Quarterly Progress Report

(LIGO Fiscal Year Ending May 1999)

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

NSF Cooperative Agreement No. PHY-9210038

LIGO-M990236-A-P

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Quarterly Progress Report

(End of May 1999)

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

NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M990236-A-P

CALIFORNIA 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 during the LIGO quarter ending May 1999.

2.0 Recent Progress and Status

Facility construction, including the vacuum system, is complete. At Hanford, all of the four Beam Tube modules have completed vacuum bake. Detector installation is in progress. The project continues to make excellent progress and is 94.9 percent complete as of the end of May 1999.

2.1 Vacuum Equipment

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

2.2 Beam Tube

As previously reported, all Beam Tube modules have been accepted, and all contract work is complete. Beam Tube module insulation and baking is discussed in Section 2.5.

2.3 Beam Tube Enclosures

Washington Beam Tube Enclosure. Construction activity is complete. We are in the process of closing the contracts for the fabrication and installation of the Beam Tube Enclosure, pending the conclusion of litigation regarding charges by a subcontractor for sales taxes.

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[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.

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

2.4 Civil Construction

Washington Civil Construction. Construction activities for the facilities are complete. The water system modification contract is complete and we have obtained the permit to operate the system. Construction of the Staging and Storage Building is proceeding on schedule at 90 percent complete.

Louisiana Civil Construction. Construction activities are complete. The construction document for landscaping and erosion control has been completed. Design of the LIGO Monument Signs for the Hanford and Livingston sites is complete.

2.5 Beam Tube Bakeout

During the past quarter we completed the bakeout of Beam Tube modules at the LIGO Hanford Observatory. The results of each bake have met or exceeded our goals, and each bake has led to improvements in sensitivity of measurements in the final state. The results are summarized in Table 1.

TABLE 1. LIGO Hanford Observatory Beam Tube Bakeout Results

	Outgassing Rates Corrected to 23 °C (all except H_2 are upper limits)					
molecule	**Goal**[a]	**HY2**	**HY1**	**HX1**	**HX2**	**Unit**
H_2	4.7	4.8	6.3	5.2	4.6	$\times 10^{-14}$ torr–liters/sec/cm^2
CH_4	48000	< 900	< 220	< 8.8	< 95	$\times 10^{-20}$ torr–liters/sec/cm^2
H_2O	1500	< 4	< 20	< 1.8	< 0.8	$\times 10^{-18}$ torr–liters/sec/cm^2
CO	650	< 14	< 9	< 5.7	< 2	$\times 10^{-18}$ torr–liters/sec/cm^2
CO_2	2200	< 40	< 18	< 2.9	< 8.5	$\times 10^{-19}$ torr–liters/sec/cm^2
$NO+C_2H_6$	7000	< 2	< 14	< 6.6	< 1.0	$\times 10^{-19}$ torr–liters/sec/cm^2
$H_nC_pO_q$	50–2[b]	< 15	< 8.5	< 5.3	< 0.4	$\times 10^{-19}$ torr–liters/sec/cm^2

air leak	1000	< 20	< 10	< 3.5	< 16	$\times 10^{-11}$ torr–liter/sec

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a. Goal: maximum outgassing to achieve pressure equivalent to 10^{-9} torr H_2 using only pumps at stations.

b. Goal for hydrocarbons depends on weight of parent molecule; range given corresponds with 100–300 AMU.

Figure 1 shows a comparison of the partial pressure for water vapor during each of the bakes. The pressure starts high as the tube is heated and then drops inversely with time while the temperature remains steady. During the first bake, the temperature of HY2 (the Hanford, Washington Y2 module) was maintained at 150 C during the first 800 hours (except for transient temperature drops related to removing heater power to service equipment), and then at 160 C from roughly hour 850 through hour 1050. During the second (HY1) bake, the tube temperature was held at 160 C from hour 350 through hour 600, then reduced to 150 C between 620 to 700 hours. In the third bake, HX1 was baked at 168 C from hour 200 through hour 375, then at 150 C from hour 400 to hour 500, while in the fourth bake HX2 was baked at 168 C from hour 100 to hour 450, then at 150 C from hour 475 to hour 550.

The reduction to 150 C at the end of each bake was done so that results could be compared. The partial pressure for H_2O at these times, during the last 50 hours before beginning the cool down, was for HX1 and HX2 at least a factor of two lower than that achieved on HY1 or HY2, but with less time at higher temperatures. These results fit our models for time, temperature and pressure.

