California Institute of Technology

Quarterly Report

(March 1995 - May 1995)

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

June 1995

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LIGO PROJECT

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1.0 Contents

2.0 Introduction

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

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

3.0 Executive Summary

During May 1995, the LIGO Project hosted a review by a panel of technical experts representing NSF. The focus of this review was the project management and related systems recently implemented in accordance with a major program milestone. The final team report has not yet been received. However, based on comments provided by the team members, LIGO management feels that the review was quite successful. A performance measurement baseline and the related management systems and reports have been put in place in accordance with the proposed schedule. For the next review we will have a history of data to demonstrate that the systems are being used and provide an effective management tool for monitoring and maintaining project cost and schedule. The timing of bringing these management systems on-line is critical to provide support for the subcontracting efforts planned for the next quarter.

Some need for improvement was noted in related management areas, specifically Subcontracts Management and Environment, Safety & Health (ES&H). LIGO Management agrees with this assessment and has already initiated processes to bolster the affected systems.

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

In March two contractors were selected in accordance with the procurement plan for Phase A runoff for the Vacuum Equipment contract. The two contractors were Chicago Bridge and Iron (CBI) and Process Systems International (PSI). LIGO is confident that both of these contractors can provide technically responsive proposals for the design and fabrication phase, and the approach used to select the final contractor assures a competitive price. The kickoff meeting was held on March 30, 1995 and the contracts were issued early in April. Each contractor will present a Preliminary Design at separate reviews June 26 and June 27.

The Beam Tube Qualification Test Review (QTR) was held on April 17 and 18, 1995 at Chicago Bridge and Iron (this is a separate contract from the Phase A effort on the Vacuum Equipment above). The QTR was judged to be a success and will provide a basis for initiating the fabrication and installation phase. CBI delivered a data package on May 26. An RFP will be issued on June 1 with receipt of a proposal from CBI expected on July 17, 1995.

The 90 percent concept design for the civil facilities was completed and Parsons, the A&E contractor, provided the 90 Percent Review Report. The 90 Percent Concept Design Review was held on April 25, 1995. Trade studies have been initiated, and Parsons has also been directed to implement several cost reduction ideas based on the cost estimates presented and an identification of the main cost drivers.

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

4.0 Summary of Work Accomplished

4.1 Facilities and Vacuum System (WBS 1.1)

4.1.1 Vacuum Equipment (WBS 1.1.1)

In early March, two contractors, Chicago Bridge and Iron (CBI) and Process Systems International (PSI), were selected to participate in a three month design competition (Phase A of the Vacuum Equipment procurement). Based on the quality of the designs produced and the associated price proposals, one contractor will be selected to proceed with Phase B, the remaining design, fabrication, installation and testing at both the Washington and Louisiana sites. Both contractors attended the Phase A "Kickoff" meeting held at CIT on March 30. One month later on April 28 the first "Update" meeting was held, also at CIT. The purpose of this meeting was to answer any questions the contractors may have had and to provide new or better defined system requirements. On June 26 and 27 the two contractors will present their preliminary designs. This will be the end of the Phase A work. The selection process will begin at this time. The goal is to have a single contractor on board in August 1995.

4.1.2 Beam Tube (WBS 1.1.2)

The Beam Tube Qualification Test bake was terminated on the 28th day on April 3, 1995, after demonstrating a water outgassing rate of less than the required 1×10^{-11} *t-l/s-cm*^{2} at the bake temperature. All significant outgassing rates were measured after cooling to ambient temperature. These are listed in the table below with pre-bake readings shown for comparison.

TABLE 1. Beam Tube Qualification Test Outgassing rates

Item	Pre-Bake Measurement	Post-Bake Measurement
H_2 Outgassing, *t-l/s-cm*^{2}	2.9×10^{-14}	8.6×10^{-14}
H_2O Outgassing, *t-l/s-cm*^{2}	2.3×10^{-11}	$< 8 \times 10^{-18}$
CO Outgassing, *t-l/s-cm*^{2}	$< 2 \times 10^{-13}$	2.5×10^{-16}
CO_2 Outgassing, *t-l/s-cm*^{2}	$< 3 \times 10^{-13}$	1.6×10^{-16}
CH_4 Outgassing, *t-l/s-cm*^{2}	$< 1 \times 10^{-13}$	$< 3 \times 10^{-16}$
Maximum leak, from Air Signature, *t-l/s*	$< 1 \times 10^{-9}$ Note: $< 1 \times 10^{-7}$ req'd	$< 2 \times 10^{-12}$ Note: $< 1 \times 10^{-11}$ req'd

The Qualification Test Review was held on April 17 and 18, 1995. The review board endorsed the fact that all aspects of the Qualification Test were met. The board concurs that LIGO is ready to commence fabrication and installation of the beam tubes.

The detailed design package for the beam tube modules was received from the contractor, Chicago Bridge & Iron (CBI), on May 22, 1995. This will be included in a request for proposal to fabricate and install the beam tube modules which will be issued to CBI on June 1, 1995.

4.1.3 Beam Tube Enclosure (WBS 1.1.3)

The 90% Conceptual Design package for the Beam Tube Enclosure was submitted by Parsons, the LIGO A&E Contractor, and reviewed by the LIGO staff. The review resulted in the initiation of a trade study by Parsons to develop three alternate options to the submitted baseline design. The options entailed the reduction of the enclosure diameter to an absolute minimum (eliminating personnel access to the Beam Tube), and replacing the concrete slab with concrete piles, located under the Beam Tube supports. The results of these trade studies were assessed. LIGO concluded that the life cycle costs and risks associated with the alternate approaches did not justify their adoption. The decision was made to maintain the original base line, and to proceed with the detailed design of the Beam Tube Enclosure.

4.1.4 Civil Construction (WBS 1.1.4)

The 60% Conceptual Design Review was held on March 16, 1995. This was followed by the 90 percent Conceptual Design submittal for the LIGO Facilities in April. The submittal was reviewed on April 25, 1995. As a result Parsons was directed to conduct Trade Studies to investigate the effects of relaxing some of the stringent requirements which appeared to be the dominant cost drivers. In addition, the studies will address the cost savings of reducing the size of the Vacuum Equipment Areas of the facilities to provide space for a fewer number of interferometers, while maintaining the ability to expand to the full complement at some future time. The results of these cost reduction studies were received from Parsons on May 26, 1995. The data are being analyzed by LIGO and will provide the basis for the final concept design direction to Parsons. Upon completion of the conceptual design phase, the detailed design will be initiated.

The clearing of the Livingston, Louisiana site has been initiated by completing the negotiation of a contract with T. L. James, Inc. to remove all trees and brush on the LIGO property. The characterization of the site was completed and the hydrology and soil characterization reports have been accepted and provided to Parsons, who has been authorized to proceed with the design of the rough grading for the Livingston Site.

Negotiations with Shell Pipeline and Enterprise Corporation. to resolve some of the outstanding issues regarding the pipeline crossings have been initiated. After the negotiations with Shell are concluded, we will contact Transco, the third major pipeline company, to initiate discussions regarding the methods proposed for protecting the pipeline crossing.

The Rough Grading at the Hanford, Washington site has been completed and the contactual arrangements with Seland, the Rough Grading contractor have been closed out. The "as-built" drawings have been received and the total cost for the task was concluded within the planned cost.

4.2 Detector (WBS 1.2)

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

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

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

WBS 1.2.2 Control and Data Systems (CDS)

WBS 1.2.3 Physical Environment Monitor (PEM) System

WBS 1.2.4 Support Equipment.

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

Detector activities began in December 1994. In general, Detector activities are proceeding on the schedule detailed in the Detector Implementation Plan adopted in January 1995 and incorporated into the Project Management baseline. Exceptions are noted below.

Activities under WBS 1.2.1 and 1.2.2 are reported below. There are no activities planned during 1995 for WBS 1.2.3 and 1.2.4.

4.2.1 Interferometer (WBS 1.2.1) Design Activities

Seismic Isolation (SEI). Documentation of the requirements for the seismic isolation subsystem was started during the reporting period. Work to optimize the baseline design concept was initiated, but subsequently delayed by the withdrawal of the selected engineering subcontractor. An interim report was generated by the subcontractor, and the effort will be continued shortly.

Prestabilized Laser (PSL). A formal design requirements review (DRR) for the PSL, including the CDS components, was conducted in February. Action items identified at the PSL design requirements review have been implemented and incorporated into the PSL design requirements document. The PSL preliminary design was completed and is scheduled for review in early June. A PSL prototype, a laboratory model of the PSL with CDS controls, was assembled. The laser has been brought under CDS operation, and the PSL/CDS servos are being tested. The PSL prototype operation, which will give data on the expected performance of the LIGO PSL subsystem, will begin within the next month.

Input/Output Optics (IOO). A conceptual optical layout of the IOO has been generated and is being used in the overall detector conceptual optical layout. The IOO design requirements and conceptual design are scheduled for review in the first quarter of 1996.

Core Optics Components (COC). COC efforts during this quarter focused on the test mass mirror prototyping activity. Two of the seven companies that responded to the polishing technology demonstration RFP were selected and will each polish two test mass blanks. The selected suppliers are Hughes Danbury Optical Systems (HDOS) in Danbury, CT and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Sydney, Australia. Contract negotiations with both companies were completed; the HDOS contract has been submitted to NSF for approval and a draft of the CSIRO is being reviewed internally. A contract for the coating technology demonstration with Research Electro-Optics, Inc. in Boulder, CO was approved by the NSF and initiated by Caltech. A contract for consulting services was initiated with Dr. Katherine Creath. With her assistance, an RFP for independent metrology of the polished and coated test mass surfaces is being prepared.

In preparation for a design requirements review, work began on the documentation of performance requirements and interfaces for the core optics components.

Alignment Sensing/Control (ASC). Work continued on the requirements, the interface definitions, and the conceptual design for the ASC. The seismic environment relevant to the alignment was characterized based on actual measurements and literature to help select the right sensing systems; particular attention was paid to the motion of the foundation of the center station with respect to the end stations. Several alternatives to the baseline conceptual design were investigated.

The draft ASC Systems Design Requirements Document was completed and circulated for comments, and on May 11 the ASC Design Requirements Review took place. Action items from this Review were generated and were incorporated into the continuing effort.

A reorganization of the Optical Lever subsystem, necessitated by the departure of the responsible engineer, is being developed with a new schedule and plan for implementation. This rescheduling does not have any impact on other subsystems.

