Fermilab

Depleted Argon from Underground Sources

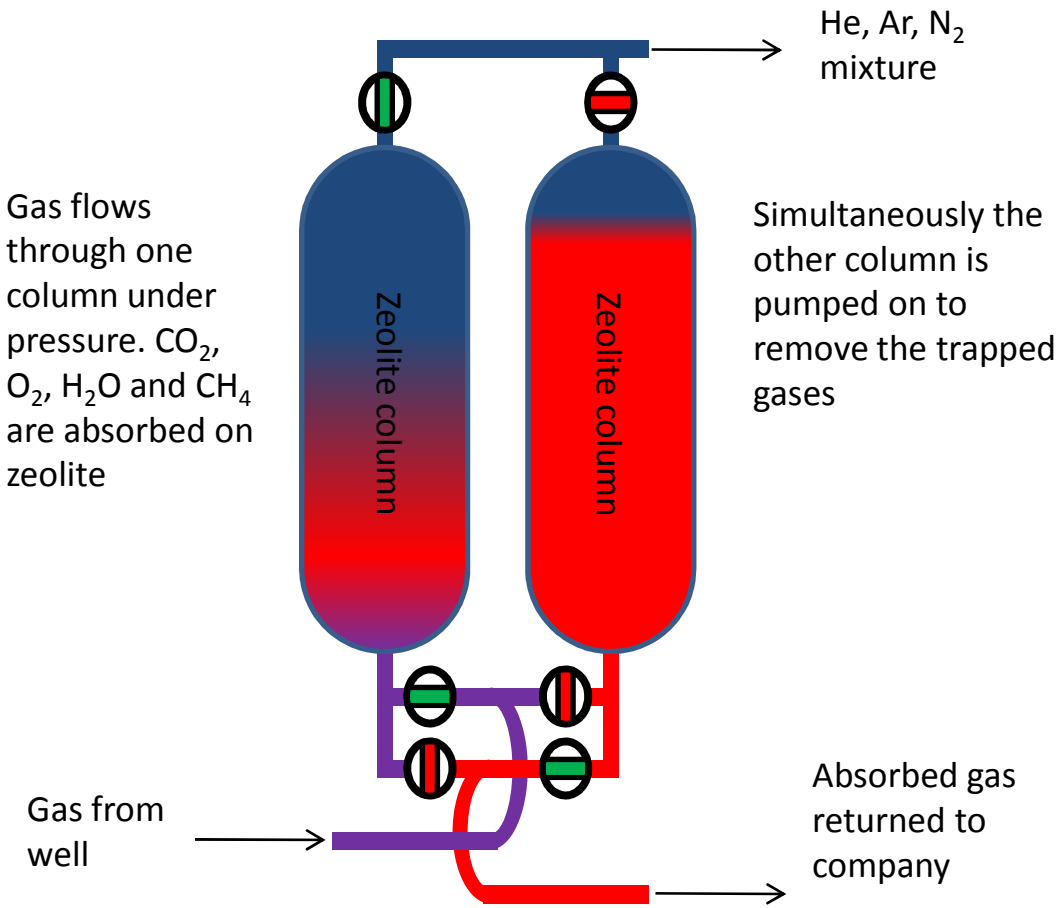
Henning O. Back – Princeton University
For the DarkSide experiment, E-1000

Augustana College – D. Alton
FNAL – C. Kendziora, D. Montanari, S. Pordes
Princeton U. – F. Calaprice, C. Galbiati, A. Goretti, Andrea Ianni, B. Loer, P. Mosteiro

Why depleted argon

- Naturally occurring ^{39}Ar is the limiting contamination in atmospheric argon
  - $^{39}Ar \rightarrow {}^{39}K + e^- + \bar{\nu}_e$ (Q = 535 keV)
  - Limits size of detectors due to pile up
- Atmospheric ^{39}Ar is produced in the upper atmosphere in $^{40}Ar(n, 2n)$ reactions
- Atmospheric concentration $^{39}Ar/^{40}Ar = 8.1\times10^{-16}$
  - Corresponds to 1 Bq/kg of atmospheric argon
  - One ton detector
    - Electron drift time across 1 ton detector (1m)= order 500μs (minimum time between events, equivalent to 2kHz)
    - Atmospheric ^{39}Ar decay rate = 1kHz/ton