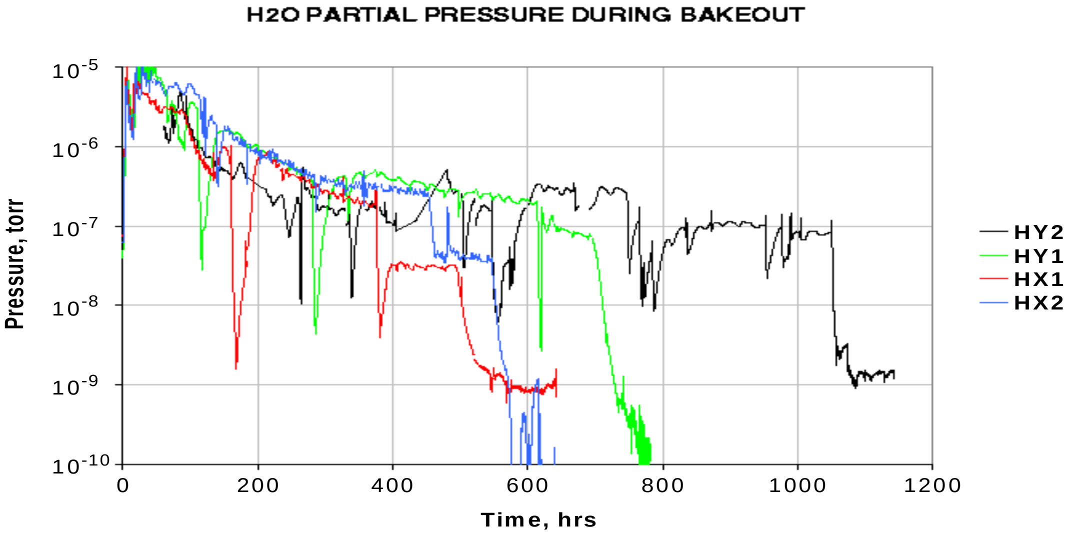

FIGURE 1. Comparison of the Evolution of H_2O Partial Pressure during the Beam Tube Bakes at the LIGO Hanford Observatory.

2.6 Detector

We are actively installing detector components at both the LIGO Livingston, Louisiana Observatory and the LIGO Hanford, Washington Observatory. We are installing the Prestabilized Laser (PSL) and the Seismic Isolation at Livingston, and the input optics (IO) servoloops are being vacuum-baked there in preparation for installation. The first multiple subsystems (PSL and IO) were tested in Hanford this quarter. The Control and Data Systems are now critical systems at Hanford, providing the backbone for communication and control as we test suspended masses. Installation activities at the observatories continued to focus on the seismic systems and the preparation and suspension of the Core Optics. We are planning a single-arm two kilometer cavity test next quarter. We continue to locate and resolve issues, developing procedures as the installation procedes. No problems affecting top-level milestones have been encountered.

Figure 2 shows the first folding mirror being installed in BSC Chamber (BSC) #8 on the Y-arm at Hanford, Washington. Figure 3 on page 5 is the Mode Matching Telescope 3” (MMT3) optic in the HAM Chamber #7.

FIGURE 2. The First Folding Mirror Being Installed into BSC Chamber (BSC) #8 in the Y-arm at Hanford, Washington.

2.6.1 Interferometer Sensing and Control

During the last quarter we shipped and installed the additional Interferometer Sensing and Control (ISC) mechanical components for the Hanford two kilometer interferometer, both for the initial alignment as well as for the operational length and alignment controls. Electronic components are being tested.

FIGURE 3. MMT3 Optic Installed into HAM Chamber #7 at Hanford, Washington.

The ISC group is responsible for the length and alignment controls for the Input Optics. Components have been tested in situ and characterized with low-power modulated laser beams, and all is ready for the integrated PSL-IO testing scheduled next quarter.

The Initial Alignment procedure uses surveying techniques for initial pointing of the beam down the Beam Tube. However, surveying has limitations and it will probably be necessary to find and correct the beam position after the vacuum system is closed by looking at scatter from baffles and beam dumps. Tests of suitable Charge Coupled Device (CCD) cameras have shown that this will be a challenge since our baffles and beam dumps have extraordinarily low scatter. This is good from the viewpoint of baffle performance, but specialized cameras may be required for detecting the faint scatter. A “spin-off” has been the development of scatterometers using CCD cameras that provide several orders of magnitude better sensitivity than those presently in use on the project.

Testing of the Length and Alignment controls hardware and software is proceeding. The integration of the data collection/controls system and the diagnostics system began this quarter. Test data are exchanged between the two systems, allowing either invasive interrogation of the servo loop from the diagnostics system or passive observation. We have resolved a number of detailed coding and handshaking problems, and others have been identified. User interface prototypes have been tested and are now in use.

2.6.2 Pre-Stabilized Laser

The Hanford Observatory Pre-Stabilized Laser (PSL) installation was completed early this quarter. The Final Design Review for the subsystem was held, as was the initial Test Review for the first article. Most aspects of the PSL met or exceeded specifications. For those aspects which did not, plans are in place for improvement. Installation of the Livingston Observatory PSL commenced this quarter. The PSL electronics rack is close to completion. All VME (Versa Modular Eurocard) modules were installed, along with DC power supplies, the 10-W laser power supply, and ancillary power supplies. Cables were dressed and the ribbon cables cut to length and terminated. The Livingston Observatory PSL reference cavity and supporting hardware, such as the vibration isolation stack and vacuum chamber were assembled. The form fit heater jackets, temperature sensors and thermal insulation were fitted to the reference cavity vacuum chamber, and is being pumped down as the quarter closes.

2.6.3 Input Optics

We completed installation of the extra-vacuum components this quarter for the Hanford Observatory two kilometer interferometer. We began characterizing the light supplied by the combined PSL-IO subsystem, with measurements of the beam profile and the intensity fluctuations at the modulation frequency (29 MHz for the two kilometer interferometer). Some excess beyond the requirement (which is of the order of a part in 10^9) was found. Efforts to make these measurements led to improvements in the optical layout, in particular in reductions of parasitic interferometers, and progress toward verifying that specifications were met.

The Input Optics and Suspensions teams dedicated significant effort towards resolving difficulties encountered in bonding magnets to the optics. This is discussed below under Suspensions. At the close of the quarter, re-installation of the corrected suspensions was nearly complete, and progress can now resume.

