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LIGO COST ESTIMATING PLAN

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LIGO PROJECT

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1.0 SCOPE

This cost estimating plan (CEP) defines the guidelines and methodology that will be used to update the LIGO cost estimate. Since LIGO utilizes a multitude of specializations, many disciplines participate in preparing a reliable cost estimate. Consequently, clear guidance is required to assure that the final product is complete, consistent, and well documented.

2.0 OBJECTIVES

2.1 Total LIGO Project Cost

The primary objective is to develop a comprehensive estimate of the total LIGO project cost. This includes costs for the necessary research and development activities as well as engineering, design, analysis, procurement, fabrication, assembly, installation, and management of the construction project. All costs will be tabulated into a single computerized relational database.

2.2 Detailed Backup Information

The cost estimating shall be performed by estimators who are experienced in the field of specialization that coincides with the various aspects of the LIGO project. During the cost estimating process, vendor quotations, engineering calculations, drawings, similarities to other systems and other pertinent data will be collected and organized into the Basis-of-Estimate (BOE). To provide traceability, the BOE shall be organized in the same manner as the LIGO Work Breakdown Structure (WBS). This BOE will furnish the reviewing organizations with the data required to substantiate all estimates. In addition, basic subsystem configuration will be defined along with a list of critical assumptions made during the estimating process. The BOE will be generated according to the guidelines established in this plan.

2.3 Contingency

Uncertainty and cost risk are associated with projects of this size, complexity, and challenge. The methodology behind developing a cost for uncertainty and cost risks shall be accomplished by utilizing standardized risk analyses. These risk analyses shall be performed by the estimators to develop contingency costs according to the guidelines established in this CEP. Estimates made prior to final design shall include projections of expected development and engineering. Thus, contingency will be developed to account for uncertainties.

Due to the complexity of the LIGO WBS, contingencies may be developed for different levels of the WBS. The lowest possible WBS level shall be assigned a specific contingency by the WBS estimator. As the estimate maturity develops, contingency analysis may be extended to lower levels.

2.4 Relation to Cost Tracking Baseline

The costs of the LIGO will be monitored and must be controlled over the life of the project. This plan will guide the development of a relational database that can provide the basis for this task. The hierarchy used in the CEP establishes costs in a format that can be translated to a formalized project management control system. Such a system could be implemented to track the actual incurred cost against the projected cost estimates. Thus, it is vital that the guidelines established by this CEP be strictly followed so that subsequent project monitoring activities may be facilitated.

3.0 BASIS

3.1 Detailed Bottom-Up Estimate

The basis for the cost estimate developed according to this CEP will be a detailed bottom-up estimate for the lowest possible WBS element. These estimates shall be based on current year dollars. Escalation factors will be applied at the top level by the Project Management to adjust costs to anticipated Funding Year basis.

3.2 Cost Estimate Development Approach

Cost estimates will be developed using a relational database (See Section 5.0), that will be based on a system-wide WBS. The WBS hierarchy to be used will delineate all subsystems and divide each of those subsystems into multiple lower levels. Cost items will define the direct funded LIGO staff labor (including consultants and travel expenses), material requirements, and contracts. The estimate reports will maintain separate accounts for each of the three aforementioned cost groups.

3.3 Basis-of-Estimate (BOE) Books

In addition to developing detailed cost items, each WBS estimator shall develop his/her own basis-of-estimate (BOE) book. This document shall contain supporting information which substantiates each cost data item including vendor quotations, engineering calculations, graphs, figures, etc. This information will be used during both internal and external reviews of the LIGO cost estimates.

3.3.1 Memo Fields

The detailed cost estimate reports for the lowest level of each WBS branch will incorporate memos describing critical assumptions or referencing documentation found in the basis-of-estimate books. Hence, narrative information will be integrated into the detailed cost estimate report. This information will also be used during both internal and external reviews of the LIGO cost estimates. The estimators responsible for each detailed estimate will also be identified on the detail report sheets.

4.0 WORK BREAKDOWN STRUCTURE

The WBS is a hierarchy which identifies all elements and their parent/child relationships. Cost estimators, working with LIGO Project Management, will develop the subsystem WBS hierarchies where it has not already been defined. These will be collected and collated into the LIGO Project WBS.

