200 Kg of Underground Argon

The Struggle for Radiopurity

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UMass, Amherst

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DARKSIDE

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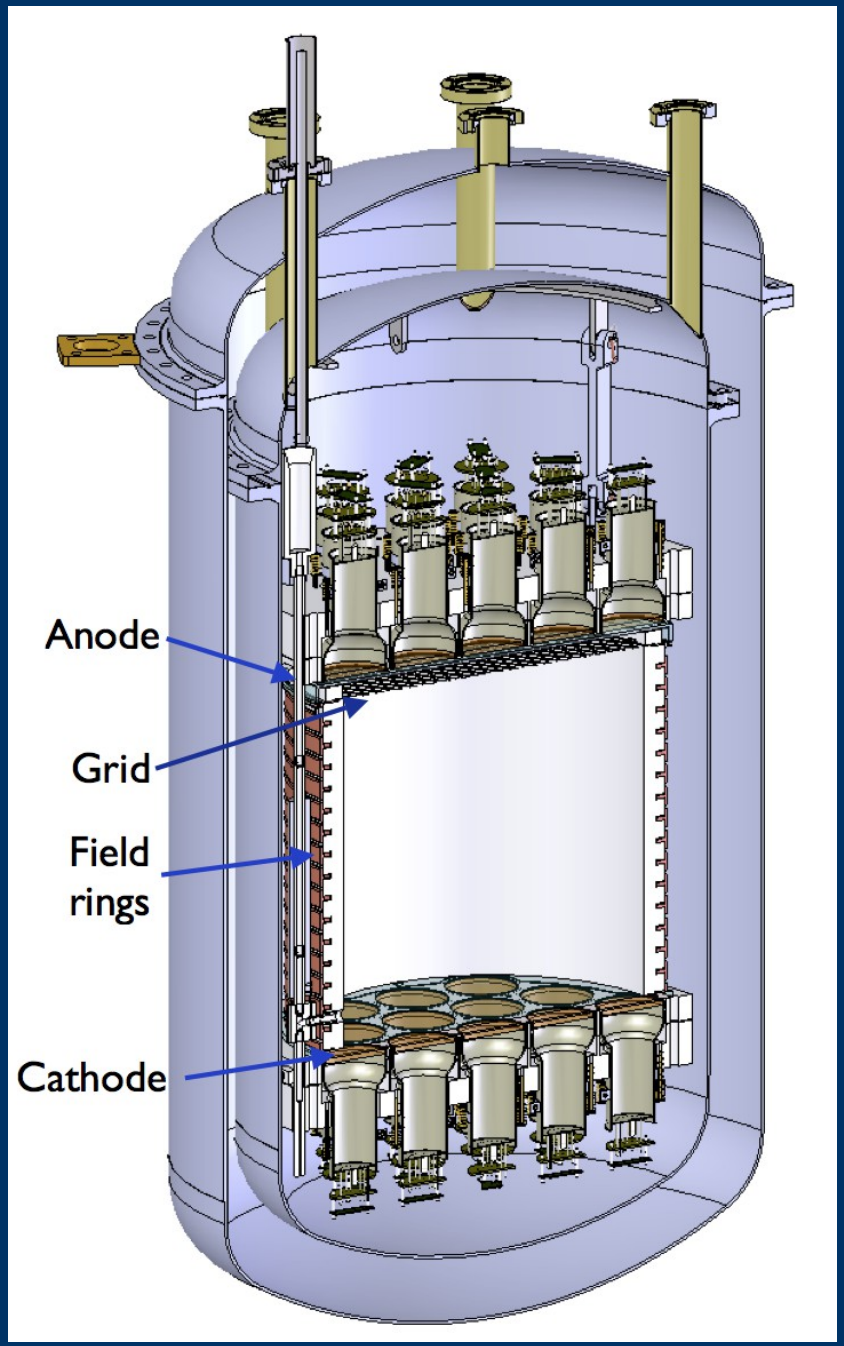
- Fermilab – The Distillation Crew
- Questions

Overview of Darkside-50*



- Liquid Argon TPC Dark Matter detector.
- Currently taking data at LNGS, since ~2016.
- Experiment is more sensitive than expected.
- *"50" because there are 50 kilograms of Argon in the "fiducial" (~central) volume.
- Actually requires 200 kg Argon.
- Very pure argon is commercially available, but there was a problem...

Why “Underground” Argon?

- Extremely pure Argon is commercially available, however...

  Commercial Argon is taken from air...

  Air is exposed to sunlight...

  Sunlight turns stable Ar40 into Ar39...

  Ar39 is radioactive, and produces noise...

