Long Term Storage Plan
for the Components of the Third Advanced LIGO Interferometer

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Contents

1 Purpose

The purpose of this document is to define the requirements and top-level plans for Long Term Storage (LTS) of the Advanced LIGO (aLIGO) Third Interferometer (3rd IFO)[1] components[2]. Detailed storage plans are defined in documentation referenced in the following sections.

It should be noted that all components of the 3rd IFO are to be stored in LIGO facilities at the LIGO Hanford Observatory (LHO), under LIGO oversight/security and within clean and environmentally controlled spaces. There are very few items which require special consideration for long term storage. In addition all of these 3rd IFO components will be tracked and controlled using the same procedures and inventory control system used for the components of the other two aLIGO interferometers.

2 Scope

The scope of this plan is strictly the LTS of the 3rd IFO components. Shipping, installation, integration and commissioning plans for this 3rd IFO are beyond the scope of the Advanced LIGO (aLIGO) project as well as this document.

3 Project Acceptance of Third Interferometer Components

Acceptance of the subsystems of the 3rd IFO and of the complete 3rd IFO will follow the guidance in “Acceptance Deliverables and Criteria for Advanced LIGO”, LIGO-M1100282, and “Subsystem-Level and System-Level Testing Requirements”, LIGO-M1000211, stopping short of installation and post-installation test. To summarize,

- The components will be fabricated, cleaned, and inventoried.
- The subsystem will complete assembly and testing to the point which best serves the needs to demonstrate that the assembly is functional, but allows storage with minimal disassembly.
- Testing is performed on the assembly and the data are archived.

[1] The third interferometer was to be the H2 interferometer at the LIGO Hanford Observatory (LHO). However the project scope was changed; The NSF has directed that this “third interferometer” be placed into Long Term Storage (LTS). It will likely be rebuilt into a third version of the “straight” interferometers (H1 and L1) and installed at a third observatory.

[2] In this plan the word component will be used generally to mean the elements of the 3rd IFO that are placed into LTS. In some cases the word component means a low level electronics component; The meaning will be clear by the context. Elements that are placed into LTS may be parts, modules, sub-assemblies or assemblies. The subsystem plans define the specifics.

- The components are placed into storage that will maintain the value of the components for a minimum period of 5 years.
- Documentation is archived, including requirements, design, fabrication and materials specifications, cleaning, assembly, test procedures, installation procedures, and unique-part data.

The subsystems will be accepted as they are ready in a 'rolling' fashion, with an acceptance review to officially note completion of the acceptance procedures and package. Once a subsystem or subsystem element is accepted, its stewardship passes from the MREFC Advanced LIGO Project to the R&RA LIGO Laboratory Operations, with ownership assigned to the US Government, as indicated in the Cooperative Agreement LIGO-M080335-00-M. Once all H2 subsystem elements are complete and accepted, the Project will consider the H2 interferometer complete and will formally accept the 3rd interferometer.

4 General Storage Requirements

There are several types of packed interferometer components that require long-term storage: "dirty" parts or packaging, "semi-clean" parts and packaging stored in clean spaces, and "clean" Class A and Class B[3] parts that have been cleaned, baked, and specially packaged.

"Dirty" items are typically those that reside outside of clean spaces in the interferometer and laboratory buildings. In a few cases, 'in-air' or Class A and B parts may be classed as "dirty" if they are stored before undergoing final cleaning procedures after fabrication. All items stored in their wooden or cardboard shipping containers must be place in "dirty" storage regardless of the cleanliness of the parts because the containers are unacceptable in a standard LIGO cleanroom setting.

"Semi-clean" parts include those destined to function "in-air" inside the clean area that houses the interferometers, but outside the vacuum system. They may also include Class A or Class B parts that are stored without having gone through final clean and bake procedures. While these items must be relatively clean in order to be stored in clean spaces, they do not require special wrappings to maintain stringent cleanliness specifications. If the "semi-clean", in-air parts are temperature or humidity sensitive, they will require climate and humidity controls. The majority of items intended for permanent in-vacuum service (Class A) or tooling that touches in-vacuum parts (Class B) are cleaned, baked, and packaged according to specific and stringent protocols.

[3] Class A parts are those that reside in the Ultra-High Vacuum (UHV) system. Class B parts are those that contact Class A parts. These definitions, and associated cleanliness protocols are defined in The "LIGO Contamination Control Plan", LIGO-E0900047 and "LIGO Clean and Bake Methods and Procedures", LIGO-E960022.

"Clean" Class A and Class B parts must be stored in clean, climate controlled space, with some of them under dry nitrogen (N2) purge to avoid humidity impacts. As mentioned previously, Class A and Class B parts that have not been clean-and-baked may be stored following the appropriate guidelines for "dirty" or "semi-clean" parts.

The following subsections define general storage requirements that are common to all subsystems and parts.

4.1 Building/Room Requirements

4.1.1 Dedicated Storage Space

All 3rd IFO parts/components/assemblies shall be located together in as few storage locations (spaces) as possible. These storage spaces shall be dedicated to the 3rd IFO parts storage and shall not be used for other storage purposes. The 3rd IFO parts shall not be commingled[4] with other parts.

LIGO management determined that 3rd IFO components shall be stored at the LIGO Hanford Observatory (LHO) until they are ready to be shipped to a third site for installation. This decision was based on efficiency, security, and logistics. At LHO, there are adequate "dirty" and "clean" spaces available for storage of all parts. LHO has highly trained staff to maintain Class A/B parts in a clean condition and to make modifications as needs arise.

Parts must be easily accessible to trained personnel for maintenance, such as periodic dry nitrogen refills, or intervention such as part modification. Every effort should be made to minimize the risks associated with untrained personnel coming into contact with parts, and with the transportation of parts off-site. There must be enough space to accommodate the parts and their storage containers.

4.1.2 HVAC

The storage spaces must have both temperature and humidity control given the impact of these factors on the continued cleanliness and viability of parts. The LTS spaces must meet

[4] Commingling is the process by which materials common to multiple projects or contracts are stored in a single location where, upon being mixed with other materials, they lose their identity or association with a specific interferometer. For example, while stored in sealed bags that are clearly identified as to a given interferometer, stock materials such as nuts, bolts, and screws are considered to be co-located rather than commingled. When the bags are opened and the contents poured into a bin with other stock materials, the items have been commingled, such that the association with a given interferometer of each nut, bolt or screw cannot be identified.

typical temperature and humidity control limits for laboratories and offices, specifically 72F +/- 3.5F and 20% to 70% relative humidity.

4.1.3 Cleanliness

Long term storage areas for all parts (Class A, Class B and out-of-vacuum parts) must be constructed with materials compatible with ISO Class 7.7 level (Fed Std 209e Class 50,000) or better, maintained at ISO Class 7.0 (Fed Std 209e Class 10,000) or better, and supplied with HEPA filtered air. Packaging and storage containers provide the final level of protection for the Ultra-High Vacuum (UHV) parts.

4.1.4 Fire Detection and Alarms

The existing LIGO buildings' fire detection and alarming systems meet local fire codes and are sufficient for long-term storage; no special considerations are required.

4.1.5 Security

LHO facility security measures are sufficient for protecting the third interferometer components in long term storage; no special considerations are required.

4.1.6 Earthquake Considerations

All shelving and cabinets will be bolted to the floor and walls to prevent toppling in the event of an earthquake. Items placed on pallet racks or shelving will be attached to the shelving individually, or will be stored in attached containers or pallets.

4.1.7 LTS Locations

All the spaces described below comply with the environmental, cleanliness, fire safety, and security requirements identified in the previous section for LTS (for details[5] see LIGO-C961574).

4.1.7.1 Vacuum Preparation Warehouse

Storage space for "in-air" parts and "clean" Class A and Class B parts is provided in the Clean Storage area of the Vacuum Preparation Warehouse (VPW). The VPW contains pallet racks and desiccant cabinets dedicated to 3rd IFO parts and/or operations spares. Ample floor space

[5] Mel Weingart, Richard Savage, LIGO Civil Construction Facilities: Design Configuration Control Document (DCCD), Final Issue, LIGO-C961574-x0, July 1996.

exists to provide lay down areas for large install tooling such as the E-module and Mechanical Test stands that are not housed in the LVEA. See Figure 1 for details.

4.1.7.2 H2 Electronics Building

Electronics and cables can be stored in the H2 Electronics Building. Populated 3rd IFO electronics racks will be wrapped in anti-static plastic, supplied with desiccant, and clustered in the center of the H2 Electronics Room, which will have controlled access. See Figure 2 for details.

4.1.7.3 Optics Laboratories

Optics Labs in the Laboratory Science Building (LSB) and the Operations Support Building (OSB) will provide clean and secure storage space for core optics in travel cases placed in dedicated, lockable shelving. This space will also house suspension prisms, ears, etc. in locked cabinets, and will have desiccant cabinets for humidity-sensitive optics components like wires and small optics.

