.11 \times 10^{-12}$ T

$\Delta P = 7.11 - 5.87 = 1.24 \times 10^{-12}$ T

$$q = \frac{1.24 \times 10^{-12} \; (30L)}{5S \quad 7.5 \times 10^{4} \; CM^2} = \underline{9 \times 10^{-18} \; TL/S\,CM^2}$$

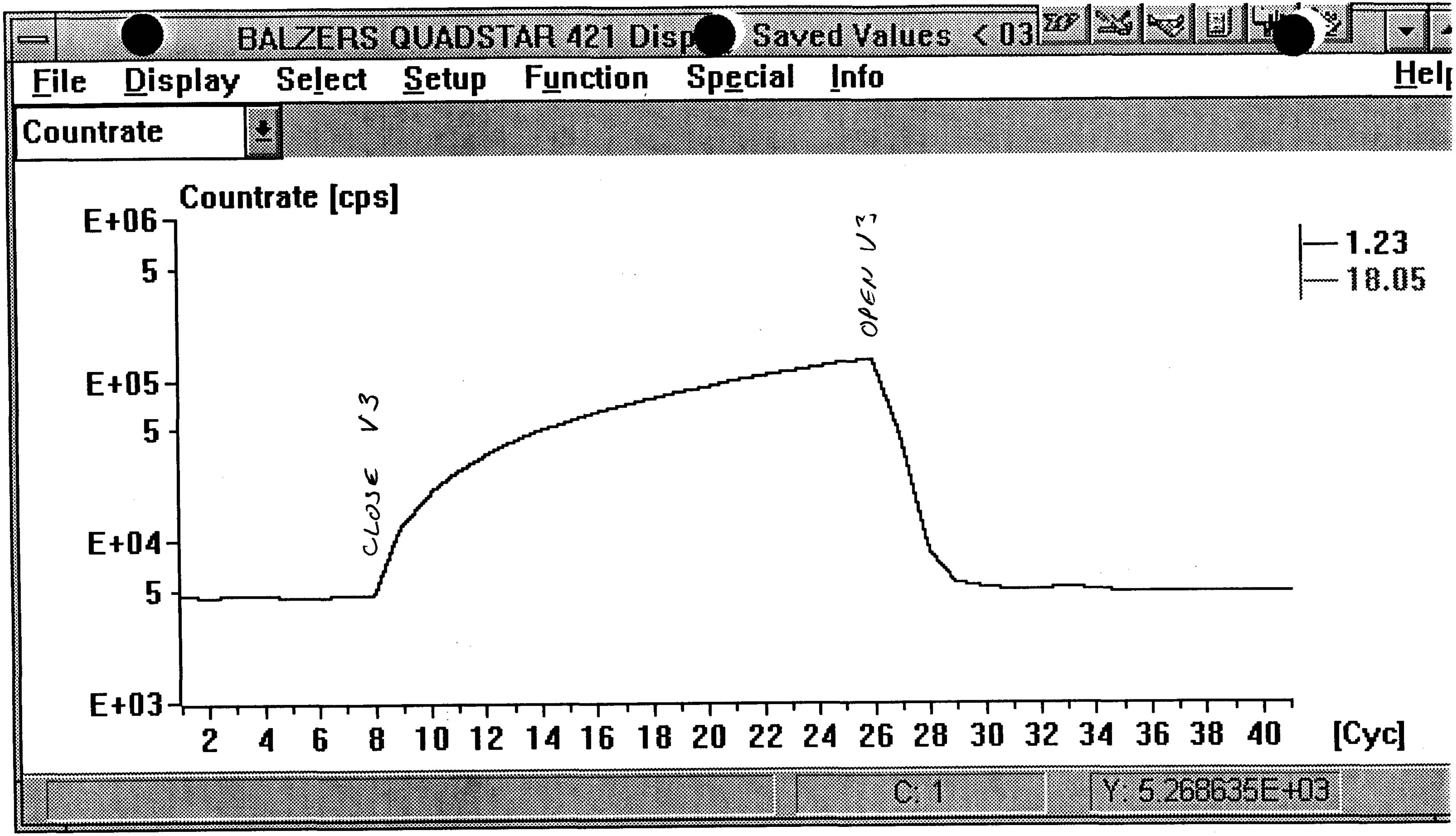
TUBE OUTGASSING = $1.51 \times 10^{-17} - 9 \times 10^{-18}$ =

= $\underline{\underline{6.1 \times 10^{-18} \; TL/S \; CM_2}}$

SUBJECT	CBI OFFICE	REVISION		REFERENCE NO. 930212
	MADE BY WAC	CHKD BY	MADE BY	CHKD BY	SHT 2 OF 2
	DATE 3/27/95	DATE	DATE	DATE	