The source of depleted argon

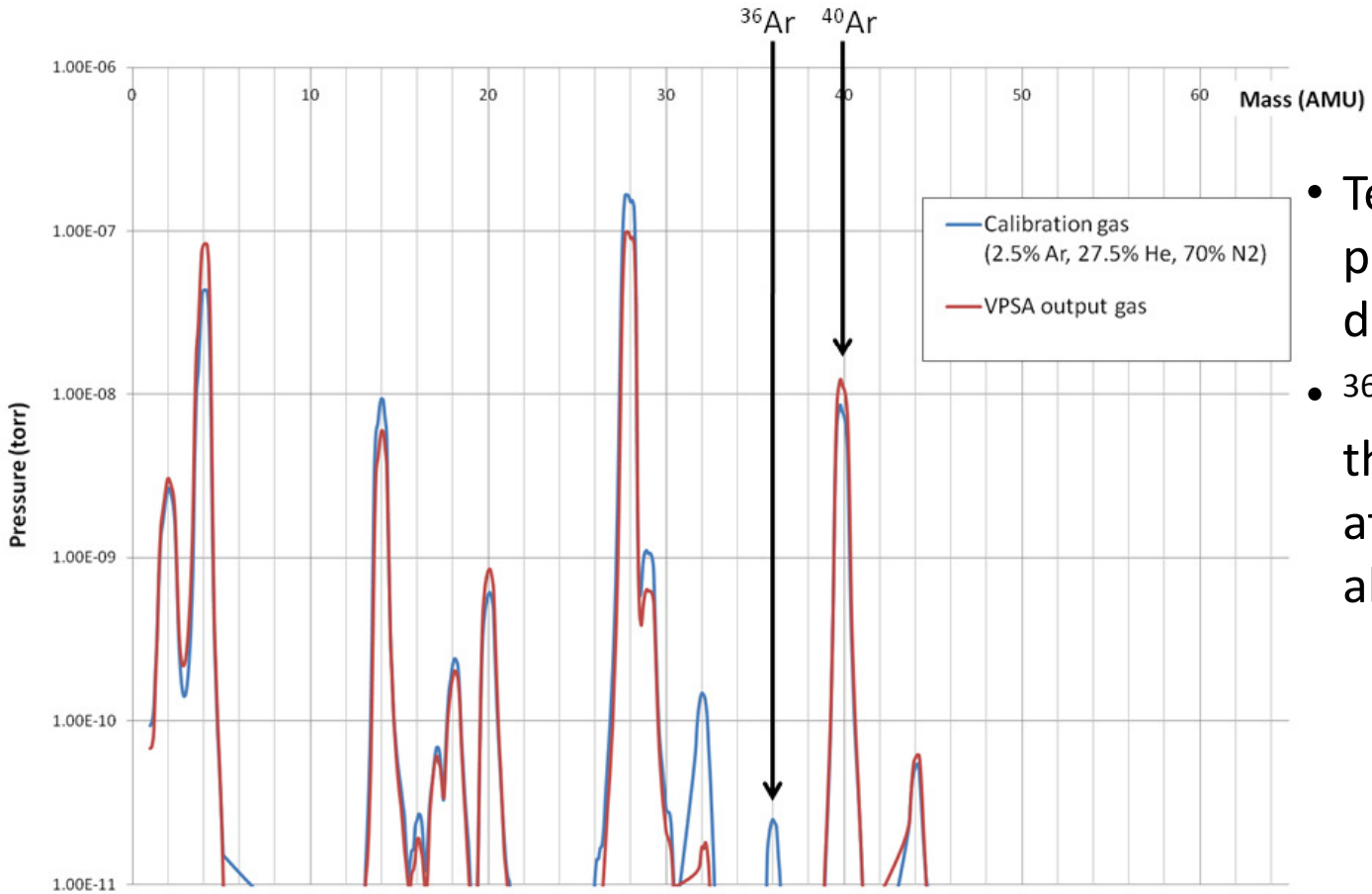


- Argon from deep underground is shielded from cosmic rays
- CO_2 gas well in SW Colorado has **400 ppm argon**
- Concentrate Ar, He, and N_2 through Vacuum Pressure Swing Absorption (VPSA) on Zeolite
  - Unwanted gases trapped on Zeolite columns under pressure
  - Zeolite regenerated by evacuating column
  - Two columns are used to have a nearly continuous flow of gas
- **Collected gas**
  - **N_2 – 70%**
  - **He – 27.5%**
  - **Ar – 2.5%**
- **Recent plant adjustments raised argon fraction to ~4%**

VPSA plant

- Production rate 0.5 – 0.8 kg/day
- **44 kg of depleted argon collected to date**
- Depletion level at least a factor of 25 less than atmosphere