Length Sensing/Control (LSC). Definition of the interface requirements and performance requirements of the LSC subsystem continued, with an emphasis on determining how the performance requirements of the LIGO interferometers flow down to produce primary requirements on the LSC. Documentation of these design requirements began, with current knowledge detailed in outline form.

A study of the expected length fluctuations over the 4 km interferometer baseline was initiated, using measurements at the Hanford site and publications on seismology as sources of information. This study has led to a conceptual design for applying length corrections to the 4 km arm cavities. The LSC subsystem will use the suspended mirror actuators for acquiring lock and for making length corrections in the operating mode on time scales of minutes and shorter; the stack support actuators will be used for making length corrections on time scales much longer than a minute.

Operations Mode Modeling (On-Resonance Model): Progress was made on determining the small signal frequency response of the interferometer error signals to motions of the interferometer mirrors. A discrepancy between two separate modeling codes was resolved, and the two models now give the same results when applied to a single cavity. We are presently checking the transfer function responses for the more complicated interferometer configurations.

Acquisition Mode Modeling (Off-Resonance Model): The acquisition modeling work focused on the development of an optical response model for two coupled Fabry-Perot cavities, one of the building blocks needed for developing the model of the LIGO recycled interferometer. The most time-consuming part of the task has been validating the code, which is being done by checking its on-resonance, small signal output against the operations models mentioned above. At this point, the optical response code appears to be correct.

Suspension Design (SUS). The requirements, interfaces, and the conceptual design of the suspension subsystem were established and documented in the SUS Design Requirements Document. A formal review is scheduled for early June.

It was determined that the suspension sensor is marginally adequate to maintain the orientation of the suspended optical components within a range which can ensure the acquisition of the locking. To provide adequate margin, the ASC optical lever sensors will be used to provide orientation information in the acquisition mode.

The SUS schedule has been rearranged to allow completion of the 40 m suspension design (see R&D report, below) first (by mid-June) and then to proceed to the preliminary design of the LIGO suspension.

Systems Engineering (SYS). The Systems Engineering work was primarily of three types: informal communications with subsystem task leaders, to help set the scope and delineate major interfaces (this interaction has been heaviest in the least developed subsystems, such as SEI and IOO); establishing a detector system-wide integrated optical and mechanical model with emphasis on specifying interfaces; helping to structure design requirements reviews (PSL, and ASC and to a lesser extent SUS), participating in the reviews, and assisting with the formulation, assignment, and completion of action items resulting from the reviews.

4.2.2 Control and Data System (WBS 1.2.2) Design Activities

The most significant effort completed during the reporting period was the installation of the prototype PSL control system in the optics laboratory at Caltech (part of WBS 1.2.2.1.1.2). This work included the design and manufacturing, installation, software development, and commissioning of the required hardware. The PSL controls preliminary design (part of WBS 1.2.2.1.1.2) was started in parallel with the PSL controls prototype development.

The Data Acquisition conceptual design (part of WBS 1.2.2.1.3) continued; some concepts were implemented and tested as part of a demonstration of lock acquisition on the 40m interferometer.

4.3 Research and Development (WBS 1.3)

4.3.1 40 m Interferometer Investigations

The main activity this quarter has been to reconfigure the 40 m interferometer to operate with direct optical recombination of the light from the two arms, instead of the electronic comparison that was previously used. This change will permit higher power operation and is required before recycling can be implemented. The configuration adopted for the recombined interferometer requires that a small asymmetry (approximately 50 cm) be introduced in the Michelson arms. The physical modification of moving the test masses was completed last quarter. The early part of this quarter was devoted to verifying that the performance of the interferometer had not been degraded by this move.

After the performance of the interferometer was restored to its previous level, the final steps toward recombination were completed. The circulators which diverted the beams toward independent photodiodes in the old configuration were removed from the two arms. New servoelectronics to extract the signals and feed them back to the two arms and to the beamsplitter were installed and debugged. Stable lock was achieved relatively quickly and noise characterization in the new configuration has begun. The initial noise level was high because the various servos were not optimized. Substantial progress has been made toward restoring the performance to the level achieved prior to the reconfiguration.

An investigation of the physics of lock acquisition on the 40 meter interferometer was completed. A detailed model of the optical, electronic and mechanical portions of the second arm servosystem was constructed. This model predicted that the analog servosystem could only acquire lock when the second arm cavity swings through optical resonance with a velocity below a critical threshold, and this behavior was verified experimentally. Based on these results a computer controlled lock acquisition was implemented. The analog servo is disabled and the arm allowed to swing through resonance; the discriminator signal is sampled and analyzed by the computer to determine the relative velocity of the second arm test masses. The computer then applies an impulse to one of the test masses to send it back toward resonance with a velocity below the critical threshold and the analog servo is enabled. The result was an order of magnitude decrease in the average time to acquire lock. Similar techniques may be applicable to the more complex LIGO interferometers. A short paper describing the results is being prepared for publication.

4.3.2 Suspended Mode Cleaner

A 12 meter long mode cleaner using separately suspended mirrors is being developed as a LIGO prototype and for testing on the 40 m interferometer. Off-line characterization of this mode cleaner was completed during this quarter and a performance review was held. The principal results are the following:

- The theory that describes the rejection of beam position and angular fluctuations by the mode cleaner was tested and confirmed.
- The frequency stabilization of the laser to the mode cleaner was verified. Final confirmation that the frequency noise is satisfactory will follow from the tests with the 40 m interferometer. Some excess rf intensity noise was observed and this will be investigated further.
- Long term stability of the output beam direction is not sufficient for either LIGO or the 40 meter interferometer. This result had been anticipated and plans to provide long term active stabilization of the output by developing a Beam Pointing Control Unit are underway.

Preparations for the installation of this mode cleaner on the 40 m interferometer continued. The physical layout for the installation was designed and approved. An additional vacuum chamber needed to accommodate the mode cleaner was completed and is being tested. The mode cleaner mirrors, suspensions and in-vacuum cabling were tested for outgassing and meet the level required for installation in the 40 m interferometer. All electronics needed to support the installation in the 40 m interferometer were completed. Installation will begin as soon as the current testing of the 40 m in its recombined configuration is completed.

4.3.3 Suspension Development

Design of new test mass suspensions for the 40 m interferometer is underway. The new design incorporates the key elements planned for the LIGO detector suspensions and corrects for some deficiencies in the current design, specifically, mechanical resonances with frequencies near 100 Hz which lead to large peaks in the 40 m noise spectrum. A prototype of this suspension will be fabricated and installed in the 40 m interferometer later this year to test its performance and to provide feedback to the LIGO detector design.

An apparatus to measure the Qs of both internal and suspension mechanical modes for full-size LIGO test masses has been completed. This apparatus replaces a smaller one used to investigate the techniques for obtaining high Qs in the the current 40 m test masses, which led to the improvements in the noise spectrum achieved in 1994. A full-size prototype test mass has been installed in the test stand and preliminary checkout of the apparatus has begun.

4.3.4 Phase Noise Research

To attain the high sensitivity to gravitational wave strains in the frequency range of interest, the LIGO interferometer must make a very precise measurement of the optical phase of the light (10^{-10} rad/rHz). This is a complementary demonstration to the position sensitivity (for which the 40m interferometer is the primary tool), as both phase and position sensitivity are needed for the LIGO. This research effort is designed to demonstrate the technology for the shot-noise limited interferometer operation at initial LIGO power levels and to achieve the required phase sensitivity using the 5 m facility at MIT. In this quarter, the construction was completed for the first research phase: a Michelson interferometer, using the planned modulation technique of an asymmetry in the arm length.

The final steps in this construction effort were

- the installation of soft-wall clean-rooms. This allows a class-1000 clean-room environment around the vacuum system in a class-75,000 high bay so that installation and alignment of very low-loss optics can be performed without fear of contamination, even for extended periods of exposure.
- the assembly, vacuum preparation, balancing, and installation of suspended optical components; some discoveries about the need for electrostatic shielding were made in the process.
- completion of the input optics chain. This task required a re-design when problems with the vacuum preparation of a planned single-mode fiber developed, but a satisfactory solution has been found and implemented.
- the characterization of the pre-stabilized laser and its frequency control system.

The Michelson interferometer has been operated at atmospheric pressure to check the overall operation; however, convection currents disturb the mirrors so that precision measurements must await the pumpdown of the vacuum system. This is underway as the quarter closes.

It is anticipated that the system will be ready for initial measurements in the first week of June.

The Active Isolator system manufactured by Barry Controls received further attention. Barry engineers and MIT LIGO scientists worked together to find some problems in the isolator mechanical assembly. Once these problems were fixed, the isolator delivered impressive performance in the vertical direction (giving a factor of 100 reduction in the seismic noise from 2-30 Hz), and a factor of 10 in the horizontal direction (not as much as expected, but still useful). In the MIT environment, this isolator offers a ‘quiet site' in a very noisy environment; and it has applications in LIGO to reduce control system dynamic range and to allow higher resonant ‘Q' of the seismic isolation stack.

4.3.5 Interferometer Alignment Investigations

This research effort is directed toward providing the operational system of alignment for the LIGO initial interferometer. A test of the target wavefront sensing system has been initiated on the MIT fixed mass interferometer, where the discriminants at all interferometer ports will be measured and compared with the semi-analytical model. This test will be the first prototype to employ the modulation and configuration system which has been selected for the initial LIGO, and this aspect of the experiment (the length control system) has been the primary focus of the effort this quarter.

The semi-analytical model has been exercised to provide the detailed design for the configuration, and the design process has been refined and (through a technical note) transferred to the Systems Engineering Interferometer Configuration effort for the LIGO design.

The light source, with two carrier frequencies and three sideband frequencies, has been coupled through a single mode fiber to the experimental table. The light has been characterized for unwanted intensity modulation and found satisfactory.

A new design for the actuators (using Piezo-electric transducers) has been developed. The goal is to provide a uniform transfer function to frequencies above 50 kHz, allowing tight control over the mirror positions. The design has its first resonance at 70 kHz with a ‘Q' of 10, which will permit a simplification of the length control design and a reduction in deviations from the desired operating point.

Fabrication of angle monitor systems (diode lasers, short optical levers, and quadrant photodiodes) is underway in MIT's CSR shop for delivery in June.

A study of the data acquisition system has been started, with the goal of realizing some of the important features of the initial LIGO interferometer system (hardware and software).

