Heat and Mass Transport in Ullage Space

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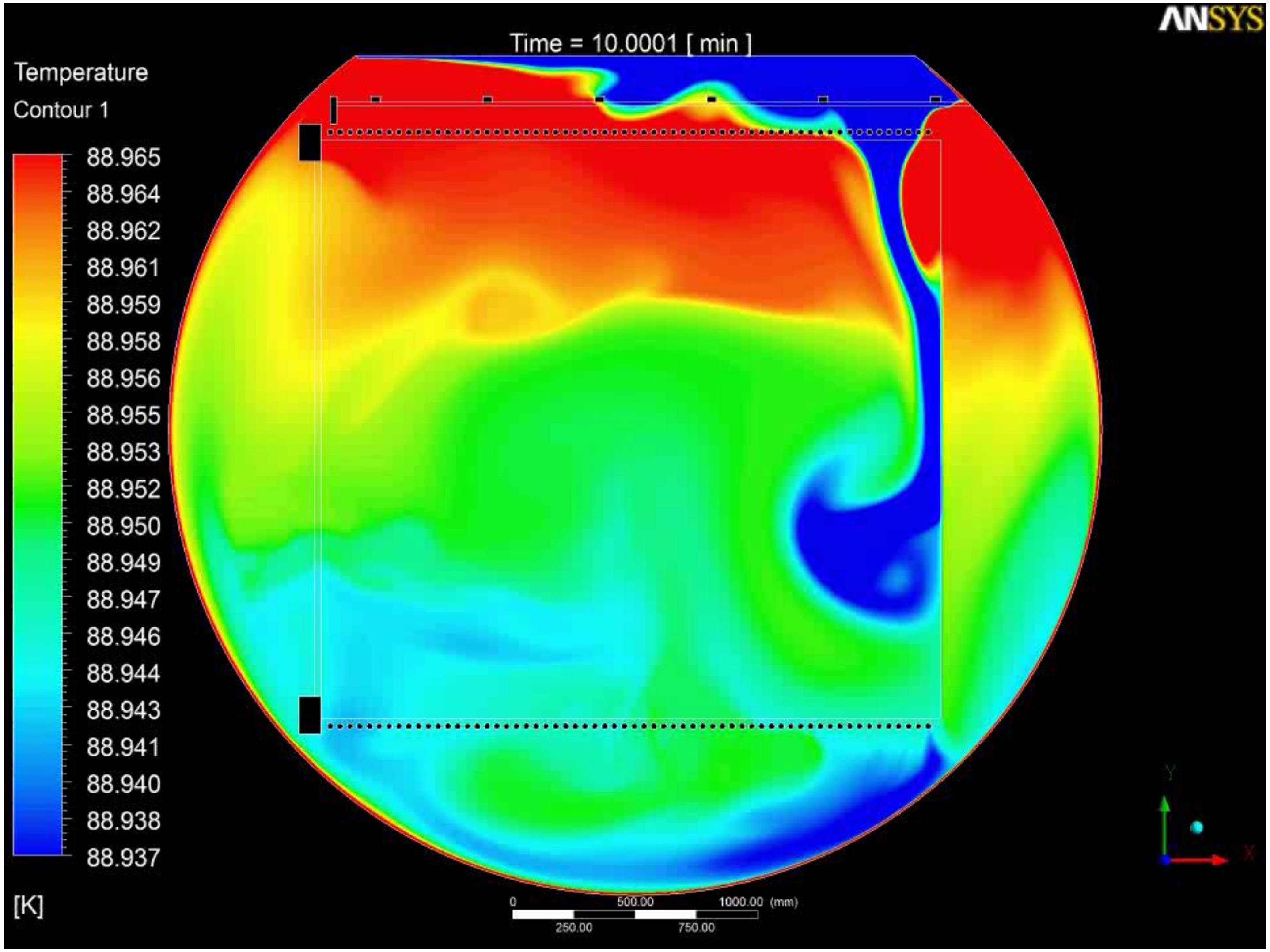
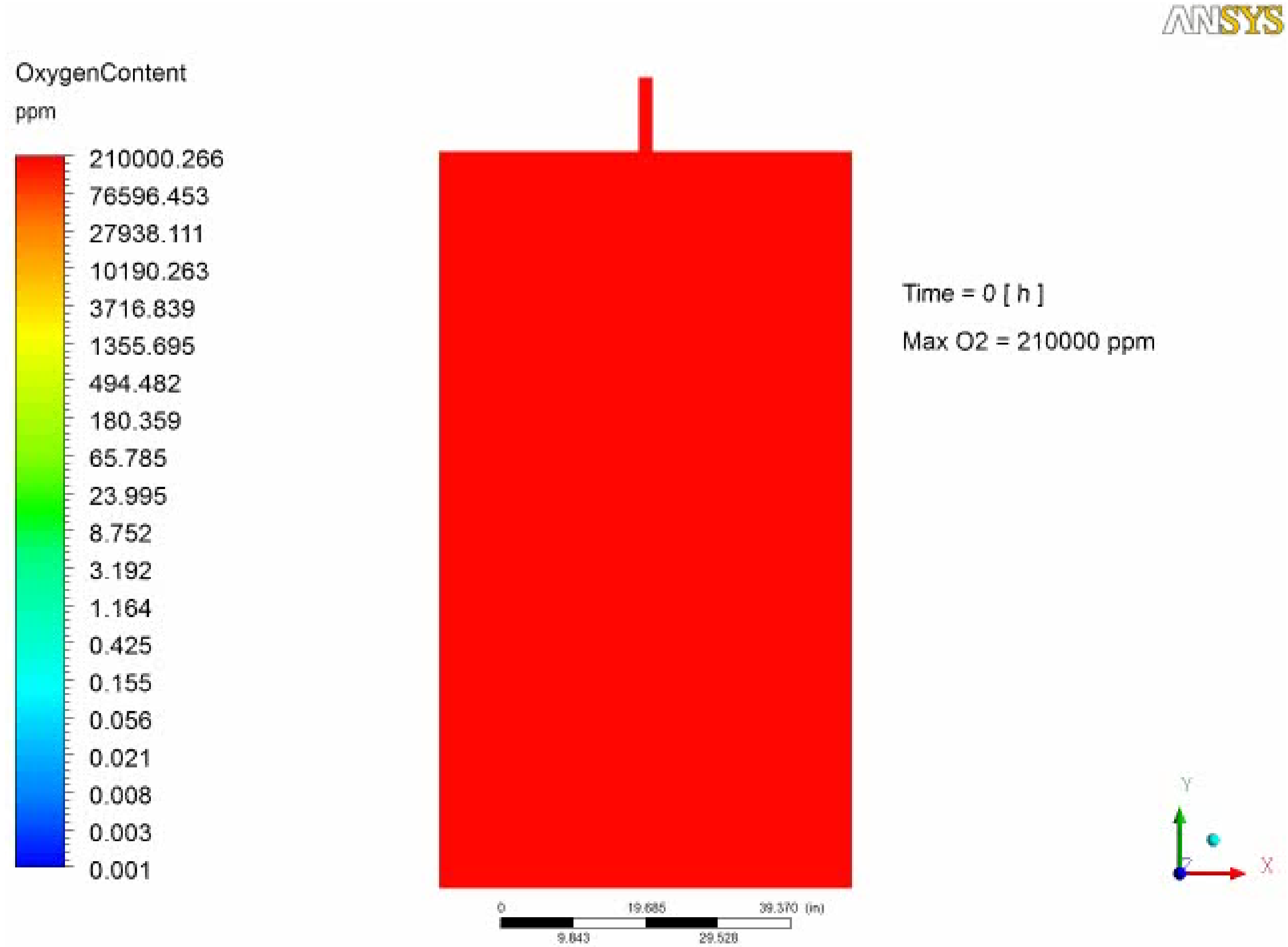
Presentation Contents

