LBNE Cryogenics Systems and Cryostat Issues

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For the LArTPC R&D Workshop
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Overview

- Design Choices Related to 10-kton Surface Detector
- Lessons Learned Related to 35 ton Prototype

Quick Review:
Overall GAr/LAr & LN2 Process

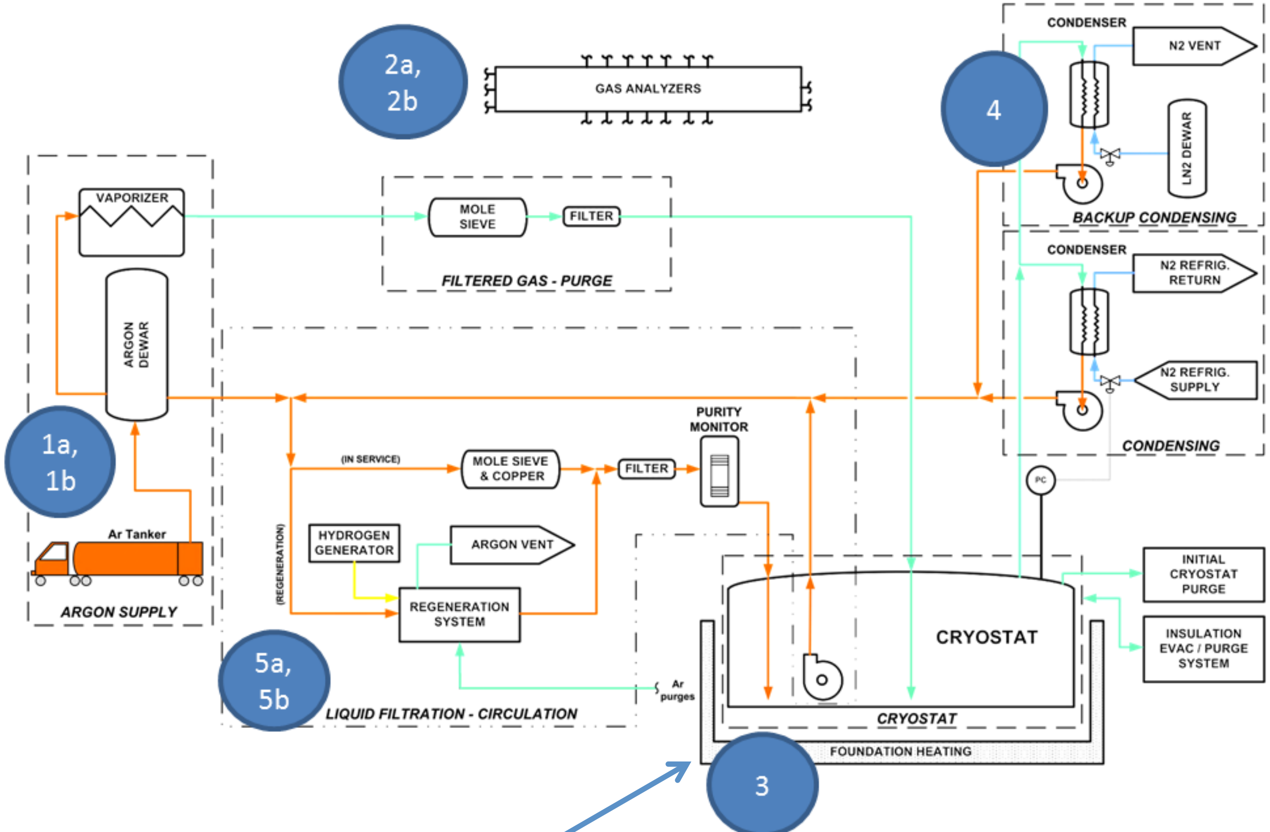
1a. LAr/GAr Delivery
1b. Pipe Systems for LAr

2a. Gas Purge Equipment
2b. Gas Analysis Equipment

3. Liquid Pumps in Cryostat

4. Condenser Systems

5a. Liquid Filtration
5b. Regeneration Systems



Each cryostat = 9.4 kton

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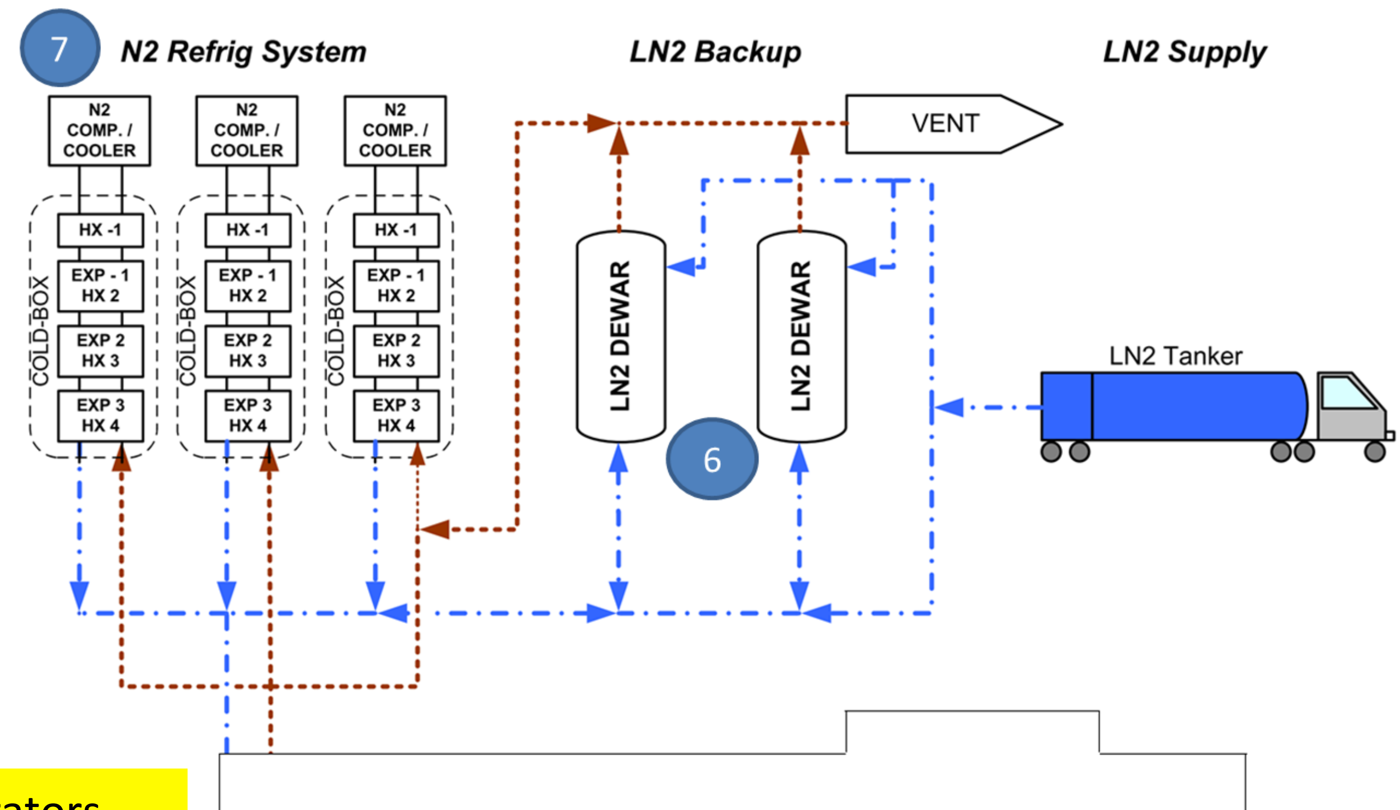
LN2 Cycle

