REQUIREMENTS ON THE BUILDING STRUCTURES THAT WILL HOUSE THE VACUUM CHAMBERS OF THE LASER INTERFEROMETRIC GRAVITATIONAL WAVE DETECTORS

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I. Introduction

There are stringent requirements on the outgassing of materials that will be installed in the vacuum chambers of the laser interferometric gravitational wave detectors. Since the chambers have to be opened to air in order to install new equipment and to maintain the old equipment that are already installed, the building that houses the chambers have to be built with special precautions to keep the vacuum system from being contaminated. The building will also house a large array of powerful lasers which require a large amount of electrical power and a cooling system which removes the dissipated heat efficiently without harming the lasers. The building has to be kept at a relatively constant temperature independent of the variations of the temperature outside. Large pieces of heavy equipment will frequently have to be moved in the building when the vacuum chambers are open to air. This will require a special crane system to be installed in the building. The lighting of the building has to be designed carefully to avoid unnecessary waste of power while supplying adequate amount of light for the people who are installing and maintaining the parts of the laser interferometer. The purpose of this memorandum is to establish guidelines for the engineers that will design and construct these buildings.

I. The General Building Structure

The building should be easily expandable and it should be constructed with insulated walls. This will reduce the demands on the air-conditioning system. The building must be sealed against dust, insects, rodents and other small animals. There should be no water leakage into the building. All electrical cables inside the building should be in metal or plastic conduits. The cables that connect the buildings together must be in waterproof metal or sufficiently thick plastic conduits. One of the not-so-obvious reasons for this requirement is the enormous appetite of rodents and some other small mammals for cable insulation. There should be open cable conduits for routing the ever-changing signal cables. These conduits should be easily expandable. The cables that go through the walls of the main building that houses the chambers into the office areas which are occupied by people should have seals around the holes where they pierce through the wall. These seals should be insect-proof and they should be easily removable for adding or removing cables. All pipes that are carrying liquids into the chamber area must be thermally insulated and sealed where they pierce through the walls. All doors leading to the chamber area must be sealed against dust, water, insects and other small animals. These seals must be easily replaceable. These doors should have reinforced glass windows which are equipped with pull-down curtains on the non-chamber side. Near each of these doors, there should be a warning light which gives an indication of safe-entry to the chamber area. It would be very helpful if an intercom station is installed near each of these doors which allows communication with stations in the chamber area. The floors of the chamber area should be constructed in such a way that the undesirable fluids (like machine or pump oil) do not get absorbed into them easily. The ceiling should be constructed in such a way that it does not have any areas that can accumulate large quantities of dust which can be dislodged by external vibrations.

II. Human Access into the Chamber Area

All passages from the human quarters to the chamber area must be made through small cleaning rooms with two doors: One of the doors should lead to the chamber area, the other should lead to the human quarters. These doors should meet the criteria mentioned above. The cleaning room should be equipped with portable vacuum cleaners to clean any dust and insects that may be carried in with the clothing. Overalls and slippers which should be worn only in the chamber area must be stored in this room and all personnel that go into the chamber area should wear them. The people which are working on or near the vacuum chambers should wear head covers which prevent hair from falling into the chambers. Gloves must be worn in handling all internal vacuum equipment. Adequate amount of eye and head protection equipment as well as medical first-aid kits should be available in stations scattered throughout the chamber area.

III. Equipment Access into the Chamber Area

All equipment that are shipped from a remote location to be admitted to the chamber area should be packed in the following manner: First, the equipment should be placed in an appropriate sealed "bag". This bag should be opened only after the equipment is admitted to the chamber area. The bag should then be placed in a cardboard-box with appropriate packing material. The cardboard-box should then be placed in another sealed "bag" and the bag should be packed inside a crate with the appropriate packing material. This crate is then transported to the building receiving dock which prepares it for admission into the building. The receiving dock of the building should be constructed in the following manner: First, an external receiving area which will admit the trucks that are making the delivery should be constructed. This external receiving area should be like a room with a roof with either one wall missing or with a large sliding door in the place of the missing wall which is spacious enough to permit the largest of the delivery trucks to back into the room. The receiving dock should be placed in such a way that the prevailing winds at the site almost never blow in to room through the opening. After the truck is backed into the room, the crate should be removed from the truck and it should be placed on a platform. After the truck has left and the door is closed, the crate should be opened, the first bag containing the cardboard-box should be removed and thoroughly vacuumed and passed into an intermediate receiving area which is sealed from the first receiving dock. This room should also be sealed from the main chamber area. In this room, the cardboard-box should be opened, the second bag should be removed and again, it should be throughly vacuumed before being passed into the chamber area. In the chamber area, the equipment should be carried to near its final location by the overhead cranes still sealed in its bag. The final seal should then be broken and the instrument should be installed into the vacuum system. These receiving docks are required at all stations in a LIGO site.