4.4 Project Office

4.4.1 Project Management (WBS 1.4.1)

Staffing. The LIGO staff currently consists of 73 equivalent. Of these, eight are contract employees. During the quarter LIGO added the following personnel:

TABLE 2. New LIGO Employees (March 1995 - May 1995)

Hiro Yamamoto	Senior Scientist - Integration Group - CIT
Richard Fischer	Special Assistant to the Project Manager - Contract Employee - CIT
Gabriela Gonzalez	Scientist - R&D Group - MIT
Thomas Nguyen	Computing Support - Integration Group - Contract Employee - CIT
Edward Jasnow	Subcontracts Manager - Project Controls Group - CIT/JPL
Janeen Hazel	Senior Mechanical Engineer - Detector Group - CIT

TABLE 2. New LIGO Employees (March 1995 - May 1995)

Daniel Sigg	Scientist - R&D Group - MIT
GariLynn Billingsley	Senior Optical Engineer - Detector Group - CIT
Otto Matherny	Senior Civil Engineer - Facilities Group - CIT
Mark Coles	Group Leader - Facilities Group - CIT
Norbert Solomonson	Scientist - Detector Group - CIT
Kent Blackburn	Senior Scientist - Integration Group - CIT

Fifty-seven LIGO staff are located at CIT including four graduate students. Sixteen are located at MIT including five graduate students.

NSF Review. The regular semi-annual review of the LIGO Project was conducted by a review committee of experts on behalf of the National Science Foundation on May 22-24, 1995 at Caltech. The focus of this review was the newly-implemented Project Management Control System and other related management topics. Written materials were provided to the committee prior to the review, oral presentations were given, and small focus groups met to review details of the project. The committee report is not yet finalized, however, in general committee comments were favorable. Specifically the committee noted that the recently implemented project management systems are appropriate to the mission, are being used by LIGO management, and are expected to perform the project tracking and planning tasks. This review represents closure of the milestone to establish a Performance Measurement Baseline discussed below.

The committee also noted that the plan for commissioning and operating the LIGO facility that was presented during the review provides a credible basis for planning and projecting the budgets and staffing required.

Schedule Status. In accordance with milestones proposed during the NSF review in June 1994, a LIGO Project Performance Measurement Baseline has been prepared. This Performance Measurement Baseline is based upon a cost estimate maintained to reflect approved change board actions and actual cost experience, an integrated project schedule, and a time-phased budget based on estimates assigned to individual tasks in the project schedule. The LIGO Integrated Project Schedule (IPS) has been prepared and a report summarizing the status of major project milestones is attached to this report. The IPS and the schedule status were also presented during NSF Review May 22-24, 1995. The budget has been assigned to measurable milestones wherever possible so that the value earned for work completed can be readily calculated.

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

Beam Tube Fabrication." The status of the significant milestones identified in the Project Management Plan is summarized in Tables 3 and 4.

TABLE 3. Status of Significant Facility Milestones

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

TABLE 4. Status of Significant Detector Milestones

Milestone Description	Late Date		Completion Date	
	Washington	Louisiana	Washington	Louisiana
BSC/TMC Seismic Isolation Final Design Review	11/96			
Core Optics Support Final Design Review	11/96			
HAM Seismic Isolation Final Design Review	12/96			
Core Optics Components Final Design Review	01/97			
Detector System Preliminary Design Review	01/97			
I/O Optics Final Design Review	06/97			
Prestabilized Laser Final Design Review	08/97			
CDS Networking Systems Ready for Installation	09/97			

TABLE 4. Status of Significant Detector Milestones

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

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

Performance Status. In accordance with milestones proposed during the NSF review in June 1994, a LIGO Project Performance Measurement Baseline has been prepared. This Performance Measurement Baseline was initially based upon the Cost Estimate presented to NSF during the September 1994 review and subsequently to the National Science Board in November. The estimate was reviewed and adjusted to assure that all effort was uniquely covered. Next an integrated schedule was developed based upon the same breakdown of work as the cost estimate. This provided a means for tying the cost estimates to the schedule to create a time phased budget baseline. The final step was to assign all budget to measurable milestones, with the exception of level-of-effort activity, to facilitate the calculation and reporting of value earned for work completed on an ongoing basis.

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

In addition graphical reports have been attached which show the same data, as a function of time, for the three months ending with May.

As of the end of May, the most significant unfavorable schedule variances are in the Beam

Tube Enclosure (WBS 1.1.3) and in R&D (WBS 1.3). The unfavorable schedule variance for the Beam Tube Enclosure (BTE) reflects an anticipated two to three month slip relative to the baseline. However, there is sufficient float in the BTE schedule to avoid impacting project milestones. The negative schedule variance in R&D represents a one month behind schedule position primarily in the 40 meter test mass suspension development effort and the phase noise research effort.

The most significant unfavorable cost variance is in the Detector (WBS 1.2) due primarily to rate variances in the Control and Data Systems and the prepaid costs for EPICS (control systems) support services to be provided by Los Alamos.

There are large favorable cost variances in the Facilities WBS elements, especially in the Beam Tube (WBS 1.1.2) . These variances are primarily caused by delayed invoicing by the contractors. One system enhancement that LIGO is currently investigating is to accrue costs for large contracts as the work is completed. This would alleviate the distortion caused by late billing or payment for major contracts.

The favorable cost variance in R&D (WBS 1.3) is partially due to the normal delay in costs reported by MIT, but also reflects a favorable cost variance relative to the budgets assigned for work completed.

Change Control and Contingency Allocation. A LIGO Change Request Form has been prepared. The first meetings of the LIGO Change Board were held in May. The new forms and procedures will be used to manage the technical configuration as well as to control the performance measurement baselines including contingency.

The following Change Requests have been approved. $433K has been <u>returned</u> to the contingency pool, increasing the funds managed in the contingency pool.

TABLE 5. Approved Change Requests

Change Request No.	Description	Submitted By	Date	Status
CR-950001	Improve Beam Tube Cleaning Process	L. Jones	April 14, 1995	Approved $137,000
CR-950005 B	Contract for clearing Livingston site	F. Asiri	April 21, 1995	Approved $135,735
CR-950007	Vacuum Equipment - Change Specification to Rev 1 (Tube Termination Interface)	J. Worden	May 3, 1995	Approved
CR-950008	Vacuum Equipment - Getter Pumps	J. Worden	May 3, 1995	Approved ($1.29M)
CR-950010	FY 1994 Actual Cost Allocation	P. Lindquist	May 12, 1995	Approved $584,000

4.4.2 Systems Engineering (WBS 1.4.3)

Engineering Specifications and Documentation. A draft Science Requirements Document was completed and distributed at the LIGO Science and Integration Meeting at the end of May. A second iteration will be issued by the end of June incorporating the recommendations of the LIGO team.

Work has commenced on the LIGO Systems Specification. An important next-step will be to work with the Detector Group to develop an allocation of allowable errors to the major Detector subsystems to ensure that the Detector will achieve the LIGO design sensitivity goal.

The issue of facilities and detector availability was studied during the completion of the Science Requirements Document. Using the programming environment Mathematica, simplified single, double and triple coincidence failure rate probability models were developed to determine the sensitivity of these modes to interferometer failure rates. This task needs additional work before it will be completed. Additional refinement will attempt to take into account the estimated down time required for maintenance (as opposed to equipment failure). This will include facilities-related maintenance and preventative maintenance of detector subsystem hardware. As Detector subsystems become defined in the Detector reviews, the model can be updated.

A number of LIGO interfaces have been defined and will be included in Interface Control Documents. To date, the interfaces addressed have been: Vacuum Equipment-Beam Tube interfaces; Beam Tube-Facilities (Beam Tube Enclosure) interfaces; and Detector-Vacuum Equipment control and signal interfaces. Work will commence in the next quarter towards addressing the functional layout of the Laser and Vacuum Equipment Areas (halls) within the corner, mid-, and end-station buildings. Issues needing resolution include: cabling for Detector and Vacuum Equipment; material handling requirements for installing and working on detector components; portable clean room requirements; acoustic noise from electronics equipment within the vicinity of the test masses and seismic isolation systems; and Vacuum Equipment-Detector-Facilities mechanical interfaces.

In addition grounding and shielding requirements are being defined. LIGO will enlist the support of an outside consultant with expertise in this area to review our approach and to review the A&E firm's proposed implementation.

The proposal for the LIGO Operations Phase was completed and submitted for consideration to the NSF. Included in the document is a detailed estimate of the manpower loading requirements to support installation and integration of the detector system at both observatory sites. As part of this effort a preliminary LIGO integration approach was outlined. This will be expanded in the coming year as detector subsystem preliminary designs mature and testing and installation approaches are identified.

Beam tube baffle design. Measurements by LIGO during the Beam Tube Qualification at the contractor facilities (CBI) showed the beam tube backscatter (BRDF) was more than one order of magnitude higher than expected. This finding led to several related decisions:

1. to baffle the first 100 m of beam tube near the test masses to preclude direct viewing by the cavity mirrors of the beam tube anywhere;
2. to seek materials or coatings for the baffles with better backscatter properties;
3. to arrange the baffles in a geometrical progression of increasing distance between baffles as one moves away from a test mass. This progression is maintained until the midpoint between two test masses is reached, where the progression is reversed. In doing this, the total number of baffles are kept to a minimum while the contribution to scattered light arising from diffraction at small angles is minimized.

We enlisted the firm BRO to review material options for the LIGO baffles. They provided a report outlining two broad categories of materials that, in their judgement, represented cost effective solutions: black glass, similar to the VIRGO approach, and inexpensive teflon-based fabric-like materials. LIGO reviewed these recommendations and determined that use of fabric-like materials was a too large a departure from the baseline to allow consideration without an involved R&D evaluation; the black glass will most likely be utilized in controlling scattered light within the chambers and beam manifolds. LIGO has identified two options to pursue with regard to the beam tube subsystem:

1. Martin Black, a diffuse, absorptive material which is routinely used in space-based applications on optical systems. There is concern regarding potential outgassing and optical contamination from organic compounds used in the manufacture of the material. LIGO is subcontracting MIT's Plasma Fusion Center to evaluate the material's vacuum properties. Results should be available by early July. Two other issues that need to be addressed involve cost of the material in bulk quantities and its availability.
2. LIGO has determined that using cold rolled stainless steel (CRSS) with a smooth mill finish and which has been oxidized in air at elevated temperature is an attractive candidate: oxidation reduces the metallic specular reflectivity sufficiently, and the smooth, semi-polished finish of the cold rolling process imparts a particularly low backscatter characteristic to the material. These combined properties make it especially attractive, since there is no risk associated with vacuum compatibility. Evaluation tests with different oxidation thicknesses and at both 0.5 μm and 1 μm wavelengths are being conducted at MIT. Preliminary tests of a single sample using the green HeNe line indicate that it is possible to oxidize the steel to within LIGO requirements; additional work is planned in July to identify an optimal oxidation layer thickness. It is desirable to maintain the oxidation layer thickness to a minimum because in general the oxidation process roughens the surface and the backscatter increases.