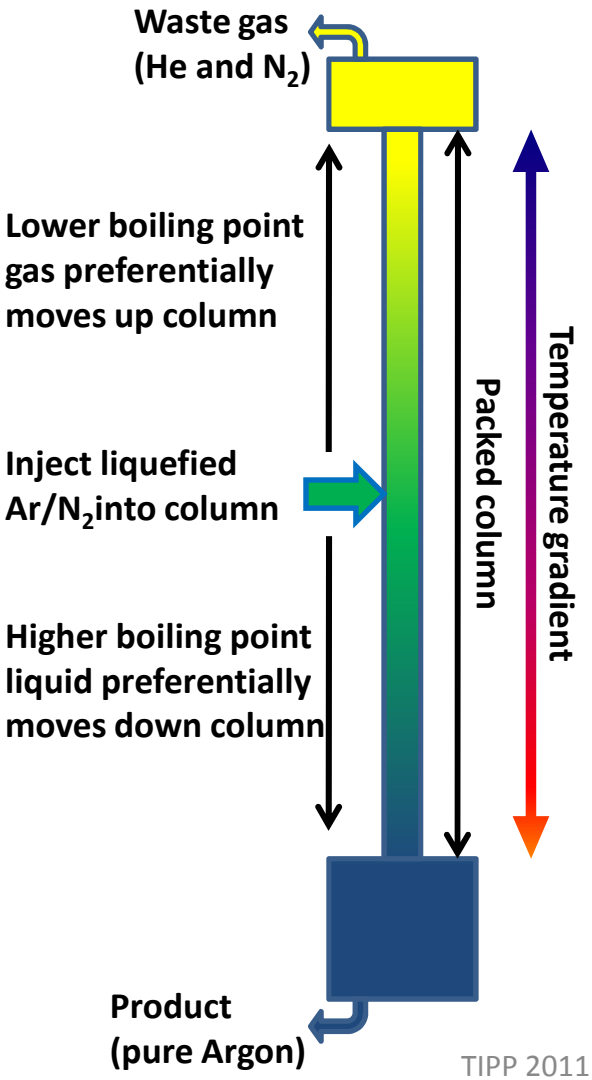
Argon from VPSA is born underground

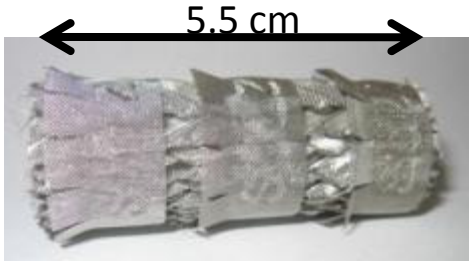


- Terrestrial ^{40}Ar primarily from ^{40}K decay
- ^{36}Ar produced in the sun and has an atmospheric natural abundance of 0.35%

Cryogenic Distillation

Purification of gas from VPSA plant

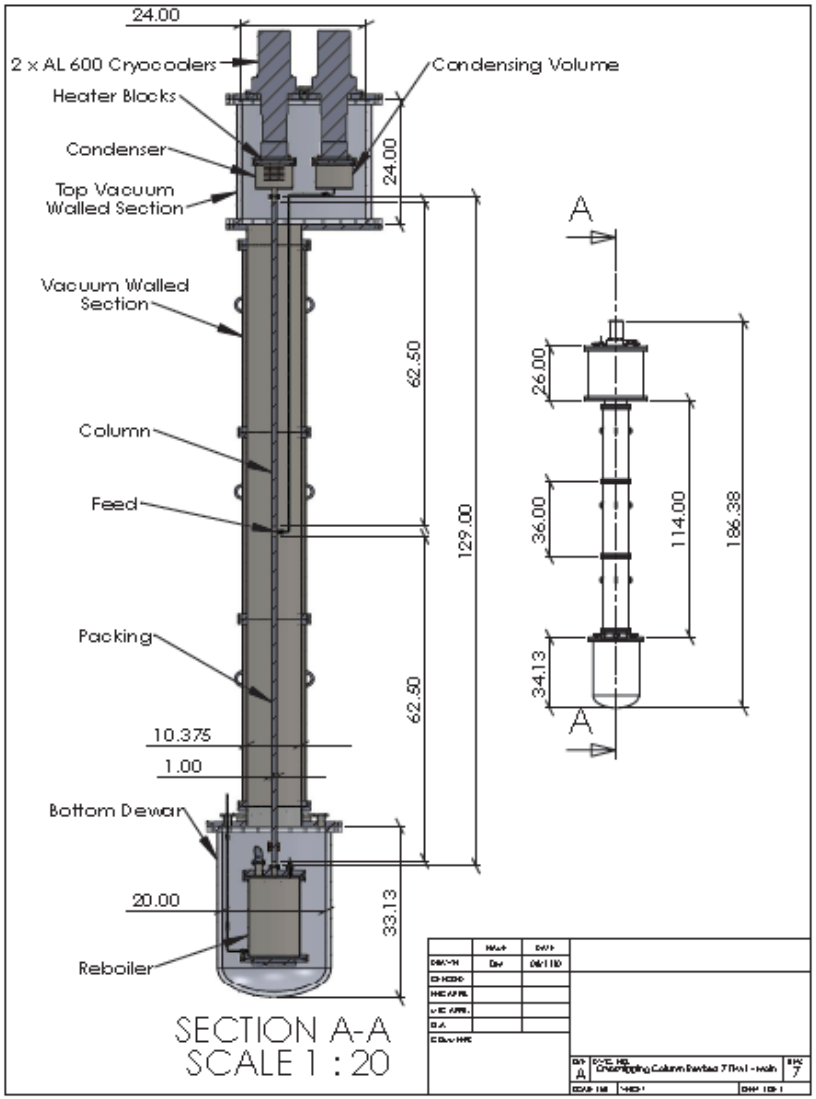




Column packing material

- Purification by distillation based on difference in boiling points
- Boiling happens on the surface of column packing material
- Our gas has helium, which is not liquefied and just passes through system

