COMPONENT SPECIFICATION

TITLE

BEAM TUBE MODULE INSULATION

APPROVALS:		DATE	REV	DCN NO	BY	CHK	DCC	DATE
DRAWN:	WEA	8/13/97	A	E970128	n/a	n/a	n/a	n/a
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APPROVED:	FJR	8/22/97						
DCC RELEASE:								

1. Purpose

This document defines the requirements for beam tube module insulation materials and installation at the LIGO Livingston Observatory. Each beam tube module is to be covered with a continuous insulation blanket in accordance with this specification. The insulation is needed to reduce daily temperature variations of the beam tube, reduce sound (acoustic) transmission to the beam tube, and reduce heat loss during a 300 °F bakeout.

2. Applicable Documents

Beam Tube Module configuration drawings (from Chicago Bridge & Iron, Inc. (CBI), the beam tube fabrication and installation contractor):

Content	CBI Drawing No., Sheet No.	LIGO Drawing No.
Overall layout and module configuration	Drwg. 1, sh. 1-4	LIGO-D950031-06-B
Tube section (sub-assembly) configuration and dimensions	Drwg. 4, sh. 1-7	LIGO-D950034-07-B
Stiffener ring details	Drwg. 15, Drwg. 16	LIGO-D950040-05-B LIGO-D950041-06-B
Guided support configuration, details	Drwg. 19, sh. 1-2	LIGO-D950044-09-B
Fixed support configuration, details	Drwg. 6 Drwg. 7, sh. 1 Drwg. 8, sh. 1	LIGO-D950035-08-B LIGO-D950036-09-B LIGO-D950037-10-B
Pump port configuration Pump port with valve, port hardware	Drwg. 13 Drwg. 102, sh. 2	LIGO-D950039-03-B LIGO-D951303-01-B

Beam tube enclosure configuration drawings (from Parsons, the enclosure design contractor):

Content	Parsons Drawing No.	LIGO Drawing No.
Overall layout and enclosure configuration	LA-S-502 (SW arm) LA-S-502A (SE arm)	LIGO-D961236-00-O LIGO-D961237-00-O
Beam tube enclosure cross-sections	LA-S-503	LIGO-D961238-00-O

3. Description

The LIGO beam tube modules are stainless steel tubes under vacuum, approximately 49 inches (1.2 m) in diameter by approximately 6,500 feet (2 km) long. There are four such modules at each LIGO site. Each module consists of 50 sections of stainless steel tube with $^1/_8$ inch (3 mm) wall thickness, each approximately 130 feet (40 m) long, joined by stainless steel expansion joints (bellows) designed to accommodate the thermal expansion of the 40 m sections during a bakeout at 300 °F (150 °C). The tube sections are supported by structures designed to accommodate the thermal expansion and to minimize heat loss through the mechanical connections. The tube sections and expansion joints are welded together to form a continuous vacuum-tight tube. The ends of the 2 km long modules are terminated by large gate valves. There are seven 10 inch (25 cm) diameter pumping ports distributed at approximately 800 feet (250 m) intervals along the module. The beam tube is enclosed in a concrete protective cover with access doors at each pump port location (see Parsons LA-S-502, LA-S-502A, and LA-S-503 for details). There are also smaller emergency access doors midway between the pump ports. A road parallels the beam tube enclosure.

The beam tube module thermal insulation has been designed to reduce heat loss during the bakeout and to provide long-term thermal and acoustic insulation for the beam tube during LIGO operation. During bakeout, the beam tube is heated by passing DC current through the beam tube walls, using the electrical resistance of the wall material as the heating element. The installed insulation thickness must be highly uniform to avoid undesirable variations in the beam tube bakeout temperature.

The expansion joints compress during beam tube bakeout by nearly 4 inches (10 cm). In addition, they can expand as much as 1 inch (2.5 cm) due to ambient temperature variations (expansion amount depends on ambient temperature at the time of insulation installation). The insulation installation must provide for this motion.