During the next quarter we will also addresses the mechanical design and mounting concepts for the baffles within the beam tube modules.

Interferometer Baseline Configuration Definition. This effort has been slowed due to lack of available personnel to address the task. It will be initiated by mid-June. Issues which will be addressed in the course of the present effort include:

- location and kind of signal pick-offs (i.e., mirrors) needed within the interferometer to sense the length degrees of freedom which need to be controlled;
- location of the frequency carrier and subcarriers;
- sensitivity of these frequencies to potentially interfering higher-order cavity modes and;
- a complete end-to-end sensitivity analysis of the GW signal for the completely defined interferometer configuration;

Design of HR and AR coatings for Dual Wavelength Operation. Preliminary results from ongoing efforts at Stanford University aimed at developing scientific and commercial versions of diode-pumped Nd:YAG laser technology indicate that frequency-doubled solid state lasers operating at CW power levels needed for LIGO interferometers may be available at about the time LIGO is scheduled to begin operations.

Unfortunately, the LIGO core optics specifications and optics procurement will need to be in place earlier than it will be possible to assess whether Nd:YAG laser technology can be routinely available for LIGO in time to adopt the technology in the initial interferometer design. However, a prudent risk-reduction approach for LIGO is to provide, if technically feasible, for agility in operating LIGO lasers at either of the two laser lines (Ar+ @ 514.5 nm and Nd:YAG @ 532.0 nm).

The anti-reflecting coating was extensively studied to explore the applicability to support two wavelengths (Ar laser 514.5 nm and frequency-doubled Nd:YAG laser 532 nm) by the same coating. It was shown that it is possible to design coatings for most of the mirrors which provide almost identical performances for the two wavelengths in terms of reflectance and phase, with a caveat that the electric field on the surface cannot be set to as low as the case for the coating for the single wavelength case and that we have to understand the effect of the high field on the surface.

Trade Study - Nd:YAG (1064 nm) Laser vs. Ar+ (514.5 nm) Laser. The results of a LIGO-VIRGO management meeting earlier in the year lead us to reconsider LIGO's baseline approach which is based on an Ar+ laser light source.

Issues of reliability and power dictate a different light source for advanced interferometers. Therefore, it has been decided to initiate a trade study to assess the feasibility of changing the baseline laser source in the initial LIGO detector design. The trade study will address the following issues: 1) realistically available commercial sources for Nd:YAG lasers; 2) expected power output and MTBF; 3) the impact of the cost, schedule, and technical risk to the Detector design; and 4) the design changes required in other affected Detector subsystems. The trade study will be completed by mid-July, and an internal technical meeting will be scheduled to present results and to determine a course of action. The study will also address long-term collaboration with other institutions to provide the required technology.

LIGO End-to-End Simulation and Analysis Environment. The Advanced Visualization System (AVS) software package was adopted and installed on the LIGO computer network during this quarter. The software is working quite nicely, though several bugs have been found and reported to the AVS support group. Uses of the software at this time have included the analysis and visualization of data collected from the 40 meter interferometer and the modeling of dual wavelength coatings for LIGO optics. Both time and frequency domain data sets taken from the 40 meter interferometer can now be analyzed and displayed using AVS. Efforts are currently underway to find ways to automate the data acquisition from the HP3563A analyzer. This will increase the reliability and self documentation of the data as it is brought into the AVS environment for analysis and visualization.

Discrepancies between model results for the interferometer frequency transfer functions by two models, one originally written by Prof. Rainer Weiss from MIT and Dr. Martin Regehr from Caltech, have been resolved. After fixing one programming error, the two models agreed very well for the single Fabry-Perot case. Comparison has been extended to other cases, such as a coupled cavity, to verify that the basis for future calculations is well understood. This is an important first step toward developing an end-to-end LIGO interferometer model. Additional work planned in the coming quarter will include developing the LIGO interferometer model within AVS and compiling the model for the noise sources within the same environment.

5.0 Financial Status Report

Actual cost through the second quarter of FY 1995 have been allocated to the new LIGO Project WBS and are summarized in Table 6.

Table 6: Actual Costs and Commitments Through April 1995.

WBS	Description	Allocation of Costs through Nov 1994	First Quarter FY 1995	Mar 1995	Apr 1995	May 1995	Cumulative Costs	Open Commitments	Total Costs Plus Commitments
1.1.1	Vacuum Equipment	$487,273	$51,332	$13,562	$32,310	$16,983	$601,459	$593,806	$1,195,265
1.1.2	Beam Tubes	$1,339,077	$624,770	$35,986	$33,685	$164,933	$2,198,451	$442,996	$2,641,447
1.1.3	Beam Tube Enclosures	$8,149	$9,137	$3,263	$3,263	$4,242	$28,054		$28,054
1.1.4	Facility Design and Construction	$3,284,754	$750,737	$292,359	$487,081	$11,753	$4,826,684	$4,792,520	$9,619,204
1.2	Detector	--	$599,814	$287,391	$113,886	$167,986	$1,169,077	$377,279	$1,546,356
1.3	R&D	$10,407,161	$662,558	$156,034	$119,486	$144,187	$11,489,426	$846,021	$12,335,447
1.4	Project Office	$4,729,283	$899,809	$312,618	$527,532	$304,421	$6,773,663	$1,003,781	$7,777,444
	Unassigned[a]	$1,670	($415)	$0	($1,424)	$0	($169)	$187,379	$187,210
1.0	Total Project Costs	$20,257,368	$3,597,741	$1,101,213	$1,315,820	$814,504	$27,086,646	$8,243,782	$35,330,428
Cumulative Project Costs		$20,257,368	$23,855,108	$24,956,322	$26,272,141	$27,086,646			
Open Commitments		$3,531,398	$7,221,014	$8,897,155	$7,208,434	$8,243,782			
Costs Plus Commitments		$23,788,766	$31,076,122	$33,853,477	$33,480,576	$35,330,428			
NSF Funding		$47,088,935	$47,088,935	$47,088,935	$121,481,109	$121,481,109			

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

CONTRACTOR: Caltech LOCATION: Pasadena, CA	CONTRACT TYPE/NO: PHY-9210038	PROJECT NAME/NO: LIGO Master Merged PMB - WBS 1.0	REPORT PERIOD: 30APR95-31MAY95	SIGNATURE: TITLE / DATE:

CONTRACT DATA

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

PERFORMANCE DATA

	CUMULATIVE TO DATE					AT COMPLETION		
	BUDGETED COST			VARIANCE				
MPR Level	(1) WORK SCHEDULED	(2) WORK PERFORMED	(3) ACTUAL COST WORK PERFORMED	(4) SCHEDULE (2-1)	(5) COST (2-3)	(6) BUDGETED	(7) ESTIMATE AT COMPLETE	(8) VARIANCE (6-7)
1.1.1 : Vacuum Equipment	673	1031	601	358	429	45061	45061	0
1.1.2 : Beam Tubes	2814	2814	2198	0	616	43922	43922	0
1.1.3 : Beam Tube Enclosur	353	209	28	(144)	181	18062	18062	0
1.1.4 : Facility Design &	4560	4737	4827	177	(90)	49750	49750	0
1.2 : Detector	967	887	1169	(80)	(282)	48338	48338	0
1.3 : Research & Developme	12285	12070	11489	(215)	581	23400	23400	0
1.4 : Project Office	6865	6865	6774	0	91	21471	21471	0
SUBTOTAL	28517	28612	27087	96	1525	250005	250005	0
CONTINGENCY	▨	▨	▨	▨	▨	0	42095	(42095)
MANAGEMENT RESERVE	▨	▨	▨	▨	▨	42095	0	42095
TOTAL	28517	28612	27087	96	1525	292100	292100	0

19JUN95 17:20:58 Thousands of $ COBRA (R) by WST Corp.

