



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Guidelines for Advanced LIGO
Detector Upgrade Development Review

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1 Introduction

This document provides programmatic guidelines for the development phases of the proposed Upgrade Projects to the advanced LIGO (aLIGO) detector from the requirements and conceptual design phase through fabrication.

2 Related Documents

[L1500105](#) R&D task approval and tracking workflow

[M1500262](#) Procurement Workflow for Detector Upgrades

[M1200274](#) Engineering Change Request (ECR) Process

3 Upgrade Project Definition

Upgrade Projects, in the context of this guide, include the following:

- Performance enhancements/upgrades (increased sensitivity, decreased glitch rates, etc.)
- Availability enhancements/upgrades (including adaptation to an changing environment)
- Re-engineering to cope with parts & system/platform obsolescence, and sourcing issues
- Re-engineering for technology insertion
- Re-engineering for life extension of aging components/subsystems

Repairs and replacements of components, consistent with the baseline design (i.e. no change in the design, just substitutions of components) are not upgrade projects.

4 Connection with R&D Projects

Efforts often (but not always) start in a research phase before being selected for development leading to an upgrade to the LIGO detectors. The review/approval and management process for these R&D efforts is defined in [L1500105](#). Usually the more speculative efforts start with an R&D phase. The handover from research to development is generally associated with the Preliminary Design Phase (at the start, the end, or within this phase).

5 Waivers

Systems Engineering can decide to waive the Design Requirements and Conceptual Design Review (DRR/CDR) and/or the Preliminary Design Review (PDR) for Upgrade Projects that are mature and not overly complex. Systems Engineering can also waive some of the content for the reviews if deemed appropriate. In both cases Systems Engineering should document any waivers in writing and identify the specific checklist items for reviews which are not required, as well as the reason(s) for the waiver.

6 Design Requirements Phase

6.1 Requirements definition

Identify and document, in a Design Requirements Document (DRD), the information necessary to define the Upgrade Project and quantify its relationship to other subsystems, and the system. Typical contents of the Design Requirements Document (DRD) include:

- Scope and objectives of upgrade development activities
- Interface requirements (taking particular care to review existing interface documents before any significant modifications are planned)
- Functional and performance requirements
- Physical and environmental requirements
- Documentation requirements
- Design considerations
- Testing criteria
- Principal safety hazards and design implications
- Plans for the Preliminary Design phase, in particular for prototyping and testing

Quantification of some items listed in the Design Requirements Document may be deferred until the preliminary design phase. These are listed with values To Be Determined (TBD).

6.2 Conceptual design

Generate and document, in a Conceptual Design Document (CDD), a conceptual design of the subsystem in sufficient detail to show that the subsystem is completely characterized by the entries in the Design Requirements Document (DRD) and is understood well enough to proceed with preliminary design.

The CDD must include a table cross-referencing the DRR/CDR checklist items from the Appendix.

6.3 Design Requirements & Conceptual Design Review (DRR/CDR or DRR for short)

The content of the DRD and CDD are presented to a design review board appointed by Systems Engineering. Guidelines for the review are outlined in Appendix A. The review board may approve the DRD and CDD, agreeing that they are complete and sufficient to proceed into the preliminary design phase, or conditionally approve it with recommended modifications (defined by the review board in specific Action Items in their review report).

Following the DRR, Systems Engineering issues written authorization for proceeding with the Preliminary Design Phase, specifying any changes to be incorporated into the documentation (by reference to the DRR-recommended Action Items).

7 Preliminary Design Phase

7.1 Preliminary Design Development

The preliminary design phase consists of the following principal tasks:

- Develop the subsystem to the point where *all design issues are resolved*, lacking only the detailed engineering drawings, specifications and contract documents needed for implementation. Summarize the design in a Preliminary Design Document (PDD) which points to other relevant documents.
- Complete those detailed specifications/engineering drawings needed for long-lead procurements (at the PDR, provide justification to proceed with these items before the Final Design Review).

- Complete the Design Requirements Document by quantifying all "TBD" items and incorporating changes adopted from the DRR.
- Before the Preliminary Design Review (PDR), the Design Requirements Document (DRD) is signed off by the Upgrade Project Manager and Systems Engineering.

The PDD must include a table cross-referencing PDR checklist items from the Appendix.