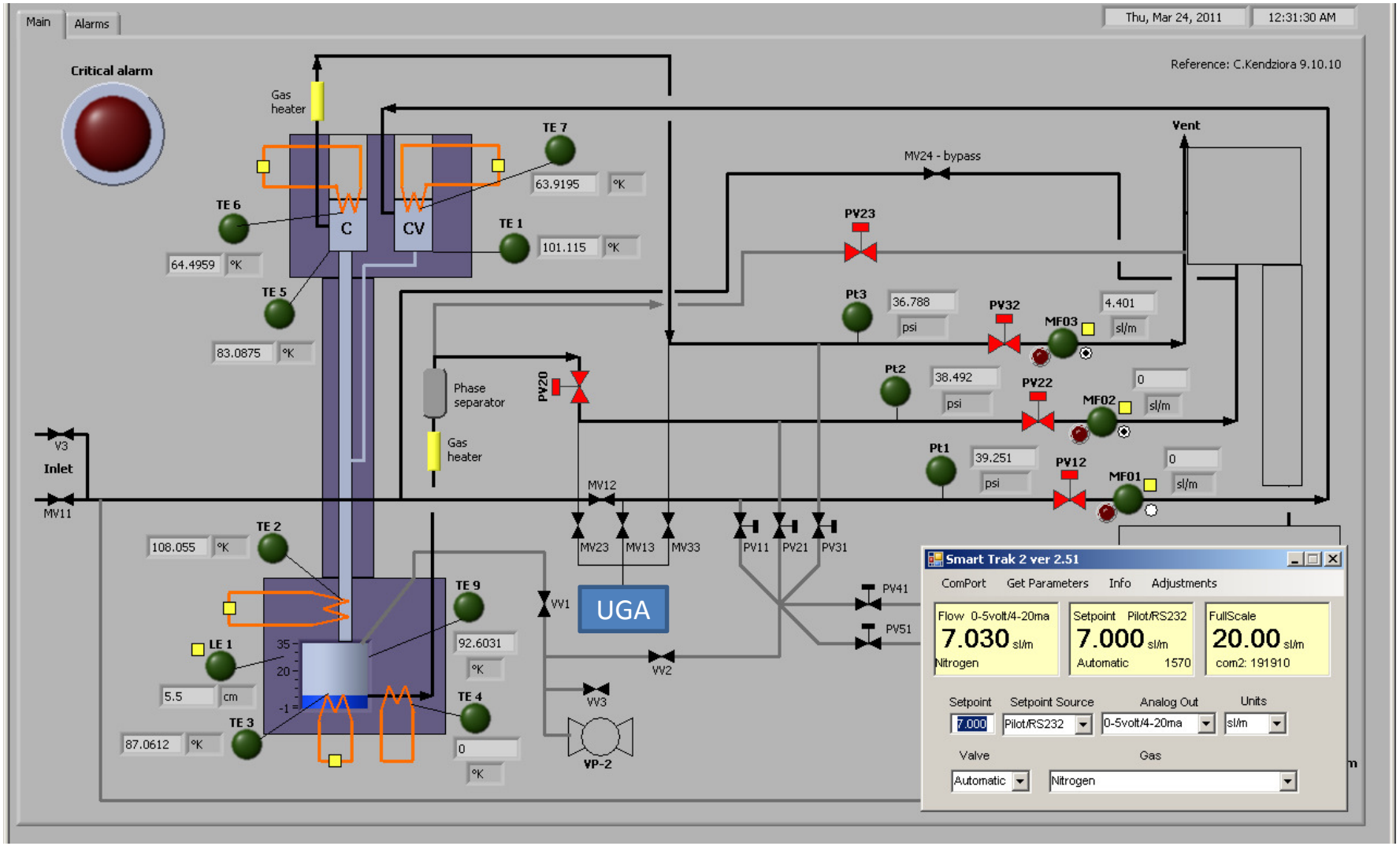
Our design



- 2 – 600W cryocoolers
  - Balanced with 700W heaters for temperature control
- Reboiler cooled by liquid from column
  - Temperature controlled with 700W heater
- Active PID temperature control
- Active mass flow control
- Pressure and temperature monitoring throughout
- Multiple input RGA measures gas at three points
  - Input
  - Waste
  - Product


