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Inferred Effects of Water on Electron Drift Lifetime in Liquid Argon

Abstract

A material test system (MTS) was developed at FNAL to assess the suitability of materials for use in a large liquid argon time projection chamber. During development of the MTS, it was noted that controlling cryostat pressure with a raining condenser reduced the electron drift lifetime in the liquid argon. The effect of condensing was examined using a series of materials to filter the condensate. These results, in addition to the results of material tests performed using the MTS, indicate water concentrations in the low ppt affect the electron drift lifetime in liquid argon.

Introduction

Liquid argon time projection chambers (LArTPCs) offer an opportunity for novel neutrino physics (1). They function by drifting ionization electrons created by particle tracks to readout planes composed of thin wires. A principal challenge for large LArTPCs is the removal of electronegative impurities that attach to ionization electrons and prevent their detection. The Material Test System (MTS) has been created at FNAL to develop liquid argon purification techniques (2) and characterize electronegative impurities used in the construction of a large LArTPC. A schematic of the MTS is included below as Figure 1.

Some of the features of the MTS relevant to this note are the following.

- *Scrubber filter.* This filter actively filters liquid argon using a combination of zeolite (3) and activated copper (4) and essentially no moving parts. It can be used to maintain the purity of the argon in the cryostat and also to remove impurities that may be introduced during materials testing. A description of filter operation can be found in (2).
- *Purity monitor.* Modeled after the purity monitors of the ICARUS Collaboration (5), this apparatus allows for the direct measurement of the electron drift lifetime, the relevant representation of electronegative impurities for liquid argon time projection chambers. A brief discussion of the electron drift lifetime and its calculation can be found in (2).
- *Raining condenser to control cryostat pressure.* Argon vapor enters the condenser through a central tube and contacts surfaces cooled with liquid nitrogen pressurized to 35 psig. The condensed argon flows down the condenser walls and drips into one of four filters before entering the liquid of the cryostat. When the condenser is not operating, argon is continuously vented. A closed system is desirable during material tests so that material-introduced impurities remain in the cryostat and their effect on electron drift lifetime can be monitored.
- *Return filter for filtering condensed argon.* Below the condenser is a set of four filters, any one of which may be placed beneath the condenser outlet to catch and filter the condensate before it enters the bulk liquid. For the purposes of this note, there was a filter

of sintered metal, one of sintered glass, one consisting of a thin tube, and one consisting of a hole. Please see Fig. 3 for details.

- *Mechanisms for material insertion.* Materials may be placed into a sample cage inside the airlock, evacuated and/or purged with argon vapor from the MTS cryostat, and then lowered into the cryostat and set on a lift platform equipped with an RTD to indicate temperature. The airlock may then be closed and the material may be lowered into the bulk liquid.

Operation of the MTS involves evacuating the cryostat, filling it with filtered commercial argon, inserting a material sample, and monitoring the electron drift lifetime. Upon evaluation, the sample may be removed and another sample material inserted. The condenser and internal filter may be operated as desired or needed.

Effect of Condenser Operation on Electron Drift Lifetime

The condenser was first used to control MTS cryostat pressure in late 2007. Condensate was allowed to drip into the bulk liquid. It became apparent that condensing reduced the electron drift lifetime drastically. Se Figure 2. The ICARUS Collaboration observed a similar effect when they noted the electron drift lifetime in the argon vapor is much less that that in the liquid (6). In order to characterize the effect of condenser operation, a series of return filters were installed beneath the outlet of the condenser, as shown in Figure 1 and detailed in Figure 3. A return filter is selected by rotating a handwheel that extends outside the cryostat.

The media for the return filter were chosen for their ability to distinguish between possible condenser-associated impurities, initially thought to be either ions or ice/particulate. The thin, spiraled tube was designed to prevent the condensed argon from dripping into the bulk liquid. This would help prevent charge separation that results from fluid flow against a dissimilar surface (7) and prevent the generation of ions that might adversely affect the drift lifetime. The sintered glass was chosen for its ability to remove particulate, but not discharge any ions generated by dripping condensate. The sintered metal and steel wool were chosen for their ability to remove both ions and particulate. The hole provided a baseline to which to compare the effects of the other return filters.

The cryostat was initially filled with 29 out of 40 inches of argon, enough to cover the outlets of all the return filters except the hole. The effect of filtering the condensate through each of the returns was observed and results are shown in Fig. 4. The impurities in the cryostat were modeled assuming there was an infinite reservoir of condenser-associated impurities and that condenser operation introduced these impurities to the bulk liquid at a constant rate. Each of the return filters was allowed to reduce the rate of introduction by a constant fraction. For modeling purposes, scrubber filter operation was allowed to remove any impurities in the bulk liquid. Without active filtration, condenser-independent impurities accumulate in the bulk liquid but the condenser-associated impurities are allowed to passively exit.