2.6.4 Core Optics Components

The Core Optics team concentrated on metrology this quarter. The three-flat-test technique was used to measure the two kilometer interferometer beam splitter. It has a radius of curvature of -140 kilometers with a rough uncertainty of +74 kilometers -44 kilometers. This uncertainty band puts it within reach of the specification: >720 kilometers concave and >200 kilometers convex.

We also surveyed the four coated End Test Masses polished by General Optics. They are well matched, with only a 20 meter difference in the radius of curvature of numbers 03 and 04. However, the absolute radius of curvature appears to be roughly 800 meters longer than our goal of 7400m, and 580 meters longer than the outside tolerance. At this radius of curvature our uncertainty is fairly small, approximately 130 meters. This prompted a reassessment of the requirements, with the conclusion that we are quite tolerant of the common-mode error this implies; the principal sensitivity to curvature errors is in the differential mode, where errors would lead to excess light at the gravitational-wave measurement port. Thus, these parts are perfectly satisfactory for use and have been qualified for installation.

2.6.5 Core Optics Support

We continued fabricating the Core Optics Support components this quarter. The pick-off telescope parabolic mirrors are being coated, with primary and secondary alignment mirrors received. Fixtures to hold the alignment mirrors for the initial pick-off telescope alignment are being fabricated. The first article for the end test mass pick-off telescope has been assembled and adjustments made to the design as needed. After successful testing and subsequent installation of the first article beam splitter beam dump structures, purchase orders were placed for the production units for both Hanford and Livingston.

2.6.6 Seismic Isolation

Walker & Sons, the vendor we use for final cleaning of the fluorocarbon spring seats in the seismic isolation system, was hit by the tornado which devastated regions of Oklahoma early in May. Their entire plant was destroyed. At the time, there were many Fluorel parts at the Walker plant, either in process or waiting to be processed. These included 2100 left-hand seats, 850 right-hand seats, 735 pieces of cable clamp liners, and a batch of chamber stop tips. Between 1,200 and 1,300 seats were found undamaged. Orders were immediately placed with Molding Solutions to replace the lost items. There will be a delay as a result, and its extent depends on how quickly Molding Solutions can ship. Walker & Sons was able to re-establish its operation and can quickly process the material as soon as it is available. We are currently using our stock for continued installation.

There are delays in the fabrication of positioning parts external to the vacuum. Hand Precision, the manufacturer, is not maintaining schedule for the production of the scissors tables (which allow adjustment of the vertical position of the isolation systems), nor the optic axis actuators (which off-load some of the large, slow motion from the suspended optic controllers). We have continued to install other seismic components to work around this delay, and a just-in-time delivery in early June is promised by the vendor. We have instituted closer monitoring of their production and believe that they will meet their stated goal.

2.6.7 Suspensions

At the close of the last quarter we reported problems (unevenness in the strength of bonds, and weak bonds in general) with the bonding of attachments (magnets and standoffs) to the suspended optics, and established a “tiger team” to address the difficulties. This team conducted experiments and analyzed the process of preparing the mirrors, and discovered two basic problems with the bonds: the presence of contaminants; and a cleaning process which weakened the bonds to the point of failure.

The contaminant was silicone from an adhesive tape used in packaging the optics by our coating vendor. We developed a method for removing the silicone and applied it to all suspect optics as well as tools that might have come in contact with the contaminated optics. This solved the problem of scatter in the bond strength. The general weakness of the bonds was due to the cleaning process, which called for soaking the optic in a water-based detergent solution after the magnet had been bonded. Performing an air cure at elevated temperatures before cleaning, and minimizing the time of the soak on the side of the optic carrying the magnets, resulted in reliable bonds with sufficient strength. In addition, we improved the gluing fixtures to reduce the likelihood of bond breakage during handling, and many small changes were incorporated into the overall approach and material handling for a faster, more reliable optics preparation process. With this new process, a Core Optic (the Hanford Observatory two kilometer Y-arm folding mirror) and all of the suspended Input Optics have been re-worked and successfully installed.

2.6.8 Physics Environment Monitoring System

Installation continued at Livingston and Hanford. Elements of the Physics Environment Monitoring (PEM) System are now used regularly during installation and testing of Detector components.

2.6.9 Global Diagnostics System

A successful Final Design Review of the Global Diagnostic System (GDS) was held in early May, affirming the software and hardware architecture. Coding of that architecture is now essentially complete, and detailed elements of the parts are in development or test. The principal elements are the Data Monitoring Tool (DMT), the Diagnostic Tests, and the Excitation Engine.

The DMT receives all of the data in real time from the interferometers and can perform at least a rudimentary analysis on each channel while keeping up with the data rate. This allows simple checks of normal performance (limit tests, calculations of RMS values, searches for unusual peaks, “dead channel” tests) on all channels and also will allow more sophisticated tests on a limited number of channels (e.g., calculation of seeing distance for binary inspirals as an overall sensitivity measure). This is a production tool, continuously monitoring the Observatory.

The Diagnostic Tests along with the Excitation Engine can carry out invasive and non-invasive testing to characterize in more detail the interferometer performance and sensitivity to the environment. For example, excitation of “shakers” can be made while acquiring data from accelerometers and the interferometer to measure the complete transfer function of the isolation and suspension system. These data can be combined with passive measurements of the seismic environment to form a prediction for the low-frequency noise in the interferometer to be used in subsequent data analysis and to plan incremental improvements.