- Using Computational Fluid Dynamics (CFD) methods to study heat and mass transport related to LAr purification.
- Comparing to experimental data for model validation.
- After methods validated use for future predications and design considerations
- Sources and magnitudes of Impurities
- Advection and diffusion of Impurities

Use Computational Fluid Dynamics (CFD) to study fluid behavior

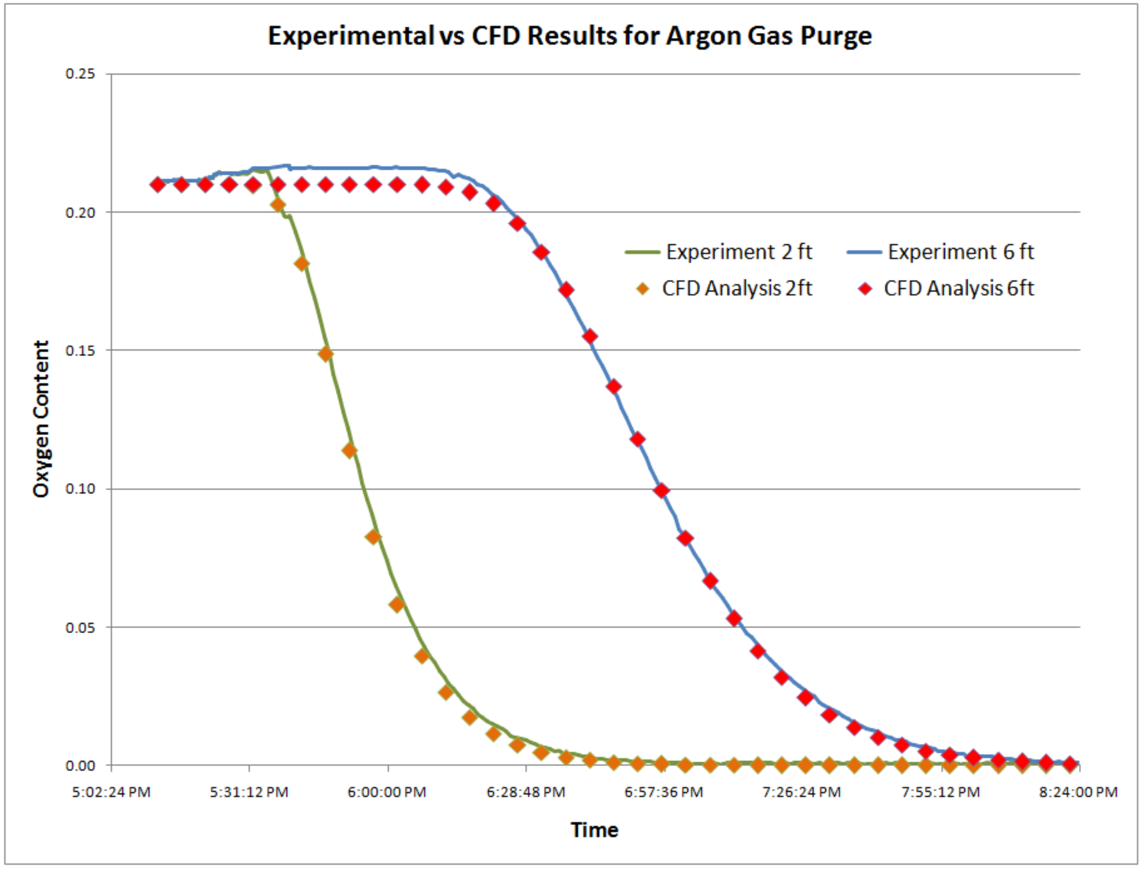


CFD Model of Argon Purge

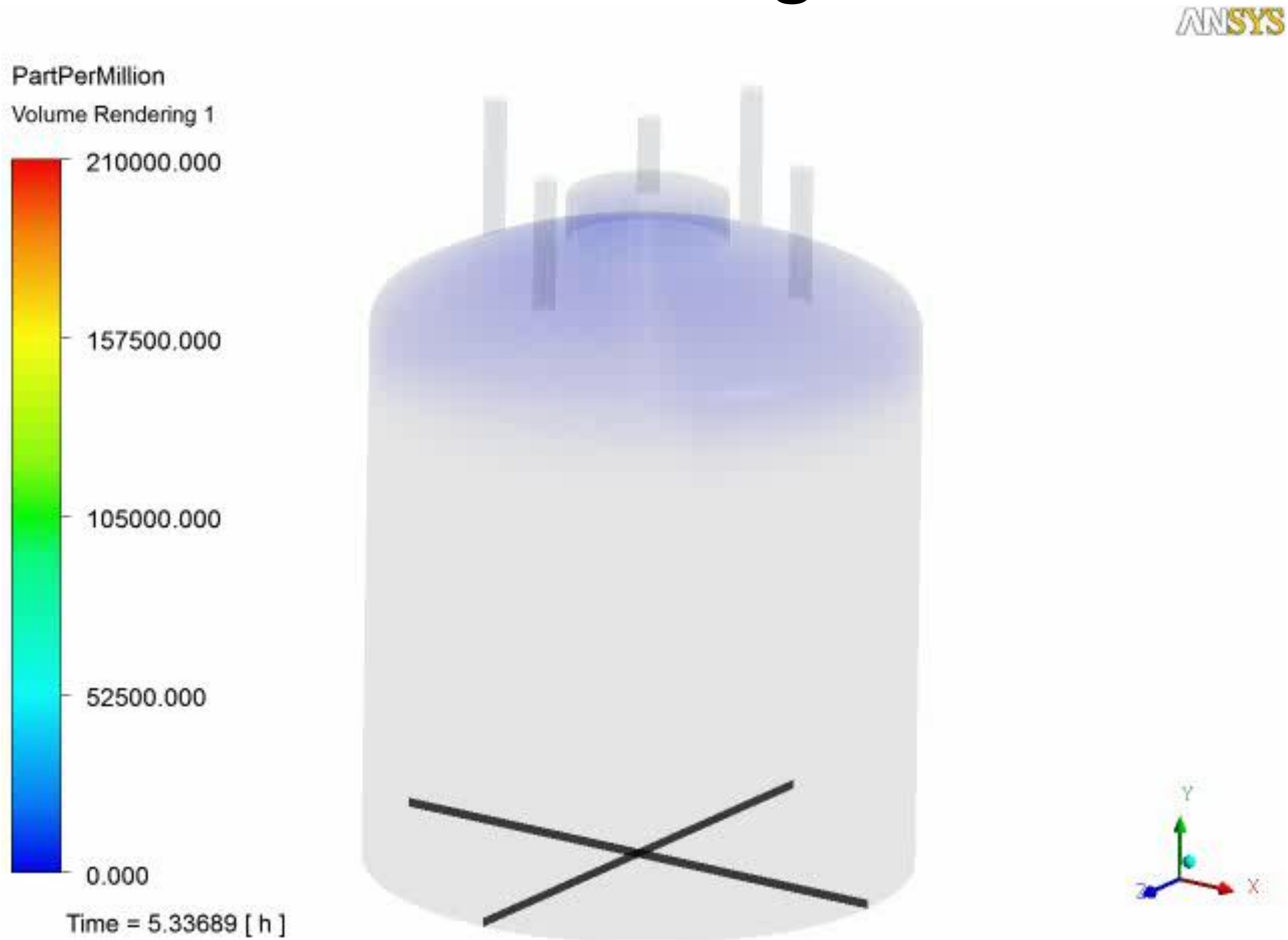


CFD Model of Argon Purge

- Measurements vs. CFD model

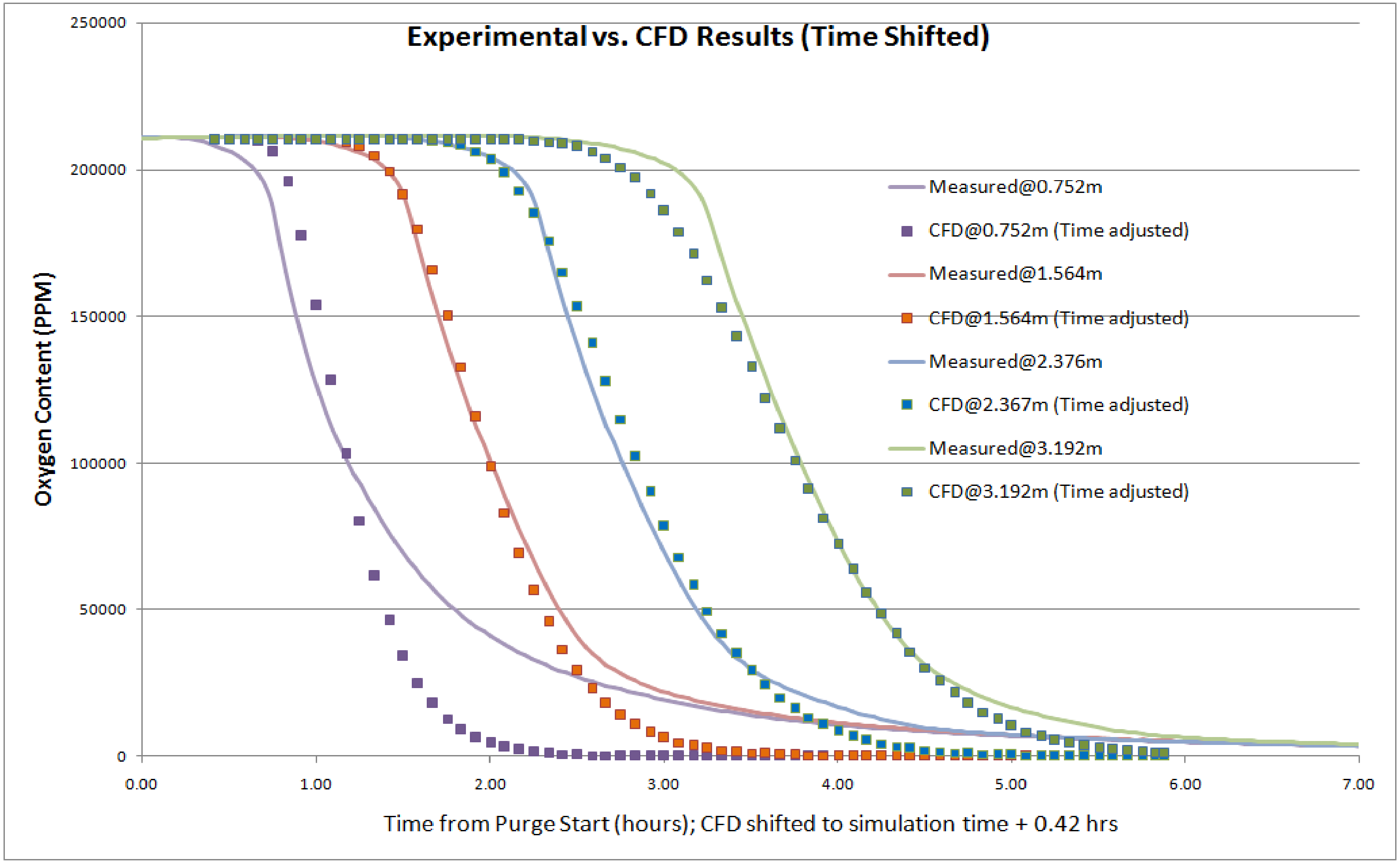


LAPD Purge



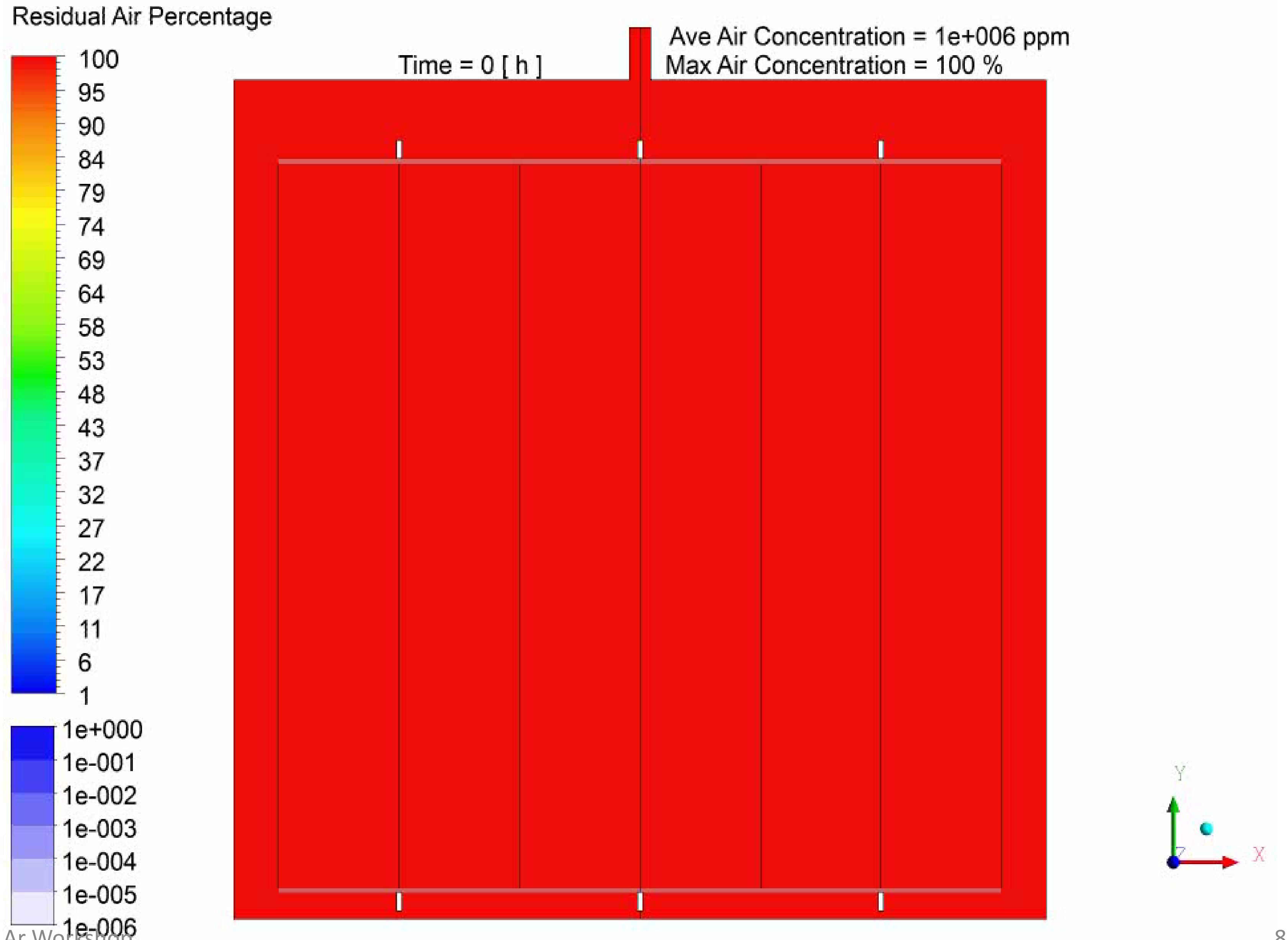
PartPerMillion
Volume Rendering 1
210000.000
157500.000
105000.000
52500.000
0.000
Time = 5.33689 [h]
Y
X

