LAPD Run 2 Results and Notes

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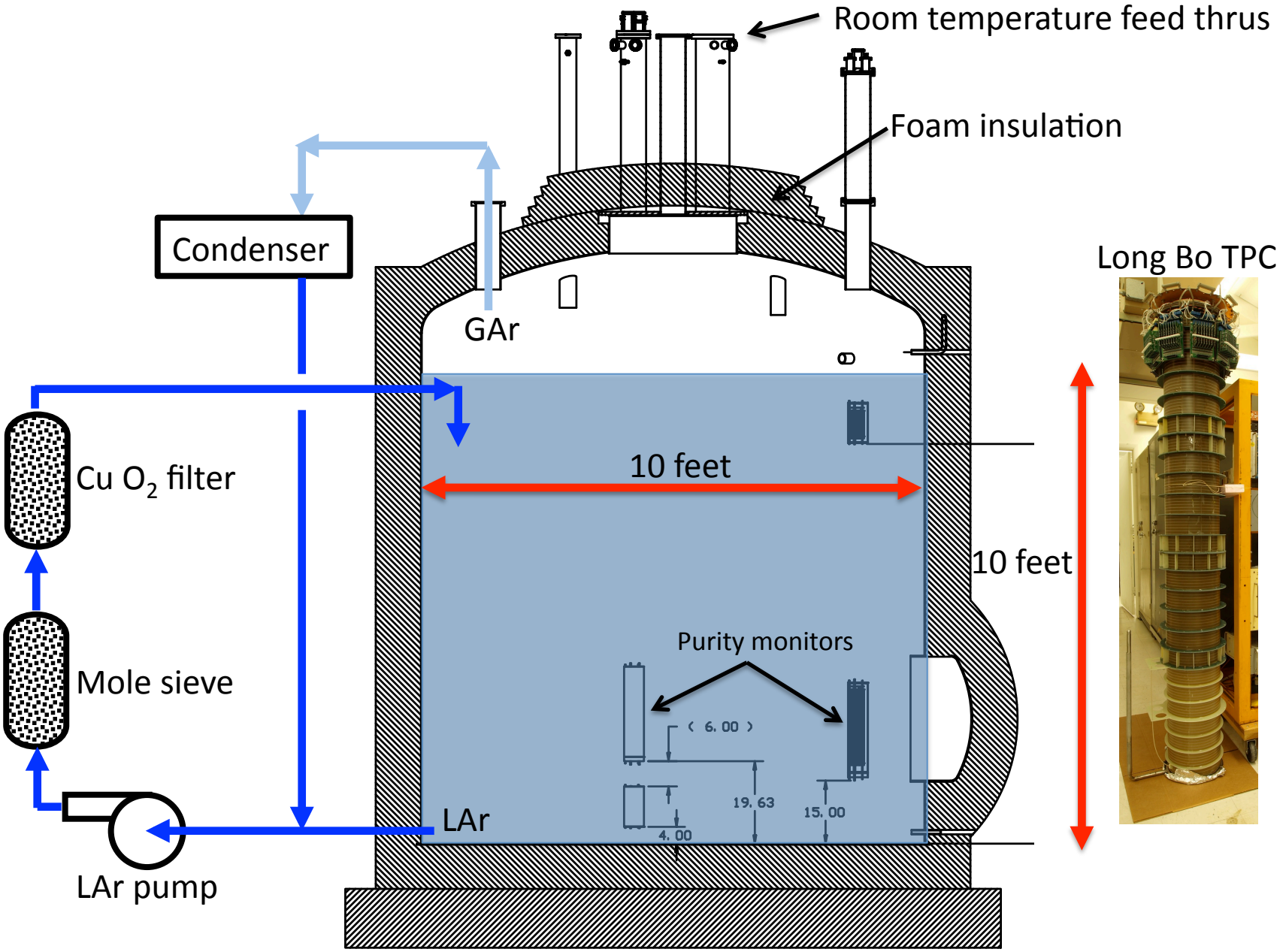
3.19.13

What is the Liquid Argon Purity Demonstrator?

- 30 ton liquid argon tank (5,875 gal, 22,240 L)
- Cannot be evacuated
- 1st run was Winter 2011-2012
  - Achieved 3+ ms lifetime
  - Only filled 1/3 full due to commissioning caution
- 2nd run under way now (started late December)
  - Tank is “full”
  - Includes “Long Bo” TPC with 2 meter drift
  - Has again achieved and sustained 3+ ms lifetime


Room temperature feed thrus
Foam insulation
Condenser
GAr
Cu O_2 filter
Mole sieve
LAr pump
10 feet
10 feet
Purity monitors
6.00
19.63
15.00
4.00
LAr
Long Bo TPC

Filter Regeneration

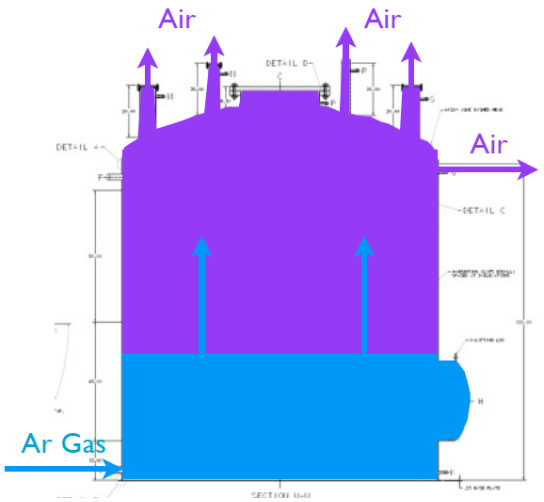
- Copper based oxygen filter
  - External heaters warm a mix of hydrogen and argon gas to 200 C
  - Hydrogen combines with oxygen to create water
  - Hydrogen in Argon at levels > 2.7% is considered flammable by commercial gas suppliers
  - Reaction is exothermic such that the filter self heats
  - If 250 C is exceeded filter may sinter and Cu surface area and thus filter capacity is reduced
  - For the 80 liter LAPD filter size 0.3% H2 in Ar created self heating at a rate of 10 C/hr
  - 2.5% H2 in Ar led to runaway self heating
  - H2 should be slowly bled into the primary argon flow while filter temperature is monitored
  - Filter is evacuated while it cools

Filter Regeneration

- Molecular sieve (4A)
  - External heaters warm inert gas to 200 C
  - If nitrogen is used for regeneration its very hard to remove such that the mole sieve will outgas nitrogen into a purge argon gas stream
  - Filter is also evacuated while it cools

