Quarterly Progress Report
(June 1995 - August 1995)

The Construction, Operation, and Supporting Research and Development of a Laser Interferometer Gravitational-Wave Observatory (LIGO)
NSF Cooperative Agreement No. PHY-9210038

September 1995

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THE CONSTRUCTION, OPERATION, AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

NSF COOPERATIVE AGREEMENT No. PHY-9210038

September 1995

CALIFORNIA INSTITUTE OF TECHNOLOGY

1.0 Contents

2.0 Introduction

This Quarterly Report is submitted under NSF Cooperative Agreement PHY-9210038[1]. The report summarizes Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from June 1, 1995 through August 31, 1995.

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[1] Cooperative Agreement No. PHY-9210038 between the National Science Foundation, Washington, DC 20550 and the California Institute of Technology, Pasadena, CA 91125, dated May 1992.

3.0 Executive Summary

During May 1995, the LIGO Project hosted a review by a panel of technical experts representing NSF. The focus of this review was the project management and related systems recently implemented in accordance with a major program milestone. A performance measurement baseline and the related management systems and reports were put in place in accordance with the proposed schedule. For the next review (scheduled in October 1995) we will have a history of data to demonstrate that the systems are being used and provide an effective management tool for monitoring and maintaining project cost and schedule.

Some need for improvement was noted in related management areas, specifically Subcontracts Management and Environment, Safety & Health (ES&H). LIGO Management agreed with this assessment and initiated efforts to bolster the affected systems. Specifically, Ed Jasnow was added as a Subcontracts Manager for Facilities at the end of the last quarter, and arrangements with JPL are in process that have resulted in the addition of QA and ES&H personnel to the LIGO team.

This reporting period has been and the next quarter will be pivotal for Facilities. The LIGO Project is in the process of issuing contracts for several major procurements including 1) the vacuum equipment, 2) the beam tube, and 3) the facilities design and construction.

In March two contractors were selected in accordance with the procurement plan for Phase A runoff for the Vacuum Equipment contract. The two contractors were Chicago Bridge and Iron (CBI) and Process Systems International (PSI). Each contractor presented a Preliminary Design at separate reviews held on June 26 and June 27. Technical, management, and cost volumes from the two contractors were evaluated. The Source Selection Board met on July 28, 1995. PSI was selected to proceed with the Final Design, Build and Install task (Phase B). Negotiations commenced early in August. The resulting procurement was presented to NSF at the end of August. The contract for Phase B will be placed with PSI in September 1995. The Preliminary Design Review update is scheduled for October 3, 1995. All significant Vacuum Equipment milestones in 1995 have been met on time and on budget.

The Beam Tube Qualification Test Review (QTR) was held on April 17 and 18, 1995 at Chicago Bridge and Iron (this is a separate contract from the Phase A effort on the Vacuum Equipment above). The QTR was judged to be a success and will provide a basis for initiating the fabrication and installation phase. CBI delivered a data package on May 26. An RFP for the Phase B Fabricate and Install task was issued on June 1 and a response was received from CBI on July 29, 1995. Negotiations are currently in progress. Negotiations are being conducted with the possibility of terminating negotiations and competing the Phase B task.

A Cost/Schedule Status Report (CSSR) as well as graphical reports that summarize cost and schedule performance as of the end of August are attached. These reports are based on the newly implemented performance measurement baseline and an assessment of work completed as of the end of August. A schedule status report is also attached depicting the current 'float' status of all major LIGO Project milestones.

4.0 Summary of Work Accomplished

4.1 Facilities and Vacuum System (WBS 1.1)

4.1.1 Vacuum Equipment (WBS 1.1.1)

In early March, two contractors, Chicago Bridge and Iron (CBI) and Process Systems International (PSI), were selected to participate in a three month design competition (Phase A of the Vacuum Equipment procurement). On June 26 and 27 the two contractors presented their preliminary designs. This was the end of the Phase A work. Both companies provided technically responsive proposals. Technical, management, and cost volumes from the two contractors were evaluated. The Source Selection Board met on July 28, 1995. PSI was selected to proceed with the Final Design, Build and Install task (Phase B), and both bidders were notified. Negotiations commenced early in August. The resulting procurement was presented to NSF at the end of August. The contract for Phase B will be placed with PSI in September 1995. The Preliminary Design Review update is scheduled for October 3, 1995. All significant milestones in 1995 have been met on time and on budget.

4.1.2 Beam Tube (WBS 1.1.2)

A request for proposal to fabricate and install the beam tube modules was issued to the beam tube contractor, Chicago Bridge & Iron (CBI) on May 24, 1995. CBI's response was received on July 21 and 29. The proposal has been evaluated and contract negotiations have begun. Negotiations are still in progress at the end of the quarter.

4.1.3 Beam Tube Enclosure (WBS 1.1.3)

The A-E Contractor, the Ralph M. Parsons Company, was authorized to proceed with the completion of the preliminary design for the Beam Tube Enclosure (BTE) for the Hanford site on June 5, 1995. The Preliminary Design Review (PDR) package was submitted to LIGO on August 14, 1995. It was reviewed by LIGO project management staff on August 25. Parsons was instructed to proceed with the completion of the final design for the BTE on August 28, 1995 incorporating the comments submitted by the LIGO Project. The present design is similar to the original base line and provides for personnel access to the Beam Tube. The Final Design Review package for the BTE is due on October 3, 1995. The preliminary cost estimate for the BTE design is within the LIGO budget.

4.1.4 Civil Construction (WBS 1.1.4)

The 90% Facility Concept Design for the Hanford site was submitted by the A-E contractor, the Ralph M. Parsons. The LIGO Project Management staff reviewed and provided comments by June 2, 1995. Parsons was directed to complete the final Facility Concept design for reducing and rescoping the size of the Laser Vacuum Equipment Area (LVEA) on June 5, 1995. The LVEA provides for two interferometers at the corner station and the Vacuum Equipment Areas (VEAs - mid and end stations) provide one each vacuum chamber (2-1-1 configuration) at the Hanford site. At the Livingston site, the LVEA provides room for two interferometers installation at the corner station and the VEA at the end station provides room for two vacuum chambers (2-0-2 configuration). The design will facilitate future expansion. Parsons completed the Final Concept Design with a cost estimate and submitted the package for approval on July 21, 1995. The LIGO project management staff approved the Final Concept Design and instructed Parsons to proceed with the Preliminary Design of the LIGO facility on Aug. 21, 1995.

A dedication was held at the Livingston, Louisiana site on July 6, 1995. At that time there was also a meeting between LIGO management and local labor representatives.

T. L. James completed the clearing and grubbing of the Livingston site on August 15, 1995 on schedule and within the approved budget. The Final Rough-Grading Design package for the Livingston site was completed by The Ralph M. Parsons Company. The package was reviewed and approved by LIGO management on August 14, 1995. The bid document for the rough grading was issued on August 30, 1995 and bids are expected late in September.

The ambient ground vibration measurements at the Hanford, Washington site were completed in June and a report has been issued. Negotiations with the electric utility companies to provide electricity to the Hanford site have also been completed with favorable costs projected for providing the needed site power.

