Argon Purification: Lessons from Icarus and Design of a Purification System for a Very Large Detector

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FLARE Workshop, November 3

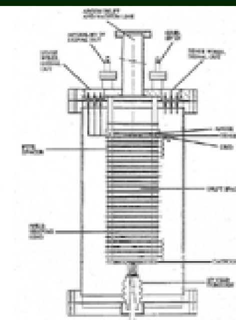
Outline

- Liquid Argon Time Projection Chamber: a mature technology
- Neutrino oscillations opportunities with the NuMI beam
- Liquid Argon detector for the NuMI off-axis experiment
- 'Other' physics with the LAr detector

➢ FLARE: Fermilab Liquid Argon Experiments. Letter of Intent P942, http://www-off-axis.fnal.gov/flare
➢ FLARE Workshop: 'All about Liquid Argon Detectors', Fermilab, November 4-6

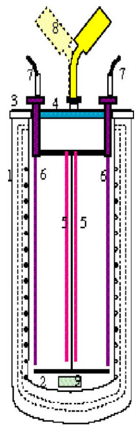
Many years of intense R&D

24 cm drift wires chamber



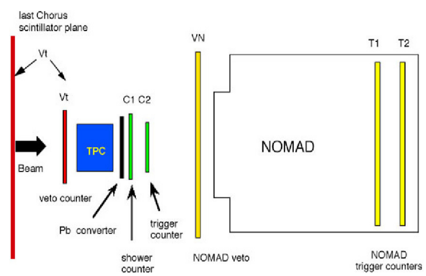
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

50 litres prototype
1.4 m drift chamber

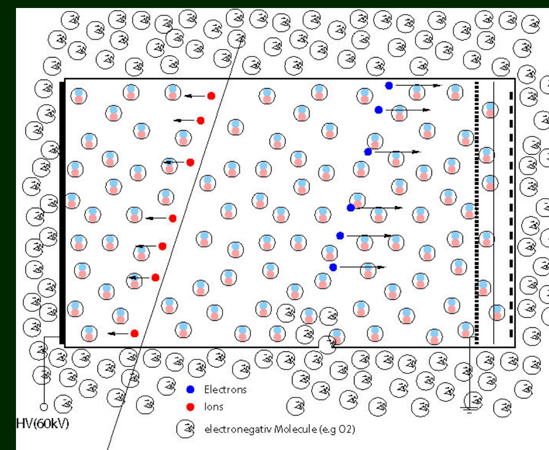


1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

10 m^3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

Drifting electrons over long distance (3m)?



- V_{drift} = f(E). Use E= 500 V/cm
  - ✓ HV across the drift gap = 150 kV
  - ✓ V_{drift} = 1.55 mm/μsec
  - ✓ t_{drift} = 2msec
- Number of collisions/sec ~10^{12}
  - ✓ 2×10^{9} collisions along the longest path
  - ✓ 'none' of them must 'eat' an electron
  - ✓ Concentration of electronegative (O_2) impurities < **10^{-10}**
- Rule of thumb: 1 ppb←→ 250 μsec, 10 msec ←→ 25 ppt

Measuring argon purity below 0.1 ppb ?

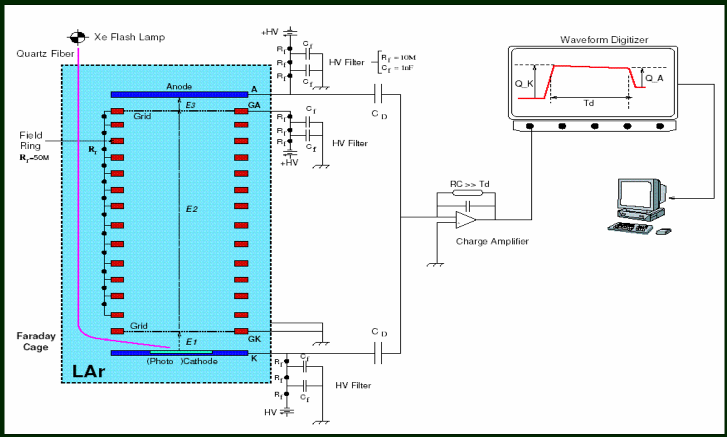
- Best commercial O_2 gauge: least count 0.2 ppb (not bad at all, but nut good enough)
- How do you know that there are no other impurities, not detectable with your purity ,monitors, which absorb electrons (remember MarkII?)
- Electron lifetime detector