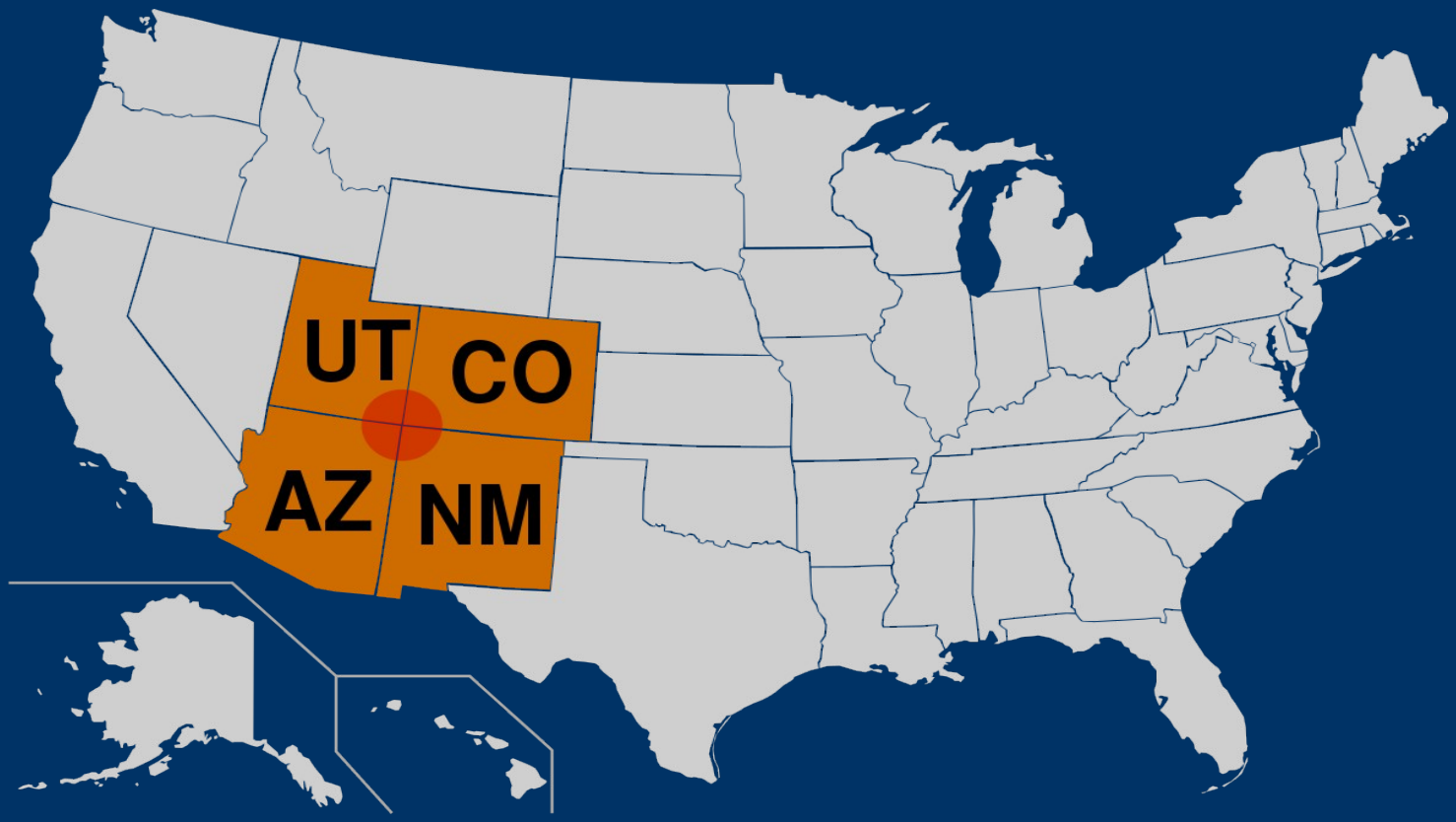
  This noise would destroy the signal...

  Signal is needed for dark matter detection

- Therefore: We took Argon from Underground and purified it ourselves.

Underground Argon: but Where?

A gas company called Kinder Morgan had argon gas in their CO_2 well. This gas has been underground for thousands of years and contains no radioactive isotopes. They kindly allowed us to extract gas for our experiment.
Located at the “Four Corners” in Colorado.



Stages 1 & 2: “Vacuum Pressure Swing Adsorption”

- Starting gas:
- Contained: CO_2, Helium, Nitrogen, Argon-40, Methane (CH_4) (& other hyrdocarbons) Oxygen, and misc. (but these “misc” things are in small number and come out easily).
- Zeolite[1] and Carbon[2] filters on-site in Colorado remove CO_2, some Nitrogen, and much of the hydrocarbons.

The Remaining gas is primarily:

Helium (~70-85%)
Nitrogen (~10-20%)
Argon-40 (~5-10%)

...But still contains Oxygen and Methane.

The Gas Racks

15 cylinders/rack

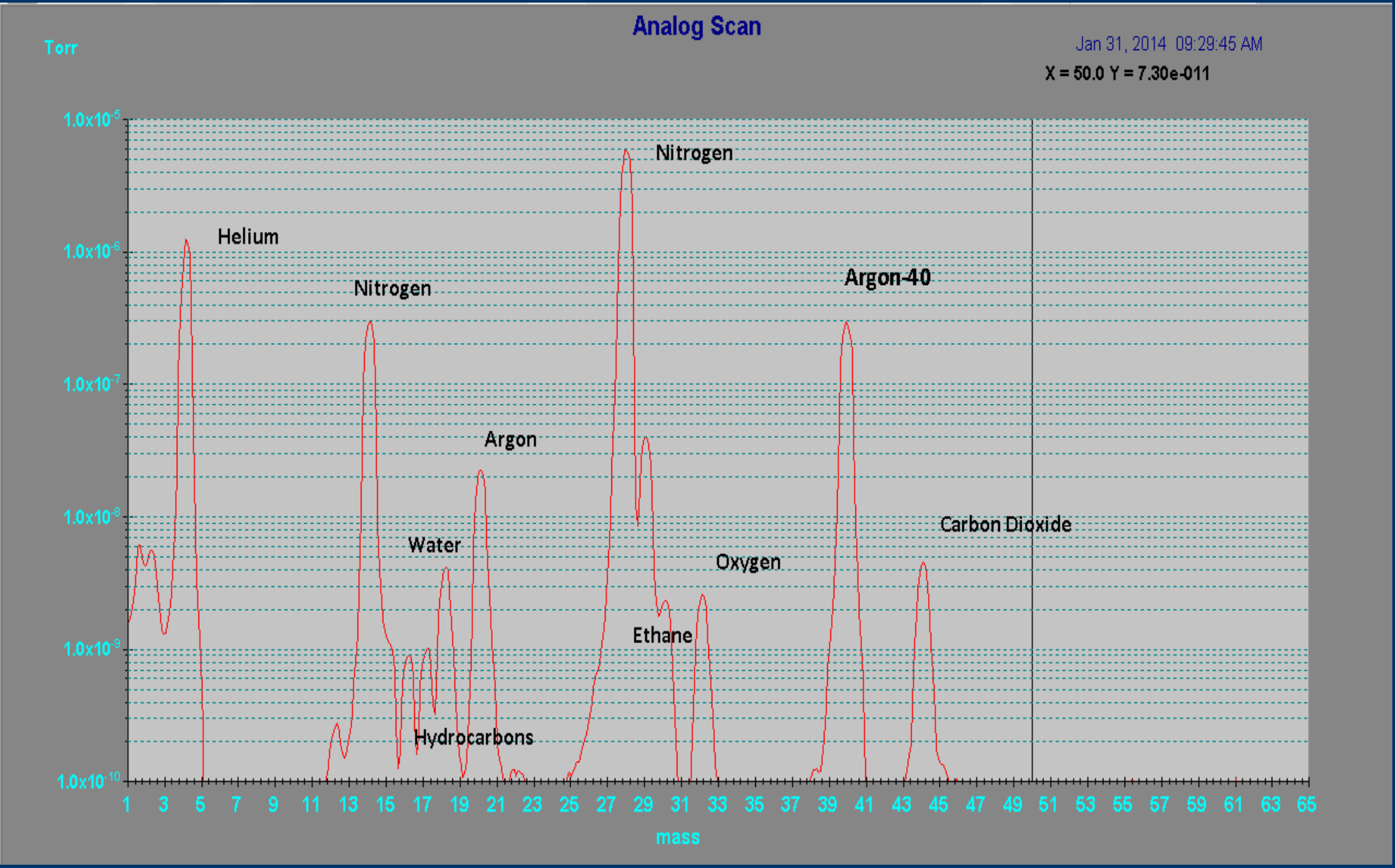
45 L / cylinders
4000 psi =
267 atm
~5-10% Argon