AED

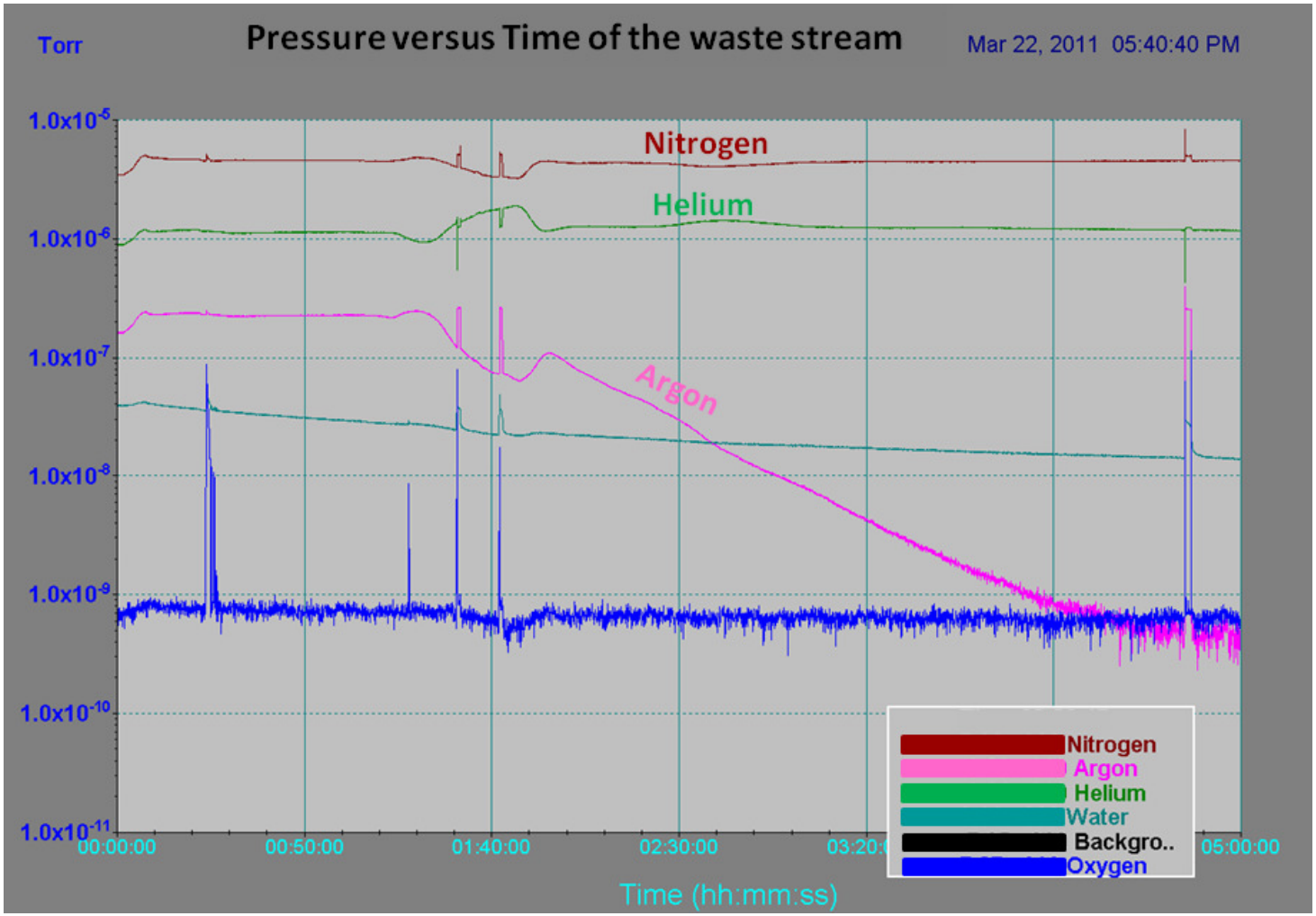
Control system



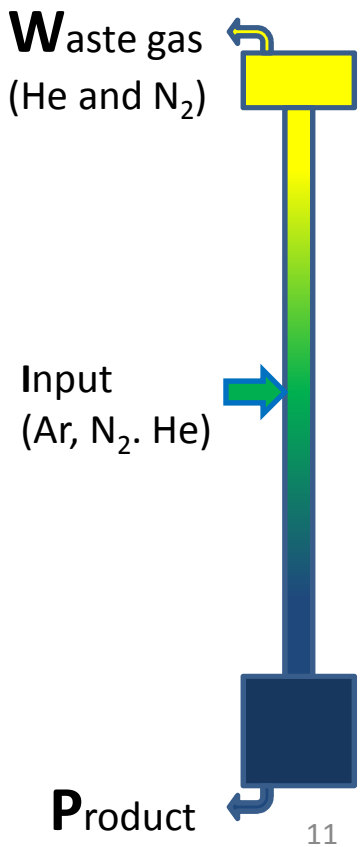
Commissioning

- Pre-safety review
  - Verify temperature control while under vacuum
  - Verify mass flow control
  - Measure gas composition of gas from Colorado
    - Found concentration to be: Ar – 2.5%, He - 27.5%, and N_2 – 70%
- Post safety review
  - Temperature control with gas load
    - Controls temperature to within 0.5K
  - Column cool down (Ar and N_2)
    - Column can be cooled in ~5 hours
  - Full commissioning run (Goals)
    - Use same gas mixture as Colorado gas (N_2 = 70%, He = 27.5%, Ar = 2.5%)
    - Show that Distillation Column can condense all Ar, even at low concentrations
    - Show continuous distillation is possible
    - Show that batch distillation works