4.1.7.4 Laser Vacuum Equipment Area (LVEA)

Clean space will be needed for Class A and Class B assemblies/parts. The Laser-Vacuum Equipment Area (LVEA) is the largest of the available clean storage spaces. Much of the floor space and the lowest 15 feet of wall space on the H2 side of the LVEA will be designated for storage. The majority of floor space will be required for large Class A assemblies like Internal Seismic Isolation units (ISI) and the larger optic suspensions (SUS). These and other humidity-sensitive items will be stored in custom metal storage containers equipped for humidity monitoring and dry nitrogen purging. In addition, two large containers, originally intended for shipping seismic isolator units from one site to another, will be used as long term storage for in-air components that do not require sealed containers with dry nitrogen flow-through.

Non-humidity sensitive Class A assemblies or unassembled parts will be palletized and placed on pallet racks (~15 ft high) or in lay-down areas on the floor. See Figure 3 for additional detail. In-air large install tooling such as Mechanical Test Stands, E-Module, and Spiral Staircase will also be stored in the LVEA.

4.1.7.5 Mid-Station Spaces

“Dirty” space will be needed for those parts/assemblies which are in wooden crates and unlikely to be unpacked prior to final shipment. For example, the 3rd IFO Pre-Stabilized Laser (PSL) parts are still in the crates used for their shipment from Germany to LHO, and Optical Lever (OpLev) piers are still in their original shipping containers. These items are inspected then re-packed and stored in mid-station Vacuum Equipment Areas (VEAs) since a high level of cleanliness is no longer required in those spaces for interferometer operations. Other “dirty” storage spaces include the mid-station receiving/cleaning bays, labs, and mechanical rooms. See Figure 4 for additional detail.

4.1.8 LTS Layout Plans

See the following pages for layouts of storage spaces, with locations for the major containers and shelving.

Figure 1: LTS Layout in the LHO Vacuum Preparation Warehouse (VPW)

The building is divided into three spaces: the "dirty" side ("Warehouse Area"), Clean and Bake Operations, and Clean Storage Area. The clean storage space will house four desiccant cabinets along one wall. Two of these cabinets are used for Input Optics (IO), Pre-Stabilized Laser (PSL), and Thermal Compensation System (TCS) optical components, and ISC. The remaining two cabinets are used for 3IFO sensitive hardware for subsystems such as operations spares. In addition, several pallet racks will be used FOR Class A/Class B parts which may not fit into the available LVEA storage space. Floor space in the clean storage area is also available for large items such as the Mechanical Test Stand (D080464) andE-Module parts (D1002926). Note that these two large items will not be erected in the VPW, but rather stored as disassembled parts. The LTS layout for the VPW can be found in drawing D1300035.

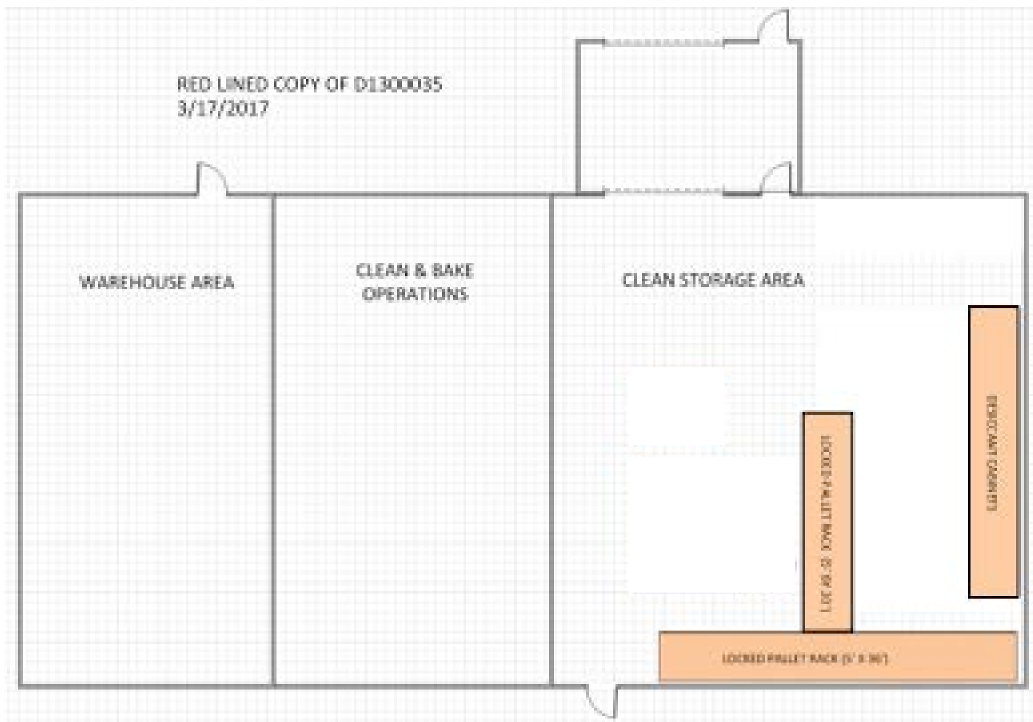

Figure 2: LTS Layout in the H2 Electronics Building

Populated 3rd IFO electronics racks will have desiccant units and moisture indicator cards (MIC) inserted and then wrapped in plastic as a moisture and pest barrier. Racks are shown in blue. The LTS layout for the H2 Electronics Building can be found in drawing E1300047.

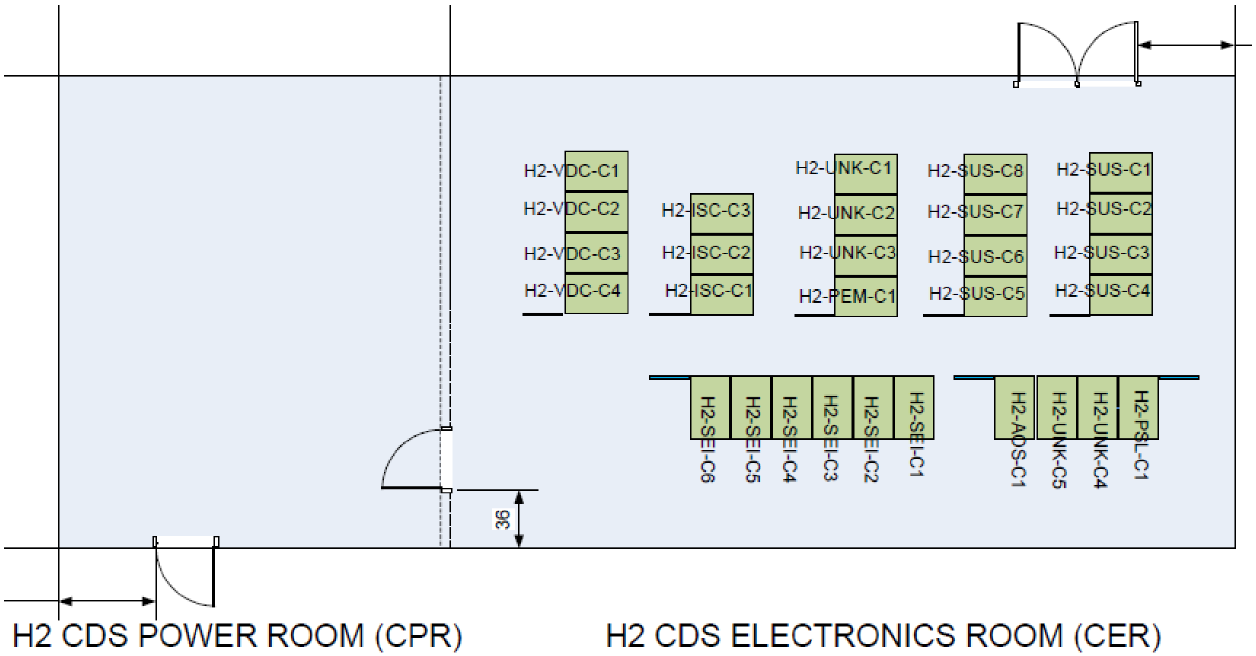

Figure 3: LTS Layout in the LHO Laser Vacuum Equipment Area (LVEA)

All 3rd IFO LTS is in the area of the LVEA, which was originally reserved for the H2 IFO. Pallet Racks are located along the walls. Laydown space for the HAM-ISI and BSC-ISI storage containers is available adjacent to the input and output tubes. The clean storage space will house three re-purposed HAM-ISI storage/shipping containers for storing humidity sensitive components from subsystems other than SEI. (See D1300032, LTS LVEA Layout)