4.1 WBS Dictionary

The cost estimate for each WBS element is based on a scope of work for that given element. A WBS Dictionary is essential to define the scope of work for each element.

5.0 COSTING METHODOLOGY

Each WBS estimator will complete data input forms detailing information to be translated into the SUCCESS format. The costs associated with each item on the data input forms is distributed over a certain number of years and is categorized into direct funded labor, material and contracts. This information will enable SUCCESS to generate reports summarizing the desired information.

5.1 Relational Cost Database (SUCCESS)

SUCCESS is the cost estimating program that will be used to collect all information for the LIGO cost estimate. SUCCESS is a relational database application that operates in Microsoft Windows (Version 3.0 or greater). The reports that will be generated from the database will include, but are not limited to, the following:

- WBS Summary Reports
- Rollup Reports for each parent level
- Detail Reports for each lowest level WBS element

5.2 Collection of Cost Information

Previously prepared data input forms will be converted into the SUCCESS format. These forms shall include fields for the WBS no., title of the level, estimator, BOE, and description of work to be done. Additionally, quantity, unit of measure, and the year in which work is to be accomplished for direct funded labor, material, and contracts shall be included and distributed over the required years. SUCCESS reports will be submitted to LIGO for verification of accuracy. The Supporting Data Tables (SDT's), discussed later in the CEP, will also be prepared from previous spreadsheets or an electronic spreadsheet copy (EXCEL Format) of the WBS may be forwarded, upon request, as a starting point. The SDT's should be part of the cost basis books.

5.3 Cost Estimate Report Book

The cost estimate report book for annual NSF submission will consist of the SUCCESS generated reports, supporting data tables (SDT), and basis-of-estimate information. The SDT's shall be generated using EXCEL (Version 3.0 or greater) spreadsheets that are vertically synchronized with the WBS elements. The SDT's will contain (at a minimum) pertinent estimate information that is defined later in the CEP.

5.3.1 Basic Cost Information

The SUCCESS database contains the basic cost information for each WBS element. Material, labor, and contract costs driven by unit costs will be estimated for each line item component. Roll-ups of total costs from subelements to higher level elements are performed internally within the SUCCESS framework. Labor rates, material estimating strategies, and contingency methodology are defined in subsequent sections.

5.3.1.1 Contingency

Contingency for the LIGO Project cost estimate shall be based on a standardized risk analysis (see attached risk analysis/contingency sheet). Each estimator shall perform the risk analysis identified in Section 7.0 and enter the associated contingency in an SDT and for application within the SUCCESS project. Depending upon the particular subsystem being analyzed contingency may be applied at the lowest WBS level or at a higher rollup (parent) level. It is the responsibility of the estimator to make this determination. However, the lowest level possible is the preferred option. In any case, the estimators are responsible for assuring that each and every component has appropriate and defensible contingency applied.

5.3.2 Supporting Data Table

The SDT's, which may be divided into one or more matrices, provide important supporting data to the cost estimates. Estimators are required to provide input to these tables and submit it to LIGO Project Controls Group for additional processing into the SUCCESS framework. The information contained in the SDT is essential for interpreting the cost estimates, reviewing them and temporarily distributing the costs to permit accurate cost projections to the end of the project. Please note: The SDT information is only applied to WBS elements. All cost items internal to a given WBS element will be treated within the SDT information.

5.3.2.1 Quantity (QTY) and Units of Measure (UM)

The QTY and UM parameters identify the basic cost unit that was used to determine the cost and the total number of the units that was assumed.

5.3.2.2 Estimate Types

Each cost item within a lowest level WBS element shall be tagged with a cost basis descriptor which characterizes the type of estimate that was used. The four categories established for the LIGO project are:

- **Engineering Estimates (EE)**
- **Vendor Quotations (VQ)**
- **Placed Order (PO)**
- **Actual Costs (AC)**

5.3.2.3 Risk Factors

The risk analysis described in Section 7.0 is used to calculate contingency. In the three columns provided in the SDT, technical, cost and schedule risk factors are input fields. Standard ranges for these parameters are 1 to 15 for technical and cost risk, 2 to 8 for schedule risk. In some cases the standardized risk parameters may not be appropriate. Higher values may be used as described in Section 7.