Figure 4 shows the relative success of stainless steel and sintered metal as a return filter. Based on its performance relative to the hole, we estimate the sintered metal return removes 90-95 percent of condenser-associated impurities present in the condensate. The performance of the other returns does not conclusively support the hypothesis that condensing introduces ions or ice/particulate into the bulk liquid. A new hypothesis was formed that condenser-associated impurities are emitted from warm metal surfaces but adsorb to cold metal surfaces. Return filter performance is related to the amount of cold metal surface area presented to the condensate. This hypothesis was adopted because it accounts for the difference in return filter performance as well as the passive removal of condenser-associated impurities from the bulk liquid. As a check on this hypothesis, the amount of cold metal surface area presented by the return filters to the condensate was decreased by lowering the liquid level in the cryostat. The filters removed fewer condenser-associated impurities in this new operating condition. See Table 1.

Return Filter	**Cold Metal Surface Area Presented to Condensate**		**Electron Lifetime**	
	29 Inches LAr	*16 Inches LAr*	*29 Inches LAr*	*16 Inches LAr*
Hole	0	0	1.1	1
Thin Tube	150 cm^2	70 cm^2	1.5	1.3
Sintered Glass	300 cm^2	Near 0 cm^2	2.4	1.2
Sintered Metal	A lot	A lot	5 to 8	5 to 8
N/A (Venting)	N/A	N/A	10-20	10-20

Table 1: Electron Drift Lifetime as Related to Return Filter and Liquid Level.

Condenser-associated impurities can be actively removed with the scrubber filter, suggesting the source of these impurities is not liquid argon but the cryostat, which is evacuated before fill. Water is well known to remain on metal surfaces in vacuum (8) and may be cryopumped, making it a likely appellation for condenser-associated impurities.

Material Tests and Inferred Effects of Water on Electron Drift Lifetime

A Tiger Optics moisture analyzer (9) with a 2 ppb detection limit and 1 ppb resolution was used to monitor the water concentration in the MTS cryostat. The argon vapor was monitored for moisture content because the moisture analyzer was not sensitive to concentrations in the liquid. When using the sintered metal return and operating the scrubber filter, we estimate the water concentration in the liquid is 1/500th of that in the vapor. This ratio varies depending on the operational parameters of the cryostat and associated apparatus and on the condition of the sintered metal return filter.

The airlock volume was connected to the cryostat volume to test the hypothesis that warm metal surface area introduces water and reduces the electron lifetime. During this test, the scrubber filter was operational and the sintered metal was used as the condenser return. The results, shown in Figure 5, provide some confirmation of our hypothesis. The water concentration in the argon vapor increases when the airlock is joined to the cryostat and also is an indicator of electron lifetime: the product of the electron lifetime and water concentration remains roughly constant.

A series of material tests was performed to determine the effect of various materials on the electron lifetime (see Table 2) and the role of water. Test materials were inserted in the airlock and evacuated and purged with argon from the cryostat and then lowered into liquid argon and subsequently raised into vapor. Material tests were conducted with the scrubber filter operational and the sintered metal as the return filter. During materials testing, it was noted that the water concentration in the argon vapor was indicative of electron drift lifetime (see Fig. 6) in a way similar to that of joining the cryostat and airlock volumes. The product of the electron lifetime and the water concentration once again remains constant. In both scenarios, [Electron Lifetime in ms]*[H2O Concentration in ppb]≈17. It was also noted that upon evacuation in the airlock (for a few days) prior to testing, PC board materials had little effect on the electron drift lifetime (see Fig. 7). These characteristics suggest water may be the sole significant electronegative impurity introduced by various materials and metal surfaces.

