

System to Test the Effects of Materials on the Electron Drift Lifetime in Liquid Argon and Observations on the Effect of Water

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Abstract

A material test system (MTS) has been 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 the cryostat pressure with a ‘raining’ condenser reduced the electron drift lifetime in the liquid argon. The effect of condensing has been investigated using a series of passive materials to filter the condensate. We report the results of these studies and of tests on different candidate materials for detector construction. The inferred reduction of electron drift lifetime by water concentrations in the parts per trillion is of particular interest.

Key words: LArTPC, Liquid Argon, Purity

1. Introduction

2 Liquid argon time projection chambers (LArTPCs) offer an opportunity for
3 novel neutrino physics [1, 2]. They can provide bubble-chamber quality event
4 images by drifting ionization electrons created by the passage of charged par-
5 ticles through the liquid to readout planes. Since argon is cheap and plentiful,
6 one can conceive of detectors with multi-kiloton active volumes. A principal
7 challenge for large LArTPCs is the removal of electronegative impurities that
8 capture the ionization electrons. The Material Test System (MTS) has been
9 built at FNAL to develop liquid argon purification techniques [3] and to qualify
10 materials for use in a large LArTPC by measuring their effect on the electron
11 drift lifetime. A photograph of the MTS is included as Figure 1 and a schematic
12 of the MTS cryostat is included as Figure 2.

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Figure 1: Photograph of the materials test system (MTS) at FNAL.

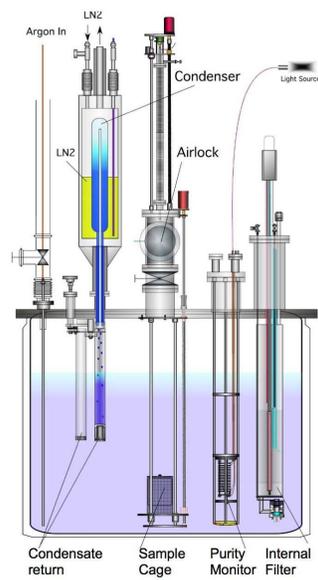


Figure 2: Schematic of the materials test system (MTS) cryostat at FNAL.

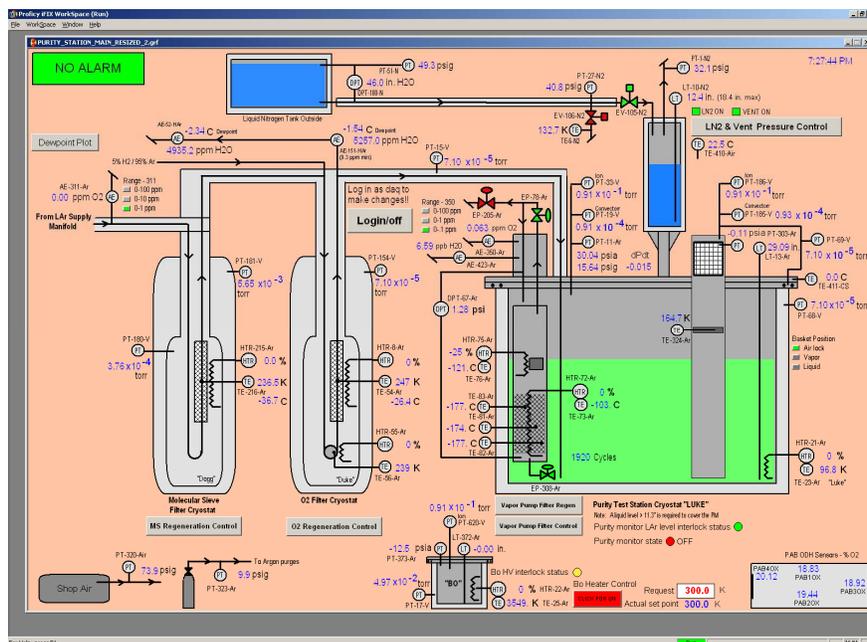


Figure 3: The iFIX graphical user interface for the MTS controls.

2. The Materials Test System

14 The Materials Test System has two major physical components—the argon
 15 source, a single-pass system to provide clean Argon from standard commercial
 16 argon dewars, and the MTS cryostat in which the lifetime and other measure-
 17 ments are made. The supply piping conforms to ASME B31.3 and the cryostat
 18 conforms to ASME Section VIII DIV 1. The components used in the construction
 19 of the MTS are listed in [4].