Printed In USA

GO 64 REV SEP 84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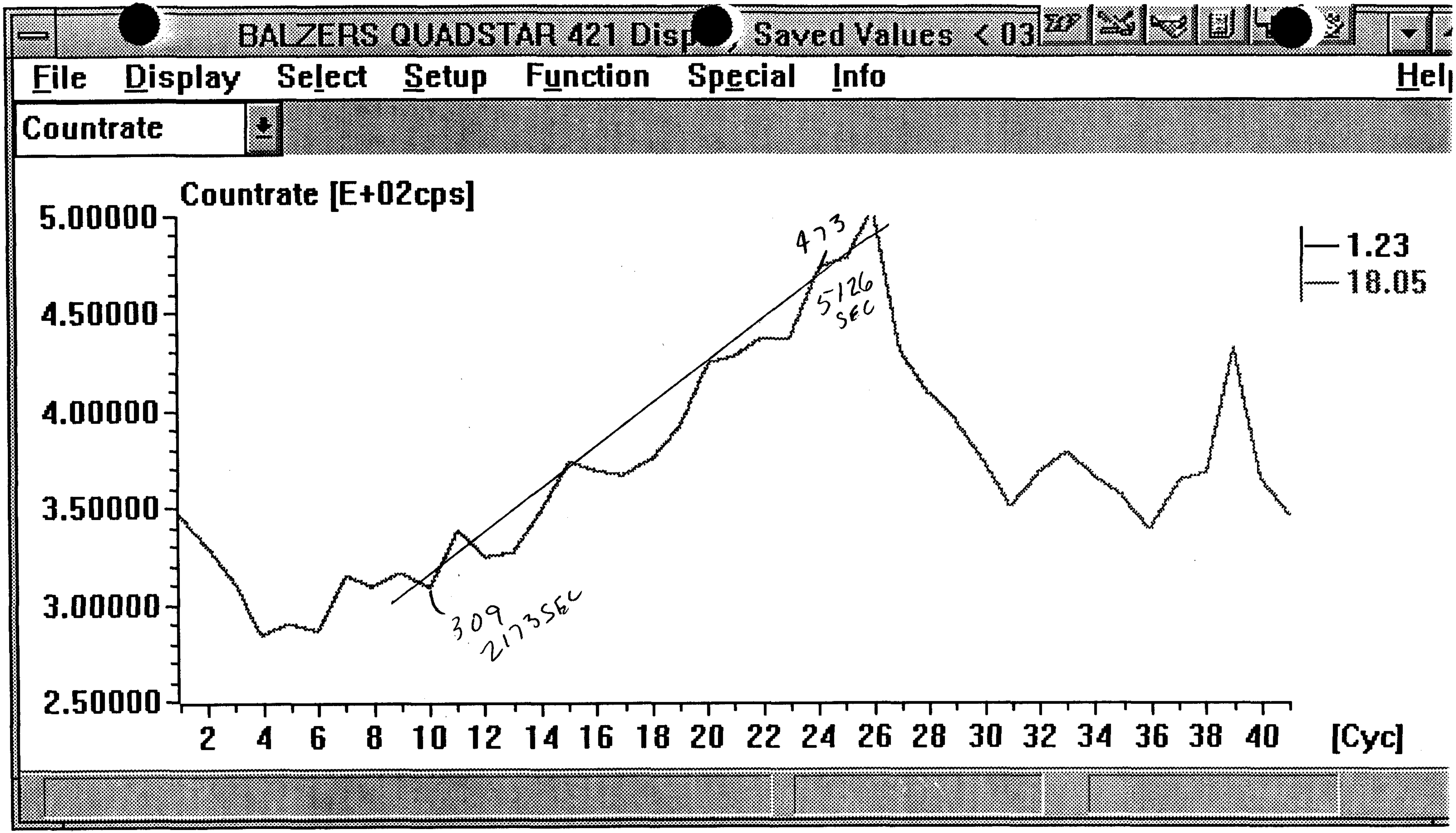
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309
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BEAM TUBE OUTGASSING RATE CALCULATION

GAS TO BE INVESTIGATED =	H2O POST BAKE	
RGA FILE FOR TUBE MEASUREMENT =	030792.ASC	
RGA FILE FOR LEAK MEASUREMENT =	030991A.ASC	
LEAK FLOW RATE =	6.30E-08	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.75E+02	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	6.35E+04	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	0.00E+00	
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE = 1.22E-16 TL/S CM2 STEADY STATE APPROACH

SECTION 2.G.10 APPENDICES

BEAM TUBE OUTGASSING RATE CALCULATION

GAS TO BE INVESTIGATED =	H2 POST BAKE	
RGA FILE FOR TUBE ACCUMULATION =	30991.ASC	
RGA FILE	30991.ASC	
TUBE ACCUMULATION SPIKE HEIGHT =	1.14E+06	CPS OR AMPS
TUBE ACCUMULATION TIME =	1.25E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	1.03E+06	CPS OR AMPS
LEAK ACCUMULATION TIME =	1.20E+01	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.55E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.68E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.51E+05	
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**1.24E-13**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**8.79E-14**	**TL/S CM2**	**STEADY STATE APPROACH**