==>

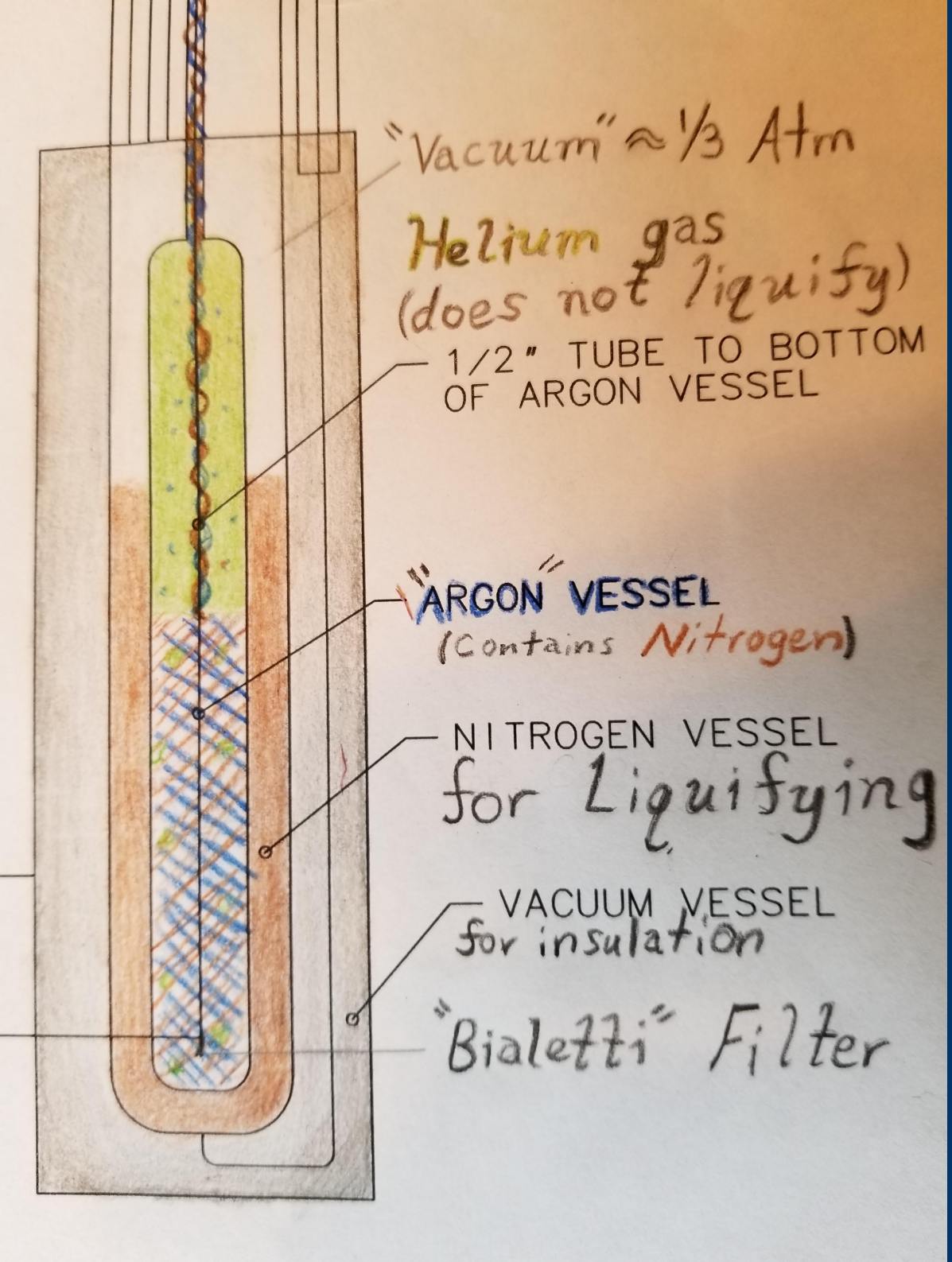
So roughly 15-25 kg Argon per rack.

...So we needed to purify >10 racks.

Shipped to Fermilab


Analog Scan
Torr
Jan 31, 2014 09:29:45 AM
X = 50.0 Y = 7.30e-011
1.0x10-5
1.0x10-6
1.0x10-7
1.0x10-8
1.0x10-9
1.0x10-10
Helium
Nitrogen
Argon
Water
Hydrocarbons
Nitrogen
Ethane
Oxygen
Argon-40
Carbon Dioxide
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
mass

