CALIFORNIA INSTITUTE OF TECHNOLOGY

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Date: August 21, 1998
Refer to: LIGO-L980370-00-P

Ms. Carol A. Langguth
Grants Officer
Division of Grants and Agreements
National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230

Subject: LIGO Project Quarterly Progress Report, LIGO-M980158-00-P

Reference: NSF Award No. PHY-9210038

Dear Ms. Langguth:

Four copies of the LIGO Project Quarterly Progress Report providing status information for the quarter ending May 1998 are enclosed in accordance with the requirements of the award referenced above. Please forward three (3) copies to Dr. Berley.

Sincerely,

Philip E. Lindquist
LIGO Project Controls Manager

Concurrence for Caltech:

____
Richard Seligman
Director, Sponsored Research

PEL:pel

cc:

G. Sanders
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Chronological File
Document Control Center

Quarterly Progress Report

(Quarter Ending May 1998)

The Construction, Operation and Supporting Research and Development of a Laser Interferometer Gravitational-Wave Observatory (LIGO)

NSF Cooperative Agreement No. PHY-9210038

LIGO-M980158-00-P

Quarterly Progress Report

(End of May 1998)

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

NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M980158-00-P

CALIFORNIA INSTITUTE OF TECHNOLOGY

1.0 Introduction

This Quarterly Progress Report is submitted under NSF Cooperative Agreement PHY-9210038[1]. The report summarizes Laser Interferometer Gravitational-Wave Observatory (LIGO) Project status for the quarter ending May 1998.

2.0 Recent Progress and Status

The project continues to make excellent progress and is 83 percent complete as of the end of May 1998.

2.1 Vacuum Equipment

Commissioning activities in Hanford, Washington and installation in Livingston, Louisiana continue. The commissioning schedule in Washington is six weeks behind schedule due to design and fabrication defects in the large 44 inch gate valves. Every gate valve for the project must be re-inspected (see next paragraph). Livingston, Louisiana installation continues on schedule. Mechanical completion has been achieved in all Hanford, Washington buildings. Acceptance testing is complete in the Hanford Y-arm buildings, and is in progress in the X-arm buildings and the corner station. All components have been shipped to Louisiana except for vendor equipment to be used by PSI for testing. Alignment and positioning of equipment in Livingston, Louisiana began in May, and all end-station components are now in place. Fabrication and testing of the MIT LIGO components is complete except for the Beam Splitter Chamber (BSC) which is being re-baked to eliminate unacceptable levels of hydrocarbons discovered after testing. The large gate valves continue to be critical procurements.

In April, PSI discovered vacuum leaks on two of the GNB gate valves installed at Hanford. After investigation, GNB found that they had made an error in the early stages of valve design. This resulted in insufficient margin for the compression of the main bellows feedthrough. This bellows varies from an extended length of six feet to a compressed length of two feet. Apparently, in some

1. *Cooperative Agreement No. PHY-9210038 between the National Science Foundation, Washington, D.C. 20550 and the California Institute of Technology, Pasadena, CA 91125, May 1992.*

valves, it would be possible to over compress the bellows by as much as one inch depending on limit switch adjustment. As the bellows are supported internally by rigid spacers, this one inch can result in bellows damage.

To deal with the problem, PSI and GNB have embarked on an inspection program in the field (Hanford and Louisiana). All valves will have their internals removed to facilitate a 50 point inspection and repair program. A number of parts will be inspected for proper fit and replaced or adjusted as necessary. Mechanical stops will be installed to limit bellows compression should a limit switch fail. Additionally, LIGO has requested that the inspection program address possible O-ring and O-ring groove mismatch which could allow an O-ring to be pulled out of its groove following an extended bakeout. PSI and GNB have agreed to the expanded scope and the work is underway. This work will result in a delay of PSI's Hanford work but should not affect contract completion in Louisiana.

2.2 Beam Tube

Beam Tube Installation at Hanford is complete. All four modules have been accepted.

All 400 Beam Tubes for the Livingston site (all that will be required) have been formed, tested for leaks, cleaned, and shipped to the site. Three hundred eighty-nine Beam Tube sections have been installed at Livingston. Twenty-two girth welds required inside repairs. Three hundred eighty-eight of these welds were tested for leaks with no failures found.