BEAM TUBE OUTGASSING RATE CALCULATION

GAS TO BE INVESTIGATED =	H2 POST BAKE	
RGA FILE FOR TUBE ACCUMULATION =	30991.ASC	
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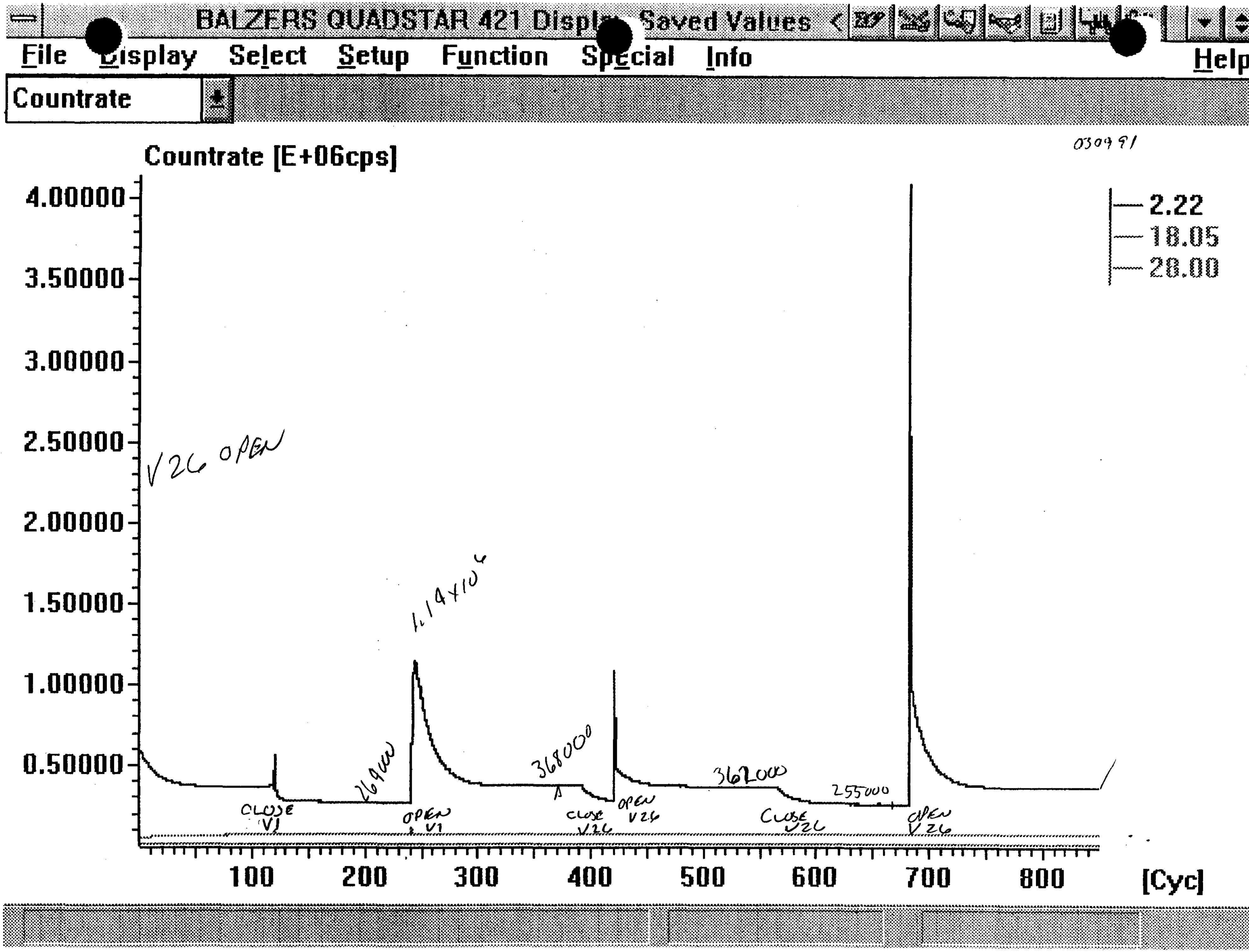
TUBE ACCUMULATION SPIKE HEIGHT =	1.14E+06	CPS OR AMPS
TUBE ACCUMULATION TIME =	1.25E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	4.90E+05	CPS OR AMPS
LEAK ACCUMULATION TIME =	3.00E+00	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.55E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.68E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.51E+05	
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**1.66E-13**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**8.79E-14**	**TL/S CM2**	**STEADY STATE APPROACH**