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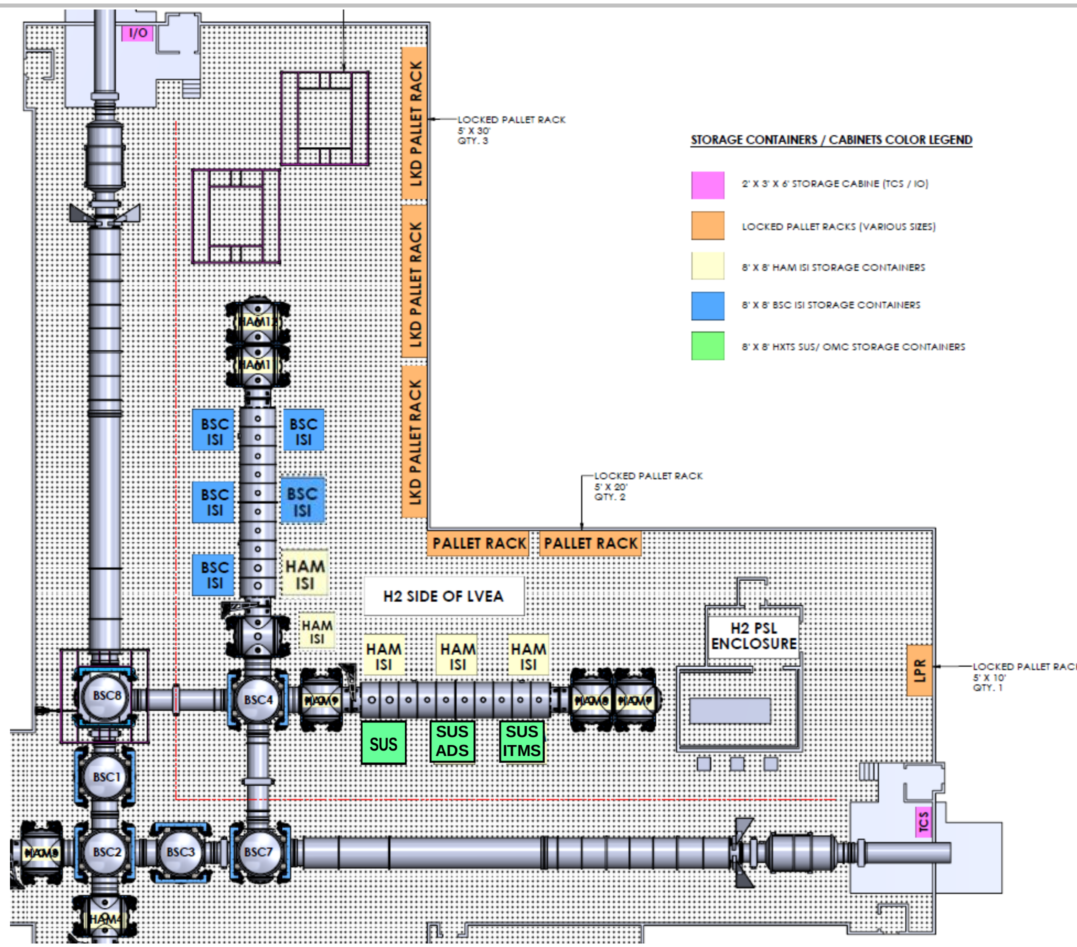
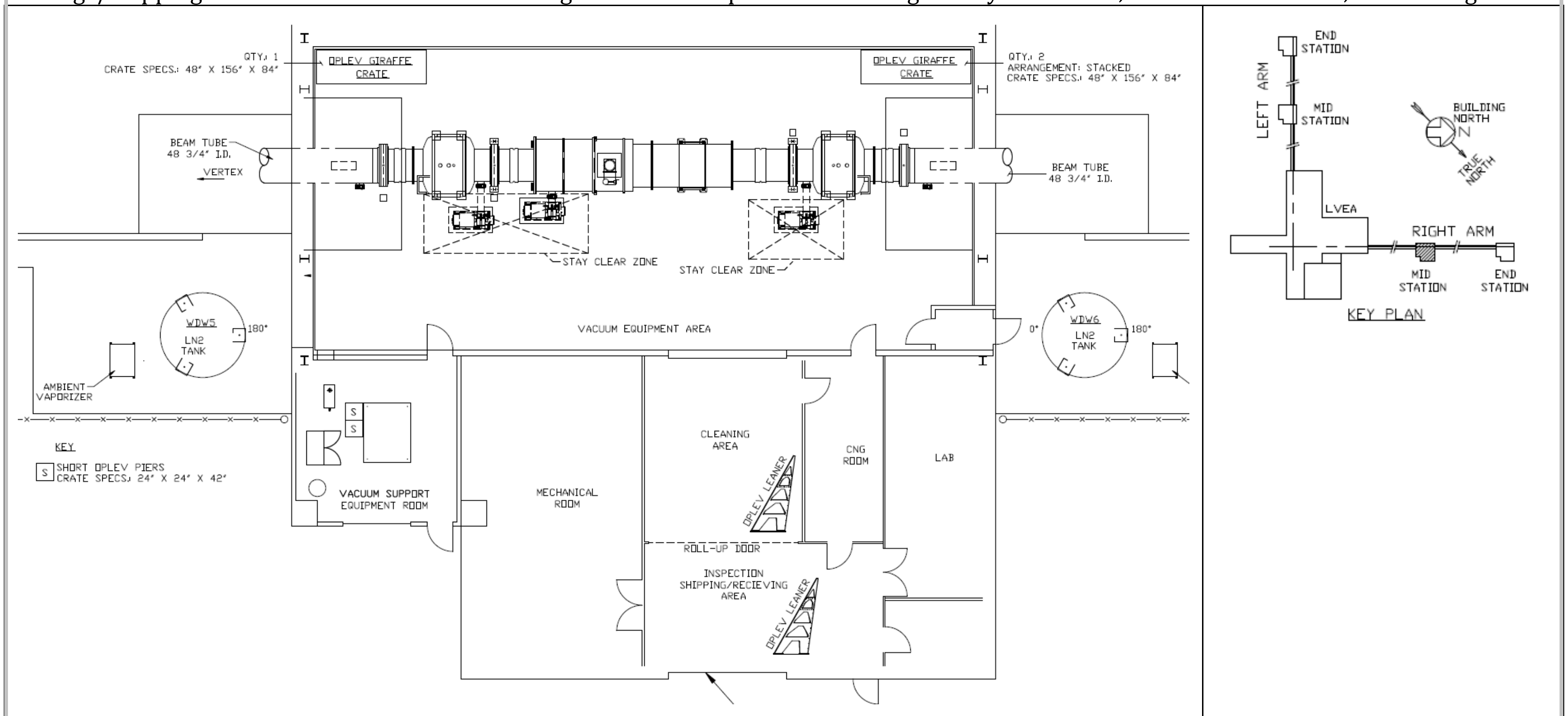


Figure 4: LTS Layout in the Mid Station Building

“Dirty” space layout for wooden crates and pallets in the VEA space of the mid-stations. See D1300003, ALIGO, Washington right mid station long term storage (LTS) layout and D1300004, ALIGO, Washington left mid station long term storage (LTS) layout. Three of the HAM-ISI storage/shipping containers will be used for storing SEI in-air components including twenty HEPI units, electronics modules, and cabling.



4.2 Environmentally Controlled Containers and Cabinets

UHV components that require humidity controls will be placed in appropriate containers with dry nitrogen. Humidity sensitive in-air components will be stored with either dry nitrogen or desiccants. Dry nitrogen containers will have gauges and alarms that indicate loss of gas pressure or changes in humidity. Signals from the monitoring systems and alarms will be transmitted to the control room and will be under constant observation.

4.3 Inventory and Access Control

4.3.1 Bill Of Materials (BOM)

A Bill of Materials (BOM) list (E1300044) for the 3rd IFO shall be defined and maintained in the LIGO Document Control Center (DCC). This BOM shall be defined at the level of assembly that components are placed into LTS. (Note that currently E1300044 is a draft document that will ultimately include all of the individual BOMs defined at each major assembly/sub-assembly level in a single cohesive document with standardized organization and presentation.) In addition, this collective BOM shall indicate those 3rd interferometer and facility parts that are placed into LTS and those that are not (i.e., are not intended to be provided by LIGO Lab for an implementation of the 3rd interferometer).

4.3.2 Access Control

Physical access control is required for the 3rd IFO components. Storage will consist of locked or otherwise physically controlled containers, cabinets, shelves, or rooms designated as dedicated storage space. Only authorized personnel shall be permitted into the LTS areas. Management will maintain a list of authorized personnel. In addition, a Working Group will agree on rules to govern interactions involving 3rd IFO parts/assemblies. Rules include the following:

- All access to 3rd interferometer parts requires pre-approval from Management;
- All containers, crates, boxes, etc. will be sealed with tamper evident indicators;
- All parts will be placed in controlled, limited-access storage, including SEI containers, caged or sealed-off areas, locked cabinets/shelving, and locked rooms/buildings; and
- All parts will have a check-out/check-in procedure.

One staff member will be responsible for controlling access to the LTS areas and for ensuring that routine inspections occur.

LIGO management will periodically undertake a review to ensure that all required routine inspections are being performed and that the integrity of the LTS area has not been compromised.

4.3.3 Inventory Control

All existing components of the third interferometer (3rd IFO) shall be identified in the LIGO Inventory Control System (ICS)[6] as belonging to the 3rd IFO (aka H2) and located in LTS. Parts and assemblies will be placed into storage loads. ICS can accommodate site, location, and sub-location information[7] for individual parts and assemblies.