CFD vs. Measurements



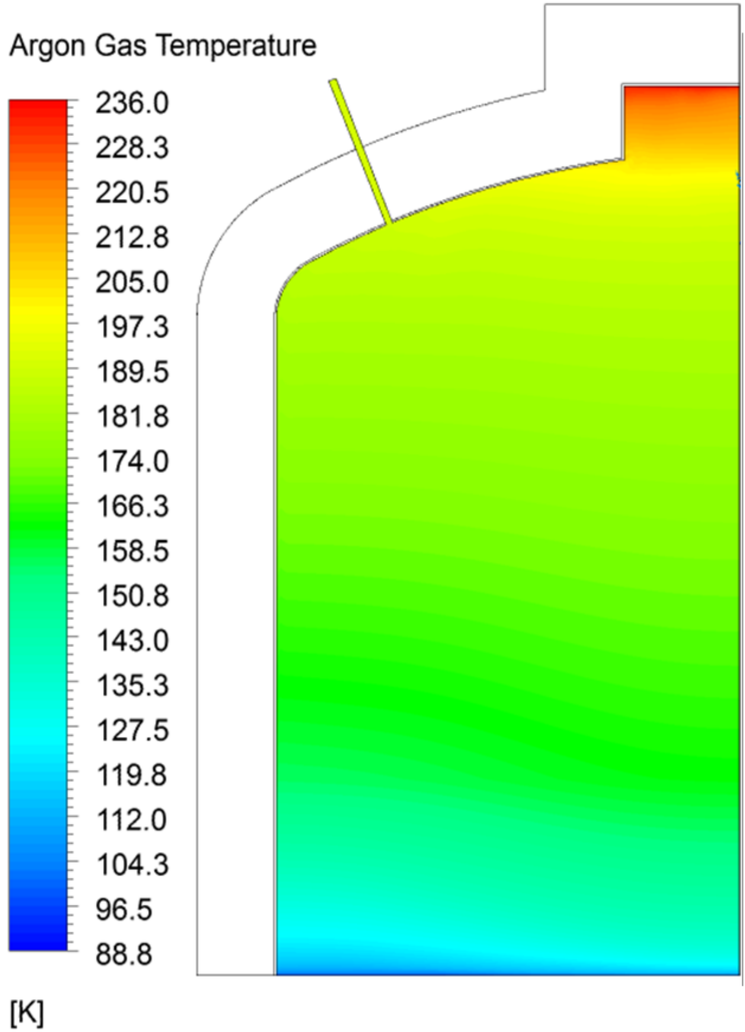
Differences at lower part of cryostat due to measurement technique (siphoning gas) and inconstant pressure during purge.

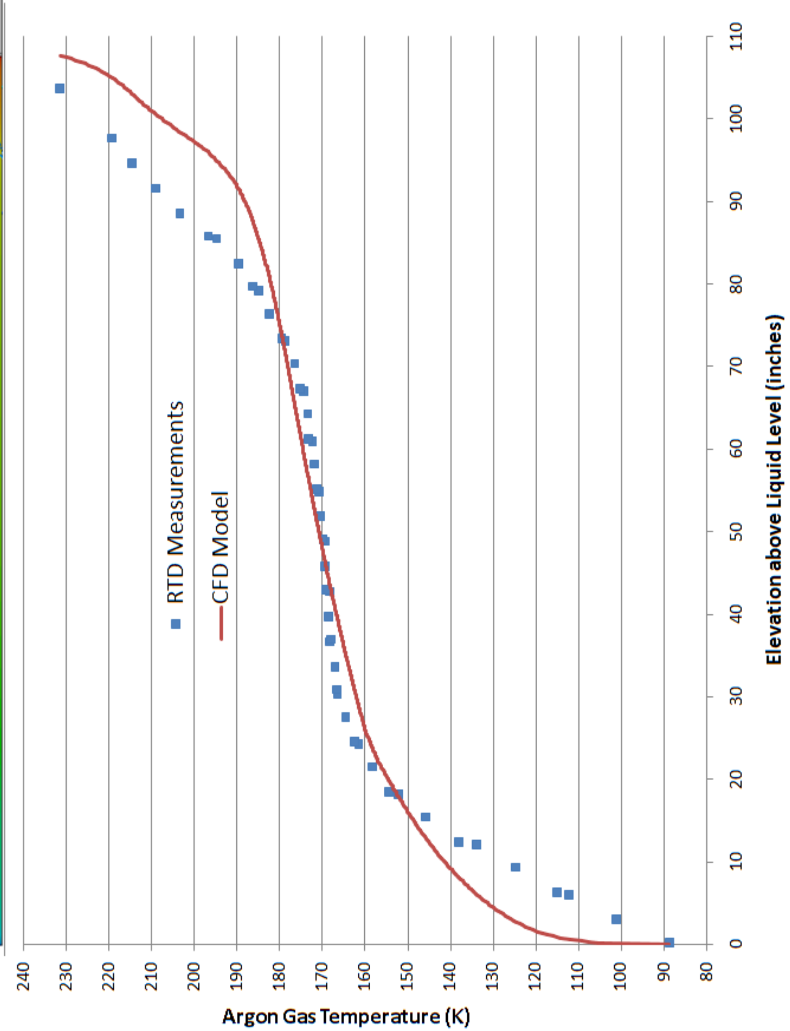
10kT LBNE Vessel



Impurities releasing into Ullage Space

- Warm ullage space causes release of water.





Initial Impurities in Cryostat

- Cryostat filled with air
  - Contaminants in the air
- Water Sources
  - On surface of vessel walls
  - On all other surfaces
  - Inside of non-metallic parts
    - wire insulation, FR4, etc.