On May 28 a drive belt was removed from the X-arm mid-station gate valve at Livingston with the gate in the open (up) position and the gate locking pin mistakenly in the disengaged position. As a result the gate descended quickly to the bottom of its travel. Measurement of the gate screw position indicates that the gate “lockover guides” (travel stops) are likely broken, sheared at the welds to the valve body. This conclusion is reinforced by the fact that approximately 200 liters per second conductance is observed when the valve should be sealing internally. Options for repair are being considered.

2.3 Beam Tube Enclosures

Two thousand six hundred seventeen Beam Tube Enclosure segments have been cast for the Livingston site. Of these, 2405 have been installed, and the X-arm is complete. The service road along the X-arm has been paved with asphalt. Current activities are focused on completing the Y-arm.

2.4 Civil Construction

Washington Civil Construction. Construction activities for the facilities are essentially complete. Activities during this reporting period focused on the completion of punch list items, consolidation of comments for the “as built” drawings, and general project closeout. Bid packages for water system integration and for a new staging and storage building has been prepared.

Louisiana Civil Construction. Joint occupancy has been achieved for all buildings. LIGO staff moved into the office buildings February 17, 1998. The construction phase experienced delays due to inclement weather of 50 and 62.5 days for the Hensel Phelps and Woodrow Wilson subcontracts respectively. Since the facilities are now under roof, the affect of weather on construction progress is considerably reduced. Accomplishments during this period include the completion of nearly all outstanding “punch list” items. Consolidation of comments for the “as built” drawings and the closeout of the subcontracts are now in progress

2.5 Beam Tube Vacuum Bake

Most of the equipment for the Beam Tube vacuum bake arrived at Hanford this quarter. Now on site are heater jackets and controllers, vacuum pumps, electrical power transformers, power distribution panels, DC power supplies (borrowed from Fermilab), power supply cooling units, and reels of cable for distributing the megawatt of electrical power used for heating. An electrical contractor, Sun River Electric Service, Inc., began assembly and initial installation of the portable AC power distribution panels and portable 500 kW DC power supply assemblies for use during the bakeout. Each DC power supply is being mounted in a weather shelter on a 40 foot flatbed truck trailer, with its primary power transformer and switchgear, cooling water system, and metering and monitoring equipment permanently connected for easy portability.

A data acquisition system has been built and programmed in-house to measure temperatures, electrical parameters, Beam Tube vacuum, and other performance parameters. Data from this system will be integrated with data from a commercial residual gas analyzer (RGA) to thoroughly monitor the tube during and after the bakeout.

The vacuum bake of the first Beam Tube module at Hanford is scheduled to begin during the next quarter.

2.6 Detector

40 Meter Laboratory. Continued the process of characterizing the power recycled Michelson configuration. This effort was performed in parallel with work to bring the arm cavities into the optical system. Wavefront sensing, required for the cavities to function correctly, was installed and checked during the period. New diagnostic techniques were developed for the precision measurement of lengths and cavity losses using multiple RF modulation frequencies.

Interferometer Sensing and Control. The Initial Alignment subsystem Final Design Review (FDR) was held April 30, 1998. The precision metrology fixtures, optical levers, viewports, and camera systems are being fabricated. There have been significant advances made in the design of the length control system both in the acquisition and operational modes. The maximum velocity of test mass motion for which a successful “capture” can be achieved was increased, and a numerical estimate of the time to initial lock is 10 seconds. The model for the fully digital length control system was modified to a combined analytical/numerical approach to improve the quality and speed of the results. During this process, it was realized that further refinement is needed to meet the requirements for length control due to a larger-than-anticipated vertical “bobbing” motion of the test masses. Tests of prototype detection hardware for both the alignment and the length control systems were completed using the interferometer test facilities (the Phase Noise Interferometer, PNI, and the 40 Meter Interferometer).

A particularly useful test of the digital length control system was started using the Phase Noise Interferometer (PNI). The dynamic range and absolute intensity of the light fluctuations at the main sensing port of the PNI closely matches that anticipated for LIGO, as does the dynamics of the mechanical and optical systems and the mirrors close to the beamsplitter in LIGO. This allows a test of the hardware and software with considerable realism. During this quarter the digital servo system, the analog input- and output-filters, and diagnostic access modules were assembled and individually tested.

Laser. The first deliverable 10 W laser was tested for 2500 hours, and demonstrated excellent intensity stability and met performance requirements, although some slow alignment drift was noted. The second laser was delivered with improvements in mounts to reduce this drift, and tests are beginning. The first laser has been returned for updating. The stabilization and control system wrapped around the laser was tested with its digital interface. The very slow (the so-called “tidal servo”, tracking daily variations) and high-speed (intensity stabilization) servo control systems were refined.