The ICS manages cradle-to-grave logistics associated with 3rd IFO parts including receiving for storage, storage location data, check-out/check-in, preparation for shipment, tracking through shipment, and eventual delivery. A single administrator will oversee preparation of storage facilities, receive parts for storage, assign storage locations, coordinate access to stored parts (including for maintenance and modification), and maintain records. Tamper evident seals will be used on any containers or cabinets that contain multiple items to aid in inventory control. A special Bill of Materials for storage kitting will be created that is specific to the assembly level at which all 3rd IFO parts are placed into the LTS.

4.3.4 Check-in and Out procedure

Parts and assemblies may be checked out for various allowed and pre-approved activities – generally for converting from H2 to H1 design, up-dating to the latest design modifications, or use in training exercises. Only authorized personnel will be allowed to check out equipment for these pre-approved activities. A standard ICS procedure will be followed for checking equipment in and out of storage, with a single individual responsible for signing for approval or denial on submitted request forms. The individual responsible for check-out and check-in will maintain records of the location of the parts and note when parts are returned to storage.

4.3.5 Restricted Use of Stored Components

The dedicated H2 interferometer equipment will not be used as spares or replacements for the other interferometers nor used for R&D unless required by extraordinary circumstances. Any requests to use these 3rd IFO components for other than the pre-approved activities (e.g.,

[6] Dwayne Giardina et. al., Advanced LIGO Inventory Control System User's Manual, LIGO- T1000279

[7] Currently ICS has only two sites, LHO and LLO. We can key in 3rd interferometer parts and assemblies as being at LHO (site), destined for the 3rd interferometer (3IFO, location) and stored in a particular building (sub-location). An ICS upgrade request has been made to add 3IFO as an additional (intended) site. Once this upgrade has been implemented, more precise location information can be tracked: building/area (location) and pallet rack/storage container (sub-location).

deployment into either of the other aLIGO interferometers in an emergency) must be approved. They will go through a management review and decision process employing a Technical Review Board (TRB). If any 3rd IFO components are taken out of the LTS system, then they must be replaced as soon as possible and the diversion of these parts must be tracked in the ICS.

4.4 Change Control & Defect Tracking

The Advanced LIGO Project scope for the H2 interferometer included updating it with changes perceived to be necessary for proper functioning (identified during e.g., integrated test of H1 and L1), up to the point in time when the three Advanced LIGO interferometers are accepted. Any modifications that are identified after the three interferometers have been accepted will be addressed by Operations. In addition, Operations will be responsible for modifying any components to “straighten” the folded H2 design to match the H1 design

The capability of the Inventory Control System (ICS) to check parts into, and out of, the storage “load” for the purpose of rework or modification will be used.

4.5 Routine Monitoring and Inspections

4.5.1 Building and Space Inspections

A weekly walk-through of the LTS areas shall be made by LIGO personnel trained to look for access violations, pest or insect intrusion, water/moisture problems, etc. In addition, inspections will be conducted whenever significant environmental events (storms, earthquakes, etc.) or facility failures (e.g., HVAC failure, piping leaks, etc.) occur. Inspection logs will be maintained for the inspections.

The spaces used for 3rd IFO storage are already subjected to periodic inspections conducted across the entire Hanford LIGO site for fire safety by the Hanford Fire Marshall and for pest control by a commercial vendor. These inspections will continue during the storage period.

4.5.2 Inspections of Stored Equipment

The stored equipment shall be inspected once a month for signs of unauthorized access to containers, damage to stored materials or containers, or other problems that indicate that the integrity of the stored equipment has been compromised. Inspection logs will be reviewed and signed by the individual designated as responsible for the stored 3rd IFO components. An exception to this once a month inspection is made for explicitly designated humidity sensitive components.

4.5.3 Monitoring of Environmentally Controlled Containers

All sealed storage containers and any cabinets that include either dry nitrogen or desiccant controls will be inspected on a weekly basis for mechanical damage, exposure of the contents to ambient air, saturation of desiccants, or other problems. Designated and trained personnel will perform the inspections and will sign off on an inspection log established for each storage area. Desiccant packets will be exchanged on a replacement schedule based upon the manufacturer's instructions.

4.5.4 Property Inspections/ Inventory Control

The stored 3rd IFO components will undergo a yearly property inspection both to satisfy terms in the LIGO cooperative agreements with NSF and to ensure that the 3rd IFO inventory is intact. The stored components will be inventoried and checked against the master BOM list. Boxes/crates/containers will not be opened if the seals are intact as this will verify that the contents are intact.

5 Transition from Project to Operations

Responsibility for the stored equipment will be transferred from Advanced LIGO project management to the Hanford Observatory Site Head (LIGO Operations) at the time of acceptance for each functional subsystem in the project. In most cases, the trained personnel who are operating, monitoring, and maintaining the equipment during the project will transition to similar positions within operations groups. Their job responsibilities with respect to the stored hardware will continue, but the source of funding for their activities will switch from project MREFC to operations M&O funding sources.

6 General Storage Requirements for Material Types

6.1 Specific Requirements for In-Vacuum Components

All components which are intended for use within the LIGO Ultra-High Vacuum (UHV) system must meet the packaging requirements defined in LIGO-E960022, LIGO Clean and Bake Methods and Procedures.

6.2 Optics and Electro-optics

Two significant factors in protecting optics are preventing deposition of dust, and controlling humidity. Damage to optical surfaces often involves the deposition of dust. Ambient humidity contributes a moisture content to the dust, which then provides a medium for reactions with surface chemicals -- bases (typical southwestern alkali dust), or acids (fumes from internal combustion engines)[8]. This establishes the storage requirements for optics and electro-optics.

All optics and optical coatings shall be kept in clean (class 100 or better) conditions and in humidity and temperature controlled environments typical of laboratories and offices. However, silver (protected and/or enhanced) metal coatings must be stored in very low humidity conditions (i.e., vacuum or purged dry nitrogen) – see section 6.2.4.

All optics shall have packaging that serves as "dust covers" and protection from scratches or marring due to handling. The optics for the Core Optics Components (COC) subsystem and for the Input Optics (IO) subsystem have dedicated, clean shipping and storage containers. The preferred packaging, for smaller optics is PET-G containers.

6.2.1 Crystals

The aLIGO system employs a number of optical crystals:

- RTP (rubidium titanyl phosphate, RbTiOPO4) crystals for Electro-Optic (Phase) Modulators (EOM)
- TGG (terbium gallium garnet) crystals for input and output Faraday Isolators (FI)
- DKDP (deuterated potassium dihydrogen phosphate) used to provide thermal compensation for the TGG crystals in the input Faraday Isolator (FI)
- lasing crystals
- pump laser diode crystals

[8] S.T. Ridgway, "Optical Coatings for CHARA Reflective Optics", CHARA Technical Report No. 91, 1 October 2004

Many of these crystals are used in high irradiance applications where particulate contamination can be a problem. A particle can act as a point absorber and cause heat damage to the crystal or its coating. Of course these crystals are generally embedded into an assembly which provides some protection from particulates. Those crystals which are in-process spares (and thus not incorporated into an assembly) can be cleaned prior to use. Nonetheless, it is good practice not to contaminate these components or their assemblies/housing. As a consequence, all of these crystals, like all of the optics which are to be used with high power, must be kept in cleanroom (ISO Class 5 or better) environments and packaged appropriately for a cleanroom (i.e., with non-shedding, non-outgassing packaging).

Most of these crystals are not sensitive to moisture. However DKDP has high hygroscopic susceptibility. As a consequence the FI assembly must be kept in a low humidity environment.

6.2.2 Fused Silica and Glass optics with Dielectric or ZnSe Coatings

All Core Optics Component (COC) subsystem optics and most Pre-Stabilized Laser (PSL) and Input Optics (IO) optics have dielectric coatings on fused silica or other glass substrates. Experience has shown us that dedicated containers stored in designated LIGO laboratory spaces are sufficient for long term storage.

The periscope mirrors used for Thermal Compensation System (TCS) have a proprietary, dielectric, Zn Se coating over a fused silica substrate. The manufacturer advises us to store the optics in a sealed moisture barrier package that is purged with an inert gas.

6.2.3 Gold coatings on copper alloy substrates

The Thermal Compensation System (TCS) uses gold coatings, with an yttrium overcoat, on copper 110 alloy substrates, both large and small. Initial and enhanced LIGO experience has indicated that these coatings do not degrade in typical LIGO lab environments. Similarly, no additional storage considerations are required for these optics.

6.2.4 Silver and Protected Silver Optical Coatings

The optics in the Transmission Monitor System (TMS) suspended telescope have an enhanced, protected silver coating. Sulfur is generally considered the most serious enemy of silver coatings, even protected silver coatings because the sulfur can penetrate through pinholes in the protective coating[9]. In major metropolitan areas, it can be expected that sulfur will be present in the atmosphere due to fossil fuel combustion . However the Hanford site has been

[9] S.T. Ridgway, "Optical Coatings for CHARA Reflective Optics", CHARA Technical Report No. 91, 1 October 2004.

demonstrated to have very low levels of atmospheric sulfur[10,11]. Oxygen and moisture also attack/oxidize silver coatings. Consequently these coatings will be stored in vacuum or in very-low humidity containers with a dry nitrogen purge[12].

