LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-M060045-00-M *ADVANCED LIGO* 28 April 2006

Advanced LIGO Risk Management Plan

Carol Wilkinson, David Shoemaker

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California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW17-161
175 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

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1.0 INTRODUCTION

This Risk Management Plan describes principles and processes to continuously manage risks in an analytical, forward-looking, structured, and informative manner. Implementation of this Risk Management Plan supports successful completion of the Advanced Laser Interferometer Gravitational Wave Observatory (LIGO) Project by:

- Increasing the probability that the Project will conclude successfully,
- Identifying risks early and implementing mitigation actions in a timely manner, and
- Ranking and evaluating risks to focus limited resources on those that have the highest potential impact on the Project.

From the inception of the Advanced LIGO Project, risks were identified and strategies to mitigate these risks incorporated into Project planning. Mitigation strategies included reforming comprehensive prototyping, implementing formal design review processes, providing in-process spares, pursuing alternative technologies, and starting procurement early for long lead items. This plan provides a formalized approach to continue management of previously identified risks and to actively identify and manage new risks.

2.0 RISK MANAGEMENT METHODOLOGY

2.1 Definitions

Risk - Any unplanned event or circumstance that, if it occurred, would have a negative consequence to the Advanced LIGO Project. *Risk* is a measure of the potential inability to achieve overall Project objectives within defined scope, cost, schedule, and performance constraints. The two components of risk include the *probability* of failing to achieve a particular outcome, and the *consequence* of failing to achieve that outcome. *Risks* are “Unusual events" that are not common and may include such things as: losing a sole source vendor, experiencing an unexpected failure mode of a component, or exposing design flaws during integration that require a major redesign and re-engineering.

Risk Management – An organized, systematic, decision-making process that efficiently identifies risks, categorizes and evaluates risks, and effectively reduces or eliminates threats to achieving Project objectives. Risk management is concerned with future events, whose exact outcome is unknown, and how to manage these uncertainties by identifying and examining a range of possible outcomes. The alternative to risk management is crisis management, a resource-intensive process that is normally constrained by a restrictive set of available options.

2.2 Risk Management Process

The Risk Management Process consists of the five major elements described below and depicted in Figure 2-1. The process is iterative and serves to continuously manage risk.

- Identify the event or circumstance (and their sources) that pose a risk.
- Categorize the risks relative to four Project objectives (cost, schedule, scope, and performance).
- Evaluate the risks to assess the probability, the consequences, and the overall risk rank.
- Develop and approve risk mitigation strategies and monitor progress.
- Communicate the risk, its impact, the mitigation strategies, and the effectiveness of the mitigation process to Project team-members.

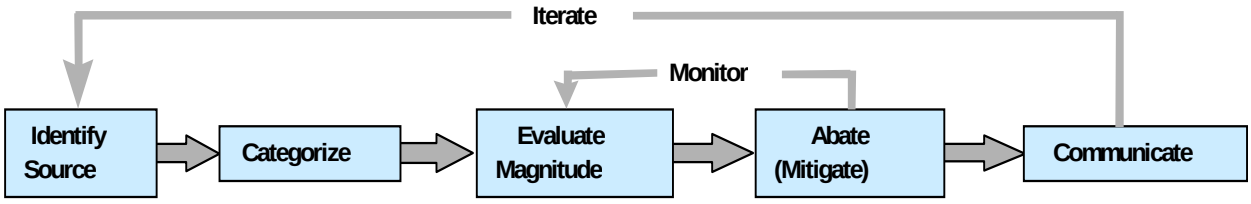


Figure 2-1. Risk Management Process.

• Internal • External	• Cost • Schedule • Scope • Performance	• Risk Characteristics • Risk Ranking • Critical Risks	• Accept • Mitigation Action	• Meetings • Risk Register Review

A Risk Register is the main tool used to implement the Advanced LIGO Risk Management Processes. A sample (or "snapshot in time") of the Advanced LIGO Risk Register (Risk Register) is shown as Appendix A. The highest priority risks from the Risk Register are also documented on a Major Threat List. A sample (or "snapshot in time") of the Advanced LIGO Major Threat List is shown as Appendix B. Further discussion of the Risk Register and Advanced LIGO Major Threat List is contained throughout this plan and in Section 4.0, Risk Management Tools.

