1.1 - System equipment and operation description (*revised for the 2nd LAPD run*)

During the last 5 years, the Liquid Argon Time Projection Chamber (LArTPC) R&D effort has successfully developed a Materials Test Station, an Electronics Test Station, and operated a small LArTPC (ArgoNeuT) in the NuMI beam. LArTPCs are an attractive detector option for future long-baseline neutrino oscillation physics and present several engineering challenges.

When a high energy charged particle passes through a medium, the particle leaves a path of ionization electrons which can be detected, tagging the path of the incoming particle. In a LArTPC, the medium is liquid argon (LAr) and the paths of ionization electrons are detected by drifting the electrons over meters to wire planes. These wire planes are oriented in such a way that the magnitude and position of each path can be reconstructed. Thus a data acquisition system records many snapshots of the appearance of ionization electrons each second [at 2-3 MHz]. Put in sequence, physicists can reconstruct each particle's path, which results in gorgeous bubble-chamber-like images. From the topology and energy deposited along each track, specific interactions can be reconstructed.

The Materials Test Station helps determine what materials can be used to construct a detector without polluting the argon. Purity is an issue because polar molecules and atoms without full outer electron shells (which every element has except for noble gases, which argon is) attract electrons. These contaminants - predominantly water and oxygen - will absorb the ionization electrons to make themselves happy, at the expense of the evidence of the particle interaction. Liquid argon calorimeters have been successfully operated at Fermilab with electro-negative contaminants at the level of 10^{-7}. The liquid argon TPC requires oxygen equivalent contamination on the order of 10^{-11} or 10 parts per trillion (ppt).

To measure such contamination levels, a purity monitor is used. The purity monitor measures purity by firing a light pulse from a xenon lamp at a photocathode and then drifting the ejected electrons to the anode with an electric field. The fraction of electrons surviving the transit from the cathode to the anode gives a measure of the argon purity. This measure is described as the electron lifetime. An electron lifetime of 10 ms is equivalent to a 30 ppt level of oxygen contamination.

Physics requirements indicate that liquid argon detectors larger than 5 kilotons are required. Previous LArTPC cryostats operated in Europe by the ICARUS collaboration and in the US have been evacuated and then backfilled with argon. As the size of the cryostat increases, the mechanical strength required for evacuation and the size of the vacuum pumping system becomes prohibitive.

The Liquid Argon Purity Demonstration (LAPD) has shown that LArTPC purity requirements can be reached in an industrial style cryogenic tank without evacuation. The PC4 enclosure is the test location.

LAPD system component descriptions:

Tank

The LAPD tank is a single wall, cylindrical, flat bottom, dished roof tank 10 ft. in diameter and 10 ft. high. This results in a liquid volume of 5,875 gallons or 22,240 liters. *For perspective, the oxygen content in this tank when full of liquid argon must not exceed 0.0075 grams to achieve a 10 ms electron lifetime.* The shell is constructed from 7 gauge SA-240 304 stainless steel. Large field erected tanks are made per API 620, Design and Construction of Large, Welded, Low Pressure Tanks, Appendix Q. While this tank was shop-built and delivered to Fermilab by truck, it follows the requirements of API 620 where applicable. The tank has a maximum internal working pressure of 3 psi and a maximum external working pressure of 0.2 psi. The tank roof is populated with several conflat flanges. The vendor's fabrication drawings are shown in Midwest

Steel Fabricators drawing #Y08-125. The tank is insulated with a combination of fiberglass and foam as shown FNAL drawing #466366.

A single pilot operated relief valve handles all tank over pressure and vacuum relieving scenarios. Actuated cryogenic valves controlled by the PLC are intended to vent excess pressure before the pilot relief opens. Actuated valves also provide argon gas to the tank to prevent the vacuum relief from opening and drawing air into the tank.

For the 2nd run a new center flange has been fabricated for the tank. The flange supports a small TPC detector. The flange details are shown in drawings # and #. A FEA analysis is included with the drawings.

Condenser, phase separator, and LN2 piping

A liquid nitrogen powered condenser is used to condense the liquid argon boiloff. Liquid nitrogen is supplied by a FNAL owned 4,000 gallon trailer. The nitrogen flows from the trailer to the phase separator and condenser thru foam insulated 1" Type K copper piping. The condenser consists of three separate coils of tubing thru which liquid nitrogen flows housed in an argon vessel which is in communication with the LAPD tank vapor space. Each coil is controlled independently. The condenser is mounted above the LAPD tank such that vapor flows up to the condenser and then liquid either falls back into the tank or flows to the liquid pump suction depending upon the mode of operation. A phase separator ensures liquid is supplied to the condensing coils as a single phase without vapor. The condenser and phase separator layout drawings supplied to the fabricator are shown in FNAL drawings #466642 and #466663. Both vessels are foam insulated.

During the 1st LAPD run the LAr condenser exhibited some vibration during cool down. It did not exhibit the vibration under steady state heat loads. It is believed that the vibration was caused by two-phase flow in the LN2 coils which caused the coils to lengthen and vibrate. To reduce this cool down vibration the condenser has been opened by an ASME code shop and restraints added to prevent the coils from lengthening. While the vessel was open the LN2 coils were inspected and no signs of damage due to vibration were observed. Restraints were added to the two largest coils. The restraints consist of 4 straight tubes that run the length of the coils and cable at each end that wraps around the end coil. This will stop the coil from entering into a lengthening oscillating vibration regime. The pressure retaining features of the vessel are unchanged. The existing pressure vessel engineering note has been amended to note the repair.