6.3 Electronics

Stored LIGO electronics can be in four basic forms or levels of integration: components (e.g., photodiodes, pump laser diodes, etc.), circuit boards, modules, and racks. All devices or components are commercially manufactured items with storage specifications; custom equipment is based on standard circuit board fabrication that undergoes cleaning and prep suitable for long-term service, and is thus prepared for long-term storage.

In addition to circuit boards, modules, and racks, the Electronics category also includes batteries, UPS units, power supplies and cabling. Below is a synopsis of concerns. For more detail see T1300002.

6.3.1 Aging

No failure mechanisms associated with LTS have been identified[13] that would compromise the electrical functionality or performance or circuit reliability, at the device level.

6.3.2 ESD

Electro-Static Discharge (ESD) can be a threat/hazard for electronics. In particular, packaging or storage containers must not present an ESD hazard to the electronics. Studies[14] have shown that static dissipative properties of tubes or tape and reel do not degrade over a period of up to at least 32 months. Inspections will be used to determine if ESD (and other) packaging must be replaced periodically for the duration of the storage, if warranted.

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10 During the last 10 years, carbon monoxide, sulfur dioxide, and nitrogen dioxide have been monitored periodically in communities and commercial areas south-southeast of Hanford. These urban measurements are typically used to estimate the maximum background pollutant concentrations for the Hanford Site because of the lack of specific onsite monitoring.
J. P. Duncan (ed.), "Hanford Site National Environmental Policy Act (NEPA) Characterization", Pacific Northwest National Laboratory, PNNL-6415, Rev 18, 9/2007.

11 Sulfur dioxide (SO2) measurements in Richland in 2007 were 5 ppb which is on the low end of the typical range (1 to 20 ppb) for rural–suburban environments.
Mioduszewski, John et. al., "In-situ monitoring of trace gases in a non–urban environment", Atmospheric Pollution Research 2 (2011) 89-98

12 LIGO experience and informal advice from coating vendors.

13 R. R. Madsen, “Component Reliability After Long Term Storage”, Texas Instruments Application Report, May 2008

14 R. R. Madsen, “Component Reliability After Long Term Storage”, Texas Instruments Application Report, May 2008

Some assemblies will be stored in very low humidity environments to prevent corrosion or mechanical damage. Static charging/discharging can occur in such low moisture environments during handling. If electronics are stored with these assemblies, then each of the electrical inputs and outputs must be grounded (e.g., with the use of a grounding connector). Some examples are the Optical Sensors and Electro-Magnetic actuators (OSEMs), stored as parts of the suspension assemblies, and the Sensor "pods", stored as parts of the Internal Seismic Isolation (ISI) assemblies.

6.3.3 Humidity

Humidity control is important for the long-term viability and reliability of electronics. Tests of Moisture Barrier Bags (MBB) designed for electronics components have demonstrated that storage for up to 5 years is viable[15]. Inspections will be used to determine if Moisture Barrier Bags (MBB) and any other packaging must be replaced for the duration of the storage.

6.3.4 Connector Resistance/Corrosion

There is no evidence (of which we are aware) that storage in standard lab or office-like controlled conditions degrade electrical connectors, whether biased or not.

6.4 Mechanics & Materials

The common materials used in aLIGO components are addressed in the following subsections. See LIGO-E960050 for a list of in-vacuum materials[16].

6.4.1 Atmospheric Corrosion

The LTS environment will preclude immersion or wetting of the parts and assemblies. However corrosion could still occur due to moisture and contaminants in the atmosphere. The term "atmospheric corrosion" refers to corrosion of metal exposed to the air as opposed to metal immersed in a liquid. Air pollutants such as sulfur dioxide, hydrogen sulfide, oxides of nitrogen, and chlorides have been found to contribute to atmospheric corrosion.

The corrosion of metals in the open air depends on the "time of wetness" (the time of wetness refers to the period during which a metal's surface is sufficiently wet for corrosion to occur[17])

[15] Ibid.
[16] D. Coyne, LIGO Vacuum Compatible Materials List, LIGO-E960050.

and the composition of the surface electrolytes. Surface wetness is usually the result of vapor condensation. The onset of vapor condensation depends on the moisture content of the air (relative humidity) and the temperature of the surface. The time of wetness is normally considered to be the time interval when relative humidity (RH) exceeds 80% and, at the same time, the temperature is above 0°C , i.e., when condensation forms[18].

Several metals used in aLIGO are susceptible to corrosion and therefore require storage in low humidity environments. These include aluminum alloys and maraging steel. Other materials are of less concern but may show signs of corrosion if exposed to a humid environment for durations exceeding one month. Corrosion may damage critical surfaces and degrade function or performance. Corrosion may also create particulate contamination due to potentially frangible oxide layers.

Regardless of whether a material is susceptible to corrosion, as a general good practice, and to maintain cleanliness and the integrity of the packaging materials, all of these parts shall be stored in conditioned spaces (office or lab environments). However, in some cases (see subsections below) desiccant or dry-air/N2 purging is also required.

When desiccant is to be used in the storage container, molecular sieves will be used because of their high adsorption capacity at low relative humidity. The storage container environment will be kept to < 10% RH using molecular sieve technology. Desiccant units shall meet or exceed MIL-D-3464E, Type II (non-dusting)[19] and the desiccant material shall be zeolite (a microporous, aluminosilicate mineral).

For the extremely critical applications cited in the subsections below, dry nitrogen purging is required. Experience with dry nitrogen purging of the HAM ISI containers has demonstrated[20] < 4% RH.

Another required practice is for all parts or assemblies to be wrapped at laboratory/storage ambient temperature and not warmer. Warm parts heat the surrounding air trapped within the packaging, which then increases the moisture content in this trapped air. Once the parts cool to the room temperature the moisture may condense out onto the parts.

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[17] N. Xu, et al., "Laboratory observation of dew formation at an early stage of atmospheric corrosion of metals", Corrosion Science 44 (2002), 163-170.

[18] Aluminum Design, Aluminium's corrosion resistance: http://www.aluminiumdesign.net/design-support/aluminiums-corrosion-resistance/

[19] Military Specification: "Desiccants, Activated, Bagged, Packaging Use and Static Dehumidification", MIL-D-3464E

[20] G. Grabeel, "LHO HAM Shipping & Storage Container Nitrogen Purge Humidity Data", T1000714 and LHO electronic log entry: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=3146

6.4.1.1 Carbon Steel

The only carbon steel materials used in the LIGO UHV system are high-strength, high carbon, "music" wires per ASTM A 228/A 228M, used in most of the suspension stages. In order to maintain low mechanical loss these wires are not coated with a corrosion protection layer.

We have had long-term experience in eliminating surface corrosion with the use of an anti-corrosion paper wrap, use of a desiccant bag, purging the plastic shipping bag with inert gas and double bagging[21]. Use of a non-shedding, desiccant bag in a sealed storage container is adequate to prevent corrosion (see requirements on desiccants in section 6.4.1).

6.4.1.2 Aluminum Alloys

Most of the aLIGO in-vacuum parts are comprised of aluminum alloys (primarily 2024 and 6061). Some are in the form of weldments. All are in stiffness critical, not strength critical, applications. In normal rural atmospheres, and in moderately sulfurous atmospheres, aluminum's durability is excellent. In highly sulfurous atmospheres, minor pitting may occur. However, generally speaking, the durability of aluminum is superior to that of carbon steel or galvanized steel. The presence of salts (particularly chlorides) in the air reduces aluminum's durability, but less than is the case for most other construction materials[18].

All aluminum alloys exposed to the atmosphere develop a tightly bound oxide layer. If water condenses onto the surface, then over a relatively short time a thick oxide scale can form[22]. This scale can be frangible and become the source for particulate generation, which can be problematic for LIGO. In order to avoid surface oxide scale from forming, all aluminum parts must be stored in non-condensing environments. In particular care must be taken not to wrap the parts when warm.

6.4.1.3 Stainless Steel

The most commonly used stainless steels for LIGO are 304 and 304L which are members of the 300 series of stainless steel alloys. Alloy 304 is a general purpose austenitic grade for enhanced corrosion resistance, whereas 304L is a low-carbon modification of type 304 for welding applications. The 300 series is very corrosion resistant to distilled water, tap water, and river water[23]. Most of the fasteners are comprised of type 316 stainless steel (or a similar

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[21] J. Lewis, "Advanced LIGO Music Wire Specification", LIGO- E1100187.
[22] During Hurricane Isaac power was lost exposing the ISI assembly at Livingston to humidity. Parts made of 2024 aluminum showed signs of corrosion after 2 to 3 days.
[23] INCO the International Nickel Corporation, "Corrosion Resistance of the Austenitic Chromium-Nickle Stainless Steels in Chemical Environments", CR 1963.

alloy) due to the ease of fabrication/machining. The molybdenum in grade 316 results in generally better corrosion resistant than grade 304.

