



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

*LIGO Laboratory / LIGO Scientific Collaboration*

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Guidelines for Advanced LIGO  
Detector Improvement Project Review(s)

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*v4: Added checklist for IRR (section 11.4)*

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## 1 Introduction

This document provides programmatic guidelines for the development phases of the proposed Detector Improvement (DI) Projects (aka enhancements, upgrades) 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 Improvements (DI)
- [M1200274](#) Engineering Change Request (ECR) Process

## 3 Detector Improvement (DI) Project Definition

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

- Performance improvements/enhancements/upgrades (increased sensitivity, decreased glitch rates, etc.)
- Availability improvements/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 DI projects.

## 4 Technical Readiness Level (TRL)

**Technical Readiness Level (TRL)** To assess the technical readiness of the technologies discussed in this report, we have tried to apply the Technology Readiness Level (TRL) method used by NASA, DoD, and industry, which rates technical maturity on a scale of 1 to 9 (9 being the most mature). A common practice is to require all enabling technologies to be at a TRL of 6 or higher before a concept can enter the project phase. We recommend that we begin to use this criterion for LIGO technologies, although it may take some trial-and-error to apply and adapt the standard TRL designations. The full list of TRLs is given in Appendix A.

Starting at preliminary design review:

- firstly, the reviewees evaluate the technologies on the TRL scale, and attempt to establish the criteria to achieve a TRL of 6 or higher.
- secondly, the reviewers include as part of their report supporting comments or objections to the level and reasons stated.

**Then again at the final design review:**

- firstly, the reviewees as part of the documentation completed include a description of the items completed to achieve a TRL of 6 or higher.
- secondly, the reviewers include as part of their report supporting comments or objections to the level and reasons stated.

TRL Example: For a stand-alone instrument, such as a new inertial sensor for the Internal Seismic Isolation (ISI), to be at TRL 6 it should be operating and have the target noise performance. The ‘relevant environment’ would be a vacuum system. The instrument wouldn’t need to be LIGO UHV compatible but must have a reasonable path to achieving that.

## 5 Connection with R&D Projects

Efforts often (but not always) start in a research phase before being selected for development leading to an improvement 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).

## 6 Expedited and Abbreviated Reviews and Waivers

Systems Engineering can decide to waive the Design Requirements and Conceptual Design Review (DRR/CDR) and/or the Preliminary Design Review (PDR) for DI Projects that are mature and not overly complex. In fact for many small scale DI projects approval of an ECR is often sufficient. More significant projects (in scope, complexity or funding level) will require at least one design review. Only the most complex and large scope DI projects require the full sequence of formal reviews defined in the following sections. System Engineering makes a determination as to the nature and depth of the required reviews. Systems Engineering can also waive some of the content for the reviews if deemed appropriate.

## 7 Design Requirements Phase

### 7.1 Requirements definition

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

- Scope and objectives of improvement 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).

## 7.2 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.

## 7.3 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).

# 8 Preliminary Design Phase

## 8.1 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 DI Project Manager and Systems Engineering.
- As part of the documentation completed include a definition of the Technical Readiness Level (TRL) and the criteria required to establish the criteria to achieve a TRL of 6 or higher.

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

## 8.2 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.

## 9 Final Design Phase

### 9.1 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
- As part of the documentation completed include a description of the items completed to achieve a TRL of 6 or higher.

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

### 9.2 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

### 9.3 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.

## 10 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 Improvements (DI)”, [M1500262](#).

### 10.1 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)

### 10.2 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).

All subsystems must document the plan for capture of redlines noted during assembly and installation into the DCC. This may be simple red-lines and reference to alogs.

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

Refer to checklist in section 11.4 below.