Product in Transit to Fermilab



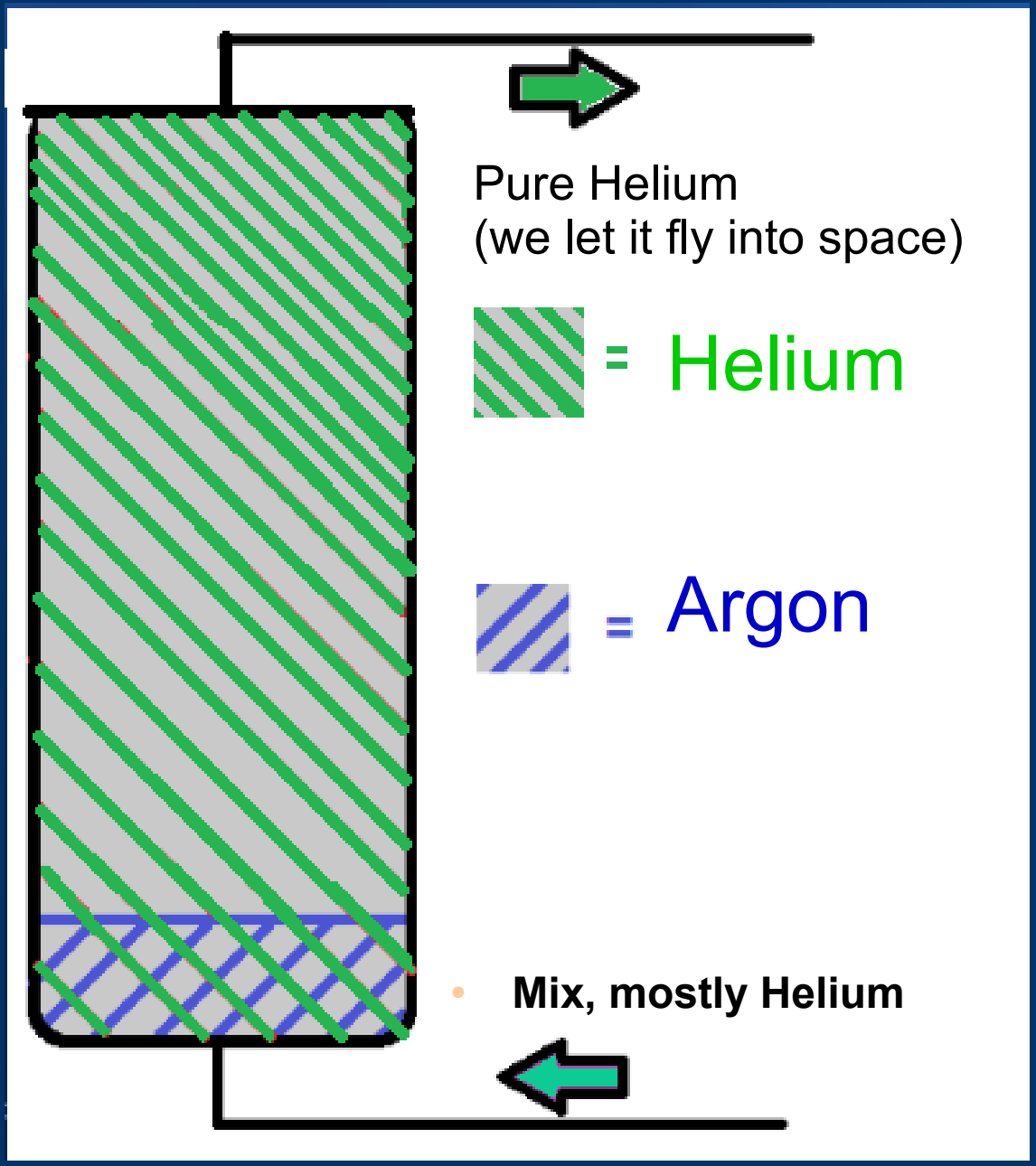
Stage 3: The "Condenser Booster"

- Helium Remover.
- First stage at Fermilab.
- A liquid nitrogen jacket cools the sides of the tank, liquifying Argon and Nitrogen, but leaving Helium a gas.
- Ar/N_2 mix is stored...
- While Helium is then vented through the Charcoal Traps[4]...

Stage 4: Charcoal Traps

- "Activated Carbon" ≈ "Charcoal"
- Charcoal is extremely porous.
- Between 300 and 2500 square meters per gram.
- Pretty much everything gets adsorbed by Charcoal
- Gasses Adsorb with: Cold/Pressure
- Gasses Desorb with: Heat/Vacuum

Charcoal Filters & How They Work



We vented the Helium from the Condenser Booster through the Charcoal Traps.

Charcoal captures Argon and lets Helium fly by.

When the Charcoal became saturated with Argon, we stopped the flow of gas, and removed the Argon from the charcoal by warming it up.

The Argon was sent back to the Condenser Booster and the Charcoal was ready to be used again.