20 The MTS controls are automated using a Beckhoff Programmable Logic
 21 Controller (PLC). The PLC reads out the pressure, liquid level, various tem-
 22 peratures, and the gas analysis instrumentation. Based upon the monitored
 23 instrument values, the PLC performs tasks such as opening and closing valves
 24 to control the cryostat pressure and sounding audible alarms that alert opera-
 25 tors of undesirable conditions. The PLC communicates with iFIX software run
 26 on a Windows PC. The iFIX software allows entry of temperature and pressure
 27 set points and other operational parameters, displays real-time instrument val-
 28 ues, and archives instrument values for historical viewing. The iFIX graphical
 29 user interface is shown as Figure 3.

2.1. Argon Source

30 Commercial argon [5] is passed through molecular sieve [6] to remove water
 31 and activated copper [7] to remove oxygen and other electronegative impurities
 32

before entering the MTS cryostat. The liquid argon is supplied through vacuum-jacketed $\frac{3}{8}$ inch diameter tubing that consists of both stainless steel and copper sections. Small diameter tubing was chosen to limit the system throughput to match the capacity of the cryostat relief valve. The molecular sieve and activated copper filter material are each housed in $2\frac{3}{8}$ inch diameter stainless steel tubing capped with ConFlat flanges. All valves in the delivery system are metal seal to atmosphere to prevent the diffusion of oxygen through o-ring or stem packing seals. Piping relief valves with o-ring seals have an argon purge on the exhaust to prevent diffusion of ambient. This setup provides liquid argon with an electron drift lifetime of many milliseconds [8].

2.2. MTS Cryostat

The MTS cryostat is a 250 liter vacuum insulated vessel equipped with a Nitrogen-cooled condenser to allow it to operate as a closed system up to a pressure of 35 psig. The cryostat itself contains a lifetime monitor, a dynamic filter, and a set of selectable return paths for the condensed argon. A mechanism is provided for the insertion of materials into the cryostat.

2.2.1. Internal Filter

This novel filter sits in the MTS cryostat and contains a combination of molecular sieve and activated copper. It is used to maintain the purity of liquid 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 [3].

2.2.2. Lifetime Monitor

Modeled after the ‘purity’ monitors of the ICARUS Collaboration [8, 9], this device allows for the direct measurement of the electron drift lifetime.

2.2.3. Condenser to Control Cryostat Pressure

Argon vapor enters the condenser through a central tube and contacts surfaces cooled with liquid nitrogen maintained at 50 psia to prevent argon from freezing on the contact surface. The condensed argon flows down the condenser walls and drips into one of four condenser return paths before entering the bulk liquid. When the condenser is not operating, argon is continuously vented. A closed system is desirable during materials testing so that material-introduced impurities remain in the cryostat and their effect on electron drift lifetime can be observed.

2.2.4. Return Paths for Condensed Argon

A wheel below the condenser allows the selection of a return path for the condensate. There are four paths available: a $1\frac{1}{2}$ inch diameter tube with stainless steel wool enclosed in sintered metal, a similar tube with a disk of sintered glass at the end, a thin spiral tube, and a hole which allows the condensate to fall directly into the bulk liquid. Figure 4 shows details of this system. Other return paths, described in Section 3.1, were used briefly.

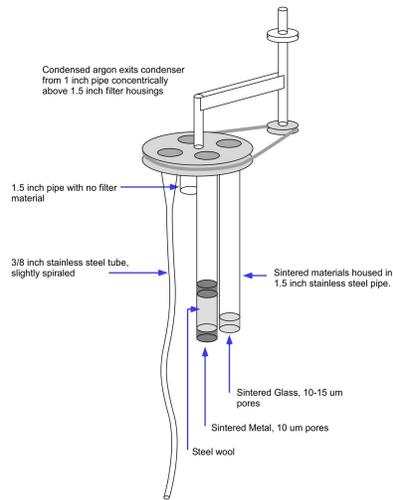


Figure 4: Detail of return mechanism. The return mechanism contains four return paths: a thin tube, a tube that contains sintered glass, a tube that contains steel wool and sintered metal, and a pipe stub with no filter media. The thin tube extends approximately 36 inches into the cryostat, which has a depth of 40 inches. The pipes for the sintered metal and sintered glass extend approximately 20 inches into the cryostat. A handwheel, fed through the top flange of the cryostat, is used to select the return path into which condensate drips.

2.2.5. Mechanism for Material Insertion

74 An airlock, separated from the cryostat by a large gate valve, sits above
 76 the cryostat. A sample material is placed into a sample cage inside the airlock
 and prepared for insertion by purging with clean argon gas from the cryostat
 78 or by evacuation. The gate valve is then opened and the cage lowered into the
 cryostat via a rod attached to the top of the cage. Once in the cryostat, the
 cage is set on a lift platform. The rod is then retracted, the gate valve closed,
 80 and the cage lowered further into the cryostat. The lift platform is equipped
 with an RTD to measure the temperature of the sample.