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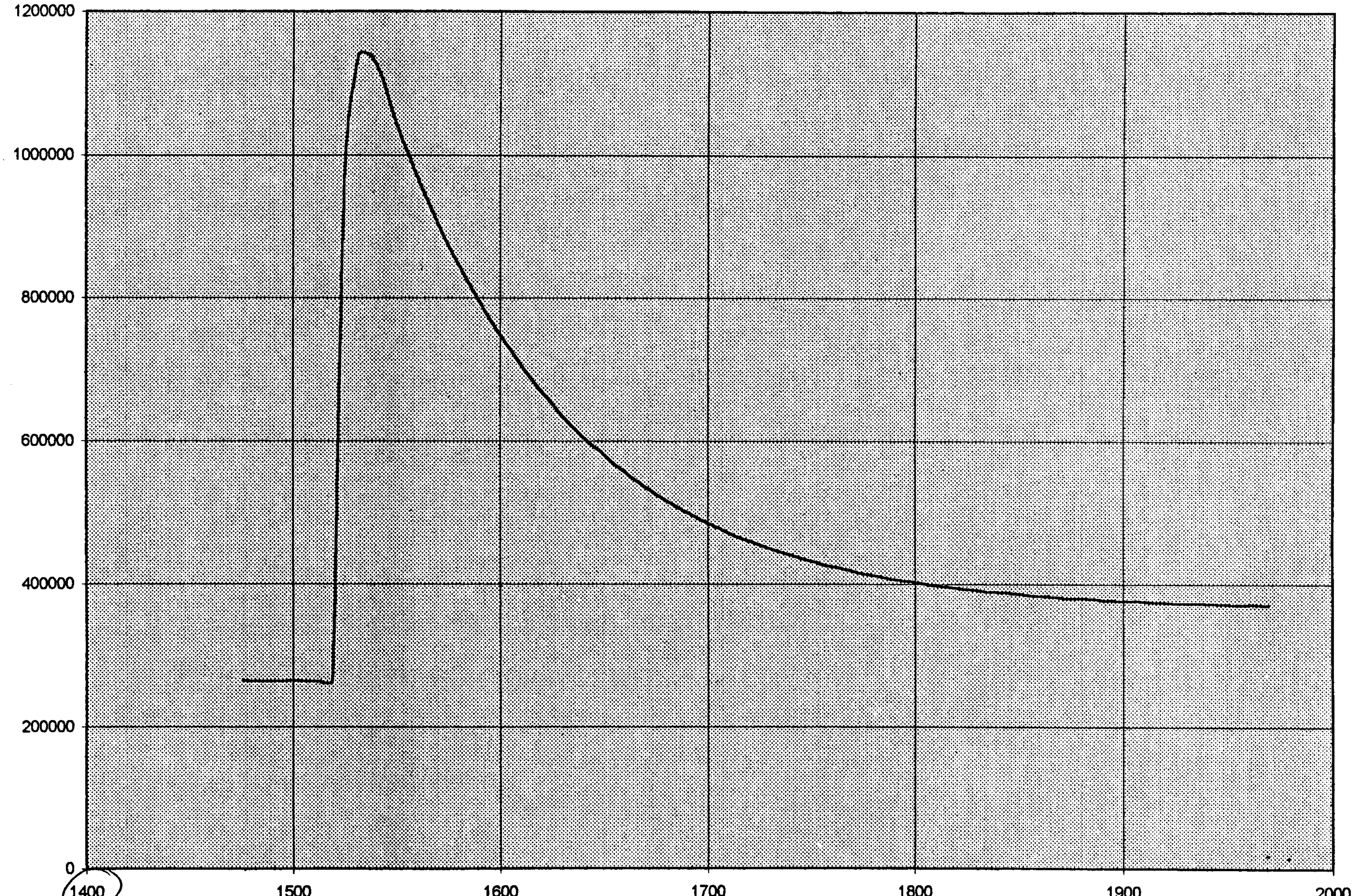