The major elements of the Risk Management Process and how these elements relate to the Advanced LIGO Project are discussed in the following sections.

2.2.1 Identify Risks

Risk identification starts with open communication at all levels. Any Advanced LIGO team-member may identify a risk. The team-member communicates the risk and background information to the Project Manager (PM). The PM reviews the risk, interfaces with cognizant team-members (as necessary), and determines if the risk should be added to the Risk Register. If the risk is added to the register, the PM represents the risk as an "if, then" statement (to illustrate the probability and consequence components of the risk) and assigns a unique risk identification number.

2.2.2 Categorize and Evaluate Risks

The PM works with cognizant team-members (as necessary) to determine the probability of occurrence, the consequences if it occurs, the correlation to the four Project objectives, and the overall "risk rank."

Consequences are considered relative to the following four Project objectives:

- Scope,
- Performance,
- Schedule, and
- Cost.

Each risk is evaluated for its impact on each objective. Risk consequences are rated from 1 to 5, with 1 having the least impact and 5 having the greatest impact. Risk probabilities are also addressed on a scale of 1 to 5, with 1 being less likely to occur and 5 being most likely to occur. An overall "risk rank" (high, medium, or low) is assigned by using a risk scoring matrix (and other Project data if appropriate) to evaluate the probability of the risk with respect to the highest impacted Project objective. Guidelines for risk probability, risk consequence, risk scoring, and the 5 by 5 risk scoring matrix are provided in Appendix C, Guidelines for Risk Categorization and Evaluation. Risk categorizations and evaluations are reviewed by the Risk Management Team (RMT).

2.2.3 Mitigate Risks

The PM interfaces with cognizant team-members (as necessary) and the RMT to finalize risk mitigations. Risks are mitigated using the following strategies:

Accept – Accept the risk level and continue on the current plan. There is either a very low risk, the cost of reduction/mitigation outweighs the possible risk consequence, or there is no appropriate mitigation.

Mitigation Action – These actions lessen the probability of a risk occurring and/or reduce its negative consequence on the Project if it occurs.

Mitigations associated with risks identified on the "Major Threat List" will be planned and implemented to reduce the consequences and/or probability before impacts occur. Mitigation actions for other risks may be implemented based on RMT prioritization of mitigations with respect to cost effective management, other LIGO activities, and resource availability. The PM, with input from cognizant team-members (as necessary), is responsible for managing risk mitigations.

The PM, with support from Advanced LIGO team-members, is responsible for implementing all mitigations/actions.

2.2.4 Monitor and Review Risks

Risks are monitored on a periodic basis and are reassessed as conditions change or more information becomes available. Risks on the Major Threat List are reviewed monthly at RMT meetings. All other risks are reviewed quarterly at RMT meetings.

The PM is responsible for revising the Risk Register as a result of RMT input relative to re-categorization, re-evaluation, and monitoring and review of mitigations (consistent with responsibilities identified in Table 3-1).

2.2.5 Communicate Risk Information

Risks information is communicated to top management through RMT meetings and to all appropriate team-members through staff meetings and through review of the posted Risk Register.

3.0 RISK MANAGEMENT ROLES AND RESPONSIBILITIES

Accountability for risk management is a responsibility levied upon each individual working on the Advanced LIGO Project. The Project Leader (PL) has overall responsibility for Advanced LIGO risk management. Implementation and management of risk management processes is the responsibility of the PM. The PL and PM work in conjunction with the RMT to administer Advanced LIGO risk management processes. The RMT is chaired by the PL and consists of the following members:

- Advanced LIGO PL,
- Advanced LIGO PM,
- Advanced LIGO System Scientist (SS),
- Advanced LIGO Project System Engineering Lead (SE) , and
- Any additional members appointed by the PL.

Table 3-1 describes risk management responsibilities for the Project.

Table 3-1. Advanced LIGO Project Risk Management Responsibilities.

