Quarterly Progress Report

(End of May 2001)

THE CONSTRUCTION, OPERATION AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)
NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M010198-00-P

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1.0 Introduction

This Quarterly Progress Report is submitted under NSF Cooperative Agreement PHY-9210038[1]. The report summarizes the progress and status of the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project for the LIGO fiscal quarter ending May 2001.

Facility construction, including the vacuum system, is complete. All Beam Tube modules have completed vacuum bake, and we are installing and commissioning the detectors. The project continues to make excellent progress and is 97.1 percent complete as of the end of May 2001[2].

2.0 Vacuum Equipment

All Process Systems International (PSI) field activities are complete. All scheduled payment milestones are complete, and the PSI contract is closed out.

3.0 Beam Tube

All Beam Tube modules have been accepted, and all contract work is complete.

4.0 Beam Tube Enclosures

Washington Beam Tube Enclosure. Construction activity is complete. The contracts for the fabrication and installation of the Beam Tube Enclosure are closed.

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.
2. Percentage completion is calculated by dividing the budget for work completed by the total budget (BCWP/BCWS). The allocation of budget tends to hold down the percent complete by increasing the BCWS. Recent allocations of contingency by the LIGO Change Control Board to restore scope originally removed to manage program risks have retarded the reported percent complete.

Louisiana Beam Tube Enclosure. Fabrication and installation of all enclosure segments are complete. The contractor has finished all construction activities along both arms and the contract is closed.

5.0 Civil Construction

Washington Civil Construction. Construction activities for the facilities are complete. This includes the completion of the Staging and Storage Building. An Architect/Engineering firm, NTD Architects of Glendora, CA, has been selected to design an additional Office and Laboratory building including an auditorium and other facilities for outreach activities. No additional Construction funds will be required.

Louisiana Civil Construction. Construction of the facilities is complete and the contracts are closed. Erosion control and landscaping are complete. We issued a contract during the first quarter to Brunt Construction Company of Independence, LA for the construction of the Staging and Storage Building. Work is in progress.

6.0 Beam Tube Bakeout

We completed the bake of all four Beam Tube modules at Hanford during 1999 and finished the final module at the Livingston site in June 2000. One module at Livingston (LY1) appears to have a very small leak. Attempts to localize and repair this leak were unsuccessful because the rate is so small. We continue to monitor the vacuum in this module to determine if some future action is necessary. At this time, the magnitude of this leak does not present an obstacle to continuing commissioning activities.

7.0 Detector

The Detector group is focusing on the installation and commissioning at the observatories. In parallel we are revising designs based on commissioning experience. Installation is nearing completion, with re-work after initial commissioning a continuing important activity.

7.1 Installation and Commissioning Progress Overview

The installation highlights for the past quarter are:

- We have operated the Livingston four-kilometer interferometer as a recombined Fabry-Perot interferometer for periods up to several hours. We have also exercised other optical configurations.
- We held the fourth engineering run May 11-14, with coincident data collection between the Livingston interferometer in recombined mode and the environmental monitors at Hanford.
- Installation of in-vacuum components is almost complete for the Hanford four-kilometer interferometer.
- We completed the repair and re-installation of the Hanford two-kilometer interferometer during this quarter.

- Both the two-kilometer and four-kilometer system lasers and mode cleaners have operated simultaneously, allowing the start of cross-correlation studies.

Just before the beginning of the quarter, a magnitude 6.8 earthquake (the strongest in Washington State since 1949) struck near Olympia. The ground motion was severe enough to break control magnets off some of the suspended optics in the two-kilometer interferometer. We immediately initiated repairs, which were completed during this quarter in parallel with the four-kilometer interferometer installation. The first diagnostics and the first look down the Beam Tubes indicate that the reconstructed two-kilometer interferometer is better aligned than the initial installation, with several improvements having been successfully incorporated. The damage required roughly three months to repair including changes to the caging system to prevent such damage in the case of a repeat event.

7.2 Lasers and Optics

7.2.1 Pre-Stabilized Laser

At the close of the quarter, we are regularly using both Hanford Pre-stabilized Lasers and the Livingston Pre-stabilized Lasers. Based on experience from the earlier lasers, we have implemented a simplified optical layout on all lasers. This and the addition of acoustical shielding around the table have significantly reduced the measured number and height of resonant peaks in the rebuilt two-kilometer mode cleaner. A comparison of the frequency noise at the output of the laser before and after the alterations is shown in Figure 1. The system now exceeds requirements at low frequencies, and is within a linear factor of two at high frequencies.

We have designed and built a prototype of an intensity stabilization servo, and tests are beginning at Hanford in situ. We are modifying the servo systems of all the lasers to bring them to a uniform design and level of performance based on commissioning experience at both observatories. A number of lasers have been returned to the fabricator, Lightwave, for repairs, principally due to ageing master laser pump diodes, but sufficient spares exist to operate with backups.

7.2.2 Input Optics

The Mode Cleaners for the Livingston four-kilometer interferometer continue to function reliably supporting other commissioning activities, and to play a key role in understanding pre-stabilized laser performance. Post-earthquake repair of the two-kilometer Mode Cleaner at Hanford was initiated and completed this quarter, and the installation of the four-kilometer Hanford Mode Cleaner was also completed. Initial testing indicates that the installations were very successful.

In particular, we have replaced the local sensors for the suspensions in the Hanford interferometers to reduce sensitivity to stray Nd:YAG laser light. Previous to this rework, it was impossible to increase the laser power at the input to the Mode Cleaner beyond several hundred mW without seeing the effects of cross-coupling as an increase in the angular motion of the optics. After the rework, the two-kilometer Mode Cleaner operates without difficulty up to the full six Watt input laser power.