4.2 Detector (WBS 1.2)

Detector activities are organized according to the LIGO WBS as follows:

WBS 1.2.1 Interferometer (IFO) System, which is organized into subsystems:

Seismic Isolation (SEI)
Suspension Design (SUS)
Prestabilized Laser (PSL)
Input/Output Optics (IOO)
Core Optics Components (COC)
Core Optics Support (COS)
Alignment Sensing/Control (ASC)
Length Sensing/Control (LSC)

WBS 1.2.2 Control and Data Systems (CDS)

WBS 1.2.3 Physical Environment Monitor (PEM) System

WBS 1.2.4 Support Equipment.

In addition, there is a Detector System Engineering/Integration (SYS) activity (WBS 1.2.1.9).

During the reporting period, detector design advanced on five fronts: technical subsystem design, development of interface structure between detector subsystems and between the detector and the LIGO facilities, formalization of flowdown of requirements from LIGO science objectives, initiation of detector design work that falls outside of subsystem boundaries, and prototype testing and development.

The advances in technical design included a review of the Suspensions (SUS) Design Requirements and approval by a review board. A Preliminary Design Review was held for the Prestabilized Laser (PSL).

The interfaces between subsystems are being systematically developed with a structure that will provide the basis for Interface Control Documents, the writing of which will start next quarter. We have developed standardized diagrammatic and nomenclature conventions to help assure that interfaces are complete and self-consistent. Identification of some of the more critical interfaces has resulted in design specifications; for example, examination of the interface between Seismic Isolation and Suspensions has led to a specification of the displacement range for the test mass actuators and sensors.

We have also made progress in developing the logical flowdown of subsystem requirements, starting with the scientific objectives of LIGO. This flowdown, which is being developed by Detector System Engineering/Integration (SYS), identifies sources of noise that are fundamental (such as Brownian motion) and non-fundamental (such as imperfect electronic amplifiers), and allocates the noise budget among subsystems to satisfy the science-driven requirements of sensitivity and "availability" (fraction of the time that LIGO is operating with a specified sensitivity).

The most critical interfaces between the detector and LIGO facilities have been specified. For example, the seismic isolation stack connects to the building via support pillars; an analysis of the required rigidity and available floor space has resulted in a specification of the footprint of these pillars.

There has been progress on two detector design initiatives that fall outside the original WBS subsystem structure: Interferometer Configuration and Optical Layout. The objective of the Interferometer Configuration effort is to analyze the coupled optical cavities that make up the detector, including the propagation of imposed phase modulation, and to specify critical parameters, such as recycling cavity length and modulation frequencies. There are preliminary results from this nascent effort. The Optical Layout development is also at an early stage. Its emphasis is on specifying the three-dimensional optical paths, including the selection of parameters such as test mass wedge angles, precise location of primary and secondary optics, and the detailed design of beam-expanding optics. To tap optical industry expertise and computer software, the Optical Layout effort is progressing with the assistance of an optical consulting firm.

There was significant experimental progress in the most developed of the detector systems, the Prestabilized Laser. A prototype similar in most respects to the planned LIGO PSL, including computer-controlled servoamplifiers, was successfully operated. This step included the first implementation of a self-contained subset of the CDS hardware and software that will be used in LIGO detectors. A rigorous test of the PSL subsystem will be conducted next quarter.

Activities under WBS 1.2.1 (Interferometer System) and 1.2.2 (Control and Data Systems) are detailed below. There are no activities planned during 1995 for WBS 1.2.3 (Physical Environment Monitor) and 1.2.4 (Support Equipment).

4.2.1 Interferometer Design Activities (IFO, WBS 1.2.1)

Seismic Isolation (SEI). Documentation of the requirements for the seismic isolation progressed, including the requirements imposed on isolation stack actuators, requirements relating to isolation performance, and constraints imposed by the interaction with other subsystems. The baseline design concept is being reviewed for possible weight reduction and control of internal resonances. Modeling efforts included creating a one-dimensional lumped mass model of a 4-stage isolation stack, with thermal noise, and an analysis of isolation performance as a function of isolator stage mass ratios.

Suspension Design (SUS). The SUS Design Requirements Review was held on June 8. The requirements, interfaces, and the conceptual design of the suspension subsystem were presented to a design review board, and conditionally approved, with recommended modifications. Fulfillment of action items identified in that review has started, and the SUS preliminary design started on July 6, as scheduled.

While designing a new suspension system for the 40 m interferometer (see R&D report), the design concept for the detector suspension was embodied and confirmed. Aside from scaling, the suspension systems for LIGO and the 40 m test masses will be essentially identical.

Prestabilized Laser (PSL). A preliminary design review of the PSL subsystem held in June included a presentation of the final PSL design requirements document, a preliminary design of the LIGO PSL, and a plan for testing of the PSL prototype. Feedback from the review has been incorporated. The PSL prototype test, a laboratory test of the LIGO PSL subsystem, is about to begin. This test will study the noise and availability performance of the PSL under varying environmental conditions, including vibration, acoustic, and temperature variations.

Input/Output Optics (IOO). A conceptual optical layout of the IOO has been generated for incorporation in the Optical Layout task. A rigorous calculation of the performance requirements of the Input Optics has been started. The IOO design requirements and conceptual design are scheduled for review in the first quarter of 1996.

Core Optics Components (COC). Activity on the COC "pathfinder" prototyping has progressed well. Two polishing technology demonstration contracts (to CSIRO, Sydney, Australia and HDOS, Danbury, CT) have been awarded and substrates have been shipped to them. In a parallel effort based on rapid best-effort production, test mass prototypes have been completed and delivered from polishing and coating vendors (General Optics and REO, respectively). Preliminary evaluation is proceeding on these samples.

The pathfinder coating development contract with REO is also progressing as scheduled. A plan to construct cleaning facilities at REO for LIGO size optics has been agreed upon, and optimization of a large coating facility chamber for LIGO optics is underway. Test sample mirrors produced in this chamber have scattering and absorption losses well within our specifications.

Several in-house tests to verify pathfinder performance are in progress, including measurements of mechanical Q and coating spatial uniformity, and the development of ultra-cleaning procedures.

In conjunction with a specialist hired as consultant, we are adopting a plan for the demanding metrology program necessary to verify the COC optical surfaces. Preparation of a COC design requirements document has proceeded to a draft form that specifies performance requirements and interface definitions.

Alignment Sensing/Control (ASC). Several internal milestones for the ASC were achieved in this quarter. The basic sensing system for the Initial Alignment, using a combination of diode arrays to get the beam down the tube and CCD cameras for the approach to acquisition alignment, has been selected and documented. The Centering System requirements, basic sensors, and sequences were developed and documented. A draft of interfaces to the overall ASC system was drawn up.

The Wavefront Sensing system underwent both modeling and hardware design development through interaction with the Interferometer Configuration task and through common effort with the R&D Wavefront task. This will support the Detector Wavefront prototype and test sequence (planned for FY 96 and 97).

A new responsible mechanical engineer for the Optical Lever subsystem started late in the quarter, with the first goal to develop a new plan and schedule. A task duration of roughly 9 months is targeted, which will leave the delays encountered to date with no impact on other subsystems of the ASC or on the overall Detector.

Length Sensing/Control (LSC). The work this quarter was focused on developing code that simulates the locking of two coupled suspended Fabry-Perot cavities. This problem was given a high priority since many of the control system issues that appear in the coupled cavity configuration are similar to those expected for a recombined/recycled interferometer.

Last quarter we completed tests in simulation to verify that the optical response part of the code is valid. During this quarter the feedback controller dynamics were added to the code to create a complete system model of the acquisition process. This model is currently being used as a testbed for acquisition controller design. A straightforward servo design has been shown, in simulation, to lock a coupled cavity interferometer. More investigation is required to gain a deeper understanding of the important issues in designing feedback controllers for the acquisition of interferometers with coupled degrees of freedom.