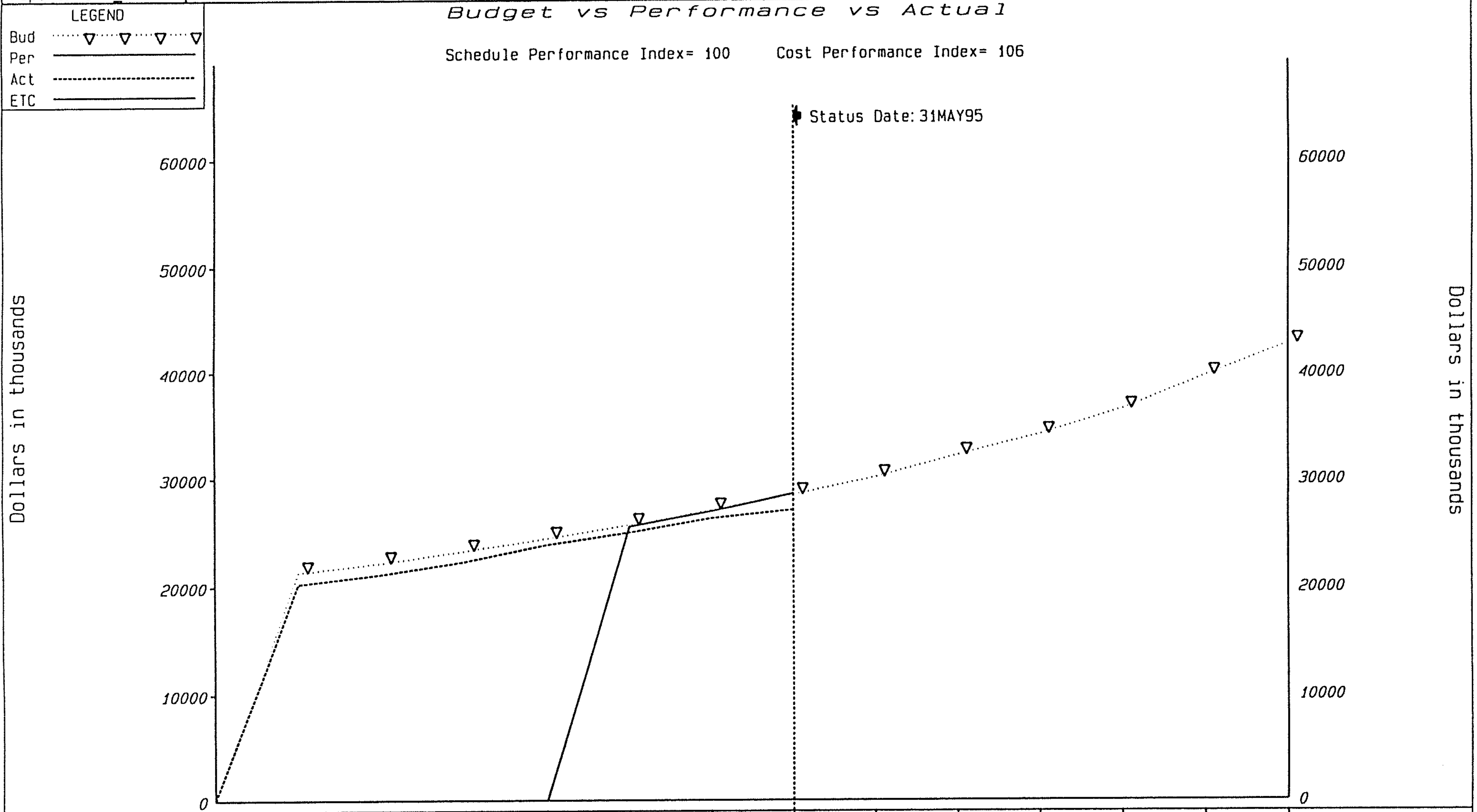
COBRA (R)
Report: SPA_XM

LIGO PROJECT
1 LIGO Construction

Date: 9JUN95
Program: PMB_0595

Budget vs Performance vs Actual

Schedule Performance Index= 100 Cost Performance Index= 106



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	21,332	22,222	23,301	24,415	25,665	27,127	28,517	30,133	32,174	34,092	36,488	39,641	42,673	K$
Performance	0	0	0	0	25,491	26,946	28,612							K$
Actual/Forecast	20,255	21,173	22,343	23,853	24,955	26,272	27,086							K$
Schedule Variance	-21,332	-22,222	-23,301	-24,415	- 174	- 181	95							K$
Cost Variance	-20,255	-21,173	-22,343	-23,853	536	674	1,526							K$

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

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

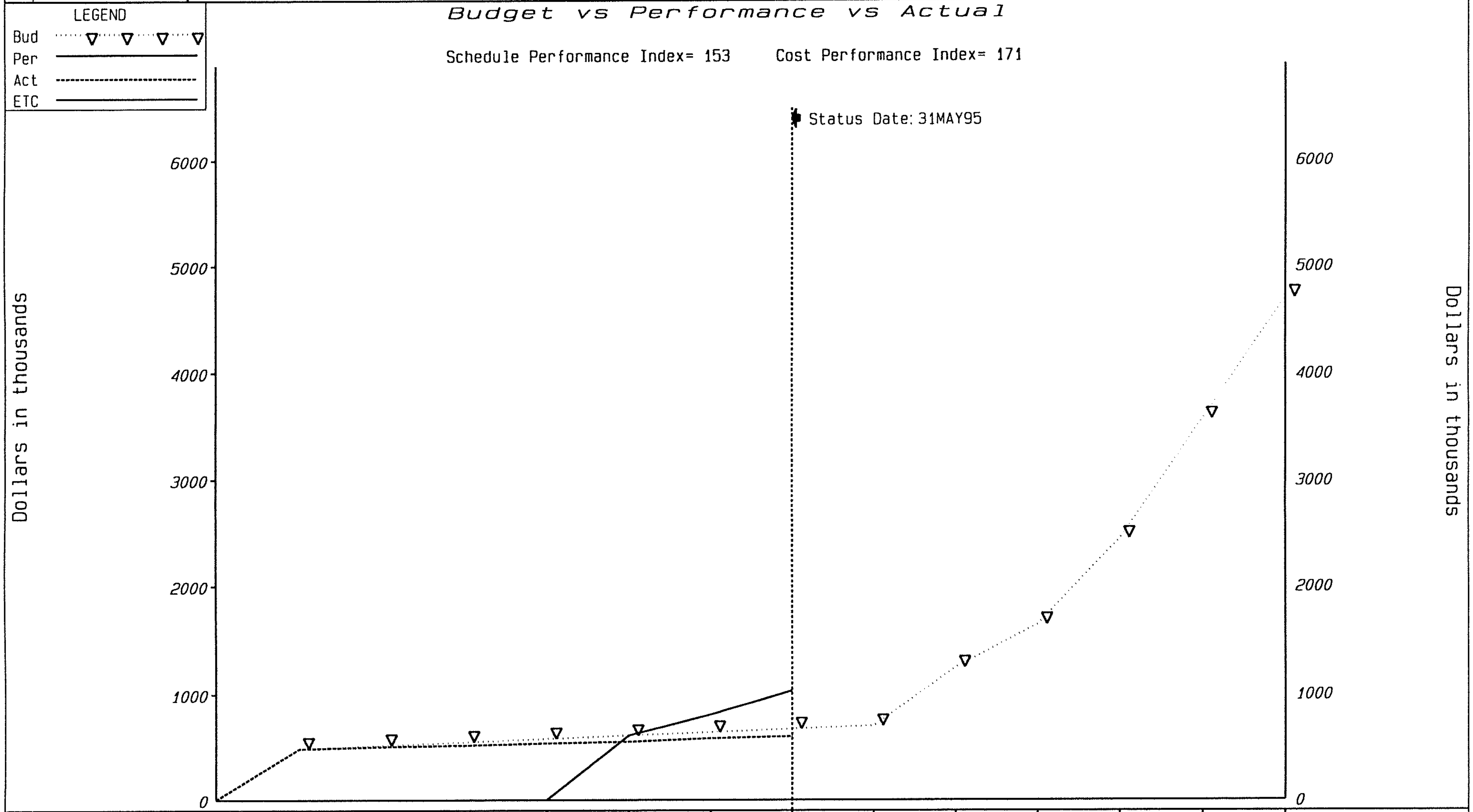
COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1.1.1 Vacuum Equipment

Date: 22JUN95
Program: PMB_0595

Budget vs Performance vs Actual

Schedule Performance Index= 153 Cost Performance Index= 171



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	487	518	549	580	611	642	673	704	1, 246	1, 642	2, 441	3, 568	4, 695	K$
Performance	0	0	0	0	611	811	1, 031							K$
Actual/Forecast	487	505	517	538	552	584	601							K$
Schedule Variance	- 487	- 518	- 549	- 580	0	169	358							K$
Cost Variance	- 487	- 505	- 517	- 538	59	227	430							K$

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

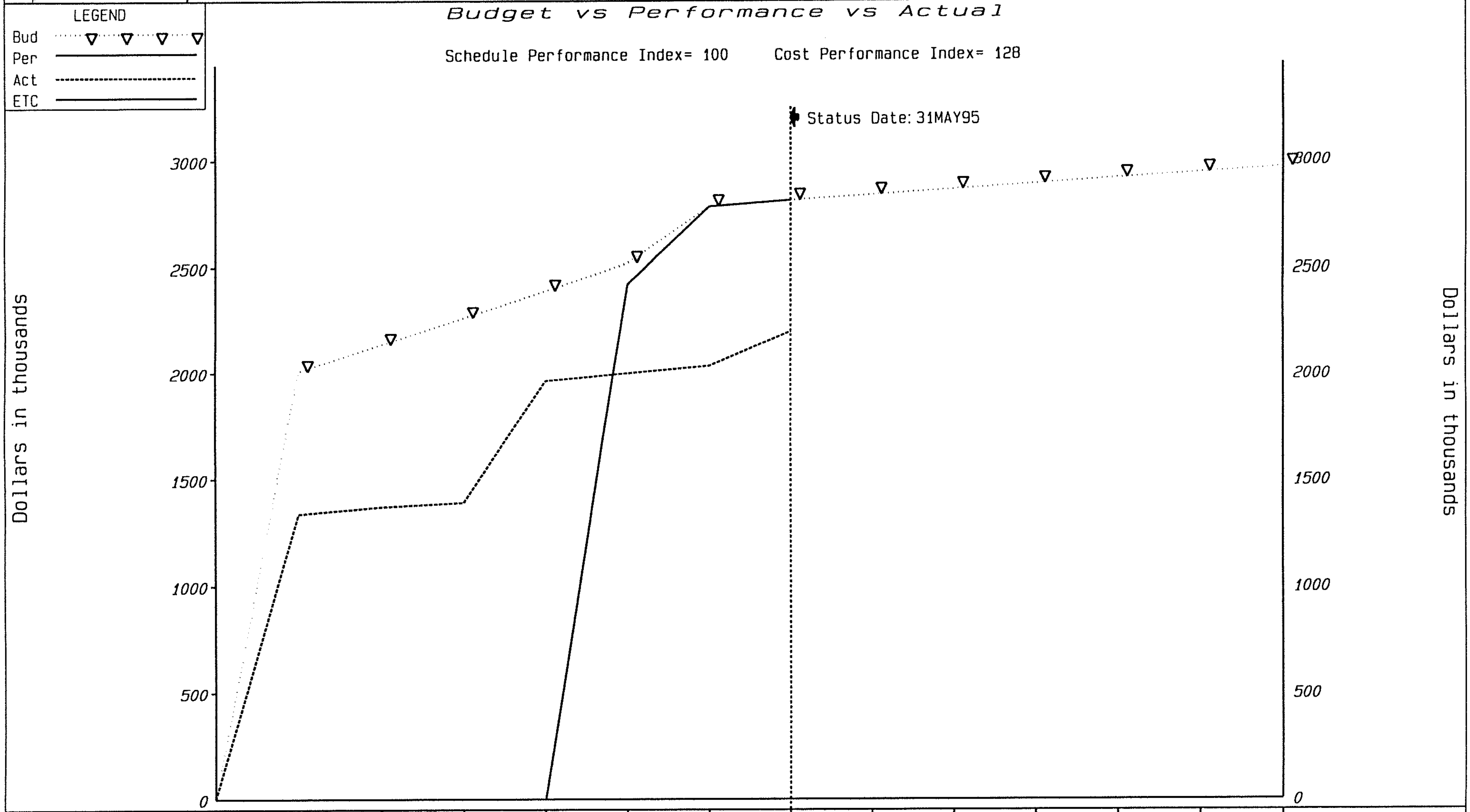
*** Prepared by LIGO Project Controls Group ***

COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1.1.2 Beam Tubes
Budget vs Performance vs Actual