82 The MTS airlock has the ability to prepare materials for insertion by purging
 with argon because it may not be possible to evacuate the cryostat of a future
 84 large LArTPC. Samples may also be subject to evacuation, but this procedure
 is not routinely used since evacuation might remove contaminants that would
 86 not be removed by purging.

2.2.6. Data Acquisition

88 The data acquisition system for the lifetime monitor consists of a Visual
 Basic program run on a Tektronix 5054NV digital oscilloscope. The system is
 90 fully automated and takes measurements at a user-specified interval. A commu-
 nication program sends the lifetime data to the Ifix interface where it is stored
 92 with the MTS system information.

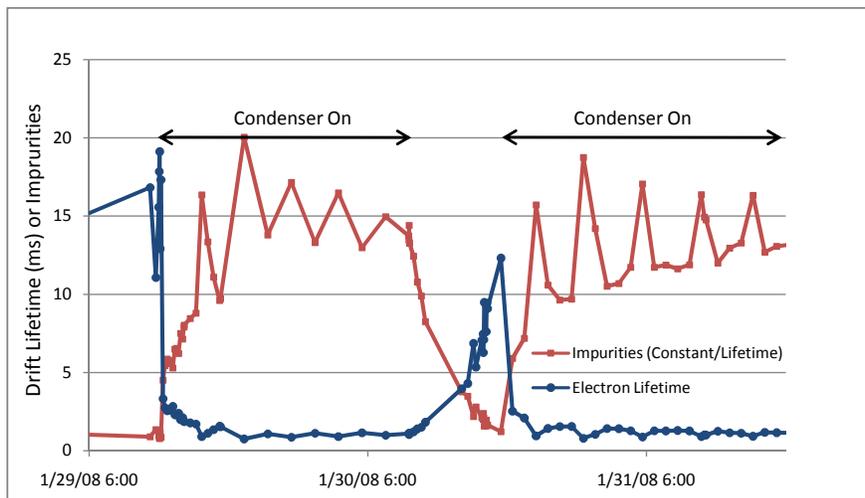


Figure 5: Effect of condenser operation on electron drift lifetime. The impurities, defined as a constant divided by the drift lifetime, represent the physical contaminants in the argon. When the condenser is off, the drift lifetime approaches 20 ms; when the condenser is on, the lifetime quickly degrades to 1 ms or less. The oscillations in the drift lifetime are related to cycling of the condenser.

2.3. Operation

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

98 3. Effect of Condenser Operation on Electron Drift Lifetime

100 After many millisecond electron drift lifetimes were obtained at FNAL with
 an open system [8], the condenser was first used to control the MTS cryostat
 102 pressure in January 2008. The condensate was allowed to drip directly into
 the bulk liquid and it immediately became clear that condensing reduced the
 104 electron drift lifetime dramatically, from ten milliseconds to less than one mil-
 lisecond, as shown in Figure 5¹. This prompted us to begin characterization of
 impurities introduced during condenser operation.

¹When the raining condenser was designed, we were not aware of relevant work done by the ICARUS Collaboration [10] that shows a high impurity concentration in the argon vapor relative to the liquid.

106 *3.1. Characterization of Condensing-Associated Impurities*

108 Since the cryostat had been evacuated to below 10^{-6} Torr and there was
110 little material in the vapor region of the cryostat other than the three coaxial
lifetime monitor cables, it did not seem likely that chemical impurities were
112 introduced into the liquid during condensing. It was initially thought that the
decrease in lifetime was caused by argon ions that formed as the condensate
dripped from the metal surface of the condenser down to the liquid [11].

114 Direct modification of the condenser to bring the condenser return pipe into
the liquid would have been difficult since the condensate return surrounds the
gas inlet. A pipe was therefore installed beneath the outlet of the condenser
116 that contained a section filled with stainless steel wool enclosed by sintered
metal discs, the idea being to discharge any ions. This addition to the system
118 allowed for drift lifetimes of several milliseconds. There was, however, still some
uncertainty in our minds about the action of this new feature. To confirm that
120 ions were indeed the impurity introduced during condensing, the steel wool and
sintered metal section of the return pipe was replaced with a section containing
122 an electrically isolated metal rod at its center. With a potential difference of $1\frac{1}{2}$
kV between the rod and the pipe, any argon ion would have plenty of time to
124 reach an electrode given the flow rate of the condensate through the pipe and
the pipe's physical dimensions.

126 In practice we observed very little difference in lifetime whether the so-
called ion rod was set to be a cathode, or an anode, or grounded directly to the
128 cryostat, implying that the effect of the steel wool and sintered metal was not due
to discharging ions. When the steel wool was examined under a microscope to
130 see if the effect was from trapping some particulate, the material was pristine—
suggesting that if the metal was trapping something, the trapped material had
132 evaporated when warmed to room temperature.