Due to the enhanced corrosion resistance of the 300 series, no special considerations are required to prevent corrosion from water moisture, when the parts are not under significant load (stress). However, for long term storage of 300 series stainless steel that is under load (stress), see the discussion below regarding stress-corrosion cracking.

Type 440C stainless steel, a very hard high strength alloy, is used in the locker assembly of the Internal Seismic Isolation (ISS) assemblies. This material is moderately corrosion resistant and will show signs of corrosion after several weeks in a humid environment. It must be kept in a low humidity environment at all times, putting a requirement on the LTS approach for this material.

6.4.1.4 Maraging Steel

Maraging steel is a high strength stainless steel alloy. Maraging 300 alloy is used for the springs on both the HAM and BSC ISI assemblies. Maraging Steel 250 is used for the blade springs of all of the suspension assemblies. Although these alloys have high chromium content, they are susceptible to corrosion in moist environments. The maraging steel springs used by the SEI and SUS subsystems are plated with electroless nickel which makes them moderately corrosion resistant. However it is likely that signs of corrosion would be evident after several weeks in a humid environment[24].

Long term storage of maraging steel that is not under load shall be kept in a low humidity environment at all times. However for long term storage of maraging steel that is under load see the discussion below regarding stress-corrosion cracking of maraging steel materials.

6.4.1.5 Copper

OFHC copper is used in thermal bars to remove heat from the actuator assemblies. These parts are susceptible to corrosion after several days of exposure to humidity and shall be stored in a non-condensing environment.

[24] Anecdotal evidence:

(a) Maraging steel suspension blade springs (not nickel plated) which were exposed to a standard lab environment showed no signs of corrosion after several years.

(b) Maraging steel suspension blade springs (not nickel plated) shipped from the UK to the US exhibited rust due to the uncontrolled environment in shipping, even though wrapped and packaged. See J. Lewis, "SEM examination of spotted and rusted cantilever blades", LIGO- E1100583

A copper alloy (110) is used for the substrates of the TCS relay mirrors. This alloy has excellent corrosion resistance to weathering and very good resistance to many chemicals. It is often used specifically for corrosion resistance in electrical contact and underground applications. A non-condensing environment should be adequate to prevent corrosion.

6.4.2 Stress-Corrosion Cracking (SCC)

Stress corrosion cracking (SCC) is the growth of cracks under stress in a corrosive environment, which can lead to unexpected sudden failure. The susceptibility to SCC depends on alloy composition, structure, thermal history, stress amplitude, temperature, and environment. For the aLIGO assemblies, the only components under stress and potentially susceptible to SCC in a corrosive storage environment are:

- The maraging steel springs and flexures used in the seismic isolation system (SEI), Internal Isolation Systems (ISS) assemblies
- The maraging steel, blade springs used in the various suspension system (SUS) assemblies
- The carbon steel music wire used in the various suspension system (SUS) assemblies
- The maraging steel, blade springs used in the various Stray Light Control (SLC) assemblies
- The weld areas of the aluminum weldments of the Quad suspension and Output Mode Cleaner and Output Faraday Isolator suspensions
- The weld areas of the 304 stainless steel weldments of the HAM Small Triple Suspensions (HSTS) and of the HAM Large Triple Suspensions (HLTS)

For components that are stored under load (stress) and are susceptible to SCC, the only acceptable and approved solution is to use a dry nitrogen purge flow in the storage container.

Maraging steel has high chromium content, but is nonetheless highly susceptible to Stress-Corrosion Cracking (SCC) in the annealed and aged condition[25,26]. It is <u>not</u> our intent to unload (release) these springs and flexures prior to long term storage.

All of the components listed above must be placed into very low humidity storage containers (<5% RH, achievable with a dry nitrogen purge), or in moderately low humidity storage containers (<10% RH, achievable with desiccant) if unloaded.

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[25] R.B. Setterlund, "Investigation of Stress-Corrosion Cracking of High-Strength Alloys", Report No. L0414-01-22, May 1963, DTIC AD-404-215

[26] Anecdotal evidence: Maraging steel cantilevered spring blades loaded (50% to 75% of yield) to approximately the same stress as our suspension springs, stored in a wooden box in the southern California exterior for ~1 year failed catastrophically (cracked completely across the spring width) due to SCC.

6.4.3 Creep and Relaxation

In principal components under stress can experience time dependent deformation (or relaxation of load). Mechanical bolted joints are unlikely to relax significantly over the storage period, or lifetime, of the aLIGO equipment. The highly stressed suspension system components of the seismic isolation and suspension systems might creep somewhat, but this should be negligible relative to alignment requirements. In particular the suspension system blade springs have been baked under load[27] in order to accelerate out most of the creep due to the maraging steel blade spring.

6.4.4 Polymers

Polymers to be used outside the vacuum system are generally limited to insulation for cabling or as part of electronics packaging. Polymers intended for in-vacuum service are restricted to those listed in the LIGO Vacuum Compatible Materials List (E960050). These in-vacuum polymers are generally high temperature, highly stable, low outgassing polymers. Since all of the aLIGO parts will be stored indoors in temperature and humidity controlled environments and without exposure to UV light, we do not expect any appreciable degradation to the polymers used for aLIGO components.

6.5 Labeling

Label adhesives may fail or ink marking can fade making component/assembly identification (without removing the packaging) difficult or impossible. Electronics component labeling has been shown to have a sufficient lifetime[28]. Other exterior labeling shall be periodically inspected over time to assure that identification of components does not require opening the packaging. (All LIGO parts are permanently marked with part number and serial number in accordance with section 3.1.5 of E030350.)

[27] N. Robertson, "Some Notes on Creep/Creak Bakes for Blades", T1100289
[28] Ibid.

7 Requirements & Plans for Each Subsystem

7.1 Suspensions (SUS)

The plan for LTS of SUS subsystem components is summarized in the subsections below; see LIGO-T1200527 for details[29].

7.1.1 SUS Storage Items

The major items that the SUS subsystem must store are as follows:

- Two (2) Input Test Mass (ITM) suspensions (in metal build form)
- Two (2) End Test Mass (ETM) suspensions (in metal build form)
- One (1) Beamsplitter (BS) suspension (in metal build form)
- Seven (7) HAM Small Triple Suspensions (HSTS) (in metal build form)
- Two (2) HAM Large Triple Suspensions (HLTS)
- One (1) Output Mode Cleaner (OMC) Suspension
- SUS electronics racks
- In-process Spare suspension components/parts
- In-process Spare SUS electronics

7.1.2 SUS Concerns/Requirements

The SUS storage plans address the following specific concerns/requirements:

- Corrosion of the carbon steel suspension wire
- Corrosion/oxidation of the aluminum in-vacuum parts
- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies

7.1.3 SUS Storage Plans

Suspensions will be integrated (assembled and tested to phase 1 requirements) before placing into LTS. At this stage of integration, metal masses, not optics, are installed into the suspensions. Integration of optics into the suspensions must be done just prior to installation into an observatory facility.

The plan is to adapt one HAM-ISI storage container in order to secure and store all of the HSTS and HLTS suspensions, as well as the OMC suspension, in clean, dry nitrogen gas (GN2) purged containers.

[29] N. Robertson and J. Romie, Long Term Storage of Suspension (SUS) Parts, LIGO- T1200527

Storage boxes for the ETMs, ITMs and BS suspensions have already been fabricated and are in use. The ETMs and ITMs are disassembled into two sections to go into their storage boxes: An upper structure storage container contains the top structure and top masses of the main and reaction chain; and a lower structure storage container contains the upper intermediate, penultimate and test masses, and the equivalent reaction masses. Both containers include provision for purging with GN2 to minimize corrosion.

Small mechanical parts, including the carbon steel wire, will be stored in desiccant cabinets.

All Suspension electronics will be either:

- integrated into electronics racks, which are then sealed (non-operating) for pest and cleanliness control with desiccant for humidity control, and Humidity Indicator Cards (HIC) for monitoring, or

- stored in sealed containers with humidity control (desiccant) and Humidity Indicator Cards (HIC) for monitoring.

7.2 Seismic Isolation (SEI)

The plan for LTS of SEI subsystem components is summarized in the subsections below. See LIGO- T1200549 for details[30].

7.2.1 SEI Storage Items

The major items that the SEI subsystem must store are as follows:

- Five (5) BSC ISI assemblies
- Five (5) HAM ISI assemblies
- One (1) HAM passive stack
- Twenty (20) HEPI assemblies
- Electronics modules
- Miscellaneous in-process spare parts including instruments and in-vacuum cabling

7.2.2 SEI Concerns/Requirements

The SEI storage plans address the following specific concerns/requirements:

[30] K. Mason, B. Lantz and H. Radkins, Long Term Storage of H2 Seismic Isolation Assemblies and Parts, LIGO- T1200549

- Corrosion of the carbon steel suspension wire
- Corrosion/oxidation of the aluminum in-vacuum parts
- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies

7.2.3 SEI Storage Plans

The SEI components will be fully assembled, integrated, and tested (to phase-1 requirements) before placing them into LTS. Storage containers for HAM-ISI and BSC-ISI assemblies have already been fabricated and are in use. These containers will be purged with GN2 to reduce moisture and prevent corrosion, which is our current practice.