6. LN2 Dewar System
7. N2 Refrigeration Plant
8. Process Controls



Three LN2 refrigerators
~ 3 x 55 kW Cooling Power

8 → Process Controls (All hardware including instrumentation and Commercial Process systems such as iFix)

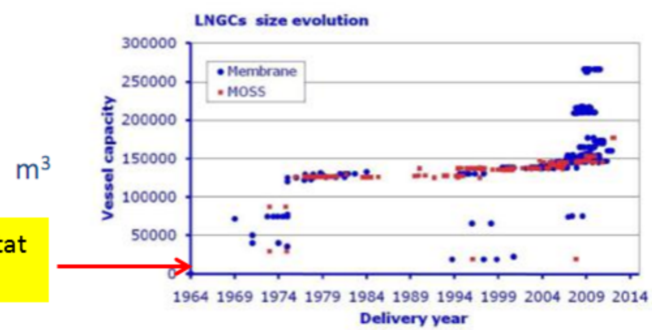
Far Detector Cryogenic Systems

- Total Volume of Stored Inventory
  - Volume is 18.8 kton LAr equally split between two cryostats
  - Each cryostat is: 15.98 m (H) x 28.56 m (L) x 15.63 m (W)
  - Cost of stored LAr ~ $25 Million; must limit loss over life of project
  - Requires ability to offload tankers in a coordinated/systematic manner to fill a single cryostat continuously
  - Requires reliable LN2 services AND backup LN2 from storage in case of equipment failures or power outages
- Using purge method on 7100 m3/cryostat
- Requires high purity (< 1.4 ms lifetime)
  - Intention is to have automated process for regeneration of the filter beds; using mole sieve and copper bed

Challenges of Cryostat

- Selected Membrane cryostat
  - Commercial product used in LNG and in much harsher conditions than the 10 kton detector
  - Meets the requirements of LAr storage, feed through capability
  - Has a history of reliability throughout the world
  - No need to build a evacuable vessel because of purge method (see LAPD results) allows for low ppm levels to be achieved w/out pumping