3.2. Characterization of Condensing-Associated Impurities with Return Paths

134 To help understand the effect of condenser operation, a mechanism was
installed beneath the outlet of the condenser that allowed one of four return
136 paths for condensate return. This device is indicated in Figure 2 and detailed
in Figure 4.

138 The different return paths were chosen for their ability to remove ions or
particulate from the condensate. The thin, spiraled tube was designed to stop
140 condensed argon from dripping into the bulk liquid and so prevent the genera-
tion of ions. The sintered glass was chosen for its ability to remove particulate,
142 but not discharge any ions generated as the condensate dripped from the con-
denser into the return path. The sintered metal and steel wool return was used
144 because it had prior success at removing condensing-associated impurities (see
Section 3.1), presumably because it removed both ions and particulate. The
146 hole was chosen to provide a baseline to which to compare the effects of the
other return paths. The length of the sintered glass and sintered metal return
148 tubes was chosen to allow the ends to be uncovered if the argon depth in the
cryostat was below 18 inches—thus forcing the condensed argon once again to
150 drip out of the return and splash into the liquid.

152 The cryostat was initially filled with 29 out of 40 inches of argon, enough to
 153 cover the outlets of all the return paths except the hole. The effect of filtering
 154 the condensate through each of the returns was observed and results are shown
 155 in Figure 6.

156 In order to clarify the effects of the return paths and internal filter opera-
 157 tion, the impurity concentration in the cryostat was modeled using three ‘types’
 158 of impurities, each with different behavior. The unit of impurity is inverse
 159 lifetime—i.e., the impurities are not true concentrations but are characterized
 160 in terms of their effect on the electron drift lifetime.

161 The first class of impurities, base impurities [I1], provides a constant impu-
 162 rity concentration that limits the maximum electron drift lifetime. This vari-
 163 able combines any non-ideal or not-understood behavior of the MTS into one
 164 quantity. The second class, condensing-independent impurities [I2], accumu-
 165 lates as surfaces release contaminants directly into the liquid. The third type,
 166 condensing-associated impurities, accumulates at a rate proportional to con-
 167 denser activity. The first class [I1] is simply a constant in time; see equation
 168 (1). The source of the second class of impurities is modeled to decrease in time
 169 similar to a surface under vacuum and these impurities are removed by the action
 170 of the internal filter—see equation (2). The third type of contamination arises
 171 directly from operation of the condenser. The rate at which these condensing-
 172 associated impurities are added to the liquid is affected by condensing rate and
 173 the return path in use, each of which is assumed to remove a constant fraction of
 174 the impurities from the condensate before returning it to the bulk liquid. Once
 175 the contaminant is in the liquid, it is removed by internal filter operation and
 176 another passive mechanism that is clearly present² (see Figure 6). The time
 177 dependence of this third type of impurity is described in (3).

178 The sum of the three impurity concentrations gives the total impurity con-
 179 centration in the liquid. The electron drift lifetime in milliseconds equals

$$[I1] = \textit{Base Impurities} \quad (1)$$

$$\frac{d[I2]}{dt} = (\textit{Cond. Indep. Source})/t^{1/2} - (\textit{Int. Filter Rate.}) \times [I2] \quad (2)$$

$$\begin{aligned} \frac{d[I3]}{dt} = & (\textit{Cond. Assoc. Source}) \times (1 - \textit{Frac. Removed by Return}) \\ & - (\textit{Int. Filter Rate.} + \textit{Gettering Const.}) \times [I3] \end{aligned} \quad (3)$$

180 The sintered metal and steel wool return path removed a large fraction
 181 ($\approx 90\%$) of the condensing-associated impurities, but the performance of the
 182 other returns did not conclusively distinguish between ions or particulate. Our

²We attribute this to the gettering ability of cold surfaces.

