BEAM TUBE MODULE SPECIFICATION

LIGO Specification 1100004

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CALIFORNIA INSTITUTE OF TECHNOLOGY
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LIGO PROJECT

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1. SCOPE

This specification defines the technical requirements for the design, qualification, fabrication, installation, and acceptance testing of the LIGO (Laser Interferometer Gravitational-Wave Observatory) Beam Tube Modules.

The LIGO includes two installations at widely separated sites, called Site 1 and Site 2, in the U.S. Each installation includes laser interferometers in an L shape with 4-km long arms, a vacuum system for the sensitive interferometer components and optical beams, and other support facilities. The beam tube modules, each 2-km long, provide the vacuum environment for the optical beams along the 4-km length of each arm (see Figure 1), and interconnect stations which provide access to the vacuum system. There are four beam tube modules at each site.

The beam tube modules are terminated at each end by a valve and pump set assembly (see Figure 2), furnished and installed under separate contract. Each module has seven equally spaced pumping ports with valves, for future pump installation. Baffles are installed in the tube to control stray light. The Site 1 and Site 2 installations are slightly different; the beam tube modules are longer at Site 2 because there are no mid station buildings at that site.

Beam tube modules are installed on a foundation slab furnished under separate contract (see Figure 3). Expansion joints and tube supports are included as required. The beam tube modules will be covered by a concrete enclosure. The tube will be insulated and baked out under vacuum during initial facility operations; insulating and baking are performed under separate contract.

Cleaning, alignment and leak checking are critical processes. Tube joints are welded, rather than flanged, to reduce leakage risk; internal access after installation is not required. Vacuum level during operation is nominally 10^{-9}–10^{-10} torr.

2. APPLICABLE DOCUMENTS

If more than one document applies to a technical requirement, the more stringent standard shall have precedence. Requirements set forth in this specification shall have final precedence.

2.1 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code

- Pressure Vessels, Section VIII, Division I
- Welding and Brazing Qualifications, Section IX

2.2 American Society of Civil Engineers

- Minimum Design Loads for Buildings and Other Structures, ASCE 7–88

2.3 American National Standards Institute

- Power Piping, ASME Code for Pressure Piping, ANSI B31.1 and B31.3

2.4 "Standards of Expansion Joint Manufacturer's Association", published by Expansion Joint Manufacturer's Association (EJMA)

2.5 Government Standards

- Building and safety codes: local, state, and federal, including OSHA

2.6 American Welding Society

- All applicable codes

2.7 LIGO Drawings

- Drawing 1101004, Baffle, Beam Tube, Edition 03–11–92, attached

2.8 LIGO Specifications

- Specification 1100007, Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products, dated April 5, 1993.

3. SYSTEM SPECIFICATION

3.1 Beam Tube Module Configuration Each beam tube module shall be approximately 2 km long as shown in Figure 2.

The ends of the beam tube modules shall be terminated with a joint that is either welded or flanged.

The installed beam tube shall meet the clear aperture requirement defined and specified in 3.2.2. The beam tube design shall include a means to check beam tube module alignment during LIGO operation.

3.1.1 Beam Tube Sections The beam tube modules shall be field assembled from factory built tube sections, with length limited by practical shipping considerations.

3.1.2 Expansion Joints Expansion joints shall be provided along the beam tube module to:

a. accommodate thermal expansion/contraction of the tube during bakeout (a minimum of 20 bakes at 140°C), and diurnal and seasonal temperature variations; and
b. aid alignment during installation and alignment adjustments during operation.

3.1.3 Pumping Ports Seven ports shall be installed, equally spaced at nominally 250 m, along each module. Each port shall consist of a 25 cm diameter tube port with metal seal flange, directed horizontally at a right angle to the beam tube axis. A gate valve with a blind flange shall be bolted to each pumping port.

3.1.4 Baffles Baffles per Drawing 1101004B (Edition 5–17–94) shall be installed within the tube in accordance with the spacing shown in Figure 2.