Input/Output Optics (IOO). The Input Optics Final Design Review was held March 25, 1998, and components for the subsystem were released for fabrication. The large optic which matches the beam into the interferometer is being polished, and a coating cycle is planned in July. The circularly symmetric segmented photodiode used to measure the quality of the mode match into the interferometer was received, and a manufacturer of low-loss vacuum-compatible polarizers was identified.

Core Optics Components (COC). CSIRO continued the polishing of critical substrates and is maintaining schedule for delivery to our coating vendor, REO. Further analysis was performed of trial coatings with very positive results; the surface characteristics continue to meet the specification after the coating process. A new laboratory was set up at Caltech to support the development of cleaning procedures, with tests on three inch substrates. A potential schedule problem, due to the failure of a vendor to deliver a phase-shifting infrared interferometer, was averted when an alternate vendor (Veeco, Inc.) was identified who will be able to support our requirements. The successful Final Design Review (FDR) for the Core Optics was held late in the quarter.

Core Optics Support (COS) . As a result of the Preliminary Design Review (PDR) a telescope design which meets strict requirements for wavefront flatness (to assure that the automated alignment system will perform correctly) and absence of scatter (to eliminate parasitic interferometers between these components and those of the main interferometer) was adopted for coupling out signal beams. This design is also producible and cost effective, using stock off-axis parabolas to make an all-reflective system that is vacuum-compatible and does not compromise seismic or thermal noise budgets. The design and placement of baffles were also established, and the final design is in progress.

Seismic Isolation Systems (SEI). An initial lot of 19 prototype spring elements was successfully evaluated for dynamic properties (stiffness, uniformity of stiffness, damping) as well as vacuum properties, and a follow-on subcontract was awarded for the fabrication of 400 springs for the first article tests of the seismic isolation systems. Other components of the system were also tested including coarse and fine actuators, air bearings, and controllers. The vacuum properties of some samples of in-vacuum components were tested, and a residual gas analyzer (RGA) signature detected. As a result a review of the machining and cleaning procedures was conducted at the manufacturer's facility, and a repeat test planned early next quarter is expected to validate an improved process. Hardware for the Horizontal Axis Module Seismic first article test is being shipped to Hanford, and the test setup and plan were developed.

The investigations into the improved cleaning process have contributed to minor delays in the First Article Test and subsequent fabrication. Installation of the Seismic Isolation system will commence in August, and will be paced by fabrication schedules during the first few months. Work-arounds to maintain the overall schedule are being considered.

Suspensions. Contracts for the Large Optics Suspension fixtures and components were awarded this quarter. The vendors have provided prototypes of some components for evaluation, and we have been iterating the design with the manufactures as required. The first article main cage is being fabricated. One modification made this quarter is in the material to be used for the sensor/actuator "head," from a machinable ceramic to alumina; this more desirable material is easier to machine and has superior performance.

Systems Engineering. The Systems Engineering activities focused on planning and coordinating the physical integration of the detector. The first real test of the plan comes with the first article test of the seismic isolation system, just starting this quarter. This will provide a calibration of the manpower, time, and risk estimates that have been used. Other efforts included the qualification of materials for use in vacuum. Light Emitting Diodes and Photodiodes, as well as Kapton cables and connectors were tested and found to be acceptable based on exhibiting no significant increase in the absorption of light by mirrors under constant laser illumination. There was progress in the design for the diagnostics planned for the interferometer; software prepared this quarter will be exercised in the digitally-controlled Phase Noise Interferometer next quarter.

Physics Environment Monitoring (PEM) System. There has been significant activity procuring, fabricating, and installing equipment for Physics Environment Monitoring (PEM). The standalone computer systems used for early and independent data acquisition were configured, and sample programs used to test the acquisition hardware. They are now on site at Hanford to support the first-article seismic testing. The identification of a superior accelerometer-amplifier unit, used throughout the two sites to monitor ground motion, will allow a better signal-to-noise ratio for this sensor. An effort to make early correlation measurements between the two sites has led to simultaneous observations of lightning strikes at Hanford and Livingston. Seismic measurements will be undertaken next quarter.

Control and Data Systems (CDS). The Data Acquisition Final Design Review (FDR) on May 8, 1998 affirmed the proposed architecture and specific hardware designs, and software development is now underway. The organization of the shared "reflective memory" was defined, and the relationship between the closely-associated but distinct acquisition and diagnostics computation and memory was established. Other specific points receiving attention included the digital signal processors (to be used for the length closed-loop controller and for diagnostics FFT calculation), time definition and propagation using custom Global Positioning Satellite (GPS) receivers and slaves, and software data viewer development.