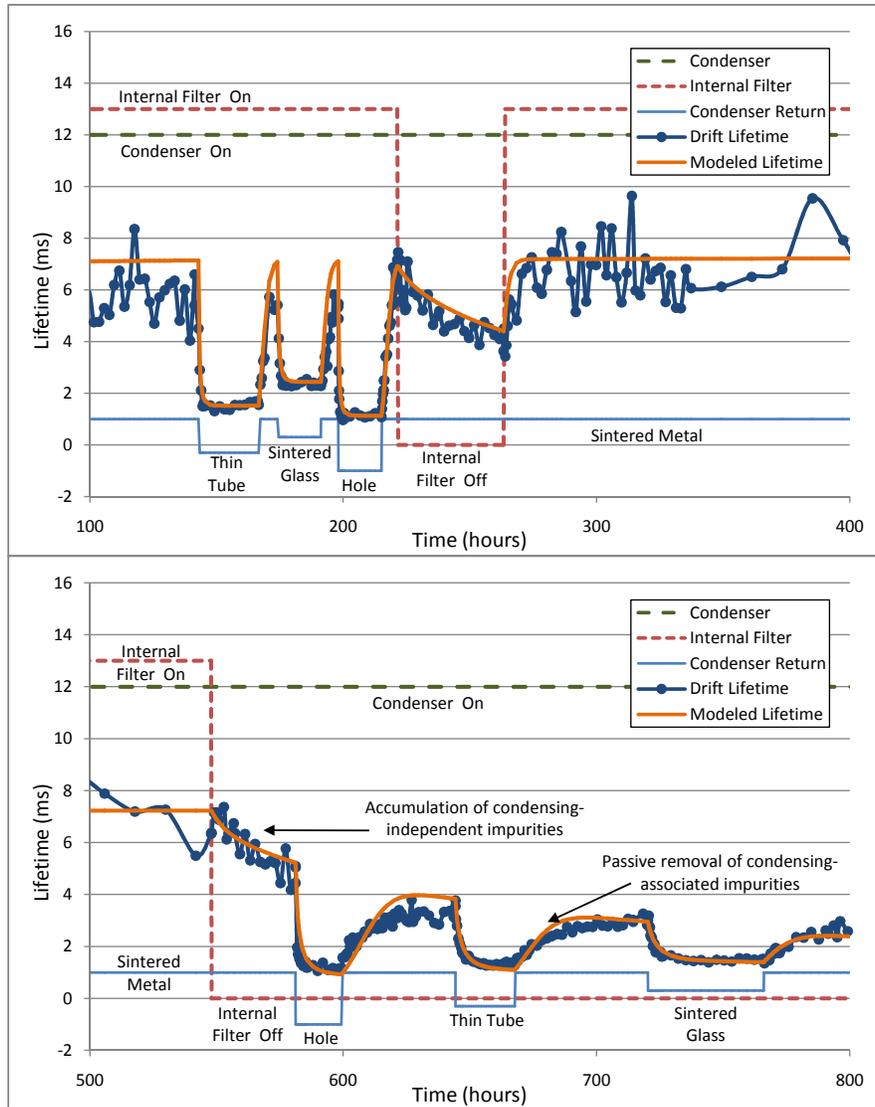


Figure 6: Electron drift lifetime as a function of return path and internal filter operation. The dashed red line and the dashed green line indicate, respectively, internal filter and condenser operation: high for on, low for off. The light blue line and its associated labels indicate which condenser return was in use. The dark blue and orange lines show, respectively, the observed drift lifetime and the modeled drift lifetime. The figure shows the effect of the different return paths on the drift lifetime with the internal filter both on (first part of Figure 6) and off (second part of Figure 6). For reference, when the condenser is off, the drift lifetime is 10–20 ms.

Constant	Value	Units	Comment
Base Impurities	0.07		Determined from drift lifetime while venting with internal filter on.
Condensing-Independent Source	0.027	1/hour	Determined from fit.
Condensing-Associated Source	0.16 or 0.64	1/hour	0.16 if int. filter is off, 0.64 if on. Ratio determined by condenser LN2 consumption.
Fraction Removed by Return	Hole	0	Defined as zero.
	Thin Tube	0.28	Determined from fit.
	Sintered Glass	0.58	Determined from fit.
	Sintered Metal	0.92	Determined from fit.
Internal Filter Rate	0.63	1/hour	Determined from internal filter rate.
Gettering Constant	0.16	1/hour	Determined from fit.

Table 1: Constants for modeled impurity concentration in the liquid of the MTS cryostat. The electron drift lifetime in milliseconds equals $1/([I1]+[I2]+[I3])$. Some values of the parameters were estimated from operational measurements; others were determined from a least-squares fit to the observed drift lifetime.

182 preferred explanation for the observed effects of the return paths is that condensing-
184 associated impurities desorb from ‘warm’ metal surfaces and mix with the argon
vapor. These contaminants are effectively mixed into the condensate and thus
186 into the liquid by the action of the condenser. These impurities also adsorb to
‘cold’ metal surfaces and can thus exit the liquid argon. Return path behavior
188 depends only on the amount of cold metal surface area presented to the condensate.
This explanation accounts for differences in return path performance and
also accounts for the passive removal of condensing-associated impurities from
190 the bulk liquid as they attach to the walls of the cryostat. As a check on this explanation,
the amount of cold metal surface area presented by the return paths
192 to the condensate was decreased by lowering the liquid level in the cryostat to
16 inches, fully exposing the return tubes in the vapor region of the cryostat.
194 The return paths removed fewer condensing-associated impurities in this new
operating condition, as shown in Table 2. The continued success of the sintered
196 metal and steel wool return in this condition also eliminates the possibility of
ions as the condensing-associated impurity. With the lower level of argon in
198 the cryostat, ions would have been generated as the condensate dripped from
the sintered metal return into the bulk liquid and decreased the electron drift
200 lifetime—an effect which was not observed.