Project Team-Member	Responsibility	Frequency
PL	Overall responsibility for risk management.	Continuously
	Chair the RMT meetings (See Appendix D for a sample meeting agenda).	Once a month (more often if necessary)
PM	Point of contact for risk management process.	Continuously
	Manage Advanced LIGO Project Risk Register – including management and monitoring of all risks and mitigations.	Continuously
	Implement risk training.	Continuously
	Provide risk management reporting for the Project.	Once a month (more often if necessary)
	Provide input to RMT regarding Advanced LIGO Major Threat List.	Once a month (more often if necessary)
	Provide input to RMT regarding risks not on Advanced LIGO Major Threat List.	Once a quarter
The RMT	Review risk management implementation.	Once a month (more often if necessary)
	Review and approve risk categorizations, evaluations, and mitigations.	Once a month (more often if necessary)
	Identify risks at Project and subsystem levels.	Continuously
Each Advanced LIGO Team-Member	Identify potential risks within their sphere of influence, communicate risks to PM, assist PM in performing risk categorizations and evaluations, and provide input regarding possible risk mitigations.	Continuously
	Monitor Project risk status by reviewing the posted Risk Register.	Continuously

4.0 RISK MANAGEMENT TOOLS

4.1 Advanced LIGO Project Risk Register and Advanced LIGO Major Threat List

The Risk Register is the main tool used to implement the Risk Management Processes. It is a "living" list of risks including categorization and evaluation data as well as mitigation information. The Advanced LIGO Major Threat List documents the highest priority risks contained on the Risk Register. It is also a "living" document where risks appear and are removed depending on identified risks and mitigation activities. The current Risk Register and Advanced LIGO Major Threat List are located on the Advanced LIGO Project Center Website and are maintained/controlled by the PM.

4.2 Uncertainty Analysis

The purpose of uncertainty analyses is to quantify a level of confidence in the Project's basis documents regarding cost and schedule. Uncertainty, for analysis purposes, is determined from risk consequence data and Project planning data. Uncertainties (usually with respect to estimate and schedule) are defined in terms of probability density functions (pdfs). The uncertainty pdfs

are then propagated through the Project estimate and schedule data using Monte-Carlo techniques. Uncertainty-based analyses determine the impacts to the Project from uncertainty associated with risk consequences and Project planning data. Normally, sensitivity analyses are run as part of uncertainty analysis to provide major cost and schedule drivers that must be successfully managed to complete the Project (or Project activity) as planned. Uncertainty analyses are performed using the methodology described above and shown in Figure 4-1 below.