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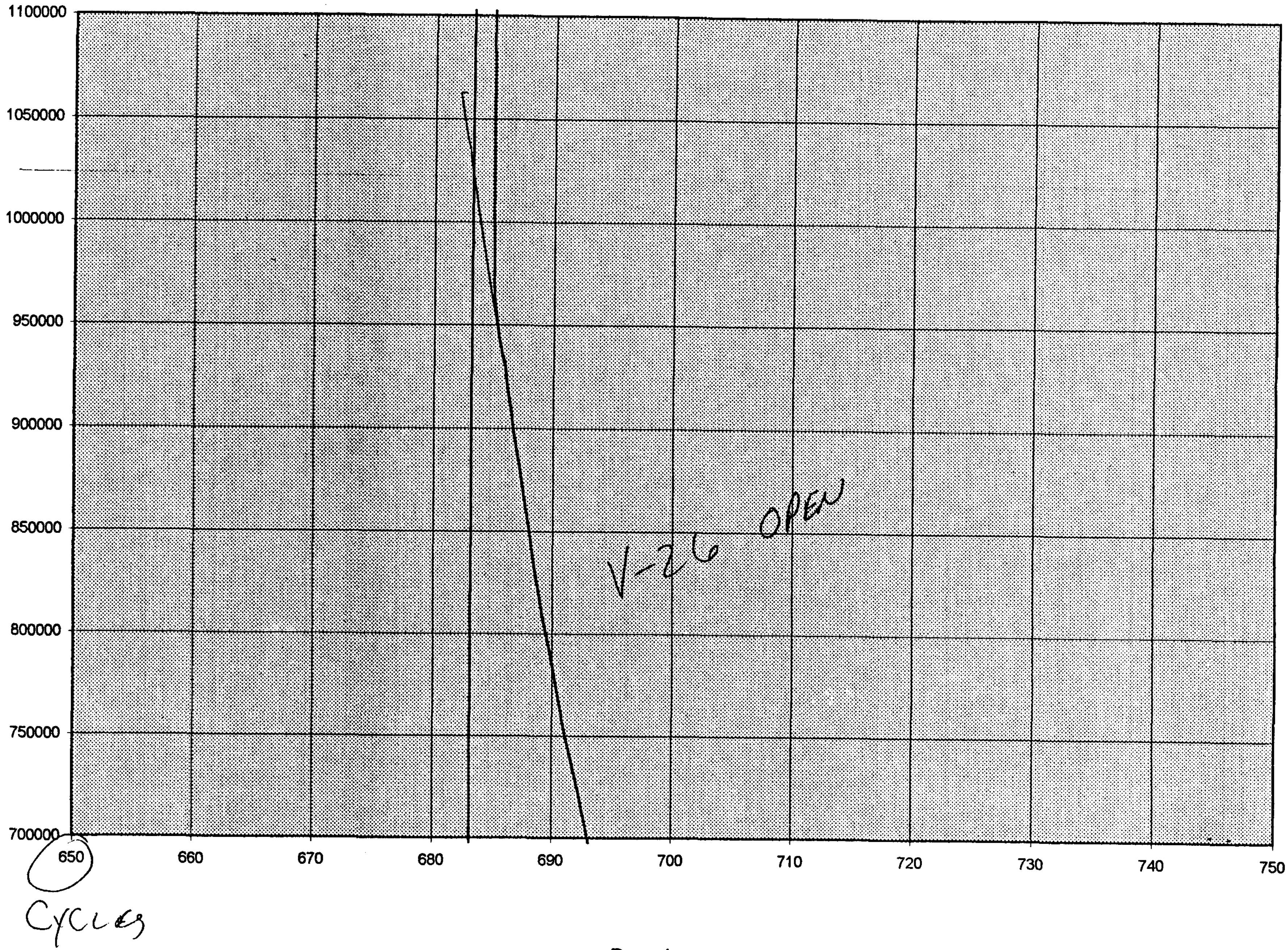
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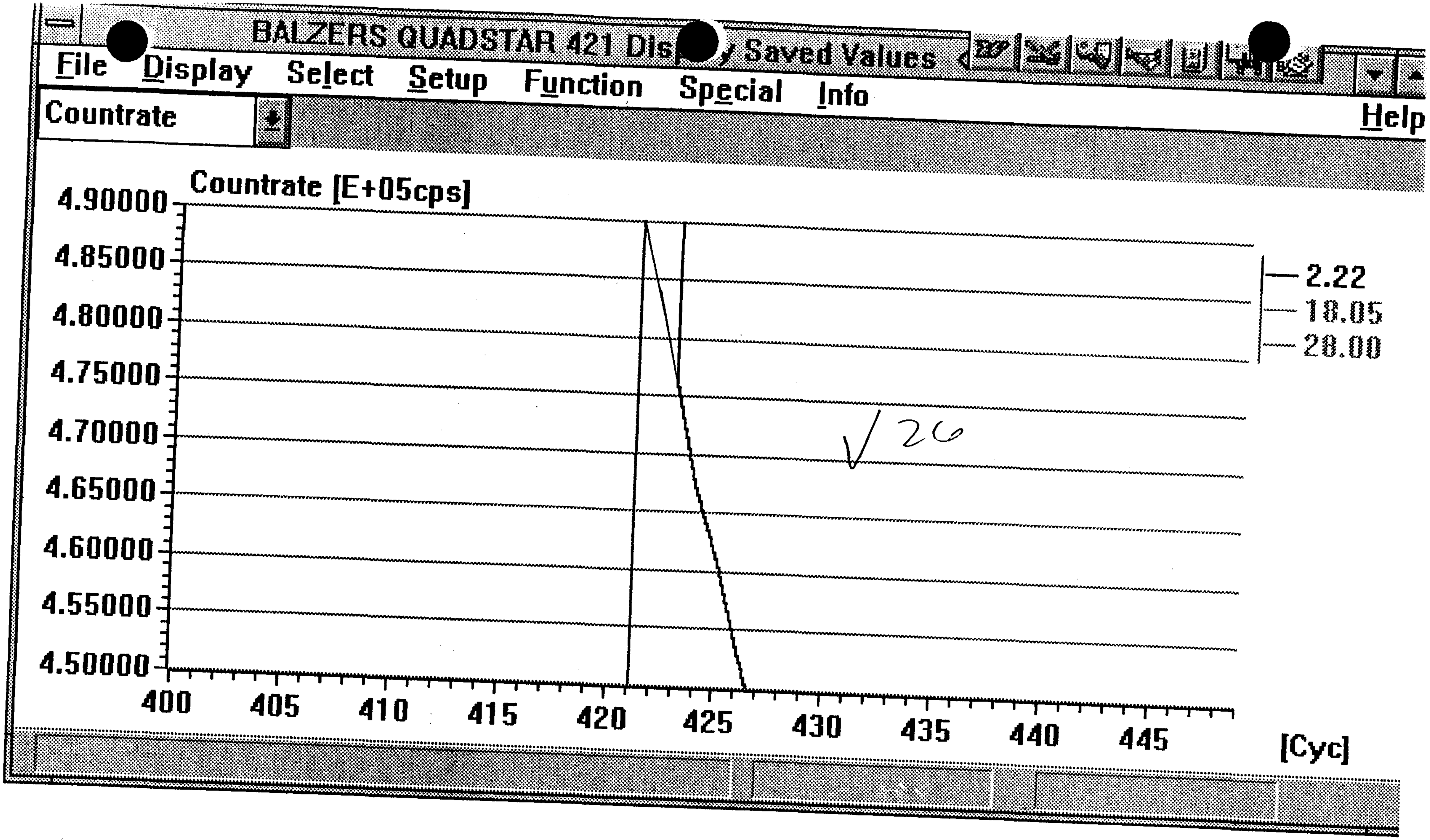

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BEAM TUBE OUTGASSING RATE CALCULATION