Carugno,Dainese,Pietropaolo,Ptohos

NIM A292 (1990) 580:

- ✓ Extract electrons from a cathode
- ✓ Drift over a certain distance
- ✓ Measure charge along the path

$$Q(t) = Q_0 e^{-\frac{t}{\tau}}$$

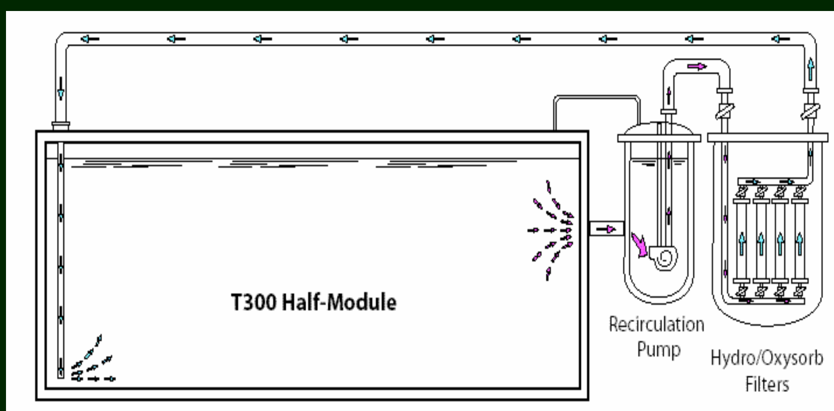


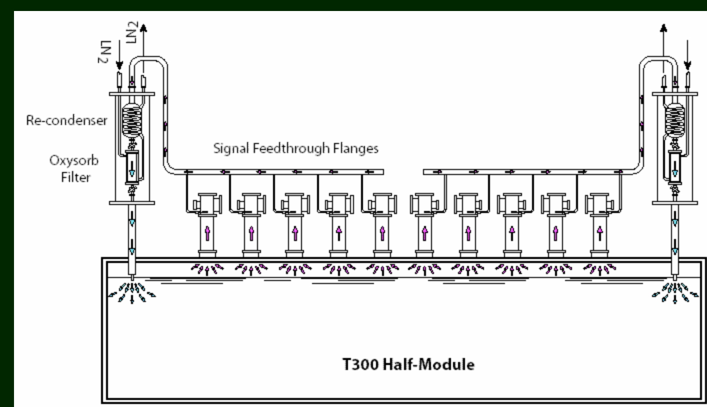
Argon purification: early attempts

- Use commercial filters/getters designed to purify gaseous argon inserted into a corcuit for argon boil-off recovery
- Works, albeit slowly
- A major breakthrough: (at least some of) these can be applied to purify liquid (need cryogenic cartridges/lines)
- Much larger mass can be purified, much shorter time constant.

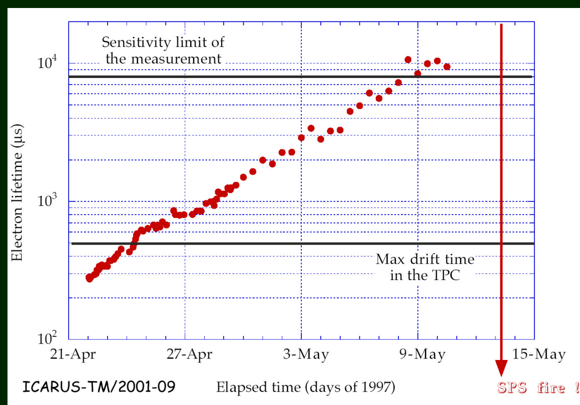
Argon purification: liquid and gas phase

- Re-circulate liquid/gaseous argon through standard Oxysorb/Hydrosorb filters (R20 Messers-Griesheim GmBH)
- ICARUS T600 module:
  - ✓ 25 Gar m^3/hour/unit
  - ✓ 2.5 Lar m^3/hour