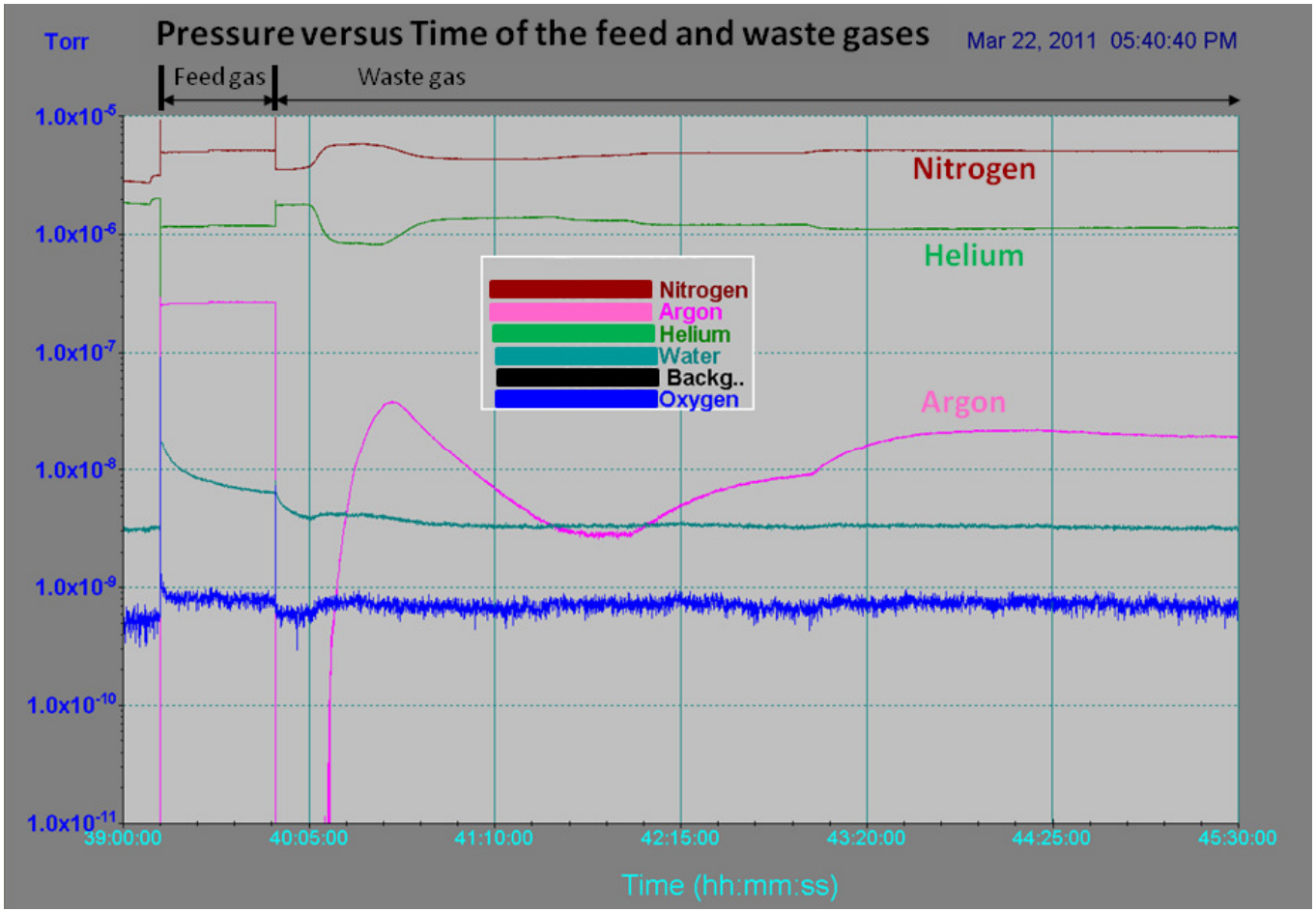
Argon condensation



- **5 hours after start up, we are condensing all the argon!**



First continuous distillation



Helium is not liquefied; it just passes through the system

Normalizing to Helium allows a direct comparison of input and waste gases

Input gas