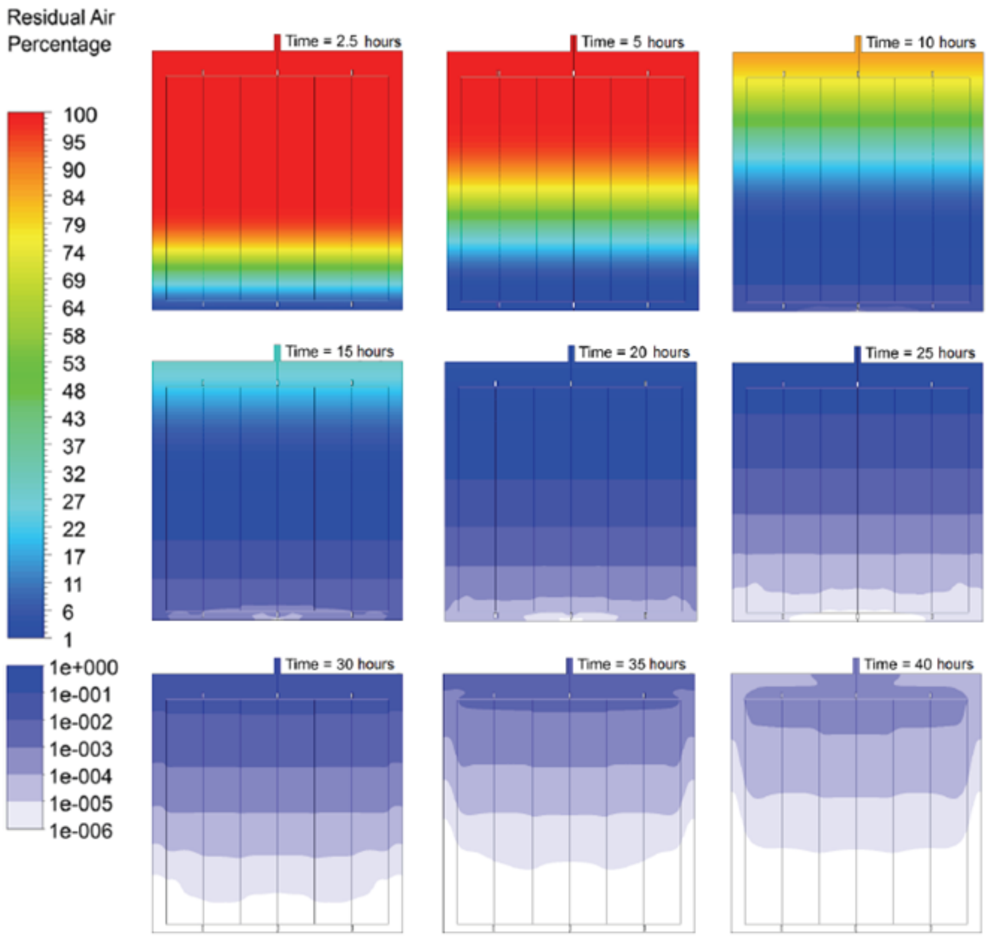
Each LBNE cryostat is 7100 m3



Membrane Wall with Wave Approaching

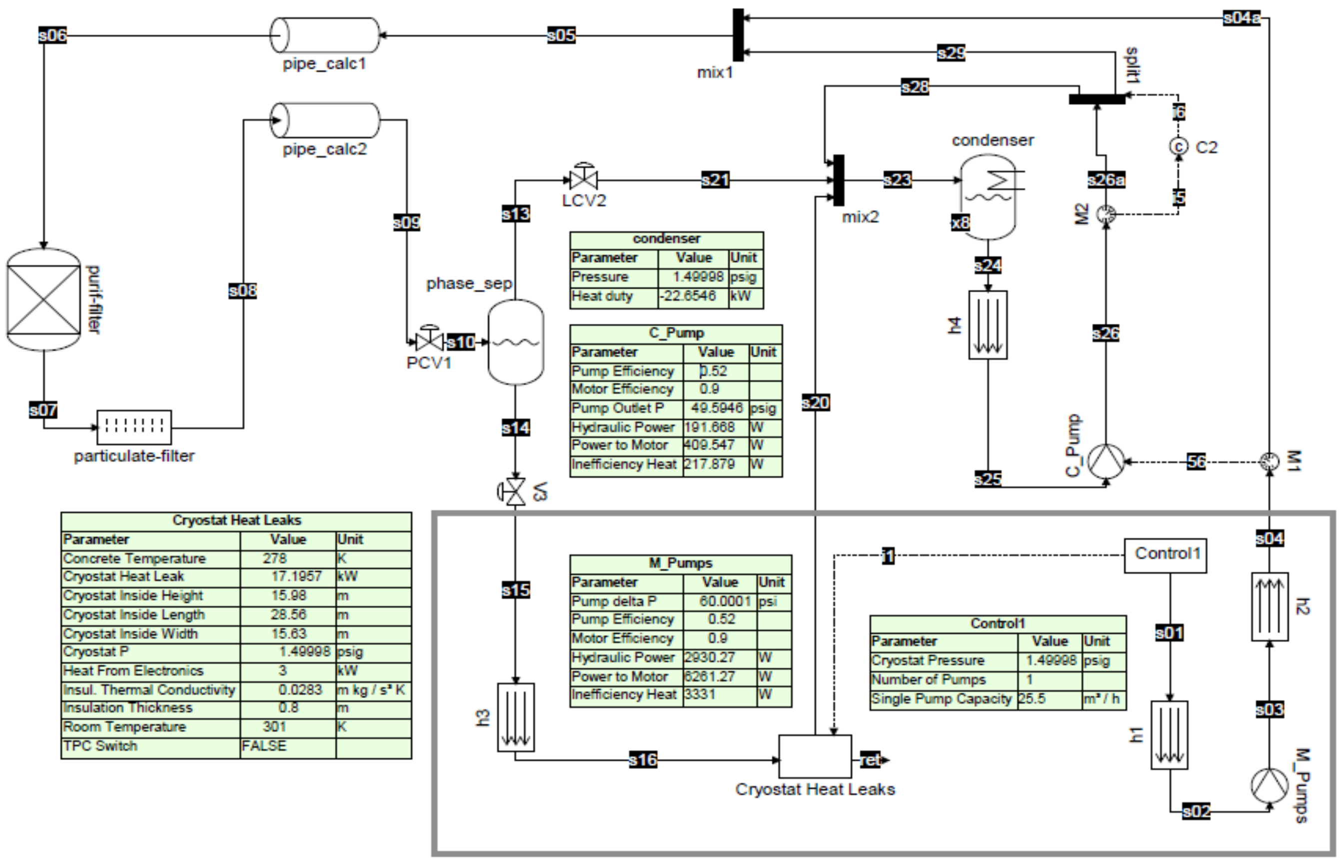
- Possible negative: Two vendors that we are aware of : IHI and GTT with IP issues not 100% resolved with GTT but an apparent solution exists if GTT uses a company as a EPC

Simulation of Purge Method for 10kton Cryostat



Air concentration falls to 1 ppm in ~ 40 hours

Computer Modeling/Simulation



condenser		
Parameter	Value	Unit
Pressure	1.49998	psig
Heat duty	-22.6546	kW

C_Pump		
Parameter	Value	Unit
Pump Efficiency	0.52	
Motor Efficiency	0.9	
Pump Outlet P	49.5946	psig
Hydraulic Power	191.668	W
Power to Motor	409.547	W
Inefficiency Heat	217.879	W

Cryostat Heat Leaks		
Parameter	Value	Unit
Concrete Temperature	278	K
Cryostat Heat Leak	17.1957	kW
Cryostat Inside Height	15.98	m
Cryostat Inside Length	28.56	m
Cryostat Inside Width	15.63	m
Cryostat P	1.49998	psig
Heat From Electronics	3	kW
Insul. Thermal Conductivity	0.0283	m kg / s³ K
Insulation Thickness	0.8	m
Room Temperature	301	K
TPC Switch	FALSE	