Baffle installation shall require no fastening; free design parameters, such as baffle thickness and unconstrained helix diameter shall provide sufficient friction and stability for secure positioning.

3.1.5 Beam Tube Supports The beam tube supports shall provide the following features:

a. support the tube, plus all applicable loads (note: tube may be exposed to wind and snow prior to enclosure installation);
b. allow thermal expansion/contraction of the tube during bakeout and during diurnal and seasonal temperature changes, without allowing relative motion between the support points and the tube (to prevent the occurrence of stick-slip, and its resulting impulsive mechanical or acoustic noise);
c. a convenient means of adjusting the alignment of the tubes at installation and after subsequent settling or shifting of the slab. An adjustment range of ± 7.5 cm in both the vertical and horizontal is required. Tube axis height above the nominal (mid variation range) slab plane shall be approximately 1.1 m; and,
d. adequate thermal insulation at points of support to limit calculated tube wall temperature differential to less than 10°C with a bulk tube wall temperature of 140°C (assuming heating by I^2R losses in tube wall; see Information for Potential Contractors, Section VI-C-3–b).

3.2 Performance Requirements

3.2.1 Leak Rate The helium leak rate into each beam tube component shall not exceed 1 x 10^{-10} atm cc/s. The helium leak rate into each beam tube module shall not exceed 1 x 10^{-9} atm cc/s.

3.2.2 Clear Aperture Each beam tube module shall have a minimum clear aperture of 1.07 m. Clear aperture is defined as the diameter of the cross section of a right circular cylinder between beam tube terminations, whose volume is unobstructed. The axis for the required clear aperture will be defined by Caltech relative to reference monuments at 250 m intervals. The contractor shall ensure that no part of the beam tube, including the baffles, intrudes into the clear aperture as located by the reference monuments, per Figure 4.

3.2.3 Outgassing Performance LIGO Specification 1100007, "Process Specification for Low Hydrogen, Type 304L Stainless Steel Vacuum Products", shall be employed for all surfaces exposed to vacuum.

3.3 Design Requirements

3.3.1 Structural Design System element design, fabrication, and inspection shall be in accordance with the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, as applicable, and its subsequent addenda (except as noted in 3.3.2 below), plus applicable portions of all other referenced standards.

System elements shall be designed to withstand the loadings exerted by insulation weight (assume 2.4 x 10^4 kg/km) and all other applicable loads in accordance with the provisions of all applicable codes and standards. To determine the probability of earthquakes and seismic coefficients in various areas of the United States, ASCE 7–88 (*Minimum Design Loads for Buildings and Other Structures*) shall be applied.

All vacuum seals shall be metal. Joints between sections of the beam tube shall be welded.

3.3.2 Welding All welding exposed to vacuum shall be done by the inert-gas, tungsten-arc welding process. Full penetration welds shall be used. The exterior of weld joints shall be exposed for access in applying helium gas for vacuum leak checks. All vacuum welds shall be, wherever practical, internal and continuous.

All vacuum weld procedures shall include steps to avoid contamination of the heat affected zone with air, hydrogen, or water. This requires that inert purge gas, such as argon, be used to remove unwanted gases over the vacuum side of heated sections. A particular concern is the welding of stiffening rings after tube formation; here, the heated inside of the tube shall be shielded with inert purge gas while welding.

3.3.3 Materials All materials used in the beam tube modules are subject to Caltech approval.

3.3.4 Surface Finish Tube wall material shall have an internal surface finish no smoother than 2.5 microns rms roughness. If stainless steel is used, HRAP (hot rolled, annealed, and pickled) surface is acceptable. Any alternate finish is subject to approval.

3.3.5 Design Life The contractor shall design the beam tube modules for a minimum life of 20 years.

3.3.6 Environmental The beam tube module shall be designed to withstand ambient conditions existing at the field sites. The modules will be covered by a concrete enclosure, installed one to three tube section lengths behind the beam tube installation. These enclosures, which are not the contractor's responsibility, will provide wind and precipitation shields, with minimal ventilation.