We conducted tests on a variety of GDS elements this quarter: the excitation engine hardware and software, the rather intricate relationship to the length sensing controls via the digital servocontrols, analysis routines to emulate familiar stand-alone spectrum analyzers familiar to the interferometer scientists, and of user interfaces. As the quarter closes, orders are being placed for the hardware to enable the use of the GDS in the two kilometer single-cavity system tests.

2.7 Modeling and Simulation

Optics. We completed the model implementations of the core optics components (COC) and the pre-stabilized laser (PSL) this quarter. All primitives and summation cavities needed for the simulation of the optics have been written based on the time domain model. Optics primitives for the input optics have also been implemented using a different method called Mode Composition-Decomposition. Efforts to complete the PSL model are continuing at the sites. Components will be ready in June, and integration into a full PSL is planned in July.

Mechanical Systems. Progress with modeling mechanical systems includes a simple matlab model for a single suspended mirror. The results of this model have been compared with a more sophisticated model with agreement in the valid domain. The simpler model includes important aspects of three dimensional motion and is adequate for use as the preliminary basic mirror in the end-to-end model.

There is also a modular (C++) mechanical model which will calculate the equilibrium point of the combined system around which mechanical motion can be linearized. The modular design makes it easy to integrate the model into the end-to-end framework. The results of this model compare favorably with measured data.

The initial implementation of the Seismic Isolation System (SEI) will be very crude. It will use a convolution of the ground motion and measured transfer functions for the BSC and the HAM seismic systems.

End-to-end Model Support. The end-to-end model is now being supported at all LIGO sites as well as in the LIGO Science Collaboration (LSC) experimental groups. Mail lists (FAQs) have been established to facilitate information sharing, and “autoconfig” and “automake” have been adapted to support various platforms. GEO (British/German Cooperation for Gravity-Wave Experiment) and TAMA (Japanese Interferometric Gavitational-Wave Detector Project) are now being configured to run LIGO's end-to-end model. MIT has initiated Fabry-Perot arm lock acquisition and stability studies using the end-to-end model. The basic framework of the end-to-end model and the single-mode optical model for the LIGO interferometers was implemented last year. Validation of this model is complete. The basic implementation of the multi-mode model to support tilted mirrors and non-Gaussian beam profiles was completed this quarter.

2.8 LIGO Data Analysis System (LDAS)

LIGO Databases. We focused significant effort this quarter on the development of LIGO Database Analysis System (LDAS) database components. We installed a server with IBM's commercial database DB2. We wrote an interface to DB2, called the LDAS metadataAPI (application programmer's interface), developed using the DB2 Development Kit. The API is the junction database client and is a stand-alone layered Tcl[2] and C++ UNIX process. The Tcl layer is respon-

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[2] Tcl: Tool command language is a simple textual language and a library, intended primarily for issuing commands to interactive programs such as text editors, debuggers, illustrators, and shells. It has a simple syntax and is also programmable, so Tcl users can write command procedures to provide more powerful commands than those in the built-in set. Source: FAQ page at http://www.neosoft.com/tcl/whatistcl.html.

sible for command communications, and for developing the SQL (structured query language) statements that ingest data into and query information from the tables managed by the DB2 server. The C++ layer is object oriented and used to manage the database client and its proprietary communications protocol with the server. IBM's DB2 client-to-server communications driver was incompatible with the re-entrant design of the metadataAPI. A third-party driver from OpenLink was substituted. This required only trivial modification to the metadataAPI since the ODBC[3] database standard had been used for the interface design.

The LDAS database design has evolved as common relationships have been identified during the process of ingesting data from simulated datasets. To date, several gigabytes of simulated data have been ingested.

The LDAS alpha release is scheduled for July. It will consist of a set of application programmer interfaces: the genericAPI, the frame API, the managerAPI, the metadataAPI, the lightweightAPI, a reduced set of the dataconditionAPI, and a reduced user API. We began software development on some aspect of each of these during the quarter. Two installation visits to the Hanford site are scheduled for June and July to configure the LDAS hardware system and to install the alpha release version. The alpha release of the LDAS system will run on top of Solaris 7 and RedHat Linux 6.0. Extensive testing of the LDAS dependent software components on these platforms has identified no serious conflicts.We also started developing meta-macros that will be used to control process flow from user requests from within the managerAPI. Meta-macros supporting the transmission of frame formatted data have been developed and tested, and are being extended to support data conditioning and metadata manipulation in preparation for the alpha release.

LDAS Lightweight Data Format. The LDAS lightweight data format is based on XML[4]. The design of the application programmer's interface (lightweight API) is being developed using a public source distribution of a C++ XML parser developed at IBM as part of its next generation of DB2 server environments.

LIGO/LIGO Scientific Collaboration (LSC) Algorithm Library. The core of the data analysis system depends on a set of computationally intensive filtering algorithms to perform various types of optimal Wiener filtering in the frequency domain. Much of LIGO data analysis will be accomplished in parallel across a large number of distributed nodes in a Beowulf computer cluster. The numerical algorithms will be contributed by a number of LIGO collaborators. To permit participation by as many scientists as possible, it was decided to develop the initial library in procedural C even though all compiled code within LDAS is C++. To enforce design uniformity and preclude many common pitfalls in joint code development, we developed a coding specification that addresses, among other things, commenting styles, header structure, code behavior, LIGO-specific data types, and data input/output structures. The draft specification was circulated for

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3. ODBC: Open Database Connectivity is a widely accepted application programming interface (API) for database access. It is based on the Call-Level Interface (CLI) specifications from X/Open and ISO/IEC for database APIs and uses Structured Query Language (SQL) as its database access language. Source: ODBC Section of the Microsoft Universal Data Access Web Site.