Material	Sample Surface Area	Effect of Material on Electron Drift Lifetime (LT)			Comments
		94 K liquid	≈120 K vapor	≈225 K vapor	
GC Electronics Red-X Corona Dope on stainless steel	100 cm^2	None	None	LT reduced from 8 to 1 ms; recovery observed.	H2O Concentration not monitored. Sample has tendency to flake off substrate when cooled.
Deactivated Rosin Flux on stainless steel	200 cm^2	None	Not Tested	LT reduced from 8 to 1.5 ms; recovery observed.	H2O Concentration not monitored
FR4	1000 cm^2	None	Not Tested	LT reduced from 8 to <1 ms	Outgassed enough water vapor at 200K to saturate sintered metal return filter.
Taconic, Grade TPG-30	600 cm^2	None	Not Tested	LT reduced.	Sample outgases water at 225 K.
Hitachi BE 67G	300 cm^2	None	Not Tested	LT reduced; recovery observed	Sample outgases water at 225 K.
TacPreg	200 cm^2	None	None	LT reduced; recovery observed	Sample outgases water at 225 K.
FR4 board prepared by Brookhaven Nat. Lab.	225 cm^2	None	None	LT reduced from 8 to 3 ms.	Sample is a y-plane wire endpoint for MicroBooNE detector. Sample outgases water at 225 K.
FR4 board prepared by Brookhaven Nat. Lab.	225 cm^2	None	None	None	Sample is a y-plane wire endpoint cover for MicroBooNE detector. Sample was evacuated before introduction to cryostat.
Devcon 5-minute epoxy	100 cm^2	None	None	LT reduced from 10 ms to 6 ms; some recovery observed	Sample outgases water at 225 K.

Table 2: Summary of Material Test Results.

While materials testing and characterization are incomplete, the results presented in Table 2 indicate a variety of materials outgas water when warm (≈225 K) and affect the electron lifetime in the MTS cryostat. This outgassing has been observed to initially decrease over a period of a few days in certain materials; the extent of its decrease has not been characterized.

Summary and Inferences

Investigation of the relationship between raining condenser operation and electron lifetime in the MTS cryostat and the results of material tests indicate that low (10 ppt) concentrations of water in liquid argon affect the electron drift lifetime. We have not demonstrated a direct relationship between water concentration in liquid argon and electron drift lifetime. However, based on our results, we suggest water moves through the cryostat in the following way. Warm metal surfaces and other unevacuated, warm, and (perhaps) recently-introduced materials release water into the argon vapor. Condenser operation introduces the water-contaminated vapor into the liquid of the cryostat where water naturally exits the liquid because of its affinity for cold metal surfaces. The equilibrium concentration of water determines the electron lifetime. Water may be prevented from entering the liquid by filtering the condensate before it enters the liquid.