3.3.7 Cleaning Contamination on all surfaces exposed to vacuum shall be removed in accordance with procedures approved by Caltech prior to installation; surface recontamination shall be prevented during all subsequent processes.

All items shall be wrapped securely after cleaning to maintain cleanliness through handling, transportation, and storage. Care shall be taken to minimize exposure to corrosive environments, such as chloride compounds.

No visible contaminant material of any form shall be left inside the tube when installed (for example: water, dust, sand, hydrocarbon film, etc.).

4. RELIABILITY AND QUALITY ASSURANCE REQUIREMENTS

4.1 General

4.1.1 Test Plans Detailed plans (including descriptions of the test equipment and procedures) for the qualification, screening, and acceptance tests shall be approved by Caltech prior to use.

4.1.2 Control of Contamination Detailed plans to insure control of cleanliness shall be approved by Caltech.

4.2 Qualification Tests The contractor shall fabricate, assemble and test a representative Sub Assembly length consisting of two sections of beam tube and one expansion joint with related equipment in accordance with a procedure approved by Caltech, measuring the outgassing rates and demonstrating that leak rate and alignment requirements are met.

LIGO

4.3 Screening Tests

4.3.1 Material Sample Tests Measurements shall be made and documented on samples of material to be exposed to vacuum to confirm acceptable properties. No material to be exposed to vacuum shall be used for fabrication until its acceptability is assured.

Additional samples shall be taken from each processing lot of material to be exposed to vacuum and provided to Caltech in accordance with approved sizing, handling, and shipping procedures.

4.3.2 Beam Tube Section Leak Tests The contractor shall measure and document total helium leakage rates on each beam tube section as part of the fabrication process. No beam tube section shall be field installed without first demonstrating acceptable leakage.

4.3.3 Beam Tube Section Dimensional Tests The contractor shall measure and document each beam tube section to ensure that the clear aperture requirements in 3.2.2 will be met after field installation. No beam tube section shall be field installed without first demonstrating acceptable geometry.

4.4 Acceptance Tests The contractor shall measure and document total leakage rates on each installed beam tube module.

The contractor shall verify and document that the tube alignment complies with the clear aperture requirement in 3.2.2.