Purge from Air

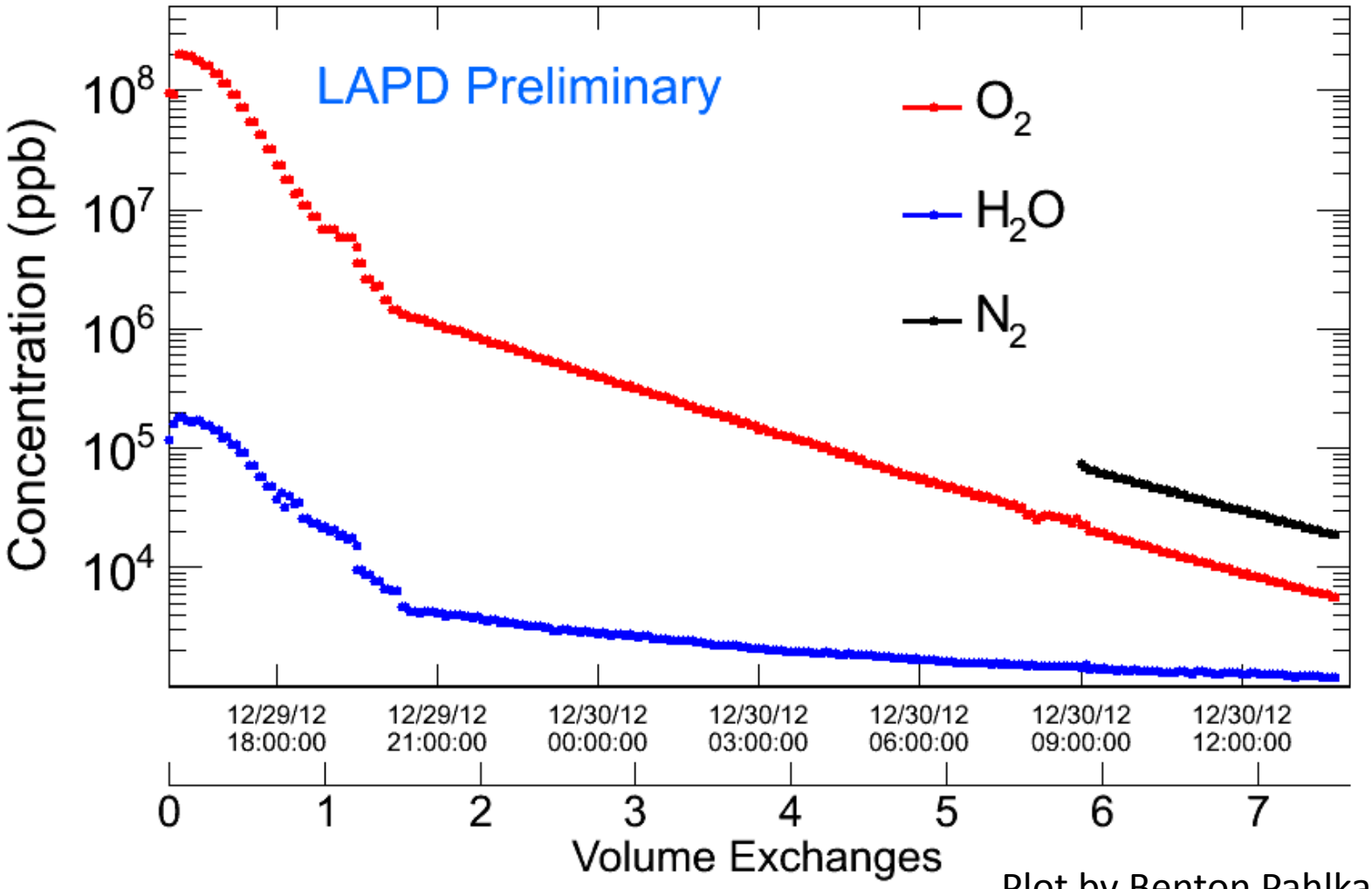
- Room temperature argon gas injected into tank bottom pushes less dense air out the top
- After the argon piston pushes the majority of air out of the tank this becomes a perfect mixing purge
- 5 ft^3/min argon gas injection rate
  - 3.8 ft/hr argon piston rise rate
  - 2.9 hrs per volume change
  - 7.5 total volume changes
- O_2 - 21% to 6 ppm
- N_2 - 78% to 18 ppm
- H_2O – 200 ppm to 1.2 ppm
- *Tank was actively purged with breathable air during the 9 months between runs 1 and 2 to protect from ambient moisture*



Purge from Air

- How important is the purge?
- Due to the 841x mass difference between warm argon gas and liquid argon
  - 6 ppm O_2 vapor contamination adds 7 ppb O_2 to the equivalent liquid volume
  - 18 ppm N_2 vapor contamination adds 21 ppb
- Unlike O_2/N_2, H_2O outgases "forever"
- Must purge out piping and other "dead" volumes attached to the tank that can't be evacuated