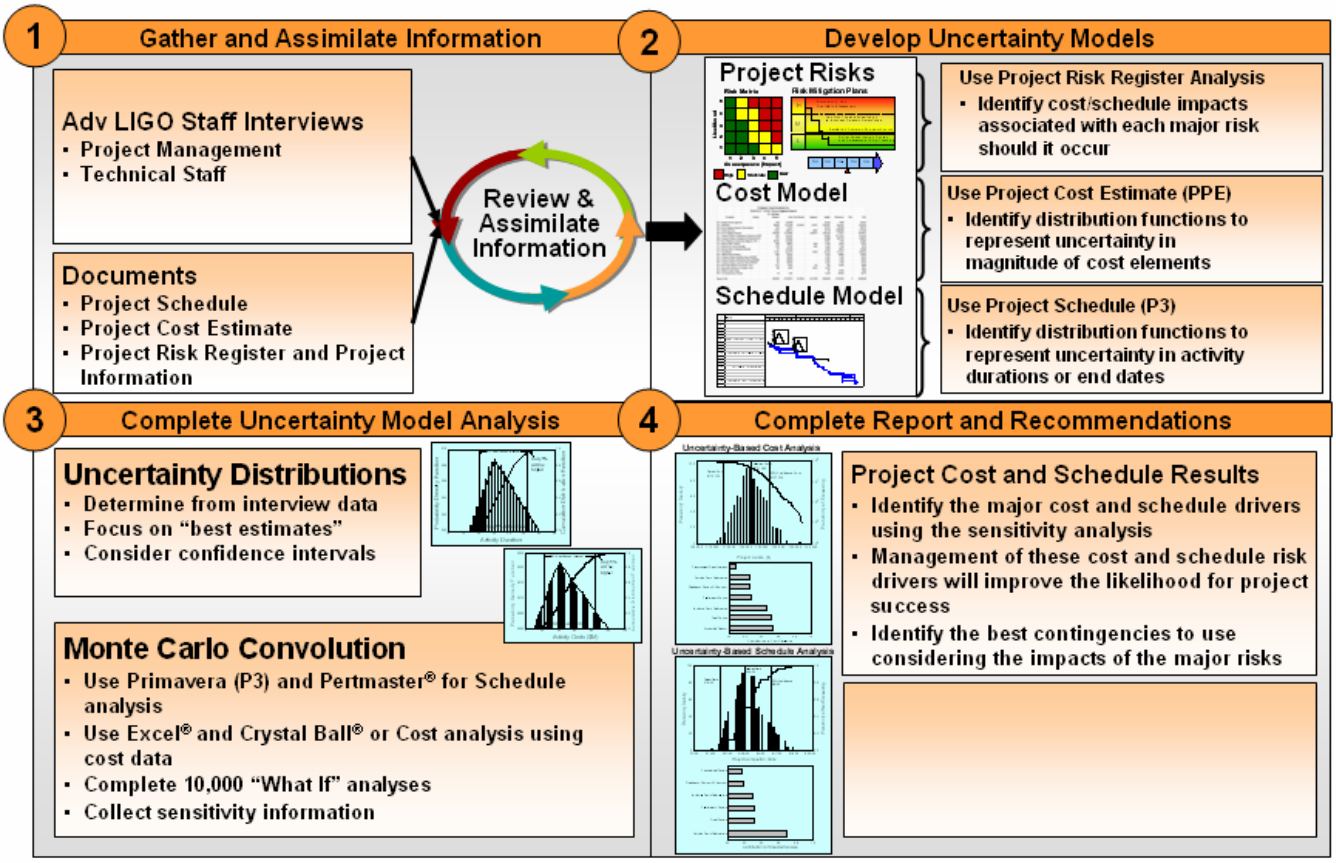


Figure 4-1. Uncertainty Analysis Process.

5.0 TRAINING

The PM is responsible for providing risk management training for the Advanced LIGO Project team members. Each Subsystem Lead is required to undergo initial risk management training when this plan is approved and implemented (see Appendix E). The PM is responsible for providing periodic risk management training to the Subsystem Leads. The Subsystem Leads are responsible for providing informal training to the employees working in his/her subsystem.

APPENDIX A

ADVANCED LIGO RISK REGISTER - SAMPLE

Risk Value	Probability
5	Extremely Likely – 90% probability of occurrence over the project life
4	Highly Likely – 70% probability of occurrence over the project life
3	Moderately Likely – 50% probability of occurrence over the project life
2	Unlikely – 30 % probability of occurrence over the project life
1	Highly Unlikely – 10% probability of occurrence over the project life

Risk Value	Scope Consequence	Cost Consequence	Schedule Consequence	Performance Consequence
5	Unacceptable	> $3M	> 4 mos.	Unacceptable
4	Major overall Consequence	$500K to $3M	2 - 4 mos.	Doesn't meet SRD
3	Some major areas Consequenceed	$250K to $500K	1 - 2 mos.	Doesn't meet SRD in some areas
2	Minor Consequence	$50K to $250K	<1 mon.	Doesn't meet high goals
1	Negligible	<$50K	Negligible	Negligible