Take 5ive

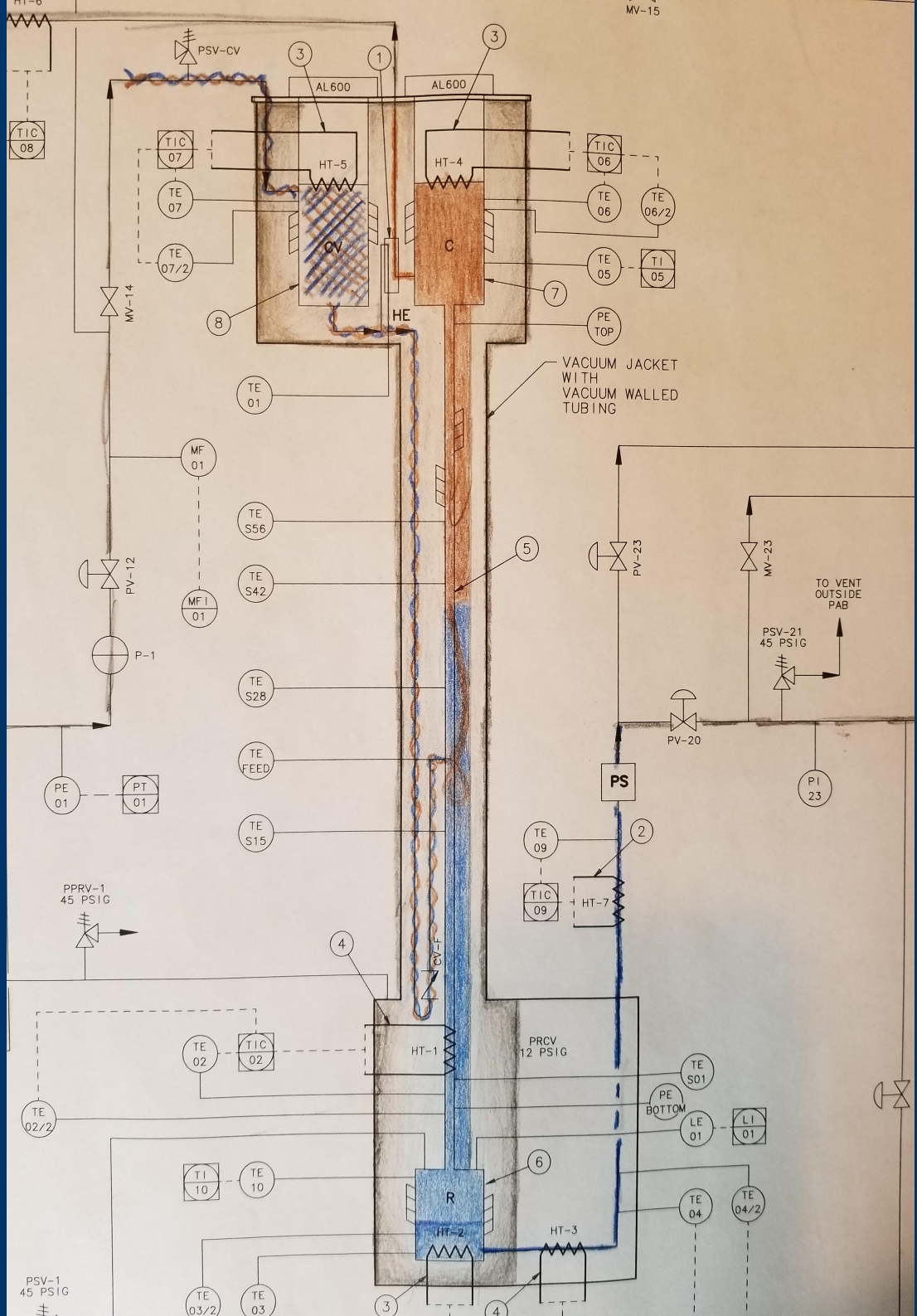

VENT
ARGON
ARGON

Stage 5: Cold Traps

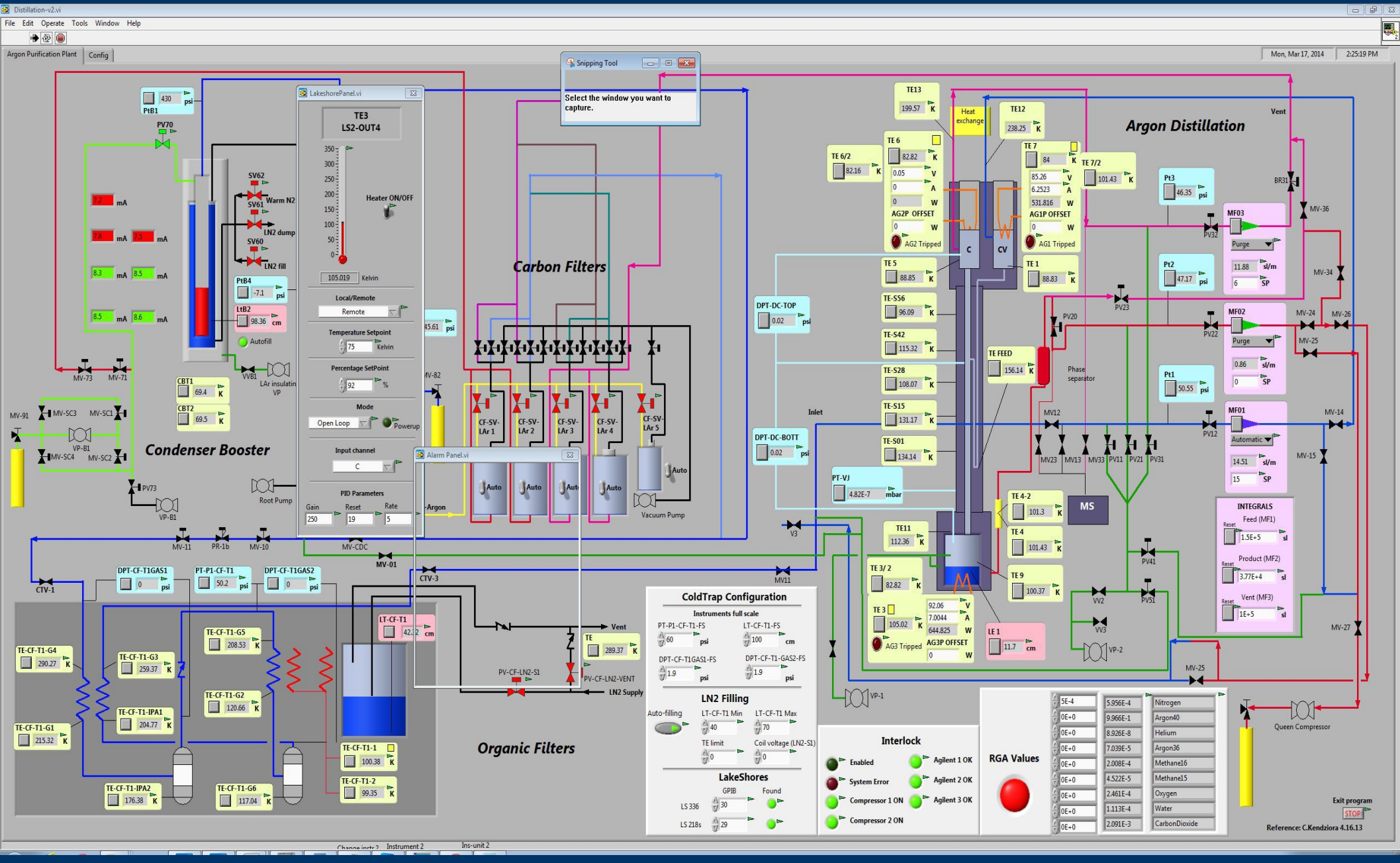
- Simple, similar to the Condenser Booster[3].
- Cooled by Liquid Nitrogen.
- Freezes all remaining CO_2, many of the remaining hydrocarbons, and miscellaneous impurities.
- Gas passes straight into the Distillation Column[6]
- The outgoing (and incoming) gas is largely Argon and Nitrogen

Stage 6: Distillation

- Picture shows column in use.
- Up to 600 watts is applied at the bottom to boil argon.
- Boiled argon collides with liquid Nitrogen in the center of the column. Argon liquifies, falls back down, and nitrogen boils up.
- The cooler at the top re-condenses Nitrogen.
- Vent unwanted Nitrogen, and collect liquid argon