7.2 Preliminary Design Review (PDR)

The content of the completed Preliminary Design Document (PDD) including its references, and any updates/changes to the Design Requirements Document (DRD), are presented to a design review board appointed by Systems Engineering, showing how the design meets all of the identified requirements. The review board either a) approves the preliminary design (and updated DRD) as presented, or b) recommends changes to be incorporated during the final design phase (defined in specific Action Items in the review board's report).

Following the PDR, Systems Engineering issues written authorization for proceeding with final design and long-lead procurements, directing any changes to be incorporated. Changes to the Design Requirements Document (DRD) are incorporated as soon as possible and then signed off by Systems Engineering, with a Document Change Notice (DCN), i.e. issued as a controlled document.

8 Final Design Phase

8.1 Final Design Development

Generate a final design package, including:

- A main Final Design Document (FDD) which summarizes the design and points to other relevant documents
- A revised Design Requirements Document (DRD)
- Detailed engineering drawings/specifications
- Detailed procurement specifications/contract documents
- Detailed inspection plans/procedures
- Detailed test plans/procedures for the fabrication phase, including whether a first article(s) will be produced and tested before committing to the balance of production
- Detailed integration plans/procedures
- If a prototype was constructed, incorporate results of the Prototype Test Review into final design documentation

The FDD must include a table cross-referencing the FDR checklist items from the Appendix.

8.2 Prototype

If applicable (i.e. if a prototype was proposed and approved at the PDR), a prototype will be built and tested as part of the final design phase;

- Develop prototype hardware to the point where all hardware issues are resolved for the final design
- Generate a test report documenting test procedures and results to support details of the final design implementation

8.3 Final Design Review (FDR)

Present the contents of the final design package to a review board appointed by Systems Engineering. Show that all issues raised during the PDR have been resolved. The review board either a) approves the final subsystem design or b) recommends changes to be incorporated prior to fabrication (specified as Action Items).

Upon accepting the review board's report, Systems Engineering issues written authorization for proceeding with implementation, or directs changes to be incorporated immediately prior to proceeding with fabrication. After Action Items have been incorporated, the final design documents are signed off by Systems Engineering and released as controlled documents with a Document Change Notice (DCN). Fabrication may not proceed until all Action Items are closed out, final design documents have been approved and released, and written authorization to proceed is issued.

9 Fabrication/Test Phase

The fabrication/test phase consists of the following principal tasks:

- Fabricate and test items as specified in the final design documents
- Document and resolve all discrepancies from approved fabrication drawings/specifications
- Document and resolve all discrepancies from approved inspection and test plans/procedures
- Package the fabricated items for shipment to the LIGO observatories

See also the “Procurement Workflow for Detector Upgrades”, [M1500262](#).

9.1 First Article Fabrication/Test

If the fabrication phase will include a first article fabrication and test effort (for all applicable components, or the entire subsystem if appropriate, as defined and approved at the FDR), then:

- Produce and test a first-article unit in accordance with the final design documents
- Generate a test report documenting test procedures and results, showing compliance with the final design documents (or proposing changes to the final design documents necessary to achieve compliance)

9.2 Installation Readiness Review (IRR)

The fabrication and test records, including any first article testing, along with all reports of problems encountered during fabrication and testing and documentation of their resolution, are presented to a review board appointed by Systems Engineering. The review board either a) recommends installation of the items, or b) recommends additional actions to close out open issues (specified as Action Items).

Upon acceptance of the review board's report, the Systems Engineering issues written authorization for installation, or directs additional actions to be taken.

10 Appendix A: Review Responsibilities and Process

10.1 Systems Group

- Assigns an Upgrade Project Manager
- Determines which reviews are needed based on the maturity and complexity of the Upgrade Project
- Determines the required content for each review (a subset of the checklists in this document). By default all content is required.
- Issues a memo (or email) appointing review board, conveying charge, date and location for the review (ideally four weeks before the review)
- Chairs the review by default, but can assign a chairperson
- Receives review board report, accept/reject/modify action items as needed, and track their execution
- Ensures action items resolved
- Closes out review by ensuring delivery of a copy of the review archive document (reviewed documents, presentation material, review board report and action item closeout memoranda) to the LIGO document control center (DCC)