Figures

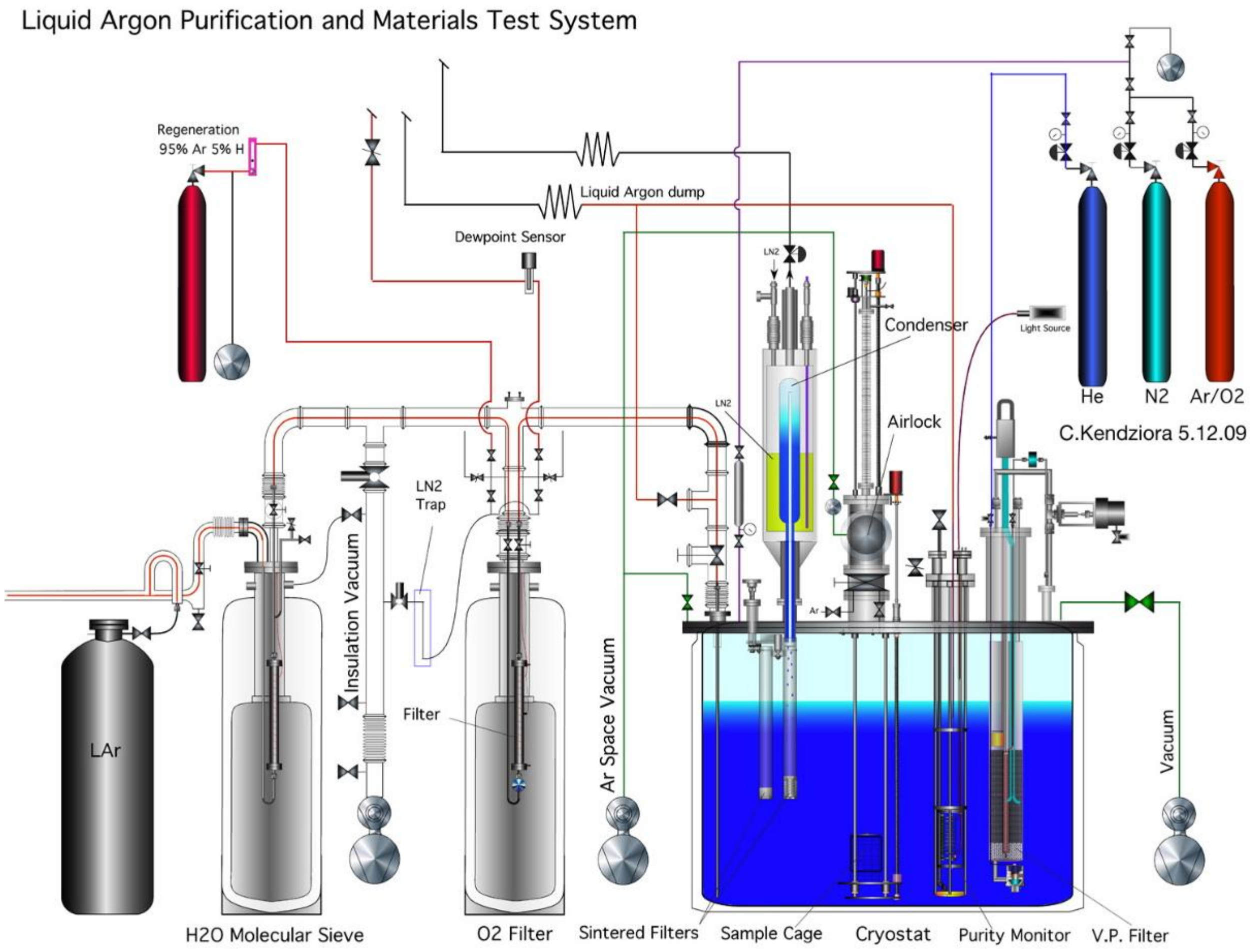

Figure 1: Schematic of the Materials Test System (MTS) at FNAL.

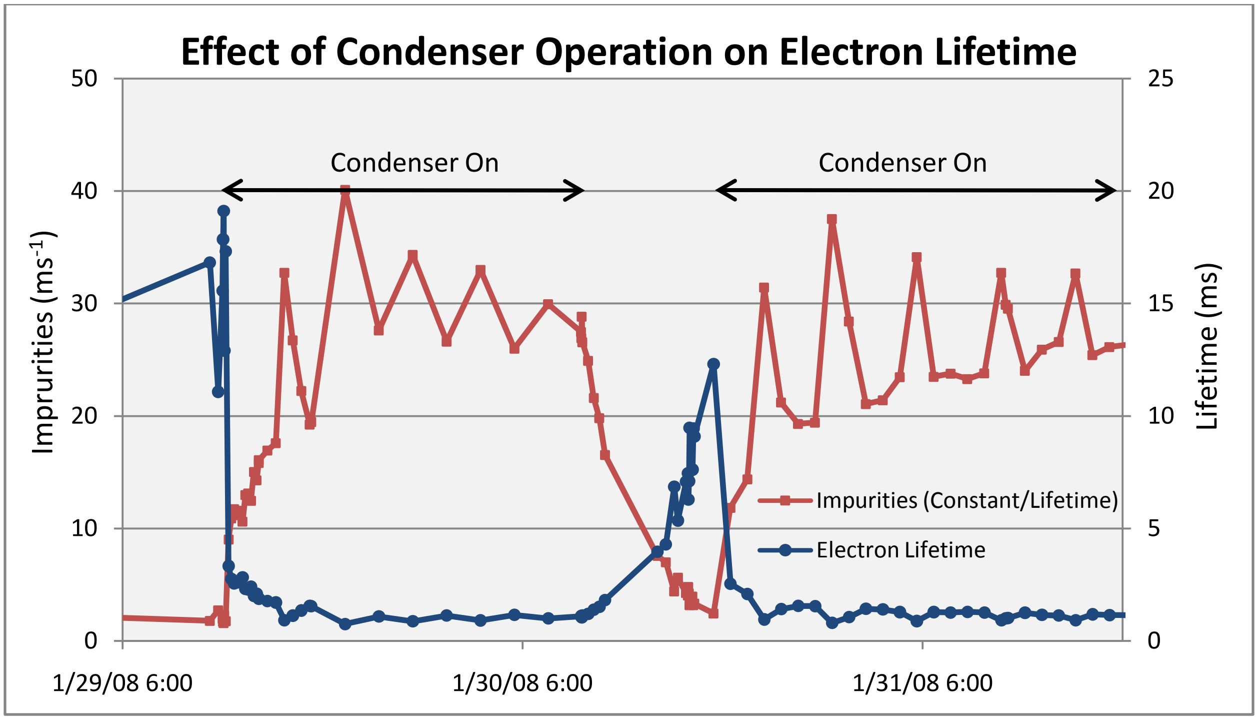

Figure 2: Effect of Condenser Operation on Electron Drift Lifetime. Imps is a quantity defined as a constant divided by the drift lifetime.