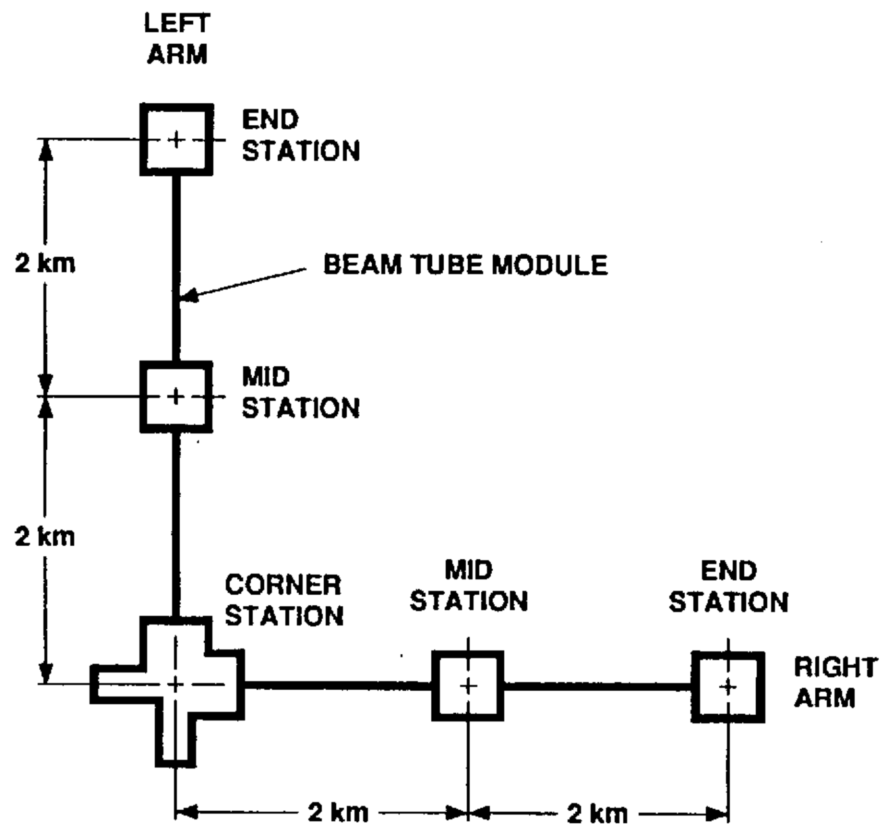

Figure 1. LIGO Geometry

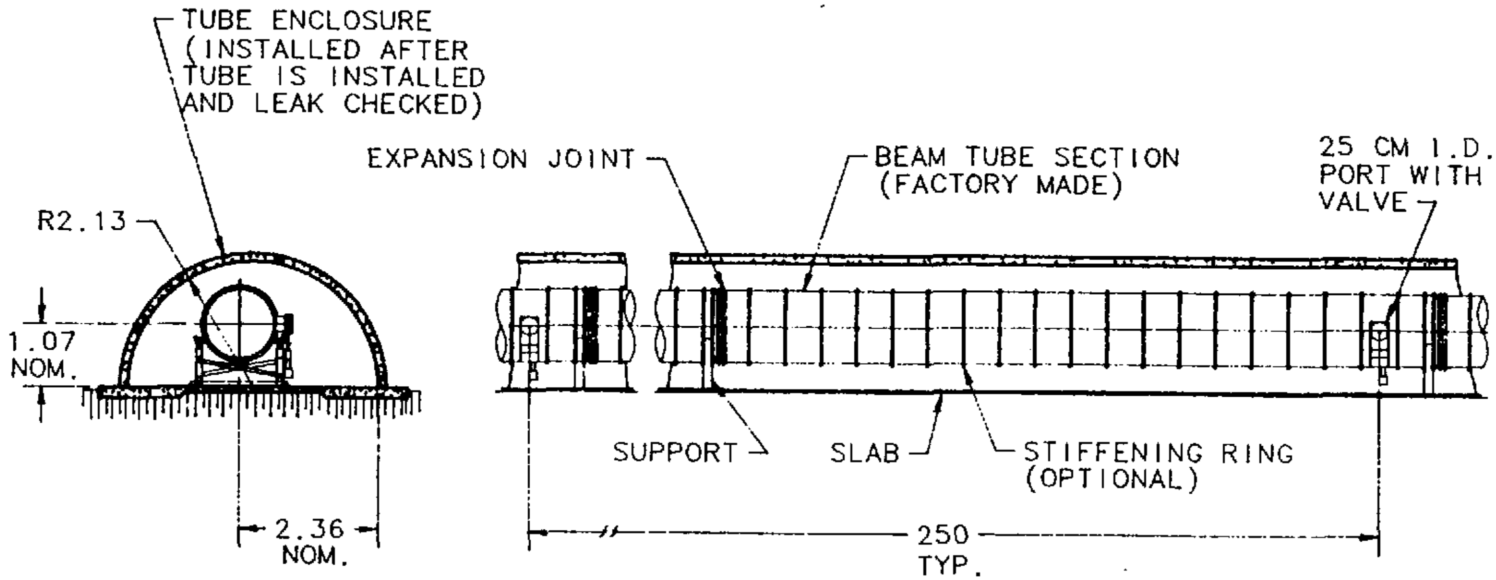

FIGURE 3 BEAM TUBE INSTALLATION