Plot of purge from Air to Argon



Plot by Benton Pahlka

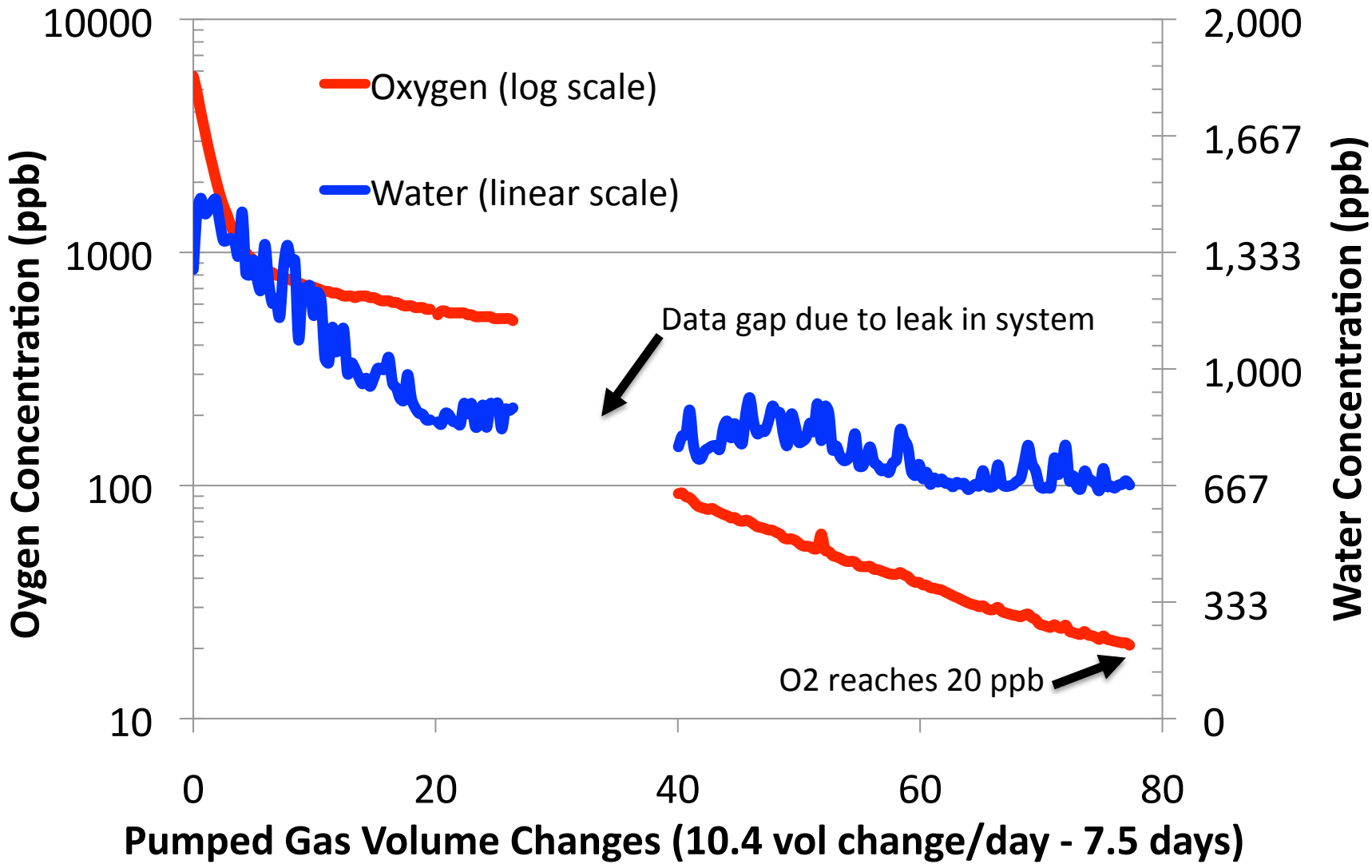
Gas Recirculation

- A bellows pump pulls room temperature argon gas from the feed thrus at the top of the tank
- Gas is pumped thru the mole sieve and oxygen filters at a rate of a volume change every 3.4 hours.
- Same filters/piping used for liquid filtration
- Gas recirculation phase is a useful debugging phase prior to liquid introduction
  - Find leaks missed by other forms of leak checking
  - Verify that filters are properly regenerated
- Commercial gas analyzers are a necessary diagnostic.
  - A leak was found in the system when the recirculation hung up at 520 ppb O2

Gas Recirculation

- Gas recirculation ran for 77 volume changes which is about 1 week
- O_2 was reduced to 20 ppb (still falling)
- H_2O reduced to ~667 ppb and stable
- H_2O outgases “forever” and outgassing rate eventually matches filtration rate
- N_2 is not filtered – its only reduced by the slow dilution of argon makeup gas that replaces gas sent to the commercial analyzers
- N_2 was reduced to 13 ppm

LAPD Run 2 Room Temperature Gas Recirculation



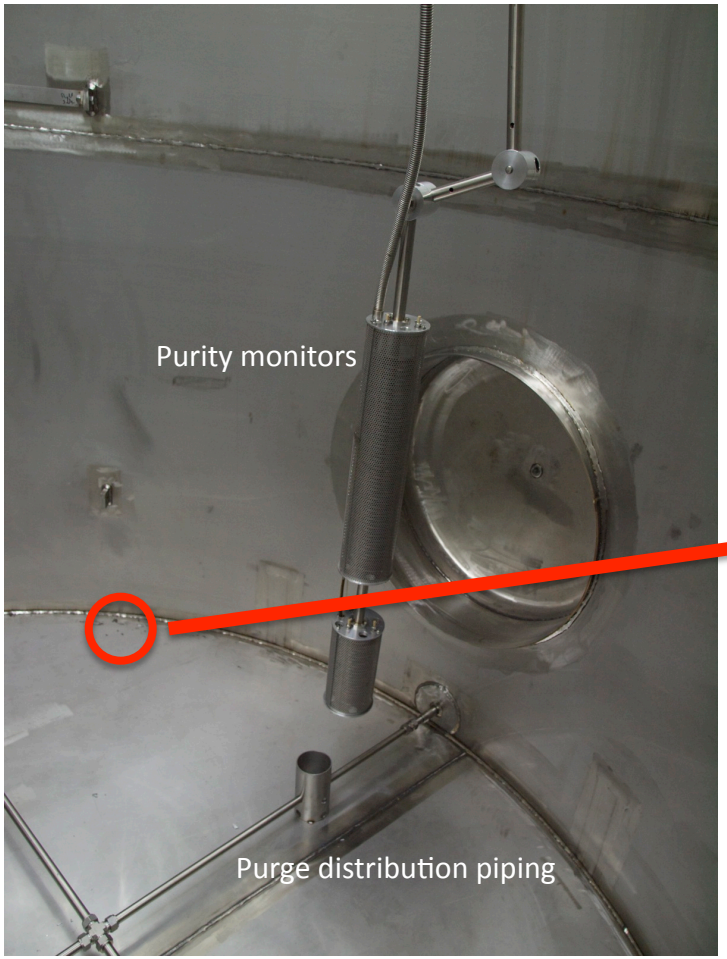
Liquid Fill

- LAPD was filled with LAr from the DZER0 calorimeters in 4 trailer loads
- Important to verify supply LAr contamination prior to system introduction
  - First 5,000 gallon LAr trailer supplied by commercial vendor for LAPD run 1 was rejected
  - It did not meet PO spec and would have led to an impractical # of filter regenerations
  - DZERO LAr contamination (very good)
    - < 200 ppb O_2
    - 8 PPM N_2
    - Unable to measure H_2O in liquid – answer is always zero

Liquid Fill

- Particulate filters to protect tank very important
- Upon entry into LAPD tank after Run 1 shocked by amount of particulate in tank
  - Not a problem for electron lifetime but may be attracted to HV surfaces
- This was despite careful pipe cleaning
- Also recommend pressurizing and then blowing down piping to blast out particulate prior to closure of piping sections
- First Run 2 fill attempt revealed a Kimwipe left in the piping – must be vigilant
- Also 1st LAr trailer load plugged fill line particulate filter