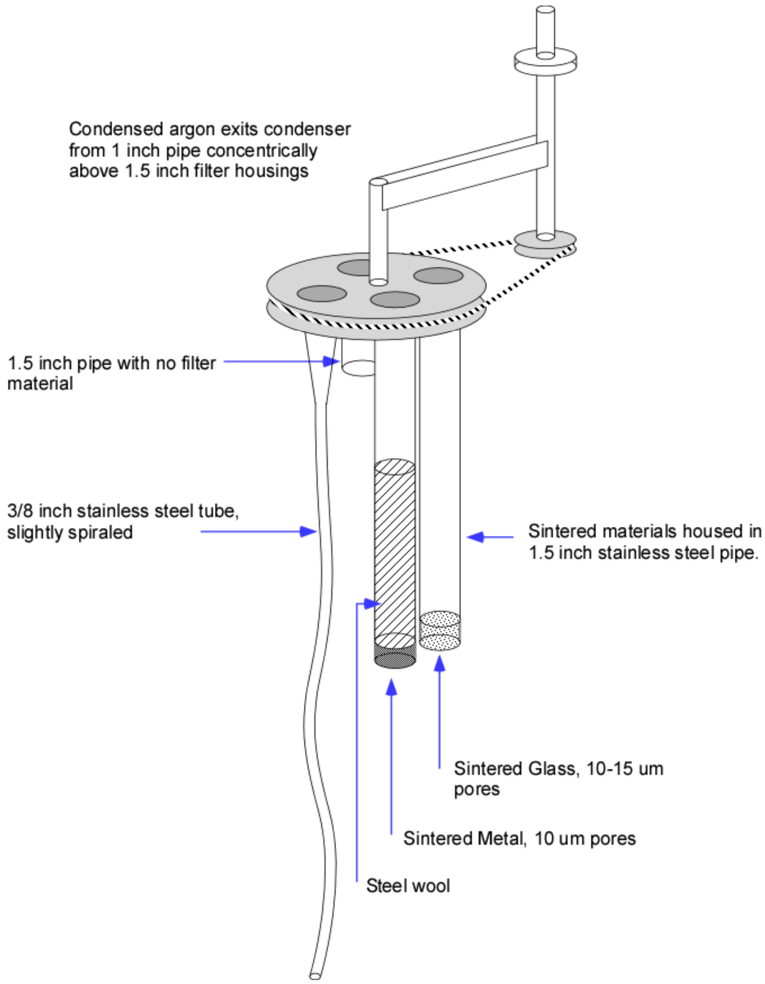

Figure 3: Detail of Return Filter Mechanism. The thin tube extends approximately 36 inches into the cryostat, which has a depth of 40 inches. The housings for the sintered metal and sintered glass extend approximately 20 inches into the cryostat.