There was progress in the design of the control systems for the Detector. The FDR was held for the suspension controllers. The Input Optics Preliminary Design Review (PDR) also occurred on

May 13. This review touched on most aspects of the full LIGO interferometer controls in miniature, and the completeness and integration of the design was particularly reassuring.

2.7 Systems Engineering

Integration Schedules. Unified schedules for staging the integration of the LIGO Hanford and Livingston Observatories were developed from a draft schedule for the Washington two kilometer power-recycled, short Michelson interferometer. This schedule was then modified to include the integration of the two kilometer interferometer with Fabry-Perot arms at Hanford. The same build sequence was used to develop the schedule for the four kilometer interferometer at Livingston, and the integration schedule for the four kilometer interferometer at Hanford was a natural extension.

Global Coordinate System for Hanford. Field survey data from multiple sets of measurements of the “as built” beam tube-vacuum equipment interface markers were analyzed using a Chi-square non-linear regression technique to obtain a right handed coordinate system which best describes the “as built” arms. The regression produced the following results:

RMS residuals for fit to two orthogonal axes	0.0052m
Vertex location	Height = 142.554m above WGS84 ellipsoid
	ϕ = " " N 042° 27 ' 18.5280 "
	λ = " " W 119° 24 ' 27.5657 "
X arm bearing (geodetic)	N 35.9994 W, dips 0.0006195 radians below local horizontal
Y arm bearing (geodetic)	S 54.0006 W, dips 0.0000125 radians below local horizontal

Reliability Analysis. The Physics Environment Monitoring (PEM) and Data Acquisition (DAQ) Systems Reliability Prediction Reports provide reliability predictions and availability predictions indicating the contribution of the individual subsystems to the top level LIGO availability. The PEM Reliability Prediction Report was revised to reflect final design documentation. The original release of the DAQ Reliability Prediction Report was based upon preliminary design documentation. The LIGO Maintenance Plan will identify corrective and preventative maintenance tasks, and a spares list for each of the LIGO subsystems. Sections have been prepared for the PEM, Core Optics Components (COC), Suspensions, DAQ, and Input/Output Optics (IOO) subsystems.

2.8 Meetings

The first full meeting of the Gravitational Wave International Committee (GWIC) was held in Livingston, Louisiana on April 22 and 23, 1998. This was followed by the fourth meeting of the LIGO Program Advisory Committee (PAC) on April 23 and 24. Joint meetings and discussions were held April 23.

3.0 Project Milestones

The status of the project milestones identified in the Project Management Plan (PMP) for the LIGO Facilities is summarized in Table 1.

TABLE 1. Status of Significant Facility Milestones

Milestone Description	Project Management Plan Date[a]		Actual (A)/Projected (P) Completion Date	
	Washington	Louisiana	Washington	Louisiana
Initiate Site Development	03/94	08/95	03/94 (A)	06/95 (A)
Beam Tube Final Design Review	04/94		04/94 (A)	
Select A/E Contractor	11/94		11/94 (A)	
Complete Beam Tube Qualification Test	02/95		04/95 (A)	
Select Vacuum Equipment Contractor	03/95		07/95 (A)	
Complete Performance Measurement Baseline	04/95		04/95 (A)	
Initiate Beam Tube Fabrication	10/95		12/95(A)	
Initiate Slab Construction	10/95	01/97	02/96 (A)	01/97 (A)
Initiate Building Construction	06/96	01/97	07/96 (A)	01/97 (A)
Accept Tubes and Covers	03/98	03/99	03/98 (A)	10/98 (P)
Joint Occupancy	09/97	03/98	10/97 (A)	02/98 (A)
Beneficial Occupancy	03/98	09/98	03/98 (A)	09/98 (P)
Accept Vacuum Equipment	03/98	09/98	07/98 (P)	12/98 (P)
Initiate Facility Shakedown	03/98	03/99	07/98 (P)	12/98 (P)

a. Project Management Plan, Revision C, LIGO-M950001-C-M submitted to NSF in November 1997

LIGO has assumed “Beneficial Occupancy” of all buildings in Hanford. “Joint Occupancy” has been achieved for the Livingston site buildings.