Particulate in Tank After Run 1

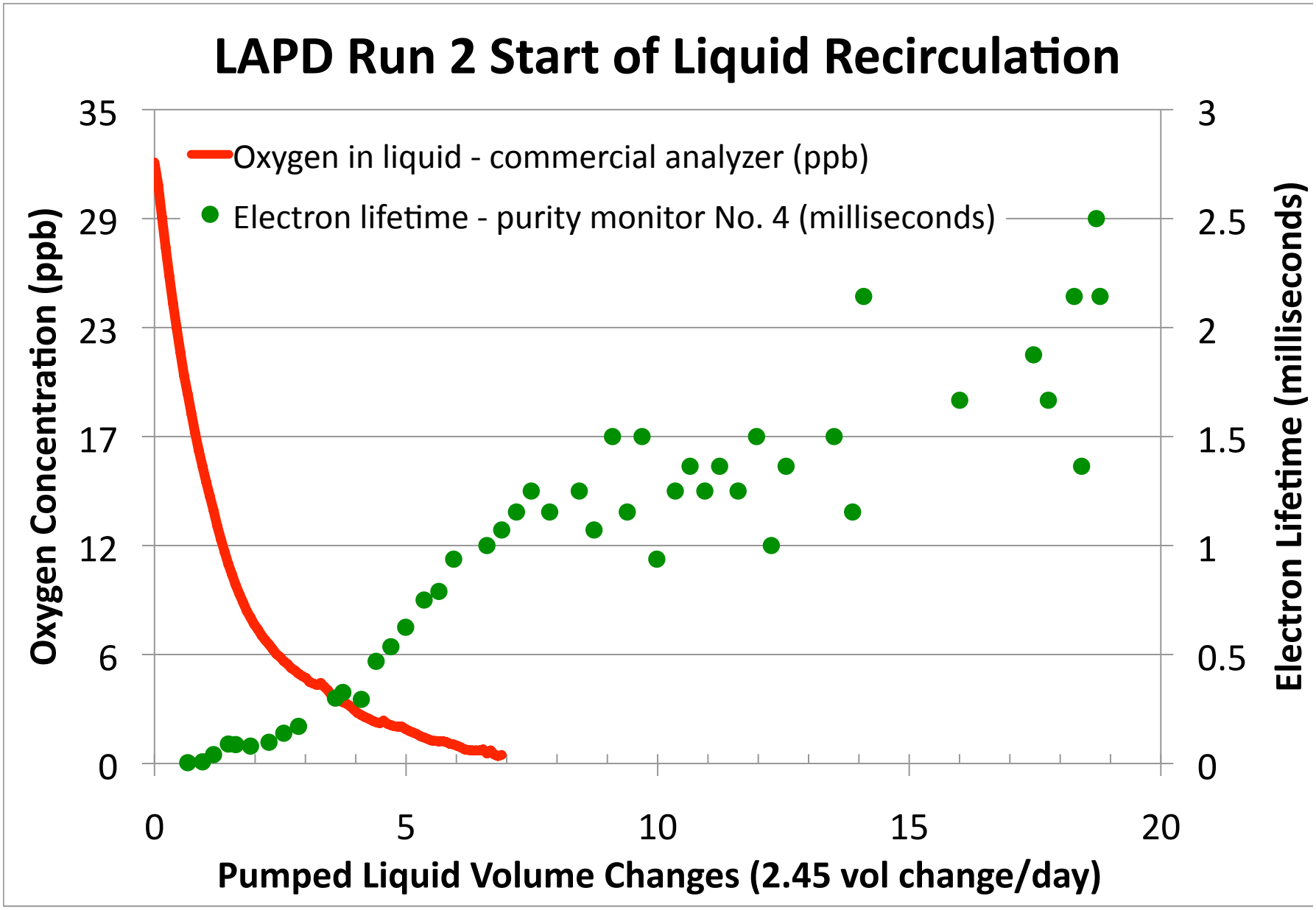


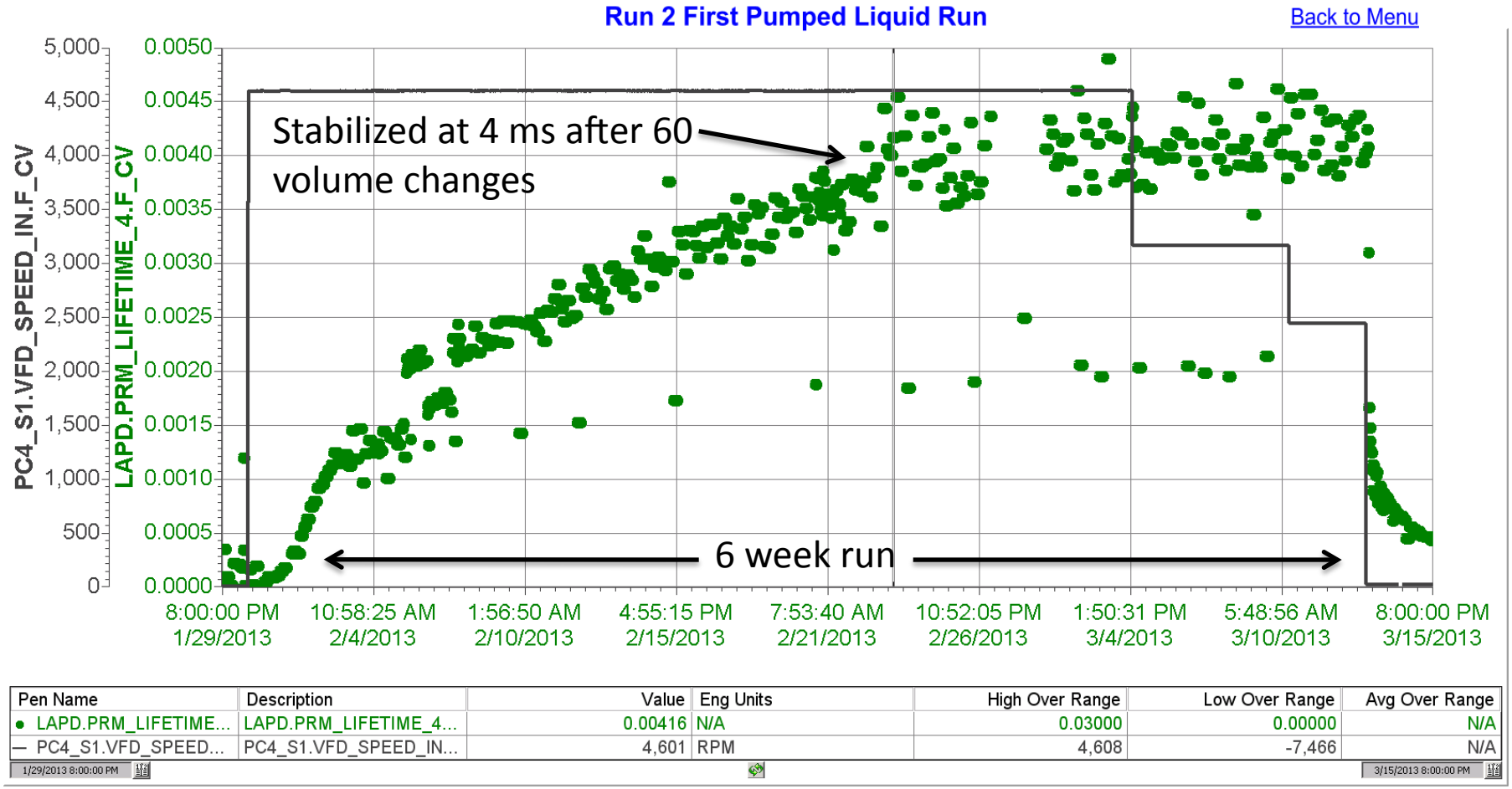
Extraction from Cold Tank

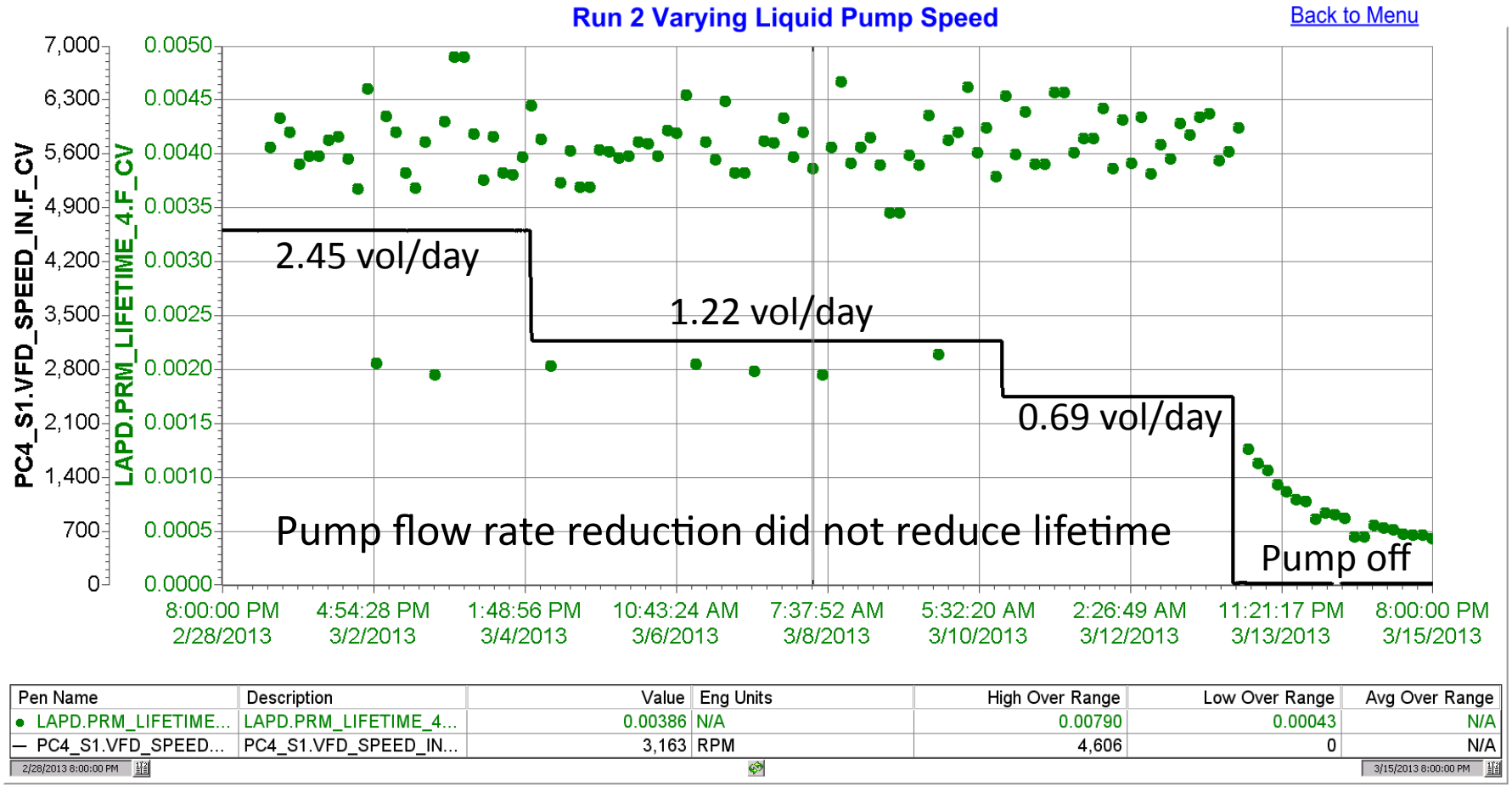
- Prior to the start of liquid recirculation a translating RTD device was removed from the tank liquid (Archimedes' principle)
  - Tank was depressurized to ambient pressure
  - Four inch diameter aperture opened
  - Tank boil off gas vented from aperture into room during device removal
  - Boil off gas should intercept most contamination
  - O_2 in liquid increased from 6 to 26 ppb after extraction
- Conclude devices can be reasonably extracted cold

Liquid Recirculation

- Contamination at the start of liquid recirculation
  - Liquid phase
    - 30 ppb O_2
    - 8 PPM N_2
- Recirculation started at 2.42 vol change/day
- 1 millisecond electron lifetime achieved after 6.6 volume changes
- Stabilized at 4 ms after 60 volume changes
- Reduction of pumping speed did not reduce lifetime
- 6 weeks of successful pumped liquid purification demonstrated


LAPD Run 2 Start of Liquid Recirculation
Oxygen in liquid - commercial analyzer (ppb)
Electron lifetime - purity monitor No. 4 (milliseconds)
Oxygen Concentration (ppb)
Electron Lifetime (milliseconds)
Pumped Liquid Volume Changes (2.45 vol change/day)
35
29
23
17
12
6
0
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20