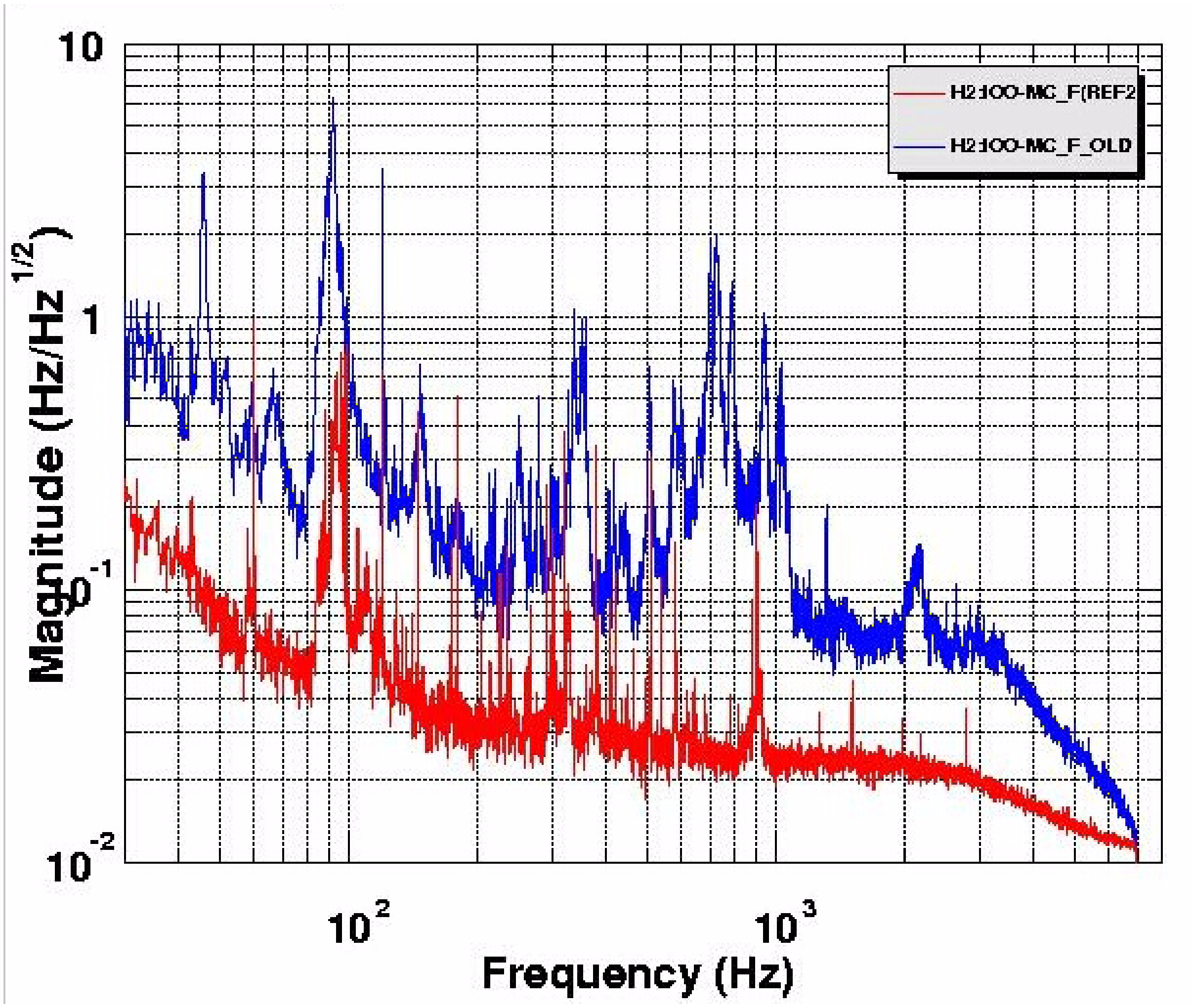

FIGURE 1. The frequency noise of the Pre-Stabilized Laser, as measured by the Mode Cleaner, for the Livingston two-kilometer system. Note the reduction in the height and number of narrow features, and the overall reduction in noise floor.

7.2.3 Core Optics Components

We have characterized the core optics for all three interferometers and delivered them to the sites for installation. All but one (an end test mass in the four-kilometer Hanford interferometer) have been installed. We have returned some spares with unsatisfactory or damaged coatings to our polisher to be reworked.

7.2.4 Core Optics Support

We have completed installation and alignment of all core optics support components.

7.3 Isolation

7.3.1 Seismic Isolation System

We completed the installation of the in-vacuum seismic isolation system last year. The design of the fine actuator system to be used to correct for the tidal motion was completed last quarter. We are installing the control electronics for the two-kilometer interferometer, and testing will begin now that earthquake repairs are complete.

7.3.2 Suspensions

This quarter we focused on modifications of the suspensions to improve resistance to earthquake damage. Several incremental changes provide a significant improvement:

- Procedures had not ensured that top and bottom stops (eight total) were set to a proper distance, allowing excess motion. With the rebuild of the two-kilometer interferometer and the installation of the four-kilometer interferometer at Hanford, and with rework of the Livingston interferometer starting now, all stops are being set to small well-controlled distances.
- It proved difficult to set chamfer stops (eight total) to a proper distance due to thread runout, blunt tips, and coarse threads. The stops have been re-worked to reduce the runout.
- We developed a new design with a conical tip, and these are being installed (see Figure 2.) This increases the damping if the mass bounces against the stop, and makes precise setting of the tip possible because of the accurately manufactured surface.