ALL LENGTHS ARE IN METERS

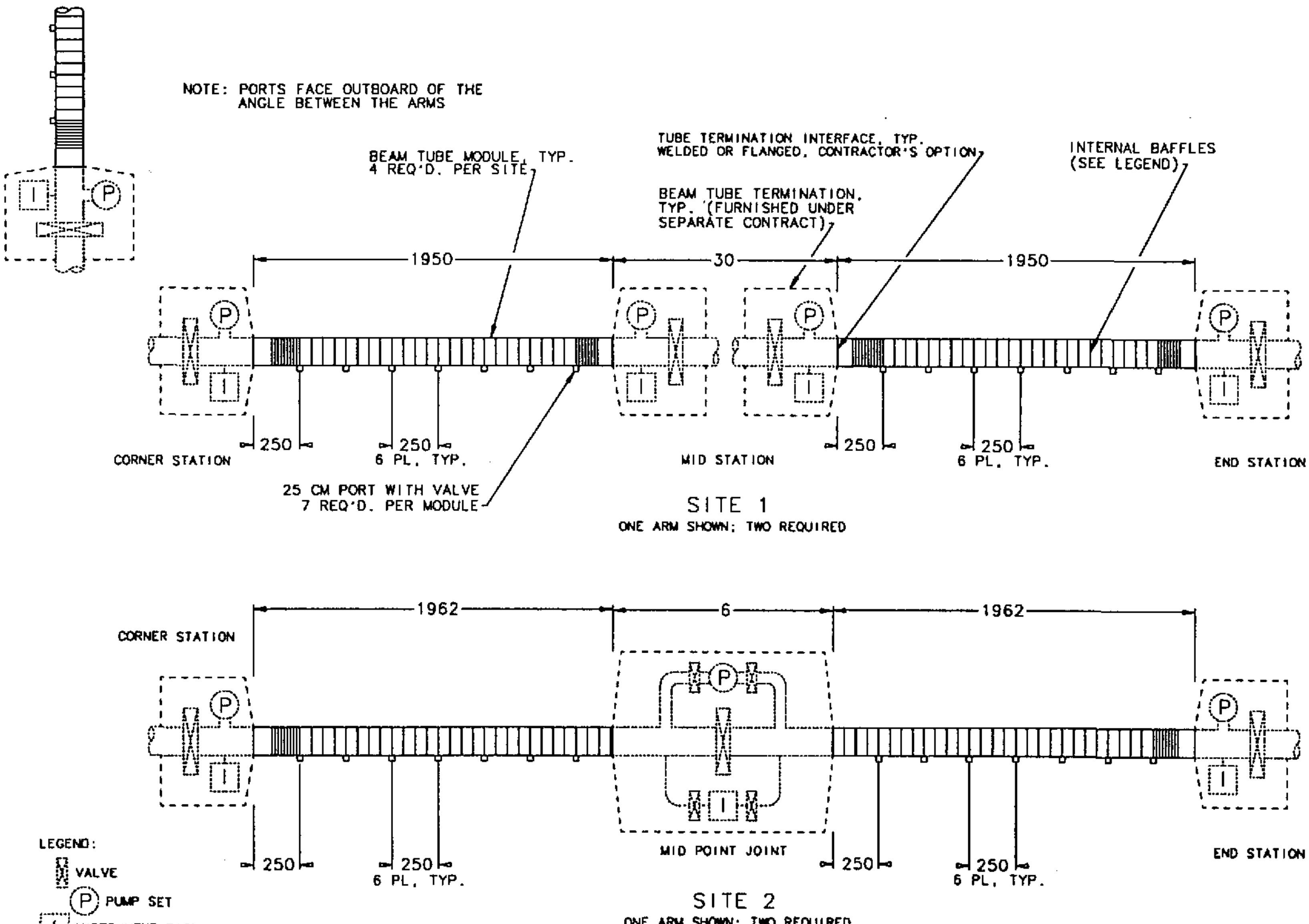

FIGURE 2 BEAM TUBE MODULE CONFIGURATION