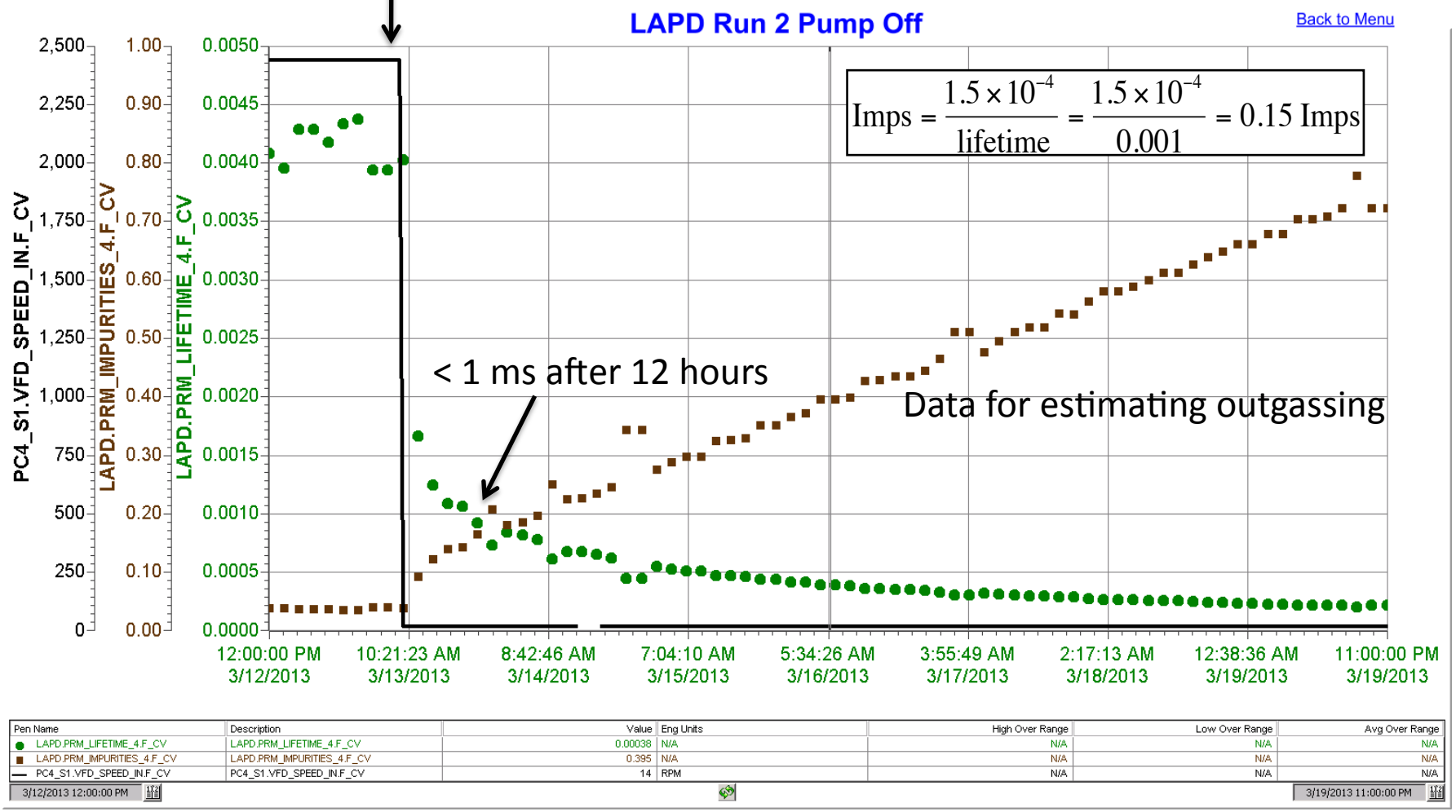

Run 2 First Pumped Liquid Run
Back to Menu
PC4_S1.VFD_SPEED_IN.F_CV
LAPD.PRM_LIFETIME_4.F_CV
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0.0050
0.0045
0.0040
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
Stabilized at 4 ms after 60 volume changes
6 week run
8:00:00 PM 1/29/2013
10:58:25 AM 2/4/2013
1:56:50 AM 2/10/2013
4:55:15 PM 2/15/2013
7:53:40 AM 2/21/2013
10:52:05 PM 2/26/2013
1:50:31 PM 3/4/2013
5:48:56 AM 3/10/2013
8:00:00 PM 3/15/2013
Pen Name | Description | Value | Eng Units | High Over Range | Low Over Range | Avg Over Range
LAPD.PRM_LIFETIME... | LAPD.PRM_LIFETIME_4... | 0.00416 | N/A | 0.03000 | 0.00000 | N/A
PC4_S1.VFD_SPEED... | PC4_S1.VFD_SPEED_IN... | 4,601 | RPM | 4,608 | -7,466 | N/A
1/29/2013 8:00:00 PM
3/15/2013 8:00:00 PM



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range	Avg Over Range
● LAPD.PRM_LIFETIME...	LAPD.PRM_LIFETIME_4...	0.00386	N/A	0.00790	0.00043	N/A
— PC4_S1.VFD_SPEED...	PC4_S1.VFD_SPEED_IN...	3,163	RPM	4,606	0	N/A

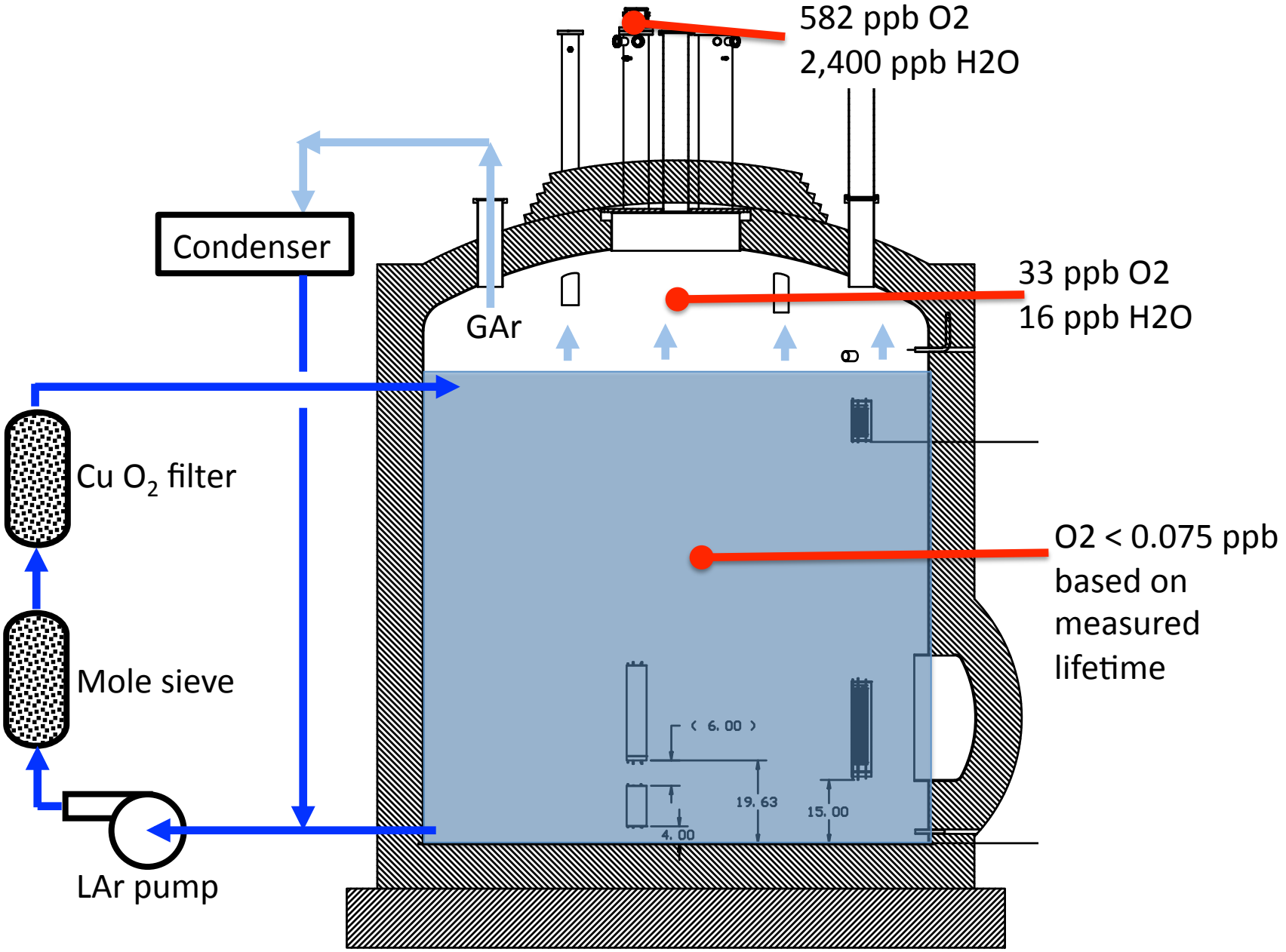
2/28/2013 8:00:00 PM 3/15/2013 8:00:00 PM