5.3.2.4 Risk Percentage

The applied risk percentages are dependent on two factors. The first is whether the risk is associated with technical, cost or schedule concerns. The second is whether these concerns involve design, manufacturing, material cost or labor rate uncertainties. Acceptable values which range from 1% to 4% are defined in Section 7.0. These percentages are multiplied by the corresponding risk factor to determine the total contingency which should be applied.

5.3.2.5 Contingency Total

This parameter is the sum of the products of the individual risk factors and corresponding risk percentages.

6.0 LABOR RATES

6.1 Direct Funded Labor Rates

WBS estimators have supplied the labor categories and rates (1994-$K/MM) to be used for the subsystem cost estimates. Labor categories include, Scientist, Engineer, Technician, Graduate Student, Undergraduate Student, Management Staff, and Administrative Support, Consultants, and Travel. The rates used are fully burdened with all associated costs including nonproductive time such as sick leave, vacation, holidays, etc. In essence, the rates established in the LIGO estimate are Full Time Equivalent (FTE) rates. Hence, non-productive time is accounted for in the FTE rates used for estimating purposes.

6.2 Contract Labor Rate

Contract labor rates will be based on historical cost data from standardized resources indexed to the locality of the project.

6.3 Level of Effort Assessment -

Level of Effort (or manpower requirements) will be estimated based on productive time units for labor efforts. The FTE rates characterized above will account for nonproductive periods.

7.0 RISK ANALYSIS/CONTINGENCY

7.1 Risk Analysis

Risk analysis shall be performed at WBS elements as described in Section 2.3. Results of this analysis will be related to a contingency which shall be listed for each WBS element. Risk analysis parameters shall be listed in the SDT with equivalent contingency aggregate values also calculated.

7.2 Risk Assessment Methodology

This method is based on estimator evaluation of technical, cost and schedule risk for every WBS element. For technical risk, the value of 1 implies "normal industry supplied off the shelf item" and 15 is reserved for components "way beyond the current state-of-the-art." For cost risk values, 1 is used to indicate "vendor quote or catalog price for a specific item" and 15 is used for estimates where no data is available. Schedule risk factors range from 2 to 8. The technical risk factor is multiplied by a risk percentage which is categorized below. The resulting percentages are added together to establish the total contingency for a particular WBS element. The minimum contingency percentage under this approach is 5% and the maximum is 98%.

Table 7. Risk Factor

Risk factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off the shelf or catalog item	not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive modifications to an existing design	Vendor quote with some design sketches	not used
4	New design within established product line	In-house estimate for item within current product line	Delays completion of non-critical path subsystem item
6	New design different from established product line. Existing technology	In-house estimate for item with minimal company experience but related to existing capabilities	not used
8	New design. Requires some R&D development but does not advance the state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances the state-of-the-art	Top down estimate from analogous programs	not used
15	New design way beyond the current state-of-the-art	Engineering judgment	not used

Table 8. Risk Percentage

	Condition	Risk percentage
Technical	Design or mfg concerns only	2%
	Design and mfg concerns	4%
Cost	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
Schedule		1%

7.3 Good Judgment

There may be special cases where the parameter limitations defined above are inappropriate. Some high risk elements may deserve contingencies greater than 98%. In these cases, at the discretion of the estimator, higher values may be used. Justification for these cases must be provided in the estimator's BOE.

8.0 ESCALATION

The LIGO estimate is based on 1994 dollars. The previous estimate was based on previous year dollars and has been escalated to 1994 based on the NSF inflators (see attached NSF inflator sheet).

9.0 RESPONSIBILITIES

Cost estimating responsibilities are as follows:

LIGO WBS Element	Responsible Person
1.1 Facilities and Vacuum Systems	G. Stapfer
1.2 Detector	R. Vogt
1.3 Research & Development	S. Whitcomb
1.4 Project Office	G. Sanders