The beam tube has been manufactured on precision equipment and is highly uniform. More than 90% of the beam tube module wall area consists of tubing $48^7/_8 \pm ^1/_8$ inches (1241 ±3 mm) in outside diameter (OD) with $^3/_{16}$ inch (5 mm) thick by $1^{13}/_{16}$ inch (4.6 cm) high stiffener rings installed at $29^1/_2 \pm ^1/_2$ inches (756 ±7 mm) intervals (see CBI Drwg. 4, sheets 1-7 and Drwgs. 15 and 16 for details and Drwg. 1, sheets 1-4 for overall layout). This precision manufacturing with tight tolerances means that pre-cut insulation material may be efficiently used. The insulation contractor is encouraged to adopt material preparation and installation procedures that take full advantage of this highly regular geometry.

There will be thermocouples and other bakeout monitoring instruments and associated wiring installed on the beam tube at the time insulation is installed. The thermocouples and wiring present minor variations in the otherwise smooth beam tube surface which are of no concern to the insulation installer. The instrument and wiring attachments are secure but require moderate care to avoid damage.

Prevention of leaks or potential leaks into the vacuum tube is of paramount importance. The stainless steel wall is subject to long-term stress-induced corrosion due to chemical attack. The chemicals in many glues and adhesives may promote corrosion (and could temporarily mask a small leak) and their use must therefore be carefully controlled. In addition, the use of any power tools inside the beam tube enclosure requires advance LIGO approval.

3.1 Site Conditions

Work area: A work space of approximately 4,000 square feet inside the site warehouse (see site map, Appendix B) is available for the contractor's use. The contractor is responsible for erecting a temporary barrier to contain loose particles and for clean up of the work space at the completion of the job.

Power: There is no electrical power available along the beam tube enclosure. The insulation contractor shall be responsible for providing temporary electrical power as needed to perform the insulation installation work.

Lighting: There is no lighting inside the beam tube enclosure. The insulation contractor shall be responsible for providing temporary lighting as needed to install the insulation.

Confined space: LIGO considers the beam tube enclosure to be a confined space. The contractor shall be responsible for furnishing adequate lighting and ventilation in the work area and providing for other safety considerations according to a safety plan submitted by the contractor and approved by LIGO.

Coordination of activities: The contractor is required to coordinate his activities with other contractors on site and with LIGO staff. The contractor shall not block the roadways at any time.

4. Requirements

The insulation consists of two layers of thermal insulation materials. The first (inner) layer is a fiber glass blanket material rated for 650 °F (343 °C). It complies with the requirements of ASTM-C-795 for controlling stress corrosion of stainless steel. The second (outer) layer is a fiber glass material with a Foil-Scrim-Kraft (FSK) moisture-barrier facing, rated for 250 °F (120 °C). The beam tube bellows (expansion joints) generate more heater power than the beam tube wall during bakeout, and so are insulated with only an outer layer. Special fitting of extra thickness of the inner layer material is needed at the fixed support locations. Specific requirements are provided in the following sections.

4.1 Materials

Inner layer: Knauf KN-75 or equivalent*, 0.75 lb/cu. ft. (12 kg/m^3) density, 3 inch (7.5 cm) thickness.

Outer layer: Knauf Duct Wrap or equivalent*, with an FSK vapor barrier jacket, 0.75 lb/cu. ft. (12 kg/m^3) density, 3 inch (7.5 cm) thickness. The FSK jacket shall include a 2 inch (5 cm) flange

Vapor barrier sealing material: FSK or other material suitable for maintaining the vapor barrier at discontinuities in the outer layer FSK jacket, rated for service at 150 F (65 C) or higher.

Attachment bands: Kraft paper, 3 in. width, or equivalent*, rated for service at 150 °F (65 °C) or higher.

Aluminum foil tape, pressure sensitive: Shall be rated for service at 150 °F (65 °C) or higher.