The milestone “Accept Vacuum Equipment (WA)” was slipped four weeks during the summer of 1997 to reflect the expected late completion of the X-arm buildings at Hanford. The NSF milestone was not changed because it was anticipated that Process Systems International (PSI) would not require the entire four weeks to finish. The additional six weeks, delaying the milestone to July 1998, are due to a recent floor elevation change order. The floors in the Laser and Vacuum Equipment Area (LVEA) and Vacuum Equipment Area (VEA) at Hanford proved to be more than an inch too low. As a result the subcontractor, PSI, had to order new anchor bolts. Delivery required approximately nine weeks. During this time PSI was only able to work effectively in one building (Y-arm mid-station).

The milestone “Accept Vacuum Equipment (LA)” slipped to reflect the delays in Hanford. The two installations are serially linked because common subcontractor staffing is planned for accomplishing the work. However, the subcontractor is still targeting a Louisiana completion date of

December 1998. The "Initiate Facility Shakedown" milestones are tied to the vacuum equipment acceptance milestones.

Table 2 on page 8 shows the actual and projected status of the significant Project Management Plan (PMP) milestones for the Detector. Every effort has been made to prioritize critical-path tasks as required to support Detector installation.

TABLE 2. Status of Significant Detector Milestones

Milestone Description	Project Management Plan Date		Actual (A)/Projected (P) Completion Date	
	Washington	Louisiana	Washington	Louisiana
BSC Stack Final Design Review	04/98		06/98 (P)	
Core Optics Support Final Design Review	02/98		08/98 (P)	
HAM Seismic Isolation Final Design Review	04/98		06/98 (P)	
Core Optics Components Final Design Review	12/97		05/98 (A)	
Detector System Preliminary Design Review	12/97		07/98 (P)	
I/O Optics Final Design Review	04/98		03/98 (A)	
Prestabilized Laser Final Design Review	08/98		10/98 (P)	
CDS Networking Systems Ready for Installation	04/98		03/98 (A)	
Alignment (Wavefront) Final Design Review	04/98		07/98 (P)	
CDS DAQ Final Design Review	04/98		05/98 (A)	
Length Sensing/Control Final Design Review	05/98		07/98 (P)	
Physics Environment Monitoring Final Design Review	06/98		10/97 (A)	
Initiate Interferometer Installation	07/98	01/99	07/98 (P)	01/99 (P)
Begin Coincidence Tests	12/00		12/00 (P)	

The I/O Optics Final Design Review (FDR) was held March 25, 1998. The Data Acquisition FDR was held May 8, 1998. The Core Optics Components FDR was held late in the quarter. Installation of the CDS Networking Systems also began this quarter.

The Seismic Isolation (BSC and HAM) FDR is scheduled for June 12, 1998. This review will focus on the structural components with an update for the actuation system to be held at a future date.

The projected completion date for the Core Optics Support final design review is now August 1998. Significant scope originally in this task has been moved to the suspension task (the final design review has already been completed), and this deferred some “need” dates for the Core Optics Support. The delay leaves unaffected the target date for first operation of the LIGO interferometers. A better understanding of the requirements and design for the Core Optics Support has reduced the expected fabrication time, and all critical components are expected to be ready in time to avoid installation delays.

The Core Optics Components final design review has also been delayed by approximately three months. In this case, an aggressive procurement strategy has been instituted which permits initial fabrication steps to begin prior to the final design review without incurring significant risk and, in fact, reduces costs by allowing time for rework of any parts damaged as opposed to requiring additional spares.

The initial alignment component (for which site deliveries are required late in 1998) has been uncoupled from the other Alignment Sensing and Control tasks, and the final design for initial alignment has been completed and reviewed. The remaining Alignment Sensing and Control and Length Sensing and Control components are not required for integration until May 1999. The revised final design review dates are thus consistent with timely fabrication and integration, and are not expected to affect site operations.

Delaying reviews of the Length Sensing and Control and the remaining components of the Alignment Sensing and Control until summer 1998 allows us to complete extensive closed-loop testing at Caltech and the Phase Noise Interferometer (PNI) at MIT. These tests are in progress and should be essentially complete by June, with required modifications incorporated into the designs before the final design review.

4.0 Financial Status

Table 3 on page 10 summarizes costs as of the end of May 1998.