3.3. Water as a Candidate for the Condensing-Associated Impurity

202 Condensing-associated impurities that appear in the liquid are removed by
the internal filter. This suggests that the argon cannot be the long-term source

Return Filter	Cold Metal Surface Area Presented to Condensate (cm ²)		Drift Lifetime (ms)	
	29" LAr	16" LAr	29" LAr	16" LAr
Hole	0	0	1.1	1
Thin Tube	150	70	1.5	1.3
Sintered Glass	300	Near 0	2.4	1.2
Sintered Metal	≈5000	≈5000	5 to 8	5 to 8
N/A (Venting)	N/A	N/A	10-20	10-20

Table 2: Electron drift lifetime as related to return path and liquid level. The sintered glass return path had less metal surface area that contacted the condensate and removed fewer impurities at the lower liquid level. This supports the explanation that return path performance depends on the amount of cold metal surface area presented to the condensate.

204 of these impurities. Since the cryostat is evacuated before filling with argon,
the source is unlikely to be in the gas-phase. Water, however, is well known to
206 remain on metal surfaces in vacuum [12] and has an affinity for cold surfaces.

In order to further investigate the effect of water, a Tiger Optics moisture
208 analyzer [13] with a 2 ppb detection limit and a 1 ppb resolution was used to
monitor the water concentration in the MTS cryostat. The argon vapor was
210 monitored for moisture content because the moisture analyzer was not sensitive
to concentrations in the liquid. For example, when using the sintered metal
212 return and operating the internal filter, we estimate the water concentration in
the liquid is $\approx \frac{1}{500}$ of that in the vapor as follows. The sintered metal leaves
214 only $\frac{1}{10}$ of the impurities in the condensate; this ratio is further reduced by the
internal filter, which filters liquid 50 times faster than the condenser adds liquid.
216 The final ratio of the concentrations depends on operational parameters of the
cryostat and associated apparatus and on the condition of the sintered metal
218 return.

To see the effect of exposing warm metal surface on the lifetime and the wa-
220 ter concentration in the argon vapor, the airlock volume was connected to the
cryostat volume after being held under vacuum. The water concentration in the
222 vapor was monitored; the internal filter was operated and the sintered metal re-
turn path was used. The results are shown in Figure 7. The water concentration
224 in the argon vapor increases when the airlock is connected to the cryostat and
this concentration is also an indicator of drift lifetime in that the product of
226 the drift lifetime and water concentration remains roughly constant—providing
initial indication that water may be the condensing-associated impurity.

228 4. Material Tests and Inferred Effects of Water on Electron Drift Lifetime

230 A number of material tests, summarized in Table 3, have been performed
to determine the effect of various materials on the drift lifetime and the role
232 of water. Test materials were inserted into the sample cage in the airlock and

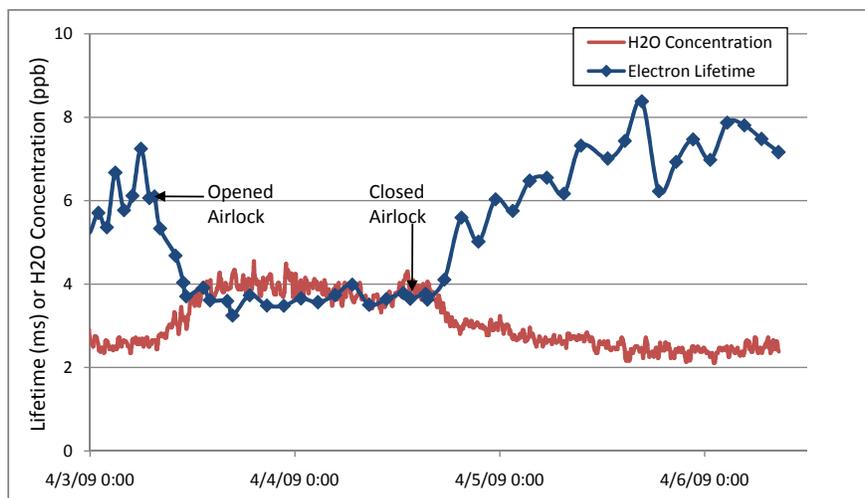


Figure 7: Effect of connecting cryostat and airlock volumes. The cryostat was connected to the airlock by opening the gate valve that typically separates the two. Prior to opening, the airlock was under vacuum. The increase in water concentration is attributed to the additional warm metal surface area in contact with the argon vapor. The relationship between water concentration and drift lifetime is similar to the relationship observed during materials tests (e.g. Figure 8). The material test was performed with 15 inches LAr in the cryostat.

then evacuated and/or purged with argon from the cryostat. The cage with the material was then lowered into the liquid argon and subsequently raised into vapor. The RTD attached to the platform supporting the cage recorded the temperature of the sample. Lifetime data were recorded continuously throughout the process. The internal filter and condenser were operating continuously during these tests and the condensate passed through the sintered metal return.