Pump off – “dirty” condensed LAr returns to tank unfiltered



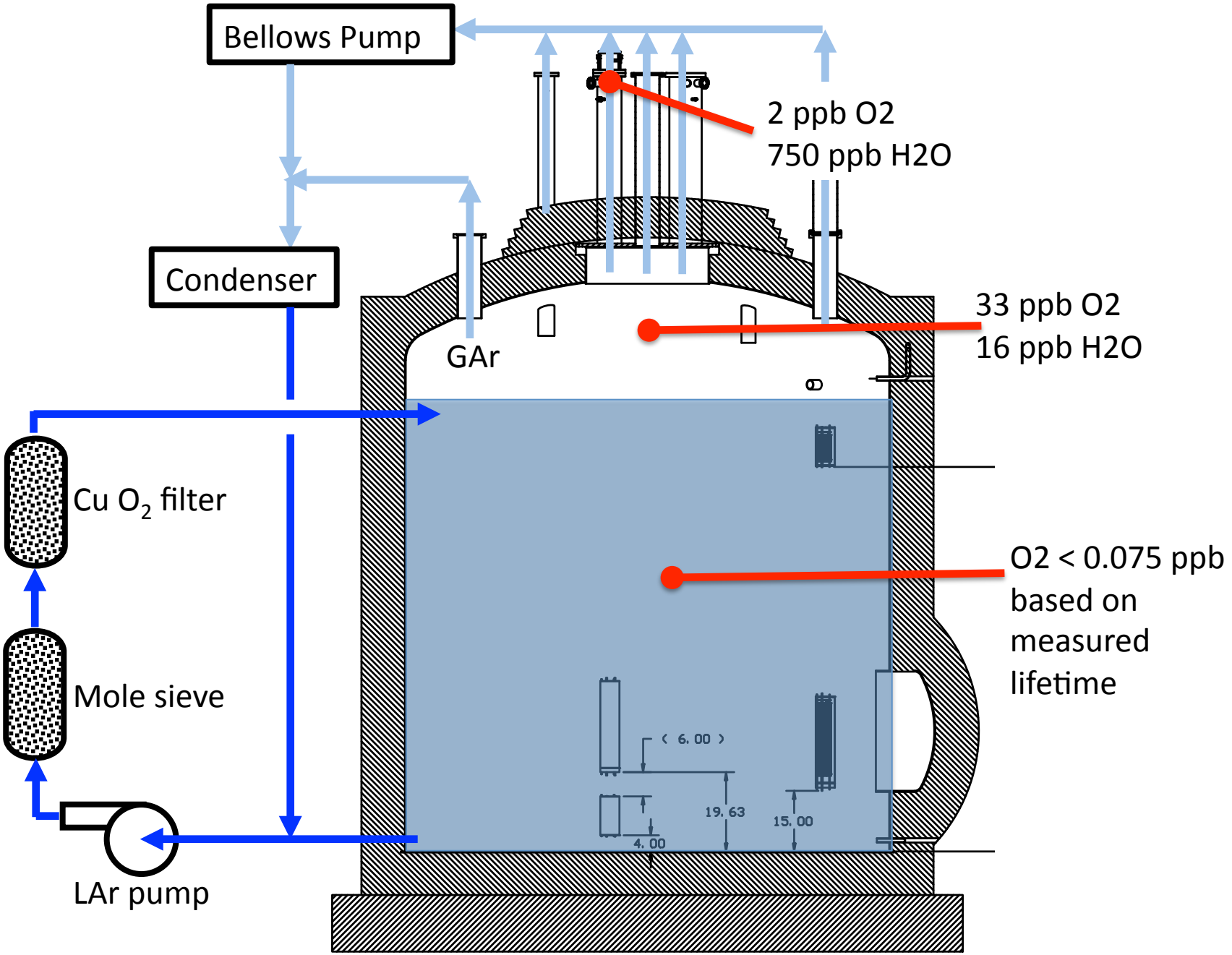
Warm Feed Thrus

- For most of the 2nd run the warm feed thrus have been stagnant
- Sampling at the TPC signal feed thru
  - 582 ppb O2
  - 2,400 ppb O2
  - Sample flow rate gives 300 vol change/day
- Despite this gross contamination, liquid a few feet below is ultra clean
- Conclude boil off gas intercepts contaminants diffusing out of signal feed thru risers