NSF INFLATORS

	GDP IMPLICIT PRICE DEFLATOR		GROSS DOMESTIC PRODUCT (BILLION $)	
YEAR	CALENDAR YEAR	FISCAL YEAR	CALENDAR YEAR	FISCAL YEAR
1953	0.220	0.219	370.0	363.4
1954	0.222	0.221	370.9	367.4
1955	0.229	0.226	404.3	383.9
1956	0.236	0.234	426.2	415.2
1957	0.244	0.243	448.6	437.2
1958	0.249	0.249	454.7	447.1
1959	0.256	0.255	494.2	478.7
1960	0.260	0.261	513.4	505.9
1961	0.263	0.263	531.8	516.9
1962	0.269	0.268	571.6	554.3
1963	0.272	0.272	603.1	585.0
1964	0.270	0.276	648.0	626.5
1965	0.284	0.283	702.7	671.4
1966	0.294	0.291	769.8	738.6
1967	0.303	0.301	814.3	791.3
1968	0.318	0.312	889.3	849.8
1969	0.334	0.328	959.5	925.6
1970	0.352	0.346	1010.7	985.6
1971	0.371	0.363	1097.2	1051.6
1972	0.388	0.382	1207.0	1145.8
1973	0.413	0.402	1349.6	1278.0
1974	0.449	0.433	1458.6	1403.3
1975	0.492	0.476	1585.9	1511.0
1976	0.523	0.512	1768.4	1685.1
1977	0.559	0.554	1974.1	1919.7
1978	0.603	0.596	2232.7	2156.4
1979	0.656	0.647	2488.6	2431.9
1980	0.717	0.706	2708.0	2644.5
1981	0.789	0.778	3030.6	2964.7
1982	0.838	0.836	3149.6	3124.9
1983	0.872	0.870	3405.0	3317.0
1984	0.910	0.909	377.2	3696.7
1985	0.944	0.943	4038.7	3970.9
1986	0.969	0.971	4268.6	4219.6
1987	1.000	1.000	4539.9	4453.3
1988	1.039	1.036	4900.4	4810.0
1989	1.085	1.082	5250.8	5170.1
1990	1.133	1.127	5546.1	5481.8
1991	1.177	1.168	5722.9	5674.1
1992	1.211	1.203	6038.5	5940.8
1993	1.242	1.235	6374.0	6294.9
1994	1.274	1.266	6745.9	6651.2
1995	1.310	1.301	7129.5	7032.8
1996	1.348	1.338	7534.3	7430.6
1997	1.388	1.378	7962.5	7853.6
1998	1.430	1.420		

NSF INFLATORS

1999	1.473	1.463		

LIGO - DATA INPUT FORM

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WBS NO.											
TITLE:											
ESTIMATOR:											
BOE:		(EE - Engineering/Bottom Up/Parametric, VQ - Vendor Quotation, PO - Place Order, AC - Actual Costs)									
DESCRIPTION:											
IN-HOUSE LABOR		Unit of Measure	1992 Quantity	1993 Quantity	1994 Quantity	1995 Quantity	1996 Quantity	1997 Quantity	1998 Quantity	1999 Quantity	2000 Quantity
Scientist		Manmonth									
Engineer		Manmonth									
Technician		Manmonth									
Grad Student		Manmonth									
Undergrad Student		Manmonth									
Management Staff		Manmonth									
Admin. Support		Manmonth									
Consultants		Total Cost									
Travel		Total Cost									

MATERIAL DESCRIPTION	Quantity	Unit Of Measure	1992 Unit Cost	1993 Unit Cost	1994 Unit Cost	1995 Unit Cost	1996 Unit Cost	1997 Unit Cost	1998 Unit Cost	1999 Unit Cost	2000 Unit Cost

CONTRACTS DESCRIPTION	Quantity	Unit Of Measure	1992 Unit Cost	1993 Unit Cost	1994 Unit Cost	1995 Unit Cost	1996 Unit Cost	1997 Unit Cost	1998 Unit Cost	1999 Unit Cost	2000 Unit Cost

