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Workshop on Cryogenic Operations

Terry Tope

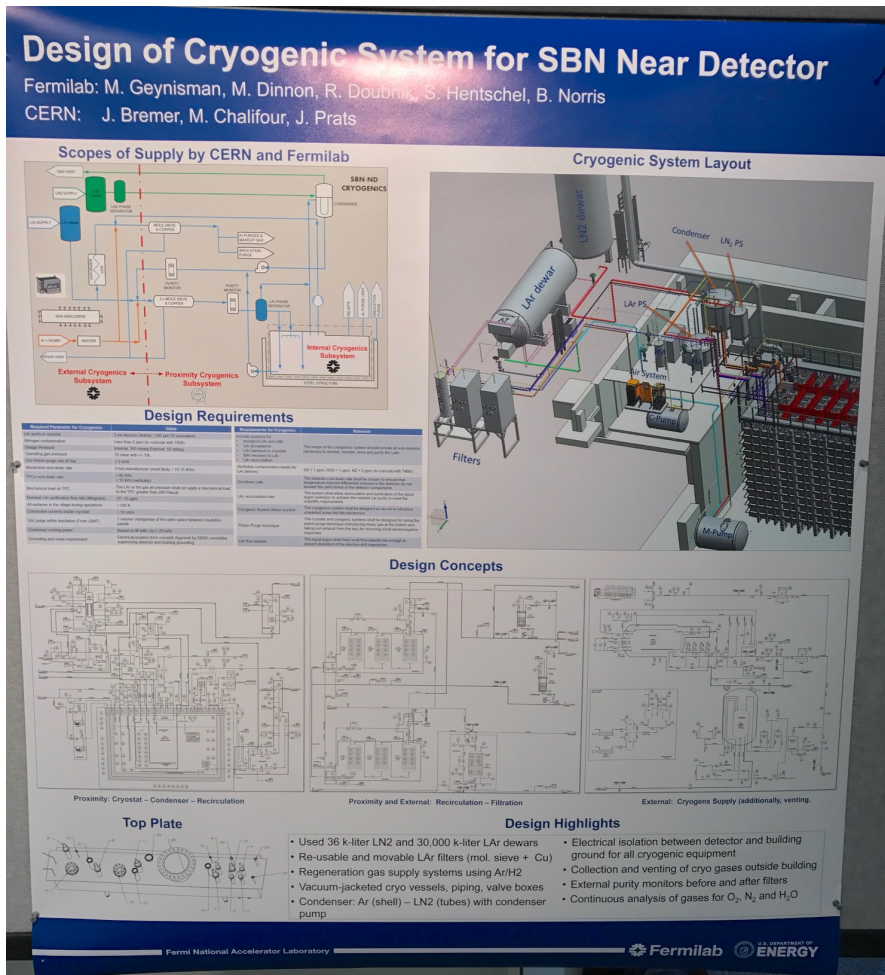
Poster Session II Summary

26 October 2016

List of Poster Session II Presenters

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- *14. Low Energy RHIC electron Cooling (LEReC) 704MHz SRF cavity superfluid thermal analysis using ANSYS 17, Paul Orfin (BNL)*
- *15. Annual Maintenance of CHL2 Compressors, Sasa Radovic (Jefferson Lab)*