IV. The Requirements on the Hauling Equipment In the Chamber Area

The equipment that will be installed into the LIGO chambers will be too large to be lifted by humans. A good network of overhead cranes and independent small fork lift trucks will be needed and provisions for these in the chamber area should be supplied. All such equipment should be operated by electricity. These load carrying equipment should be carefully chosen so that they operate without leaking lubricating liquids. This is especially important for the overhead cranes. They must never drip oil into the chambers when they are lowering equipment into them. Their tracks should be built in such a way that the grease could never creep up and out of them into the chambers. There should be catchers installed under the parts that are attached to the roof to stop material dislodged from the roof by the vibrations induced by the crane from falling into the chambers. There should be swing arms over the chambers carrying plastic covers to be swung into position when the top chambers are removed for an extended period of time to install equipment into the chambers. Any external load carrying and transportation equipment should be carefully screened for oil leaks. If they leak oil on to the floor of the chamber area this oil can contaminate an open chamber easily by evaporation and these liquids are extremely hard to remove from the floors once they are absorbed into them.

V. Air-Conditioning Requirements in the Chamber Area:

The air-conditioning system should be large enough to keep the temperature constant within a few of degrees centigrade over a period of a day. Instead of having a very large, single air-conditioner there should be several distributed air-conditioners that are individually controlled. The air-conditioning units should be built in such a way that they move large quantities of air at low speeds in order to achieve the cooling that is needed. Their vents should be placed in such a manner that they never directly blow air on any parts of the interferometer. The outlets should be oriented not to blow over areas that can accumulate dust. All vents should be equipped with air-flow indicators. The standard pneumatic servos that control the air-conditioners are somewhat inadequate; newer, all-electric servos should be used. All large motors that are driving the fans should be vibrationally and acoustically insulated from the chamber area. The air conditioning system should be equipped with de-humidifiers to keep the humidity at a safe level to prevent excessive condensation when the chambers are open to air. The fresh air that has to be taken in by the air-conditioner should be filtered to remove dust and pollen.

VI. Laser Cooling Requirements in the Chamber Area:

The first generation of LIGO interferometers will use argon-ion lasers which are well-known for their inefficiency. They consume about 50 KW of electricity to produce about 5W of light output in the visible green. The rest is dissipated into heat in the laser tube and this heat must be removed by the laser cooling system. The current high-power argon-ion lasers generally use chilled water cooling systems. This kind of cooling system should be carefully designed to extend the life of the tube as much as possible. In the chamber area there will be several lasers operating at the same time. The cooling system should be designed in such a way that the heat exchanger of each laser is independent of the others. The heat exchanger for an individual laser should be constructed in the following way: There should be a large capacity chilled water system passing near all the laser stations. This main system can be built using thermally insulated copper pipes and it should not contain any other metal to prevent corrosion. At each laser station, the heat will be exchanged into this copper chilled water system through a local stainless steel closed loop that serves the laser. The stainless steel is chosen to prevent building up of any corrosive material in the laser tube. The part of the local loop that is made out of stainless steel is the part that actually performs the exchange of heat into the main system. The rest of the loop is formed by reinforced nylon hose and stainless steel couplings that carry the chilled water to the laser. On this local loop a pump, a temperature servo, a water filter of appropriate size, a pressure regulator, a flow meter, an anti-bacterial and anti-algae device and a de-ionizer have to be placed. The anti-bacterial and anti-algae device is constructed out of a quartz tube through which the water flows. The quartz tube is surrounded by mercury-ultraviolet lamps that kill the bacteria and the algae. The advantage of this system is that the failure of one or more lasers will not effect others' operation. Since the loops are as short as possible, the accumulation of unwanted material is also kept to a minimum.

VII. Laser Power Requirements in the Chamber Area

Since the lasers consume a large amount of electrical power, the cables that connect their power supplies to the laser head carry very large currents. Because of this the cables have to be relatively short requiring the power supplies to be near the laser heads. The laser power supplies are also cooled by the same chilled water loops that cool the laser heads. Since the lasers will be scattered throughout the building, relatively high-voltage three-phase electrical power has to be brought to the laser power supplies. The distribution of these lines should be arranged carefully not to cause excessive pick-up at the line frequency and at its harmonics in the sensitive electronic equipment that is monitoring the interferometer. All of these cables should be placed in thick metal conduits which are properly grounded.

VIII. Liquid Coolant and Inert Gas Requirements in the Chamber Area

The various pumping stations that are used to evacuate the LIGO chambers are equipped with chilled-water and liquid-nitrogen traps that stop the back-streaming mechanical pump oil and other contaminants from entering the chambers. These traps have to be supplied with chilled water and liquid-nitrogen continuously. The main chilled water system that is used to cool the lasers can be used for this purpose if its capacity is not exceeded. Otherwise a separate closed loop of chilled water is needed to service the chilled water traps. The liquid nitrogen has to be distributed among the pumping stations by a similar network of pipes. It will not be practical to put canisters of liquid nitrogen and to replace them as they empty. This requires that the canisters will have to be taken in and out of the building which will eventually bring a lot of dirt near the chambers. It is also not practical to generate liquid nitrogen on site. Hence a large cryogenic storage tank will have to be built near the receiving dock area to store liquid nitrogen. The fluid will then be distributed to the pumping stations through a proper network of thermally insulated pipes and valves. The storage tank will be replenished with cryogenic tankers which are readily available. Note that one of these cryogenic storage tanks are needed at each building. High purity gas nitrogen should also be supplied to each chamber in the building. This will be used to bring the chamber back to atmospheric pressure. Local air should not be used for this purpose. This also requires that a sufficient automatic venting system is installed in the building since with repeated openings of each tank in a given day, the nitrogen content of the ambient air can raise to unhealthful levels. It may be possible to arrange a high purity nitrogen-oxygen mixture to be used for this purpose. This will eliminate the health hazard.