**Proposed equivalents must be preapproved by the LIGO Project. Appendix A lists important characteristics of the insulation materials. Data on these characteristics for any proposed alternate must be submitted with any request for approval of a material substitution.*

4.2 Installation

4.2.1 General requirements

- All materials shall be installed in accordance with best industry practices by skilled workmen regularly engaged in this type of work.
- All materials shall be installed in accordance with manufacturers' recommendations, applicable building codes and industry standards.
- The contractor shall be responsible for obtaining any required permits and arranging any required inspections.
- Only the inner layer insulation material shall be placed in contact with the beam tube wall and stiffener rings. No other materials may be applied to the beam tube surfaces. No welded, adhesive or spray glue attachments to the beam tube are permitted (note that these attachments are permitted on the support structures.

4.2.1.1 Inner layer:

- The inner layer shall be fitted firmly against the beam tube wall. The inner layer is permitted to have gaps at the butt joints or between adjacent wraps where the smallest dimension of the gap is not greater than $^3/_8$ inch (1 cm).
- The inner layer shall be secured in place with bands installed on 15 inch (30 cm) centers, at the $^1/_4$ and $^3/_4$ points between stiffener ring pairs.
- After installation, the insulation material loft shall not be reduced in thickness (including local compression under the attachment bands) by more than 0.25 inch (6 mm).
- Material shall not sag at the bottom by more than 1 inch (2.5 cm).
- Installation of the inner layer shall be inspected and accepted by a LIGO representative prior to installing the outer layer.

4.2.1.2 Outer layer:

- Edges of adjacent wraps and ends of each wrap shall be firmly butted together.
- Avoid placing butt joints over the joints or gaps of the inner layer.
- Secure in place with pressure sensitive aluminum foil tape.
- After installation, the insulation material shall not be reduced in thickness by more than 0.25 inch (6 mm).
- Material shall not sag at the bottom by more than 1 inch (2.5 cm).

4.2.1.3 FSK vapor barrier

- The FSK vapor barrier shall form a continuous unbroken moisture and vapor seal over the entire length of the beam tube module; the vapor seal at the ends and at the pump ports shall be finished by LIGO.

- The FSK jacket flanges shall overlap the adjacent outer layer material and shall be sealed with pressure sensitive foil tape.
- The FSK jacket shall not contact the beam tube wall or stiffener rings to ensure that electrical isolation of the beam tube is maintained. The FSK layer is permitted to contact the guided support cables and fixed support legs.
- Foil tape may be used to patch small punctures or tears (up to 12 inch, 30 cm) in the FSK layer.

4.2.2 Location-specific requirements

4.2.2.1 Tube wall between stiffener rings

This region, making up more than 90% of the beam tube length, is illustrated in Figure 1 (see CBI Drwg. 4, sheets 1-7 and Drwgs. 15 and 16 for to-scale details).

- Each wrap of the inner layer shall consist of one piece, with the butt joint located on the roadway side of the beam tube, at least 20 degrees from vertical (top or bottom).
- Each wrap of the outer layer shall consist of one piece, with the butt joint located on the roadway side of the beam tube, at least 20 degrees from vertical, but at least 4 inches (10 cm) from the butt joint of the inner wrap.