- N_2/He ~ 4.23
- Ar/He ~ 0.22

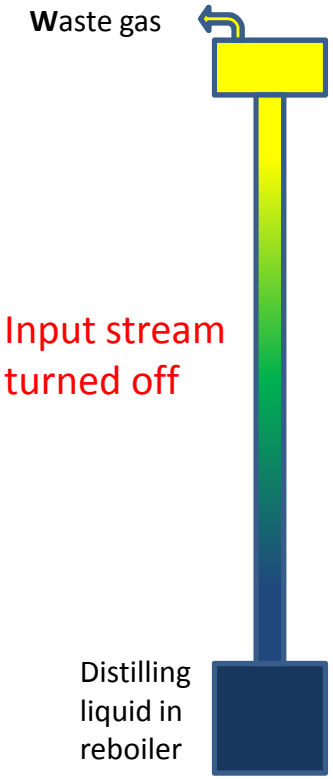
Waste gas

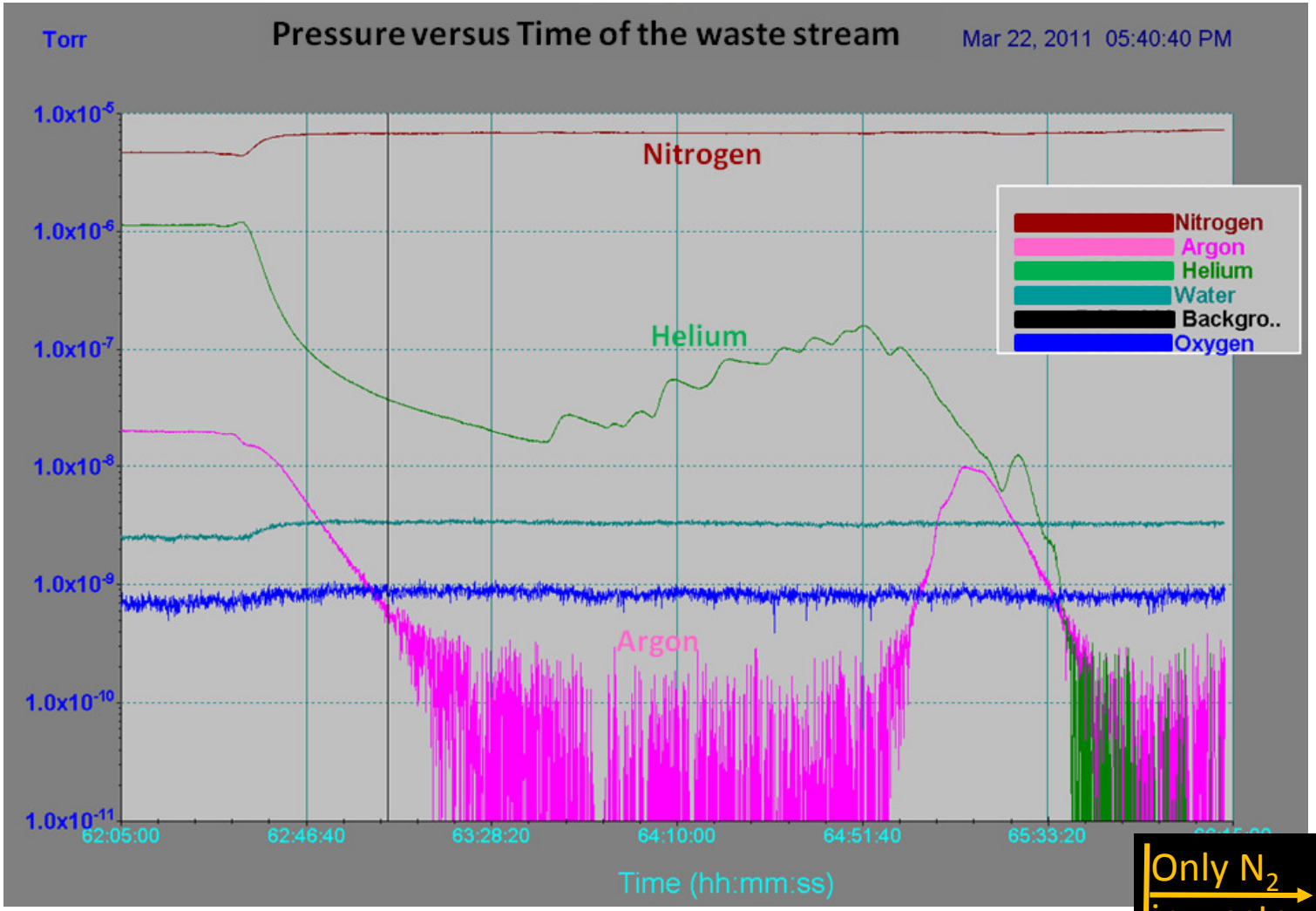
- N_2/He ~ 4.43
- Ar/He ~ 0.02

Conclusion

- More argon is entering than leaving (~90% is being collected)
- More N_2 is leaving than entering
- **First continuous distillation!**

