Overview of the Long-Baseline Neutrino Facility Cryogenic System

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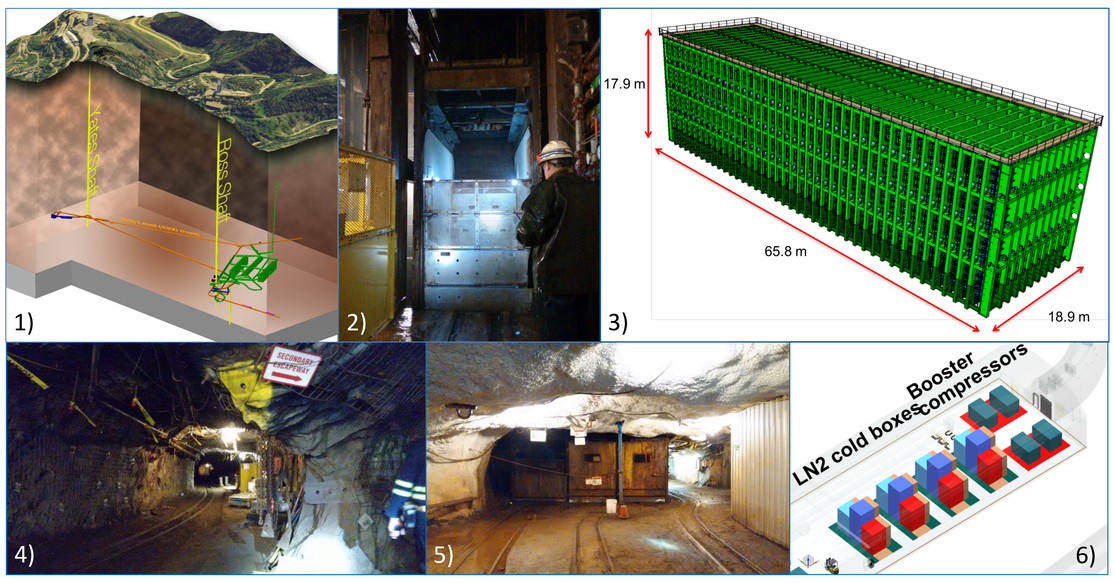
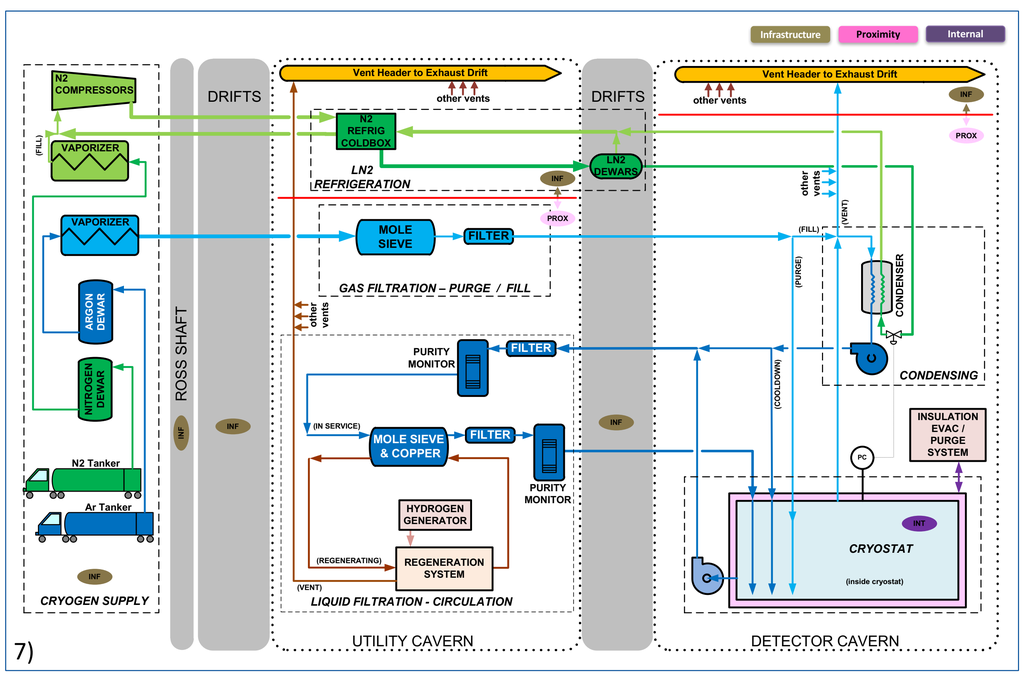
Introduction