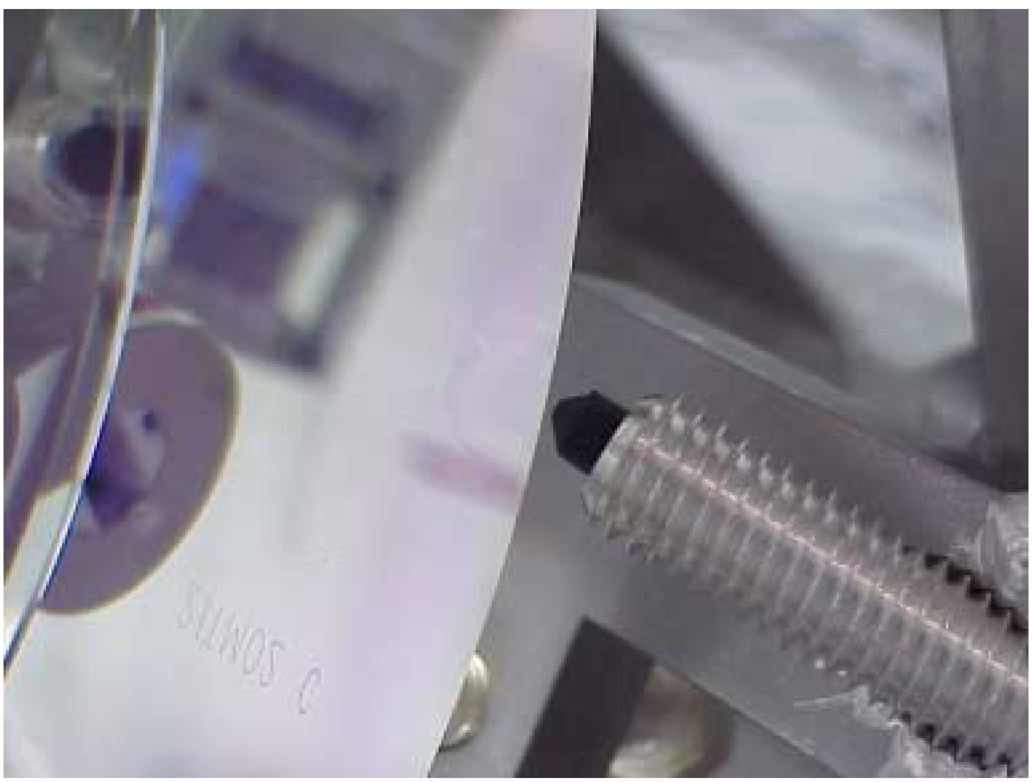

FIGURE 2. Close-up photograph of the new conical tip and the small spacing (0.5 mm) to the edge of the suspended optic to limit motion.

Additional design changes are being considered that would be installed during future windows of opportunity, but we believe the current design will survive another earthquake of this severity without the loss of attachments that necessitated reconstruction this time.

We completed the installation and alignment of the vertex large optic suspensions for the Hanford four-kilometer interferometer this quarter, and in parallel finished the post-earthquake re-installation of a number of the Hanford two-kilometer suspensions. These suspensions incorporate a new design for the sensors used for local damping of the suspended optics; the previous design proved susceptible to stray Nd:YAG light from the main laser. This can cause misalignment of the optics as the interferometer is locked and the laser light builds in the cavities.The sensors on the Livingston interferometer will also be replaced in conjunction with other planned in-vacuum activities. As noted, initial tests on the Mode Cleaner optics with the new sensors show that they perform well and solve the coupling problem.

We completed the initial characterization of the Livingston Mode Cleaner and prepared a list of issues to be corrected when the Livingston vacuum system is vented; in particular, the mechanical Q of some of the suspended optic pendulum motions is anomalously low and may require re-suspension of the optics in question.

We have installed new digital suspension controllers on the Hanford four-kilometer interferometer. These controllers allow frequency dependent matrices relating either the sensors or external inputs to the drive forces on the mirrors, which will be important for reducing the cross-coupling between the angle and translation feedback signals as we approach our overall design sensitivity. The initial tests with the new controllers indicate that they function correctly, and fabrication and installation for the other interferometers will proceed.

7.3.3 Control and Data Systems (CDS)

The Control and Data Systems (electronics and software) group continues essential contributions during installation and commissioning of the subsystems and during system level testing. The data acquisition system is operating at both sites.

This quarter we accelerated work on the computation model for the digital length control servo system. As the locking process was refined on the Hanford two-kilometer interferometer, the need became apparent for additional capability and accessibility to more internal test points in the code. Newer, faster CPUs have been implemented, requiring some changes in the servo coding and in interfaces to the overall system (e.g., high/low byte swapping). We are now testing the new functionality.

Another emphasis has been to upgrade the operating system to the most recent release of Sun Solaris; this is necessary to interface correctly to the LIGO Data Analysis System (LDAS) code. We intend to freeze all code to this operating system version until necessity dictates otherwise.

Adopting digital (as opposed to analog) suspension controllers (see Section 7.3.2) allows us to use common code among the various subsystems and provides enormous flexibility in the control laws that can be implemented. This has been a focus of effort in the CDS group this quarter.

7.4 Physics Environment Monitoring System

The Physics Environment Monitoring system is now functional and in regular use. Trend data (e.g., seismic activity) are regularly compiled and reviewed for anomalies or correlations with interferometer data. Verification and calibration of signals is an on-going task at both sites.

7.5 Global Diagnostics System

We regularly use the Global Diagnostics tools, together with the CDS data acquisition system, to support commissioning activities. We have made important enhancements to these tools to enable their use from outside of the main interferometer computer network.

7.6 Interferometer Sensing and Control

We continue to use and refine the Livingston sensing and control system. We have used it to lock a variety of optical configurations, and it has been key in understanding the optical and mechanical system.

At Hanford, we have dedicated most of this quarter to reconstruction of the two-kilometer interferometer and the initial installation of the four-kilometer interferometer. Initial tests of the two-kilometer interferometer vertex control system at the close of the quarter indicate that the system is functioning and ready to be used during the re-commissioning.

7.7 System Level Commissioning/Testing

Commissioning activity was significant at the Livingston Observatory this quarter. Locking of the full interferometer requires a series of systematic steps: first the power-recycled Michelson (PRM) is locked, then the PRM plus one arm, then the PRM plus both arms.

- The recombined interferometer (non-power recycled) acquires lock quickly (within 1-2 minutes) and stays locked typically for 10 minutes.
- We have also operated and studied the power recycled Michelson (no arms). It can be locked on the carrier or RF sideband resonance in the recycling cavity, and the power buildup for each case is approximately as expected. The system exhibits recycling cavity power drop transients, of duration on the order of 0.2 seconds.
- We attempted to lock the power recycled recombined Fabry-Perot Michelson. The system did not lock but there were moments when both cavities were in resonance and a power buildup over a single cavity resonance of 15 was measured.

There is some evidence that the compromise in dynamic range due to several non-functioning suspension actuator coils on both end test masses in conjunction with the relatively large seismic noise in the critical 1 to 3 Hz band at Livingston is the cause of the difficulties in locking the entire system. The actuators will be repaired during the coming quarter.

At Hanford, we focused on the reconstruction of the two-kilometer and initial installation of the four-kilometer interferometers, and the commissioning effort is just starting again as the quarter closes.