NOT TO SCALE ALL LENGTHS ARE IN METERS

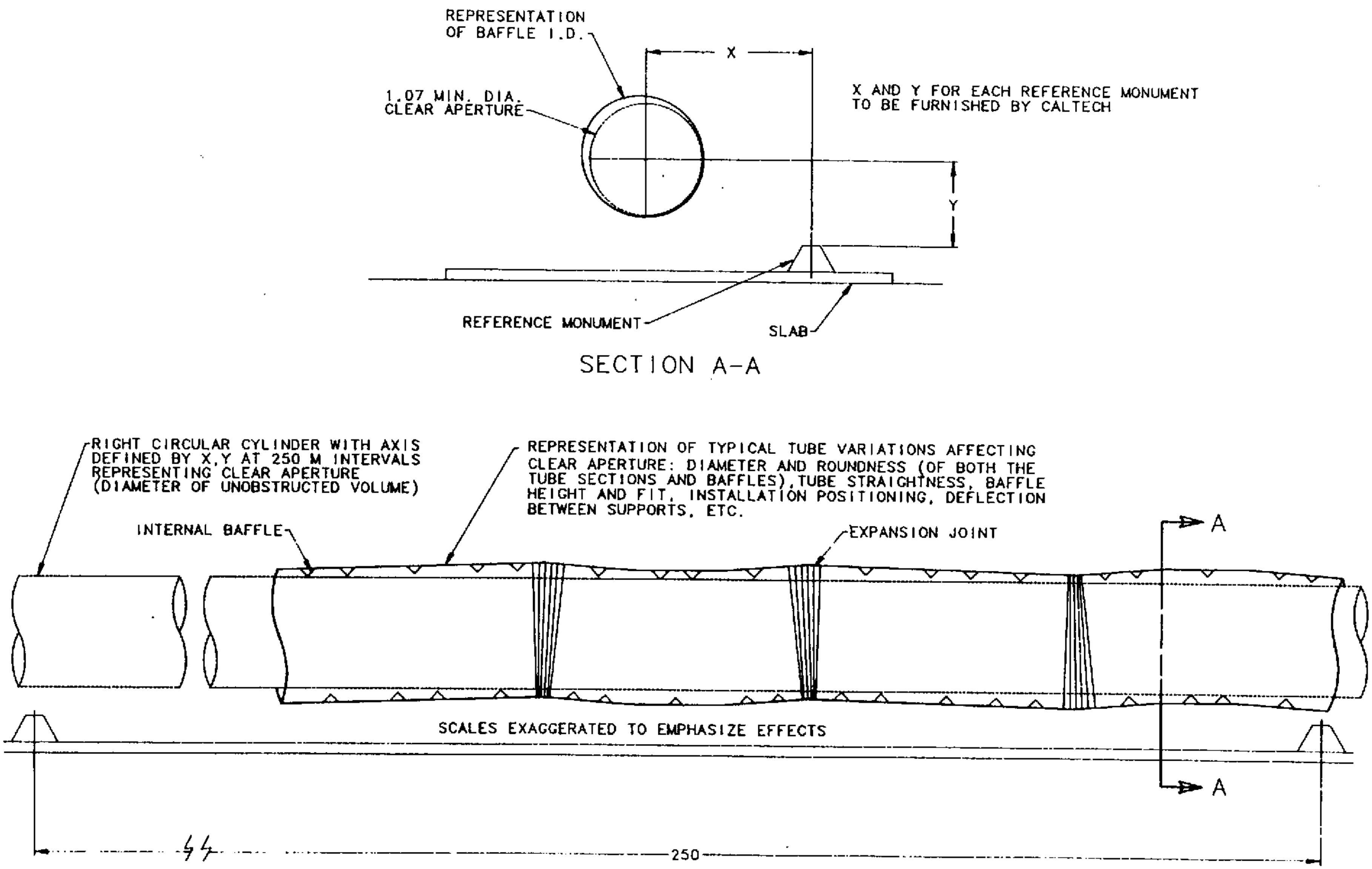

FIGURE 4 BEAM TUBE ALIGNMENT