LIGO - RISK ANALYSIS/CONTINGENCY

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WBS DEPTH	WBS NO.	WBS TITLE	RISK FACTOR			RISK PERCENTAGE			Total Contingency
			Technical	Cost	Schedule	Technical	Cost	Schedule	
0		LIGO							
1	1.1	Facilities and Vacuum Systems							
2	1.1.1	Vacuum Equipment							
3	1.1.1.1	Vacuum Equipment Design							
4	1.1.1.1.1	Vacuum Equipment Design - System Engineering							
4	1.1.1.1.2	Vacuum Equipment Design - Contracts							
3	1.1.1.2	WA Vacuum Equipment							
4	1.1.1.2.1	WA Vacuum Equipment - System Engineering							
4	1.1.1.2.2	WA Vacuum Equipment - Contracts							
5	1.1.1.2.2.1	WA Vacuum Equipment - Chambers							
5	1.1.1.2.2.2	WA Vacuum Equipment - Corner Station							
5	1.1.1.2.2.3	WA Vacuum Equipment - Left arm end station							
5	1.1.1.2.2.4	WA Vacuum Equipment - Left arm mid station							
5	1.1.1.2.2.5	WA Vacuum Equipment - Right arm end station							
5	1.1.1.2.2.6	WA Vacuum Equipment - Right arm mid station							
4	1.1.1.2.3	WA Vacuum Equipment - Equipment							
5	1.1.1.2.3.1	WA Vacuum Equipment - Instrumentation							
5	1.1.1.2.3.2	WA Vacuum Equipment - Spares							
3	1.1.1.3	LA Vacuum Equipment							
4	1.1.1.3.1	LA Vacuum Equipment - System Engineering							
4	1.1.1.3.2	LA Vacuum Equipment - Contracts							
5	1.1.1.3.2.1	LA Vacuum Equipment - Chambers							
5	1.1.1.3.2.2	LA Vacuum Equipment - Corner Station							
5	1.1.1.3.2.3	LA Vacuum Equipment - Laft arm end station							
5	1.1.1.3.2.4	LA Vacuum Equipment - Left arm mid station							
5	1.1.1.3.2.5	LA Vacuum Equipment - Right arm end station							
5	1.1.1.3.2.6	LA Vacuum Equipment - Right arm mid station							
4	1.1.1.3.3	LA Vacuum Equipment - Equipment							
5	1.1.1.3.3.1	LA Vacuum Equipment - Instrumentation							
5	1.1.1.3.3.2	LA Vacuum Equipment - Spares							
2	1.1.2	Beam Tubes (s)							
3	1.1.2.1	BT Design (s)							
4	1.1.2.1.1	BT Design SE (e)							
4	1.1.2.1.2	BT Design contracts (e)							

LIGO - RISK ANALYSIS/CONTINGENCY

WBS DEPTH	WBS NO.	WBS TITLE	RISK FACTOR			RISK PERCENTAGE			Total Contingency
			Technical	Cost	Schedule	Technical	Cost	Schedule	
3	1.1.2.2	BT Fab/Install WA (s)							
4	1.1.2.2.1	BT Fab/Install WA SE (e)							
4	1.1.2.2.2	BT WA Factory Fab (e)							
4	1.1.2.2.3	BT WA Field Installation (e)							
3	1.1.2.3	BT Fab/Install LA (s)							
4	1.1.2.3.1	BT Fab/Install LA SE (e)							
4	1.1.2.3.2	BT LA Factory Fab (e)							
4	1.1.2.3.3	BT LA Field Installation (e)							
2	1.1.3	Beam Tube Enclosures (s)							
3	1.1.3.1	BE Design (s)							
4	1.1.3.1.1	BE Design SE (e)							
4	1.1.3.1.2	BE Design contracts (e)							
3	1.1.3.2	BE Fab/Install (s)							
4	1.1.3.2.1	BE Fab/Install WA (s)							
5	1.1.3.2.1.1	BE WA site Se (e)							
5	1.1.3.2.1.2	BE WA Contracts (e)							
4	1.1.3.2.2	BE Fab/Install LA (s)							
5	1.1.3.2.2.1	BE LA site SE (e)							
5	1.1.3.2.2.2	BE LA Contracts (e)							
2	1.1.4	Civil Construction							
3	1.1.4.1	Civil Construction Design							
4	1.1.4.1.1	Civil Construction Design - System Engineering							
4	1.1.4.1.2	Civil Construction Design - Contracts							
4	1.1.4.1.3	Civil Construction - Site Investigations							
3	1.1.4.2	WA Civil Construction Fab/Install							
4	1.1.4.2.1	WA Civil Construction - System Engineering							
4	1.1.4.2.2	WA Civil Construction - Contracts							
5	1.1.4.2.2.1	WA Site Plan and Construction Supervision							
5	1.1.4.2.2.2	WA Site Development							
5	1.1.4.2.2.3	WA Buildings - Corner Station							
5	1.1.4.2.2.4	WA Buildings - Left Arm end station							
5	1.1.4.2.2.5	WA Buildings - Left arm mid station							
5	1.1.4.2.2.6	WA Buildings - Right arm end station							
5	1.1.4.2.2.7	WA Buildings - Right arm mid station							