Spare parts for the ISI assemblies will be placed into a HAM-ISI container, which is purged with GN2.

Storage containers suitable for the HEPI units (which are out-of-vacuum components) are already on-hand (re-purposed HAM-ISI shipping containers). These containers are gas sealed and will be equipped with desiccant and humidity indicators.

All SEI electronics will be either:

- integrated into electronics racks, which are then sealed (non-operating) for pest and cleanliness control with desiccant for humidity control, and Humidity Indicator Cards (HIC) for monitoring, or
- stored in sealed containers with humidity control (desiccant) and Humidity Indicator Cards (HIC) for monitoring.

7.3 Pre-Stabilized Laser (PSL)

The plan for LTS of PSL subsystem components is summarized in the subsections below. See LIGO-T1200557 for details.[31]

7.3.1 PSL Storage Items

The major items that the PSL subsystem must store are as follows:

- PSL: lasers, crystals, optical fibers, electronics, and hardware
- Outer loop: controls, photodetectors, electronics, hardware and optics
- Optical tables, hardware, optics, mounts, etc.
- Chillers and specialty plumbing supplies

[31] P. King and B. Willke, PSL Storage Plan For LIGO India, LIGO-T1200557

7.3.2 PSL Concerns/Requirements

The PSL storage plans address the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of all laser components/assemblies
- Degradation of electronics and sensors

7.3.3 PSL Storage Plans

The PSL components will be fully assembled, integrated, and tested (to phase-1 requirements) before placing them into LTS. The PSL components from Germany will be wrapped and stored in their original shipping crates. Optics and electronics will be stored per the usual methods described in this document.

7.4 Auxiliary Optics Systems (AOS)

The Auxiliary Optical Systems is a collection of miscellaneous systems with a unifying theme of in-vacuum optical layout and beam transport. The systems are sufficiently different such that storage plans are summarized separately in the following sections.

7.4.1 Stray Light Control (SLC) and Viewports (VP)

The plan for LTS of SLC and VP components in the AOS subsystem is summarized in the subsections below. See LIGO-T1300006 for details.[32]

7.4.1.1 SLC/VP Storage Items

The major items that the SLC/VP subsystem must store are as follows:

- Baffle parts: 6 baffle boxes to be suspended, 7 HAM table baffles, 1 HAM Extension table assembly, 4 Tube baffles, and 1 Quad baffle assembly
- 6 Baffle Suspensions and 1 Output Faraday Isolator (OFI) assembly
- Photodiodes and cables
- 92 Viewports (custom and commercial; see T1200220 and T1000746)

7.4.1.2 SLC/VP Concerns/Requirements

The SLC/VP storage plans address the following specific concerns/requirements:

[32] L. Austin and M. Smith, Long Term Storage of Stray Light Control Assemblies for LIGO-India, LIGO- T1300006.

- Protection of viewport glass surfaces for both optical quality and mechanical integrity
- Particulate and hydrocarbon contamination of all in-vacuum sides of viewports
- Particulate and hydrocarbon contamination of all baffles (in-vacuum parts)
- Protection of the loaded (stressed) maraging steel blade springs from stress corrosion cracking

7.4.1.3 SLC/VP Storage Plans

The SLC and VP components will be fully assembled, integrated, and tested (to phase-1 requirements as relevant) before placing them into LTS.

The baffle suspensions and the OFI will be placed into a HAM-ISI container that is purged with GN2.

All other components will be stored in humidity and temperature controlled environments typical of laboratories and offices. Parts and assemblies to be packaged and placed on pallets in designated LHO storage space.

7.4.2 Transmission Monitor Systems (TMS)

The plan for LTS of TMS components in the AOS subsystem is summarized in the subsections below. See LIGO- T1300007 for details.[33]

7.4.2.1 TMS Storage Items

The major items that the TMS subsystem must store are as follows:

- 2 units TMS Suspension
- 2 units TMS Telescope and Optic Table
- 1 unit complete in-process spare assembly
- Optics

7.4.2.2 TMS Concerns/Requirements

The TMS storage plans address the following specific concerns/requirements:

- 'Tarnishing' of protected silver reflective coatings
- Corrosion of the carbon steel suspension wire
- Corrosion/oxidation of the aluminum in-vacuum parts
- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies

[33] L. Austin and K. Mailland, Long Term Storage of TMS for LIGO-India, LIGO- T1300007.

7.4.2.3 TMS Storage Plans

The TMS components will be assembled, integrated and tested (to phase-1 requirements) before placing them into LTS.

The TMS Top Mass Assembly will be stored in storage container D1002222, which includes provision for purging with gas to minimize corrosion.

The silver-coated optics in the Transmission Monitor System (TMS) must be stored in vacuum or in very-low humidity containers with a dry nitrogen purge. We plan to use space in a re-purposed HAM container with other AOS components.

Small parts including spare blades, carbon steel wire, and clamps will be stored in desiccant cabinets.

All other components will be stored in humidity and temperature controlled environments typical of laboratories and offices. Parts and assemblies will be packaged and placed on pallets in designated LHO storage space.

7.4.3 Thermal Compensation System (TCS)

The plan for LTS of TCS components in the AOS subsystem is summarized in the subsections below. See LIGO- T1300003 for details.[34]

7.4.3.1 TCS Storage Items

The major items that the TCS subsystem must store are as follows:

- Ring Heater (RH) equipment for installation ***in***side the vacuum system
- Hartmann Wavefront Sensor (HWS) equipment for installation ***in***side the vacuum system
- HWS equipment for installation ***out***side the vacuum system
- CO2 laser Projection (CO2P) equipment for installation ***in***side the vacuum system
- CO2P equipment for installation ***out***side the vacuum system

7.4.3.2 TCS Concerns/Requirements

The TCS storage plans address the following specific concerns/requirements:

- Corrosion/oxidation of the aluminum in-vacuum parts
- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies

[34] M. Jacobson, A, Brooks, and A Heptonstall, Long Term Storage of aLIGO TCS Components, LIGO- T1300003.

7.4.3.3 TCS Storage Plans

In-vacuum Ring Heater and Hartmann Wavefront Sensor components are stand-alone tested and then Ameristat packaged and stored in purged GN2 atmosphere. Selected components for use in air, in particular, cameras, are also stored in purged GN2 atmosphere. Storage containers suitable for the HEPI units (which are out-of-vacuum components) are already on-hand (re-purposed HAM-ISI shipping containers). These containers are gas-sealed and will be equipped with desiccant and humidity indicators.

The CO2 laser and ZnSe window are also stored in the sealed purged GN2 atmosphere.

The remaining components are stored as per usual Class A or B components respectively in Ameristat bags, kitted, boxed, and in the clean conditioned environment.

Electronics will be stored according to the plan for electronics storage, T130002.

7.4.4 Optical Levers (OpLev)

The plan for LTS of OpLev components in the AOS subsystem is summarized in the subsections below. See LIGO- T1200558 for details.[35]

7.4.4.1 OpLev Storage Items

The major items that the OpLev subsystem must store are as follows:

- Pylons
- Shrouds and light-tight-coupling components
- Miscellaneous small hardware
- Lasers and fiber-optic cables
- Electronic Modules and Cabling
- In-vacuum hardware (steel, spring steel, aluminum, and coated glass mirrors)

7.4.4.2 OpLev Concerns/Requirements

The OpLev storage plans address the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies
- Degradation of electronics and sensors due to humidity and static electricity

[35] E. Black, Long-term Storage of Optical Lever Components, LIGO- T1200558.

7.4.4.3 OpLev Storage Plans

The OpLev components will be partially assembled before being placed into LTS. The majority of parts will be used outside the vacuum envelop and will not require special handling and storage. Electronics will be stored with other aLIGO electronics, according to the plan for electronics storage, T130002. In-vacuum hardware will be wrapped and stored per the procedures outlined here for the type of materials used.

7.4.5 Photon Calibration (Pcal)

The plan for LTS of Pcal components in the AOS subsystem is summarized in the subsections below. See LIGO-T1300012 for details.[36]

7.4.5.1 Pcal Storage Items

The major items that the Pcal subsystem must store are as follows:

- 2 In-vacuum Periscope Structures and mirrors
- 2 Transmitter modules
- 2 Receiver modules
- 2 Transmitter pylons
- 1 Working Standard calibration system
- Electronics modules

7.4.5.2 Pcal Concerns/Requirements

The Pcal storage plans address the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies

7.4.5.3 Pcal Storage Plans

The Pcal components will be partially assembled and pre-aligned before being placed into LTS. The majority of parts will be used outside the vacuum envelope and will not require special handling and storage. Electronics will be stored with other aLIGO electronics, according to the plan for electronics storage, T130002. In-vacuum hardware will be wrapped and stored per the procedures outlined here for the type of materials used.