Analysis of the E3 run data has provided some insight into correlations at a given site and between sites. For example, we investigated the coherence between the power line monitors and magnetometers at the two sites, at 60 Hz and harmonics. The initial results indicate:

- The broadband noise on the line monitors (between the line frequency/harmonic peaks) is about 10 times higher at Livingston than at Hanford. The Hanford line monitors show a lot of structure between the line harmonics, but any such structure on the Livingston lines is masked by the higher broadband noise.
- At a given site, the coherence between a line monitor and a magnetometer is essentially unity at the line frequency and harmonics.
- The coherence between a line monitor at Livingston and a line monitor at Hanford (at 60 Hz) is essentially unity over short time scales (less than 60 seconds), but becomes small over time scales longer than a few hundred seconds. For example, ten coherence measurements over 1000 seconds (each) yielded coherence values between 0.01 and 0.1. Over 10,000 seconds, one measurement gave a coherence of approximately 0.001.

The E4 Engineering Run took place this quarter. We operated the Livingston interferometer as a Recombined Fabry-Perot Michelson for the full duration, and at Hanford we monitored environmental signals (this was shortly after the earthquake, and we were checking the status of the interferometers and assessing damage). A number of LIGO Scientific Collaboration (LSC) visitors and many staff members were present at both observatories pursuing detector characterization investigations and assuring optimal operation. Numerous *Data Monitoring Tool* (DMT) processes produced valuable information during the full run, mostly relating to detector diagnostic studies and investigations. We recorded approximately 400 Gigabytes of reduced data, with good performance from the data acquisition and analysis systems.

7.8 Work planned next quarter:

During the next quarter we plan to:

- lock the full Hanford four-kilometer interferometer and start commissioning activities,
- bring the Hanford two-kilometer interferometer back into operation and continue commissioning activities,
- complete the re-work and upgrade of the Livingston interferometer, and re-commence commissioning,
- perform an Engineering Run with the two Hanford interferometers, and the Livingston four-kilometer interferometer.

8.0 Data and Computing Group

8.1 Modeling

During this quarter the Modeling Group:

- completed an algorithm for calculating the power spectral density of data streams with wide dynamic range,

- incorporated an alternative linear prediction tool into the end-to-end model that can provide a better estimate of the power spectrum,
- prepared a software tool for converting end-to-end data into the standard frame format defined for LIGO and other gravitational-wave detectors (the tool is ready to provide simulated data to the Mock Data Challenge groups and test data for LDAS),
- continued in our efforts to improve the stability and flexibility of the *alfi* graphical user interface (*alfi* started simple, but has evolved with the simulation engine to fulfill complex new requirements. The current legacy code is difficult to maintain, and we are considering a rewrite using JAVA.)

8.2 LIGO Data Analysis System (LDAS)

8.2.1 Software Systems

LDAS Software Releases. We released three new versions of LDAS this quarter. The first, *ldas*-0.0.15 released March 6, 2001, was used during the E3 Engineering Run. *ldas*-0.0.16 released April 9, fixed bugs and provided enhancements in response to experience gained during E3. *ldas*-0.0.17 released on May 14, included the new *dataPipeline* user command interface needed to support the Inspiral Upper Limits Group Mock Data Challenge as well as minor enhancements to support future engineering runs. Each release has improved software reliability.

LDAS Engineering Runs. Utilization of LDAS during the LIGO Engineering Runs steadily increased during this quarter. LDAS was responsible for collecting the data and writing frame files to tape. LDAS staff at Caltech was responsible for manually ingesting this data into the High Performance Storage System (HPSS) tape storage system located at the Caltech Center for Advanced Computing Research (CACR). No frames from the data acquisition system (DAQS) *framebuilder* software were lost.

With the E3 Engineering run, LDAS also began to analyze datasets using the existing infrastructure for selecting channel data for user specified epochs and perform various statistical and signal processing steps using the *dataConditionAPI*. The results were also inserted into the LIGO/LDAS database using the same LDAS infrastructure and the *metaDataAPI*. All of this functionality was available to users of LDAS during the engineering run with the *conditionData* LDAS user command. Figure 3 below illustrates one of the more complex calculations performed using the *dataConditionAPI*. Differential seismic motion between seismometers in the interferometer arms was analyzed for coherence with the anti-symmetric quad phase of the length sensing control signal for each of the three independent axes. These calculations required processing 30 minutes of data for each of ten channels every hour during the E3 run.

LDAS Mock Data Challenges. The only Mock Data Challenge (MDC) scheduled this quarter was the *Inspiral Upper Limits Inchpebble MDC*. This was the first suite of tests to use every LDAS software component in a single user command called the *dataPipeline* command.Using this command, we collected data from *frame* files based on channel selection and time epoch specified by the user using the *frameAPI*. The integrated dataset was sent to the *dataConditionAPI* where the signal was processed for broader search strategies to be conducted on the parallel cluster of compute nodes (Beowulf).Two different classes of search codes were then executed on the cluster to look for binary inspiral events. Event results were sent to the *eventMonitorAPI* where