System Engineering/Integration (SYS). The SYS function continued to participate in all subsystem reviews and the preparation of the resulting reports. Guidance was provided to subsystem designers concerning the constraints imposed by the scientific requirements of sensitivity and availability, and also concerning the definition of interfaces. The Optical Layout task was given attention, resulting in a complete, though as yet lacking in detail, layout of the entire optical chain.

4.2.2 Control and Data System Design Activities (CDS, WBS 1.2.2)

Tests of the PSL prototype verified that the CDS electronic control systems meet the requirements for frequency and intensity stabilization. These tests also verified general concepts that will be used throughout the LIGO project for electronic and software systems. Detailed testing of the PSL will continue through September.

Work continued on specifying the design requirements for global CDS and Data Acquisition systems - preliminary designs for the PSL are 95% complete. The preliminary design review, scheduled for November 1, will follow final testing of the prototype.

Work was started on the design requirements and conceptual design for intra-vacuum cabling and vacuum feedthroughs; a Design Requirements Review is tentatively scheduled for October 31.

4.3 Research and Development (WBS 1.3)

4.3.1 40 m Interferometer Investigations

The main activity this quarter has been to continue the reconfiguration of the 40 m interferometer to operate with direct optical recombination of the light from the two arms, instead of the electronic comparison that was previously used. This change will permit higher power operation and is required before recycling can be implemented. The configuration adopted for the recombined interferometer required that an small asymmetry (~50 cm) be introduced in the Michelson arms. New servo-electronics to extract the signals and feed them back to the two arms and to the beamsplitter were installed in the previous quarter.

This quarter, the effort has centered on a complete characterization of the operation of the interferometer in its new configuration and on developing an understanding of the sources of noise. This new configuration introduces several new aspects to the servo-controls which hold the interferometer in lock. The servo loops in the old configuration were all of the single-input/single-output variety; the new loops include multiple inputs and multiple outputs. In trying to understand the noise in the new configuration, new versions of diagnostic tests must be developed taking into account the interaction of the different loops. Significant progress is being made but much still remains to be done.

Another set of investigations has been directed toward measuring and understanding the contrast of the interference between the two arms. Good contrast is essential for effective recycling, and the specification of new optics for the recycled configuration require an understanding of the sources of imperfect contrast. Measurements of the contrast with the end test masses misaligned (effectively a simple Michelson configuration) gave values as high as .998, though the value varied significantly with time as the test mass orientation changed. Measurements with the arms in lock gave significantly lower values; several possible causes for the lower contrast are under investigation.

A strong aftershock of the Northridge earthquake struck on June 27. This earthquake did no serious damage to the 40 m interferometer, but did cause a misalignment which required venting of the vacuum system to atmospheric pressure for realignment. Counting the time for venting and evacuating, the realignment itself, and the loss of continuity in the ongoing characterization of the recombined interferometer, the total delay in the 40 m program due to this event was approximately 3 weeks. Further earthquake activity in late August caused further interruptions to the R&D activities, requiring additional, but less extensive, remedial work.

4.3.2 Suspended Mode Cleaner

A 12 meter long mode cleaner using separately suspended mirrors is being developed as a LIGO prototype and for testing on the 40 m interferometer. Preparations for the installation of this mode cleaner on the 40 m interferometer continued during this quarter. Two additional vacuum chambers needed to accommodate the mode cleaner were leak-tested, cleaned and baked as preparation for installation on the 40 m interferometer. Fabrication of the seismic isolation stack parts for the new chambers was completed; these were Design of a laser beam pointing control unit needed to provide the long term pointing stability into the interferometer was completed, and all required parts are on order. Installation of the mode cleaner will begin as soon as the current testing of the the 40 m interferometer in its recombined configuration is completed.

4.3.3 Suspension Development

An effort to install new test mass suspensions for the 40 m interferometer is underway. The preliminary design of the new suspension was completed this quarter and an internal design review was held. The new design incorporates the key elements planned for the LIGO detector suspensions. The suspension eliminates the control block from the current design which is the source of mechanical resonances with frequencies near 100 Hz which lead to large peaks in the 40 m noise spectrum. Instead, the test masses will be suspended from a single loop of wire, with orientation control forces exerted directly on the test masses. The suspension design incorporates the features required to achieve high Q's in all mechanical modes to reduce thermal noise. Fabrication of a prototype of this suspension has begun, and it will be installed in the 40 m interferometer later this year to test its performance and to provide feedback to the LIGO detector design.

An apparatus to measure the Q's of both internal and suspension mechanical modes for full-size LIGO test masses has been completed. This apparatus incorporates an electrostatic drive for exciting the internal modes of the test masses; an interferometer measures the decay time. The effects of different configurations for the suspension, different polishing and coating treatments, and attachments to the test mass can be investigated. A full-size prototype test mass has been installed in the test stand and preliminary checkout of the apparatus has begun.

4.3.4 Phase Noise Research

This research effort is designed to demonstrate the technology for the shot-noise limited interferometer operation at initial LIGO power levels to achieve the required phase sensitivity using the 5-m facility at MIT. In this quarter, efforts focussed on the shakedown of the newly completed system and initial measurements of the noise spectrum.

After some delays due to initial problems with the vacuum system and laser cooling system, interferometer fringes were seen and the characterization of the signals led to improvements in the laser intensity servo-control, and the interferometer differential length control system. Unexpectedly large fluctuations in the observed contrast in the interferometer fringes were traced to sensitivity to stray magnetic field variations (due to the close proximity of commercial traffic to the laboratory) in conjunction with an unbalanced control magnet configuration. Two approaches to resolve this problem (a change in the transfer function of the suspension controllers and use of wavefront sensing alignment techniques) are being implemented in parallel, with promising results as the quarter closes.

The first interferometer phase noise spectra show excess noise at both low and high frequencies, as is expected for the apparatus in this early stage. Before proceeding to the next phase (addition of recycling to the interferometer), a satisfactory level of understanding of the noise spectrum must be achieved. Candidates for the sources of noise are being investigated systematically, and significant improvements have already been seen.

4.3.5 Interferometer Alignment Investigations

This research effort is directed toward testing the wavefront sensing system planned for LIGO. This test will be the first prototype to employ the modulation and configuration system which has been selected for the initial LIGO, and will allow the measurement of the alignment discriminants at all interferometer ports for comparison with the semi-analytical model. The experiment is deep into the construction phase.

In this quarter, the actual optical interferometer was placed on the optical table. A new design of fast actuator was produced in series and characterized; RF electronics for the length sensing system were constructed; a prototype of a design for the length servo system was made, tested and sent out to be manufactured. A clean air purge system was installed (to maintain very low mirror loss) and mechanical stiffening bars were installed.

Significant progress on the wavefront sensing system per se has been made in this quarter. A LIGO-like alignment data acquisition system, using VME based hardware with a real-time operating system, will be used; it has been designed and most of the hardware received. The wavefront sensor specifications have been developed and a prototype design is under construction. A system capable of closed-loop alignment control will be assembled, with software to allow an automated experimental determination of the sensor-actuator matrix.