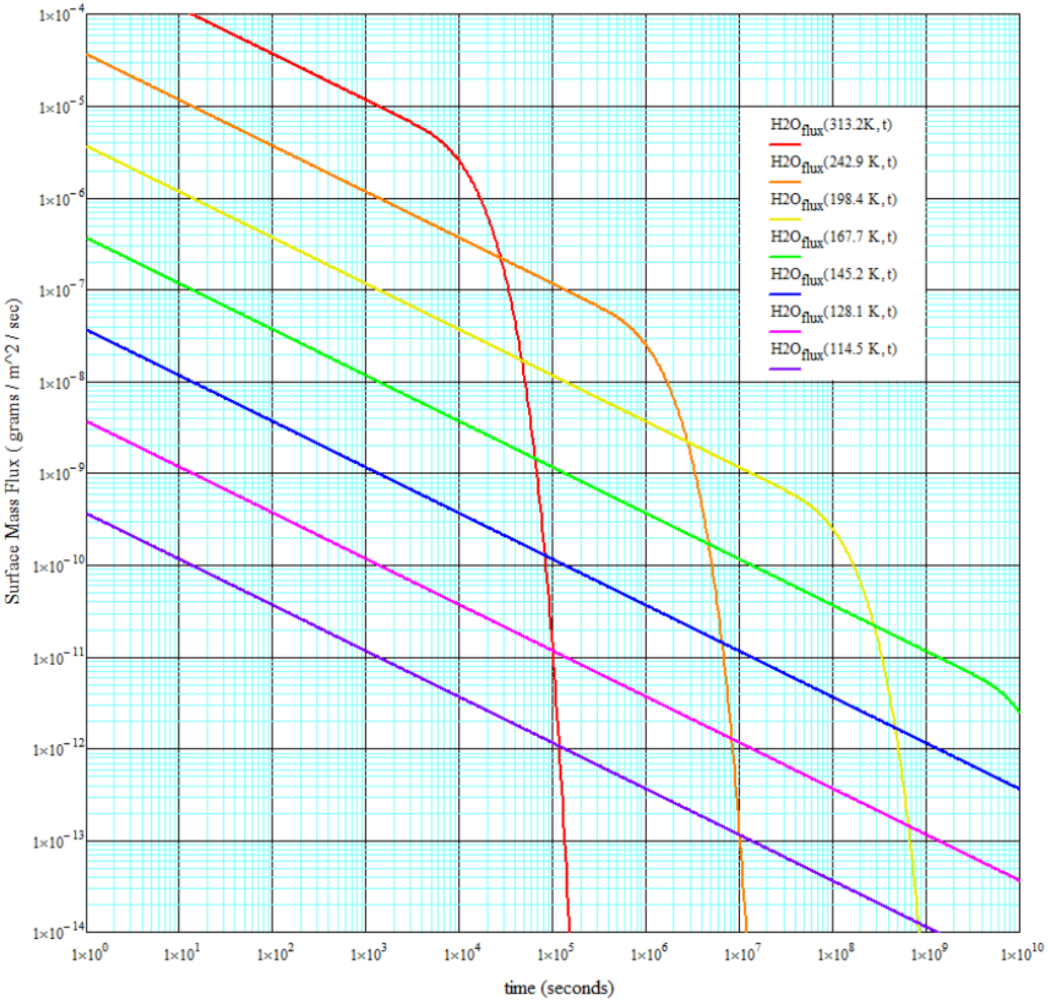
Sources of Impurities (material)

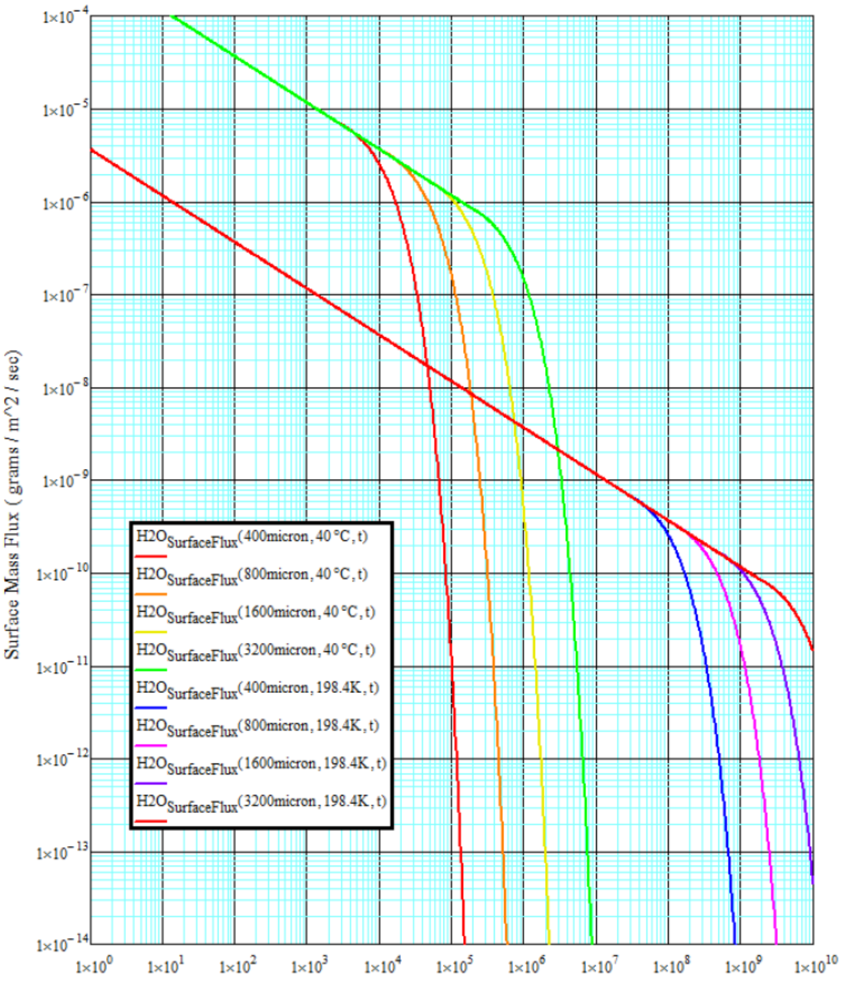
- Water concentration can vary greatly in different materials.
  - FR4 0.2% – 0.6%
  - Polyolefin 0.3% - 2%
  - PTFE 0.02%
  - Teflon 0.01%
  - PVC 0.1% - 31%(!)
  - Polyethylene 0.2% - 0.6%
    - From NASA.outgassng.gov (Baller [1])

Sources of Impurities (Temperature)

(using Teflon as example)

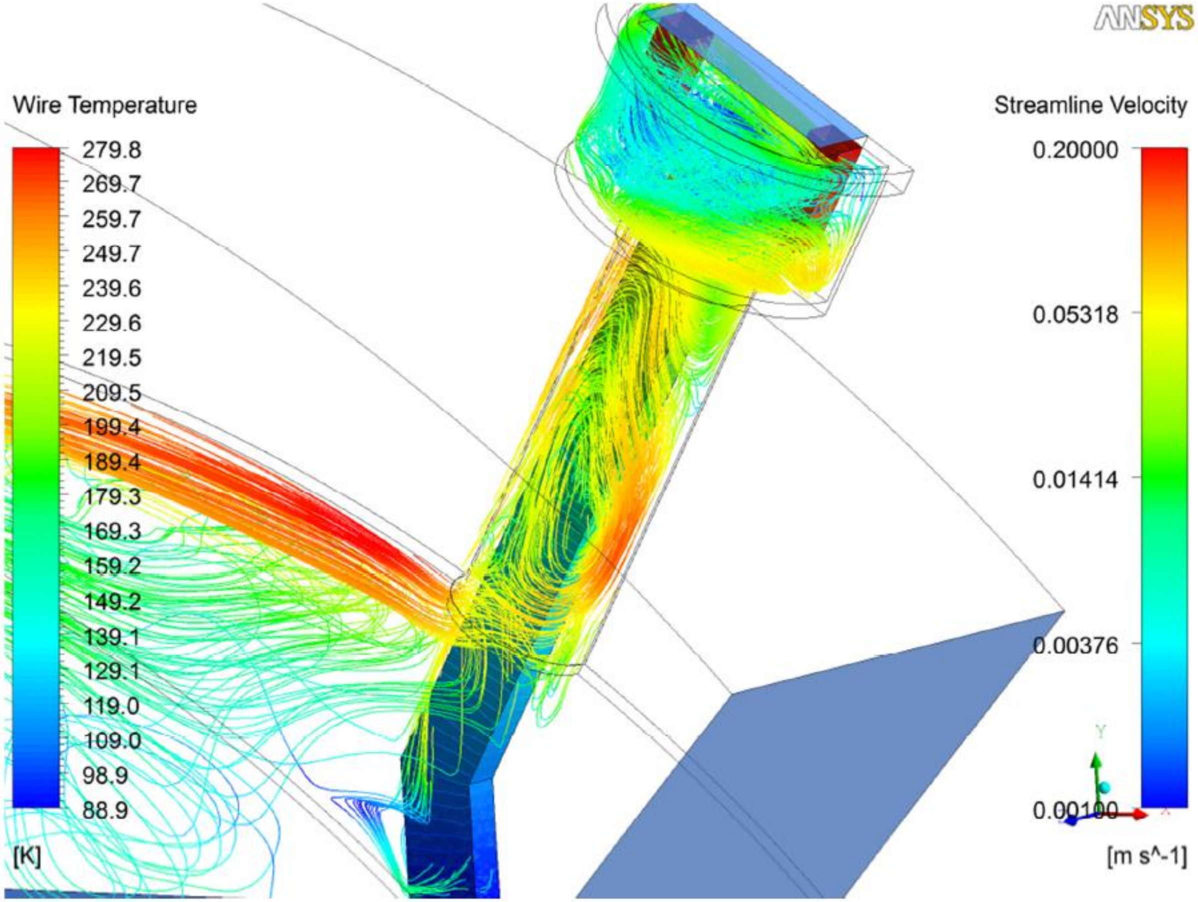
Highly temperature dependent! (Arrhenius' Law) (Baller [1])