The Deep Underground Neutrino Experiment (DUNE) collaboration is developing a multi-kiloton Long-Baseline neutrino experiment that will be located about a mile underground at the Sanford Underground Research Facility (SURF) in Lead, SD. In the current design, detectors will be located inside four cryostats each one measuring 62.0 meter in length, 15.1 m in width and 14.0 m in height (internal dimensions). These will be filled with a total of 68,400 tons of ultrapure liquid Argon (LAr) with less than 100 parts per trillion of oxygen equivalent contamination. The Long-Baseline Neutrino Facility (LBNF) is developing the infrastructure supporting this experiment, including the cryogenic system servicing the installation. The construction is scheduled to commence in the 2021 time frame with operations beginning in 2024.

To qualify the cryogenic system technology (as well as the membrane technology used for all but one cryostats) a strong prototyping effort is also ongoing: several smaller detectors of increasing size with associated cryostats and cryogenic systems are being designed and will be built in the next 1-2 years at both Fermilab and CERN as part of the Short Baseline Neutrino (SBN) Program and ProtoDUNE. Two detector technologies are being developed: Single Phase (SP) and Dual Phase (DP). A 35 ton prototype is already operational at Fermilab (SP) and a 26-ton prototype (DP) is being constructed at CERN and will be operational in the coming months. The SBN Near and Far Detectors (260 ton and 760 ton, SP) and the ProtoDUNE-SP and ProtoDUNE-DP (760 ton and 715 ton) will follow with the multi-kton detector (DUNE) as the final goal.

After commissioning, the DUNE detector(s), Time Projection Chambers (TPCs), will detect and enable the study of neutrinos from a new improved beam line from Fermilab. The LBNF cryogenic system will be engineered, manufactured, commissioned, and qualified by an international engineering team.



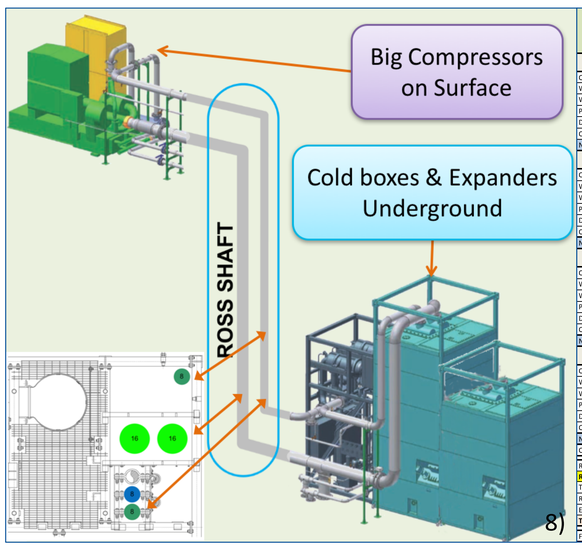


Description

The LBNF cryogenics systems include all sub-systems necessary to receive, transfer, store and purify the large quantity of LAr required by the experiment, as well as the Liquid Nitrogen (LN_2) refrigeration system to re-condense Gaseous Argon (GAr). It is comprised of several sub-systems:

- **External/Infrastructure (or LN2) Cryogenics**. This included the equipment used to store and produce the cryogenic fluids needed for the operation of the Proximity Cryogenics, including the LN_2 and LAr receiving facilities and the LN_2 refrigeration system.
- **Proximity (or LAr) Cryogenics**. Consisting of all the systems that take the cryogenic fluids from the Infrastructure Cryogenics and deliver them to the Internal at the required pressure, temperature, purity and mass flow rate, it includes the condensers, the LAr and GAr purification systems, the LN_2 and LAr Phase separators, and the interconnecting piping.
- **Internal Cryogenics.** This is comprised of all the cryogenic equipment located within the cryostats themselves, including the GAr and LAr distribution piping and the piping required to cool down the cryostats.