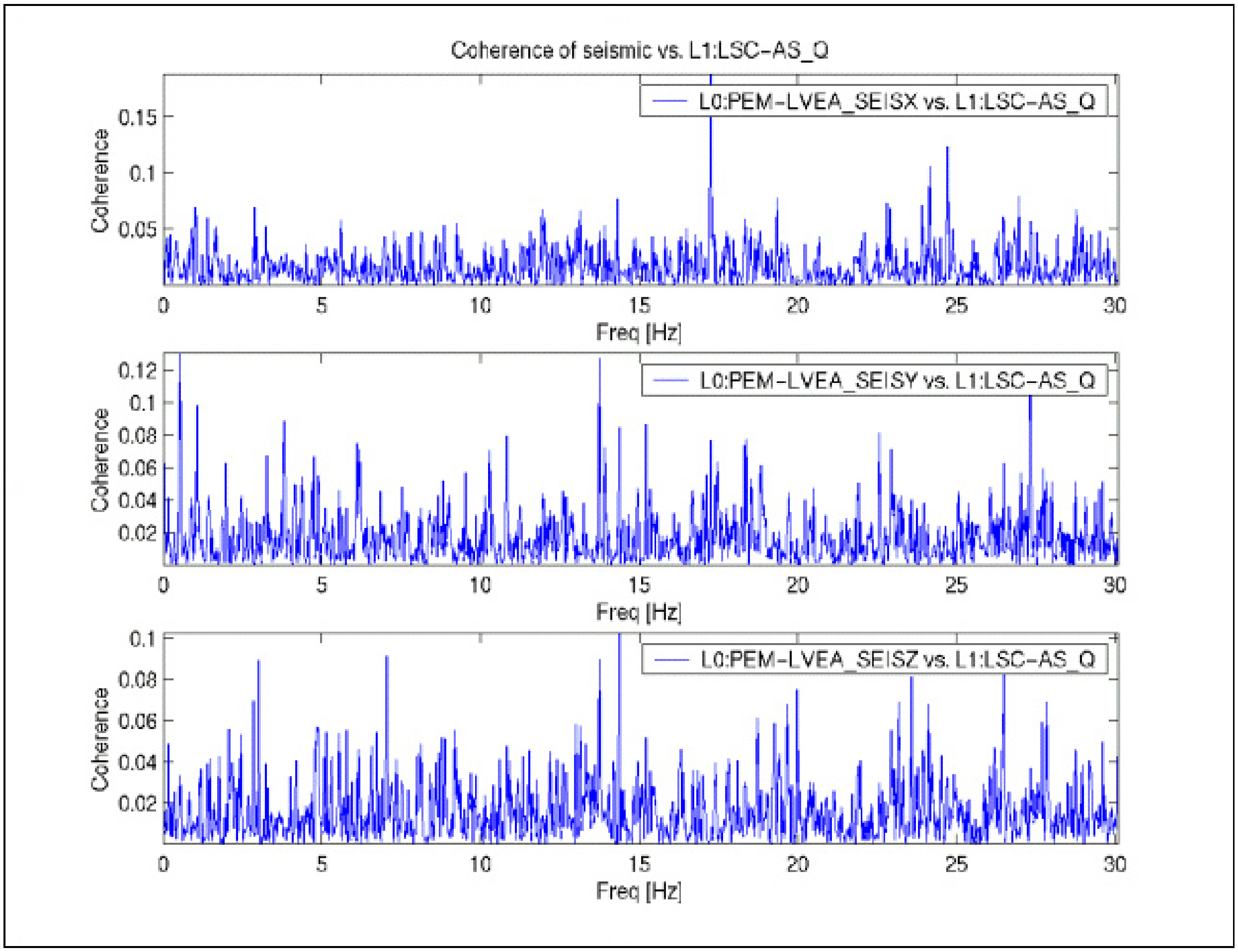

FIGURE 3. Cross-spectra and coherence measurements made during the E3 run with LDAS software operating at Hanford, Livingston, and Caltech.

they were parsed and any of three distinct types of data structures found were forwarded for insertion into the database or distribution to end users. Each step was checked and verified during the MDC.

The two unique searches conducted included for the first time a hierarchical, template-based analysis using second order post-Newtonian waveforms as well as a more general search strategy known as the *Fast Chirp Transform* (FCT) developed at Caltech. These searches were successfully executed. However, an issue identified involving the conventions and normalizations for transformation quantities with Fourier Transforms and power spectrum estimators prevented us from completing the double blind final challenge tests during the scheduled week. An effort was initiated to standardize these transformations across all LIGO and LIGO Scientific Collaboration (LSC) code development projects, and the double blind challenge will be repeated next quarter.

The third Mock Data Challenge started in January 2001 was completed during April. It rigorously tested the functionality of software components involved in inserting data into the database and executing queries to retrieve data subsets. A number of problems, many related to atypical cases and exception handling, were found and corrected. The system operated robustly during engineering runs E3 and E4, receiving a large number of environmental triggers generated by the *Data Monitoring Tool*. The system will support LIGO's projected needs.

LDAS Boot Camp. We invited the members of the LIGO Scientific Collaboration (LSC) to attend a one week workshop focusing on the skills needed to develop code using LDAS and the LIGO/LSC Algorithm Library (LAL). This workshop, which we called the LDAS "Boot Camp," was held at Caltech during the first week of June 2001. We also addressed development using the Diagnostic Monitoring Tool (DMT) in a parallel session. Approximately 25 LSC members attended the workshop.

8.2.2 Hardware Systems

We continue to archive all trend frames from both observatories as well as the full frames from the engineering runs. The current archive contains 13 Terabytes of data[3]. We successfully captured and sent to Caltech all of the full frames recorded during the E4 Engineering Run.

We have installed and configured the phase I equipment for LDAS. The system comprises 28 Terabytes of disc storage, a 6000-slot tape silo, and Beowulf clusters for Hanford and Livingston. We have ordered the remaining phase I equipment for MIT and it is being delivered.

8.2.3 Data Analysis Activities

Hierarchical Search Code Enhancements. We initiated two research efforts to improve the hierarchical binary search algorithms by taking advantage of the frequency dependence of the signal-to-noise ratio.

The first, the Multi-Band Template Analysis (MBTA), was undertaken by Dr. Benoit Mours, who has been on a sabbatical visit from VIRGO for the 2000/2001 academic year. The technique splits the detector output into several non-overlapping frequency bands to minimize FFT computational costs. It offers an efficient, built-in hierarchical approach and is extensible for multiple detectors. Analysis indicates a potential for improving performance by as much as a factor of 100. We have, therefore, initiated development of prototype code.

During a six-week visit by Professor S. Dhurandhar (Inter University Center for Astronomy and Astrophysics, Pune, India), we investigated an alternative using the novel idea of decimation in time. The hierarchical search algorithm, developed by Mohanty and Dhurandhar and being implemented by the LIGO Scientific Collaboration (LSC) Upper Limits Inspiral Group, uses two template grids, one coarse, one fine. During the first stage, the coarse templates are employed to identify candidates, which are then evaluated using the fine grid templates. The improvement relative to a search performed using only a fine grid search was demonstrated to be a factor between 20 and 30. Further reductions in computational costs are possible if we truncate the waveform to take advantage of the fact that most of the signal power is in the lowest frequencies. Estimates indicate computational efficiencies comparable to the MBTA approach.

3. see http://www.srl.caltech.edu/personnel/sba/ligo/hpss.

We need to improve the estimates by tiling the parameter space more efficiently taking into account boundary effects, waveform upper limits for larger masses, etc., and this work is in progress.