Advection of Impurities
(MicroBooNE Feedthrough)

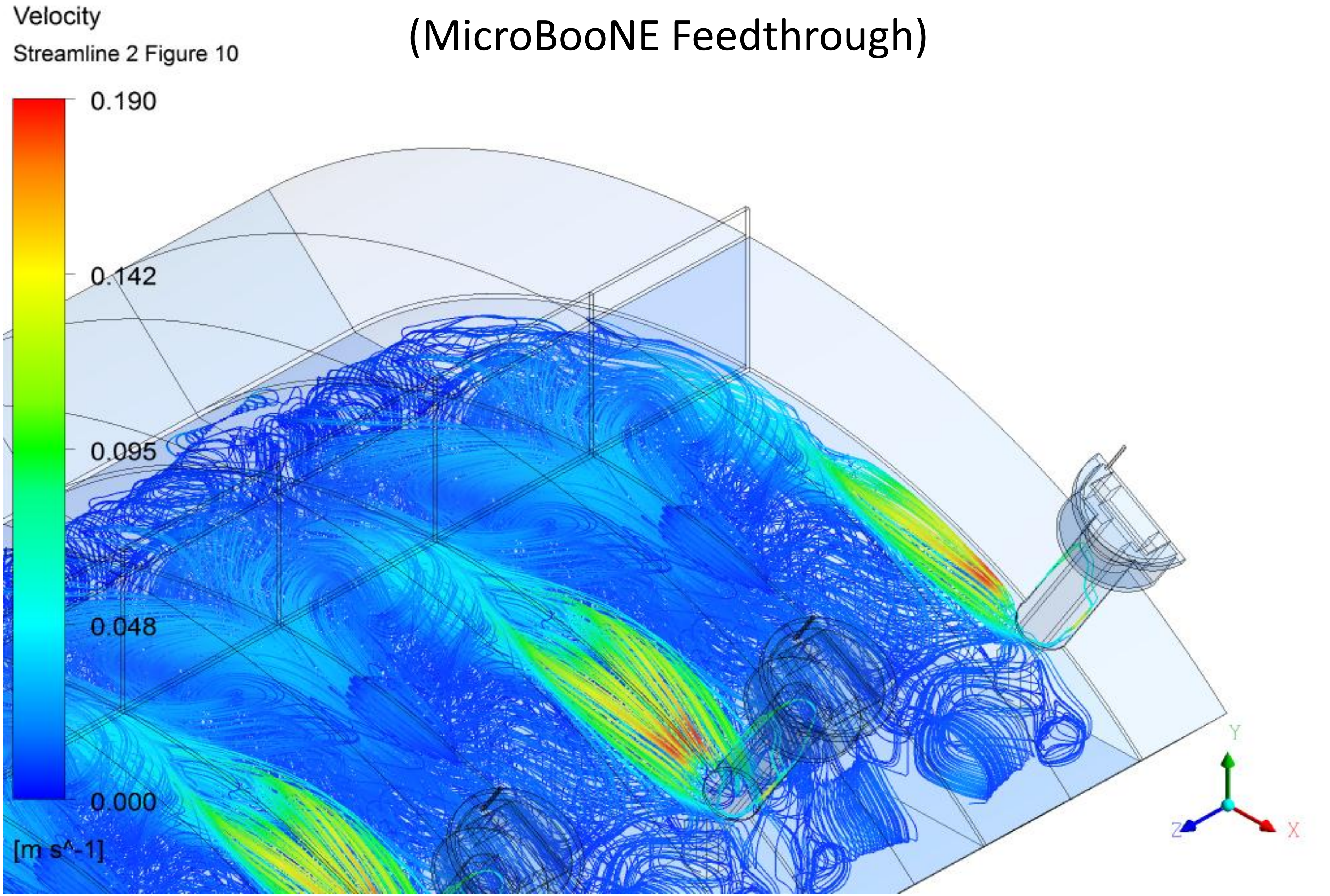
- Adventive motion and turbulence will mix gas enough to cause some impurities to be absorbed by liquid surface.



Buoyant circulation of argon gas in one of MicroBooNE's purged wire chimneys, as predicted by CFD methods. This increases mass transport and severely reduced the effectiveness of purging the chimneys.

Advection of Impurities

(MicroBooNE Feedthrough)