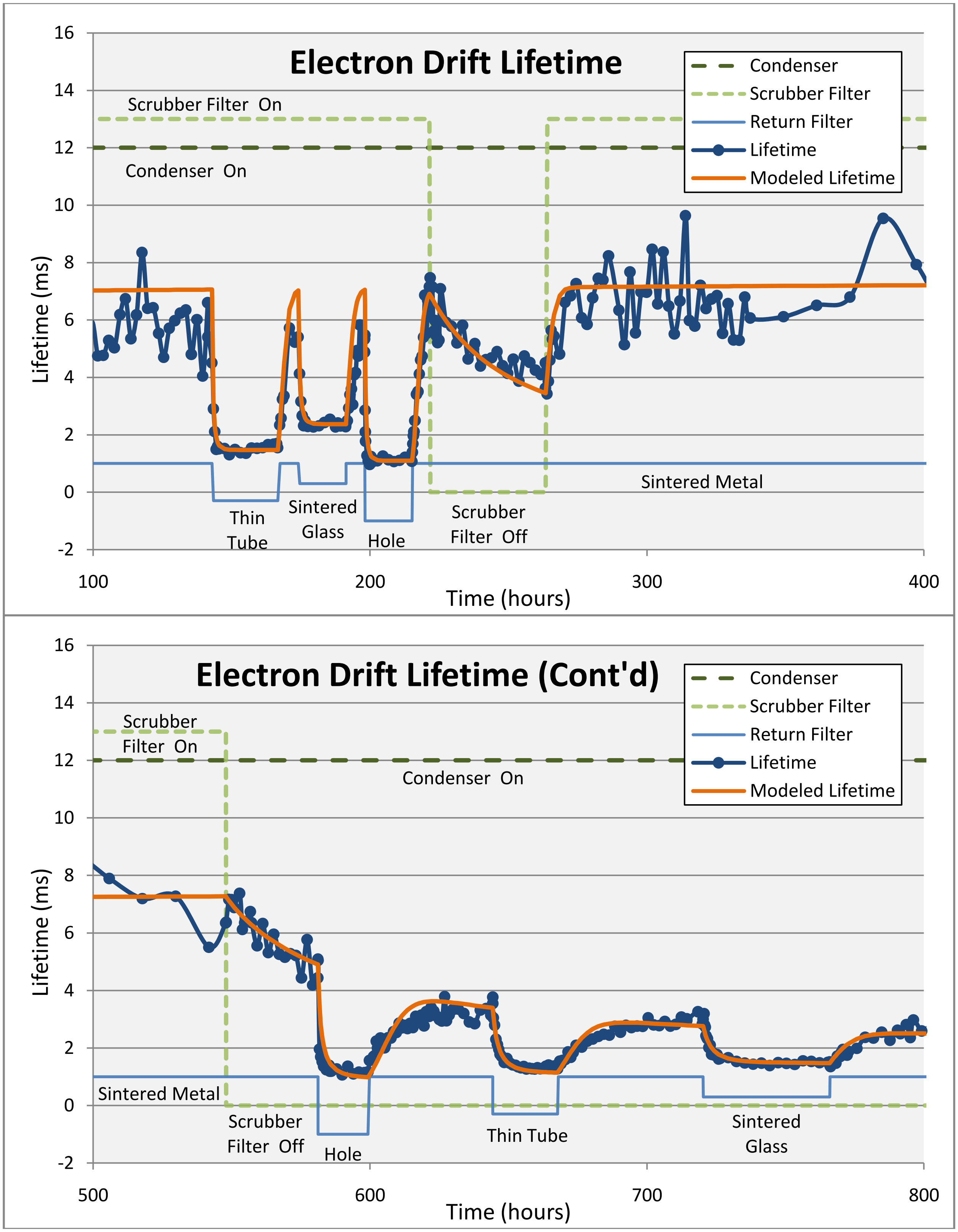

Figure 4: Electron Drift Lifetime as a Function of Condensate Filtering. The levels representing the condenser, scrubber filter, and condenser filter indicate their operational status.