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RGA FILE	30891.ASC	
TUBE ACCUMULATION SPIKE HEIGHT =	1.27E+06	CPS OR AMPS
TUBE ACCUMULATION TIME =	1.25E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	1.35E+06	CPS OR AMPS
LEAK ACCUMULATION TIME =	1.50E+01	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.79E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.98E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.64E+05	
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**1.19E-13**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**9.23E-14**	**TL/S CM2**	**STEADY STATE APPROACH**

BEAM TUBE OUTGASSING RATE CALCULATION

GAS TO BE INVESTIGATED =	H2 POST BAKE	
RGA FILE FOR TUBE ACCUMULATION =	30891.ASC	
RGA FILE FOR LEAK ACCUMULATION =	30891.ASC	
TUBE ACCUMULATION SPIKE HEIGHT =	1.27E+06	CPS OR AMPS
TUBE ACCUMULATION TIME =	1.25E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	5.33E+05	CPS OR AMPS
LEAK ACCUMULATION TIME =	3.00E+00	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.79E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.98E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.64E+05	
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**1.68E-13**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**9.23E-14**	**TL/S CM2**	**STEADY STATE APPROACH**

BEAM TUBE OUTGASSING RATE CALCULATION

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RGA FILE	30814.ASC	
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TUBE ACCUMULATION TIME =	1.25E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	1.29E+06	CPS OR AMPS
LEAK ACCUMULATION TIME =	1.50E+01	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.76E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.96E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.69E+05	CPS OR AMPS
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**1.26E-13**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**8.52E-14**	**TL/S CM2**	**STEADY STATE APPROACH**

BEAM TUBE OUTGASSING RATE CALCULATION

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TUBE ACCUMULATION TIME =	1.25E+01	MINUTES
LEAK ACCUMULATION SPIKE HEIGHT =	7.10E+05	CPS OR AMPS
LEAK ACCUMULATION TIME =	6.00E+00	MINUTES
LEAK FLOW RATE =	2.15E-07	STD CC/S
STEADY STATE RGA MEASUREMENT OF TUBE AND PUMPS =	2.76E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF TUBE, PUMPS AND LEAK =	3.96E+05	CPS OR AMPS
STEADY STATE RGA MEASUREMENT OF PUMPS ONLY =	1.69E+05	CPS OR AMPS
TUBE SURFACE AREA =	1.71E+06	CM2

TUBE OUTGASSING RATE =	**1.44E-13**	**TL/S CM2**	**TRANSIENT APPROACH**
TUBE OUTGASSING RATE =	**8.52E-14**	**TL/S CM2**	**STEADY STATE APPROACH**

SECTION 2.H.2 APPENDICES

CHAMBER BACKGROUND OUTGASSING RATE CALCULATION

CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
BACKGROUND TEST FILE NO. =	1010bkg1	
BACKGROUND ACCUMULATION TIME =	120	MIN
BACKGROUND ACCUMULATION PEAK RGA READING =	3.12E-11	
CALIBRATED LEAK TEST FILE NO. =	1010lek1	
CALIBRATED LEAK ACCUMULATION TIME =	125	MIN
CALIBRATED LEAK PEAK RGA READING =	1.92E-10	

OUTGASSING RATE CORRECTION FACTOR =	9626.047	
OUTGASSING RATE FOR CHAMBER =	8.46E-10	TL/S

CHAMBER BACKGROUND OUTGASSING RATE CALCULATION

CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
BACKGROUND TEST FILE NO. =	1013bkg.1	
BACKGROUND ACCUMULATION TIME =	916	MIN
BACKGROUND ACCUMULATION PEAK RGA READING =	2.73E-10	
CALIBRATED LEAK TEST FILE NO. =	1013lek.1	
CALIBRATED LEAK ACCUMULATION TIME =	66	MIN
CALIBRATED LEAK PEAK RGA READING =	1.19E-10	

OUTGASSING RATE CORRECTION FACTOR =	8200.422	
OUTGASSING RATE FOR CHAMBER =	8.26E-10	TL/S

CHAMBER BACKGROUND OUTGASSING RATE CALCULATION

CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
BACKGROUND TEST FILE NO. =	BK1222A.2	
BACKGROUND ACCUMULATION TIME =	40	MIN
BACKGROUND ACCUMULATION PEAK RGA READING =	1.70E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1222B.2	
CALIBRATED LEAK ACCUMULATION TIME =	7	MIN
CALIBRATED LEAK PEAK RGA READING =	1.65E-11	