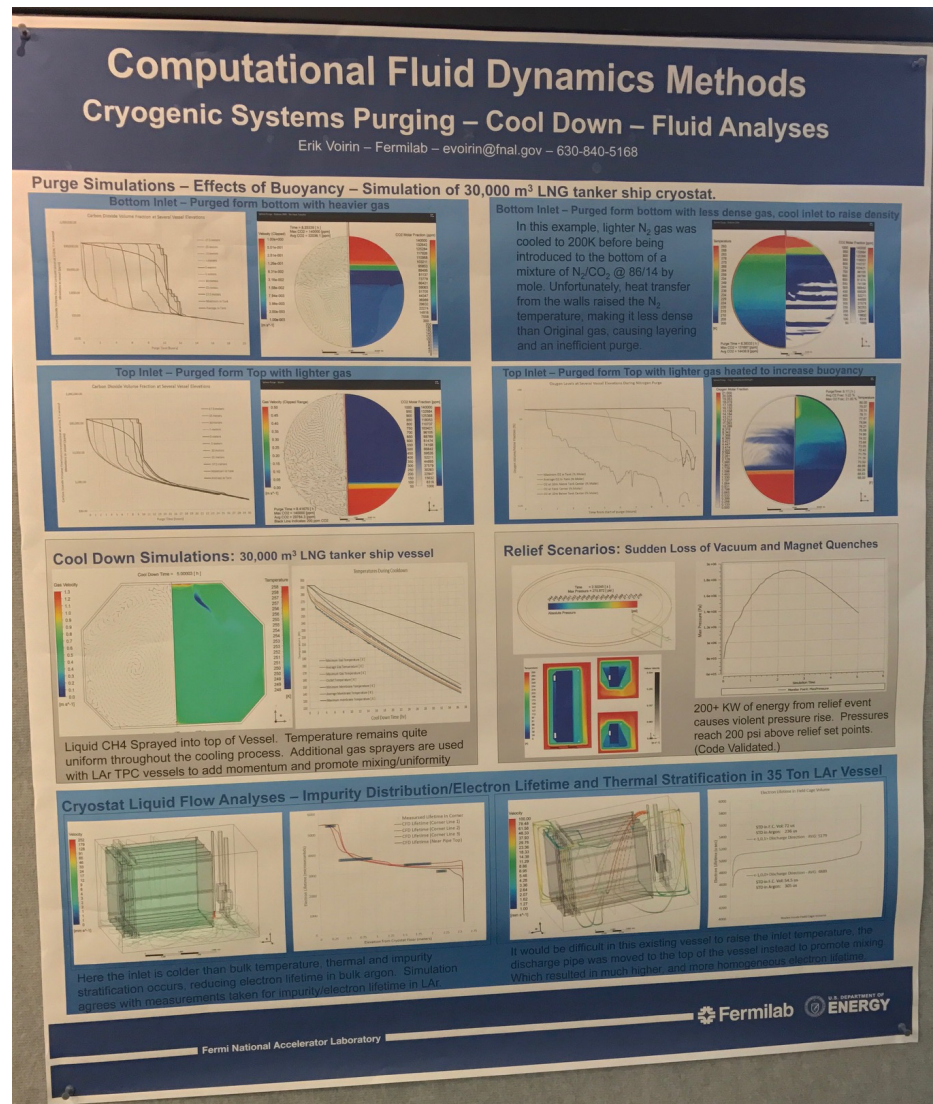
Poster #10 - Design of Cryogenic System for SBN Near Detector, Michael Geynisman



Notes

- Fermilab Short Baseline Neutrino Program (onsite)
- 260 ton LAr membrane cryostat
- LN2 dewar for refrigeration
- Tube/shell LN2/Ar HX
- LAr dewar for receiving LAr
- Regenerable and movable mole sieve and Cu filters to achieve < 100 ppt O2
- Commercial gas analyzers O2, N2, H2O
- Electron lifetime monitors
- Electrical isolation between all cryogenic services and physics detector

Poster 11 - Investigations of Purge and Cooldown Options for Liquid Argon Cryostats through CFD Analysis, Erik Voirin



Notes

- CFD analysis of many cryogenic processes
- Purging of large tanks to remove air (no evacuation)
- Dynamic simulation of pressure in piping during a quench and LOV for a LHe system
- Cool down of LAr membrane tanks with physics detectors
- Temperature distribution and stratification in liquid argon cryostats – verified by measurements

Poster 12 - Overview of the Long-Baseline Neutrino Facility cryogenic system, David Montanari