In general, none of the materials affected the drift lifetime when immersed in the liquid. When in the warmer regions of the vapor space above the liquid, however, some materials produced an increase in the water concentration in the vapor. It was noted that the water concentration in the argon vapor was correlated with the electron drift lifetime in a way similar to that observed when we connected the cryostat and airlock volumes as shown in Figure 8. In fact, the product of the drift lifetime and the water concentration in the Argon vapor was a constant, independent of material: $(\text{Drift Lifetime in ms}) \times (\text{H}_2\text{O Concentration in ppb}) \approx 17$. The increase in water concentration depended on the material and its preparation before insertion. As an example, after evacuation in the airlock for a few days prior to testing, PC board materials had little effect on the water concentration in the argon vapor and hence little effect on the lifetime as shown in Figure 9. These observations suggest that water may be the only significant contaminant introduced by materials.

Material	Sample Surface Area (cm ²)	Effect of Material on Electron Drift Lifetime (LT)			Comments
		94 K liquid	≈120 K vapor	≈225 K Vapor	
Red-X Corona Dope ^a	100	None	None	LT Reduced from 8 to 1 ms; recovery observed.	H ₂ O concentration not monitored.
Deactivated Rosin Flux ^b	200	None	Not Tested	LT reduced from 8 to 1.5 ms recovery observed	H ₂ O concentration not monitored.
FR4	1000	None	Not Tested	LT reduced from 8 to <1 ms	Outgassed enough H ₂ O at 225 K to saturate sintered metal return.
Taconic ^c	600	None	Not Tested	LT reduced.	Sample outgases water at 225 K.
Hitachi BE 67G ^d	300	None	Not Tested	LT reduced; recovery observed	Sample outgases water at 225K; outgassing reduced over time.
TacPreg ^e	200	None	None	LT reduced; recovery observed	Sample outgases water at 225 K; outgassing reduced over time.
FR4, y-plane wire endpoint for uBooNE	225	None	None	LT reduced from 8 to 3 ms	Sample outgases water at 225 K.
FR4, y-plane wire cover for uBooNE	225	None	None	None	Sample was evacuated in airlock prior to testing
Devcon 5-min epoxy	100	None	None	LT reduced from 10 to 6 ms; some recovery observed	Sample outgases water at 225 K.

^aGC Electronics, Part # 10-5002

^bKester Soldering Flux, Formula #1587, heated to approximately 450 F for 1 minute.

^cTaconic #TPG-30-0045-35, Grade TPG-30, Lot #CBD7002 107053001

^dFiberglass laminate of non-halogenated material.

^eTaconic #TLG-30-0600-HH/HH, Lot #10707111B, copper cladding mechanically removed from one side.

Table 3: Summary of material test results. Materials were inserted into the liquid argon then subsequently raised to different temperatures in the argon vapor. The water concentration in the argon vapor and the electron drift lifetime (LT) were monitored during material tests. No effects on the electron drift lifetime were seen with any of the materials while they were immersed in liquid. Most materials began outgassing water and reduced the drift lifetime when raised to 225 K. When maintained at this temperature for several days, outgassing decreased for some materials and there was a corresponding increase in the drift lifetime. The water concentration of the argon vapor was not monitored for the first two material tests. In all of the material tests in which the water concentration was monitored, it was related to the drift lifetime by $(\text{Drift Lifetime in ms}) \times (\text{H}_2\text{O Concentration in ppb}) \approx 17$.