4. XML: Extensible Markup Language, a standard metalanguage based on the SGML standard, but streamlined for use in defining markup languages that can be used on the World Wide Web. XML is defined to be Unicode compliant, so it will fully support multilingual text processing. Source: Offline 62, http://scholar.cc.emory.edu/scripts/Offline/off62.html.

critical review to the LIGO and LSC data groups. Suggestions were incorporated over several iterations, and a final draft was released. The next step is to develop several algorithms in accordance with the proposed style and to assess whether further changes are needed.

LDAS Network Design. In support of pending installation activities at Hanford, a preliminary concept for the LDAS Local Area Network (LAN) was refined, and the final definition for the Phase I configuration was completed (See Figure 4.).

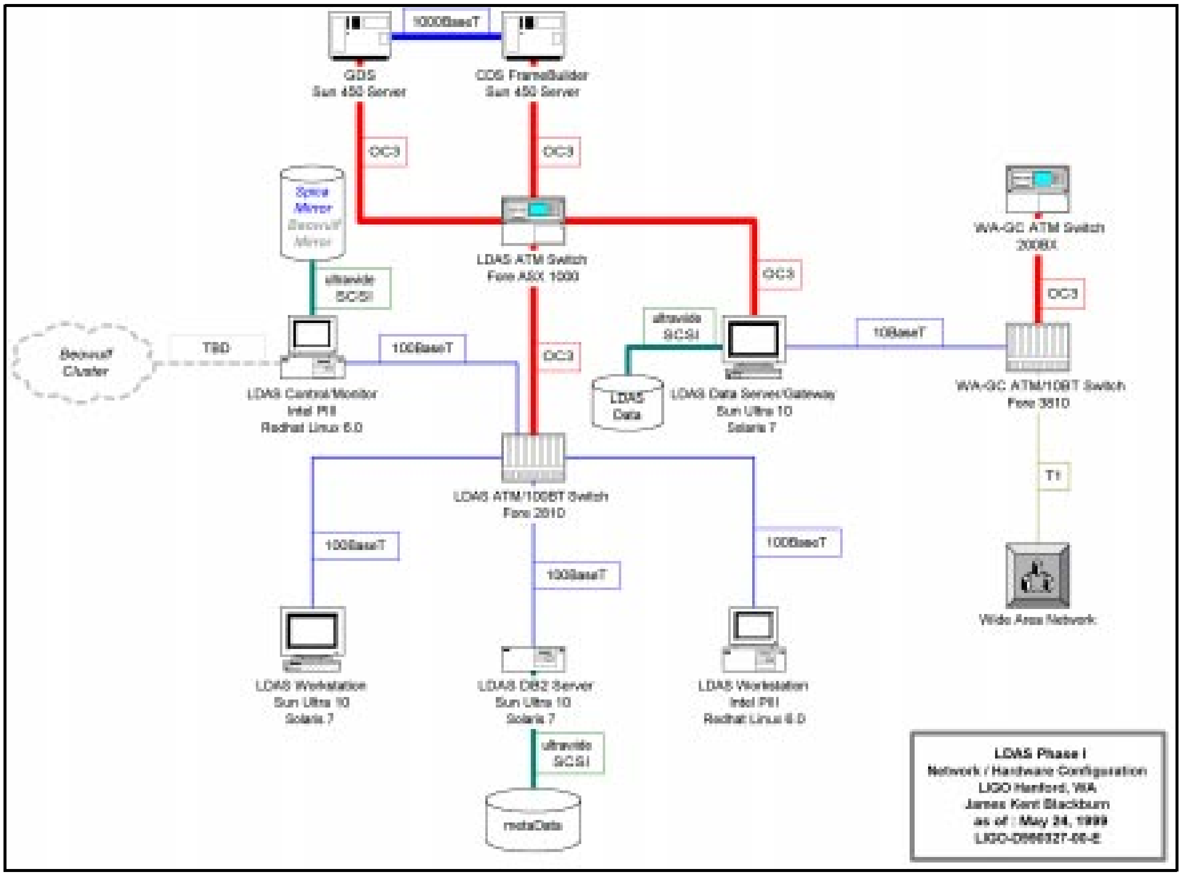

FIGURE 4. LDAS Logical Network Diagram - Phase I, Hanford, Washington.

Linux Operating System. We are fully integrating and supporting Linux as one of the primary operating systems within LDAS, and detailed work now supports the integration of Linux into the initial LDAS installation at the Hanford Observatory. In particular, the following tools are integrated: NIS+ support[5] for LDAS workstations at Caltech, to facilitate integration into the general computing network; kernel based NFS (network file system) support, for high speed reliable performance of the Beowulf cluster server which currently has 16 clients but will scale to order 100; and support and tracking of various TCP/IP (Transmission Control Protocol/Internet Protocol) technical issues within Linux, needed for optimal performance in the Beowulf cluster.

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[5] NIS+ is a new version of the network information name service from Sun. The biggest difference between NIS and NIS+ is that NIS+ has support for data encryption and authentication over secure RPC. Source: http://www.sgml-tools.org/HOWTO/NIS-HOWTO/t1143.html.