OUTGASSING RATE CORRECTION FACTOR =	6272.682	
OUTGASSING RATE FOR CHAMBER =	9.02E-10	TL/S

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH 23-11b & BLACK-1	
NO OF COUPONS =	99	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	CP1213A.2	
COUPON ACCUMULATION TIME =	41	MIN
COUPON ACCUMULATION PEAK RGA READING =	6.74E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1213A.2	
CALIBRATED LEAK ACCUMULATION TIME =	34	MIN
CALIBRATED LEAK PEAK RGA READING =	6.10E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	8241.159	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	4.58E-09	TL/S
COUPON OUTGASSING =	3.71E-09	TL/S
COUPON OUTGASSING RATE =	1.43E-13	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH 23-11b & BLACK-1	
NO OF COUPONS =	99	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	CP1212B.1	
COUPON ACCUMULATION TIME =	40	MIN
COUPON ACCUMULATION PEAK RGA READING =	6.54E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1213A.2	
CALIBRATED LEAK ACCUMULATION TIME =	34	MIN
CALIBRATED LEAK PEAK RGA READING =	6.10E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	8241.159	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	4.56E-09	TL/S
COUPON OUTGASSING =	3.69E-09	TL/S
COUPON OUTGASSING RATE =	1.42E-13	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH 23-11b & BLACK-1	
NO OF COUPONS =	99	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	COU1212.2	
COUPON ACCUMULATION TIME =	40	MIN
COUPON ACCUMULATION PEAK RGA READING =	6.74E-11	
CALIBRATED LEAK TEST FILE NO. =	LEK1212.2	
CALIBRATED LEAK ACCUMULATION TIME =	17	MIN
CALIBRATED LEAK PEAK RGA READING =	3.50E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	7181.581	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	4.09E-09	TL/S
COUPON OUTGASSING =	3.22E-09	TL/S
COUPON OUTGASSING RATE =	1.24E-13	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH	23-11c &75-11c
NO OF COUPONS =	95	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	CP1219a.2	
COUPON ACCUMULATION TIME =	50	MIN
COUPON ACCUMULATION PEAK RGA READING =	5.75E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1219a.1	
CALIBRATED LEAK ACCUMULATION TIME =	20	MIN
CALIBRATED LEAK PEAK RGA READING =	4.75E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	6225.519	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.42E-09	TL/S
COUPON OUTGASSING =	1.55E-09	TL/S
COUPON OUTGASSING RATE =	6.21E-14	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH	23-11c &75-11c
NO OF COUPONS =	95	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	CP1219b.2	
COUPON ACCUMULATION TIME =	60	MIN
COUPON ACCUMULATION PEAK RGA READING =	6.12E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1219b.2	
CALIBRATED LEAK ACCUMULATION TIME =	25	MIN
CALIBRATED LEAK PEAK RGA READING =	5.16E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	7163.57	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.47E-09	TL/S
COUPON OUTGASSING =	1.60E-09	TL/S
COUPON OUTGASSING RATE =	6.41E-14	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH	23-11c &75-11c
NO OF COUPONS =	95	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	CP1219c.2	
COUPON ACCUMULATION TIME =	93	MIN
COUPON ACCUMULATION PEAK RGA READING =	7.70E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1219c.2	
CALIBRATED LEAK ACCUMULATION TIME =	40	MIN
CALIBRATED LEAK PEAK RGA READING =	7.48E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	7906.743	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.21E-09	TL/S
COUPON OUTGASSING =	1.34E-09	TL/S
COUPON OUTGASSING RATE =	5.38E-14	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	CALTECH	23-11c &75-11c
NO OF COUPONS =	95	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	CP1220a.2	
COUPON ACCUMULATION TIME =	60	MIN
COUPON ACCUMULATION PEAK RGA READING =	5.65E-11	
CALIBRATED LEAK TEST FILE NO. =	LK1220a.2	
CALIBRATED LEAK ACCUMULATION TIME =	35	MIN
CALIBRATED LEAK PEAK RGA READING =	6.33E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	8.70E-10	TL/S
OUTGASSING RATE CORRECTION FACTOR =	8175.297	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.6E-09	TL/S
COUPON OUTGASSING =	1.73E-09	TL/S
COUPON OUTGASSING RATE =	6.94E-14	TL/S-CM2

SECTION 2.H.4 APPENDICES

CHAMBER BACKGROUND OUTGASSING RATE CALCULATION

CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
BACKGROUND TEST FILE NO. =	223bkg12	
BACKGROUND ACCUMULATION TIME =	60	MIN
BACKGROUND ACCUMULATION PEAK RGA READING =	2.27E-11	
CALIBRATED LEAK TEST FILE NO. =	223lk	
CALIBRATED LEAK ACCUMULATION TIME =	18	MIN
CALIBRATED LEAK PEAK RGA READING =	2.44E-11	

OUTGASSING RATE CORRECTION FACTOR =	10907.42	
OUTGASSING RATE FOR CHAMBER =	1.40E-09	TL/S

:ER BACKGROUND OUTGASSING RATE CALCULATION

CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
BACKGROUND TEST FILE NO. =	223bkg2	
BACKGROUND ACCUMULATION TIME =	40	MIN
BACKGROUND ACCUMULATION PEAK RGA READING =	1.65E-11	
CALIBRATED LEAK TEST FILE NO. =	223lk	
CALIBRATED LEAK ACCUMULATION TIME =	25	MIN
CALIBRATED LEAK PEAK RGA READING =	3.30E-11	

OUTGASSING RATE CORRECTION FACTOR =	11201.22	
OUTGASSING RATE FOR CHAMBER =	1.56E-09	TL/S

CHAMBER BACKGROUND OUTGASSING RATE CALCULATION

CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
BACKGROUND TEST FILE NO. =	223bkg22	
BACKGROUND ACCUMULATION TIME =	30	MIN
BACKGROUND ACCUMULATION PEAK RGA READING =	1.37E-11	
CALIBRATED LEAK TEST FILE NO. =	223lk22	
CALIBRATED LEAK ACCUMULATION TIME =	8	MIN
CALIBRATED LEAK PEAK RGA READING =	1.22E-11	

