DUSEL Cryogenic System Equipment Requirements and System Design Variation Discussions

INTRODUCTION

Some two months ago I wrote a LAr TPC Strawman Simplified Cryogenic System document that met the cooling requirements of the 5 kton proof of principle detector and, with additions, grew to service a detector facility of 100 Kton total fiducial volume. Sketches of cryogenic hardware and sub - systems are depicted along with some calculations to help explain distances, pressures, heat loads and volumes of cryogens needed make a functional DUSEL cooling system. The Strawman is also useful for us to get accustomed to an exceedingly huge everything about DUSEL. Its 4850' experiment cavern depth, kilotons of cryogens and millions of dollars in equipment are the norm.

This second document will discuss requirements of system cryogenic equipment and cryogens, note important specifications and estimate equipment costs where possible. Also, variations from the Strawman and recent design ideas will be discussed.

TRUISMS REVISITED

The greatest potential source of danger operating LAr TPC Detectors under ground is from the Oxygen Deficiency Hazard. ODH safety rules have to be strictly followed and everything must be done to preclude an occurrence of this type.

- Personnel safety is the most important activity at DUSEL.
- All LAr detectors and large cryogen volumes below the surface must be completely isolated from the DUSEL population. Possible ODH areas must be O_2 level monitored and be automatically clean air purged and vented to the surface upon attaining alarm conditions.
- The project will be easier, less expensive to construct and maintain, the closer the detectors are to the surface.
- As much equipment as possible should be located at the surface
- All systems should be designed to be remotely operated from the surface.

DETECTOR VOLUMES and HEAT LOADS

Taking Strawman volumes and heat loads is a good place to start summing up a total heat load figure for the 5 kton and the 100kton detectors as previously documented.
Detector Volumes – From David Lissauer's detector draft layout documents, amended.

- A 5 kiloton, first pass design detector as proposed.

5 kton sensitive volume is	3840m^3,	5.5 ktons.
Gross Volume is	7260m^3,	10.37 ktons

- 5 ea 20 Kton Sensitive Volumes = 100 kton total

100 kton sensitive volume is	76,800m^3,	107.5 ktons
Gross LAr volume is	120,585 m^3,	168.9 ktons

- Total LAr Sensitive Volume = 113 ktons, Gross LAr Volume Total = 179.3 ktons
  Vessel heat load per Lissauer, based on 8W/m^2 vessel mechanical insulation totals 220 kWatts which includes wiring conduction allowances etc. However, there will be purification systems, valving and Xfer lines in the caverns which raises the detector area total heat load to ~250kWatts.

Surface Cryogenic Facilities

Going to the surface and leaving the interconnecting transfer lines for last, there are two storage vessels and a refrigeration system to consider.

- A 40 kton LAr Storage Dewar

  Accepts LAr truck deliveries, Is the source of LAr for a detector filling after cool down.

  Has a volume large enough to hold contents of a 20kton detector (36.5 kton).

  Has a recondensing coil to hold LAr in its liquid state for an indefinite period and a sparger to increase the efficiency of the recondensing process for warmer return gases.

  Ballpark cost estimate for this storage vessel is about $10M. 36.5 ktons of LAr is worth ~ $25M + 20% today.

- 160,000 Gallons of Stored LN_2 Cooling

  2 ea 80,000 gallon nitrogen storage Dewars with recondensing and sparger coils. This liquid nitrogen is the source of all cooling for the entire system.

  In case of loss of refrigeration, these two Dewars have enough stored refrigeration to keep the detectors operating for a period of at least three days. Assumes repair during that time period.

  These two horizontal Dewars are catalog items, cost for each, $ 850k

- Refrigeration Systems - Assumed Surface Location

  5 kton detector system - heat load includes the detector, purification system, one 80,000 gallon storage vessel and the final transfer line system. Heat load estimate 50kW. Refrigerator sized at ~70kW. Everything useable in the 100kton system. Turn key refrigerator system cost ~ $ 2.5M

  105 kton system - heat load under normal operating conditions estimated ~ 355kW, about 160 tons of LN_2/day. Many suppliers of refrigerator systems in this size range. Linde, Air Liquide, Air Products, UIG, Cosmodyne etc. 100 ton/day Universal Industrial Gases N_2 reliquefier ~ $ 3.8M. We will need two refrigerators on line and another as a spare.