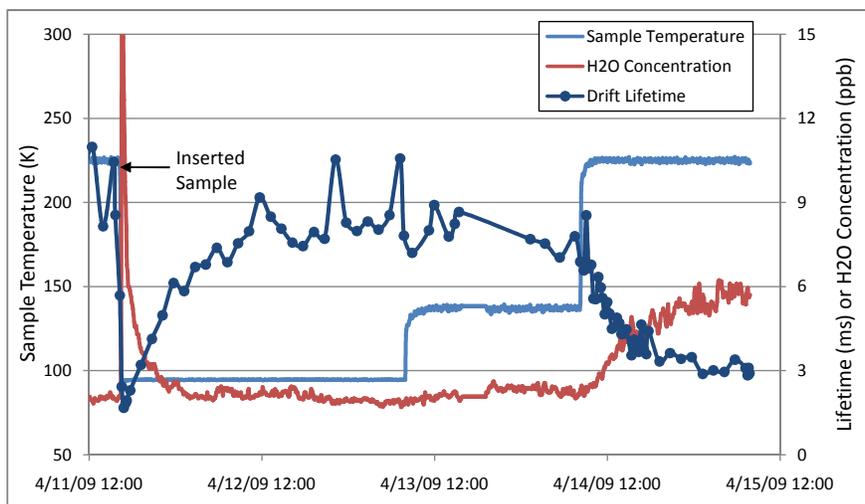


Figure 8: Material test of FR4 y-plane wire holder. The sample was first lowered into the liquid argon then raised so that the temperature of the sample was increased. When moved to 225 K, the sample began to outgas and the effect on water concentration and drift lifetime can be seen in the figure. A similar relationship between water concentration and drift lifetime was observed during other material tests, including the metal surface area test documented in Figure 7. The material test was performed with 17 inches LAr present in the cryostat.

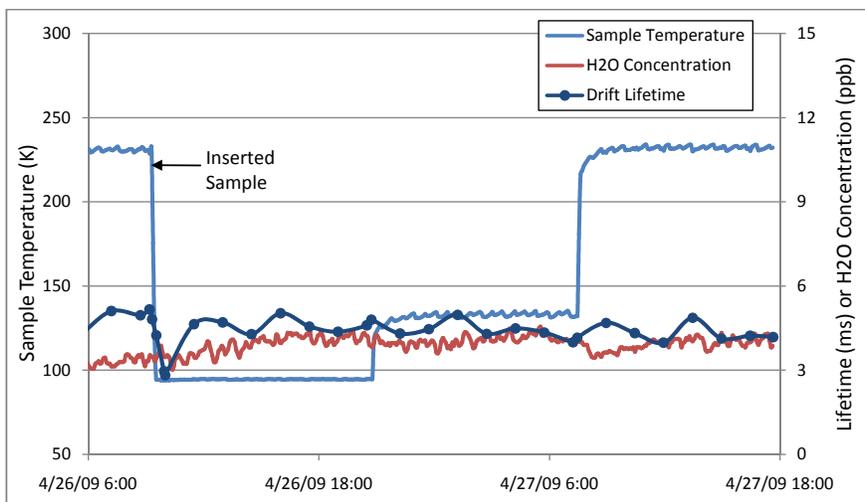


Figure 9: Material test of y-plane wire holder after evacuation. The sample was placed in the airlock and evacuated to 1 mTorr for a few days prior to testing. The sample did not outgas any water and had no effect on the drift lifetime. The material test was performed with 13 inches LAr present in the cryostat. Note that the overall level of water vapor in the system was higher throughout this test and the drift lifetime was correspondingly lower. We attribute this to the lower level of Argon during this test

5. Summary and Conclusions

254 We have built a system (the MTS) to test materials for use in a large liquid
256 argon TPC. The current system uses a raining condenser with different paths
258 for condensate return. We have found that materials inserted into the liquid
260 argon have very little effect on the electron drift lifetime. We have observed
262 a direct relation between the water concentration in the vapor above the li-
264 quid argon and the electron drift lifetime of the form (Drift Lifetime)·(Water
266 Concentration)=a constant. We can affect the water concentration by intro-
268 ducing different materials into the vapor space and the constant is independent
270 of material. We have not directly measured water concentrations in the liquid
272 but we infer that concentrations at the level of tens of parts per trillion affect
274 the drift lifetime. Based on our observations, we think water moves through our
276 system in the following way. Warmer metal surfaces and unevacuated, warm,
and perhaps recently-introduced materials release water into the argon vapor.
Condenser operation introduces the water-contaminated argon vapor into the
liquid of the cryostat where water naturally exits the liquid because of its affin-
ity for cold metal surfaces. It is also removed by operation of an internal filter.
The equilibrium concentration of water in the liquid determines the electron
drift lifetime. We find that exposing the condensate to a large cold metal sur-
face before entry to the bulk liquid can remove much of the water from the
condensate. Water may also be prevented from entering the liquid by filtering
the condensate through a molecular sieve. A condenser system that allows con-
densate to return directly to the liquid will ruin the electron drift lifetime unless
the water concentration in the vapor is well below one part per billion.

6. Acknowledgments

278 The present effort to understand liquid argon as a detection material for par-
280 ticle physics is inspired by the work of the ICARUS collaboration [1]. Recent
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286 of this project and of Ewa Skup in operations and with the construction of life-
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76CH03000.

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