OUTGASSING RATE CORRECTION FACTOR =	9695.481	
OUTGASSING RATE FOR CHAMBER =	1.50E-09	TL/S

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	HEAT 115299B/C1
NO OF COUPONS =	110
AREA OF EACH COUPON =	263 CM2
CALIBRATED LEAK SIZE =	5.00E-09 TL/S
VOLUME OF SYSTEM =	20.29 L
COUPON TEST FILE NO. =	221COU2
COUPON ACCUMULATION TIME =	60 MIN
COUPON ACCUMULATION PEAK RGA READING =	4.47E-11
CALIBRATED LEAK TEST FILE NO. =	221LK2
CALIBRATED LEAK ACCUMULATION TIME =	30 MIN
CALIBRATED LEAK PEAK RGA READING =	4.63E-11
CHAMBER BACKGROUND OUTGASSING RATE =	1.50E-09 TL/S
OUTGASSING RATE CORRECTION FACTOR =	9580.308
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.41E-09 TL/S
COUPON OUTGASSING =	9.14E-10 TL/S
COUPON OUTGASSING RATE =	3.16E-14 TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	heat 115299b/c1	
NO OF COUPONS =	110	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	221cou12	
COUPON ACCUMULATION TIME =	65	MIN
COUPON ACCUMULATION PEAK RGA READING =	5.35E-11	
CALIBRATED LEAK TEST FILE NO. =		
CALIBRATED LEAK ACCUMULATION TIME =	30	MIN
CALIBRATED LEAK PEAK RGA READING =	4.76E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	1.50E-09	TL/S
OUTGASSING RATE CORRECTION FACTOR =	9318.661	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.59E-09	TL/S
COUPON OUTGASSING =	1.09E-09	TL/S
COUPON OUTGASSING RATE =	3.78E-14	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	heat 115299b/c1
NO OF COUPONS =	110
AREA OF EACH COUPON =	263 CM2
CALIBRATED LEAK SIZE =	5.00E-09 TL/S
VOLUME OF SYSTEM =	20.29 L
COUPON TEST FILE NO. =	222cou12
COUPON ACCUMULATION TIME =	65 MIN
COUPON ACCUMULATION PEAK RGA READING =	4.54E-11
CALIBRATED LEAK TEST FILE NO. =	222lk11
CALIBRATED LEAK ACCUMULATION TIME =	30 MIN
CALIBRATED LEAK PEAK RGA READING =	4.36E-11
CHAMBER BACKGROUND OUTGASSING RATE =	1.50E-09 TL/S
OUTGASSING RATE CORRECTION FACTOR =	10173.58
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.4E-09 TL/S
COUPON OUTGASSING =	9.03E-10 TL/S
COUPON OUTGASSING RATE =	3.12E-14 TL/S-CM2

NOTE: this outgassing test was accomplished with the pumping system continuing to evacuate the system. All other tests were run with the pumps isolated from the system.

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	073524(1D.C3)	
NO OF COUPONS =	110	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	305COU2	
COUPON ACCUMULATION TIME =	60	MIN
COUPON ACCUMULATION PEAK RGA READING =	5.40E-11	
CALIBRATED LEAK TEST FILE NO. =	305LK2	
CALIBRATED LEAK ACCUMULATION TIME =	20	MIN
CALIBRATED LEAK PEAK RGA READING =	3.95E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	1.50E-09	TL/S
OUTGASSING RATE CORRECTION FACTOR =	7486.384	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.28E-09	TL/S
COUPON OUTGASSING =	7.78E-10	TL/S
COUPON OUTGASSING RATE =	2.69E-14	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	073524(1D C3)	
NO OF COUPONS =	110	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	305COU12	
COUPON ACCUMULATION TIME =	60	MIN
COUPON ACCUMULATION PEAK RGA READING =	5.49E-11	
CALIBRATED LEAK TEST FILE NO. =	305LK12	
CALIBRATED LEAK ACCUMULATION TIME =	36	MIN
CALIBRATED LEAK PEAK RGA READING =	6.53E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	1.50E-09	TL/S
OUTGASSING RATE CORRECTION FACTOR =	8151.331	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.52E-09	TL/S
COUPON OUTGASSING =	1.02E-09	TL/S
COUPON OUTGASSING RATE =	3.53E-14	TL/S-CM2

COUPON OUTGASSING RATE CALCULATION

SAMPLE DESIGNATION =	073524(1D.C3)	
NO OF COUPONS =	110	
AREA OF EACH COUPON =	263	CM2
CALIBRATED LEAK SIZE =	5.00E-09	TL/S
VOLUME OF SYSTEM =	20.29	L
COUPON TEST FILE NO. =	305COU12	
COUPON ACCUMULATION TIME =	60	MIN
COUPON ACCUMULATION PEAK RGA READING =	5.49E-11	
CALIBRATED LEAK TEST FILE NO. =	305LK32	
CALIBRATED LEAK ACCUMULATION TIME =	30	MIN
CALIBRATED LEAK PEAK RGA READING =	5.51E-11	
CHAMBER BACKGROUND OUTGASSING RATE =	1.50E-09	TL/S
OUTGASSING RATE CORRECTION FACTOR =	8050.241	
OUTGASSING RATE FOR CHAMBER AND COUPONS =	2.49E-09	TL/S
COUPON OUTGASSING =	9.91E-10	TL/S
COUPON OUTGASSING RATE =	3.43E-14	TL/S-CM2