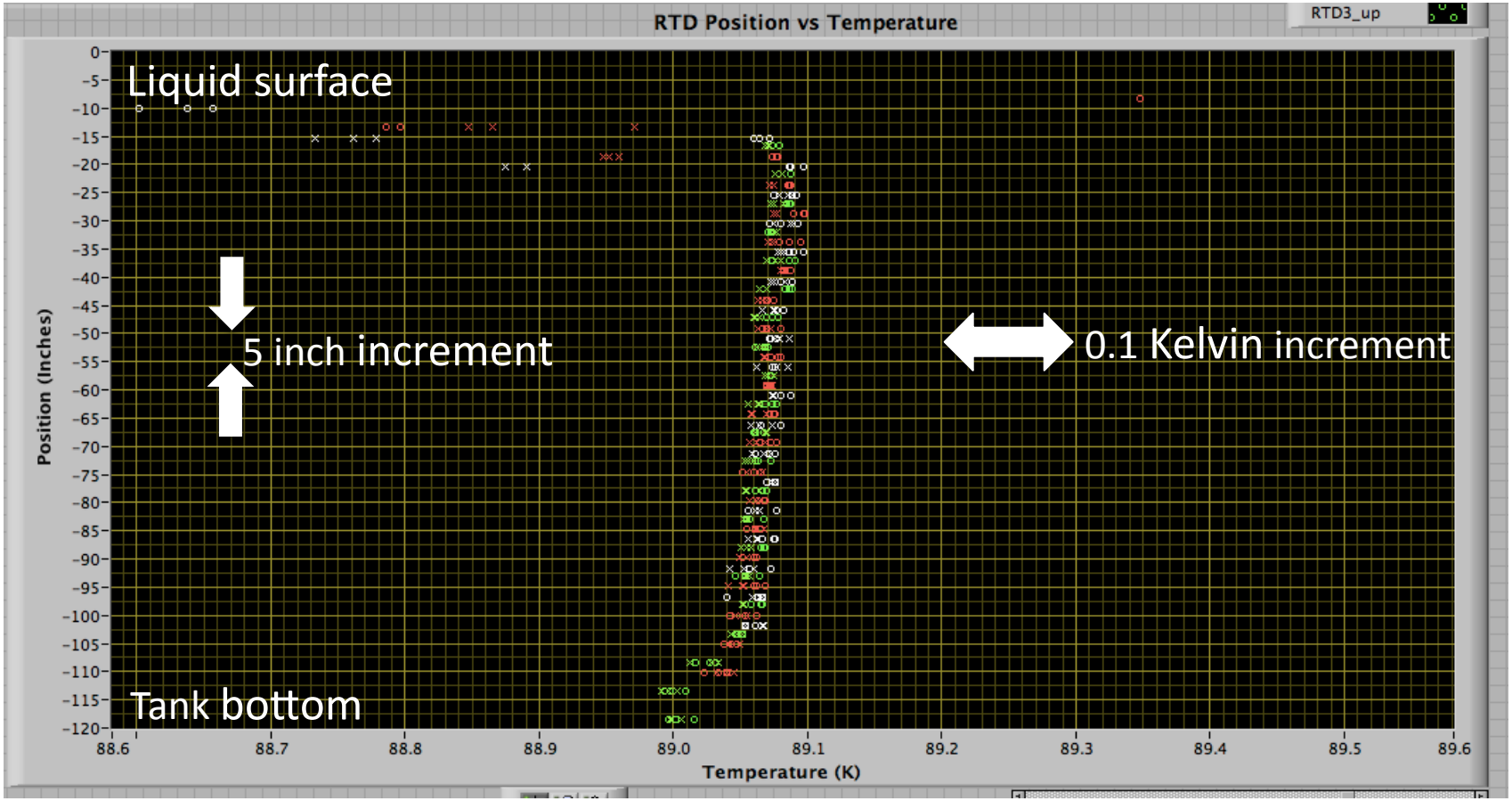

582 ppb O2
2,400 ppb H2O
Condenser
GAr
33 ppb O2
16 ppb H2O
Cu O_2 filter
Mole sieve
O2 < 0.075 ppb
based on
measured
lifetime
LAr pump
6.00
19.63
15.00
4.00

Warm Feed Thrus

- Used a bellows pump to pull gas thru all of the warm feed thrus and send the gas to the condenser
- Sampling at the TPC signal feed thru during pumping
  - 582 ppb O2 reduced to 2 ppb
  - 2,400 ppb O2 reduced to 750 ppb
  - Bellows pump gives 3,500 vol change/day
- Actively pulling contamination from risers did NOT improve liquid electron lifetime
- Conclude (again) boil off gas intercepts contaminants diffusing out of signal feed thru risers

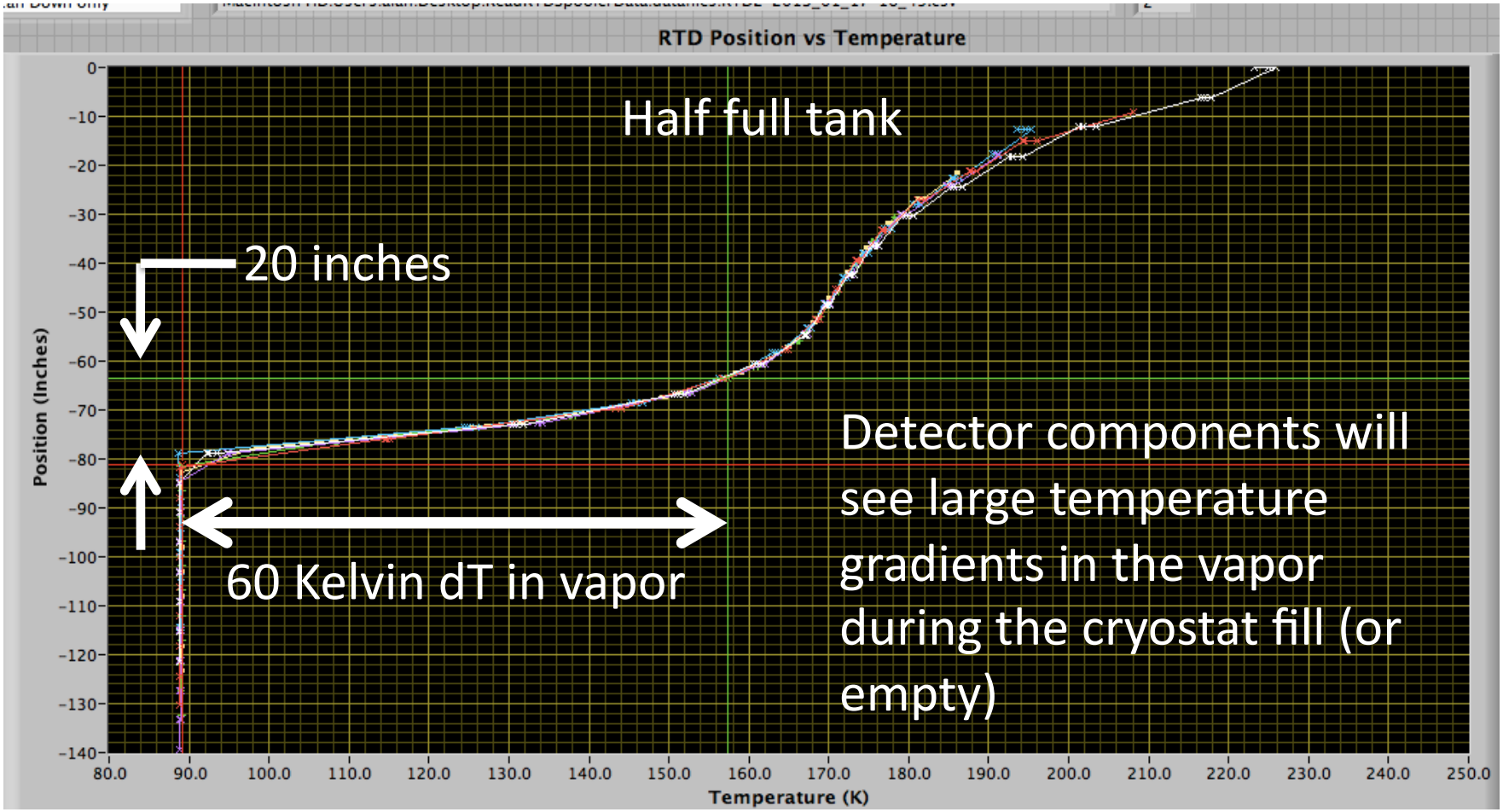

Bellows Pump
2 ppb O2
750 ppb H2O
Condenser
GAr
33 ppb O2
16 ppb H2O
Cu O_2 filter
Mole sieve
O2 < 0.075 ppb
based on
measured
lifetime
LAr pump
6.00
19.63
15.00
4.00

Bulk Liquid Temperature



Plot and measurements by Alan Hahn

Vapor Temperature Gradient



Plot and measurements by Alan Hahn

Future Work

- Filter capacity tests
  - During 1st run filters saturated in 2 weeks
  - During 2nd run filters did not saturate after 6 weeks
  - Injection of contaminants
- Modeling of contamination inside of tank
- Thanks to the many many people who have supported LAPD