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LIGO Laboratory / LIGO Scientific Collaboration

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Advanced LIGO Cost Estimating Plan

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CHANGE CONTROL LOG

Version/Section	Change	Date	Editor
V-05	Previous published version, LIGO-M990310-05-M	5/23/2003	P. Lindquist
V-06/ Sec 3.0	The base year for the cost estimate is changed from FY 2003 to FY 2006.	5/15/06	C. Wilkinson
V-06/ Sec 5.0	The methodology used to apply indirect costs for MREFC projects is defined.	5/15/06	C. Wilkinson
V-06/ Sec 5.0	An improved procedure for estimating travel costs is described.	5/16/2006	P. Lindquist
V-06/ Sec 5.2	The Web Based Cost Estimating Tool is no longer used. The new section describes the current process.	5/16/2006	P. Lindquist
V-06/ Sec 5.3	The ordering of the confidence descriptors used for estimating contingency needs has changed. The new order is described.	5/16/2006	P. Lindquist
V-06/ Sec 6.1	The method used to estimate and price direct labor has been modified. The description is changed to reflect the current method.	5/16/2006	P. Lindquist
V-06/ Sec 6.2	The method used to estimate and price contract labor is described.	5/16/2006	P. Lindquist
V-06/ Sec 6.3	This section has been added. The assumptions used with respect to state taxes and import/export duties on materials and equipment are described.	5/16/2006	P. Lindquist
V-06/ Sec 7.2	The risk assessment methodology has changed in two ways: 1) the tables have been updated to reflect design complexity and increased schedule risk, and 2) the final contingency factor was determined using the information from the risk tables and a Monte Carlo simulation of cost and schedule variances with input from a Risk Register.	5/16/2006	P. Lindquist
V-06/ Sec 8.0	The base year for escalation and the project start date are modified.	5/16/2006	P. Lindquist
V-06/ Sec 9.0	A section has been added stating who is responsible for providing and maintaining the cost estimate.	5/16/2006	P. Lindquist

1.0 Overview

The Advanced LIGO Project Cost Estimating Plan (CEP) defines the guidelines and methodology that will be used to prepare and update the Advanced LIGO cost estimate. This guidance is provided to assure that the final product is complete, consistent, and well documented. The cost estimate will be assembled and maintained in an Advanced LIGO Cost Book.

The Advanced LIGO estimating plan is based on the structure established in the LIGO Cost Estimating Plan, LIGO M-990310-05. Modifications and clarifications specific to the current Advanced LIGO cost estimate are included herein.

2.0 Objectives

The primary objective is to develop a comprehensive estimate of the total Advanced LIGO project cost. This includes the costs for engineering, design, analysis, procurement, fabrication, assembly, testing, installation, integrated system testing and management of the detector upgrade. Unless otherwise indicated, these guidelines also apply to the associated Advanced LIGO research and development costs funded by the NSF under the current Operations Cooperative Agreement (NSF PHY-0107417).

The cost estimates will be prepared by technical experts who are experienced in the fields of specialization required to accomplish the Advanced LIGO upgrade. Vendor quotations, engineering calculations, drawings, and other pertinent data including similarities to LIGO I, which are used to support the cost estimate, will be collected and organized into a Basis-of-Estimate (BOE). A copy of the BOE will be provided to Project Controls and maintained in the Cost Book with the cost estimate. The Cost Book will be organized according to the Advanced LIGO Work Breakdown Structure (WBS). This Cost Book and BOE will furnish Advanced LIGO management as well as reviewing organizations with the data required to substantiate all estimates. The documentation will include the basic configuration information and list all critical assumptions used during the estimating process. The BOE will be prepared according to the guidelines established in this plan.

Large, complex, and challenging projects entail uncertainty and cost risk. A contingency to cover anticipated costs resulting from this uncertainty will be developed using standardized risk analyses as established in this CEP. Contingencies will be developed at the same level of the WBS used to prepare cost estimates.

Advanced LIGO costs will be monitored and controlled over the life of the project. The cost estimate will be used to establish budgets in a formal project management control system. The control system will compare actual costs with the budgets established for the work accomplished. Thus, it is vital that the guidelines established by this CEP be strictly followed to facilitate subsequent project monitoring activities.