4.4 Project Office

4.4.1 Project Management (WBS 1.4.1)

Staffing. The LIGO staff currently consists of 80 equivalent. Of these, ten are contract employees. During the quarter LIGO added the following personnel:

TABLE 1. New LIGO Employees (June 1995 - August 1995)

Allen Sibley	Vacuum Engineer, Facilities, CIT
Richard Abbott	Supervisor of Technicians, Detector/CDS Group, CIT
Fred Raab	Head, LIGO Hanford Observatory, CIT
William Kells	Sr. Research Fellow, CIT
John Guerrero	Cost/Schedule Controls - Contract Employee, CIT
Dennis Coyne	Deputy, LIGO Systems Integration Manager, CIT
Dave Barker	Sr. Software Engineer, CIT
Bill Tyler	QA - Contract Employee (JPL), CIT
Ben Lucas	ES&H - Contract Employee (JPL), CIT
Jennifer Logan	Sr. Research Fellow, CIT
Melinda Scoville	Sr. Department Clerk, Administrative Support Group, CIT

Sixty-six LIGO staff are located at CIT including four graduate students. Fourteen are located at MIT including five graduate students.

Schedule Status. As of the end of the reporting period, all significant milestones can be achieved. The date for the completion of the Beam Tube Qualification Test had previously slipped by one month to March 1995 because of modifications of the cleaning process that were required. The Qualification Test review held in April 1995 formally closes out the milestone. However, the delay is projected to carry forward to a one month delay of the milestone "Initiate Beam Tube Fabrication."

The milestone for Initiating Slab Construction in Washington is projected to slip from October 1995 to February 1996. However, this reflects current replanning to combine the Slab Construction effort, Fine Grading, and construction of the Tube Enclosure. No impact to downstream major milestones is anticipated.

The status of the significant milestones identified in the Project Management Plan is summarized in Tables 2 and 3.

TABLE 2. Status of Significant Facility Milestones

Milestone Description	Late Date		Completion Date	
	Washington	Louisiana	Washington	Louisiana
Initiate Site Development	03/94	08/95	03/94	
Beam Tube Final Design Review	04/94		04/94	
Select A/E Contractor	11/94		12/94	
Complete Beam Tube Qualification Test	02/95		03/95 (QT Review 04/95)	
Select Vacuum Equipment Contractor	03/95		03/95	
Complete Performance Measurement Baseline	04/95		04/95	
Initiate Beam Tube Fabrication	10/95		Projected: 11/95	
Initiate Slab Construction	10/95	01/97	Projected 2/96	
Initiate Building Construction	06/96	01/97		
Accept Tube and Cover	03/98	09/98		
Joint Occupancy	09/97	03/98		
Beneficial Occupancy (Accept Buildings)	03/98	09/98		
Accept Vacuum Equipment	03/98	09/98		
Initiate Facility Shakedown	03/98	09/98		

TABLE 3. Status of Significant Detector Milestones

Milestone Description	Late Date		Completion Date	
	Washington	Louisiana	Washington	Louisiana
BSC/TMC Seismic Isolation Final Design Review	11/96			
Core Optics Support Final Design Review	11/96			
HAM Seismic Isolation Final Design Review	12/96			
Core Optics Components Final Design Review	01/97			
Detector System Preliminary Design Review	01/97			
I/O Optics Final Design Review	06/97			
Prestabilized Laser Final Design Review	08/97			

TABLE 3. Status of Significant Detector Milestones

Milestone Description	Late Date		Completion Date	
	Washington	Louisiana	Washington	Louisiana
CDS Networking Systems Ready for Installation	09/97			
Alignment Final Design Review	11/97			
CDS DAQ Final Design Review	04/98			
Length Sensing/Control Final Design Review	05/98			
Physical Environment Monitor Final Design Review	06/98			
Initiate Interferometer Installation	07/98	01/99		
Begin Coincidence Tests	07/00			

Schedule Status Reports prepared from the management systems database are attached. These reports show the current schedule position and total float for all major Facilities and Detector milestones. Several milestones relating to the Facilities efforts in Louisiana have negative float. This schedule position was discussed during the NSF Review in May. As presented during the review, the Louisiana schedule issues will be resolved in three steps: 1) additional work will refine the schedules (e.g., identify tasks that will be accomplished at least partially in parallel), 2) as proposals and contracts are issued to vendors, more realistic scheduling information will be available, and 3) work around plans will be developed as required.

Financial Status Report. Finance is directly applying LIGO costs and commitments to the LIGO WBS. Table 4 summarizes costs for the third quarter and commitments as of the end of August.

Performance Status. A Cost Schedule Status Report (CSSR) is attached to this report. The CSSR shows the time phased budget to date, the earned value, and the actual costs through the end of August for the NSF reporting levels of the WBS. The schedule variance is equal to the difference between the budget-to-date and the earned value and represents a "dollar" measure of the ahead (positive) or behind (negative) schedule position. The cost variance is equal to the difference between the earned value and the actual costs. In this case a negative result indicates an overrun.

In addition graphical reports have been attached which show the same data as a function of time.

The Vacuum Equipment (WBS 1.1.1), the Beam Tubes (WBS 1.1.2), and the Beam Tube Enclosure (WBS 1.1.3) are all on schedule and are reporting favorable cost variances. The cost variances are primarily due to delayed invoicing and payment. One system enhancement that LIGO is currently investigating is to accrue costs for large contracts as the work is completed. This would alleviate the distortion caused by late billing or payment for major contracts.

TABLE 4. Actual Costs and Commitments Through August 1995.

WBS	Description	Allocation of Costs through Nov 1994	First Half FY 1995	June 1995	July 1995	August 1995	Cumulative Costs	Open Commitments	Total Costs Plus Commitments
1.1.1	Vacuum Equipment	$487,273	$114,186	$44,915	$30,840	$549,714	$1,226,929	$51,838	$1,278,767
1.1.2	Beam Tubes	$1,339,077	$859,374	$413,473	$15,730	$20,850	$2,648,503	$59,699	$2,708,203
1.1.3	Beam Tube Enclosures	$8,149	$19,905	($18,600)	$129,451	$209,873	$348,778	0	$348,778
1.1.4	Facility Design and Construction	$3,238,405	$1,541,930	$132,029	$228,669	$316,457	$5,457,490	$4,179,267	$9,636,756
1.2	Detector	--	$1,169,077	$225,791	$54,436	$230,674	$1,679,978	$564,611	$2,244,589
1.3	R&D	$10,407,161	$1,082,265	$655,855	$314,228	$177,354	$12,636.863	$749,832	$13,386,695
1.4	Project Office	$4,716,180	$2,044,380	$737,796	$461,945	$468,613	$8,428,913	$1,096,546	$9,525,460
	Unassigned[a]	$1,670	($1,839)	$0	$42,048	$36,179	$78,058	$143,185	$221,243
1.0	Total Project Costs	$20,197,916	$6,829,278	$2,191,259	$1,277,347	$2,009,713	$32,505,512	$6,844,978	$39,350,490
Cumulative Project Costs		$20,197,916	$27,027,194	$29,218,453	$30,495,799	$32,505,512			
Open Commitments		$3,531,398	$8,243,782	$7,370,764	$7,305,585	$6,844,978			
Costs Plus Commitments		$23,729,314	$35,270,976	$36,589,217	$37,801,385	$39,350,490			
NSF Funding		$47,088,935	$121,481,109	$121,481,109	$121,481,109	$136,088,935			

[a] These costs have not been assigned to any LIGO account by CIT Finance but are continually reviewed to assure proper allocation.