IX. Interior Lighting Requirements in the Chamber Area

Adequate lighting should be supplied in the chamber area to allow work to continue at all times. The preferable method of lighting is using light fixtures which use incandescent bulbs. This method of lighting will consume a lot of power. It is preferable to have a three-way lighting system which consists of incandescent lights, fluorescent lights and incandescent spot lights which can be aimed at particular locations. The advantage of incandescent lights is that they are not modulated by the line frequency as strongly as the fluorescent lights. The fluorescent lights can be turned on at non-critical times and at non-critical locations. The spot lights will be used for detailed work which require a well lit area for a short period of time. Finally, electro-luminescent panels may be used to give efficient low-level lighting in areas that are lighted for safety reasons.

X. Machine Shop Facilities

Each LIGO station (central-, mid- or end-station) should have a small machine shop. Since the distance between the stations is about 2 kilometers it is not practical to have a one central machine shop on a site to cover all machining needs. If that approach is taken, then it will be necessary to clean and double seal each machined item for transportation between buildings. Given the fact that one can buy quite decent machining equipment at rather low prices due to the competition from Asian countries, it probably will be cheaper to set up individual small machine-shops at each station. These machine shops must be double sealed from the chamber area (as described in the previous document), but they can be connected to personnel quarters through a simple door. The secondary room of the receiving dock can be used as the secondary seal to the machine shop to reduce the cost of building these shops. Each machine shop should contain a small lathe, a table top mill, a drill-press, a small band saw, a grinder and a small sander together with a complete tool chest. A milling-drilling press may replace the drill-press and the table top mill, but it is better to have separate machines as they will last longer. All machines should be mounted on vibration isolation pads like EAR Corp.'s ISODAMP pads or VibraSciences Inc.'s Vib-X pads. These are specially designed to eliminate vibrations induced by machinery and they are very effective. A complete degreasing facility must be adjacent to the machine shop. This should be a separate room connected to the machine shop through a simple, sealed door. In this area, several ultra-sonic cleaners and vented fume-hoods should be installed. This room should also have running hot and cold tap-water with a large sink.

XI. Clean Room Facilities

Each LIGO station should also have a "clean room" facility to handle delicate optical devices. This room must be double sealed from the personnel quarters but, it may be connected to the chamber area through a simple, sealed door. It should contain several laminar-flow benches and it should be very well lit. Every precaution should be taken to keep this room dust-free.

XII. Pump Station Requirements in the Chamber Area

The pumping stations in the vacuum chamber area of a LIGO station will probably have to be supplied with relatively high-voltage, three-phase power to operate the mechanical, the turbomolecular and the ion pumps. These supply lines must be placed in thick, properly grounded conduits and routed carefully to avoid interference in the sensitive monitoring circuits. The mechanical pumps put out a fine mist of pump oil out of the exhaust of the pump while they are in operation. There are filters that catch most of this oil. A small portion of this exhaust does escape the output filters and it is unacceptable to have the exhaust vented into the chamber area. There should be vent hoses attached to the exhausts of the mechanical pumps that direct the oily mist to an external location. Note that the pump vents should not be close to any of the air-conditioning intake vents. This will cause the oil to be sucked right back into the building. The pump vents should probably go into a large empty tank external to the building to allow condensation of oil. The tank can be open to atmosphere through a filtered port of appropriate size.

XIII. Ordinary Electrical System in the Chamber Area

There should be many ordinary electrical outlets in the chamber area. Need for extension cords and extension outlet boxes should be completely eliminated. These should be designed in such a way that they are never in the way and they are easy to get to without stretching cables across the access ways. The proper grounding of the outlets must be designed carefully to avoid potential ground loops. This is something that sounds easy to do, but it is almost always done wrong. There should be several "earth" grounds in the building placed carefully again to avoid ground loops. An earth ground is a thick copper stake buried several feet underground together with a wire mesh spread a few feet across to provide low "to-ground" resistance. A thick copper wire is attached to the stake and is brought into the building.

XIV. General Comments

It is recommended that the buildings are specified in extreme detail, clearly showing routing of electrical cables, conduits, piping, seals, etc... Failure to do this may result in some freedom being taken by the site construction crew. Since they do not know the "overall" picture, they are likely to make the wrong decision which will cause trouble afterwards. Repairing the damage caused may take a lot of time and money.

XV. The Last Word

The last word is that this is not the last word by any means. The proper building specification document will be many times the size of this document since there is always something else to consider. The author will appreciate the comments of his colleagues and the engineering team.