3.0 Basis-of-Estimate

The cost estimate developed according to this CEP shall be a detailed bottom-up estimate performed at the lowest reasonable or “activity” level. The base year for the current estimate is FY 2006. The original Advanced LIGO Proposal was based on FY 2003 dollars. A Work

Breakdown Structure (WBS) will be used to sum estimates to intermediate and upper levels. Escalation will be applied at the top level to adjust costs to the anticipated Funding Year basis.

Cost estimates shall be entered into a relational database (see Section 5.0) indexed to the project WBS. The WBS hierarchy will delineate all subsystems and divide those subsystems into successively lower levels. For each lowest level of the WBS specific design, fabrication, procurement, assembly, quality, test, installation, integrated systems testing, and management activities will be defined. Within each activity, items to be estimated include direct funded staff labor, contract labor, equipment, travel (foreign and domestic), materials and supplies, consultants, computer costs, publication costs, sub-awards, and subcontracts.

The cost estimator shall provide supporting information in the form of a BOE for each activity. The Basis-of-Estimate (BOE) shall contain supporting information substantiating each cost data item including vendor quotations, engineering calculations, graphs, figures, etc. This information shall be provided with the cost estimate to be included in the Cost Book. Any additional detailed backup will be retained by each WBS estimator in his/her own copy of the Cost Book and appropriately archived. This information will be available for use in internal and external reviews of the Advanced LIGO cost estimates.

Narrative information including memos describing critical assumptions or referencing other documentation shall also be integrated into the Cost Book and be available for use in internal and external reviews of the Advanced LIGO cost estimates.

4.0 Work Breakdown Structure

The Work Breakdown Structure (WBS) is a product-oriented hierarchy that identifies all elements of the Advanced LIGO Project and their parent/child relationships. Cost estimators, working with Advanced LIGO Project Management, will develop the subsystem WBS hierarchies. These will be collected and defined in a Work Breakdown Structure Dictionary. The scope of work for each WBS element will be delineated in the dictionary. Each lowest-level WBS element shall be further subdivided into specific research and development, design, procurement, fabrication, assembly, test, quality assurance, installation, and integrated system testing activities or tasks. The cost estimate for each activity shall be based on the scope of work defined for the WBS element.

5.0 Costing Methodology

Each WBS estimator shall provide data for each activity. This data will be entered into a database established by Project Management for the purpose. The estimator may provide this data by completing input forms and submitting them to Project Management. The costs associated with each cost element shall be distributed by year and be categorized by labor category, equipment, travel, materials and supplies, consultants, publications/documentation costs, and subcontracts. This information will enable the generation of reports summarizing the cost estimate at various WBS levels and preparation of the summary budgets required for proposals submitted to the NSF.

The method used to apply indirect rates has been modified for this cost estimate. The previous version of the cost estimating plan original document applied both to development and project costs. For an MREFC funded project, indirect or overhead charges are applied for CIT labor and staff augmentation contract labor. CIT subcontract labor, including MIT labor, is charged indirect on the first $25,000 of each subcontract. Equipment and subcontracts to supply equipment for installation in the observatories are classified as Capital Equipment accounts and are not charged the CIT indirect costs. Material and supplies are charged for indirect costs. The cost estimating tool generates a loaded cost which is used as input into the project scheduling software program. Indirect costs and staff benefits are called out in the cost estimator/cost book but are no longer carried separately in the resource loaded plan.

Uniformity in the estimation of travel costs is enhanced by the application of travel rate tables. Estimators are allowed the choice of using the rate tables or of making their own estimate for specific trips. The table was produced by averaging the 2006 quoted rates for airfare, lodging, rental car and per diem for travel between the LIGO sites.

5.1 Relational Cost Database (Microsoft Access)

A database has been established to collect and report the Advanced LIGO cost estimate and supporting information. The reports generated in the database include:

- the WBS Dictionary,
- WBS Summary Reports,
- rollup reports for parent level WBS elements, and
- detail reports for lowest level WBS elements.

The cost estimate database will also be integrated with:

- the planning and scheduling software system used to establish and track schedules, and
- the performance measurement systems used to track cost and schedule status during execution of the Advanced LIGO program.

5.2 Collection of Cost Information

Estimators submit modified copies of the cost book sheets or subsystem cost estimator work sheets to the project controls team for updates to the cost book. Changes to the cost book are under change control once the baseline has been approved. The baseline is maintained as the target baseline and will be modified only after change control procedures are followed. A progress cost estimate will be maintained for tracking progress and forecasting.