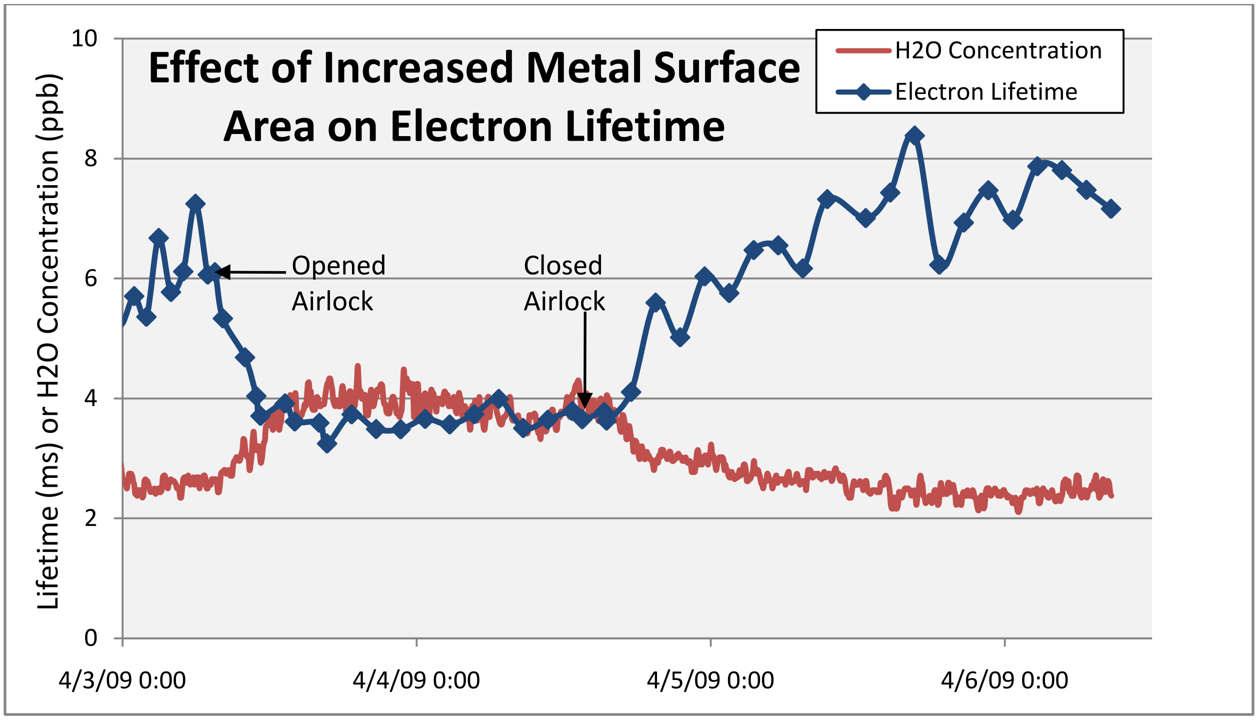

Figure 5: Effect of Connecting Cryostat and Airlock Volumes. The material test was performed with 15 inches LAr present in the cryostat.

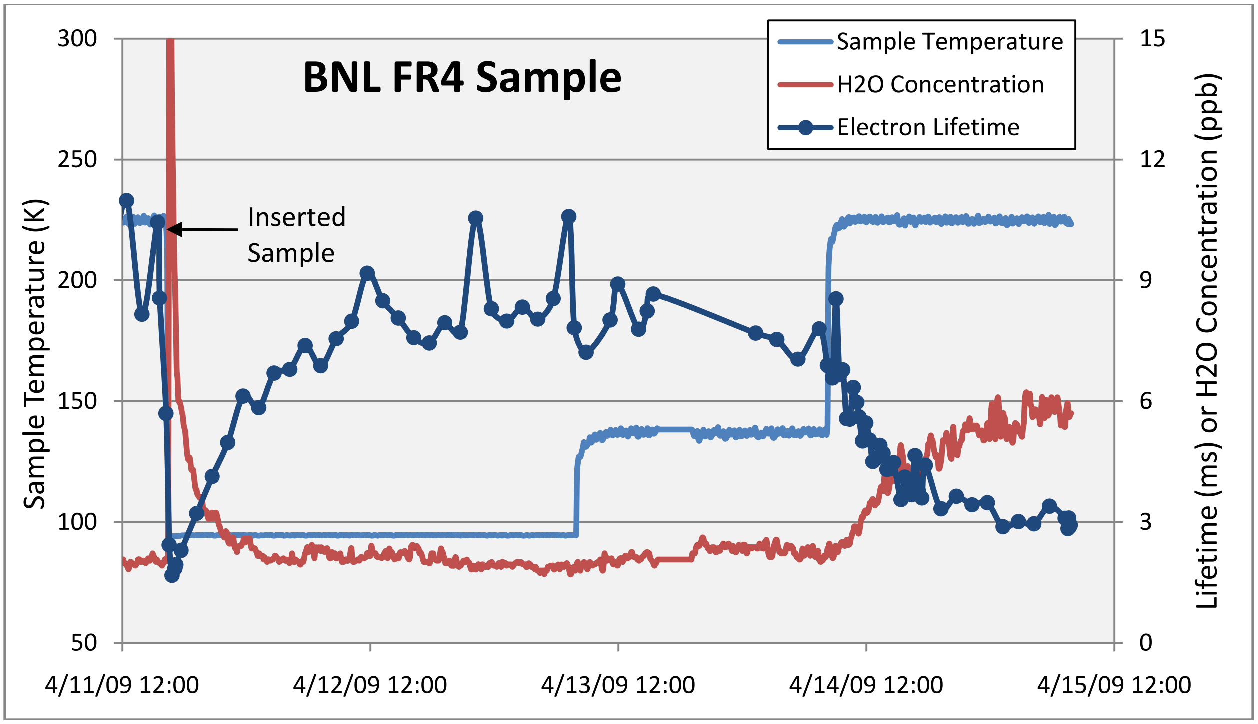

Figure 6: Material Test of BNL FR4 Y-Plane Wire Endpoint. The sample was first lowered into the liquid argon then raised so that the temperature of the sample was increased. When moved to 225 K, the sample began to outgas and the effect on H2O concentration and electron lifetime can be seen. The material test was performed with 17 inches LAr present in the cryostat.