Facility Design and Construction (WBS 1.1.4) is behind schedule. The facility design for Washington and Louisiana were planned (baselined) in parallel, but the Louisiana design effort has been delayed. In addition, the aerial survey and ground noise measurement activities for the Louisiana site are behind schedule and are minority contributors to the unfavorable schedule variance. The favorable cost variance is the result of invoicing and payment delays.

The Detector (1.2) has two active third level WBS elements, the Interferometer (WBS 1.2.1) and the Control and Data Systems (WBS 1.2.2). The unfavorable schedule variance is in the Interferometer (WBS 1.2.1) which is due to manpower resources lagging behind the levels that are required to support the plan. So far there is sufficient float in the schedule to avoid impacting major project milestones. However, LIGO is actively attempting to recruit the necessary staff. Several subcontracts have also been placed, but it was deemed premature to claim earned value at the end of August. The unfavorable cost variance was in the Control and Data Systems (WBS 1.2.2). This variance is due to 1) rate variances (labor rates paid are higher in this area than the average rate used in the plan), 2) charges have been incurred against this WBS for equipment that will be transferred to R&D when the Prestabilized Laser is moved to the 40 m lab, 3) costs for EPICS (control systems) support services provided by Los Alamos were prepaid, and 4) there was work that was completed that was not claimed (new account manager).

Research and Development (WBS 1.3) is reporting an unfavorable schedule variance and a favorable cost variance. The favorable cost variance is primarily in laboratory operations, which is level-of-effort. This will be offset in the future by costs for equipment currently on order. Favorable cost variances also reflect delays in the receipt and payment of invoices from MIT. (Approval of additional funding for MIT for FY 1995 has now been received from NSF, and contract modifications have been issued.) The schedule variance represents a 1-1/2 month behind schedule position primarily in the 40 meter recombination effort and the phase noise research effort. Available float has not been exhausted.

The Project Office (WBS 1.4) is level-of-effort and, therefore, shows no schedule variance. However, there is an unfavorable cost variance for unplanned management personnel and computer support. Change Board actions will be initiated to adjust the baseline to reflect the added scope.

Change Control and Contingency Allocation. A The following Change Requests have been approved. $1,038K has been <u>returned</u> to the contingency pool, increasing the funds managed in the pool.

TABLE 5. Approved Change Requests

Change Request No.	Description	Submitted By	Date	Status
CR-950013	Facilities Final Design Concept and Direction to Parsons	F. Asiri	July 21, 1995	Approved
CR-950014	Remove TMC Chambers (Design, Fab, Installation, Test)	J. Worden	July 25, 1995	Approved ($1,558,000)
CR-950015	Vacuum Equipment - 48 inch Gate Valves/80K Pumps	J. Worden	August 4, 1995	Approved
CR-950016	LA Rough Grading - Pipeline Crossings	F. Asiri/R. Fischer	August 14, 1995	Approved $520,000

4.4.2 Support Services

Arrangements are in progress with the Jet Propulsion Laboratory's (JPL) Office of Engineering and Mission Assurance (OEMA) to staff positions supporting quality assurance, reliability, product assurance, and ES&H. During the past quarter JPL has performed an operational safety survey of the LIGO R&D facilities at Caltech; supported the beam tube qualification test review; reviewed and provided comments concerning the vacuum equipment, beam tube, and beam tube enclosure contractor plans and preliminary designs; coordinated with OSHA the confined space emergency egress safety requirements for the beam tube enclosure; initiated development of the LIGO laser safety program; initiated a reliability review of the LIGO system functional block diagrams and the development of the system reliability block diagrams; and initiated the development of the LIGO/JPL OEMA task plan and cost estimate to support the LIGO construction project.

4.4.3 Systems Engineering (WBS 1.4.3)

Integration. Dennis Coyne, a mechanical engineer with systems engineering experience, joined the Integration and Systems Engineering group in July as its deputy. Mr. Coyne's assignments will include defining interface requirements and analyzing control, thermal, structural and servo-control issues.

Documentation. The documentation effort during the quarter included: the establishment of a documentation/specification tree; the issuance of a preliminary performance requirements document for the beam tube baffles (the final version awaits an iteration of theoretical calculations by Prof. Kip Thorne); and an update to the LIGO Science Requirements Document (SRD) (the final version will be issued pending the outcome of a meeting sponsored by Systems Engineering at MIT to review and adopt a set of physical noise models which will be used to define and characterize interferometer limiting performance).

Interfaces. A template for the LIGO Interface Control documents (ICDs) was developed and distributed. The template is a guide to the preparation of the ICDs in a common format. The template covers physical, electrical, signal and functional interfaces.

Precise interface definition among the major LIGO subsystems is essential for successful and timely development of the project. The Interface Control Documents (ICDs) are being developed to address all physical, operational and procedural interfaces between the major subsystems. The LIGO systems approach is to minimize and simplify these interfaces to the greatest extent possible. The ICDs are intended to clearly define the requirements and responsibilities on both sides of an interface and only describe the design implementation of subsystem requirements when (and to the extent) absolutely necessary. Functional and performance requirements are captured in the subsystem requirement documents, not the ICDs.

The approach used has been to gather requirements (principally associated with the interfaces) from existing documents, through discussions with LIGO designers and through System Engineering and Integration Meetings. The items on the list are then given a disposition to be either reference information, a simple requirement, or a requirement involving an interface. To date, a list of the ICD content has been prepared in draft form for the three ICDs involving the Civil Construction. The three ICDs involving the Civil Construction are in preparation and are planned to be released in draft form by the end of September.

In a related effort a CAD model has been developed for the corner station Laser and Vacuum Equipment Area (LVEA). This model lays out CAD layers with latest version of vacuum chamber footprints (VE), exclusion zone footprints required by detector mechanical and optical interfaces, and the placement of electronics equipment racks to control the detector subsystems within the LVEA. The CAD model also includes VE plumbing manifolds for roughing pumps, electrical cabling, and cooling lines. We are in the process of identifying facilities-provided access to power for the lasers, the electronic equipment racks, and the VE. Once the effort is complete, we will commence with the mid-station and end-station vacuum equipment areas. In addition, we will task the LIGO architectural engineering contractor (Parsons) to build a fully 3D model of the layouts by providing to them our model. A fully 3D model will allow us to start addressing operations-related questions of materials handling within the completely populated LVEA.

We have established a regular weekly meeting for integration and interface issues with representation from all groups. It is principally through these meetings that technical requirements and solutions associated with inter-system requirements and interfaces are addressed. A technical memorandum in response to a number of Parsons questions in their “Requirements Definition Worksheet” (as discussed and agreed upon in several Integration & Systems Engineering Meetings) was issued. A preliminary layout of the Vacuum Equipment (VE) and CDS Rack equipment, as well as support utilities (such as a coolant manifold, power and ground distribution, gaseous nitrogen supply, etc.) has been developed.

A computer program for english/metric conversion was obtained from JPL and installed for use by LIGO. Three drawings related to the beam tube interfaces to the civil construction (D950021, D950029 and D950093) were revised principally to add english units (using the JPL program) and will be submitted to the Change Control Board.