## 11 Appendix A: Review Responsibilities and Process

### 11.1 Systems Group

- Assigns an DI Project Manager
- Determines which reviews are needed based on the maturity and complexity of the DI 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)

## **11.2 DI 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 DI 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

## **11.3 Review Board Chairperson**

- Iterates the review agenda with the DI 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 DI 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 DI 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

## **11.4 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



## 12 Appendix B: Review Checklists<sup>1</sup>

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

<sup>1</sup> Modified from DIII-D Design Review Process, General Atomics, Tooker and Cary

		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"> <li>• Cost risks</li> </ul>
		<ul style="list-style-type: none"> <li>• Schedule risks</li> </ul>
		<ul style="list-style-type: none"> <li>• Technical performance risks</li> </ul>
		Lessons learned documented, circulated
		Problems and concerns

## 12.2 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"> <li>• Subsystem block and functional diagrams</li> </ul>
		<ul style="list-style-type: none"> <li>• Equipment layouts (including cabling, feedthrough, stray light and viewport considerations.)</li> </ul>
		<ul style="list-style-type: none"> <li>• Document tree and preliminary drawings (information issued)</li> </ul>
		<ul style="list-style-type: none"> <li>• Modeling, test, and simulation data</li> </ul>
		<ul style="list-style-type: none"> <li>• Thermal and/or mechanical stress aspects</li> </ul>
		<ul style="list-style-type: none"> <li>• Vacuum aspects</li> </ul>
		<ul style="list-style-type: none"> <li>• Material considerations and selection</li> </ul>
		<ul style="list-style-type: none"> <li>• Environmental controls and thermal design aspects</li> </ul>
		<ul style="list-style-type: none"> <li>• Software and computational design aspects</li> </ul>
		<ul style="list-style-type: none"> <li>• Power distribution and grounding</li> </ul>
		<ul style="list-style-type: none"> <li>• Electromagnetic compatibility considerations</li> </ul>
		<ul style="list-style-type: none"> <li>• Fault Detection, Isolation, &amp; Recovery strategy</li> </ul>
		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"> <li>• Mitigation of personnel and equipment safety hazards; refined Hazard Analysis</li> </ul>
		<ul style="list-style-type: none"> <li>• Reflected in equipment design and procedures for use</li> </ul>
		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"> <li>• In prototyping phase</li> </ul>
		<ul style="list-style-type: none"> <li>• In production/installation/integration phase</li> </ul>
		Identification of testing resources
		<ul style="list-style-type: none"> <li>• The test equipment required for each test adequately identified</li> </ul>
		<ul style="list-style-type: none"> <li>• Organizations/individuals to perform each test identified</li> </ul>
		<ul style="list-style-type: none"> <li>• QA involvement</li> </ul>
		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
		Technical Readiness Level (TRL)

### 12.3 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) including cabling, feedthrough, stray light and viewport considerations.
			Relevant RODA changes and actions completed
			Risk Registry items discussed
		Software	Software detailed design (architecture, protoyping 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
			Technical Readiness Level (TRL)

## 12.4 Installation Readiness Review (IRR) Checklist

Insert this checklist into the IRD, with the document and section columns completed (multiple entries are acceptable). For IRR the checklist can form the template for the main IRD. 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).

*Copied from section 9.2 above. 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. All subsystems must document the plan for capture of redlines noted during assembly and installation into the DCC. This may be simple red-lines and reference to alogs. 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.*

DCC#	Section	Type	Checklist Item
		Changes	Resolutions of open action items from FDR (or after). List / include for reference.
			List completed and associated DCN's since FDR
			List red-lines and relevant alogs: As noted above, include a link to the DCC page where these will be grouped via related links. These should pertain to each type of installation (if appropriate).
		Hardware/ Sub- system Design	Include relevant subsystem block and functional diagrams
			List sub-system assembly drawings
			Demonstration (via inclusion of link) that mechanical drawings are grouped/organized into a document tree