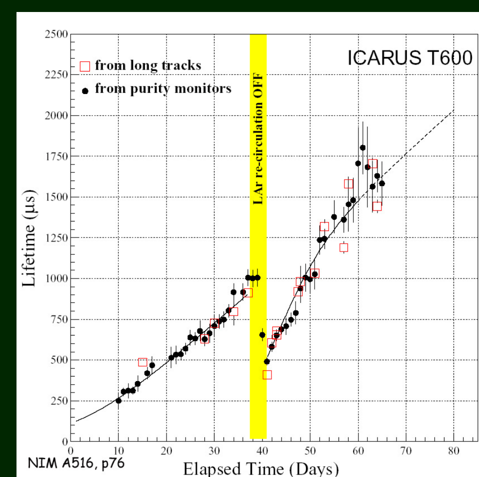
Argone purity/electron lifetime in real life ?



$$\frac{dN}{dt} = -\Phi_{out}(t) + \Phi_{in}(t) =$$

$$-\frac{N(t)}{\tau_c} + \Phi_{in}^{0} + \frac{A}{(1+t/t_0)^B}$$

- Impurities concentration is a balance of
  - ✓ Purification speed τ_c
  - ✓ Leaks $\Phi_{in}(t)$
  - ✓ Outgassing A, B
- For a T600 module: asymptotic purity/lifetime > 13 msec

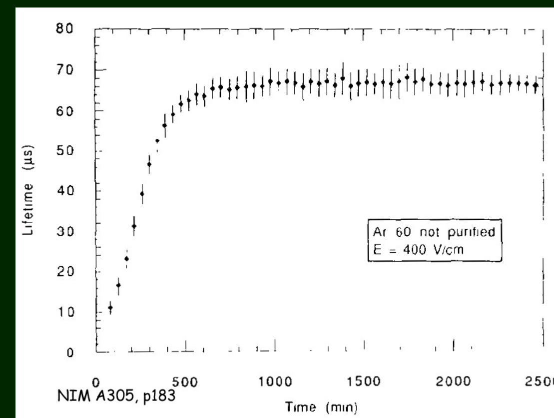


Argon purity, ctnd.

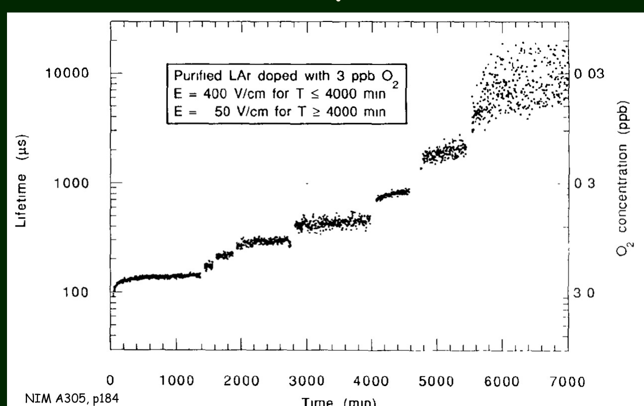
Q:Oxisorb R20 filters have design purity level of <5 ppb. How come that the results are so good (<0.1ppb)?

A: Specs refer to gaseous argon at NTP.

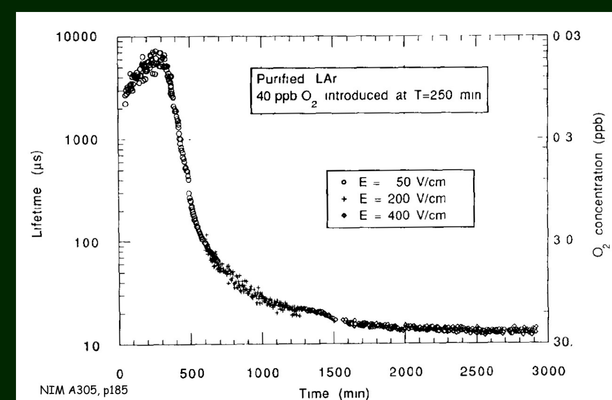
In a liquid phase impurities 'freeze out' at the vessel walls. The natural purification speed is limited by diffusion speed. (Related: B. Kephart, E706)