Requirements Definition. The weekly Systems Engineering and Integration meetings are the principal forum by which previously unstated requirements are discovered and discussed. A number of issues (involving topics such as power distribution, coolant piping, fume hood requirements, gaseous nitrogen supply, drains, etc.) are discussed and resolved at these meetings._

Work on the Systems Requirements Document (SysRD) (previously called the System Specification) was delayed in order to resolve pressing interface and requirements issues. We are in the process of revising the original SysRD table of contents in coordination with the planned content of the major subsystem requirements documents (principally the detector Requirements Document). A system block diagram has been drafted.

EMI/EMC Plan. Recognizing the need for self-imposed Electromagnetic Interference (EMI)/ Electromagnetic Compatibility (EMC), we have identified a consultant to assist us in EMI/EMC, grounding, shielding and lightning protection issues. The EMI/EMC plan will define an approach to grounding, shielding, bonding and electrical design for the program by calling out relevant design standards and guidelines, as well as defining the basic approach to be taken by LIGO in distributing power and grounds. The EMI/EMC plan will also scope the level of activities in design and test; Although we are using the DoD EMC process as a guide, we are tailoring it to suit LIGO needs and ensuring that only essential analyses and tests be performed.

Reliability Plan. LIGO Systems Engineering is also undertaking the development of a Reliability Plan. This effort will be performed by the Jet Propulsion Laboratory Reliability Group, under the auspices of LIGO System Engineering. We are beginning the effort by reviewing the LIGO Science Requirements Document as the source of reliability requirements (from a facilities availability perspective). Once the reliability requirements are defined, a reliability plan will be written showing how the reliability of the LIGO subsystems will be design, assessed, and verified to meet LIGO top level requirements. As part of this effort, LIGO will develop a fault tree analysis, needed to identify failure modes and risks. These data are also required to support a parallel effort to develop a LIGO safety plan. Ultimately a failure modes and effects analysis (FMEA) will be developed. From this analysis, sensitivity of overall system availability to the reliability of various LIGO subsystems will be quantified. The results of this analysis will be used to develop spares strategies, maintenance strategies, and to perform trade studies on identified weak points of LIGO subsystems to improve their reliability.

Systems Engineering Analyses. An analysis of the thermal environment within the Beam Tube Enclosure (BTE) and its thermoelastic effect on the Beam Tube (BT) alignment and stresses was initiated. Thermally induced distortion (bending) of the BT can potentially limit the detection capability of LIGO for periodic gravitational sources as well as cosmic background gravitational radiation by increased and periodic (diurnal) scattering. It was found through previously published studies that the principal mode of heat transfer for an enclosure such as the BTE with top surface (solar) heating is conduction, with little natural convection enhancement. The study will be concluded shortly.

A resizing of the cryogenic pumps was initiated and undertaken by Systems Engineering for two reasons: baffling geometry considerations and lifetime expectations. The cylindrical cold surface of the cryogenic pump was increased so that it could be baffled from view of the test masses in order to preclude impressing pump vibration, via backscattered light, on the LIGO signal. Cryogenic condensation of a thin layer of water significantly degrades the emissivity (and efficiency) of the cryogenic pump with a concomitant reduction in lifetime.

We are also working to develop an automatic algorithm to use distributed pumping and RGA data during the beam tube module integration to identify and to locate vacuum leaks using an air signature method.

Trade Studies. The following trade studies are in progress or have been concluded:

Nd:YAG vs. Argon Ion lasers - Systems Engineering oversaw a trade study to assess the feasibility of switching from plasma tube (Ar^+ ion) laser technology to solid state (Nd:YAG) technology. The effort was completed and the study report issued. Program management took the study under consideration and recently decided to initiate a baseline change to LIGO.

Baffle materials & geometry - The study to identify and acceptable material for baffling the beam tubes continues and is expected to be completed in the next quarter. A significant development occurred when the University of Arizona Optical Sciences Center recommended to LIGO a manufacturer of optical glass enameling frits which can be applied by firing directly to 304 stainless steel (LIGO beam tube material). We are working with Ferro-Frit Division to characterize the coating optical performance and vacuum properties. Initial assessment of optical performance indicates it is the best material we have found to date. We are awaiting delivery of a number of coupons for outgassing studies. Martin Black as a candidate material was effectively eliminated upon discovery of its reduced optical performance a 1.06 µm (wavelength of the solid state laser Nd:YAG which will now be adopted for LIGO). As a further risk reduction measure, in the event that the vacuum properties of the glazed substrate design prove unacceptable, we are also characterizing the optical performance of simple single-layer oxidation of highly polished stainless steel material. This is a zero-risk candidate from the vacuum compatibility perspective, but its optical performance is not as good as the optical glass enameled substrate.

Interferometer parameter optimization - Work continues toward definition of the complete optical specification of the initial LIGO interferometers. This effort is being conducted in order to define the cavity geometries (length, g-factors), and mirror reflectivities. In addition, the study has almost completed a trade study assessing the relative merits of a 7 m and 21 m recycling cavity. The need to address the longer option is driven by modulation algebra constraints which require the ability to accept certain modulation frequencies while rejecting other harmonics in both the input optics mode cleaner and the recycling cavity.

Modeling and Analysis. The AVS software package continues to work nicely as an environment for developing the simulations, analysis and visualization needs of the End-To-End model, though bugs and design limitations continue to be found. The AVS support group has been very effective in providing both short term and long term solutions to these. AVS software development at this time includes analysis and visualization of data collected from the 40-meter in both the time and frequency domain. Developed software also included several types of random number generators for use in noise modeling and stochastic background analysis.

The interferometer End-to-End modeling based on the AVS environment started. The model environment has two components, one Interferometer simulation and the other noise simulation. The IFO part of the End-to-End model version 1 consists of 1) Twiddle (steady state model to calculate the transfer function), 2) Modal Model (static case model including higher modes than TEM00 to calculate the effect of mirror misalignment) and 3) FFT model (static case model using FFT to include all kind of aberrations of mirrors to calculate all kind of static quantities, although very slow).

The AVS version of Twiddle has been completed, including an extension to DC cases. This version is based on the Twiddle model ported to fortran code for the speeds sake. This model has been compared with calculations and agrees to within machine accuracy. The Twiddle implementation was chosen for the basis of the End-to-End model, because the algorithm of Twiddle allows to construct fairly arbitrary IFO system very easily. In this implementation using AVS, one can construct arbitrary interferometer using graphical user interface, by dragging IFO elements, such as light sources, mirrors, and other electro-optical components.

Related efforts. The FFT program to accurately model diffractive propagation of wavefronts within resonant cavities, was developed at MIT, and is a very time-consuming program, which takes 30 hours to finish one run using Sun Sparc20. An effort has been started to collaborate with the CACR (Center for Advanced Computer Research) to speedup the program using Intel Paragon computers. Preliminary study indicates that the speed improvements of 100 could be possible by optimizing for the concurrent computing. Even without optimization, effectively we have big gain, because the number of nodes of the paragon system is 512, and we can submit and finish many jobs simultaneously.

A FORTRAN program for various sources of noise, gravnoiseplot3, was also transported to the AVS environment. This includes major sources of noises and will be used as the noise part of the End-to-End model until a completely revised version is implemented. During the development of these AVS modules, several useful programming methods were developed, including the planar topology recognition (recognition of IFO element arrangement in Twiddle model) and the parameter maintenance with the server-client structure. These will be used as the core methodology in the AVS-based End-to-End modeling.

Documentation. A draft "AVS Software Standards Guide" was completed and distributed in early September. Using recommendations from members of the LIGO and CaRT groups, a second version will be issued in mid September. The document also serves as an excellent tutorial for writing AVS modules.