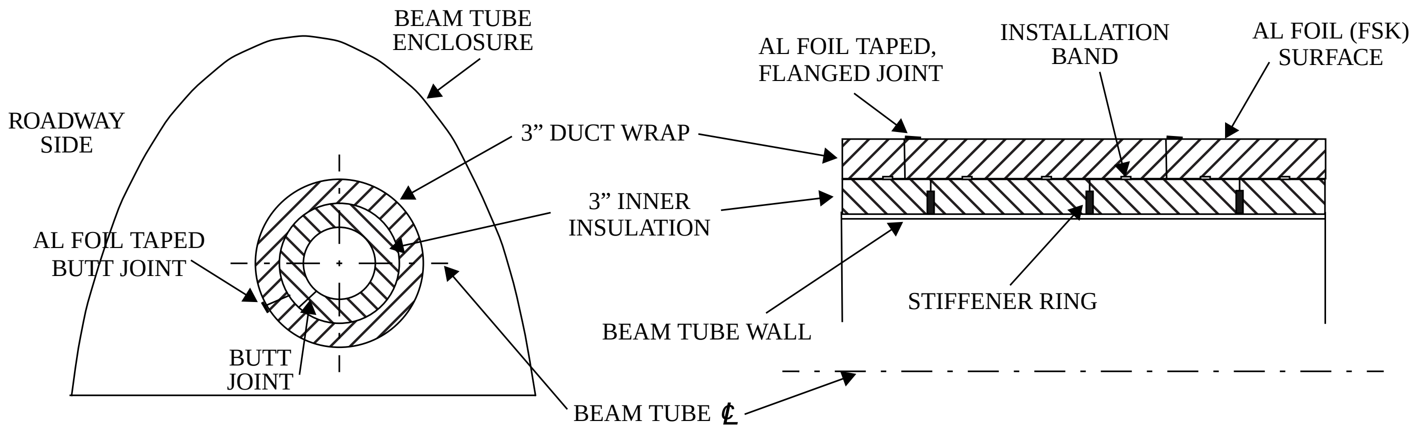

Figure 1: Beam tube wall insulation - schematic (not to scale) section views

4.2.2.2 Guided supports

Guided supports use four cable attachments to special 4 inch (10 cm) high stiffener rings on the beam tube (see CBI Drwg 19, sheets 1 and 2). Guided supports are used on each side of a bellows (expansion joint) unit, with pairs located at approximately 130 foot (40 m) intervals. There are 50 guided support pairs on each 2 km long beam tube module. Stiffener ring spacing in this area differs from the regular spacing on the main part of the beam tube.

- The inner layer shall be installed as at the tube wall between stiffener rings, but slit at the guided support attachment points (see Figure 2) and stuffed around the attachment bracket (see CBI Drwg. 19).
- The outer layer shall be installed as at the tube wall between stiffener rings, but slit and installed around the guided support cables.

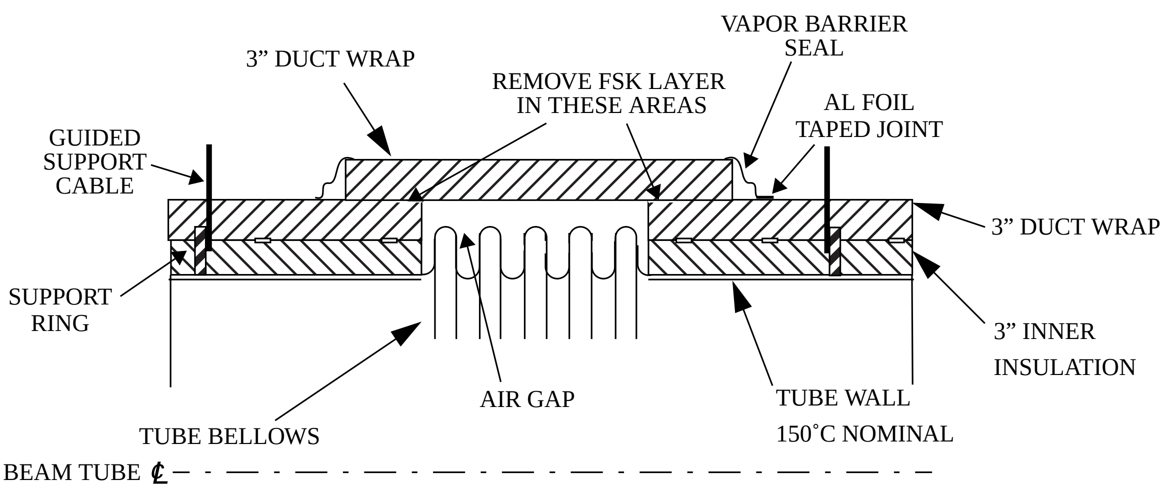

Figure 2: Schematic illustration of insulation installation at guided supports and bellows

4.2.2.3 Bellows (expansion joints) area

The bellows-area insulation forms an expansion joint for the insulation and FSK vapor barrier, to accommodate the expansion (1 inch, 2.5 cm) and compression (4 inches, 10 cm) of the bellows.