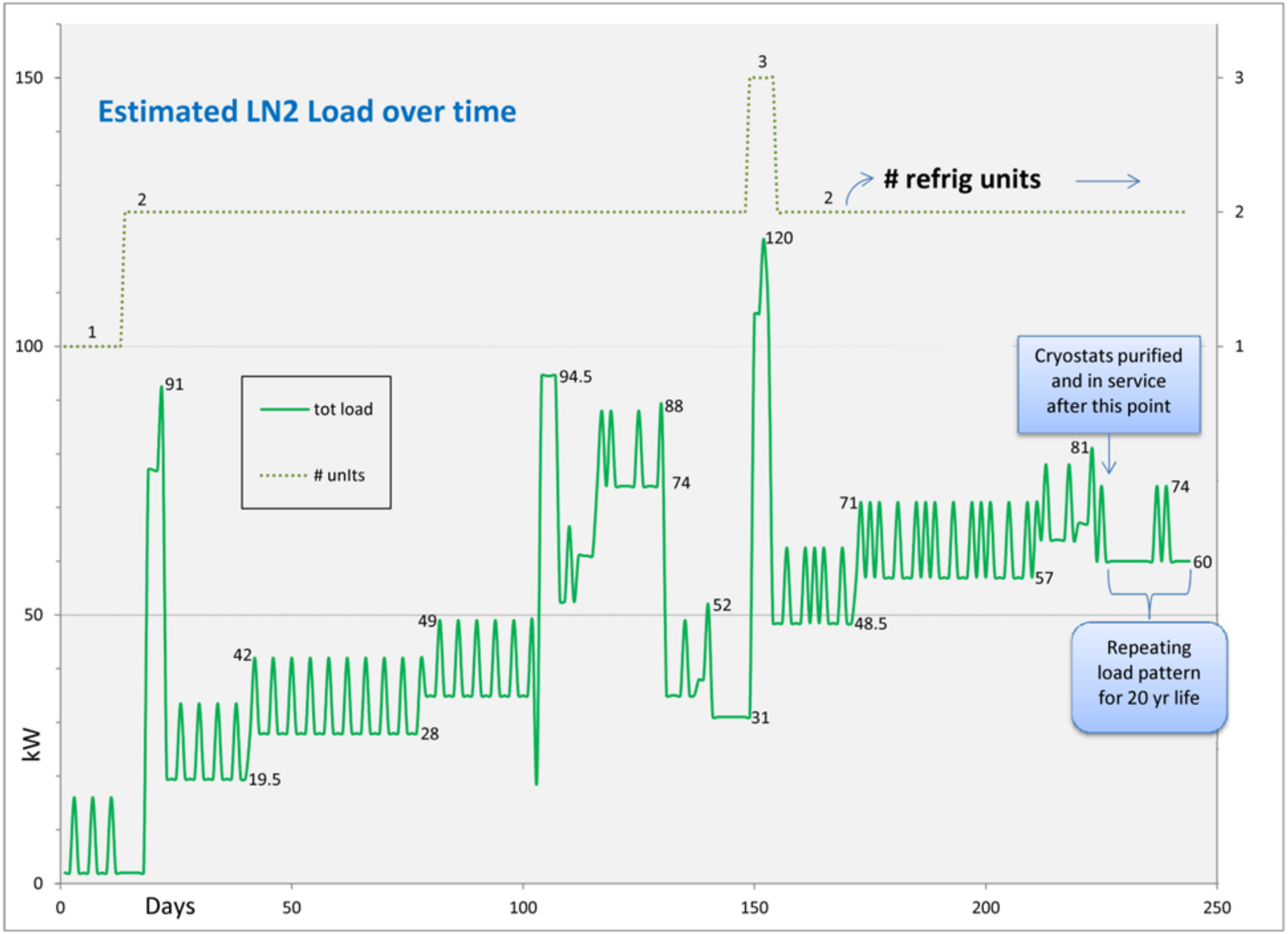
M_Pumps		
Parameter	Value	Unit
Pump delta P	60.0001	psi
Pump Efficiency	0.52	
Motor Efficiency	0.9	
Hydraulic Power	2930.27	W
Power to Motor	6261.27	W
Inefficiency Heat	3331	W

Control1		
Parameter	Value	Unit
Cryostat Pressure	1.49998	psig
Number of Pumps	1	
Single Pump Capacity	25.5	m³ / h

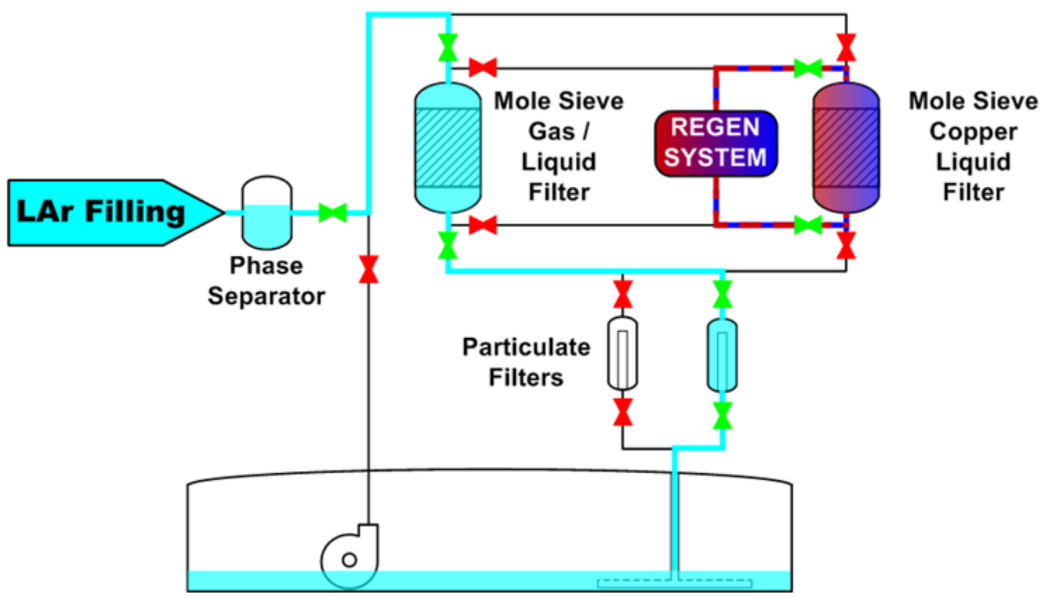
Engineer leading cryogenic systems work (Mark Adamowski) has built a computer simulation of the LAr loop and heat sources to:

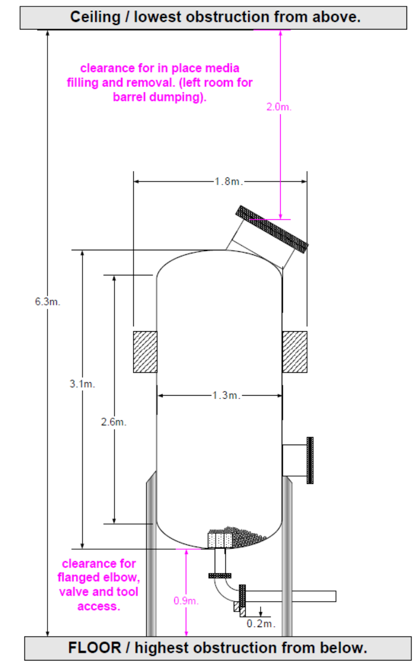
1) Improve understanding of system and component interactions
2) Verify sizing of lines, condenser, filters, pumping power, and LN2 usage

Burden vs. Time for LN2 Refrigerators

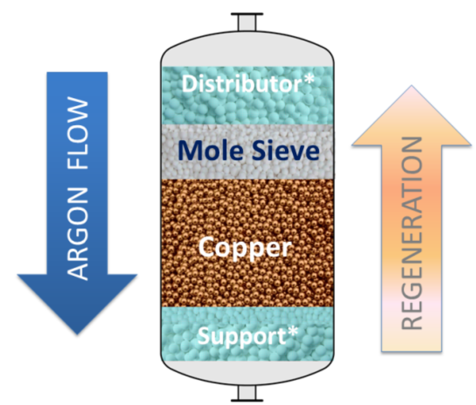


Gas and Liquid Filtration



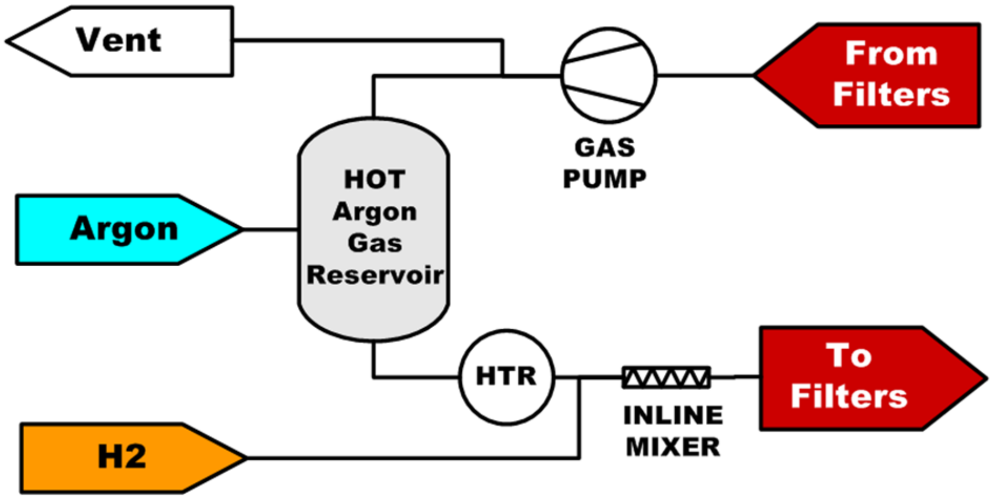


- Mole Sieve
  - Water Capture
- Copper
  - Oxygen Capture



*Distributor and support provided by alumina ballast ball

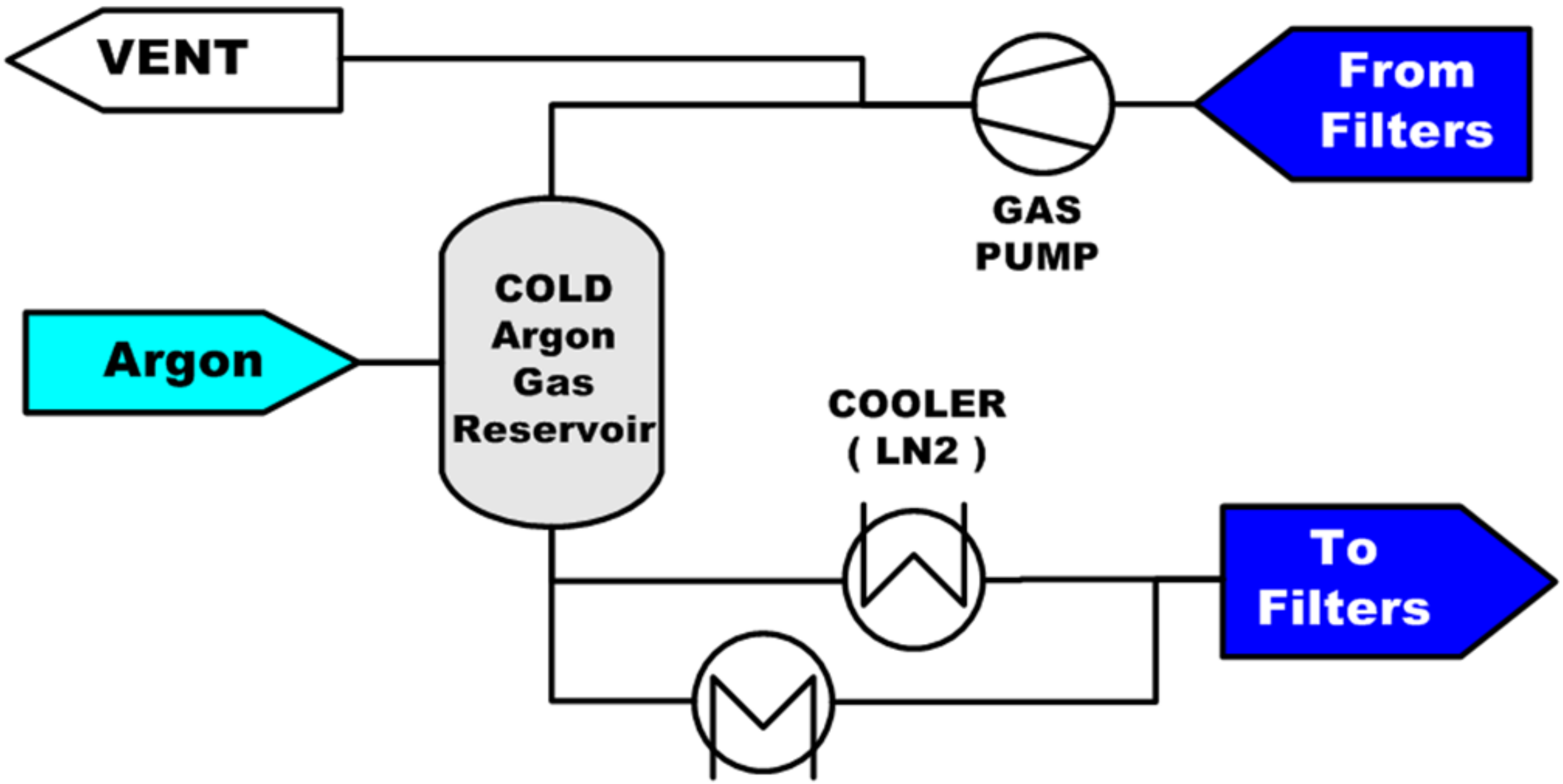
Hot Cycle for Regeneration



Safety
- Eliminated premixed Ar/H_2
- Hydrogen made as needed
- Hydrogen below flammability limit
  - 2.5% < 4% LFL/LEL

Hydrogen inventory limited
- Tubing from generator to injection point
- On board hydrogen inventory of 1.6 liters

Cool down Following Regeneration



Accepted Engineering Model for the 10 kton Design

A significant effort was spent in the Dec 2012/January 2013 timeframe, deciding what is the best model for approaching the PD & FD for Cryogenic Systems and Cryostat engineering design.

A variety of approaches were analyzed and presented to LBNE's Tech Board:

- The original idea presented at CD1 for FNAL/LBNE to oversee the engineering design but to outsource the work to an A&E firm such as ARUP, Inc. which we have used to form a Conceptual Design Report.

- The new approach uses the experiences and expertise of FNAL engineering to guide both the Cryostat design and the Cryogenic Systems design.

- The 35 ton design allowed us to gain experience working with a membrane cryostat vendor in an **oversight manner**. IHI designed the vessel based on our written specification(s). FNAL engineers worked with IHI over a ½ year period to develop the Final Design as well as with IHI during the construction period last summer/fall. **This approach is the chosen method for the future 10-kton detector** and begins with LBNE writing an RFP this Spring.

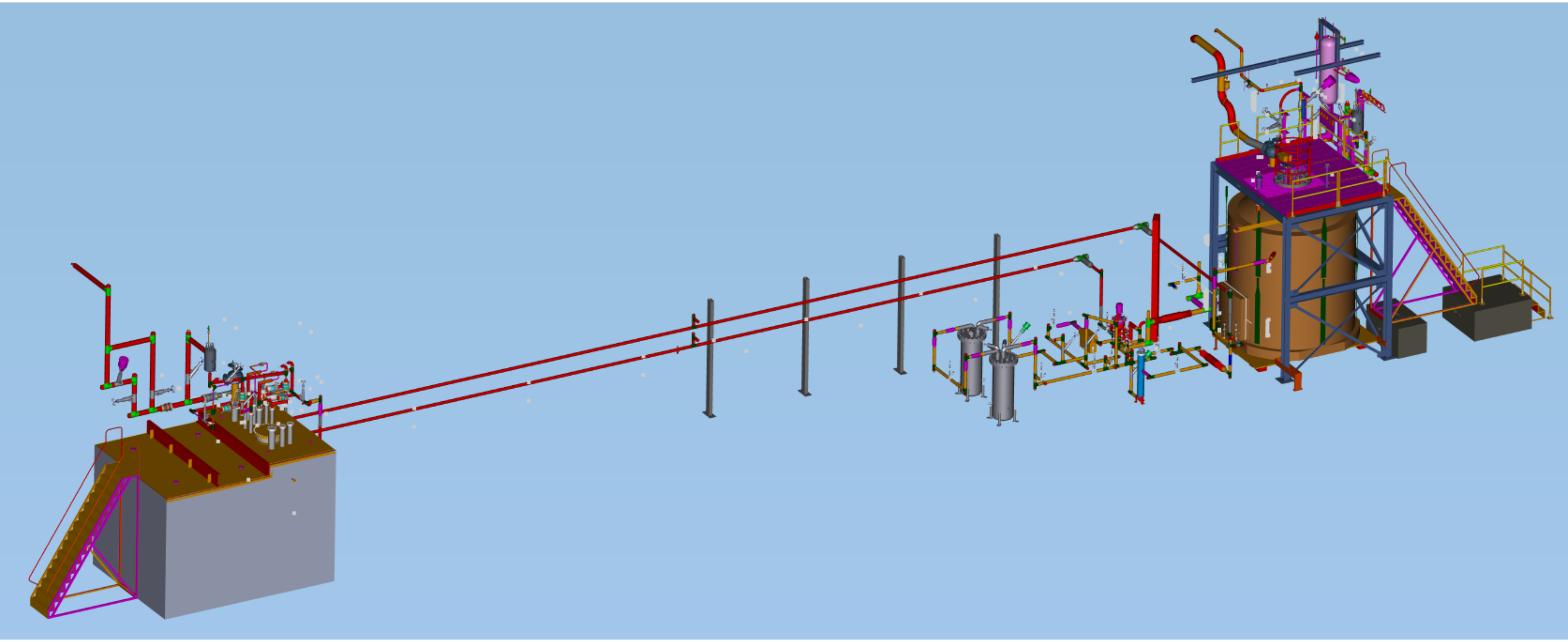
- The cryogenic systems approach **will use a team of engineers gathered from the existing cryogenic experiences as FNAL**. Elaine McCluskey is in conversation with Division leaders to form this team. We will use the experiences of outside **A&E's as needed to supplement** the work we propose in-house.