			Initial Risk Evaluation							Residual Risk Evaluation						
Risk ID	Risk Event	Affected System or WBS Level	Prob-ability	Consequence				Risk Score	Completed Mitigation Actions	Major Threat List	Prob-ability	Consequence				Resi-dual Risk Score	Open Mitigation Actions
				Cost	Sched-ule	Perform	Scope					Cost	Sched-ule	Perform	Scope		
06-001	If Test masses require aggressive thermal compensation for arm mode control, additional cost and schedule delay may occur.	AOS	1	2	3	2	2	Low	Include purchase of additional Hartmann sensors for permanent installation on test masses in plan		1	1	1	1		Low	Accept Risk
06-003	If thermal compensators inject noise into system, power stability for heater and laser will be required.	AOS	3	2	3	2	2	Med	Have backup plan to enhance power stability of ring heater and laser.		3	2	2	2	2	Med	Implement backup plan to enhance power stability of ring heater and laser.
06-005	If thermal compensation sensors inadequately sensitive, performance will be degraded.	AOS	2	2	3	2	1	Med	Added to baseline: multiplicity of installed TCS sensors		2	1	1	1	1	Low	Accept Risk
06-006	if optical spring effect in RSE is ignored in calculating the scattered light noise, then ADLIGO may not meet SRD	AOS	2	1	3	3	2	Med		Y	2	1	3	3	2	Med	Complete revision of e2e software to include optical spring in design phase
06-014	If sole-source COC vender is lost, then delays to schedule occur for long lead procurement items and costs are increased.	COC	3	3	5	2	1	High		Y	3	3	5	2	1	High	1) Use pathfinder process to vet backup vendors 2) Split order between two vendors 3) Add schedule and cost contingency to plan.
06-015	If the exchange rate for euro or Australian dollar increases by more than 20%, significant cost increases for the majority of COC procurements will occur	COC	2	3	1	1	1	Med	Account for additional contingency with Consequence in Monte Carlo simulation		2	2	1	1	1	Low	Go to NSF for additional funding for event outside normal expectations
06-020	If computer space requirements exceed projected space, then facility modifications may be required	DCS	2	2	1	1	1	Low	Requirement to maintain operations makes prbability low; add risk contingency to subsystem contingency for this purpose		2	2	1	1	1	Low	Identify space requirements early and work to provide adequate computer space
06-027	If need for bake-out established, then a delay in schedule would occur and costs increased for refurbishment/ purchase.	FMP	2	4	5	4	1	Med	Include mechanical wipeout/cleaning of chambers and vacuum equipment in baseline to minimize need for bakeout.		1	4	4	4	1	Low	Continue evaluation to establish need as soon as possible
06-030	Outgasing contamination to the ultra-high vacuum system.	INS	1	4	5	5	5	Low	Vacuum review board reviews material and provides lists of acceptable materials.		1	4	5	5	5	Low	Standard procedures and practices in UHV part cleaning, prototcols and contamination control planning. Also QA of UHV provided parts delivered from vendors/contractors.
06-031	If excessive particulate contamination to the optics or chambers occurs, the cost, schedule, and performance will be negatively Consequenceed.	INS	4	4	3	5	3	High	Improvements to the contamination control plan made; infrastructure to mitigate particulate contamination included in plan.	Y	2	4	3	5	3	Med	Continue evaluation of sensitivity/requirements and development contamination control plan.

APPENDIX B

ADVANCED LIGO MAJOR THREAT LIST – SAMPLE

Risk Value	Probability
5	Extremely Likely – 90% probability of occurrence over the project life
4	Highly Likely – 70% probability of occurrence over the project life
3	Moderately Likely – 50% probability of occurrence over the project life
2	Unlikely – 30 % probability of occurrence over the project life
1	Highly Unlikely – 10% probability of occurrence over the project life

Risk Value	Scope Consequence	Cost Consequence	Schedule Consequence	Performance Consequence
5	Unacceptable	> $3M	> 4 mos.	Unacceptable
4	Major overall Consequence	$500K to $3M	2 - 4 mos.	Doesn't meet SRD
3	Some major areas Consequenceed	$250K to $500K	1 - 2 mos.	Doesn't meet SRD in some areas
2	Minor Consequence	$50K to $250K	<1 mon.	Doesn't meet high goals
1	Negligible	<$50K	Negligible	Negligible