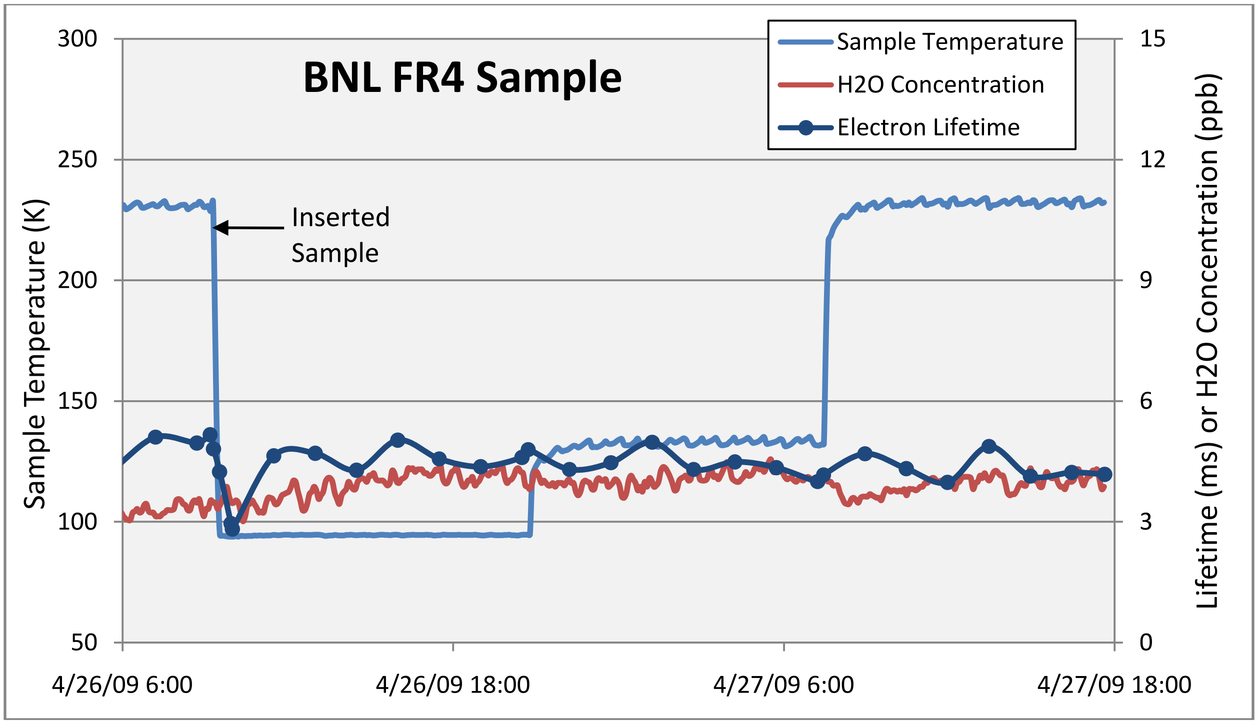

Figure 7: Material Test of BNL Y-Plane Wire Endpoint. The BNL FR4 sample was placed in the airlock and evacuated to 1 mTorr for a few days before being lowered into the liquid. When moved to 225 K, the sample did not outgas any water and had no effect on the electron lifetime. The material test was performed with 13 inches LAr present in the cryostat.

References

1. **Finley, D., et al.** A Large Liquid Argon Time Projection Chamber for Long-baseline, Off Axis Neutrino Oscillation Physics with the NuMI Beam. 2005. FN-0776-E.

2. **Curioni, A., et al.** A Regenerable Filter for Liquid Argon Purification. 2009. arXiv:0903.2066 [physics.ins-det].

3. **Sigma-Aldrich Corporation.** Molecular Sieve Type 4A.

4. **Engelhard Corporation.** MSDS for Cu-0226 S 14 x 20. 2002.

5. **ICARUS Collaboration.** Electron Lifetime and Purity Monitor for the T600 Detector. 2002. ICARUS-TM/02-14.

6. **ICARUS Collaboration**. A Three-Ton Liquid Argon Time Projection Chamber. *Nuclear Instruments and Methods in Physics Research.* 1993. Vol. A 332, pp. 395-412.

7. **Hirsch, Peter Michael.** Electrostatic Charge Generation in Hydrocarbon liquids. 1979. http://dspace.mit.edu/bitstream/handle/1721.1/30985/07183060.pdf?sequence=1.

8. **Dobrozemsky, R., Menhart, S. and Buchtela, K.** Residence Times of Water Molecules on Stainless Steel and Aluminum Surfaces in Vacuum and Atmosphere. *Journal of Vacuum Science and Technology A: Vacuum, Surfaces, and Films.* May 2007. Vol. 25 Issue 3 Pages 551-556.

9. **Tiger Optics, LLC.** HALO CRDS Moisture Analyzer.