Cryogen Transfer Section, LAR and LN_2 Transfer Lines

A nitrogen supply line brings LN_2 from the surface storage Dewar to the detectors. The return line brings cold boil off gas back to the storage Dewar where it is recondensed by the refrigerator. The LAr supply transfer line fills the detectors from the 40 kton liquid argon surface storage

Dewar. The supply xfer line can also be used as a return line to empty any of the detectors by pumping LAr back into the surface 40 kton storage vessel.

All four of these transfer lines are double walled, vacuum jacketed using super insulation to achieve a very low heat leak average value of ~ .35 Watts/foot. Here mechanical insulation would not be a desirable choice because of the very high surface area to volume ratios of the line.

Because there is 4850 foot vertical distance between the surface and detector caverns, liquid head pressures in the transfer lines would be very high, 2939 psi for LAr, 1678 psi for LN_2. Standard, off the shelf xfer lines are rated at 150 psi so pressure reducing stations will have to be used to hold the maximum pressure to a compromise of about 600 psi. At this pressure, 5 or 6 stations would be needed to reduce LAr head pressures to where valves and pumps are within their working pressure ranges. With more time, one can probably find higher pressure pumps etc, which could reduce the number of pressure reducing stations. 3 stations would suffice for the LN_2 xfer supply line. Pumps are not required on the LN_2 lines.

- Liquid Nitrogen Transfer Line System Details

  With 180kton of LAr filled vessels normal LN_2 mass flow is ~ 30 gallons /minute.

  The supply line is 2 inch NPS 304 stainless steel, SCH 40, 1900psi rating.

  Cold N_2 gas return line sized to ~ 4 inch NPS.

  Pressure reducing phase separator tank volume; 100 gallons. Volume 70% filled gives ~ 2 minute reaction time after alarm when liquid level drops.

- Liquid Argon Transfer Line and Pump System Details.

  LAr transfer supply line would be 4 inch NPS SCH 40. Size based pressure drop and time to pump 36.5kton of LAr from a detector back into the storage vessel.

  Return side would be ~ 6 inch NPT used mostly to bring warmer boil off argon gas back to the surface storage Dewar for reliquefaction.

  Six serial pumping stations could move all 36.5 ktons of LAr from a detector to the storage Dewar in 14 days if the line was cold at the start.

  The six 200 HP serial pumping stations move liquid from the detector at the rate of 300 gallons per minute. This means that LAr phase separator tanks have to be much larger than the LN_2 vessels mentioned above. 1000 gallon volume would give ample time for control.

  From my experience in taking 7 hours to cool down 120 vertical meters of xfer line to start N_2 filling an almost empty Dewar at the CERN ATLAS site, the question comes to mind; should the DUSEL LAr xfer lines always be kept ~100K cold in case of problems? If the lines are allowed to go warm cool down time, and this is a guess, could be 10 days.

  Cost of the transfer line system is difficult to estimate without going through the final design in great detail and then going out for a market survey. I phoned a few companies and got some estimates. Others are my numbers.

- Transfer Line Plus Estimate

Almost 20,000 feet of vertical xfer lines @ $500/ft.		$ 10M
Additional xfer lines, misc valves, to Dewars, refrig., etc.		$ 1.0M
Cryogenic valves, throttling and stop 30 ea.		$ 250k
Safety Valves, 15ea. + misc piping		$ 150k
Phase separating vessels,	3 small,	$ 100k
	6 large.	$ 400k
300 GPM, 600 psi Cryogenic pumps, 7 ea.		$ 350K
	Total	$ 12.250M

Detector vessel and purification costs not included.