Date: 22JUN95
Program: PMB_0595

Schedule Performance Index= 100 Cost Performance Index= 128



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	2, 008	2, 135	2, 262	2, 390	2, 520	2, 786	2, 814	2, 839	2, 864	2, 889	2, 914	2, 938	2, 963	K$
Performance	0	0	0	0	2, 421	2, 786	2, 814							K$
Actual/Forecast	1, 339	1, 371	1, 391	1, 963	1, 999	2, 033	2, 198							K$
Schedule Variance	-2, 008	-2, 135	-2, 262	-2, 390	-99	0	0							K$
Cost Variance	-1, 339	-1, 371	-1, 391	-1, 963	422	753	616							K$

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

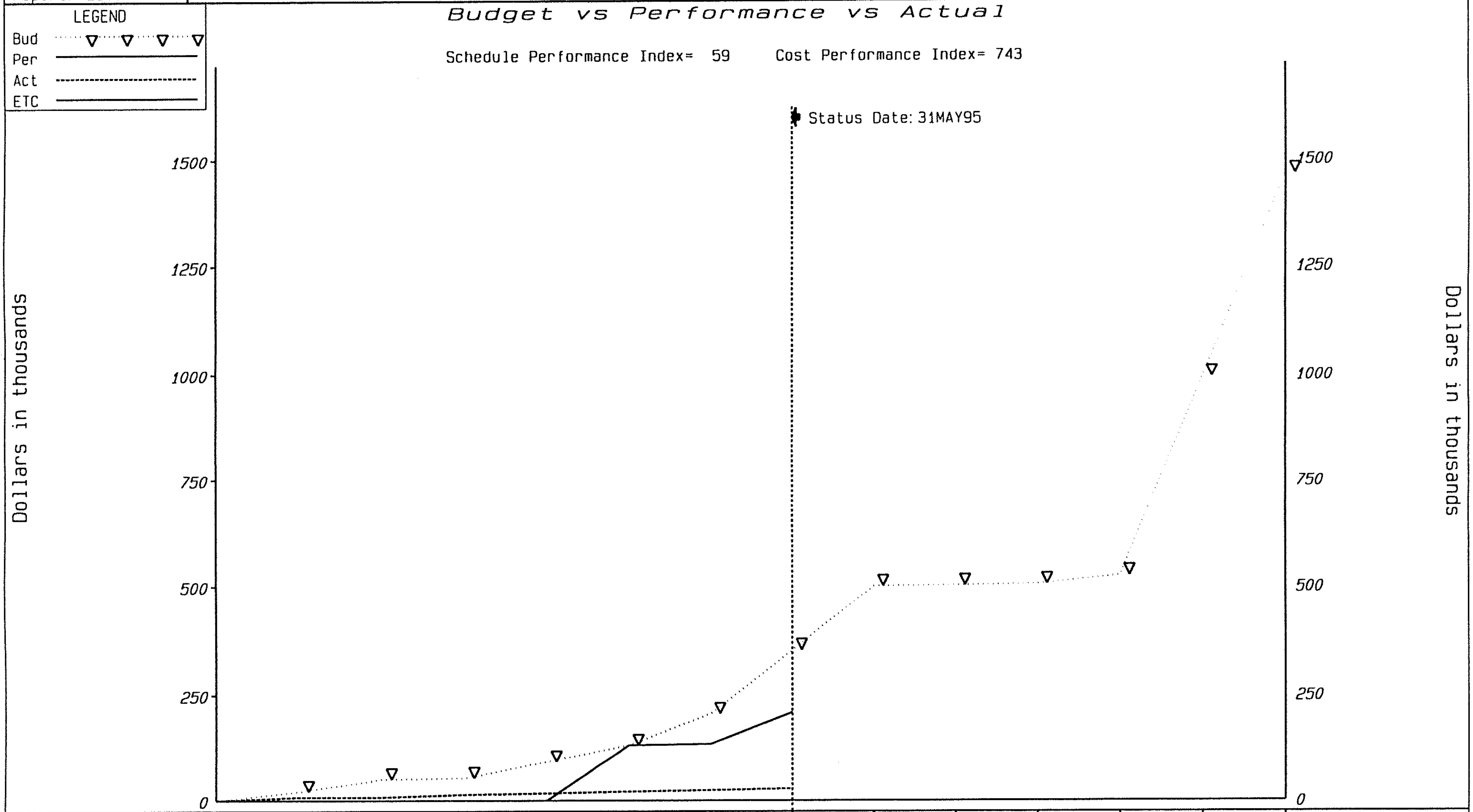
*** Prepared by LIGO Project Controls Group ***

COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1.1.3 Beam Tube Enclosures (BTE)
Budget vs Performance vs Actual

Date: 22JUN95
Program: PMB_0595

Schedule Performance Index= 59   Cost Performance Index= 743



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	21	50	53	92	131	206	353	500	502	505	525	994	1, 464	K$
Performance	0	0	0	0	131	134	209							K$
Actual/Forecast	8	8	14	17	20	23	28							K$
Schedule Variance	-21	-50	-53	-92	0	-72	- 144							K$
Cost Variance	-8	-8	-14	-17	111	111	181							K$

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

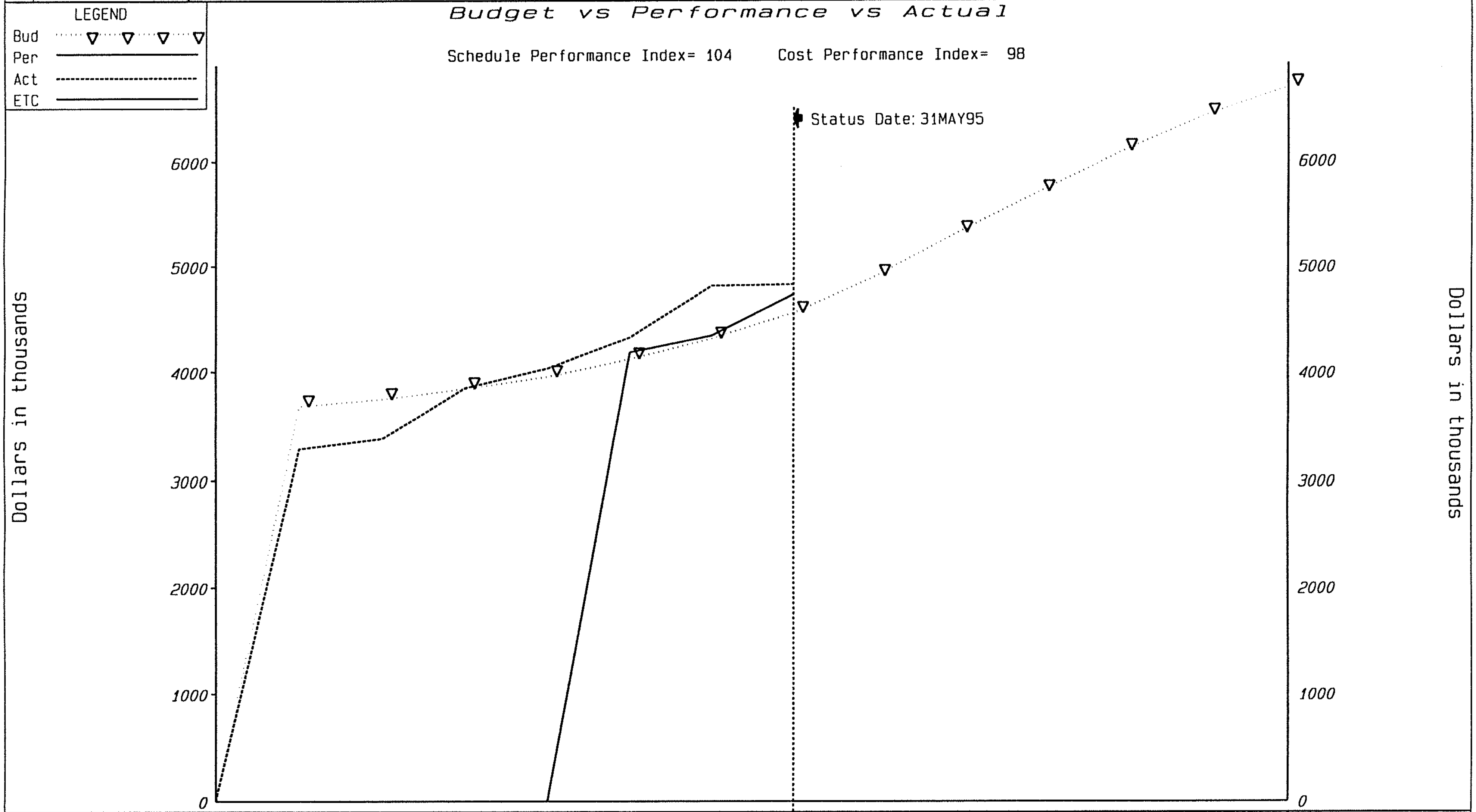
*** Prepared by LIGO Project Controls Group ***

COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1.1.4 Facility Design & Construction
Budget vs Performance vs Actual

Date: 22JUN95
Program: PMB_0595

Schedule Performance Index= 104 Cost Performance Index= 98



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	3, 680	3, 747	3, 844	3, 956	4, 121	4, 319	4, 560	4, 905	5, 320	5, 710	6, 087	6, 415	6, 682	K$
Performance	0	0	0	0	4, 185	4, 346	4, 737							K$
Actual/Forecast	3, 284	3, 379	3, 853	4, 035	4, 327	4, 814	4, 826							K$
Schedule Variance	-3, 680	-3, 747	-3, 844	-3, 956	64	27	177							K$
Cost Variance	-3, 284	-3, 379	-3, 853	-4, 035	- 142	- 468	-89							K$