Overview of the Long-Baseline Neutrino Facility Cryogenic System

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Notes

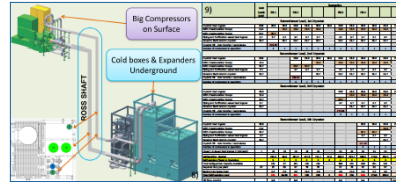
- Four very large liquid argon detector membrane cryostats
 - 1 mile underground
 - 15 m W x 14 m H x 62 m L (each!)
 - 68,400 tons of LAr (total)
 - Achieve <100 ppt purity
 - Major prototyping efforts at FNAL and CERN are underway
 - LAr purification
 - Mole sieve and copper catalyst
 - LN2 refrigeration
 - Surface compressors
 - Cavern coldboxes & return gas boosters
 - 2024 operation

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 (ppt) 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 cryostat) 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 35-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 700-ton, SP) and the ProtoDUNE-SP and ProtoDUNE-DP (760-ton and 715-ton) will follow with the multi-ton detector (DUNE) as the final goal.

After commissioning the DUNE detectors, the ProtoDUNE Detectors (PDDs) will collect 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.



Modes of Operations

The cryogenic system must address the following modes of operations:

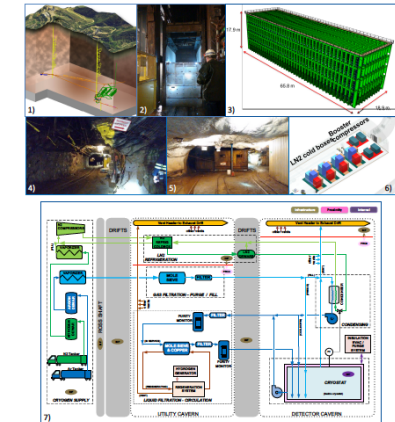
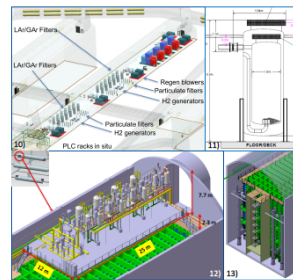
- **GA Purge:** This is the initial phase during which the contaminants are removed from the cryostat (which starts filled with air) by means of a slow GA flow that pushes the impurities from the vessel's bottom to the top and out.
- **Cool-down:** Purified LAr is mixed with GA and distributed by dedicated 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 rest of LAr/GA uniformly inside.
- **Filling:** Once the cryostat and the PDDs are cool, 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 GA 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.

LN₂ System

The LN₂ refrigeration system includes four commercial units with cold boosters and return gas boosters in the cavern and GA₂ 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 GA₂ and LAr. Each cryostat has a dedicated set of LAr filters, regen equipment and particulate filters, while the GA₂ filters are common for 1-2 and 3-4.



Description

The LBNF cryogenic 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 (LN₂) refrigeration system to re-condense Gaseous Argon (GA₂). 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 LN₂ and LAr receiving facilities and the LN₂ 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 GA₂ purification systems, the LN₂ 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 GA₂ and LAr distribution piping and the piping required to cool down the cryostats.

Parameter (per Cryostat)	Value
Pattern purge GA ₂ flow rate (2.2 m ³ /hr)	25.88 m ³ /hr
Maximum cool-down rate (K)	48 K/hr
Maximum delta T between any two points in the detector	30 K
Maximum available cooling power	300 kW
Required LAr purity	< 100 ppt
Maximum LAr turnover (8 days full volume)	36.32 kg/d

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.

References

- The LBNF and DUNE Projects: updated info in CO₂ - <http://docs.dunescience.org/gai/ShowDocument?docid=604>
- The LBNF Cryogenic Infrastructure at the Far Site - <http://docs.dunescience.org/gai/ShowDocument?docid=602>
- The Long-Baseline Neutrino Facility for DUNE - <http://docs.dunescience.org/gai/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 cool boxes - 7) Process Flow Diagram (PFD) - 8) LN₂ system - 9) Refrigeration loads and fill line - 10) Cryogenics in the utility cavern - 11) LAr filtration vessel - 12) Mezzanine - 13) LAr pumps.