Parameter (per cryostat)	Value
Piston purge GAr flow rate (1.2 m/hr)	253.68 m^3/hr
Maximum cool-down rate TPC	40 K/hr
Maximum Delta_T between any two points in the detector	50 K
Maximum available cooling power	100 kW
Required LAr purity	< 100 ppt
Maximum LAr turnover (5 days full volume)	36.12 kg/s



9)

	Unit Loads (kW)	Scenarios											
		Fill 1		Fill 2				Fill 3		Fill 4			
Recondenser Load, 1st Cryostat													
Cryostat Heat Ingress	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
With 2 Recirculation Pumps	10.4		10.4	10.4	10.4	10.4		10.4	10.4	10.4	10.4	10.4	
With 4 Recirculation Pumps	20.7	20.7											
Piping and Purification vessel Heat ingress	3.7	3.7	3.7	3.7	3.7	3.7		3.7	3.7	3.7	3.7	3.7	
Detector Electronics in cryostat	23.7		23.7	23.7	23.7	23.7		23.7	23.7	23.7	23.7	23.7	
Cryostat Fill – GAr transfer / recondense		219.78											
Number of condensers in operation		4	1	1	1	1	1	1	1	1	1	1	1
Recondenser Load, 2nd Cryostat													
Cryostat Heat Ingress	28.8			28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
With 2 Recirculation Pumps	10.4					10.4		10.4	10.4	10.4	10.4	10.4	
With 4 Recirculation Pumps	20.7			20.7	20.7								
Piping and Purification vessel Heat ingress	3.7			3.7	3.7	3.7		3.7	3.7	3.7	3.7	3.7	
Detector Electronics in cryostat	23.7					23.7		23.7	23.7	23.7	23.7	23.7	
Cryostat Fill – GAr transfer / recondense				153.22									
Number of condensers in operation				3	1	1	1	1	1	1	1	1	1
Recondenser Load, 3rd Cryostat													
Cryostat Heat Ingress	28.8							28.8	28.8	28.8	28.8	28.8	28.8
With 2 Recirculation Pumps	10.4								10.4	10.4	10.4	10.4	
With 4 Recirculation Pumps	20.7							20.7					
Piping and Purification vessel Heat ingress	3.7							3.7	3.7	3.7	3.7	3.7	
Detector Electronics in cryostat	23.7								23.7	23.7	23.7	23.7	
Cryostat Fill – GAr transfer / recondense								177.66					
Number of condensers in operation								3	1	1	1	1	1
Recondenser Load, 4th Cryostat													
Cryostat Heat Ingress	28.8									28.8	28.8	28.8	28.8
With 2 Recirculation Pumps	10.4											10.4	
With 4 Recirculation Pumps	20.7									20.7	20.7		
Piping and Purification vessel Heat ingress	3.7									3.7	3.7	3.7	
Detector Electronics in cryostat	23.7											23.7	
Cryostat Fill – GAr transfer / recondense										111.10			
Number of condensers in operation										2	1	1	1
Cavern LN dewar heat ingress (1 kW/each)	1	18	18	18	18	18		24	24	24	24	24	
Refrigeration Needed		291.0	84.6	291.0	137.8	151.1	57.6	388.0	223.7	388.0	276.9	290.2	115.2
Refrigeration Plants in Operation		**3**	**1**	**3**	**2**	**2**	**0**	**4**	**3**	**4**	**3**	**3**	**0**
Total Refrigeration Capacity Available		291	97	291	194	194		388	291	388	291	291	
Required Duty per plant	97	97	85	97	78	78		97	78	97	92	97	
Electric trim heater load		0.0	0.0	0.0	18.2	4.9		0.0	10.3	0.0	0.0	0.0	
Total Refrigeration Load		**291**	**84.56**	**291**	**156**	**156**	**0**	**388**	**234**	**388**	**276.9**	**290.2**	**0**
Fill Time, months		**4.8**		**6.8**				**5.9**		**9.4**			months

Modes of Operations

The cryogenic system must address the following modes of operations:

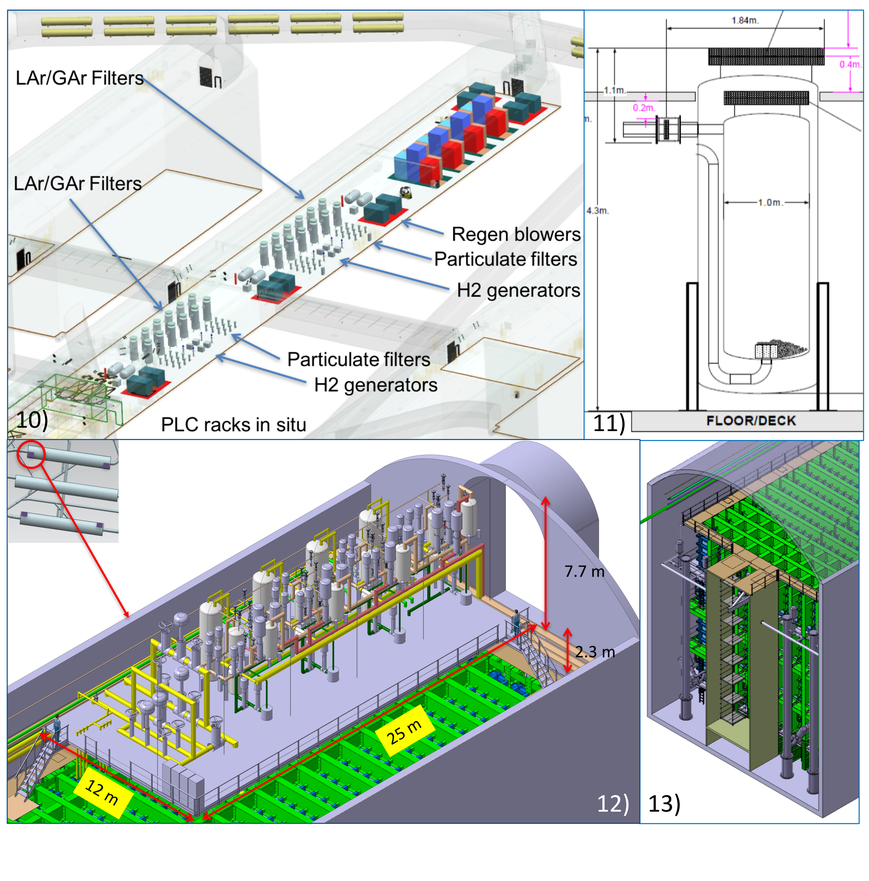
- **GAr Purge.** This is the initial phase during which the contaminants are removed from the cryostat (which starts filled with air) by means of a slow GAr flow that pushes the impurities from the vessel's bottom to the top and out.
- **Cool-down.** Purified LAr is mixed with GAr and distributed by dedicated sprayers near the top of the cryostat to cool down the cryostat and the detector to their operating temperature in a controlled way. Additional sprayers provide momentum to move the mist of LAr/GAr uniformly inside.
- **Filling.** Once the cryostat and the TPCs are cold, LAr from the condensers above the cryostat flows into the vessel, filling it with 17,100 tons of purified LAr.
- **Steady state operations.** During this phase the LAr is continuously recirculated through the LAr filtration system by means of external pumps. Boil-off GAr is re-condensed in the condensers and purified through the same LAr filtration system before being reintroduced as LAr inside the cryostat.
- **Emptying.** This is the final phase, following the completion of the experiment. The cryostat is emptied and LAr removed from the system.

LN_2 System

The LN_2 refrigeration system includes four commercial units with cold boxes and return gas boosters in the cavern and GN_2 compressors above ground. The cold box units have to be assembled underground, with the individual dimensions restricted by the transport limitations. There are three units for Cryostats 1 and 2 and a fourth unit is added for Cryostats 3 and 4. During normal operations, after reaching the required LAr purity, only three are needed and a full unit is available as spare.

LAr System

LAr System is composed of filters containing mol sieve and copper pellets to chemically adsorb water and oxygen from GAr and LAr. Each cryostat has a dedicated set of LAr filters, regen equipment and particulate filters, while the GAr filters are common for 1-2 and 3-4.



References

- The LBNF and DUNE Projects: updated Intro to CDR – http://docs.dunescience.org/cgi-bin/ShowDocument?docid=597
- The LBNF Cryogenic Infrastructure at the Far Site — http://docs.dunescience.org/cgi-bin/ShowDocument?docid=602
- The Long-Baseline Neutrino Facility for DUNE — http://docs.dunescience.org/cgi-bin/ShowDocument?docid=182

Captions

1) SURF complex – 2) Cage at SURF – 3) Cryostat – 4) SURF Underground tunnel – 5) Underground unloading area at SURF –6) LN2 cod boxes – 7) Process Flow Diagram (PFD) – 8) LN2 system – 9) Refrigeration loads and fill time – 10) Cryogenics in the utility cavern – 11) LAr filtration vessel – 12) Mezzanine – 13) LAr pumps.

Note

This contribution presents the current status of the LBNF cryogenic systems. As the design progresses and new ideas are incorporated, its appearance will change from the images shown here.

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