5.3 Confidence of Cost Estimate

Each item in the cost estimate shall be tagged with a confidence descriptor which characterizes the uncertainty associated with the estimate. The categories established for the project in decreasing order of confidence include:

- CP, catalog prices for off-the-shelf items;
- VQ, vendor quotations based on finished drawings, followed by vendor quotes on preliminary drawings;

- HD, historical data from previous LIGO experience with similar components and efforts; and
- EE, engineering estimates based on the estimator's judgment and experience.

The ranking of HD, historical data, has decreased relative to that defined in the previous cost estimating plan to reflect the fact that the Advanced LIGO systems are more complex than those in the initial LIGO. Estimates based on initial LIGO data must therefore have a component of engineering judgment when applied to similar tasks involving redesigned equipment and procedures.

For equipment, the cost basis refers to the unit price. For labor, the cost basis code refers to the estimate of labor hours. The basis of estimate code is used to guide the determination the level of contingency.

Estimators record the details of their estimates, including quantity, unit cost or rate, and basis of estimate code in a Basis of Estimate (BOE) form. The BOE for each subsystem is a controlled document and is included in the Advanced LIGO Cost Book information.

5.4 Cost Book

All detailed and summary reports as well as the supporting BOE will be collected and maintained in the Advanced LIGO Cost Book. Copies of the Advanced LIGO Cost Book will be provided to the cost estimators, project management, and cost reviewers.

5.5 Cost Book to Schedule Integration

All cost estimate data is collected at the activity level to facilitate the integration of the estimate with the schedule. The one-to-one relationship between the cost estimate and the schedule will assist the project team and reviewers to evaluate the proposal. Integration will also allow the project team to assess resource usage and determine by discipline what resources are needed to effectively execute the plan.

6.0 Labor Pricing

Material, labor, and subcontract costs will be based directly on information provided by the cost estimator. However, the estimator will provide labor estimates in hours which will be priced according to representative LIGO direct salary experience for the labor resource identified. Indirect costs and Benefits will be computed and reported by the database for the rates established by the Caltech and MIT Offices of Sponsored Research.

6.1 Direct Labor Rates

The 2006 Advanced LIGO baseline uses a labor rate table based on 2006 Caltech and MIT labor rates. Employees are separated into salary cohorts or levels, such as manager, senior scientist, engineer, technician, etc. The actual 2006 yearly salaries for the employees in each cohort are averaged to obtain the representative yearly salary for that cohort. In cases where the cohort included fewer than five individuals, the salaries for individuals in similar positions elsewhere in the institutions are included to obtain a more representative rate and to prevent any individual's salary rate appearing explicitly in the rate table. For Caltech, the base salaries are used for this purpose, and the staff benefits and indirect or overhead costs are calculated separately in the rate table to obtain the loaded labor costs. For contractors and employees at other institutions such as MIT, the yearly costs as invoiced to CIT are used to determine a loaded salary. For contractors at CIT, an overhead cost is applied as described in section 6.2 below.

The representative yearly salaries are then divided by an assumed 1800 hours of productive effort per year to obtain an hourly rate for productive work. The productive work rates therefore contain approximately a 15 percent inefficiency factor to cover holiday, vacation, and sick leave.

An additional inefficiency factor of 5 percent increase in the salary rates is included to account for loss of productive time in start up and transition times. The combined overall inefficiency factor for Advanced LIGO labor estimates is ~20 percent. Productive work consists of 80 percent of the paid hours. For historical accounting purposes, 1800 hours is still assumed to represent a year's effort. The salary rates obtained by this method are used to calculate the representative hourly rate for individuals in the cohorts.

Each cohort is identified by a labor cost code, such as EN for engineer, SS for senior scientist etc. All labor resources for Advanced LIGO are assigned to one of these resource codes. The codes also contain information about the employee's discipline or area of expertise, home institution, NSF labor code and an identifier unique to that employee. These labor codes are used for sorting purposes in Primavera or to obtain labor information required by NSF.

The cost of the estimated labor is determined by multiplying the number of estimated hours by the representative, loaded hourly rate. The loaded salary cost is then used as input to the cost in the scheduling software. Labor hours are loaded into the Resource section of the software, without unit rates. The labor costs are loaded separately as loaded costs.