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

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

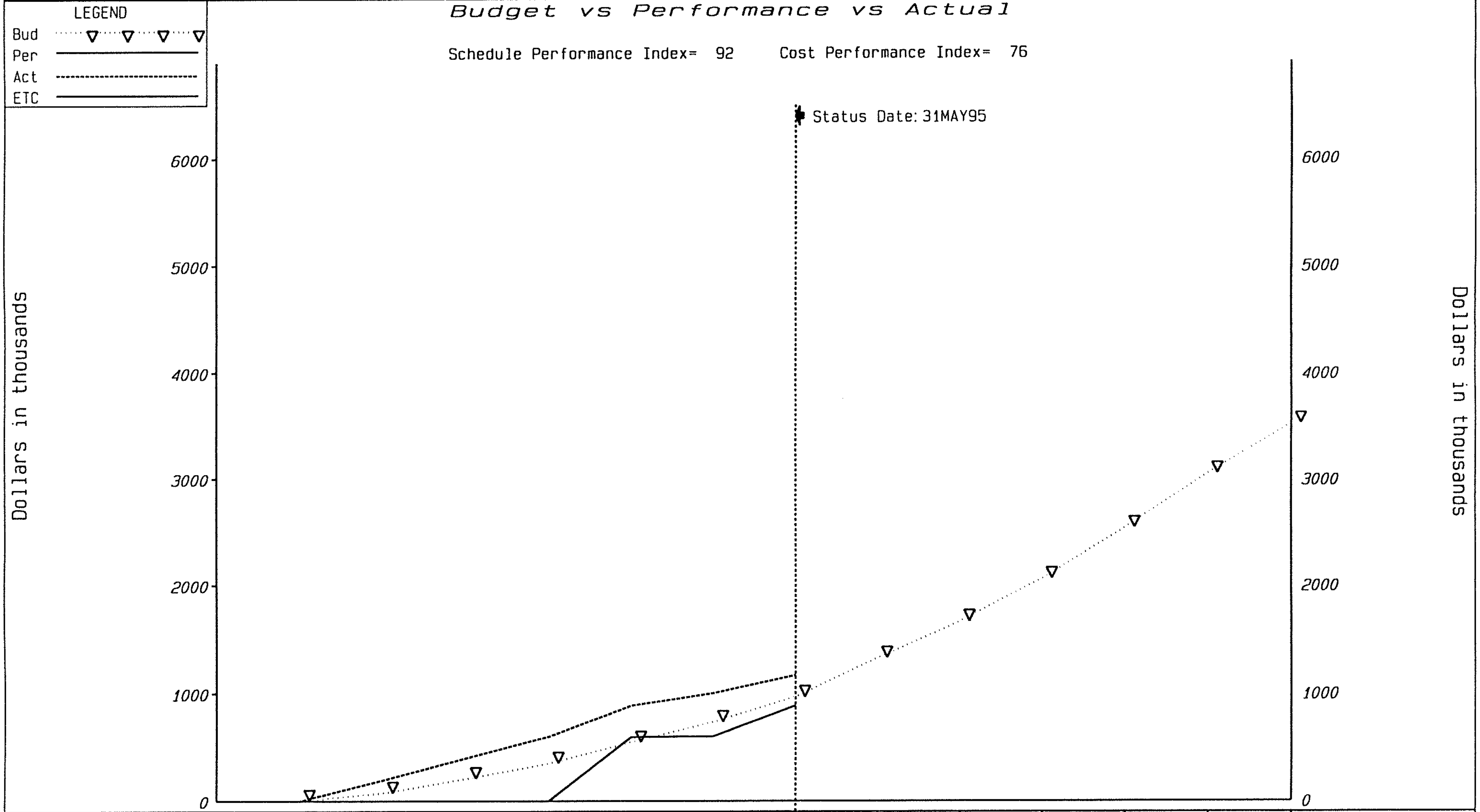
COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1.2 Detector

Date: 22JUN95
Program: PMB_0595

Budget vs Performance vs Actual

Schedule Performance Index= 92   Cost Performance Index= 76



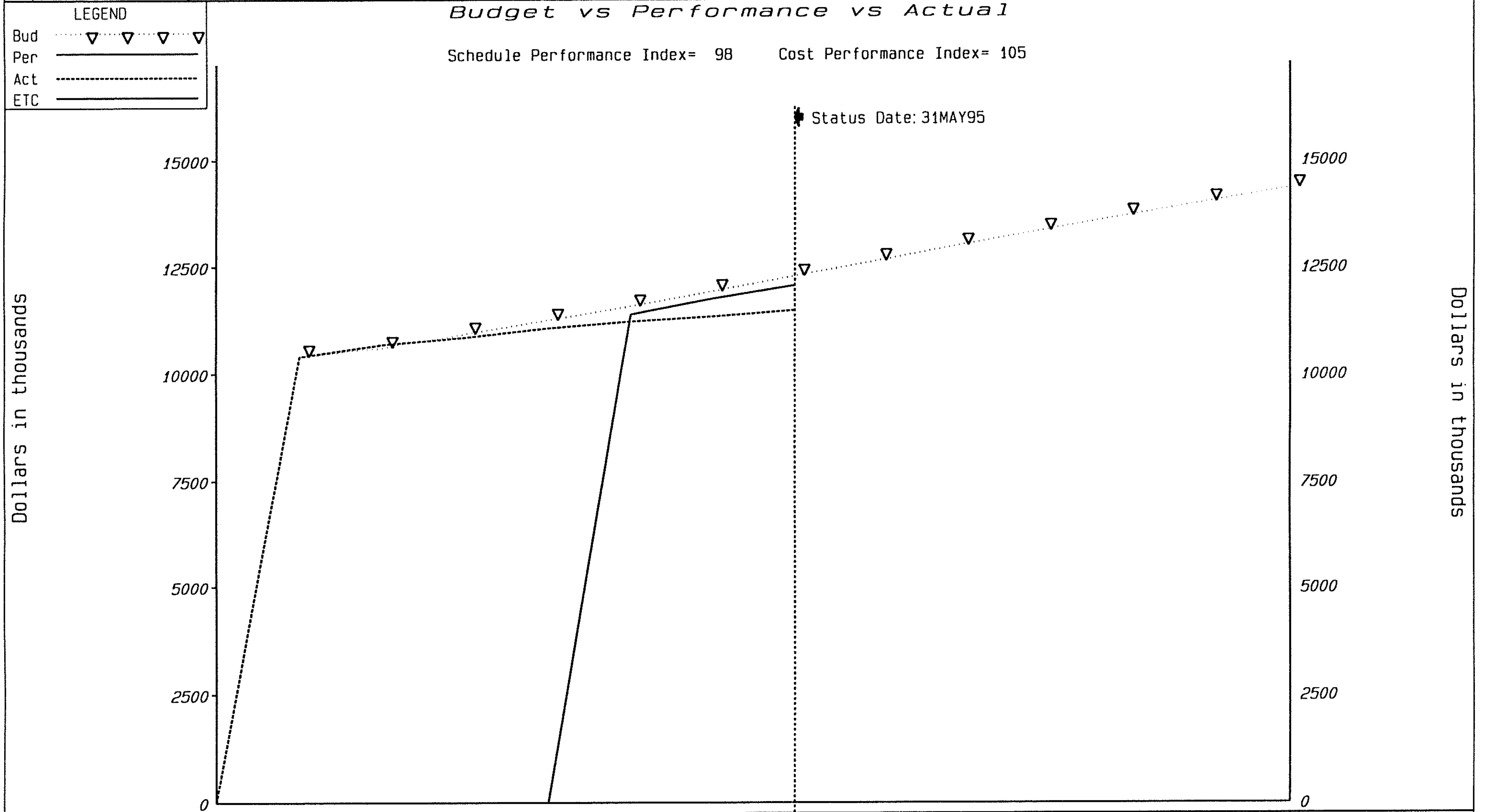
	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	0	74	207	349	546	736	967	1, 329	1, 666	2, 062	2, 538	3, 053	3, 521	K$
Performance	0	0	0	0	596	602	887							K$
Actual/Forecast	0	194	397	599	887	1, 001	1, 169							K$
Schedule Variance	0	-74	- 207	- 349	50	- 134	-80							K$
Cost Variance	0	- 194	- 397	- 599	- 291	- 399	- 282							K$

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

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

COBRA (R) Report: LIGOSPA	LIGO PROJECT 1.3 Research & Development	Date: 22JUN95 Program: PMB_0595

Budget vs Performance vs Actual



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	10,407	10,609	10,935	11,258	11,586	11,935	12,285	12,636	12,992	13,337	13,681	14,007	14,326	K$
Performance	0	0	0	0	11,397	11,763	12,070							K$
Actual/Forecast	10,407	10,683	10,854	11,069	11,225	11,345	11,489							K$
Schedule Variance	-10,407	-10,609	-10,935	-11,258	- 189	- 172	- 215							K$
Cost Variance	-10,407	-10,683	-10,854	-11,069	172	418	581							K$