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Poster 13 - Overview of the cryogenic system for the ProtoDUNE Single Phase and Dual Phase prototypes at CERN, Johan Bremer



Overview of the cryogenics systems for the ProtoDUNE prototypes at CERN

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¹CERN, ²Fermilab



Introduction

- CERN based ProtoDUNE prototypes will test liquid and gas/liquid neutrino detectors placed in a low energy beam coming from SPS accelerator.
- Continuous operation is required to operate for several years to cover the neutrino research plans in physics.
- Membrane cryostat technology from liquefied natural gas industry is selected as the solution to contain hundreds of tons of Liquid Argon under scalable, short execution time and low cost. ProtoDUNE experiments will feature the largest membrane cryostats ever built for particle physics research.

LAr Neutrino Working Principle

- Goal: to keep 700 Ton LAr cryostat contamination under 100 ppt oxygen and a stable temperature of 87 ± 0.5 K
- Redundant pumps and purity filters to ensure uninterrupted operation.

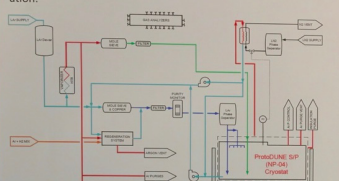


Figure 1. Conceptual diagram of NP-04 proximity cryogenics

EHN1 Extension Hall

- Since 2015, the EHN1 building has undergone an extension of about 700 m².
- The Extension hall features two beam lines, two cryostats, detector data acquisition, proximity cryogenics and external cryogenics for the two vessels.




Figure 2. Progress of EHN1 extension efforts

Neutrino Platform - ProtoDUNE Single Phase and Dual Phase

- Both neutrino detectors feature a cooling principle based on a LN2 cooled condensers for the boil off of the cryostats. The resulting liquid is purified in a copper/molecular sieve purification system.
- ProtoDUNE Dual Phase (NP-02) features a very low pressure gas/liquid argon high voltage time projection chamber. The detector pressure is very close to ambient, hence the proximity cryogenics feature a cold compressor to condense the liquid argon at a higher pressure
- ProtoDUNE Single Phase (NP-04) features a low pressure liquid argon high voltage time projection chamber. The system is equipped with a small liquid pump to deliver the condensed liquid directly to the purification system.



Figure 3. NP-02 Dual Phase cryostat




Figure 4. NP-04 Single Phase cryostat

	NP-02	NP-04
Internal Dimensions (WxLxH)	8.6x8.6x7.9 m	8.6x8.6x7.9 m
LAr mass	716 T	768 T
Operating pressure	1000 mbara	1070 mbara
Design pressure	1350 mbara	1350 mbara
Ambient pressure	970 mbara	970 mbara
O ₂ / H ₂ O purity target	100 ppt	100 ppt
Filtration rate	1.6 kg/s	1.6 kg/s
Filtration turnover	5 days	5 days
Heat load	4.6 kW	4.6 kW
Cooldown power	16 kW	16 kW

Conclusion

The contract IT4200 for the cryogenic systems of ProtoDUNE prototypes at CERN is signed and, by the end of 2017, will provide the neutrino detectors placed at EHN1 extension with a cryogenic liquid argon cooling and purification system. Both cryostats will be the testbed for LBNF technologies, testing contamination and temperature stability strategies, as well as the high voltage detector technologies.