- The inner and outer layers shall stop not more than 2 inches (5 cm) from the outermost convolution of the bellows (see Figure 2), on each side of the bellows.
- The outer layer FSK jacket shall be removed 8 inches (20 cm) from the outermost convolution, each side.
- The region over the convolutions shall be covered by a single 4 foot (1.25 m) wide wrap of outer layer material, installed to slide over the outer layer to accommodate the compression of the bellows.
- The ends of the wrap over the convolutions shall be sealed to the outer layer with FSK vapor barrier material and/or aluminum foil tape, with allowance for 2 inches (5 cm) of motion at each end.

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4.2.2.4 Fixed supports

The beam tube is attached to the fixed supports at special 4 inch (10 cm) high stiffener rings, with attachment flange pairs spaced apart by Micarta insulating mounts (see CBI Drwgs 6, 7 and 8).

- The regions between attachment flanges at the Micarta insulators (3 places at each fixed support) shall be stuffed with inner insulation material.
- Two additional 48 inch (1.25 m) wide wraps of the outer layer material shall be installed on each side of the fixed support stiffener rings (see Figure 3).

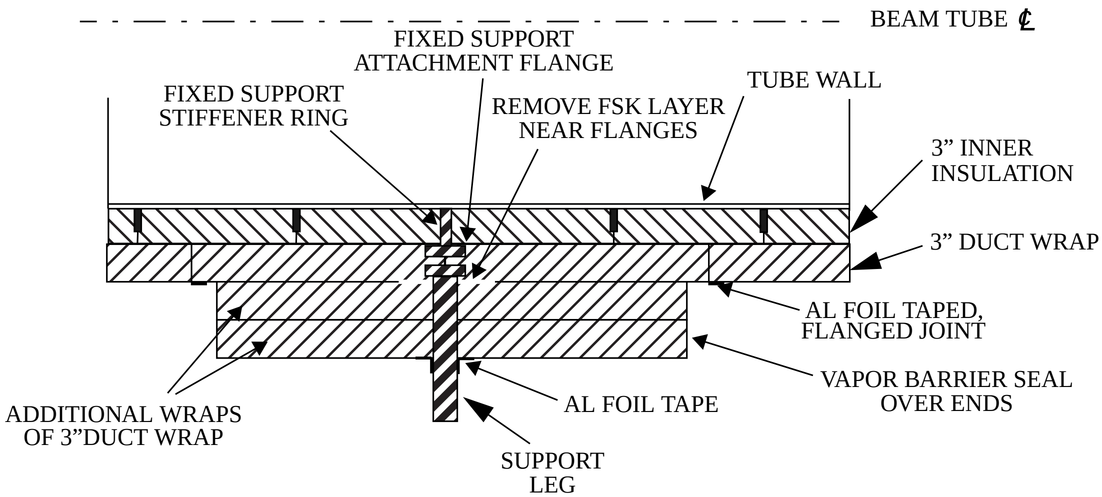

Figure 3: Schematic illustration of insulation at fixed supports

- The innermost wraps of material shall have butt joints located at the bottom of the tube because of a gusset located there.
- The FSK jacket shall be removed within 8 inches (20 cm) of the support attachment flanges and lower gusset to ensure electrical isolation of the FSK layer from the beam tube. It is not necessary to isolate the FSK layer from the support legs and brackets.
- Additional inner insulation material shall be added as needed to fully embed the support attachments. The volume within 6 inches (15 cm) of the attachment flanges shall be free of significant voids.
- The outer layers shall be fitted around penetrations at the support legs and brackets and secured so that air gaps between the layers are minimized and air circulation paths to the outside are blocked.
- The ends of the two additional wraps of outer layer material shall be sealed with FSK vapor barrier material and/or aluminum foil tape, and the outermost FSK layer shall be sealed at all fixed support penetrations will aluminum foil tape, both to block air circulation paths and to resist encroachment by insects and small animals.

4.2.2.5 Pump ports

- At seven pump ports located at the access doors along the beam tube module, the inner and outer layers shall be installed as at the tube wall between stiffener rings, but cut away to allow for the port penetration (see Figure 4; CBI Drwgs. 13 and 102 contains to-scale details).