Electron lifetime improvement in 'regular argon'



Electron lifetime in ultra-pure argon doped with oxygen



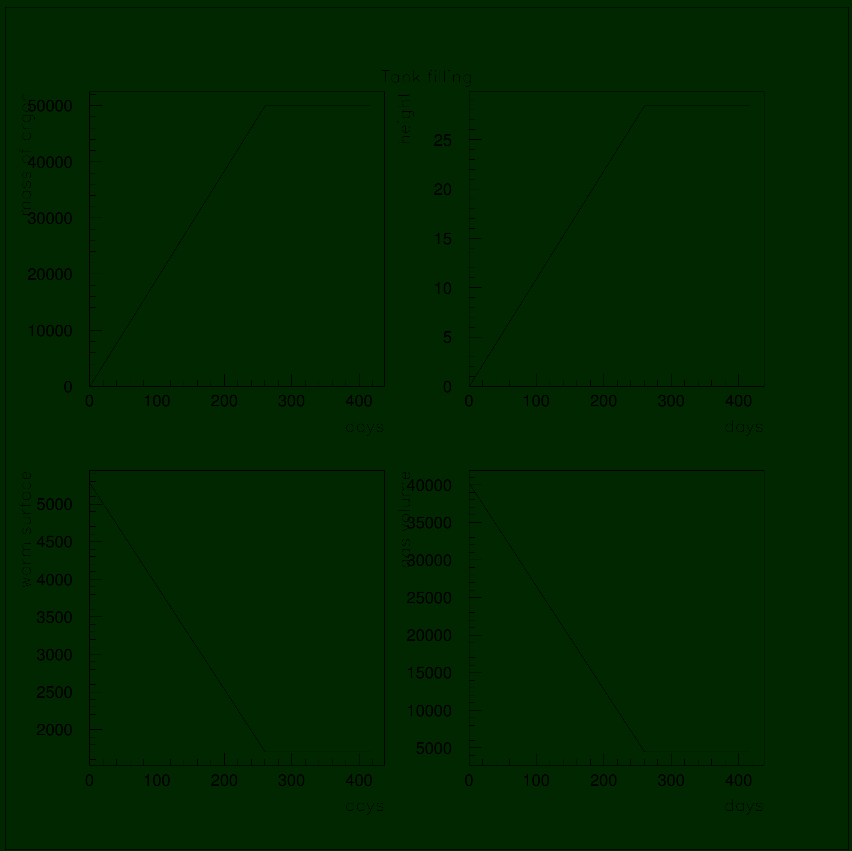
Degradation of argon purity is consistent with diffusion time

Argon purity, lessons for a very large detector

- Long electron lifetimes (~10ms)/drift distances (>3m) appear achievable with commercial purification systems
- The main source of impurities are the surfaces exposed to the gaseous argon
- Increasing the ratio of liquid volume to the area of gaseous contact helps (dilution)
- Increasing the ratio of cold/warm surfaces helps (purification)
- Role of the walls must be well understood, though, if they provide the critical step in argon purification (capacity, saturation, treatment, evacuation..)