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

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

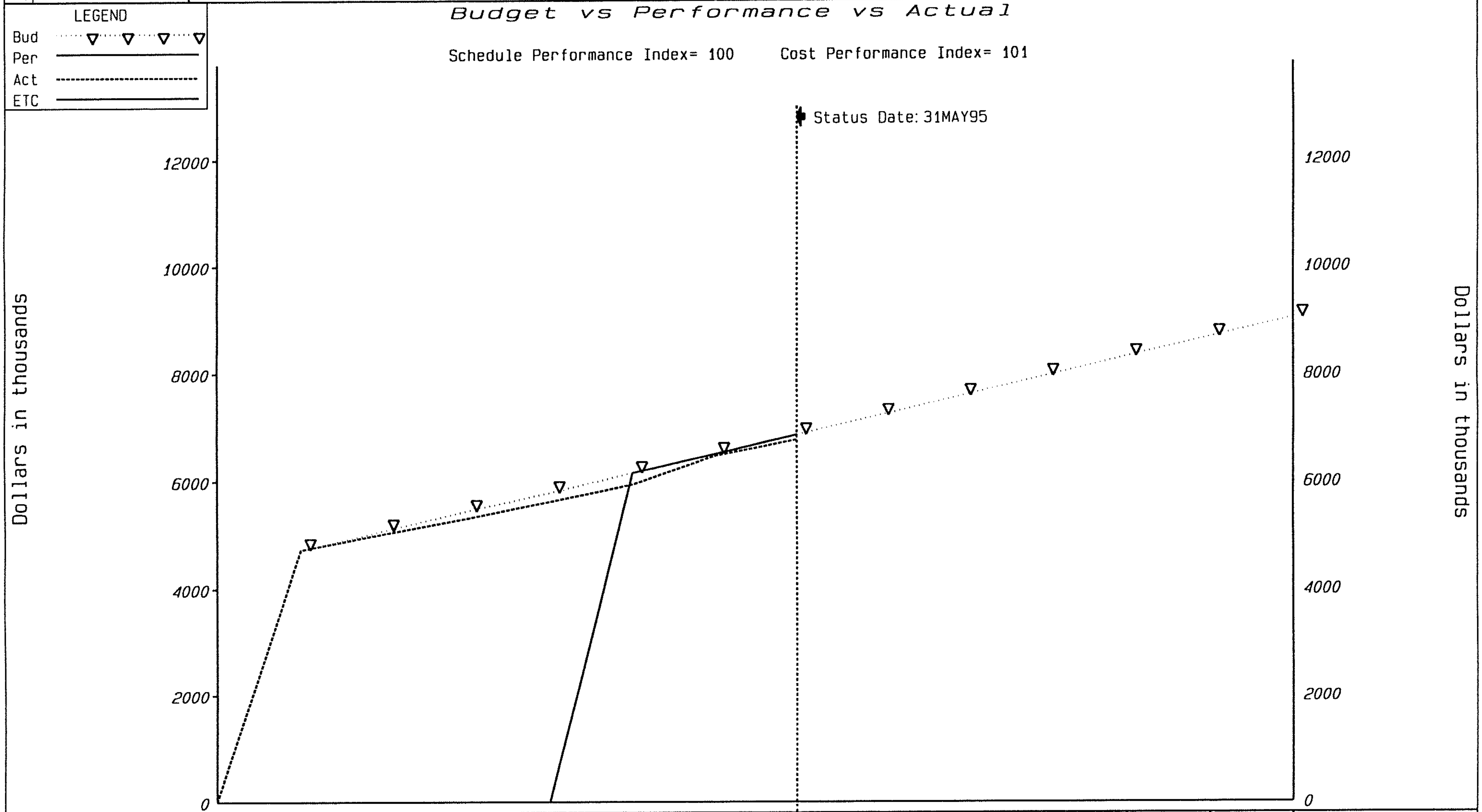
COBRA (R)
Report: LIGOSPA

LIGO PROJECT
1.4 Project Office

Date: 22JUN95
Program: PMB_0595

Budget vs Performance vs Actual

Schedule Performance Index= 100 Cost Performance Index= 101



	FY94	DEC94	JAN95	FEB95	MAR95	APR95	MAY95	JUN95	JUL95	AUG95	SEP95	OCT95	NOV95	SCALE
Budget	4,729	5,089	5,450	5,790	6,151	6,504	6,865	7,221	7,584	7,946	8,303	8,665	9,022	K$
Performance	0	0	0	0	6,151	6,504	6,865							K$
Actual/Forecast	4,729	5,031	5,315	5,629	5,941	6,469	6,773							K$
Schedule Variance	-4,729	-5,089	-5,450	-5,790	0	0	0							K$
Cost Variance	-4,729	-5,031	-5,315	-5,629	210	35	92							K$

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

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

Start: 06/01/95
Finish: 06/01/95
Time Now: 06/01/95
Project: ACILITY
Run: 06/22/95
Page: 1 of 1

Planned ▨
Critical ▨
Actual Dates ■
Milestone-Baseline ↓
Milestone-Planned ▽
Milestone-Completed ▼
Baseline Dates ■

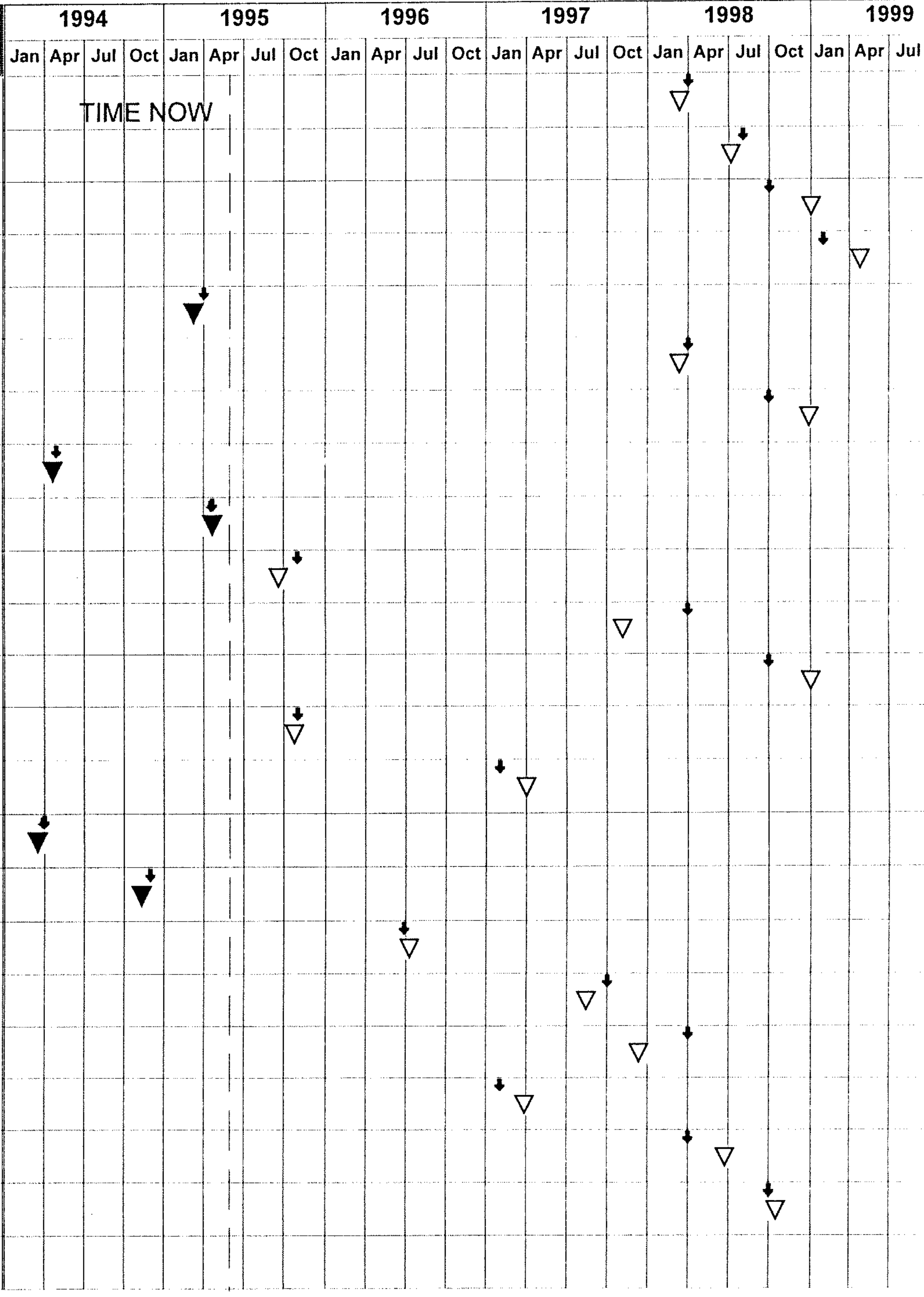
Caltech

FACILITIES LEVEL 1 MILESTONES

Open Plan Professional by Welcom Software

LIGO

Activity ID	Activity Description	BFinish	EFinish	TF
11000010	INITIATE FACILITY SHAKEDOWN - WA	03/31/98	03/11/98	14d
11000030	FACILITY SHAKEDOWN COMPLETE- WA	07/31/98	07/02/98	20d
11000110	INITIATE FACILITY SHAKEDOWN - LA	09/30/98	12/31/98	-62d
11000130	FACILITY SHAKEDOWN COMPLETE- LA	01/29/99	04/23/99	-60d
11101020	SELECT VE CONTRACTORs	03/31/95	03/08/95	-1d
11102040	ACCEPT VACUUM EQUIPMENT - WA	03/31/98	03/11/98	14d
11103040	ACCEPT VACUUM EQUIPMENT - LA	09/30/98	12/29/98	-60d
11201060	BEAM TUBE FINAL DESIGN REVIEW (FDR)	04/30/94	04/21/94	-26d
11201080	BEAM TUBE QUAL TEST REVIEW (QTR)	04/18/95	04/18/95	-26d
11201200	INITIATE BEAM TUBE (FAB) CONTRACT	10/31/95	09/18/95	-26d
11202100	ACCEPT WA BEAM TUBES AND COVERS	03/31/98	11/06/97	96d
11203100	ACCEPT LA BEAM TUBES AND COVERS	09/30/98	12/31/98	-62d
11301080	INITIATE SLAB CONSTRUCTION - WA	10/31/95	10/23/95	6d
11302080	INITIATE SLAB CONSTRUCTION - LA	01/31/97	03/31/97	-62d
11401110	INITIATE SITE DEVELOPMENT	03/30/94	03/14/94	36d
11403010	SELECT A&E CONTRACTOR	11/30/94	11/08/94	-4d
11405030	INITIATE BUILDING CONSTRUCTION - WA	06/28/96	07/08/96	-4d
11405060	JOINT OCCUPANCY - WA	09/30/97	08/15/97	14d
11405080	BENEFICIAL OCCUPANCY-WA(ACCEPT BUILDIN	03/31/98	12/10/97	74d
11407030	INITIATE BUILDING CONSTRUCTION - LA	01/31/97	03/28/97	-60d
11407060	JOINT OCCUPANCY - LA	03/31/98	06/22/98	-60d
11407080	BENEFICIAL OCCUPANCY-LA(ACCEPT BUILDIN	09/30/98	10/14/98	-10d



Start:	06/01/95
Finish:	06/01/95
Time Now:	06/01/95
Project:	TECTOR
Run:	06/22/95
Page:	1 of 1

Planned	▨
Critical	▨
Actual Dates	■
Milestone-Baseline	⬇
Milestone-Planned	▽
Milestone-Completed	▼
Baseline Dates	■

Caltech

DETECTOR LEVEL 1 MILESTONES

Open Plan Professional by Welcom Software

LIGO

Activity ID	Activity Description	BFinish	EFinish	TF
21111018	HAM FDR	12/31/96	11/22/96	22d
21112034	BSC/TMC FDR	11/30/96	11/22/96	3d
21120109	PSL FDR	08/31/97	04/24/96	340d
21134236	IOO FDR	06/30/97	01/13/97	119d
21140310	COC FDR	01/31/97	01/07/97	18d
21150407	COS FDR	11/30/96	10/17/96	29d
21163530	WVFNT FDR	11/30/97	09/17/97	50d
21170621	LSC FDR	05/30/98	05/30/97	250d
21190807	SYSTEM PDR	07/31/97	07/30/97	1d
22000003	INITIATE INTERFEROMETER INSTALLATION-WA	07/31/98	07/31/98	124d
22000013	INITIATE INTERFEROMETER INSTALLATION-LA	01/29/99	01/29/99	0
22133010	CDS DAQ FDR	04/30/98	08/05/97	184d
22262005	WA VAC & CA/NS READY TO INSTALL	09/30/97	09/02/97	19d
23100040	PEM FDR	06/30/98	06/18/98	8d