TABLE 3. Costs and Commitments as of the end of May 1998

(all values are $Thousands)

WBS		Costs Thru Nov 1997	First Quarter LFY 1998	Mar-98	Apr-98	May-98	Cumulative Actual Costs	Open Commitments	Total Cost Plus Commitments
1.1.1	**Vacuum Equipment**	30,517	3,389	2,958	1,756	479	39,097	7,907	47,004
1.1.2	**Beam Tube**	32,978	5,703	1,395	2,376	1,794	44,246	6,373	50,619
1.1.3	**Beam Tube Enclosure**	13,274	1,987	0	901	747	16,909	5,022	21,931
1.1.4	**Civil Construction**	44,681	4,249	973	(1,167)	300	49,036	5,369	54,404
1.1.5	**Beam Tube Bake**	75	704	223	499	114	1,615	884	2,499
1.2	**Detector**	14,340	4,363	1,040	1,523	1,541	22,807	12,003	34,810
1.3	**Research & Development**	19,681	670	45	124	48	20,568	1,322	21,890
1.4	**Project Management**	22,649	1,459	474	535	415	25,533	1,901	27,434
7LIGO	**Unassigned**	1	6	-	3	1	11	16	26
	Installation and Commissioning	330	840	72	107	79	1,428	678	2,106
TOTAL		178,526	23,370	7,179	6,657	5,516	221,249	41,474	262,723
Cumulative Actual Costs		178,526	201,896	209,075	215,732	221,249			
Open Commitments		62,510	47,085	43,458	40,052	41,474			
Total Costs plus Commitments		241,036	248,981	252,534	255,784	262,723			
NSF Funding		*$ 208,468*	*$ 265,089*	*$ 265,089*	*$ 291,948*	*$ 291,948*			

Note: "Unassigned" Costs have not been assigned to a specific LIGO Construction WBS but are continually reviewed to assure proper allocation

5.0 Performance Status (Comparison to Project Baseline)

Figure 1 on page 12 is the Cost Schedule Status Report (CSSR) for the end of May 1998. The CSSR shows the time-phased budget to date, the earned value and the actual costs through the end of the month 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. Figure 2 on page 13 shows the same information as a function of time for the top level LIGO Project.

Vacuum Equipment (WBS 1.1.1). The favorable schedule variance is due to being ahead of schedule with fabricating the hardware for the Louisiana site. Installation is actually somewhat behind schedule in Hanford. However, the contractor plans to complete the contract early.

The increased estimate-at-completion reflects change requests that have not yet been submitted to the LIGO Change Control Board.

Beam Tube (WBS 1.1.2). There has been significant improvement in the schedule variance due to the acceptance of all four modules at Hanford and credit taken for completing fabrication of all 400 Beam Tube sections for Livingston (14 weeks ahead of schedule), and installation of the first 389 Beam Tube sections in Livingston (16 weeks ahead of schedule).

The estimate-at-completion reflects change requests that have not yet been finalized for submittal to the LIGO Change Control Board for additional cleanliness tests, baffle cleaning, the purchase of vendor owned equipment that was used in the manufacture and installation of the Beam Tube and will be useful during facility operations, additional taxes, etc.

Beam Tube Enclosures (WBS 1.1.3). The contract for the Hanford site is complete with the exception of "punch list" items, and most of the enclosures have been cast for the Livingston site.

Installation of the Beam Tube Enclosure is approximately three months ahead of schedule primarily because installation of the Beam Tube is ahead of schedule. Dry weather has also helped.

An overtime supplement for installation of the Beam Tube Enclosure to support the CB&I installation rates was included in the budget. However, this supplement was not required by the subcontractor. In addition there are possible state tax benefits that are being negotiated with the subcontractors. These reductions have been reflected in the estimate-at-completion, and change requests will be processed when the contracts are finalized and the issues resolved.

Civil Construction (WBS 1.1.4). Civil Construction is ahead of schedule. The facilities in Hanford are complete. The subcontractor in Livingston is also pushing to complete ahead of schedule.

Detector (WBS 1.2). The Detector is behind schedule and under cost. The Detector planning continues to emphasize the delivery of hardware to support installation of the first interferometer. Priorities have been adjusted to assure that critical milestones are met.