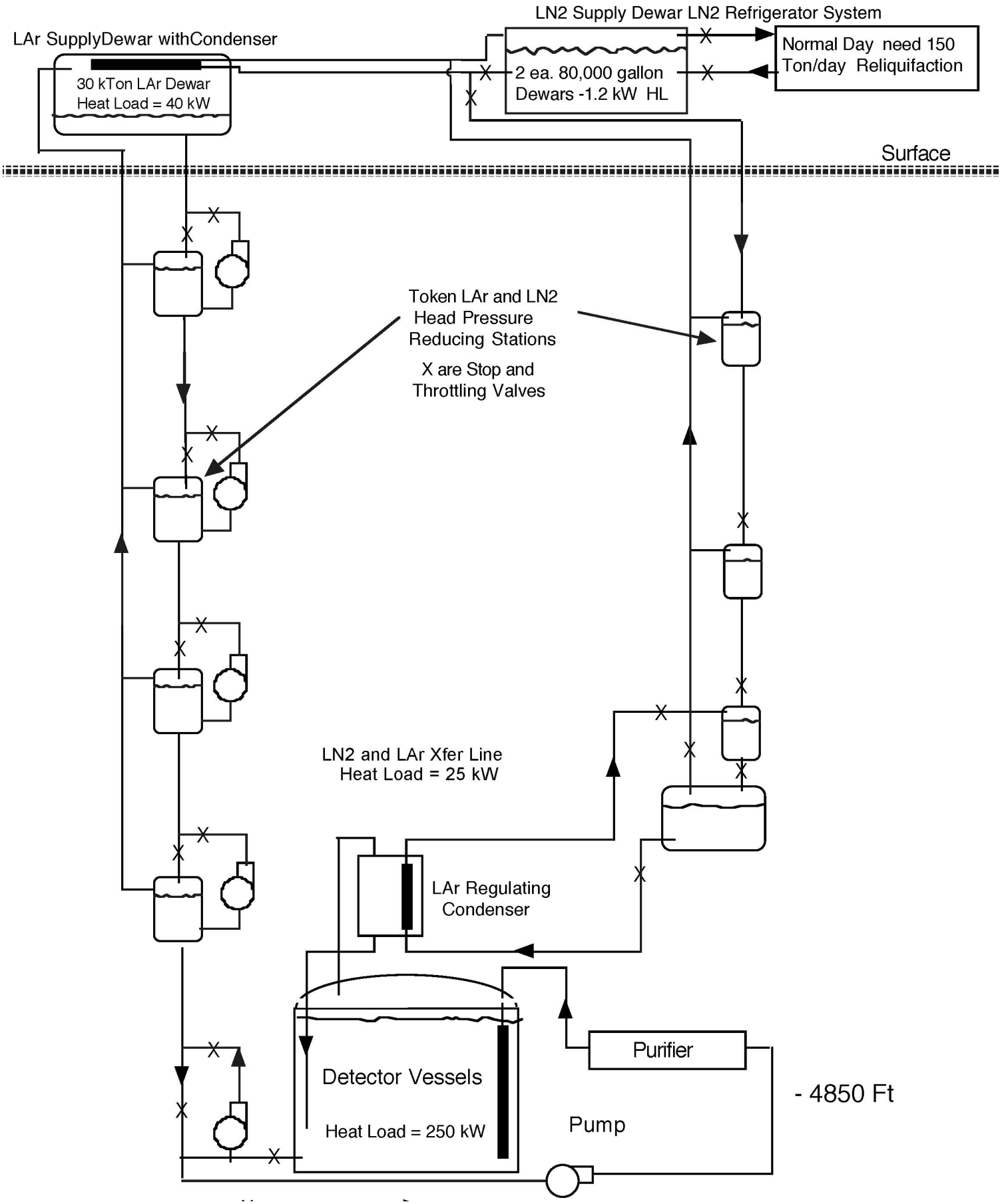
- Grand Totals

Refrigerators	$ 13.900M
40 kton Dewar	$ 10.000M
2 ea. 80,000 gallon nitrogen Dewars	$ 1.700M
Transfer lines, etc.	$ 12.250M
Grand Total	$ 37.850M

Discussions *on Cryogenic Design Variations on the Strawman and Completely New Ideas*

- Design variation #1 Move the refrigerators to the cavern to save the cost of the N_2 transfer line.

- Design variation #2 New hexagon volume layouts strong enough to be self supporting in a vacuum environment. Use cryocoolers for recondensing argon gas?

- Design variation #3

A Simplified DUSEL Cryogenic System