A draft "End-To-End Model Software Specifications Document" will begin in mid September. The distribution of the document is scheduled for late October.

40-meter data visualization. A graphical user interface (GUI) data acquisition front end to the HP 3563A based on LabVIEW was developed for the Sun workstations. The GUI takes spectral data and logs various 40-meter instrument settings and measurements. The GUI will also automatically writes the log data over the network to the Sun file server where it can easily be viewed from with AVS on any Sun workstation on the LIGO network.

COBRA (R) WST Corp.	COST/SCHEDULE STATUS REPORT	Page 1

CONTRACTOR: Caltech LOCATION: Pasadena, CA	CONTRACT TYPE/NO: PHY-9210038	PROJECT NAME/NO: LIGO Master Merged PMB - WBS 1.0	REPORT PERIOD: 31JUL95-31AUG95	SIGNATURE: TITLE / DATE:

CONTRACT DATA

ORIGINAL CONTRACT TARGET COST	NEGOTIATED CONTRACT CHANGES	CURRENT TARGET COST	ESTIMATED COST OF AUTHORIZED UNPRICED WORK	CONTRACT BUDGET BASELINE
	292, 100, 000	292, 100, 000		292, 100, 000

PERFORMANCE DATA

	CUMULATIVE TO DATE					AT COMPLETION		
MPR Level	BUDGETED COST		(3) ACTUAL COST WORK PERFORMED	VARIANCE		(6) BUDGETED	(7) ESTIMATE AT COMPLETE	(8) VARIANCE (6-7)
	(1) WORK SCHEDULED	(2) WORK PERFORMED		(4) SCHEDULE (2-1)	(5) COST (2-3)			
1.1.1 : Vacuum Equipment	1277	1277	1227	0	50	41957	41957	0
1.1.2 : Beam Tubes	2889	2889	2649	0	240	43922	43922	0
1.1.3 : Beam Tube Enclosur	505	505	349	0	157	18062	18062	0
1.1.4 : Facility Design &	6278	5733	5457	(545)	276	50405	50405	0
1.2 : Detector	2062	1279	1680	(783)	(401)	48081	48081	0
1.3 : Research & Developme	13337	12805	12637	(532)	169	23400	23400	0
1.4 : Project Office	7946	7946	8429	0	(482)	21471	21471	0
SUBTOTAL	34294	32435	32427	(1860)	7	247299	247299	0
CONTINGENCY	▨	▨	▨	▨	▨	0	44801	(44801)
MANAGEMENT RESERVE	▨	▨	▨	▨	▨	44801	0	44801
TOTAL	34294	32435	32427	(1860)	7	292100	292100	0

25SEP95 15: 07: 18 Thousands of $ COBRA (R) by WST Corp.

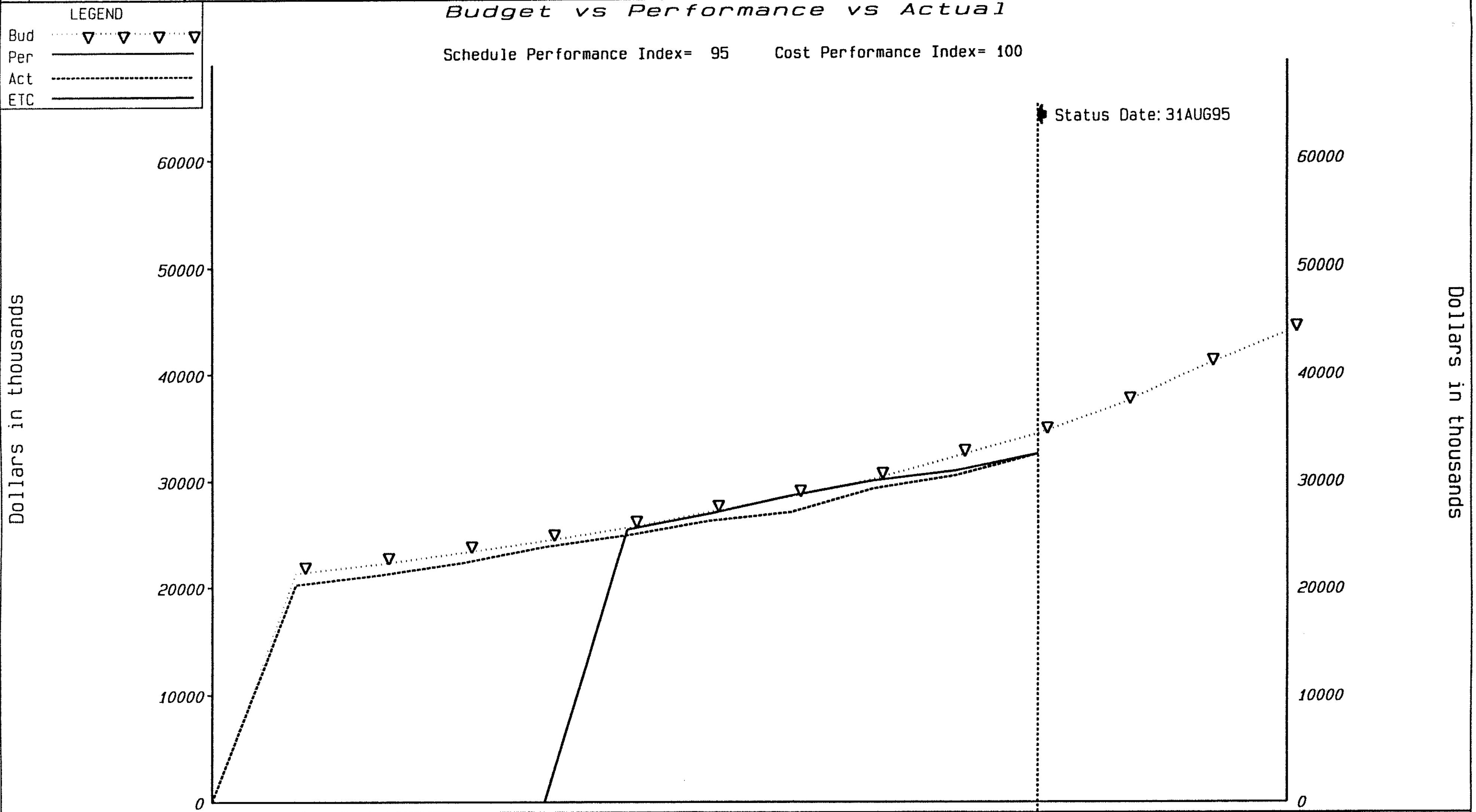
COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1 LIGO Construction

Date: 25SEP95
Program: TEST-PMB

Budget vs Performance vs Actual

Schedule Performance Index= 95 Cost Performance Index= 100



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	21, 332	22, 222	23, 301	24, 415	25, 665	27, 127	28, 517	30, 133	32, 174	34, 294	37, 105	40, 652	43, 808	K$
Performance	0	0	0	0	25, 491	26, 946	28, 612	29, 997	30, 903	32, 435				K$
Actual/Forecast	20, 255	21, 173	22, 343	23, 853	24, 955	26, 272	27, 086	29, 268	30, 453	32, 427				K$
Schedule Variance	-21, 332	-22, 222	-23, 301	-24, 415	- 174	- 181	95	- 136	-1, 271	-1, 859				K$
Cost Variance	-20, 255	-21, 173	-22, 343	-23, 853	536	674	1, 526	729	450	8				K$