Some minor valve changes and additions have been made to the LN2 supply piping. These changes are noted in an amendment to the existing LN2 piping engineering note.

Liquid pump

A magnetically coupled centrifugal pump with variable speed control housed in its own vacuum jacket pumps liquid argon from the tank thru the filtration system at flow rates of up to 12.5 GPM which is equivalent to a tank volume change every 8 hours.

A cool down line has been added that links the pump discharge to the tank vapor space to aid pump startup. This ensures that any vapor is removed from the pump prior to startup. The line consists of un-insulated ½ inch OD stainless steel tubing. The existing liquid argon piping engineering note is amended to reflect this addition.

Gas compressors

Prior to the introduction of liquid into the system, argon gas can be circulated thru the liquid filtration path using a bellows pump. A second bellows pump draws a small amount of gas out of each feed thru on top of the tank to prevent diffusion of contamination from warm feedthrus into the pure liquid. This pump sends the contaminated gas to the filtration system.

Filter cryostats and LAr piping

The purification system contains a molecular sieve filter and an oxygen filter. Each filter is vacuum jacketed and the ASME stamped inner vessel contains 77 liters of filter material. The layout drawing supplied to the fabricator is shown in FNAL drawing #466500. The inner vessel hangs from the vacuum jacket top flange such that it can be removed with a crane. This allows access to the temperature instrumentation and access to the filter material. Due to the high temperatures required by filter regeneration, radiation insulation is provided by several polished aluminum shields instead of super insulation. The filters are regenerated in place.

The molecular sieve filter (4A) is regenerated by heating the filter bed to a temperature greater than 200 ^{o}C and then evacuating the filter while it cools. The filter bed is heated by a flow of argon gas sourced from the four 180 liter liquid argon dewars outside of PC4. The argon gas temperature is raised above ambient by electric heaters.

The oxygen filter consists of a thin layer of copper on a high surface area alumina substrate, essentially a copper coated molecular sieve. The oxygen filter is heated to 250 ^{o}C in the same manner as the molecular sieve. Once the filter bed has reached 250 ^{o}C the heated gas flow is switched from argon to a mixture of nonflammable 2.5% Hydrogen/97.5% argon gas supplied by a tube trailer. At this elevated temperature the hydrogen combines with the oxygen on the filter to form water. The water is then swept out of the filter by the hot gas. As the filter cools it will also be evacuated which will remove the last traces of water.

During the 1st LAPD run some filter material made it out of the filter vessels and into the piping. The filter material was contained within the filter vessels by sintered metal discs. The spare filter vessel that was never installed was examined by borescope (LAPD purchased 3 identical filter vessels – only two of which were put into service). The top sintered metal disc was found to have a small weld crack thru which filter material could leak out. This is not a pressure containment issue. It was assumed the installed filters had this same weld crack failure from the beginning and this was later confirmed. Both filter vessels were cut out of the piping. The repair consisted of cutting off both the top and bottom pressure vessel heads that contain the sintered metal discs. New heads were fabricated and welded on the vessel that contain screen between slotted plates instead of sintered metal discs. The screens provide particulate filtration while the slotted plates support the weight of the filter material and react the forces due to the pressure drop across the bed. The screen design is shown in FNAL drawings #489456 and #489458.

First the spare filter vessel was sent out for repair. This filter vessel was installed in place of the oxygen filter used during the 1st LAPD run. A new pressure vessel engineering note was created for this vessel which is identical to the original oxygen filter pressure vessel engineering note except that the repair is noted.

The filter which held the molecular sieve was sent out as the 2nd repair. Since this filter vessel will still be used to hold molecular sieve after the repair the existing pressure vessel engineering note is amended to note the repair.

During the vessel repair 2.75 inch OD conflat flanges were added to the 1" SCH 10 liquid argon piping on either side of each filter. Edge welded bellows with restraints have been added to the vacuum jacket to allow access to the conflats. These modifications will allow for easy filter removal in the future. The existing liquid argon piping engineering note is amended to reflect these changes and other small modifications.

ODH

The ODH analysis classifies the PC4 enclosure as Class 1. A 3000 CFM blower will turn on in the event of an ODH alarm and draw gas from the floor level and exhaust the gas outside.

Sealing techniques

Where possible, seals between pure argon and air will be metallic to prevent the diffusion of ambient oxygen into pure argon. Where o-rings are unavoidable such as in relief valves, the ambient side of the o-ring will be purged with argon to prevent the diffusion of oxygen from ambient thru the o-ring.

System operational overview

1. The tank will initially be filled with ambient air. Argon gas supplied by 180L dewars will enter the tank bottom and be distributed by an internal manifold. The heavier than air argon gas will act as a piston and push the air out of the top of the tank.
2. Once the gross amounts of air have been purged from the tank the purge will be turned off. A bellows pump will pump the argon gas in the tank thru the molecular sieve and oxygen filter to remove the remaining moisture and oxygen in the tank. The shell of the tank will be heated by external surface heaters to drive off the moisture. During this recirculation phase, oxygen and water analyzers will monitor the progress. A small amount of makeup gas will be periodically added to the system to replace the gas feeding these analyzers.
3. Once the gas recirculation has achieved the desired contamination level the liquid fill will begin. Liquid argon from a tanker will be gravity fed thru the filters and then into the tank. The tank will vent during the filling process.
4. The condenser will be turned on once the tank is full of liquid. After stable pressure control is established, the liquid pump will begin circulation thru the filters.