A toy model for a very large tank operation

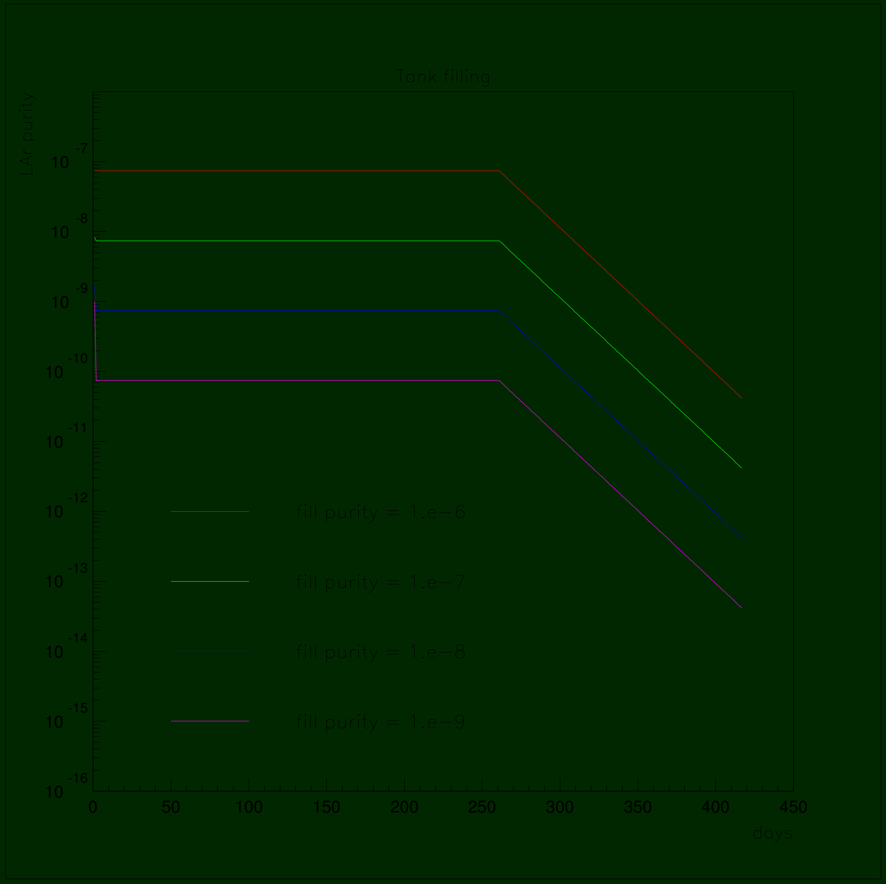
- Argon is delivered to small holding tanks. It is purified there to ensure its 'purifiability' and it is subsequently transferred to the main tank at the rate of 8t/hour.
- At the end (after 270 days):
  - ✓ total area of warm surface is 1700 m^2
  - ✓ Volume of gaseous argon is 4500 m^3



Argon pre-purification?

- Assume recirculation system in the main tank with capacity of 100 t/hour
- Oxygen level during the fill is an equilibrium between

  the new oxygen introduced with the newly pumped argon and the oxygen absorbed by a purifier. This level corresponds to ~7% of the purity of the incoming argon. After the fill is completed the purity leve improves by a order of magnitude every 50 days



More realistic model

- Liquid argon recirculation through a purifying system: 100 t/hour
- Gaseaus argon recirculation through a purifier: 1000 m^3/hour
- Oxygen balance in a liquid volume:
  - ✓ Inflow:
    - Oxygen coming with the initial fill of argon
    - Oxygen diffused from the gas phase
  - ✓ Outflow:
    - Oxygen absorbed by a purifier
- Oxygen balance in a gas volume
  - ✓ Inflow:
    - Outgassing from warm tank surfacs
    - Outgassing from cables
    - Inflow from leaks
  - ✓ Outflow:
    - Oxygen absorbed by filtering system
    - Oxygen transferred to a liquid phase

Some important facts

- In equilibrium at the liquid/gas interface oxygen concentration (per unit mass) is the same (within 10%) in the liquid the gas phase (R. Schmitt). Owing to the difference in densities practically all oxygen ends up in the liquid.
- Mixing of the ago in a tank is quite rapid. Vertical movement of the liquid is about 1 m/hour near the surface (Z. Tang) Liquid acts as a 'sponge'.
- Outgassing is reduced with time like 1/t. Only ~1% of the outgassed material is oxygen (somewhat time dependent).
- Surface of warm walls is 50% bigger than that of cables. Outgassing of walls depends on the treatment/cleaning procedure. In the following we will assume that the steel outgasses as much as cables.