LIGO Project

Cost Schedule Status Report (CSSR)

Period End Date: 30 May 1998

(All values are $Thousands)

Reporting Level	Cumulative To Date					At Completion		
Work Breakdown Structure	Budgeted Cost of Work Scheduled (BCWS)	Budgeted Cost of Work Performed (BCWP)	Actual Cost of Work Performed (ACWP)	Schedule Variance (2-1)	Cost Variance (2-3)	Budget-at-Completion (BAC)	Estimate-at-Completion (EAC)	Variance-at-Completion (6-7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.1.1 Vacuum Equipment	37,887	39,045	39,097	1,158	(52)	43,424	43,740	(316)
1.1.2 Beam Tubes	40,206	43,881	44,246	3,675	(365)	47,109	47,286	(177)
1.1.3 Beam Tube Enclosure	17,658	19,173	16,909	1,515	2,264	19,891	19,066	825
1.1.4 Facility Design & Construction	49,664	50,578	49,036	914	1,542	51,145	50,950	195
1.1.5 Beam Tube Bake	2,047	2,047	1,615	-	432	4,879	4,879	-
1.2 Detector	35,088	28,075	22,816	(7,013)	5,259	54,613	54,129	484
1.3 Research & Development	23,030	23,030	20,568	-	2,462	23,490	23,488	2
1.4 Project Office	25,007	25,007	25,530	-	(523)	33,153	34,315	(1,162)
Subtotal	230,587	230,836	219,817	249	11,019	277,704	277,853	(149)
Contingency						-	14,247	(14,247)
Management Reserve						14,396	-	14,396
Total	230,587	230,836	219,817	249	11,019	292,100	292,100	-