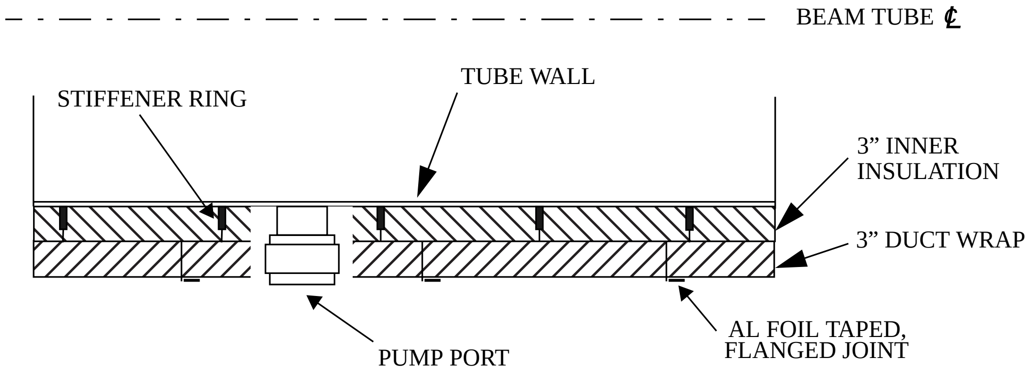

Figure 4: Schematic illustration of insulation at pump ports

- An air gap up to 3 inches (7.5 cm) around the port is acceptable.
- LIGO will be responsible for completing the FSK vapor barrier seal at the pump ports.

4.2.2.6 Module ends

- At each end of the beam tube module, the beam tube exits the concrete beam tube enclosure and penetrates the adjacent building wall.
- The insulation shall stop at the 4 inch (10 cm) high stiffener ring nearest the beam tube termination. LIGO will be responsible for completing the vapor barrier seal at the ends of the module.

4.3 Clean up

The contractor shall remove all debris and scraps of insulation material from the job site.

5. Quality assurance

- The contractor shall furnish suppliers’ certifications of compliance to specifications for all purchased materials installed on the beam tube.
- Installation of the inner layer shall be subject to inspection by a LIGO representative before the outer layer is applied.

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BEAM TUBE MODULE INSULATION

APPENDIX A

SALIENT CHARACTERISTICS OF INSULATION MATERIAL

Characteristic	Material Selection Criteria	
	Inner layer	Outer layer
Temperature rating	>400 °F (200 °C)	>235 °F (112 °C)
Thermal conductivity	<0.7 BTU in/hr ft^2 °F @ 300 °F (0.1 W/m-K @ 150 °C) <0.33 BTU in/hr ft^2 °F @ 125 °F (0.05 W/m-K @ 50 °C)	
Sound absorption	Total for two layers, 6 inches: >70% @ 125 Hz >95% @ 250 Hz >99.5% @ 500 Hz >99.9% @ 1000 Hz	
Density, compressive strength		
Available thickness and width	Obtain 6 inches with two layers	
Water vapor transmission (ASTM-E-96)		<0.02 perm
Puncture resistance (ASTM-D-781)		>25 Beach units
Stress corrosion compatibility (ASTM C 795)	Complies	Complies
Moisture absorption (ASTM-C-1104)	<5% after 96 hrs at 120 °F, 95% RH	
Mold growth resistance (ASTM-C-665)	Does not promote or sustain growth	