WBS DEPTH	WBS NO.	WBS TITLE	RISK FACTOR Technical	RISK FACTOR Cost	RISK FACTOR Schedule	RISK PERCENTAGE Technical	RISK PERCENTAGE Cost	RISK PERCENTAGE Schedule	Total Contingency
5	1.1.4.2.2.8	WA Buildings - Furnishings							
3	1.1.4.3	LA Civil Construction Fab/Install							
4	1.1.4.3.1	LA Civil Construction - System Engineering							
4	1.1.4.3.2	LA Civil Construction - Contracts							
5	1.1.4.3.2.1	LA Site Plan and Construction Supervision							
5	1.1.4.3.2.2	LA Site Development							
5	1.1.4.3.2.3	LA Buildings - Corner Station							
5	1.1.4.3.2.4	LA Buildings - Left Arm end Station							
5	1.1.4.3.2.5	LA Buildings - Left arm mid station							
5	1.1.4.3.2.6	LA Buildings - Right arm end station							
5	1.1.4.3.2.7	LA Buildings - Right arm mid station							
5	1.1.4.3.2.8	LA Buildings - Furnishings							
1	1.2	Detector Systems							
2	1.2.1	Interferometers (s)							
3	1.2.1.1	Interferometers Design (s)							
4	1.2.1.1.1	Interferometers Design SE (e)							
4	1.2.1.1.2	Interferometers Design Equipment (e)							
3	1.2.1.2	Washington Interferometers							
4	1.2.1.2.1	Interferometer 1 (s)							
5	1.2.1.2.1.1	IF1 Fab/Install SE (e)							
5	1.2.1.2.1.2	IF1 Fab/Install Equip/contracts (e)							
5	1.2.1.2.1.3	IF1 Optics Support (e)							
4	1.2.1.2.2	Interferometer 3 (s)							
5	1.2.1.2.2.1	IF3 Fab/Install SE (e)							
5	1.2.1.2.2.2	IF3 Fab/Install Equip/contracts (e)							
5	1.2.1.2.2.3	IF3 Optics Support (e)							
3	1.2.1.3	Louisiana Interferometers							
4	1.2.1.3.1	Interferometer 2 (s)							
5	1.2.1.3.1.1	IF2 Fab/Install SE (e)							
5	1.2.1.3.1.2	IF2 Fab/Install Equip/contracts (e)							
5	1.2.1.3.1.3	IF2 Optics Support (e)							
2	1.2.2	CDS							
3	1.2.2.1	CDS Design							
3	1.2.2.2	CDS Washington site							

LIGO - RISK ANALYSIS/CONTINGENCY

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WBS DEPTH	WBS NO.	WBS TITLE	RISK FACTOR			RISK PERCENTAGE			Total Contingency
			Technical	Cost	Schedule	Technical	Cost	Schedule	
3	1.2.2.3	CDS Louisiana site							
2	1.2.3	Auxiliary Physics Monitoring							
3	1.2.3.1	Design							
3	1.2.3.2	Washington site							
3	1.2.3.3	Louisiana site							
2	1.2.4	Support Equipment							
3	1.2.4.1	Design							
3	1.2.4.2	Washington site							
3	1.2.4.3	Louisiana site							
1	1.3	Research and Development							
2	1.3.1	Lab Operations							
2	1.3.2	R & D Tasks							
1	1.4	Project Office							
2	1.4.1	Project Management							
3	1.4.1.1	LIGO Management							
3	1.4.1.2	Cost and Scheduling							
2	1.4.2	Support Services							
3	1.4.2.1	Quality Assurance							
3	1.4.2.2	ES&H							
2	1.4.3	System Engineering							
3	1.4.3.1	Technical Services							
3	1.4.3.2	Documentation Services							
2	1.4.4	Office Operations							