Data Exchange and Network Analysis. Following the February 2001 Network Data Analysis Meeting organized by the Gravitational Waves International Committee (GWIC), we started to set-up the environmental data exchange with other gravitational wave detectors. A Data Monitor Tool has been written and is running at the Livingston and Hanford sites to produce data files containing seismometer, power line, and magnetometer information. The data are now available to other groups participating in this project. A similar process as been set up by VIRGO, and the data transfer from the VIRGO Cascina site to Caltech has started. The data from the two LIGO sites and the VIRGO site have been set to the same sampling rate and merged; they are now available as different channels in the same data files. We have created Web pages with minimal statistical information. The development of simple characterization methods is underway.

We have started a collaboration with the Inter University Center for Astronomy and Astrophysics in Pune, India, on network analysis for detecting coalescing binaries. The strategy for performing coherent analysis with the LIGO detectors and including VIRGO and other interferometers has been reviewed. Work is underway to delineate the different scenarios and deduce the computational implications. Figure 4 on page 12 depicts the combined antenna pattern that follows from the network analysis for the two LIGO sites, and Figure 5 shows the pattern for the combination of the two LIGO sites and VIRGO[4].

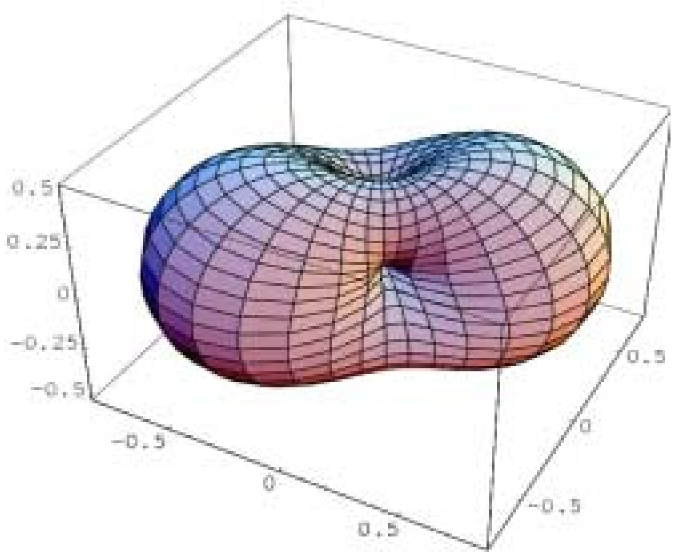

FIGURE 4. Signal-to-noise ratio for the three LIGO detectors, as a function of the source direction, averaged over the binary orientation and wave polarization. The normalization is with respect to a source with optimal orientation and polarization for all detectors. Notice the presence of two main lobes and four minima.

4. see http://wwwcascina.virgo.infn.it/otherDetectors/NdasStatus.htm

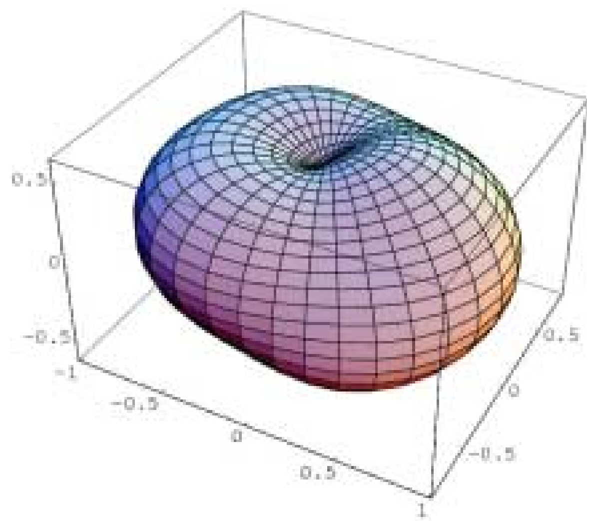

FIGURE 5. Signal-to-noise ratio including the VIRGO detector in the network. Thanks to the different orientation of VIRGO, two of the minima are filled, and the sensitivity pattern is more uniform. The plot assumes that the signals from the three LIGO interferometers plus VIRGO are analyzed coherently.

8.3 Laboratory Information Technologies Group

NSF Review panels have suggested establishing a Wide Area Network (WAN) to the observatories for distributing LIGO data, and we are investigating options. WAN enhancement in the near term will consist of installing additional T1 capacity at each site.

The NSF Review Panel also suggested that LIGO consider ways to reduce the threat of damage to LIGO data by unauthorized intruders on the LIGO network. As a first step, we are establishing a system for reporting and documenting computer related incidents, similar to that used in the Safety reporting system.

The new procedure that the LIGO Document Control Center (DCC) is now using to acquire and display documentation for the LIGO Scientific Collaboration (LSC) has proven to be a success. Many LSC colleagues have provided feedback that the improvements have been of substantial assistance in accessing the LIGO document database.

9.0 Project Management

9.1 Project Milestones

The status of the project milestones identified in the Project Management Plan for the LIGO Facilities is summarized in Table 1. **All Facilities milestones have been completed.**

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 (A)
Joint Occupancy	09/97	03/98	10/97 (A)	02/98 (A)
Beneficial Occupancy	03/98	09/98	03/98 (A)	12/98 (A)
Accept Vacuum Equipment	03/98	09/98	11/98 (A)	01/99 (A)
Initiate Facility Shakedown	03/98	03/99	11/98 (A)	01/99 (A)

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

Table 2 shows the actual and projected status of the significant Project Management Plan milestones for the Detector. Every effort has been made to prioritize critical-path tasks as required to support Detector installation. **The "Begin Coincidence Tests" milestone has been slipped to September 2001, because of the earthquake damage sustained in the Washington two-kilometer interferometer.**

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		08/98 (A)	
Core Optics Support Final Design Review	02/98		11/98 (A)	
HAM Seismic Isolation Final Design Review	04/98		06/98 (A)	
Core Optics Components Final Design Review	12/97		05/98 (A)	
Detector System Preliminary Design Review	12/97		10/98 (A)	
Input/Output Optics Final Design Review	04/98		03/98 (A)	
Pre-stabilized Laser (PSL) Final Design Review	08/98		03/99 (A)	
CDS Networking Systems Ready for Installation	04/98		03/98 (A)	
Alignment (Wavefront) Final Design Review	04/98		07/98 (A)	
CDS DAQ Final Design Review	04/98		05/98 (A)	
Length Sensing/Control Final Design Review	05/98		07/98 (A)	
Physics Environment Monitoring Final Design Review	06/98		10/97 (A)	
Initiate Interferometer Installation	07/98	01/99	07/98 (A)	01/99 (A)
Begin Coincidence Tests	12/00		09/01 (P)	

9.2 Financial Status

Table 3 on page 16 summarizes costs and commitments as of the end of May 2001.