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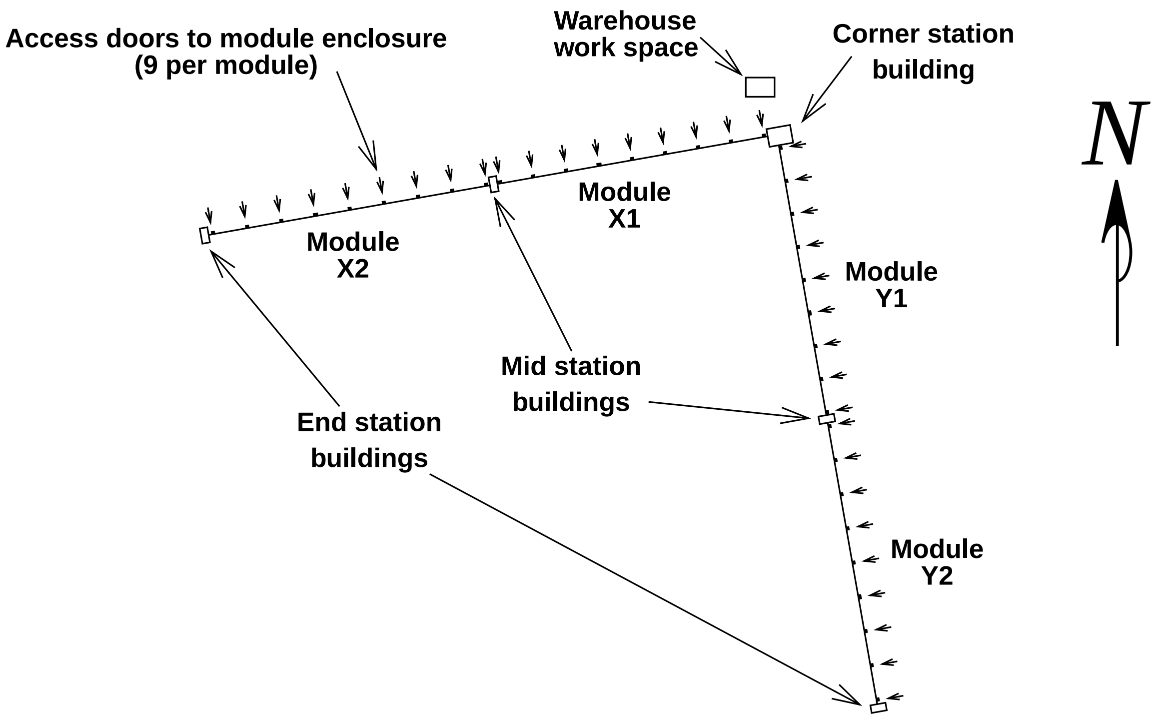
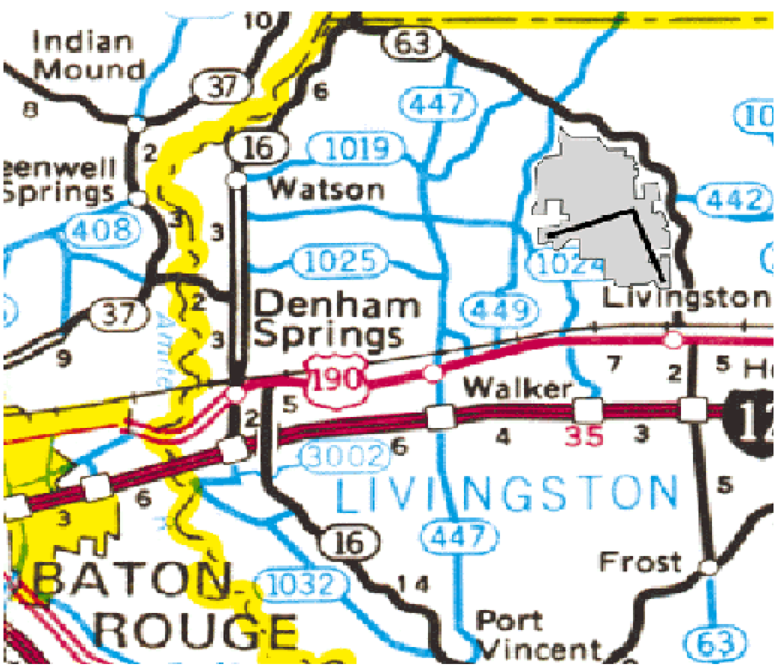
APPENDIX B: SITE MAP (not to scale)





DIRECTIONS

From I-12, approximately 25 miles east of Baton Rouge

- Exit at Livingston/Frost, Exit 22
- North on SR 63 to US 190
- West on US 190 ~.25 mi to SR 63
- North on SR 63 ~3 mi to LIGO sign
- Left on LIGO road, ~1.5 mi to Corner Station