6.2 Contract Labor

Staff benefits for sub-award and contracted employees are included in the loaded hourly rate and are not called out separately. Indirect charges are included for CIT contracted staff augmentation labor for the first $25,000 of each contract. No additional overhead rates are applied to the contractor costs.

6.3 Taxes, Duties, and Exchange Rates

The following assumptions are made with respect to state taxes and import/export duties on materials and equipment:

- California State Taxes:
    - Equipment and materials purchased in California (CA) and delivered to a site in California will incur California state taxes. Except for a few known sole source providers, the identity and location of providers will not be known until awards have been made. The possibility of incurring taxes is included in the estimator's uncertainty and risk calculations.
    - Equipment purchased outside CA, with a final destination outside CA, will not incur CA taxes even if it spends an unlimited amount of process time in

CA. Forms must be provided with the purchase order verifying the final destination in order for this exclusion to be applied.

- Local State Taxes for Other LIGO Sites
  - State taxes for equipment delivered to and installed at the MIT and the two observatory sites vary depending upon the agreements in place with the individual state governments. There are no state taxes for LIGO related equipment in Louisiana or Massachusetts. Washington state taxes will be incurred for items that are not part of the installed facility or detectors. This tax covers a small amount of equipment costs and is considered to be negligible.
  - Import and Export Duties
  - Scientific equipment in a ready to install state does not incur duties. Forms must be completed in advance of transfer in order to use this exemption.
  - Raw materials, items that require further processing to achieve ready-to-install status, may be subject to customs duties. An example is the glass substrates for detector optics. Those items require polishing and coating before they are ready for installation. Estimators check with the CIT budget office to determine whether their procurements will incur duties. If the potential for duties exist, estimators include a contingency factor based on the procurement risk table factors.
  - Raw materials that enter the US and remain for a limited period of time may be excluded from duties. Estimators and procurement personnel should determine the risk of incurring duties based on the estimated schedule times for any dwell time in the US.
- Exchange Rates
  - Estimators include the possibility of increased exchange rates in their contingency. For increases above 20 percent, a risk factor for the overall project is included in the contingency risk factor.

7.0 Risk Analysis, Contingency

Contingency established for the Advanced LIGO Project shall be based on a standardized risk analysis as described below. The cost estimator is responsible for providing risk factors for each activity. The estimator is responsible for assuring that each and every component has appropriate and defensible contingency applied.

7.1 Risk Analysis

A risk analysis is used to calculate contingency. The method is based on estimator evaluation of the technical, cost, and schedule risk for every activity. Technical, cost, and schedule risk factors are input fields on the forms used to enter data into the database. Standard ranges for these parameters are 1 to 15 for technical and cost risk and 2 to 8 for schedule risk.

7.2 Risk Assessment Methodology

The risk assessment methodology has changed in two ways:

- The tables have been updated to include design complexity and higher schedule risk. See Tables 1-3.
- The final contingency factor was determined using the information from the risk tables and a Monte Carlo simulation of cost and schedule variances generated by input from a Risk Register.

Variability or uncertainty Risk Factors are assigned as described in Tables 1-3. For technical risk, the value of 1 implies “well defined, low complexity items,” and 8 is reserved for components “undefined, high complexity items.” For procurement risk, a value of 1 is used to indicate “an off-the-shelf or catalog price for a specific item”, and 15 is used for estimates based on engineering judgment. Schedule risk factors range from 2 to 10.

Each of the three risk factors is multiplied by an associated risk percentage. The technical risk percentage is determined on the basis of whether there are design and/or manufacturing concerns and can be either 2% or 4%. The risk percentage related to the procurement risk factor is determined on the basis of whether there are material and/or labor estimate concerns and can be either 1% or 2%. The schedule risk percentage is set at 1%. Each of these percentages is multiplied by the corresponding risk factor to determine the contingency to be applied. The resulting percentages are added together to establish the total Variability contingency for the activity. The minimum contingency percentage using this approach is 5 percent and the maximum is 72 percent.

There may be special cases where the parameter limitations defined above are not appropriate. Some high-risk elements may deserve contingencies greater than 72 percent. In these cases, at the discretion of the estimator and Project Management, higher values may be used. Justification must be provided in the supporting documentation.

The Variability Risk analyses will be performed at the activity level for technical and procurement risk. It will be performed at the WBS level for schedule risks. The resulting Variability or uncertainty contingency is reported at the activity level. Results of this analysis will be summed with a Project Risk factor to compute a combined contingency that will be reported at each level of the WBS.