TABLE 3. Costs and Commitments as of the End of May 2001

WBS		*Costs Thru Nov 1997*	*Costs LFY 1998*	*Costs LFY 1999*	*Costs LFY 2000*	*First Quarter LFY 2001*	*Second Quarter LFY 2001*	*Cumulative*	*Open Encumbrances*	*Total Cost Plus Commitments*
1.1.1	**Vacuum Equipment**	30,517	11,406	2,114	10	-	-	44,047	-	44,047
1.1.2	**Beam Tube**	32,978	13,273	753	-	-	-	47,004	-	47,004
1.1.3	**Beam Tube Enclosure**	13,274	6,145	153	(233)	-	-	19,338	-	19,338
1.1.4	**Civil Construction**	44,681	6,563	1,513	823	72	542	54,194	1,672	55,866
1.1.5	**Beam Tube Bake**	75	3,078	1,845	561	11	-	5,570	-	5,570
1.2	**Detector**	14,340	20,537	17,898	3,614	401	411	57,202	799	58,001
1.3	**Research & Development**	19,681	1,661	713	46	53	(2)	22,151	-	22,151
1.4	**Project Management**	22,649	4,914	1,525	845	75	1,669	31,677	23	31,700
7LIGO	**Unassigned**	1	18	13	(1)	-	-	32	-	32
TOTAL		178,196	67,595	26,527	5,665	612	2,620	281,215	2,494	283,709
Cumulative Actual Costs		178,196	245,791	272,318	277,983	278,595	281,215			
Open Commitments		62,510	16,422	7,078	1,378	3,000	2,494			
Total Costs plus Commitments		240,706	262,213	279,396	279,361	281,595	283,709			
NSF Funding - Construction		*$ 265,089*	*$ 291,900*	*$ 292,100*	*$ 292,100*	*$ 292,100*	*$ 292,100*			

(all values are $Thousands)

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

9.3 Performance Status (Comparison to Project Baseline)

Figure 6 on page 19 is the Cost Schedule Status Report (CSSR) for the end of May 2001. The CSSR shows the time-phased budget to date, the earned value, and the actual costs through the end of the quarter for the NSF reporting levels of the Work Breakdown Structure. The schedule variance is equal to the difference between the budget-to-date and the earned value, and is a measure in dollars 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 7 on page 20 shows the same information as a function of time for the top level LIGO Project.

Vacuum Equipment (WBS 1.1.1). All work is completed.

Beam Tube (WBS 1.1.2). The Beam Tube is complete. All Beam Tube installation was successfully completed ahead of schedule.

Beam Tube Enclosures (WBS 1.1.3). The contracts for both sites are complete.

Civil Construction (WBS 1.1.4). The original scope for Civil Construction has been completed. Additional scope has been budgeted for site improvements initially removed from the plan to conserve contingency. A contract has been issued for the Storage and Staging Building at Livingston and work is in progress. A contract for Architect/Engineering effort for additional space at Hanford is being finalized. The favorable cost variance reflects normal delays in the processing of payments for the building in Livingston. All civil construction contracts are firm-fixed price.

Beam Tube Bake (WBS 1.1.5). The Beam Tube Bake has been completed. The underrun is due to favorable power rates.

Detector (WBS 1.2)

Washington Two-Kilometer Interferometer. We had completed installation of the two-kilometer interferometer and were well into the commissioning phase when the earthquake struck the Hanford facility at the end of February. We had locked the full recycled interferometer with both arms for periods up to an hour, and were working to improve the sensitivity. All repairs are completed now and the vacuum should soon be good enough to resume commissioning. Sensitivity studies and improvements will have the highest priorities.

Livingston Four-Kilometer Interferometer. We have installed all in-vacuum components including the suspended optics. We have completed an engineering run with the interferometer in the recombined mode. We are currently in the process of replacing the suspension sensors and will resume commissioning activities as soon as this is complete.

Washington Four-Kilometer Interferometer. We have completed the installation of the in-vacuum components, except for one end test mass. The prestabilized laser has been locked to the mode cleaner, the first step in the commissioning process. The basic strategy has been one of staggered overlapping installation at both sites focusing on the two-kilometer interferometer at Hanford and the four-kilometer interferometer at Livingston. Installation and commissioning of the four-kilometer interferometer at Hanford has been deliberately delayed to make the best use of available resources as well as lessons learned during installation of the first two interferometers.

In spite of encouraging progress, the Detector continues to be behind schedule. Efforts to improve the schedule were set back by the earthquake. The net effect is that detector commissioning is about three months behind schedule. We continue to adjust priorities to optimize progress toward the Science Run.

Favorable Detector Cost Variance. A significant portion of the favorable cost variance in the Detector WBS is due to delays associated with processing and recording actual costs. As shown in Table 3, open commitments at the end of May totaled $799K.

Research and Development (WBS 1.3). All LIGO Construction Related Research and Development effort is complete.

Project Office (WBS 1.4). All LIGO I Project Office activities are complete with the exception of the procurement of computer hardware associated with the LIGO Data Analysis and Computing System (LDAS). These procurements were delayed pending NSF approval of our procurement plans and also to achieve the most favorable performance per dollar ratio. The NSF approved the procurement plans early in March 2001 and the procurements are proceeding.