Our GUI

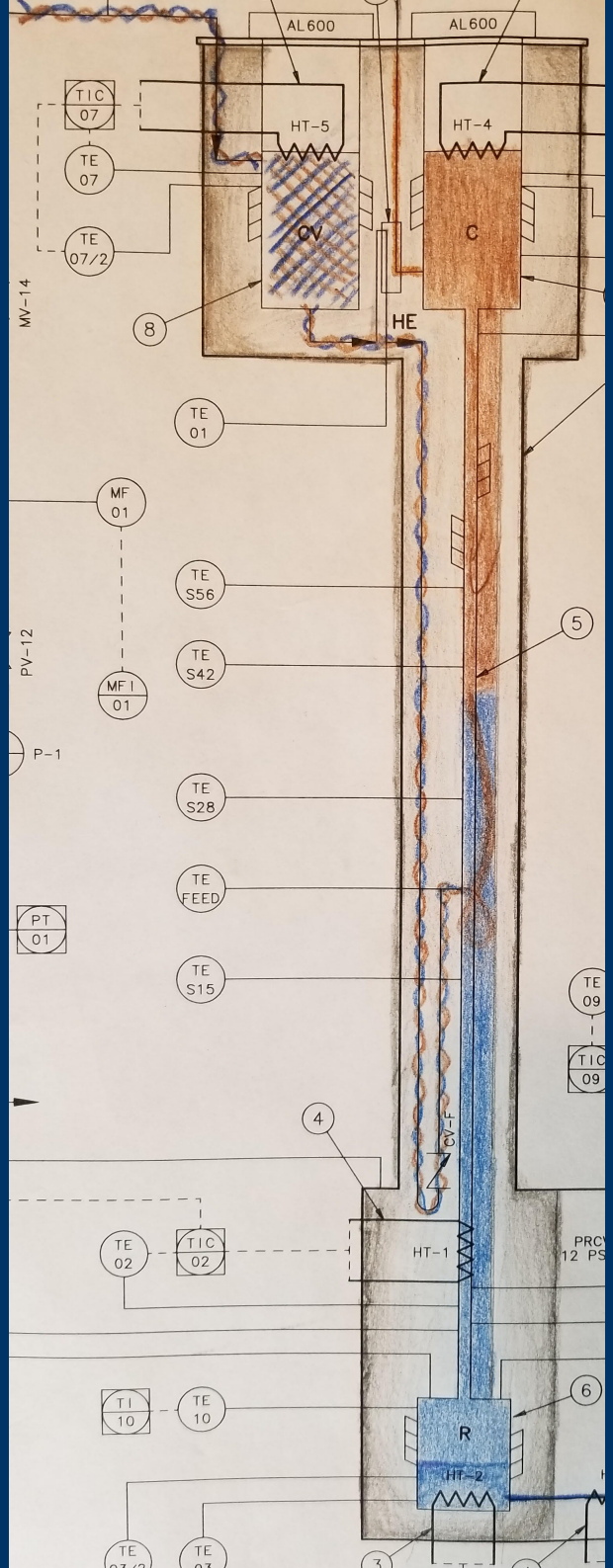

Distillation-v2.vi
File Edit Operate Tools Window Help
Argon Purification Plant
Config
Mon, Mar 17, 2014
2:25:19 PM
Snipping Tool
Select the window you want to capture.
LakeshorePanel.vi
TE3
LS2-OUT4
Heater ON/OFF
Kelvin
Local/Remote
Remote
Temperature Setpoint
Percentage SetPoint
Mode
Open Loop
Powerup
Input channel
PID Parameters
Gain
Reset
Rate
Alarm Panel.vi
Carbon Filters
Condenser Booster
Organic Filters
Argon Distillation
Heat exchange
Phase separator
Inlet
Vent
Root Pump
Vacuum Pump
Queen Compressor
MS
INTEGRALS
Feed (MF1)
Product (MF2)
Vent (MF3)
ColdTrap Configuration
Instruments full scale
LN2 Filling
Auto-filling
LakeShores
GPIB
Found
Interlock
Enabled
System Error
Compressor 1 ON
Compressor 2 ON
Agilent 1 OK
Agilent 2 OK
Agilent 3 OK
RGA Values
Nitrogen
Argon40
Helium
Argon36
Methane16
Methane15
Oxygen
Water
CarbonDioxide
Exit program
STOP
Reference: C.Kendziora 4.16.13

Stage 6: Distillation

99.9% pure Argon after Distillation:

Contains no more Helium or Nitrogen

Still contains too much Oxygen and Methane

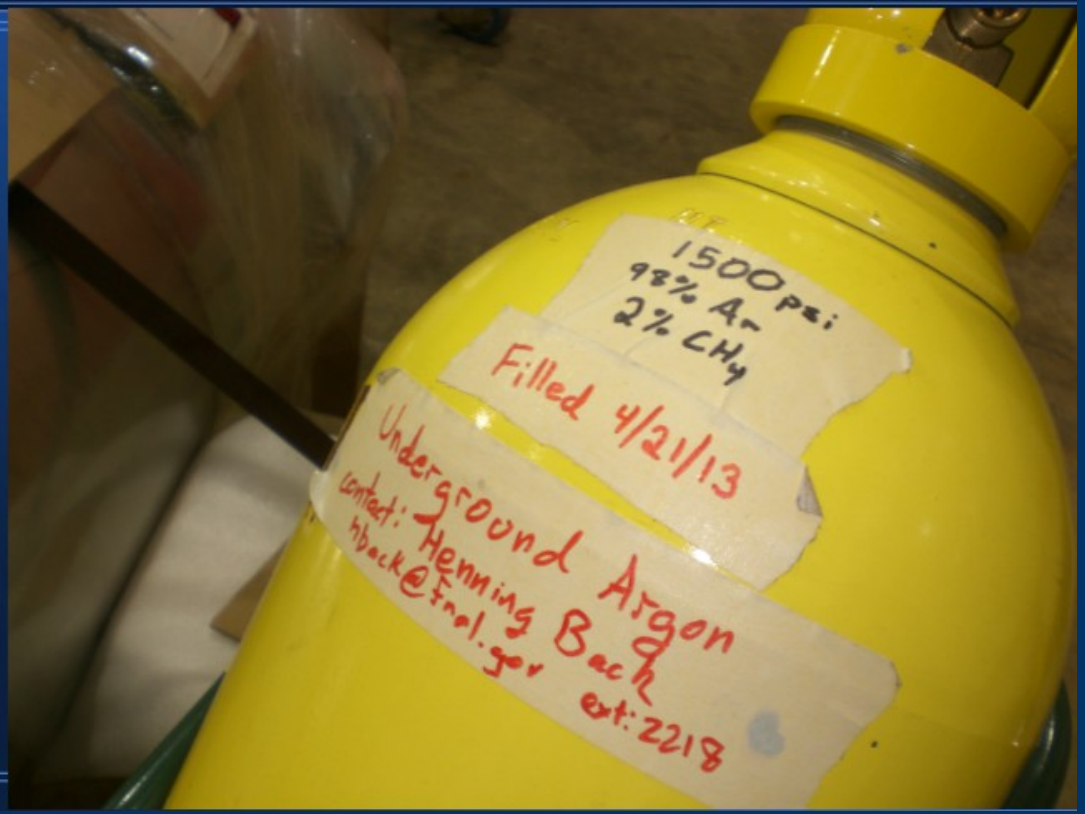


Our Methane Problem

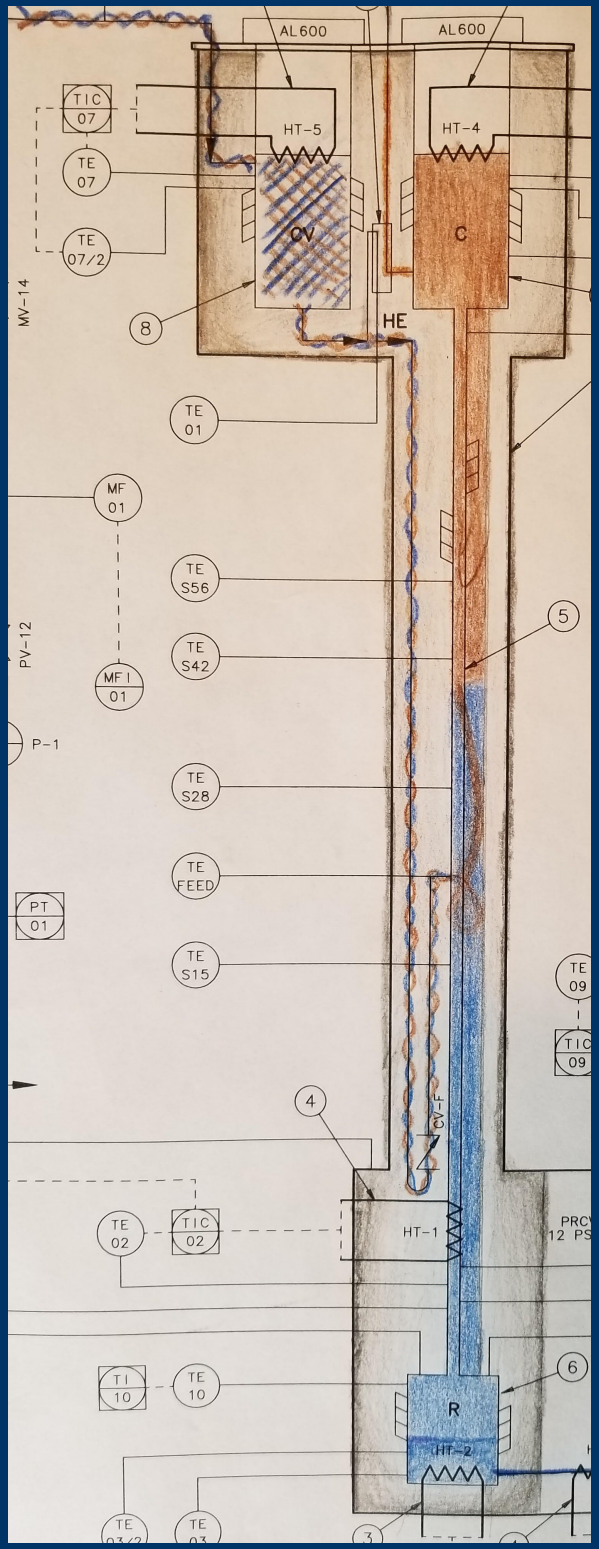
- As of the summer of 2013 we had ~4500 L of "Argon", with 90 L of Methane

Our Most Pure Gas

- 98% Ar
- 2% CH4



For years, we had no plan for how to remove the Methane, but we kept collecting...



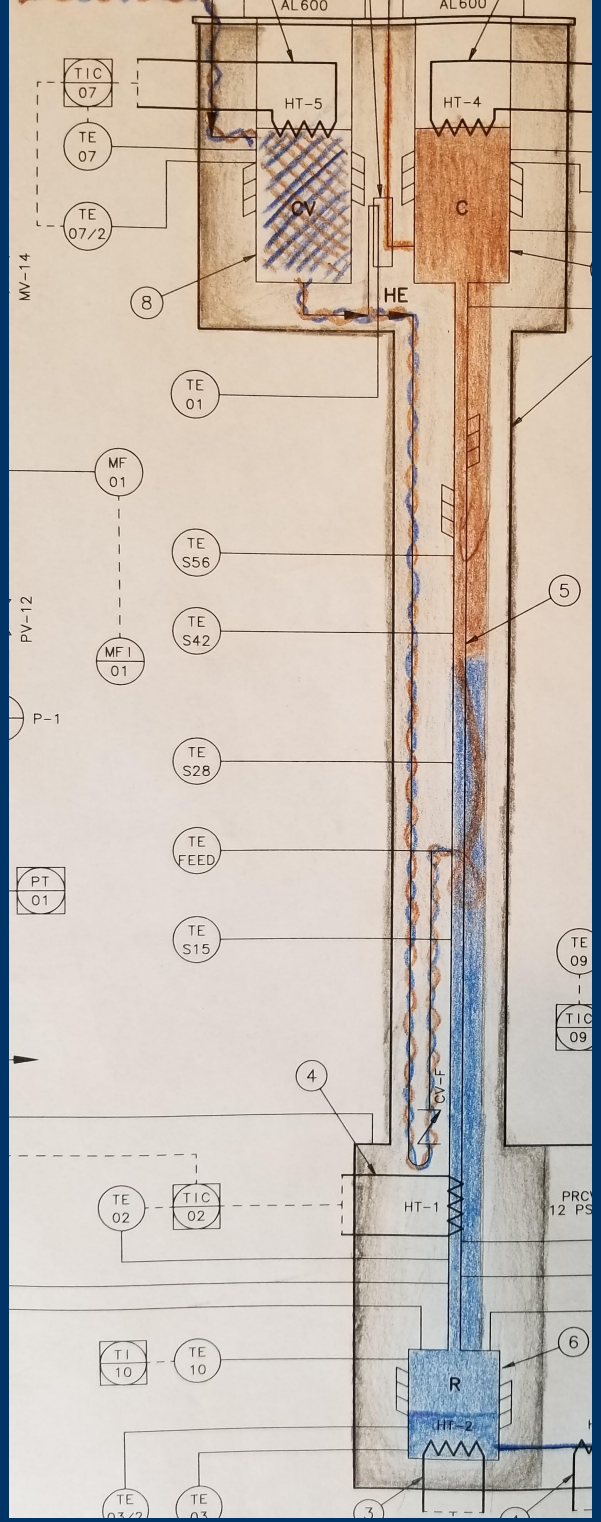
Stage 7:
Methane Distillation

- ...Eventually, we decided to use the distillation column to remove our Methane.
- Turning up the heat left liquid Methane on the bottom and pure gaseous Argon at the top.
- Reduced Methane content by better than 1/100th.
- Collected “Methane-free” Argon gas.