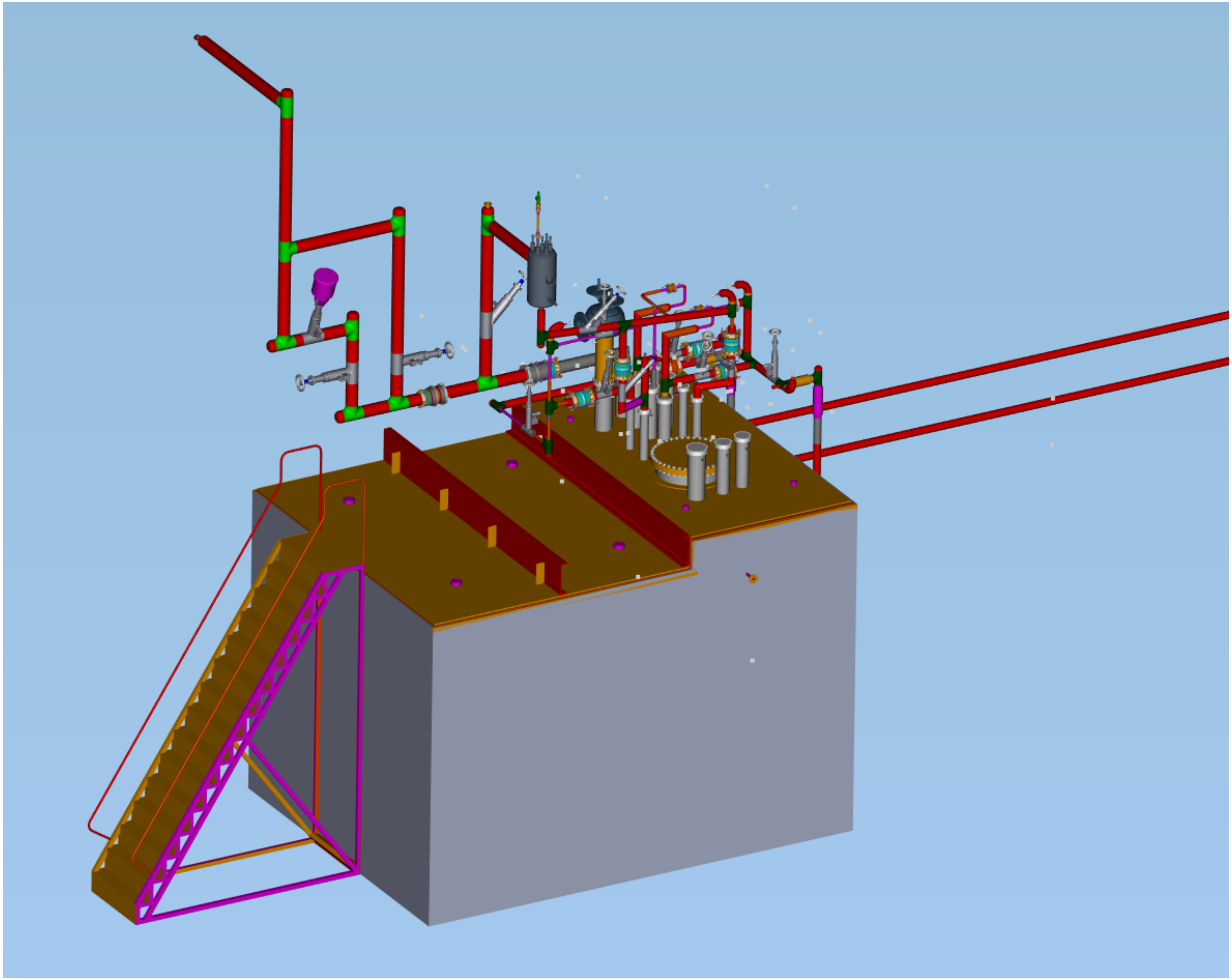
Lessons Learned for 35 ton

Features

- First Membrane Cryostat prototype for Physics experiment (Commercial technology).
  - Primary Membrane (2 mm SS 304)
  - Secondary/Sub-Secondary Membrane
  - 2 Layers of Polyurethane insulation (< 15 W/m^2 heat loss → Total 400 mm)
  - One instrumented top plate with all penetrations.
- IHI: design, procurement, supervision.
- Fermilab: build according to IHI procedures and training.
- Cryogenic system: shared with LAPD.
- Phase 1: to prove that we can achieve Purity in Membrane Cryostat without evacuation (< 200 ppt O2 equivalent, > 1.4 ms lifetime).
- Phase 2: to insert TPCs inside.