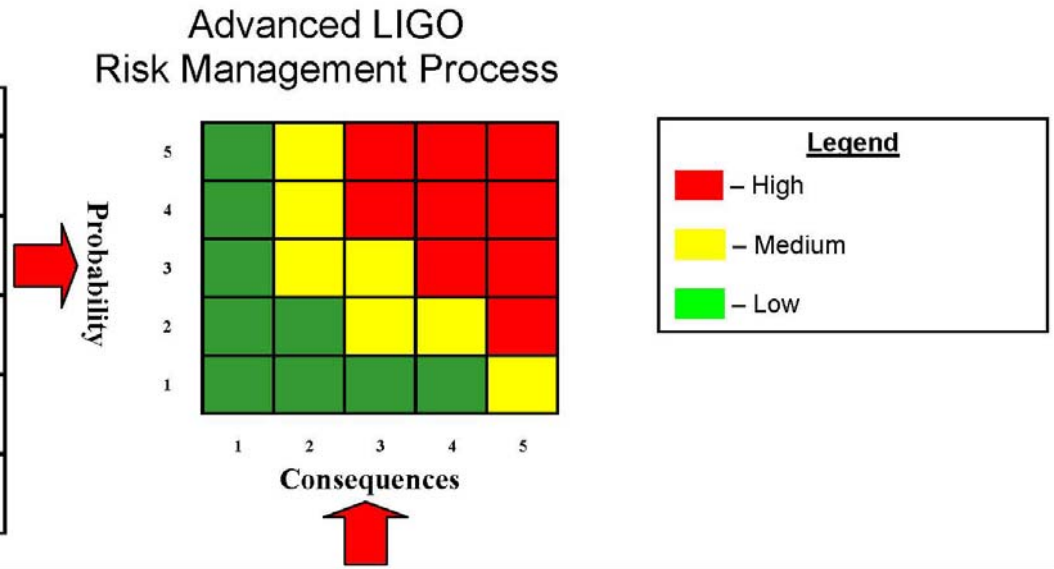
			Initial Risk Evaluation							Residual Risk Evaluation						
				Consequence							Consequence					
Risk ID	Risk Event	Affected System or WBS Level	Prob-ability	Cost	Sched-ule	Perform	Scope	Risk Score	Completed Mitigation Actions	Major Threat List	Prob-ability	Cost	Sched-ule	Perform	Scope	Resi-dual Risk Score	Open Mitigation Actions
06-006	if optical spring effect in RSE is ignored in calculating the scattered light noise, then ADLIGO may not meet SRD	AOS	2	1	3	3	2	Med		Y	2	1	3	3	2	Med	Complete revision of e2e software to include optical spring in design phase
06-007	If the sole-source vendor for expensive, long lead time, off-axis parabolic mirrors is unable to produce the PO telescope mirrors, the cost and schedule would be Consequenceed	AOS	2	3	5	5	5	Med		Y	2	3	5	5	5	Med	Pre-qualify a second source for off-axis parabolic mirrors
06-009	If core optic or coating absorption is too large, the thermal lens at full power will be larger than TCS can compensate, reducing sensitivity or forcing Advanced LIGO to run at lower power.	AOS COC	3	2	3	4	3	High		Y	3	2	3	4	3	High	Check with COC on ability to meet req's to date. 1) Design TCS with power margin. 2) Have cleaning procedure in place for absorptive core optics.
06-011	If electrostatic actuator too noisy, will need to re-instate photon drive.	AOS SUS	2	3	4	4	3	Med	Maintain R&D backup plan for Photon Drive, and appropriate optical access to TMs	Y	2	2	3	2	1	Med	Implement backup plan for Photon Drive. Keep track of optical access to TMs in layouts.
06-012	If specialized coatings vender is lost, then set-up for another vender will add significant schedule and cost to project schedule.	COC	2	3	5	1	2	Med		Y	2	3	5	1	2	Med	Work with alternate vender to scope work and possibly prepare some set-up.
06-014	If sole-source COC vender is lost, then delays to schedule occur for long lead procurement items and costs are increased.	COC	3	3	5	2	1	High		Y	3	3	5	2	1	High	1) Use pathfinder process to vet backup vendors 2) Split order between two vendors 3) Add schedule and cost contingency to plan.
06-022	If facility staging space is determined insufficient late in the project, then new facilities (or modifications to existing facilities) will be required.	FMP	2	2	3	1	1	Med		Y	2	2	3	1	1	Med	Identify space requirements early and work to provide adequate staging for delivered components
06-024	If facility modifications are required relative to vacuum chambers and beam pipes, then significant delays and cost increases to the project could occur.	FMP	2	3	3	1	1	Med		Y	2	3	3	1	1	Med	Identify the infrastructure requirements early in the project and manage interfaces.
06-025	If clean room space is inadequate for assembly needs, schedule delay and or costs will increase.	FMP	2	2	4	1	1	Med		Y	2	2	4	1	1	Med	Identify clean room requirements early and assign work space based on assembly plans.
06-028	If subsystems not ready to start installation on time, particularly those with long lead procurement and/or long lead assembly/test phases (COC, SUS, SEI), then schedule could be delayed and costs increase.	INS	3	4	4	1	3	High	Plan for adequate scheduled time and contingency in fabrication/assembly phase.	Y	3	4	4	1	3	High	Monitor and forecast schedule variances and implement risk management strategies. Determine work-arounds for delays or problems to maintain installation start dates. (e.g. can use existing laser source for a long time before the ADL higher power laser is needed).
06-029	If personnel or machine safety incident occurs during project (e.g.laser incident), project costs and schedule may be Consequenceed..	Project	3	3	2	1	3	Med	Safety engineering and procedures included in the design phase. Facility operating plans already include laser and machine safety and personnel training.	Y	1	3	2	1	3	Low	Safety plans and reviews are required. In particular laser safety will be designed into the system. All personnel undergo laser and machine (e.g. crane) safety training.