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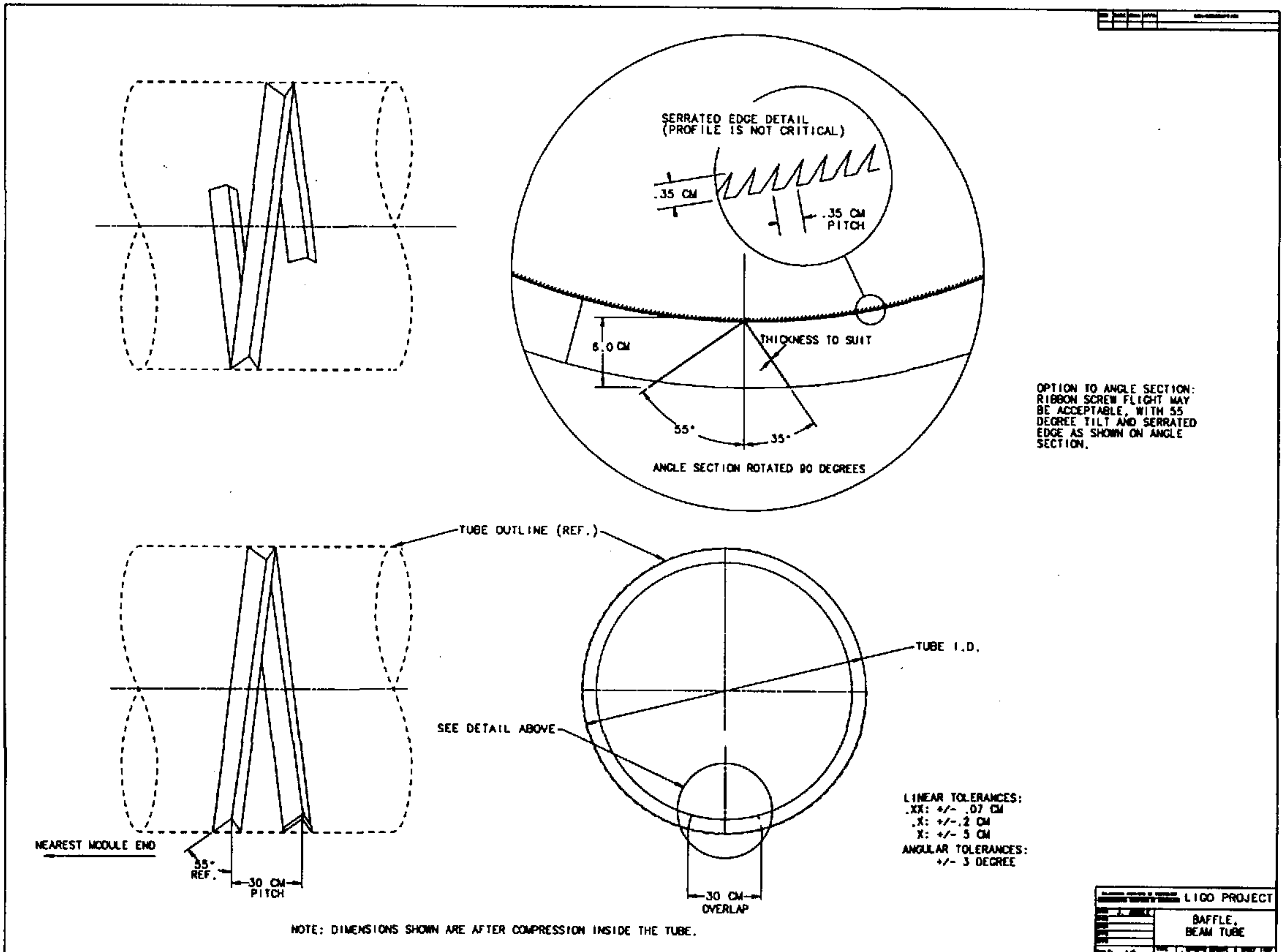

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