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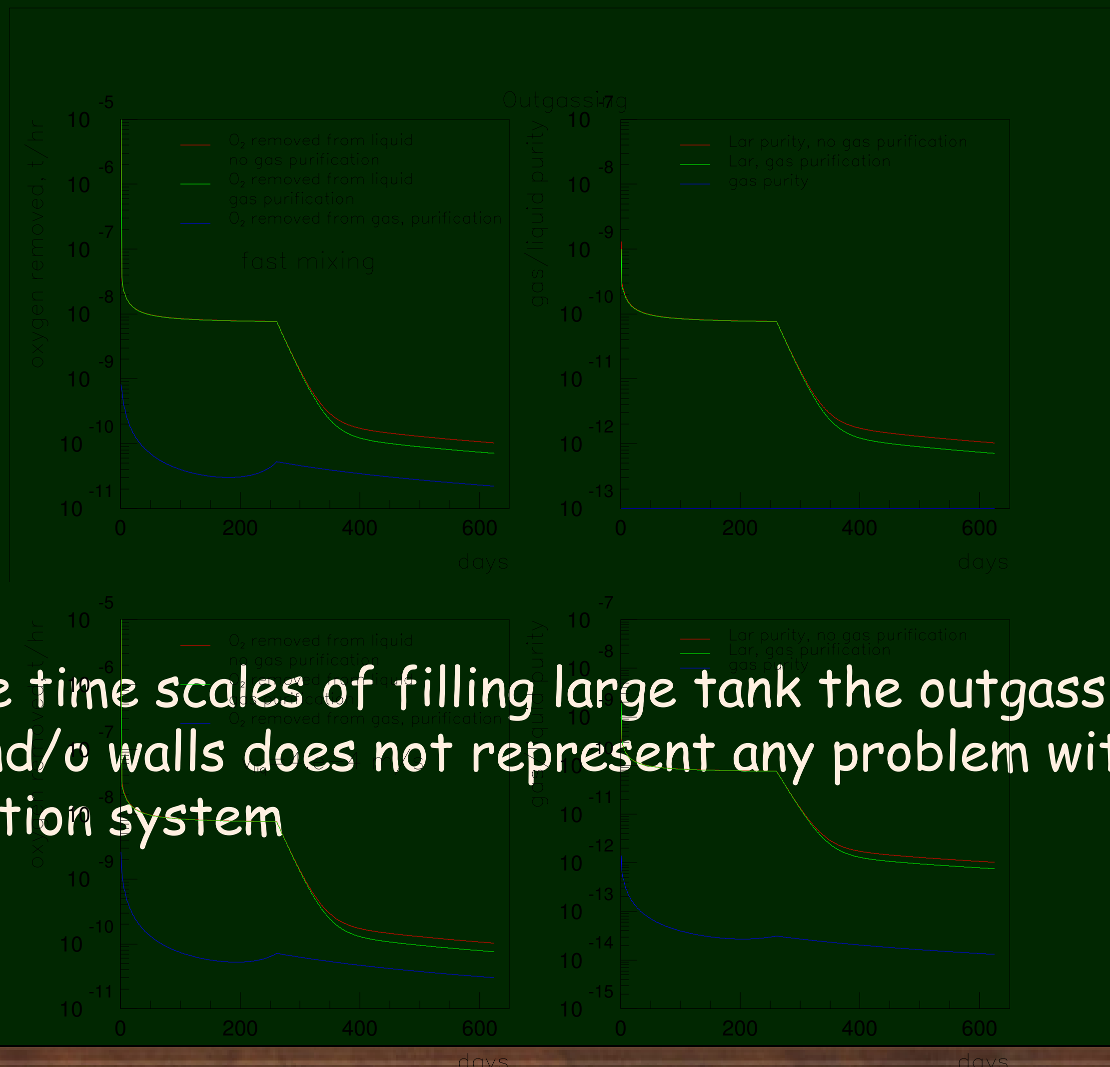
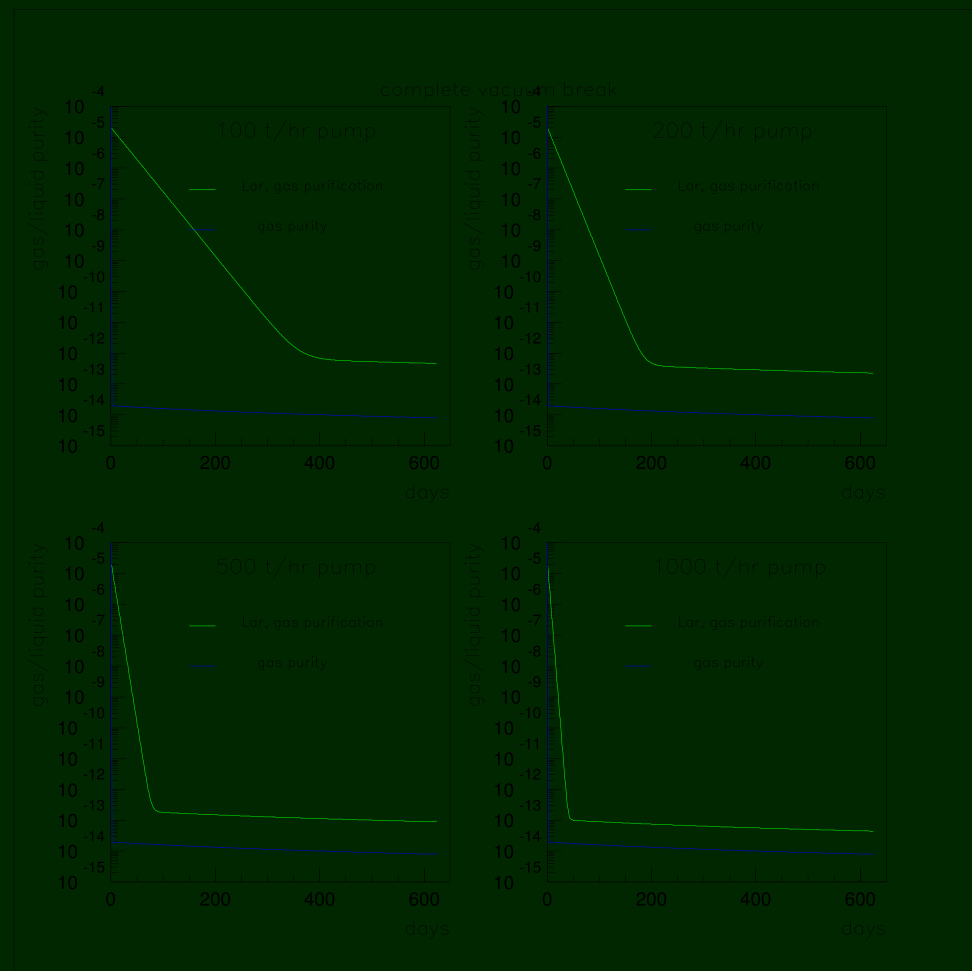
Argon purity vs outgassing?