The recipe for creating custom, bootable Linux distribution CDs has been demonstrated to support remote LDAS installations. Mirrors of the Linux kernel software and appropriate RedHat distributions are being maintained within LDAS at Caltech. And an initial mirror of the official LDAS software is being maintained at the Livingston Observatory.

Beowulf. LIGO has a prototype monolithic eight node/16 CPU parallel PC Linux cluster at Caltech which has been used to verify system setup. During the next quarter we will be preparing for the installation of the first cluster at the Hanford Observatory which is planned for late fall.

High Performance Storage System (HPSS). This quarter we continued performance and reliability testing of the Caltech's Center for Advanced Computing Research (CACR) High Performance Storage System (HPSS) installation to verify suitability for the primary LIGO data archive. With the recently upgraded CACR hardware, we were able to demonstrate bandwidths of eight megabytes per second from the 40 meter facility real-time data stream for 15 hours and a total of approximately 0.5 terabytes. Individual file transfers approached 20 megabytes per second, and we are continuing to investigate limiting performance factors. In addition, we have ordered 15 terabytes of tapes for longer tests involving larger amounts of data.

2.9 LIGO Computing Infrastructure

Amaldi Conference. A web server has been set up to support the Amaldi Conference scheduled at Caltech in July.

Performance Utilities. Utilities to provide users with information on LIGO's General Computing system have been installed. An example is the LIGO web access and usage shown in Figure 5 on page 13. Disk usage and network load are also being incorporated.

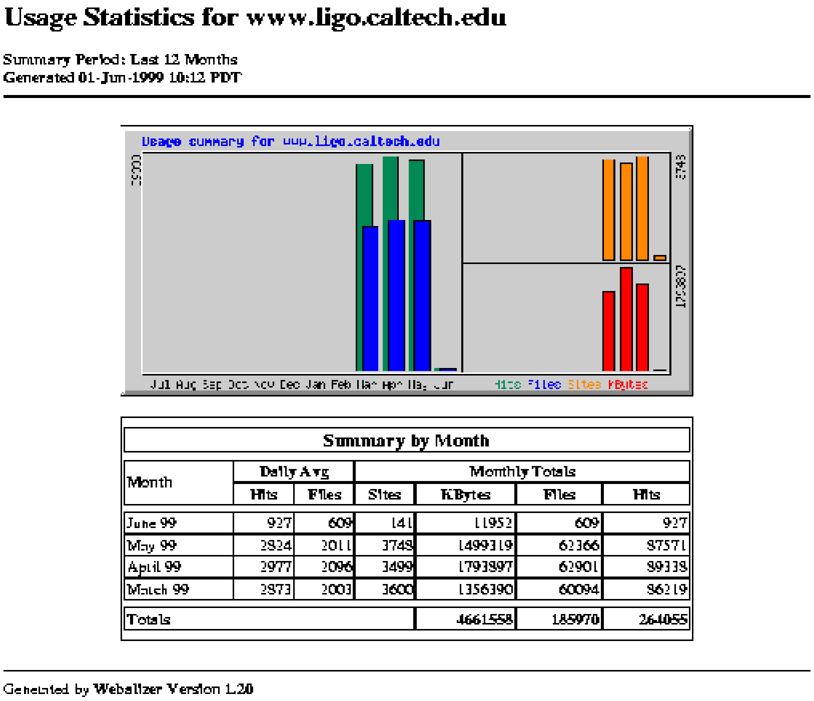
Livingston Observatory. We met with Louisiana State University (LSU) and Bell South in preparation for LSU's installation of vBNS (very high speed backbone network service). LIGO will eventually be linked to vBNS through the LSU campus. We also discussed with Bell South the installation of a fiber-optic connection from the Livingston Observatory to LSU. A first pricing quotation was received and LIGO and Bell South are reviewing requirements.

A network modem box was installed and tested. The modem pool is now being expanded.

Hanford Observatory. We met with Pacific Northwest Laboratory (PNNL/Battelle) personnel to discuss future network connections and capabilities. It appears that better and faster alternatives for connecting the Hanford Observatory to the LIGO wide area network will soon be available. Further discussion is planned in October or November after installation of a new network at Battelle.

2.10 Meetings

The next LIGO Science Collaboration (LSC) meeting is scheduled at Stanford University, California, July 19-21, 1999.



Usage Statistics for www.ligo.caltech.edu

Summary Period: Last 12 Months
Generated 01-Jun-1999 10:12 PDT

Summary by Month

Month	Daily Avg		Monthly Totals			
	Hits	Files	Sites	KBytes	Files	Hits
June 99	927	609	141	11952	609	927
May 99	2924	2011	3749	1499319	62366	97571
April 99	2977	2096	3499	1793897	62901	99338
March 99	2973	2003	3600	1356390	60094	96219
Totals				4661558	185970	264055

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FIGURE 5. Example of Utility Installed to Monitor General Computing Systems.

3.0 Project Milestones

The status of the project milestones identified in the Project Management Plan for the LIGO Facilities is summarized in Table 2. **All Facilities milestones have been completed.**

TABLE 2. 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)

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

Table 3 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. **We continue to project a December 2000 completion of the "Begin Coincidence Tests" milestone.**

The Infrared Prestabilized Laser Final Design Review was held March 18, 1999. Interferometer installation at the Livingston, Louisiana site continues.

4.0 Financial Status

Table 4 on page 16 summarizes costs and commitments as of the end of May 1999.