[36] R. Savage, Photon Calibrator Storage Plan for the 3rd aLIGO Interferometer, LIGO-T1300012.

7.4.6 Initial Alignment Systems (IAS)

The plan for LTS of IAS components in the AOS subsystem is summarized in the subsections below. See LIGO-T1300011 for details.[37]

7.4.6.1 IAS Storage Items

The major items that the IAS subsystem must store are as follows:

- Various custom optical survey targets and associated mounts
- Miscellaneous custom opto-mechanical hardware

7.4.6.2 IAS Concerns/Requirements

The IAS storage plans address the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of class 'B' hardware

7.4.6.3 IAS Storage Plans

The IAS components will be partially assembled before being placed into LTS. All components will be used outside the vacuum envelope and will not require special handling and storage.

Custom fabricated metal parts will be wrapped, following Class B guidelines in E0900022 if appropriate, and stored in plastic 'tub' containers to prevent oxidations or bruising and placed in dedicated, lockable cabinets.

7.5 Input Optics (IO)

The plan for LTS of IO components is summarized in the subsections below. See LIGO-T1200567 for details.[38]

7.5.1 IO Storage Items

The major items that the IO subsystem must store are as follows:

- Optics for HLTS suspensions, HAM Auxiliary suspensions, and fixed mounts
- Faraday Isolator TGG crystals, half wave plates, calcite polarizers, and quartz rotators
- DKDP compensation plates; hydroscopic

[37] D. Cook, AOS-IAS Long Term Storage Plan for LIGO India, LIGO-T1300011
[38] D. Tanner, Storage of the Input Optics for LIGO India, LIGO- T1200567.

- Faraday rotator magnet
- Silicon carbide and black glass baffles
- HAM Auxiliary suspensions
- Steel wire for HAM Auxiliary suspensions
- Siskiyou mounts (with manual and picomotor adjustments)
- Machined parts for in-vacuum use; in chamber periscopes, posts, forks, baffle mounts, etc.
- Installation templates and riser blocks
- Optics for Pre-Stabilized Laser (PSL) table: mirrors, lenses, polarizers, half wave plates, and beamsplitters
- Mechanical mounts
- Electronic rotation stage
- Beam dump, water-cooled
- Optical spectrum analyzer
- Periscope
- Electro-optic modulator (EOM) housing
- RTP crystal for the EOM

7.5.2 IO Concerns/Requirements

The IO storage plans address the following specific concerns/requirements:

- Corrosion of the carbon steel suspension wire
- Corrosion/oxidation of the aluminum in-vacuum parts
- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies
- Degradation of hydroscopic crystals

7.5.3 IO Storage Plans

The majority of IO components will be fully assembled, integrated and tested (to phase-1 requirements) before being placed into LTS. A few parts will be assembled after shipment to a third site and will need to be cleaned, baked, and assembled at the future site.

The HAM Auxiliary suspensions will be stored, without optics, in a sealed HAM ISI storage container purged with GN2. The dry atmosphere will protect the aluminum parts from corrosion.

All optics, both table and in-vacuum, will be stored in aluminum, PET-G, or Pelican cases before being placed in clean storage. They will be cleaned before use.

The Faraday Isolator magnets and components will be stored in a Pelican case and placed in a cabinet or container with desiccant to protect aluminum parts. The parts will be cleaned, baked, and assembled at the future site.

The steel suspension wire and the DKDP crystals will be stored in cabinets purged with GN2 to prevent rusting of the wire and absorption of water by the crystals.

Mechanical components such as the periscopes, beam dumps and mounts, and the spectrum analyzer will be wrapped for cleanliness and stored in clean space.

The remaining in-vacuum and PSL table components will be wrapped according to Class A or Class B requirements and placed in clean storage. Aluminum in-vacuum parts will be stored in cabinets or containers with GN2 purge.

7.6 Core Optics (COC)

The plan for LTS of COC subsystem components is summarized in the subsections below. See LIGO-T1300016 for details.[39]

7.6.1 COC Storage Items

The major items that the COC subsystem must store are the largest optics, as follows:

- Two (2) End Reaction Mass - ERM
- Two (2) Input Test Mass, LIGO-D080657 - ITM
- Two (2) Compensation Plate, LIGO-D080659 - CP
- One (1) Beamsplitter, LIGO-D080660 - BS
- One (1) Power Recycling Telescope Mirror Type 3, LIGO-D080663 – F-PR3
- One (1) Signal Recycling Telescope Mirror Type 3, LIGO-D080664 – SR3

7.6.2 COC Concerns/Requirements

The COC storage plans address the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of optics and optical coatings
- Degradation of gold plating over copper on fused silica or glass substrates

[39] G. Billingsley, “COC Long Term Storage”, LIGO-T1300016

7.6.3 COC Storage Plans

There are no special requirements for storage of the Core Optics, as they are not sensitive to contamination or atmospheric water and will be cleaned per procedures before any future use. The COC optics receive final coatings and are characterized at the Caltech metrology facility before being placed into LTS. Storage containers for all COC optics have already been fabricated and are in use. The optics in their containers will be placed into designated storage in clean lab space, which is our current practice.

7.7 Interferometer Sensing and Controls (ISC)

The plan for LTS of ISC subsystem components is summarized in the subsections below. See LIGO-T1300027 for details.[40]

7.7.1 ISC Storage Items

The major items that the ISC subsystem must store are as follows:

- Custom Electronics modules
- Custom and Commercial Photodetectors. For the custom detectors there are both in-vacuum units and in-air units.
- In-vacuum cabling
- Lasers. Innolight Prometheus lasers for the Arm Length Stabilization (ALS) system.
- Optics tables and enclosures
- Opto-mechanical components for in-air optics tables
- Opto-mechanical in-vacuum components

7.7.2 ISC Concerns/Requirements

The ISC storage plans address the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of all in-vacuum components/assemblies
- Degradation of electronics and sensors due to humidity and static electricity

[40] P. Fritschel, "Long Term Storage of ISC Parts", LIGO-T1300027

7.7.3 ISC Storage Plans

There are no special requirements for storage of the ISC components beyond the normal precautions taken for electronics, lasers, and in-vacuum hardware and optics. Electronics will be assembled and tested before being placed in racks and bagged with desiccants. Optics will be stored in approved boxes and stored in clean lab spaces. In-vacuum components will be wrapped according to Class A requirements and stored in dry GN2 environments. Lasers and in-air parts will be protected from dust and stored in designated clean lab space.

7.8 Controls, Diagnostics, and Monitoring System Electronics (CDS)

The plan for LTS of CDS and hardware is summarized in the subsections below. See LIGO-T1300002 for details.[41].

7.8.1 CDS Storage Items

Scope is limited to the LTS of CDS electronics that do not require special cleaning, packaging, handling and storage environment beyond that required for general, commercial off-the-shelf (COTS) electronics systems. Specific items included in this definition are:

- COTS and in-house custom electronic modules
- COTS PCIe to computer interface modules, along with the associated 100m fiber optic cable
- CDS sensor and actuator electronic interface chassis
- Timing Distribution System (TDS) electronics, including the IRIG-B timing receiver PCIe modules
- Real-time networking switches and related computer PCIe interface modules
- CDS “slow” controls and RF distribution system chassis
- Power supplies provided as part of the CDS DC power distribution system

7.8.2 CDS Concerns/Requirements

The CDS storage plans address the following specific concerns/requirements:

- Degradation of electronics and sensors due to humidity and static electricity

[41] R. Bork, R. Abbott, R. McCarthy, and V. Sandberg, Long Term Storage Plans for Third Interferometer Control and Data Systems, LIGO-T1300002

7.8.3 CDS Storage Plans

There are no special requirements for storage of the CDS components other than wrapping to prevent electrostatic discharges and to provide protection against dust. Desiccants will be included in the wrapping to regulate humidity.

7.9 Installation Tooling and Hardware (INS)

The plan for LTS of Installation Tooling and Hardware, managed by the Installation and Integrated Testing (INS) subsystem, is summarized in the subsections below. See LIGO-T1300010 for details.[42]

7.9.1 Installation and Tooling Storage Items

The major items that the INS subsystem must store are as follows:

- E-Module (D1002926) and Walking Plates (D1002410)
- Test Stands
- BSC Flooring, BSC Repair Arm, and HAM Install Arm tooling

7.9.2 Installation Tooling and Hardware Concerns/Requirements

The INS storage plans carry the following specific concerns/requirements:

- Particulate and hydrocarbon contamination of class ‘B’ hardware

7.9.3 Installation Tooling and Hardware Storage Plans

All of the Installation Tooling is class ‘B’ hardware, which must not contaminate the Class ‘A’ hardware that contacts it. Thus the equipment must be wrapped and stored in a way that does not introduce particular and hydrocarbon contamination. The environment should be a normal low humidity lab environment. The LHO space set aside for storage will be suitable.

[42] J. Worden and J. Fauver, Long Term Storage of FMP-Related and Install Tooling for the H2 LIGO Interferometer, LIGO-T1300010