10.2 Upgrade Project Manager

- Develops documentation for each review
- Submits proposed review agenda to review board chairman (ideally three weeks before the review)
- Ensures that review documents and presentation materials are consistent with the review objectives and agenda
- Distributes review documents to review board members (ideally two weeks before the review)
- Ensures that the Upgrade Project Team provides answers to the review committee's questions
- Reports to the Review Committee on action items in the review board report when completed (to enable next step in subsystem development or fabrication)
- Assembles the review archive documentation

10.3 Review Board Chairperson

- Iterates the review agenda with the Upgrade Project Manager.
- Appoints a secretary for the review board (from among members) (to record board comments and action items)
- Announces review date, materials, and telecom information to the LIGO team
- Convenes review board (ideally one week before the review start) to assemble questions for discussion at the review; delivers questions to Upgrade Project Manager
- Conducts the review, which is geared toward answering the committee's questions (i.e. not a presentation of all of the review reports).
- Assembles, with the committee aid, a consensus report, indicating if the review is successful, where concerns remain, etc.

- Develops a list of recommended action items. Ensure that the Upgrade Project Team finds the actions ‘actionable’ iterating as necessary and that the due date or timing with respect to significant events is made clear for each. Actions for those outside of the Subsystem to be flagged.
- Generates and distributes the review board report

10.4 Review Board members

- Studies the review documents before the review board meetings
- Participates in review board meeting(s)
- Documents action items initiated by board member
- Participates in the creation of the review board report

10.5 Operations Management Team (OMT)

- At the request of Systems Engineering, issues written authorization to proceed based on the review outcomes, or indicates actions needed before proceeding. See also [M1500262](#) for the process and [M1500260](#) for a log of requests for OMT approvals.

11 Appendix B: Review Checklists¹

11.1 Design Requirements Review (DRR) Checklist

Insert this checklist into the DRD as an appendix with the document and section columns completed (multiple entries are acceptable). The documents can be the DRD, the CDD or any other documents which are part of the CDR/DRR data package. If a checklist item is not applicable mark the first two column entries with NA, and explain briefly why (under the checklist item description). If a checklist item has been waived by Systems Engineering, mark the first two columns “Waived”, and cite the Systems waiver document, or provide an explanation (under the checklist item description).

Document #	Section	Checklist Item
		General performance requirements
		Preliminary technical specifications
		Requirements allocation for
		<ul style="list-style-type: none"> • Physics parameters
		<ul style="list-style-type: none"> • Engineering requirements
		<ul style="list-style-type: none"> • Conventional construction requirements
		Adequately identified/defined
		<ul style="list-style-type: none"> • Subsystem and its relationship to the total system
		<ul style="list-style-type: none"> • Function(s) of subsystem and its contribution to the achievement of the requirements and goals of the overall system
		<ul style="list-style-type: none"> • Functions required from outside of the system in order for the system (or subsystem) to accomplish its function(s)
		Pictorial representation of the subsystem function(s) presented and discussed
		One or more options presented for review
		<ul style="list-style-type: none"> • Pros and cons of each option
		Selection of the option most likely to satisfy the requirements made
		<ul style="list-style-type: none"> • Data and trade studies were presented to substantiate the selection
		Proposed hardware approaches adequately satisfy the defined subsystem

¹ Modified from DIII-D Design Review Process, General Atomics, Tooker and Cary

		function(s)
		An adequate set of draft hardware requirements presented
		Interfaces identified with draft functional requirements (as well as identifying any changes to pre-existing interface documents/definition)
		Safety hazards identified, Hazard Analysis draft; for personnel and equipment
		Draft Failure Modes and Effects Analysis (FMEA) (top-down based on concept)
		Risk Registry items discussed
		Plans for the Preliminary Design phase presented
		Plans for prototyping and testing presented
		Cost estimate presented
		Schedule presented
		Documentation requirements presented
		Risk and abatement strategy for
		<ul style="list-style-type: none"> • Cost risks
		<ul style="list-style-type: none"> • Schedule risks
		<ul style="list-style-type: none"> • Technical performance risks
		Lessons learned documented, circulated
		Problems and concerns

11.2 Preliminary Design Review (PDR) Checklist

Insert this checklist into the PDD as an appendix, with the document and section columns completed (multiple entries are acceptable). The documents can be the PDD or any other document which is part of the PDR data package. If a checklist item is not applicable mark the first two column entries with NA, and explain briefly why (under the checklist item description). If a checklist item has been waived by Systems Engineering, mark the first two columns “Waived”, and cite the Systems waiver document, or provide an explanation (under the checklist item description).