TABLE 3. 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)	
I/O Optics Final Design Review	04/98		03/98 (A)	
Prestabilized Laser 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		12/00 (P)	

TABLE 4. Costs and Commitments as of the end of May 1999

(all values are $Thousands)

WBS		*Costs Thru Nov 1997*	*Costs LFY 1998*	*First Quarter LFY 1999*	*Second Quarter LFY 1999*	*Third Quarter LFY 1999*	*Fourth Quarter LFY 1999*	*Cumulative Actual Costs*	*Open Commit-ments*	*Total Cost Plus Commit-ments*
1.1.1	**Vacuum Equipment**	30,517	11,406	1,837	189			43,949	1,558	45,507
1.1.2	**Beam Tube**	32,978	13,273	769	(17)			47,004	97	47,101
1.1.3	**Beam Tube Enclosure**	13,274	6,145	(3)	29			19,444	29	19,473
1.1.4	**Civil Construction**	44,681	6,563	395	649			52,288	748	53,036
1.1.5	**Beam Tube Bake**	75	3,078	431	536			4,120	997	5,117
1.2	**Detector**	14,340	20,537	4,544	6,117			45,538	6,361	51,899
1.3	**Research & Development**	19,681	1,661	211	442			21,994	225	22,219
1.4	**Project Management**	22,649	4,914	603	314			28,480	1,125	29,605
7LIGO	**Unassigned**	1	18	8	17			44	1	45
TOTAL		178,196	67,595	8,795	8,276			262,862	11,141	274,003
Cumulative Actual Costs		178,196	245,791	254,586	262,862					
Open Commitments		62,510	16,422	15,381	11,141					
Total Costs plus Commitments		240,706	262,213	269,967	274,003					
NSF Funding - Construction		*$ 265,089*	*$ 291,900*	*$ 291,900*	*$ 291,900*					

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 6 on page 18 is the Cost Schedule Status Report (CSSR) for the end of May 1999. 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 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 7 on page 19 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. The at-completion overrun forecast reflects payments owed to Process Systems International (PSI) for gate valve rework as well as miscellaneous quality, travel, and labor escalation charges.

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 contract for the Hanford site is complete. Contract closeout is pending resolution of litigation regarding state tax issues. The contract for Livingston is complete.

Civil Construction (WBS 1.1.4). Civil Construction is complete except for completion of the new Staging Building at Hanford which is planned next quarter. Favorable cost variances are the result of normal delays in the payment of invoices.

Beam Tube Bake (WBS 1.1.5). The unfavorable schedule variance is due to a delayed start of the first bake while awaiting completion of repairs to gate valves on the Beam Tube ports (manufactured by VAT, delivered by Chicago Bridge and Iron, and repaired by VAT under warranty).

The unfavorable cost variance is due to increased labor costs associated with the schedule delay plus substantial additional labor resources needed to prevent further delays. These costs are reflected in the estimate-at-completion.

Detector (WBS 1.2). The Detector is behind schedule and under cost. 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.

Laser and Optics - Core Optics Component fabrication is on schedule. The Pre-stabilized Laser for the two kilometer interferometer has been installed in Hanford, Washington and the installation of the laser for Livingston is underway. Input Optics fabrication is approximately one month behind schedule, but component availability is supporting installation.

Seismic Isolation - The Seismic Isolation effort is four months behind schedule. Production schedules are being managed to support initial interferometer installation. Installation is in progress at both sites.

LIGO Project

Cost Schedule Status Report (CSSR)

Period End Date: 28 May 1999

(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	43,771	43,771	43,949	-	(178)	43,771	44,164	(393)
1.1.2 Beam Tubes	46,967	46,967	47,003	-	(36)	46,967	47,041	(74)
1.1.3 Beam Tube Enclosure	19,991	19,986	19,444	(5)	542	19,991	19,502	489
1.1.4 Facility Design & Construction	52,543	53,048	52,289	505	759	53,118	53,022	96
1.1.5 Beam Tube Bake	3,827	3,640	4,120	(187)	(480)	4,879	5,600	(721)
1.2 Detector	56,470	51,073	45,539	(5,397)	5,534	58,985	57,562	1,423
1.3 Research & Development	23,490	23,490	21,975	-	1,515	23,490	23,470	20
1.4 Project Office	29,946	29,946	28,485	-	1,461	35,210	35,520	(310)
Subtotal	277,005	271,921	262,804	(5,084)	9,117	286,411	285,881	530
Contingency						-	6,219	(6,219)
Management Reserve						5,689	-	5,689
Total	277,005	271,921	262,804	(5,084)	9,117	292,100	292,100	-

FIGURE 6. Cost Schedule Status Report (CSSR) for the End of May 1999.