Schedule Variance = Perf-Budg Cost Variance = Perf-Actual Schedule Performance Index= Perf/Budg Cost Performance Index= Perf/Actual

*** Prepared by LIGO Project Controls Group ***

Project: Untitled #1
Time Now: 09/01/95
Start: 01/01/92
Finish: 01/01/92
Run: 09/25/95
Page: 1 of 1

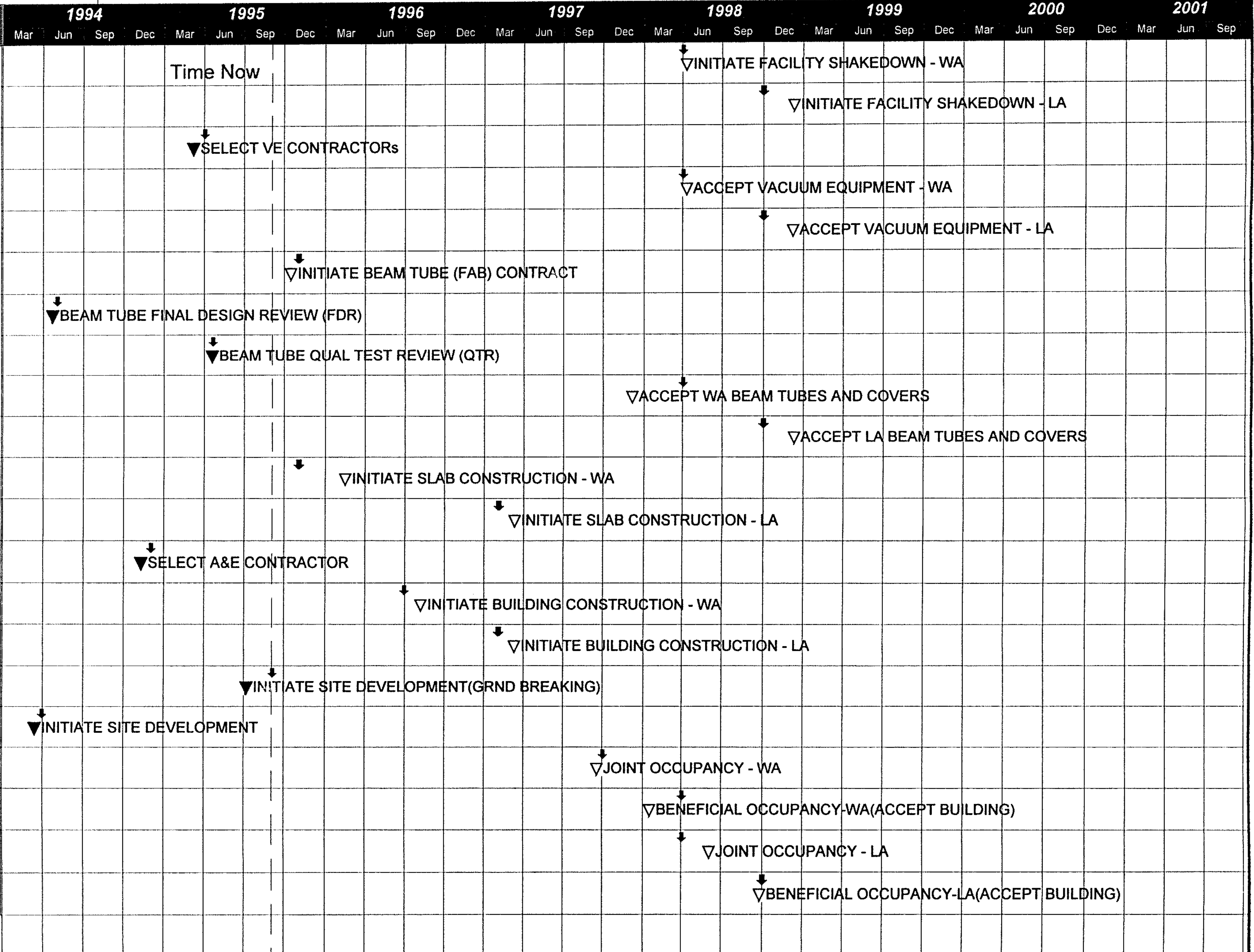
Caltech - LIGO Project

Project Level 1 Milestones

Baseline vs. Current

Critical Activity ▨
Completed/In-Process ■

LIGO



BFinish	EFinish	
03/31/98	04/09/98	▽INITIATE FACILITY SHAKEDOWN - WA
09/30/98	12/09/98	▽INITIATE FACILITY SHAKEDOWN - LA
03/31/95	03/08/95	▼SELECT VE CONTRACTORs
03/31/98	04/09/98	▽ACCEPT VACUUM EQUIPMENT - WA
09/30/98	12/07/98	▽ACCEPT VACUUM EQUIPMENT - LA
10/31/95	10/13/95	▽INITIATE BEAM TUBE (FAB) CONTRACT
04/30/94	04/21/94	▼BEAM TUBE FINAL DESIGN REVIEW (FDR)
04/18/95	04/18/95	▼BEAM TUBE QUAL TEST REVIEW (QTR)
03/31/98	12/05/97	▽ACCEPT WA BEAM TUBES AND COVERS
09/30/98	12/09/98	▽ACCEPT LA BEAM TUBES AND COVERS
10/31/95	02/15/96	▽INITIATE SLAB CONSTRUCTION - WA
01/31/97	03/11/97	▽INITIATE SLAB CONSTRUCTION - LA
11/30/94	11/08/94	▼SELECT A&E CONTRACTOR
06/28/96	08/06/96	▽INITIATE BUILDING CONSTRUCTION - WA
01/31/97	03/10/97	▽INITIATE BUILDING CONSTRUCTION - LA
08/31/95	07/05/95	▼INITIATE SITE DEVELOPMENT(GRND BREAKING)
03/30/94	03/14/94	▼INITIATE SITE DEVELOPMENT
09/30/97	09/16/97	▽JOINT OCCUPANCY - WA
03/31/98	01/15/98	▽BENEFICIAL OCCUPANCY-WA(ACCEPT BUILDING)
03/31/98	06/02/98	▽JOINT OCCUPANCY - LA
09/30/98	09/24/98	▽BENEFICIAL OCCUPANCY-LA(ACCEPT BUILDING)

Time Now: 09/01/95
Start: 09/01/95
Finish: 09/01/95
Run: 09/15/95
Page: 2 of 2

Caltech - LIGO Project

Project Level 1 Milestones

Baseline vs. Current

Critical Activity ▨
Completed/In-Process ■

BFinish	EFinish	
12/31/96	11/22/96	HAM FDR
11/30/96	11/22/96	BSC/TMC FDR
08/31/97	04/19/96	PSL FDR
06/30/97	01/13/97	IOO FDR
01/31/97	01/07/97	COC FDR
11/30/96	10/17/96	COS FDR
11/30/97	01/15/98	WVFNT FDR
05/30/98	05/30/97	LSC FDR
07/31/97	11/25/97	SYSTEM PDR
07/31/98	09/22/98	INIT INTERFEROMETER INSTALLATION-WA
01/29/99	04/16/99	INIT INTERFEROMETER INSTALLATION-LA
04/30/98	08/05/97	CDS DAQ FDR
09/30/97	09/02/97	WA VAC & CA/NS READY TO INSTALL
06/30/98	06/18/98	PEM FDR