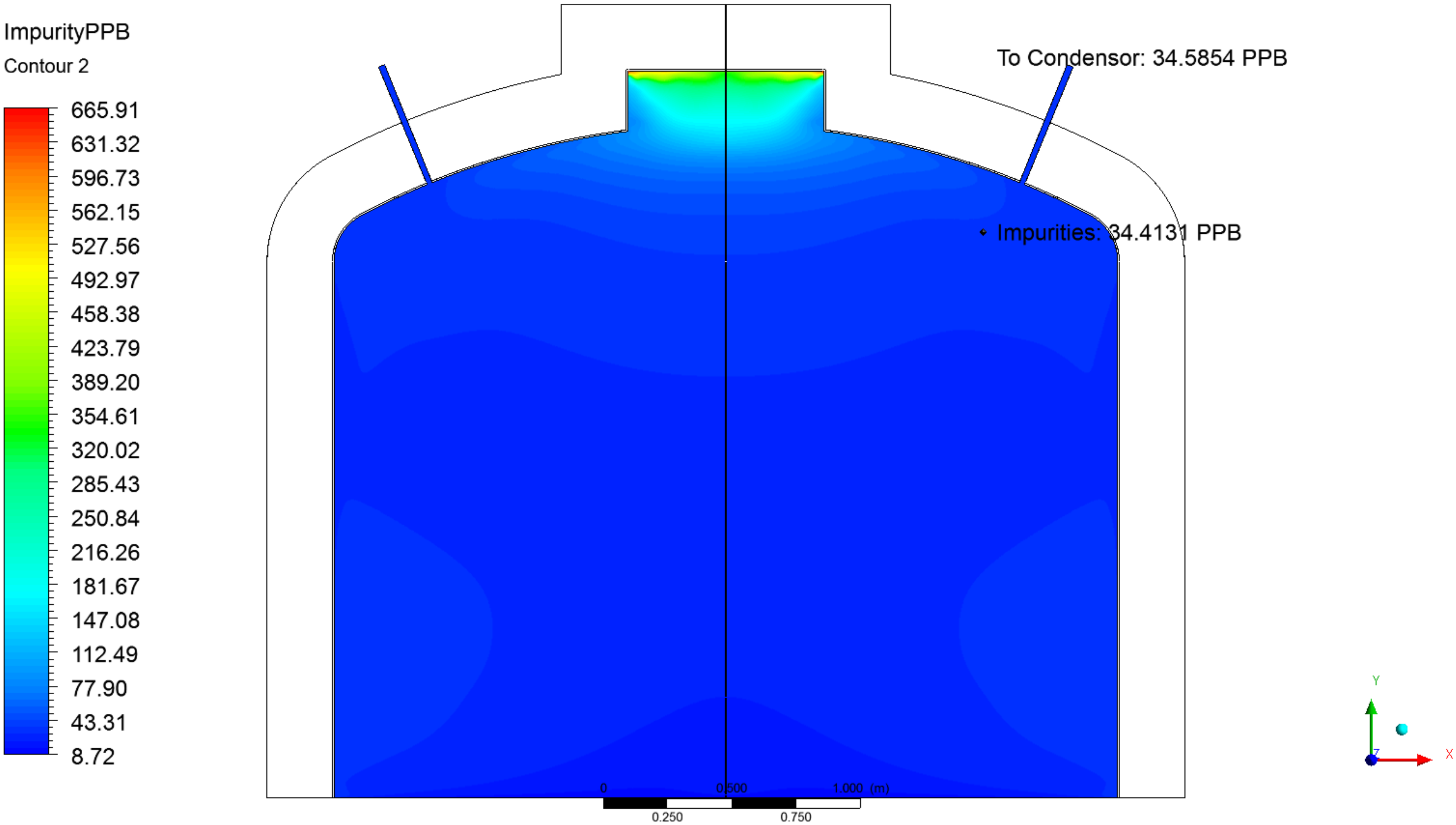
Estimate Impurities in LAr

$$MolFractionWater = \frac{ImpurityFlow * TimeToRecirculate}{\frac{M_{H2O}}{M_{Ar}} * \rho_{Ar} * Volume} + MolFractionFilteredAr$$

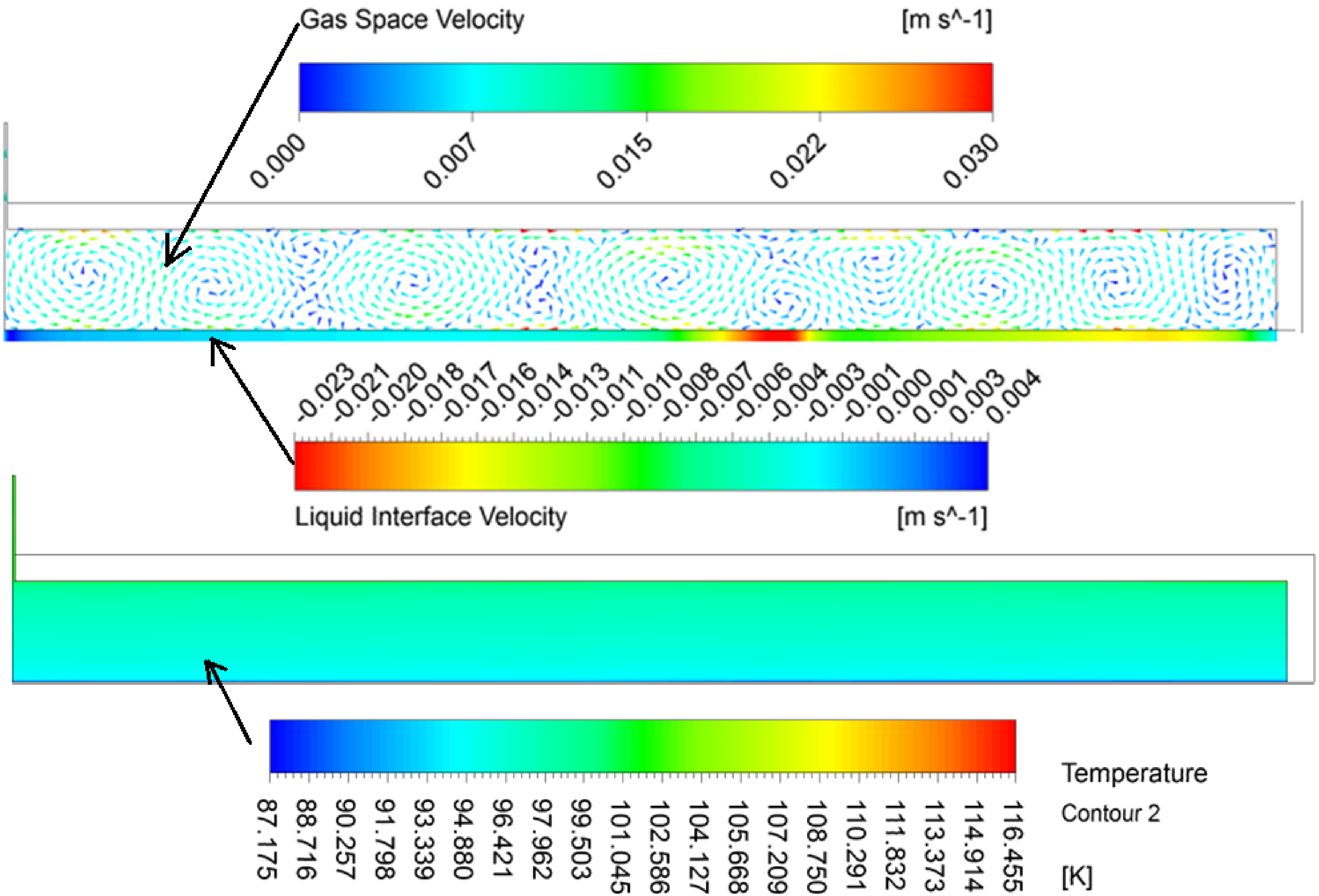
- ~20 times higher impurity magnitude if using LDPE insulation vs. Teflon
  - Due to saturated water concentration difference
- Impurities from wire in feed throughs 3-5 orders of magnitude higher than ullage space wires.
  - Due to large temperature dependence of outgassing.