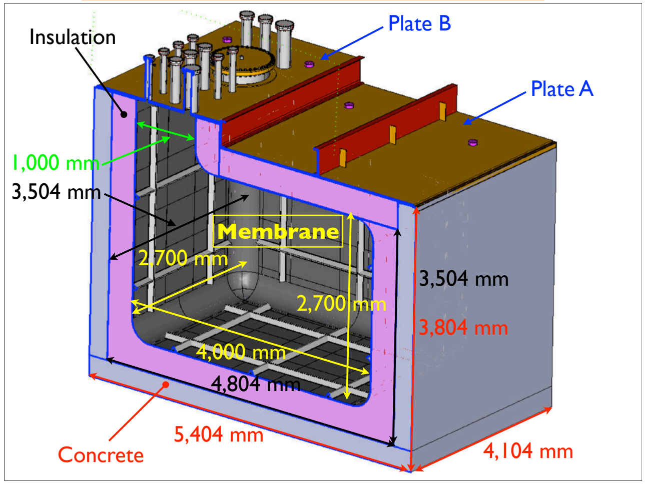
PC-4 Layout





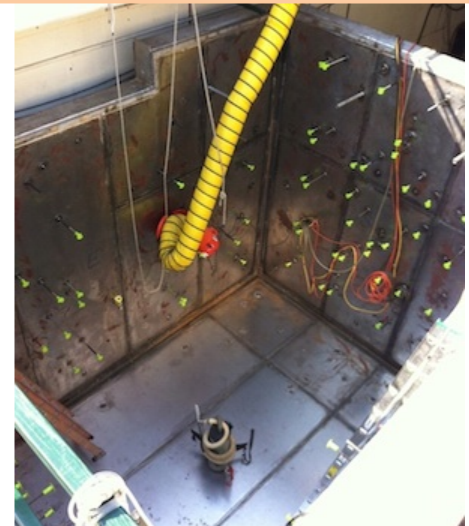
35 ton Proto in Pictures

3 D Model of IHI Tank

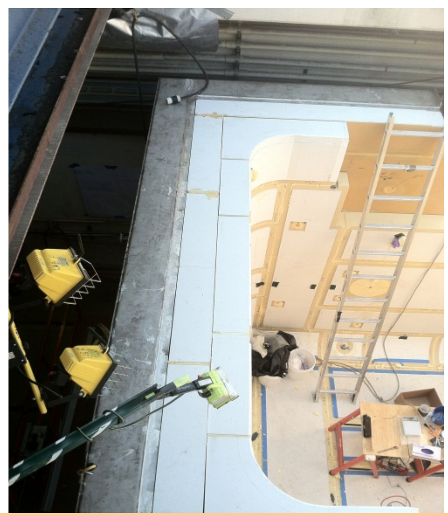


Concrete Structure @ PC4

Carbon Steel Vapor Barrier



Two layers of foam (0.4 m)



Top View of Two Layers Foam

SS membrane Insert Begins

35 ton Proto in Pictures – Photo

Membrane Cryostat Completed!!

Improving Infrastructures

Cryogenic system being assembled

A little bit of Lessons learned – 1

- Legal issues with GTT (not yet 100% resolved).
- Cultural differences with IHI: estimated that welders would be working a much greater rate than reality; estimated much more people working inside the tank at any given time; some of the IHI personnel were meticulous beyond reasonable. E.g.: we had to crate light stainless steel membrane panels (20-30 lb.) in/out of the tank instead of carrying them by hands on the man-lift, and then bang them in place with a (plastic) sledgehammer!!
- Needed to form a unified team of IHI, PPD Engineering, PPD techs, and TD welders.
- A lot of unexpected R&D (We specifically and explicitly requested IHI to list all items that required R&D or that were different from their standard practice, and we were told there was nothing). E.g.: Secondary membrane and sub-secondary membrane, manual application of liquid PUF, use of new style vacuum boxes, use of fireproof paste, use of stainless corner pieces, use of membrane anchors in corner pieces, …
- IHI was not familiar with small constructions: it is much easier to build a LARGE tank than a small one!! → They just scaled everything down, but it does not work: the effect of the corners is much larger and there are many more limitations, in space, multitasking, etc.

A little bit of Lessons learned – 2

- Schedule had no contingency and was never realistic: no clean-up time, did not account for confined space, for going in/out of the tank or limited space inside the tank.
- Procedures for the liquid insulation were antiquated and time consuming (IHI only tested the Secondary Barrier concept and the liquid insulation to fill the joints between panels. They are not part of the regular construction process).
- IHI underestimated the duration of fit-up and tack for the corner elements, which are curved and spherical and were never used by IHI before (the normal construction process uses flat pieces to approximate a circumference; and the same for the floor)
- Procedures for the membrane were not optimized for the shape of panels and very time consuming (needed long adjustable rods to push the edges of two adjacent panels against each other for tack welding).
- A lot of fit-up and adjustments on-the-field → need shop, tools and machinist(s) on-site.
- A lot of field work.

Thanks to:

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Thanks

35 ton Proto Schedule – Vapor Barrier

- Scheduled: ~8 days.
- Actual duration: ~31 days.
- Why?
  - IHI anticipated our welders would be working at a much greater rate than reality --> rate of welding and number of hours of welding.
  - Need to form a unified team of IHI, PPD Engineering, PPD techs, and TD welders.
  - Ammonia leak check did not work because the concrete was still full of moisture which dissolves the Ammonia--> switched to Helium leak check in sniffer mode.
- R&D:
  - Use of new style vacuum boxes to test the vapor barrier.

35 ton Proto Schedule – Insulation

- Scheduled: ~20 days.
- Actual duration: ~40 days.
- Why?
  - IHI estimated much more people working inside the tank (8-10) --> limited to 4 for ES&H and practical reasons (more people simply did not fit).
  - Procedures were antiquated and time consuming (IHI only tested the Secondary Barrier concept and the liquid insulation to fill the joints between panels. They are not part of the regular construction process).
- R&D:
  - Secondary membrane and sub-secondary membrane only tested, never implemented in an actual cryostat.
  - Manual application of liquid PUF (i.e. filling of gaps between vertical insulation panels).
  - Use of new style vacuum boxes to test the secondary membrane.
  - Use of fireproof paste to join adjacent fireproof boards.

35 ton Proto Schedule – Membrane

- Scheduled: ~13 days.
- Actual duration: ~28 days.
- Why?
  - IHI underestimated the duration of fit-up and tack for the corner elements, which are curved and spherical and were never used by IHI before (the normal construction process uses flat pieces modeled to approximate a circumference; and the same for the floor).
  - Procedures were not optimized for the shape of panels and very time consuming (needed long adjustable rods to push the edges of two adjacent panels against each other for tack welding).
- R&D:
  - Use of stainless steel corner pieces.
  - Use of membrane anchors in corner pieces.