ADVANCED LIGO MAJOR THREAT LIST – SAMPLE

APPENDIX C

GUIDELINES FOR RISK CATEGORIZATION AND EVALUATION

Risk Value	Probability	Description
5	Extremely Likely	90% probability of occurrence over the project life
4	Highly Likely	70% probability of occurrence over the project life
3	Moderately Likely	50% probability of occurrence over the project life
2	Unlikely	30 % probability of occurrence over the project life
1	Highly Unlikely	10% probability of occurrence over the project life



Consequence	Consequence Level (In Terms of Cost, Schedule, Scope and Performance					
	Level	1	2	3	4	5
	Cost	Insignificant Cost Increase (<$50K)	Cost Increase ($50K< I <$250K)	Cost Increase ($250K< I <$500K)	Cost Increase ($500K< I <$3M)	Cost Increase (>$3M)
	Schedule	Insignificant Schedule Slippage	Overall Project Slippage < 1 month	Overall Project Slippage 1 – 2 months	Overall Project Slippage 2 > 4 months	Overall Project Slippage > 4 months
	Scope	Scope change is negligible	Minor Areas of Scope are Affected	Major Areas of Scope Affected	Major Impact on Overall Scope	Scope Reduction Unacceptable to Client
	Performance	Quality Degradation Barley Noticeable	Only Very High Goals are Affected	Does Not Meet SRD In Some Areas	Does Not Meet SRD	Performance Reduction Unacceptable to Client

APPENDIX D

RISK MANAGEMENT TEAM MEETING SAMPLE AGENDA

Risk Management Team Meeting

Sample Agenda

The below table documents sample agenda items and correlates those items with information in the Risk Management Plan.

Agenda Item	Corresponding Risk Management Plan Information
1) Assess risk management implementation through discussions with PM	Section 3.0 - "The PL and PM work in conjunction with the RMT to administer Advanced LIGO risk management processes."
2) Approve risk categorizations/evaluations and risk mitigation activities.	Section 2.2.2 – "Risk categorizations and evaluations are reviewed by the Risk Management Team (RMT)." .Section 2.2.3 – "The PM interfaces with cognizant team-members (as necessary) and the RMT to finalize risk mitigations."
3) Discuss Risks	Section 1.0 – "Implementation of this Risk Management Plan improves the Advanced Laser Interferometer Gravitational Wave Observatory (LIGO) Project management….." Section 2.2.4 – "Risks on the Major Threat List are reviewed monthly at RMT meetings. Medium risks (not on the Major Threat List) and low risks are reviewed quarterly at RMT meetings."

APPENDIX E

RISK MANAGEMENT TRAINING FORM

I have read and understand the policies and processes documented in LIGO-M060045-00-M, Advanced LIGO Risk Management Plan.

By completely reviewing the document and understanding how the processes are to be implemented for the project, I have satisfied the training requirements identified in the plan. My signature below documents that I am trained.

Name (Print)	Signature	Date