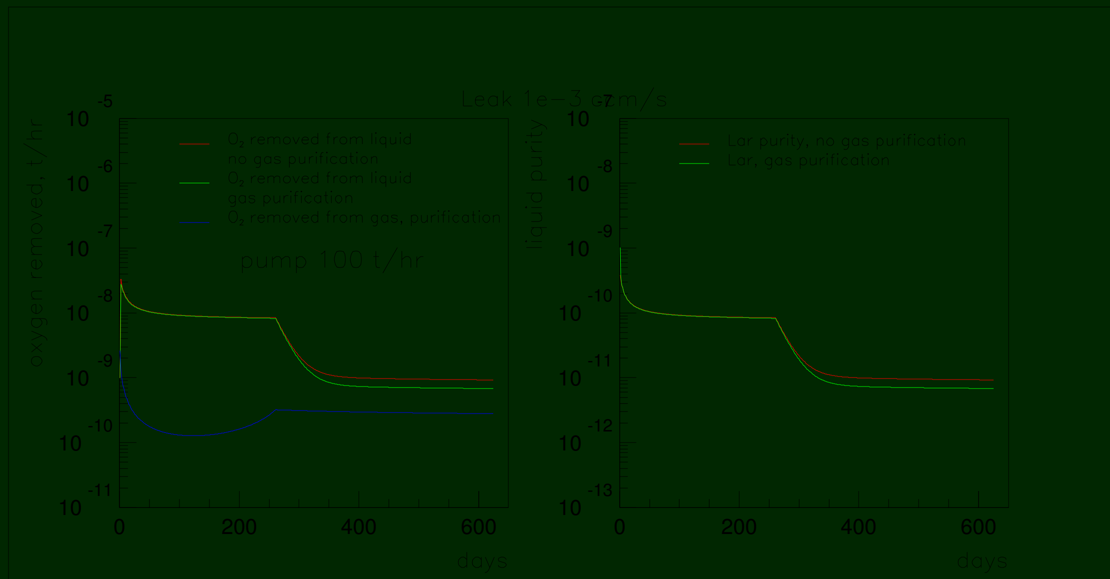
- Given the time scales of filling large tank the outgassing of cables and/o walls does not represent any problem with a recirculation system