LAPD Impurities in Gas Space

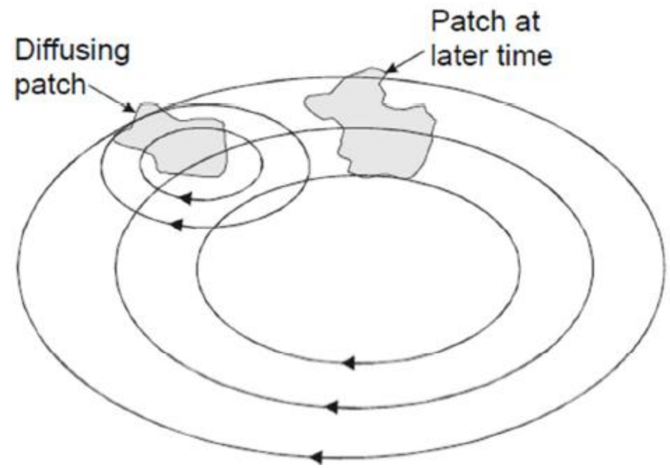
(Work in progress)

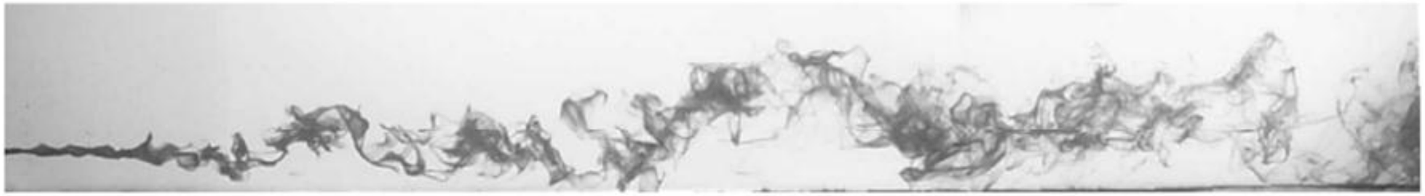


33KT Ullage (much different than LAPD)

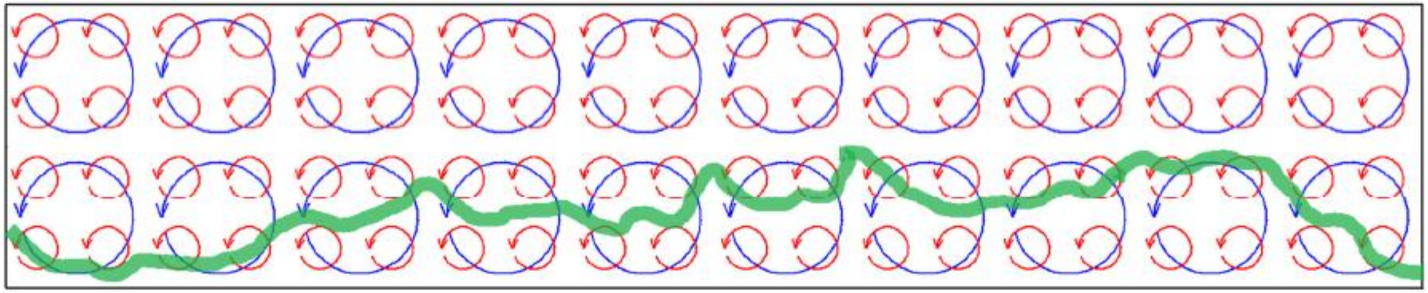


Turbulent Diffusion





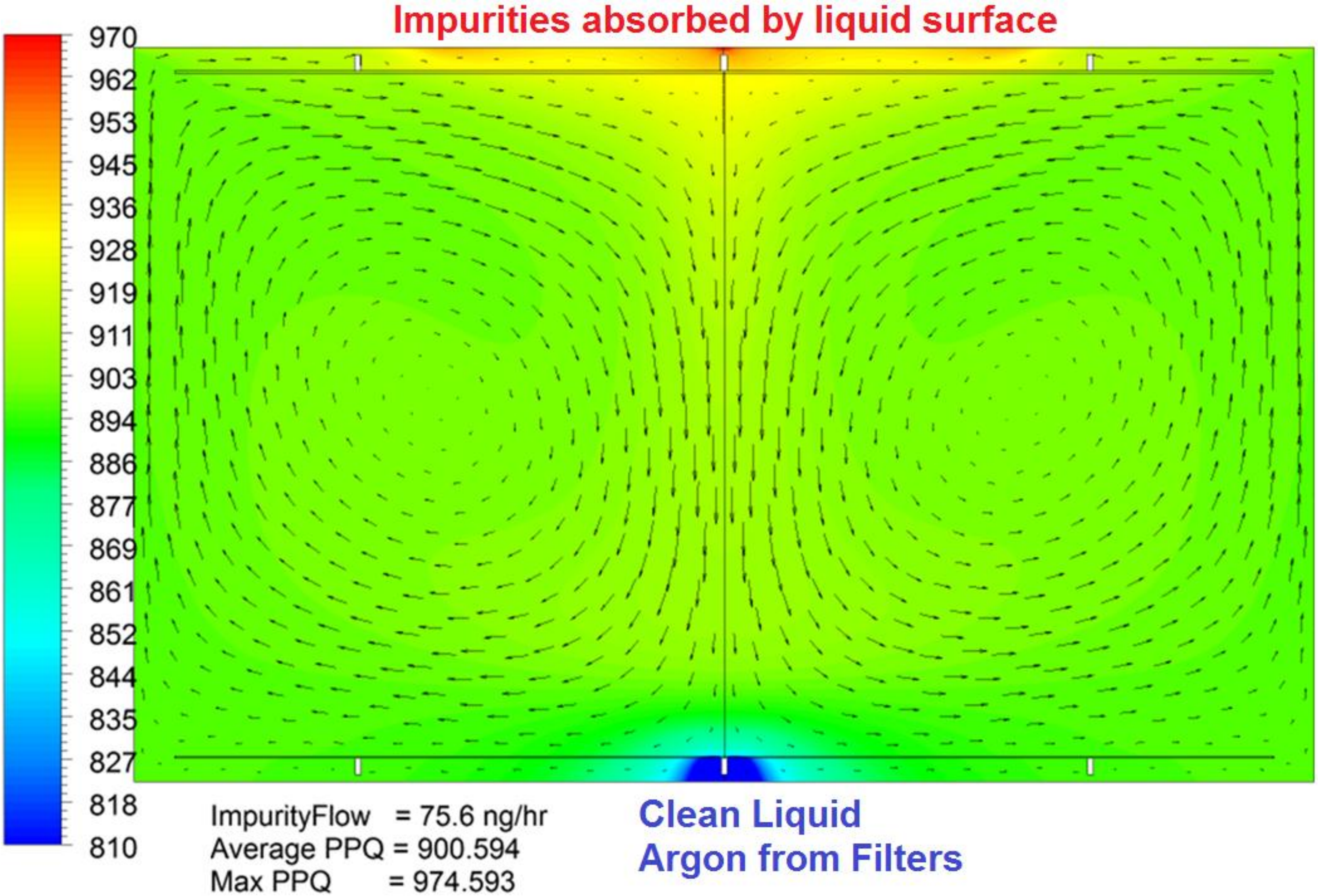
Chemical plume released iso-kinetically into fully developed open channel flow.



Example of velocity field as seen from the mean flow velocity frame of reference. The green line is an attempt to trace a path from left to right, accounting for the influence of the eddies.

Impurities In Liquid Volume

(Quite Homogeneous)



Impurity Distribution for magnitude. of impurity flow {Impurity flow estimates Bruce Baller}

References and thanks to:

All LAr R&D Personnel

1.) Baller, Bruce. LBNE Doc-3171, Diffusion and Transport in the Ullage
- http://lbne2-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=3171

2.) MicroBooNE Document 1768 - Mass Transport of Water in Teflon; a Transient Numerical Analysis
- http://microboone-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1768

3.) LBNE Doc-3085 - Argon Gas Circulation, Temperature Profile, and Molecular Diffusion in the LBNE Ullage
- http://lbne2-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=3085

4.) LBNE Doc-3862 - Diffusion Coefficients of Water and Oxygen in Argon
- http://lbne2-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=3862

5.) MicroBooNE Doc-1737 - CFD Models of Ullage Space: Temperature and Velocity Profiles
- http://microboone-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1737

6.) Turbulent Diffusion and its Effects on the Ion Distribution Field of the MicroBooNE LAr Cryostat
- http://microboone-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1895