LIGO Project

Cost Schedule Status Report (CSSR)

Period End Date: May 2001

(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	43,970	43,970	44,047	-	(77)	43,970	44,047	(77)
1.1.2 Beam Tubes	46,967	46,967	47,004	-	(37)	46,967	47,004	(37)
1.1.3 Beam Tube Enclosure	19,338	19,338	19,338	-	-	19,338	19,338	-
1.1.4 Facility Design & Construction	54,628	54,244	54,194	(384)	50	58,501	58,501	-
1.1.5 Beam Tube Bake	5,695	5,695	5,570	-	125	5,695	5,570	125
1.2 Detector	59,530	59,105	57,202	(425)	1,903	59,530	59,359	171
1.3 Research & Development	22,089	22,089	22,151	-	(62)	22,089	22,151	(62)
1.4 Project Office	32,633	31,677	31,677	(956)	-	35,509	35,450	59
Subtotal	284,850	283,085	281,183	(1,765)	1,902	291,599	291,420	179
Contingency						-	680	(680)
Management Reserve						501	-	501
Total	284,850	283,085	281,183	(1,765)	1,902	292,100	292,100	-

FIGURE 6. Cost Schedule Status Report (CSSR) for the End of May 2001.

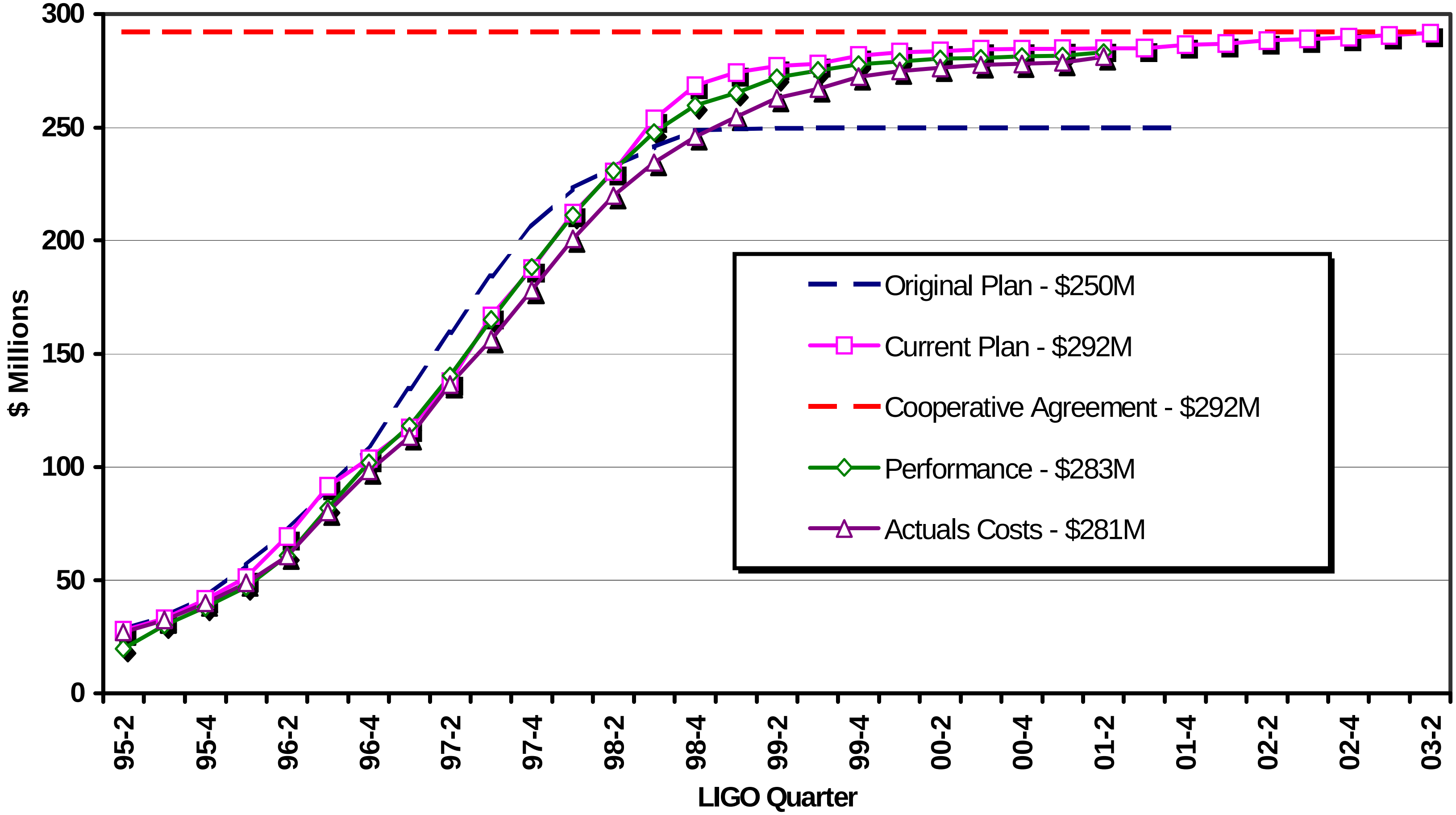

FIGURE 7. LIGO Construction Performance Summary as of the End of May 2001.

9.4 Change Control and Contingency Analysis

Table 4 summarizes the change requests approved during the second quarter of FY 2001. The budget baseline for LIGO Construction remains at $291.6 million. This leaves a contingency (relative to the budget baseline) of $0.5 million. We are forecasting a $0.2M underrun relative to the budget baseline for the scope of work currently authorized so that the contingency relative to the estimate-at-completion is $0.7 million

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TABLE 4. Change Requests Approved During Second Quarter FY 2001.

CR Number	WBS	Description	Amount
CR-000019	1.2.2	Additional Electronics Lab Equipment (Bridge)	49,000
CR-000020	1.1.4	Staging Building and Renovations to Exisiting Building at Livingston	220,500
CR-010001	1.1.4	Closeout of Civil Construction Accounts	(445,174)
CR-010002	1.2.1.6	ISC Design Account Closeout	(329,000)
CR-010003	1.2.1.1.9	Detector Systems Engineering Account Closeout	(205,000)
CR-010004	1.2.3.1	Physics Environment Monitoring (PEM) Closeout	(237,000)
CR-010005	1.1.4	Office and Laboratory Building at Hanford (OSB East)	2,500,000
TOTAL			1,553,326

9.5 Staffing

The LIGO staff currently numbers 158 (full time equivalent). Of these, 34 are contract employees. Ninety-six LIGO staff are located at CIT including eight graduate students. 18.5 are located at MIT including five graduate students. Twenty are now located at the Hanford, Washington site, and 24 are assigned to Livingston, Louisiana. LIGO staff is partially paid by the LIGO Advanced Detector R&D Program, PHY-9801158.