Document #	Section	Checklist Item
		System Design Requirements, especially any changes or refinements from DRR
		Preliminary Design Document, summarizing the design and pointing to other documents
		Justification that the design can satisfy the functional and performance requirements
		<ul style="list-style-type: none"> • Subsystem block and functional diagrams
		<ul style="list-style-type: none"> • Equipment layouts
		<ul style="list-style-type: none"> • Document tree and preliminary drawings (information issued)
		<ul style="list-style-type: none"> • Modeling, test, and simulation data
		<ul style="list-style-type: none"> • Thermal and/or mechanical stress aspects
		<ul style="list-style-type: none"> • Vacuum aspects
		<ul style="list-style-type: none"> • Material considerations and selection
		<ul style="list-style-type: none"> • Environmental controls and thermal design aspects
		<ul style="list-style-type: none"> • Software and computational design aspects
		<ul style="list-style-type: none"> • Power distribution and grounding
		<ul style="list-style-type: none"> • Electromagnetic compatibility considerations
		<ul style="list-style-type: none"> • Fault Detection, Isolation, & Recovery strategy
		Resolution to action items from DRR
		Interface control documents (as well as identifying any changes to pre-existing interface documents/definition)
		Relevant RODA changes and actions completed
		Instrumentation, control, diagnostics design approach
		Fabrication and manufacturing considerations

		Instrumentation, control, diagnostics design approach
		Preliminary reliability/availability issues
		Assembly procedure
		Installation and integration plan
		Environment, safety, and health issues
		<ul style="list-style-type: none"> • Mitigation of personnel and equipment safety hazards; refined Hazard Analysis
		<ul style="list-style-type: none"> • Reflected in equipment design and procedures for use
		Human resource needs, cost and schedule
		Any long-lead procurements
		Technical, cost & schedule risks and planned mitigation
		Test plan overview
		Planned tests or identification of data to be analyzed to verify performance
		<ul style="list-style-type: none"> • In prototyping phase
		<ul style="list-style-type: none"> • In production/installation/integration phase
		Identification of testing resources
		<ul style="list-style-type: none"> • The test equipment required for each test adequately identified
		<ul style="list-style-type: none"> • Organizations/individuals to perform each test identified
		<ul style="list-style-type: none"> • QA involvement
		Test and evaluation schedule, prototype and production
		Revised Failure Modes and Effects Analysis (FMEA) (bottom-up approach based on design)
		Risk Registry items discussed
		Lessons learned documented, circulated
		Problems and concerns

11.3 Final Design Review (FDR) Checklist

Insert this checklist into the FDD as an appendix, with the document and section columns completed (multiple entries are acceptable). The documents can be the FDD or any other document which is part of the FDR data package. If a checklist item is not applicable mark the first two column entries with NA, and explain briefly why (under the checklist item description). If a checklist item has been waived by Systems Engineering, mark the first two columns “Waived”, and cite the Systems waiver document, or provide an explanation (under the checklist item description).

Document #	Section	Type	Checklist Item
		Changes	Final requirements – any changes or refinements from PDR?
			Resolutions of action items from PDR
		Hardware/ Sub-system Design	Subsystem block and functional diagrams
			Drawing package (assembly drawings and majority of remaining drawings)
			Final parts lists
			Final specifications
			Design analysis and engineering test data
		Interfaces	Final interface control documents (or revisions/updates to pre-existing interface documents)
			Relevant RODA changes and actions completed
			Risk Registry items discussed
		Software	Software detailed design (architecture, prototyping results, etc.)
			Software configuration control plan (SVN required)
			Final software test plan(s)
		Safety	Final approach to safety and use issues
			Signed Hazard Analysis
			Final Failure Modes and Effects Analysis
			Final Failure/Stress Analyses for any safety critical elements
		Production plans	Plans for acquisition of parts, components, materials needed for fabrication
			Installation plans and procedures

			Final hardware test plan(s)
			Cost compatibility with cost book
			Fabrication, installation and test schedule
			Lessons learned documented, circulated
			Problems and concerns