Stage 8:
Copper & Zirconium Oxygen Getters

- Argon was sent directly from the Distillation column.
- Copper and Zirconium have Oxygen-adsorbing properties.
- Before Stage 8:

  99.9% Argon
  0.1% Oxygen
  Unacceptable and Variable Methane Content
- Stage 8 Eliminated Oxygen before the Argon was put in storage cylinders.



Stage 9:
Methane Getters

- ~210 Kilograms of Argon, containing only trace levels of Methane, were shipped to Gran Sasso National Laboratory in Italy.
- The contamination was removed with Methane Getters, similar in function to the Oxygen Getters, are extremely good at removing Methane.
- The detector was ultimately filled with Earth's least radioactive Argon.
- The radiopurity levels are better than expected and the detector is performing swimmingly.

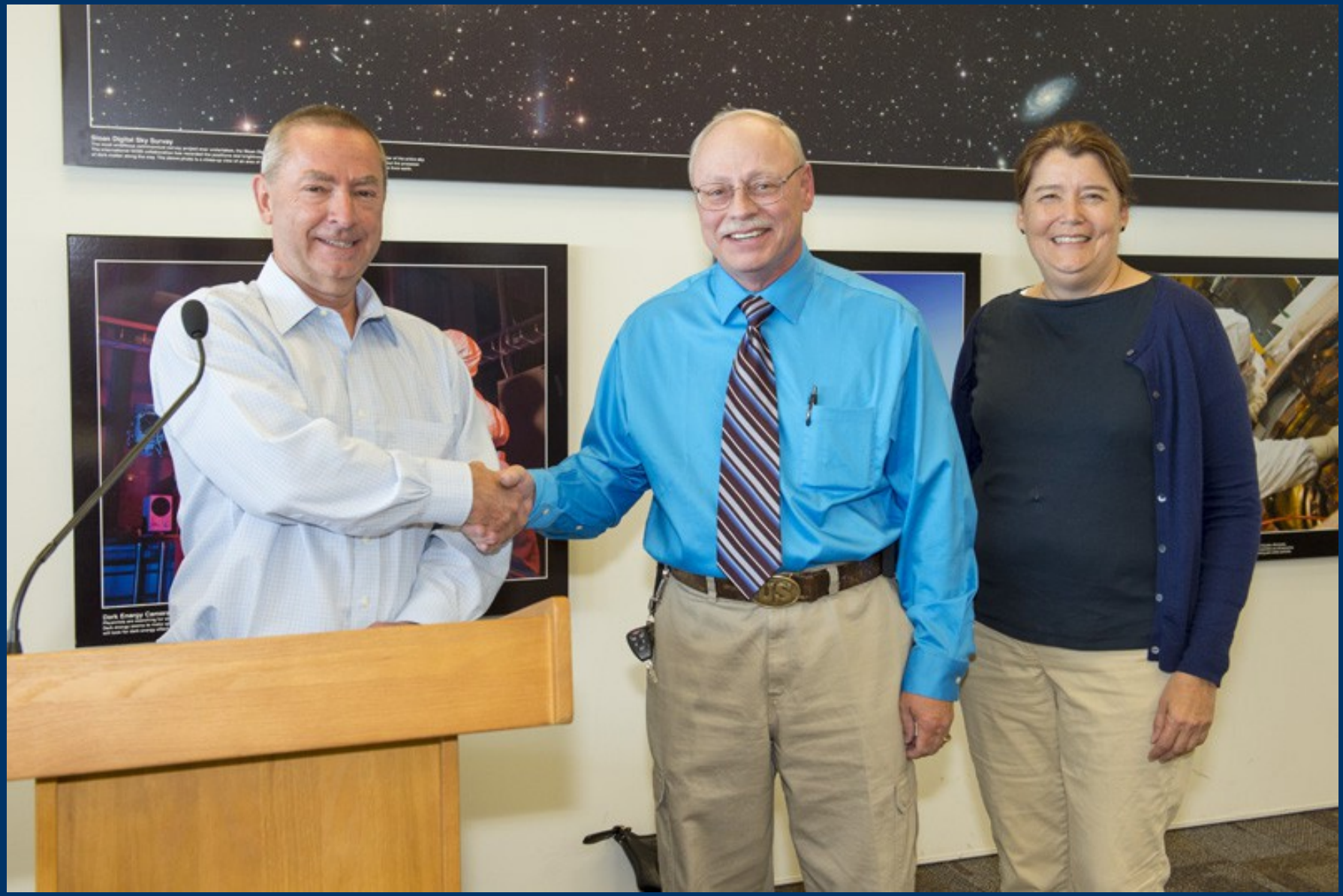
Fermilab's Distillation Crew

- Fermilab Operators:
  Thomas Alexander, Jessica Oaks, Henning Back, Jerry “Mr. Freeze” Zimmerman, Luca Pagani, “Jose”, Samantha Norris, Gary Forster, Susan Walker, Paolo Cavalcante, Michele Monstusci, Hao Chen, Federico Gabrielle
- Colorado Operator: Chris Something
- Technicians:
  Bill Miner, Kelly Hardin, Ron Davis, Bob Barger
- Scientists and Engineers:
  Henning Back, Cary Kendziora, and David Montanari
- Continued Guidance from
  Stephen Pordes and PNNL scientists Jeter Hall and Paul Humble


DISTILLATION


NOTICE
CLARK
CLARK
Kimwipes


Advancing the Technology of Cryogenic Sys
APD CRYOGENICS INC
2012
Curél
KIMTECH
Kimwipes


Sloan Digital Sky Survey
Dark Energy Camera

Questions?

Thank you all very much for your attention.