		Interfaces^  <i>Specified as: interface concerns or considerations related to installation and acceptance testing</i>	List relevant systems level (e.g. chamber level, HAM table balancing) and interfaced subsystem documentation (e.g. cabling, feedthrough allocation*).  <i>*also called out in expanded electronics section below.</i>
			Proof that mechanical resonances won't interfere "downward" to ISI controls or "upward:" won't create scattered light resonances or a nasty peak in IFO cavity performance (B&K hammering of one instantiation, eg. waivers if FDR FEA prediction didn't match, or if we're mitigating with vibration absorbers).
			Top-level document branches is hooked up to appropriate systems drawings document tree trunks
		Mechanical / Electrical Interfaces / Definitions wrt other control systems	Sensor actuator naming conventions and their location within other coordinate systems, e.g. <ul style="list-style-type: none"> <li>• <a href="#">"Controls arrangement posters"</a></li> <li>• <a href="#">"Sensor and Actuator Conventions"</a></li> <li>• <a href="#">"Optical Sensors Graphic"</a></li> </ul> Try to avoid the need for 16 different coordinate systems in FDR, but if needed <a href="#">"HAM6 Coordinate Systems Definitions"</a>
		Mass	As per <a href="#">T1100174</a> weigh and record all items that are to be installed on a HAM-ISI or from a BSC-ISI.
		Electronics	Include link to design intent docs discussing frequency response of signal processing electronics
			Include links to discussion of sufficient actuation range / sensor noise of full chains (e.g. "Does your sensors' raw voltage fit in the range of the ADC?" and "are there correctly assigned nBits of ADCs/DACs")
			Include links to wiring diagrams and drawing document tree, including: <ul style="list-style-type: none"> <li>• In-vacuum wiring chain map "cable harness" docs,</li> <li>• Feedthru allocation / assignment "Flange Layout" docs.</li> <li>• Ex-vacuum wiring chain map including rack U height assignments and ADC / DAC card locations with IO chassis ("Wiring Diagram" docs).</li> </ul>



			<ul style="list-style-type: none"> <li>• Wiring diagrams and linked chassis component drawings.</li> <li>• Chassis drawings and linked PCB/circuit board drawings/front&amp;back panels etc.</li> </ul>
			Link to documentation (if relevant) with discussion on electrical grounding / E&M radiation.
		Software <sup>^^</sup> <i>Specified as: "software implementation status and unique software aspects for the intended installation"</i>	Pointers to Simulink / Beckhoff / Acromag libraries and top-level code or diagrams (location in a version control system)
			Pointers to MEDM screens / user interface (aLOGs with screenshots is fine)
			"ISC ADC/DAC Channel list" or equivalent info/look-up table on Wiring Diagrams
			If has fast front-end controls, DCUID/computer assignment
		Controls Design	If a dynamical system, show that dynamics perform as expected
			Proof of principle / installation tests that prove the control system <i>*will*</i> work as designed, or simple (untuned) designs that showed it does work (or "we've built exactly what we've built before" proof is fine too)
			Proof that control design goals can be met with this design (e.g. sufficient reduction of resonance Qs, sufficient suppression of RMS)
		Fabrication	Fabrication and Inspection records
		Safety	Reference Final approach to safety and use issues (from assembly / installation procedures)
			Present Signed Hazard Analysis.
		Assembly / Testing	Summary and or any issues and resolutions from Clean and Bake documented. List relevant Bake Load numbers, ICS and VRB rulings. Also list any relevant issues with supply chain history

			Results and or any issues or defects and resolutions from testing and or first article testing
		Installation plans	Installation schedule (including status of components)
			Installation procedures
			Test schedule (including any existing testing results)
			Comment further on any lessons learned post FDR including any new lessons learned

**KEY**

*^ specified as "interface concerns or considerations related to installation and acceptance testing", such as:*

- prerequisite installations (e.g. the alignment of the OMC requires the SRC to be installed and aligned first)*
- unique aspects of the installation (e.g. due to proximity of SUS A and SUS B, they share a custom dog clamp)*
- functional testing prerequisites (e.g. in situ, in-air transfer function testing requires switching off the purge air flow)*

*^^ specified as "software implementation status and unique software aspects for the intended installation":*

- implementation status of software necessary for in situ functional testing*
- unique software aspects for the installed plan (e.g. control system 'model(s)', GUI screens, channel names, etc.)*

Appendix A: **Technical Readiness Level (TRL)** number, definition & description

Level	Definition	TRL Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical & experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include the integration of "ad hoc" hardware in the laboratory
5	Component and/or breadboard validation in relevant environment	The Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Generally all scientific risk is considered retired beyond TRL 5
6	System/subsystem model or prototype demonstration in a relevant environment.	A representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness.
7	System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluations of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system has proven through successful mission operations.	The actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