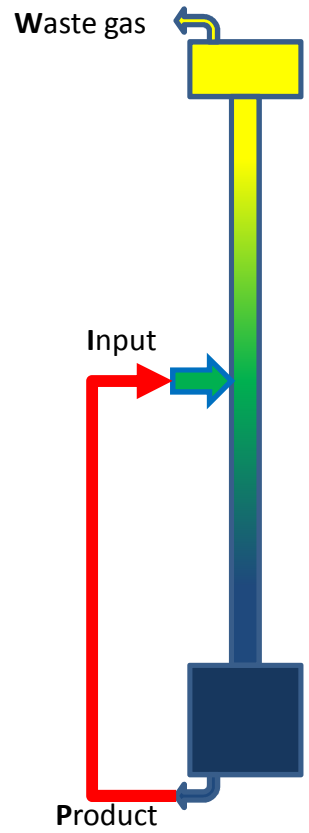
Batch Distillation



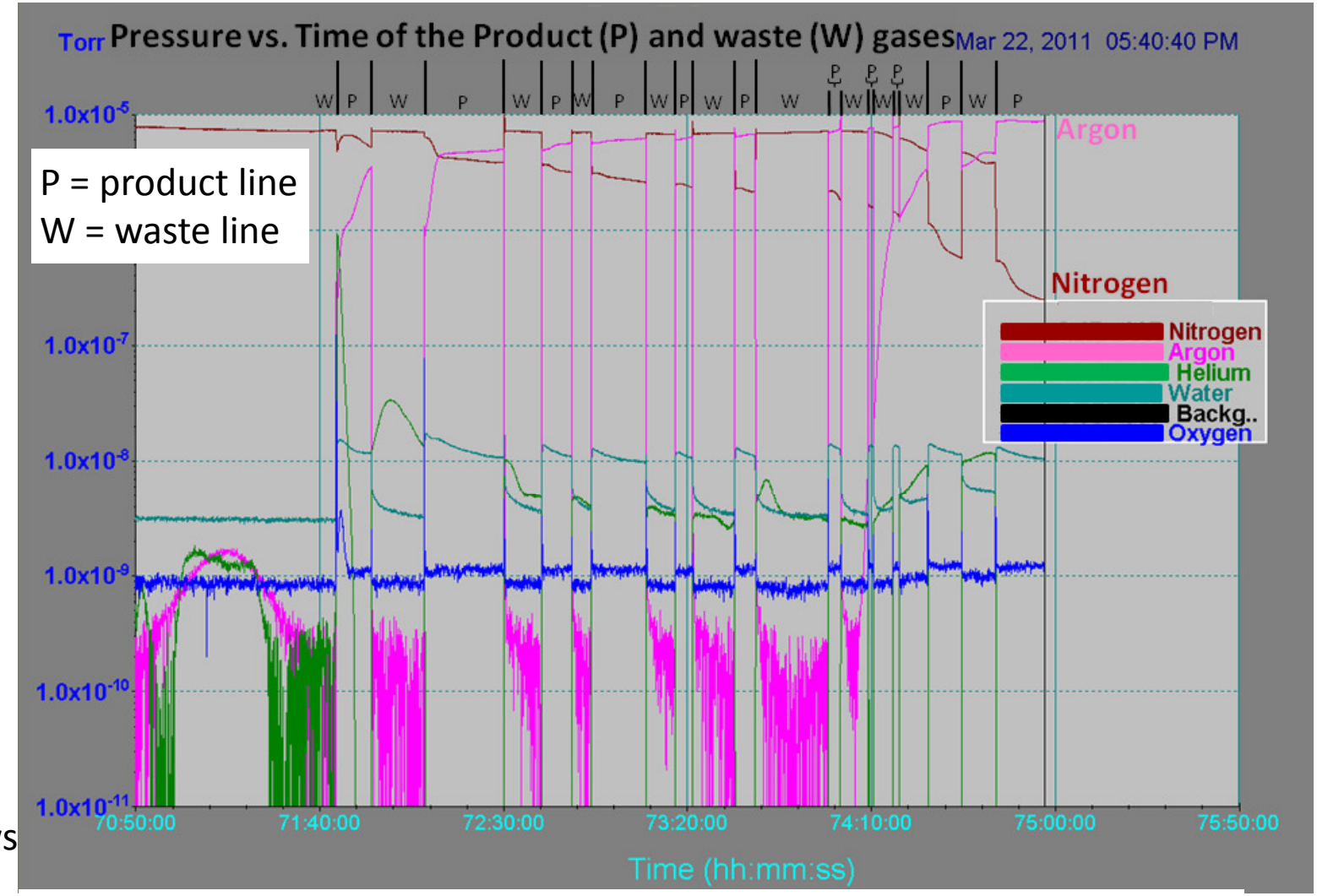


Batch distillation in progress!

Batch Distillation



Product line shows concentration of Ar and N_2 in reboiler.



N_2 concentration in reboiler is dropping throughout distillation run – **Batch distillation works!**

Start – Ar:N_2 = 1:30
Stop – Ar:N_2 = 33:1

} **~ Factor 1000 reduction**

Conclusions and Future

- Conclusions
  - It is possible to condense 100% of the argon
  - First successful continuous distillation
  - Batch distillation produces very pure Argon in reboiler
- Future work
  - Increase temperature monitoring capabilities
  - Further study of continuous and batch distillation
    - Goal: 1ppm N_2
  - Install product gas collection system (Condenser Booster)
  - Increase throughput to reach 5kg/day production