The additional Project Risk factor is determined by a Monte Carlo simulation of cost variation at the activity level. The method uses the estimated cost, the Variability Risk factor, and the weighted inputs from the Risk Register to obtain an Overall Project Risk. A description of the Risk Register and the methodology of the Monte Carlo simulation for estimating contingency is given in the Advanced LIGO Risk Management Plan LIGO-M060045-00 and the pending Report from ARES Corporation on the Risk Analysis of Advanced LIGO Project. The difference between the combined Variability Risk for the entire project and the Monte Carlo Overall Project Risk is the Project Risk factor.

The Project Risk factor is distributed to the various subsystems as a Subsystem Project Risk factor at the judgment of the Project Manager. The Project Manager’s assignments are guided by the Monte Carlo report on the effectiveness of each subsystem as a driver of the overall project cost risk. Once the Project Risk has been assigned at the subsystem level, a contingency risk factor is calculated at each activity level by summing the Variability Risk for that activity with the assigned Subsystem Project Risk. Thus, the final contingency factor for each activity is the sum of the activity Variability Risk and the subsystem Project Risk.

The subsystem Project Risks are distributed such that the average contingency for the overall project obtained by this method is equal to the Monte Carlo Overall Project Risk.

While contingencies are estimated at the same level as the bottom-up cost estimate, during execution of the project contingency will be held at the top level by the Project Manager and allocated as needed to address problems and items or activities that have been overlooked during the estimating process. A formal change control process will be used to allocate contingency to specific activities.

8.0 Escalation

The Advanced LIGO estimate is in fiscal year 2006 dollars. The project is slated to begin in FY 2008. An escalation factor will be determined in agreement with the National Science Foundation. This factor will be applied at the top level of the WBS.

9.0 Responsibility

Responsibility for the subsystem estimates lies with the subsystem leader appointed by the Advanced LIGO Project Leader.

Table 1, Procurement Related Estimate Variability Risk

Procurement Related Estimate Variability	
Variability % Value	Variability % Description
1.00%	Material cost **OR** labor estimate concerns
2.00%	Material cost **AND** labor estimate concerns
Variability Factor	Variability Factor Description
1	Off-the-shelf or catalog item
2	Vendor quote from established drawings
3	Vendor quote from design sketches
4	In-house estimate for item within current production item
6	Based on minimal experience; capabilities exist
8	Based on minimal experience; capabilities may not exist
10	Top down estimate from analogous programs
15	Engineering judgment only

Table 2, Technology Related Estimate Variability

Technology Related Estimate Variability	
Variability % Value	Variability % Description
2.00%	Design **OR** manufacturing concerns
4.00%	Design **AND** manufacturing concerns
Variability Factor	Variability Factor Description
1	Technology/Interface is **well defined**; System has **low** complexity; Technology exists; Functionality is documented.
2	Technology/Interface is **well defined**; System has **high** complexity; Technology exists (or is a modification to existing design); Functionality is documented or partially documented
3	Technology/Interface is **partially defined** (minimal R&D); System has **low** complexity; Demonstrated concept (full scale prototype) or modification to existing prototype
4	Technology/Interface is **partially defined** (moderate R&D); System has **high** complexity; Demonstrated concept (bench scale, etc.)
6	Technology/Interface is **undefined** (significant R&D); System has **low** complexity; Concept is defined; Functionality understood but not demonstrated
8	Technology/Interface is **undefined** (significant R&D); System has **high** complexity; Concept is loosely defined; Functionality not understood and not demonstrated

Table 3, Schedule Related Estimate Variability

Schedule Related Estimate Variability	
Variability % Value	Variability % Description
1.00%	All schedule concerns
Variability Factor	Variability Factor Description
2	Delay in activity results in **negligible** increase in effort to complete subsystem milestones
4	Delay in activity results in **minor** increase in effort to complete subsystem milestones (approx. 2 weeks of effort)
6	Delay in activity results in **moderate** increase in effort to complete subsystem milestones (approx. 1 month of effort)
8	Delay in activity results in **significant** increase in effort to complete subsystem milestones (approx. 3 months of effort)
10	Delay in activity results in **massive** increase in effort to complete subsystem milestones (approx. 6 months of effort)