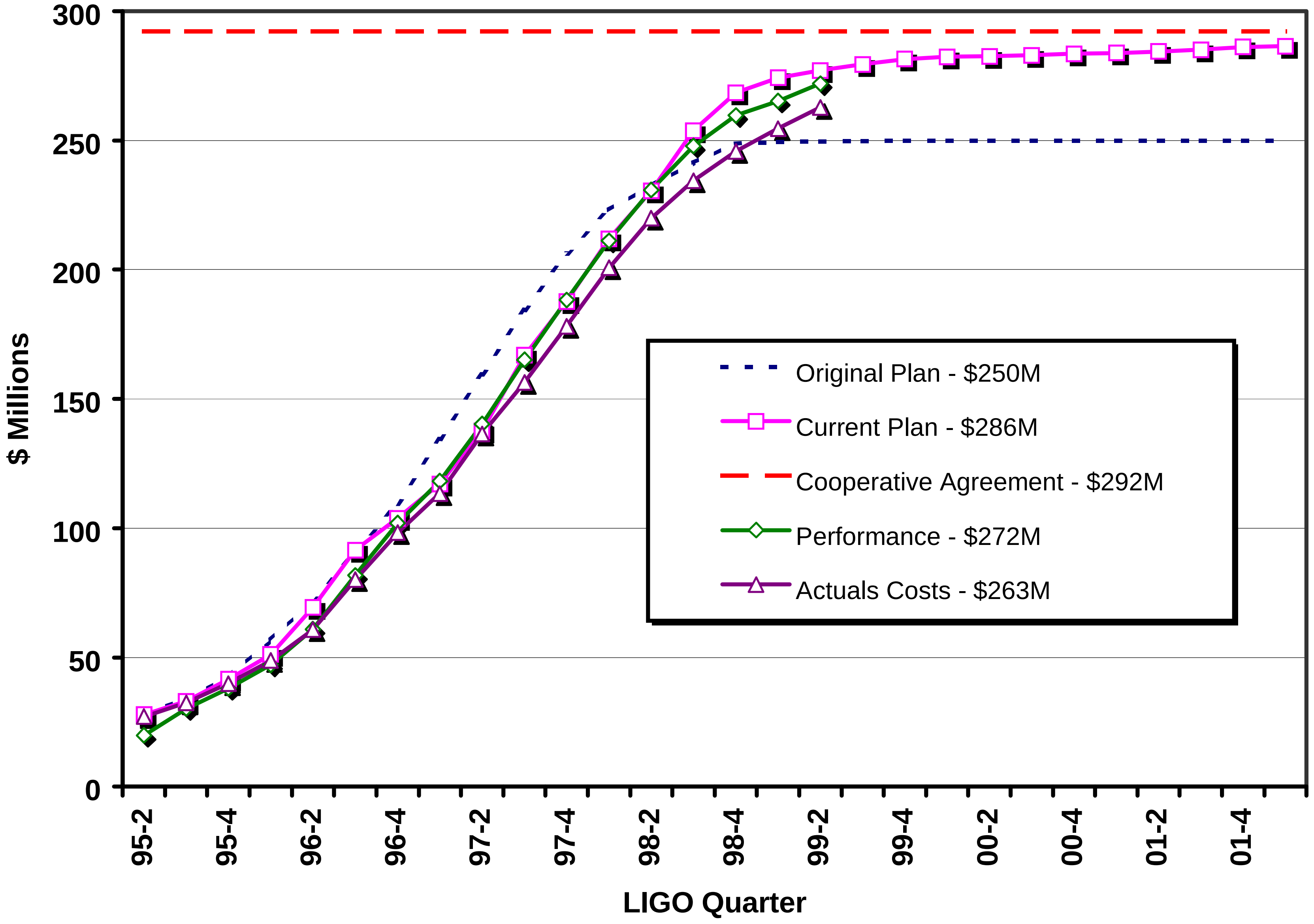

FIGURE 7. LIGO Construction Performance Summary as of the End of May 1999.

Alignment Sensing and Control - The Alignment Sensing and Control effort is behind schedule due to the design of the input optics controls. The Initial Alignment System, needed first for installation, is on schedule.

Control and Data Systems - There are minor behind schedule positions reported, but the group continues to support immediate needs.

Project Office (WBS 1.4). The Administrative Support functions are over budget by approximately $275K. Most charges against the Project Office Construction accounts have ceased, and a change request is in process to close out the Administrative accounts.

6.0 Change Control and Contingency Analysis

Fourteen change requests (see Table 5) were approved during the quarter. These change requests allocated $2,655,447 from contingency with corresponding additions to the budget baseline. The current contingency is $6.2 million.

7.0 Staffing

The LIGO staff currently numbers 135 (full time equivalent). Of these, 33 are contract employees. Eighty-five LIGO staff are located at CIT including six graduate students. Eighteen are located at MIT including six graduate students. Eighteen are now located at the Hanford, Washington site, and 14 are assigned to Livingston, Louisiana.

TABLE 5. Change Requests Approved During Second Quarter LIGO FY 1999

CR Number	WBS	Description	Amount
CR-970035(A)	1.4.4	Infrastructure Computers for Hanford	150,000
CR-970036(A)	1.4.4	Infrastructure Computers for Livingston	150,000
CR-990004	1.1.4	Livingston Site Erosion Control	467,975
CR-990006	1.2.1	Seismic Isolation System CO2 Cleaning of Springs	22,500
CR-990007	1.1.2	Beam Tube Closeout	(236,000)
CR-990008	1.1.1	Vacuum Equipment Milestones and Changes	201,916
CR-990009	1.2.1	ACS Additional Hardware for Initial Alignment	61,000
CR-990010	1.4.4	Tape Drives for LDAS at Hanford and Livingston	600,000
CR-990011	1.2.1	Additional Detector Staffing Support	245,000
CR-990012	1.2.2	Control and Data Systems Global Diagnostics	316,400
CR-990013	1.2.2	CDS LSC Controls	401,400
CR-990014	1.2.2	CDS Additional VME ADC Modules	120,000
CR-990015	1.1.1	VE Stiles, Scaffolding, Vacuum Cleaning	5,256
CR-990016	1.1.4	Completion Outside of Staging Bldg. at Hanford	150,000
		Total	2,655,447