FIGURE 1. Cost Schedule Status Report (CSSR) for the End of May 1998

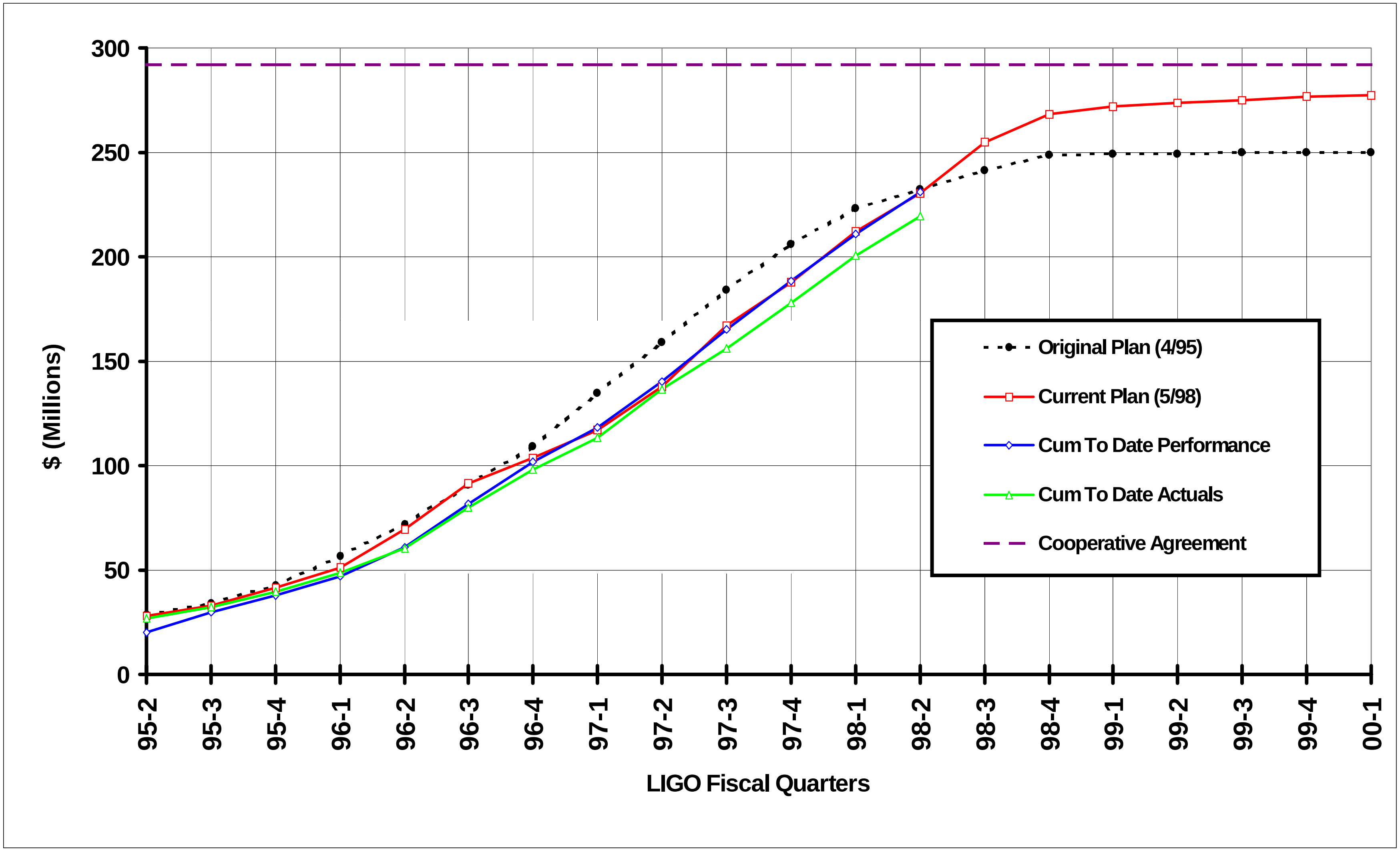

FIGURE 2. LIGO Construction Performance Status as of the End of May 1998

Laser and Optics - Core Optics Component fabrication is on schedule. The Prestabilized Laser prototype is being tested and will be available for shipment to Hanford, Washington when needed. Input Optics fabrication is approximately one month behind schedule, but components will still be available to support installation.

Seismic Isolation - The Seismic Isolation effort is approximately two months behind schedule. The procurement process has proved to be more time consuming than anticipated, and technical issues with welding and cleaning have taken considerable effort to resolve. First article assembly and testing is underway for both the Beam Splitter Chamber (BSC) and Horizontal Access Module (HAM) Seismic Isolation systems. Installation will begin as soon as the Vacuum Equipment is available, but will be paced by fabrication schedules. Components are being released for fabrication as soon as their designs are proven in the first article test to minimize delays.

Interferometer Sensing and Control - The Alignment Sensing and Control (ASC) effort is behind schedule. The Initial Alignment System (needed first for installation) is on schedule. The Length Sensing and Control (LSC) effort benefited from final testing of a digital servo on the Phase Noise Interferometer (PNI). Final Design Reviews for the ASC and LSC are scheduled for July.

Control and Data Systems - There are minor behind schedule positions reported for the controls for the Pre-stabilized Laser (one month), the Alignment Sensing and Control System (the Preliminary Design Review is one month late), and the Length Sensing and Control System (the Preliminary Design Review is two months late).

Project Office (WBS 1.4). The Project Office is reporting an unfavorable cost variance. The added costs have been incurred to support scheduling and integration activities, and general computing. The overrun is being reflected in the Estimate-at-Completion, and change requests are being prepared to address the added scope.

6.0 Change Control and Contingency Analysis

Fourteen change requests (see Table 4) were approved during this reporting period. These change requests allocated $8.7 million from the contingency pool with corresponding additions to the budget baseline used for preparing the end-of-May 1998 reports. The current contingency pool is $14.2 million (relative to the estimate-at-completion).

TABLE 4. Change Requests Approved During the Second Quarter LIGO FY98

CR Number	WBS	Description	Amount
CR-970037 A	1.4.3-4	LIGO Data Analysis System (LDAS)	5,579,000
CR-980005	1.1.4	Extension of Parsons Support at Hanford	68,000
CR-980006	1.2	Seismic Isolation - Increased Costs for Cleaning Springs and Fabricating Bellows	147,052
CR-980007 A	1.1.5	Beam Tube Bake - Adjustments to reflect actual costs and current bids	1,008,000
CR-980008	1.1.1	Vacuum Equipment Miscellaneous Changes	164,241
CR-980009	1.1.1	Vacuum Equipment Changes	472,020
CR-980010	1.1.2	Beam Tube Taxes/Module End Conditions	59,574
CR-980011	1.1.5	Beam Tube Bake - Electrical Power	307,000
CR-980013 A	1.1.4	Added Scope (Field Work Directives) at Livingston	272,430
CR-980014	1.1.4	Added Scope (Field Work Directives) at Hanford	139,645
CR-980015	1.1.1	Vacuum Equipment contract modifications for Payment Milestones	55,335
CR-980016	1.1.4	On-site telephone upgrade - Hanford	60,000
CR-980017	1.2.2	CDS Spares, Suspensions Test Statnds, and Travel	265,580
CR-980018	1.1.3	Asphalt paving of Service Roads at Livingston	95,351
		Total	8,693,228

7.0 Staffing

The LIGO staff currently numbers 132 (full time equivalent). Of these, 42 are contract employees. Ninety LIGO staff are located at CIT including seven graduate students. Eighteen are located at MIT including six graduate students. Sixteen are now located at the Hanford, Washington site, and eight are assigned to Livingston, Louisiana.

TABLE 5. LIGO Staffing as of the May 1998