An impossible mishap ?

- An example: total volume of argon above the liquid level is replaced by air.
- The recovery time is inversely proportional to the capacity of the recirculation/purifica tion system
- With 100 t/hour pumping speed it takes ~ 9 month to reastablish working conditions



Leaks(?)



Assume leak rate 0.001 cm^3/sec (air entering the tank). With 100 t/hour recirculation an equilibrium is reached at 10 ppt level.

1. Tank is run at some overpressure: prevents outside gas from entering tha argon volume.
2. There is no air outside the tank/pipes. All lines are vacuum lines, argon fills the volume between tank walls.
3. Welded steel tanks DO NOT LEAK

Conclusions

- A relatively modest liquid argon purification/recirculation system with capacity of 100 t/hour provides a significant overkill capacity to ensure argon purity level exceeding the requirements even under unrealistically pessimistic assumptions
- Fast mixing of argon within the tank makes the gas purification system of very limited use, probably not worth the complication of the installation and operation of such a system

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Thermal analysis of a 50 kT liquid argon tank

Rough analogy: big boiling pot

Vapor bubbles at the surface only (hydrostatic pressure)

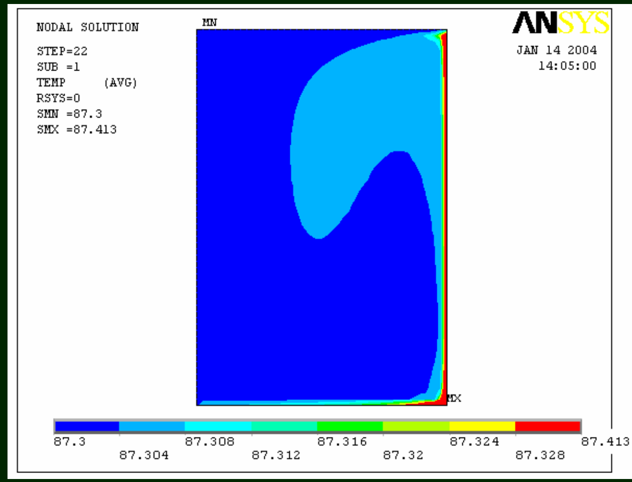
Total heat leak: 49 kW

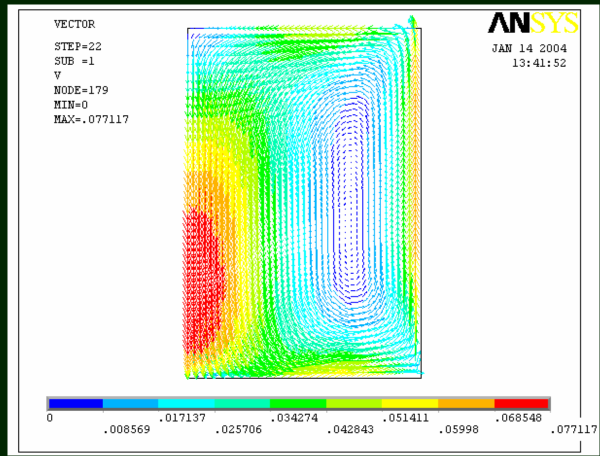
Maximal temperature difference ΔT_{max} = 0.1°C

Temperature difference over most of the volume 0.01°C

Maximum flow velocity: 7.7 cm/s

Heat leak through a signal feed-through chimney 48W/chimney





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