Notes

- Two prototype membrane cryostats at CERN for the Long Baseline Neutrino Facility
- 700 tons LAr each
- Tank fabrication is underway
- 8.6 m W x 8.6 m L x 7.9 m L
- Testing two detector technologies
 - Single Phase
 - TPC contained in LAr
 - Dual Phase
 - TPC contained in LAr with gas phase detector
 - Requires tight liquid level control
- LN2 refrigeration
- Mole sieve and Cu filters to achieve < 100 ppt O₂

Poster 14 - Low Energy RHIC electron Cooling (LEReC) 704MHz SRF cavity superfluid helium thermal analysis using ANSYS 17, Paul Orfin

Low Energy RHIC electron Cooling (LEReC) 704MHz SRF cavity superfluid helium thermal analysis using ANSYS 17.0

Poster# 14
October 26, 2016

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U.S. DEPARTMENT OF ENERGY
BROOKHAVEN
NATIONAL LABORATORY

Abstract: An existing 704 MHz superconducting Radio frequency half-cell cavity will be modified for its use as an accelerating cavity in the coming LEReC experiment. A thermal analysis of the upstream beam assembly was done including the modeling of the superfluid liquid helium. The discussion will review the system modeling in ANSYS and provide a practical approach to cryogenic thermal analysis.

Assumptions

- Simplified thermal analysis without the use of computational fluid dynamics in ANSYS 17.0
- Helium modeled as a solid with temperature varied thermal conductivity
- Kapitza resistance simulated with a thermal resistance value at element connections

Kapitza Resistance

- Kapitza Resistance is an interface's resistance to thermal flow
- Due to the differences in electronic and vibrational properties in dissimilar materials, when an energy carrier (phonon or electron) will scatter as it attempts to cross the interface
- Typically a significant contributor to temperature difference at low temperatures

$R_k = (10.7)T^{-(3.55)}$

$K_s = 1/R_k$

Superfluid Thermal Conductivity

- Peak heat flux in wide channel assumption used to derive superfluid thermal conductivity
- A 90 cm long channel was used in the integrated heat conductivity function to derive an effective conductivity for each temperature

Model and results

- Model was simplified and reduced to include relevant features
- Cylindrical symmetry was applied reducing the model to 1/18th of the original

Boundary Conditions

- 1.9K Temperature
- 295K Temperature
- Heat Flux, 20 Watt total

Meshed 3/4 Model

Heat into helium bath
-1.225 Watts per segment X 18 = -22.05 Watts Total

20 Watts from Beam halo effect
+2.05 Watts from static heat leak =
22.05 Watt total

Temperature Profile

Heat Flux - Section

Summary and conclusions

- Good agreement between ANSYS and hand calculations.
- Design review was completed and manufacturing started
- Further examinations will be done to verify and improve modeling techniques for superfluid helium in ANSYS

* Work is supported by Brookhaven Science Associates, LLC under contract No. DE-AC02-98OR21400 with the U.S. DOE.

Notes

- Super fluid thermal analysis of a SRF cavity
- Existing half cell cavity to be modified for the LEReC experiment
- ANSYS used to determine cavity temperature distribution while in a super fluid helium bath
- 20 W of beam heating and 2 W of ambient heat leak
- Helium modeled as a solid with k(T)
 - Avoids complications of CFD
- Kapitza resistance modeled at element connections
 - Significant at low temps when photons and electrons scatter at an interface

Poster 15 - Annual Maintenance of CHL2 Compressors – Sasa Radovic

Annual Maintenance of Jefferson Lab CHL 2 Compressors

S. Radović, M. Wright, M. Stapleton

Introduction

- There are six Jlab designed, PHPK built compressors skids at CHL 2
- Five commissioned in Spring of 2013, one to be brought on line next year
- Compressors made by Howden Compressors Limited
- Electric motors made by TECO-Westinghouse Motor Company
 - Four 800 HP compressors (1 medium pressure, 3 low pressure units)
 - Two 2500 HP compressors (one presently running)
- General electrical and mechanical maintenance done on annual basis
- All maintenance activities recorded in electronic Cryogenic Task List
- The manufacturer recommends a general annual maintenance and a major compressor overhaul after approximately 74,000 hours of operation

CHL 2 C4 (medium pressure) Compressor

CHL 2 C4 (medium pressure) Compressor

CHL 2 C8 (high pressure) Compressor

Compressor Total Run Time

Number of hours each compressor has been run since commissioning

Electrical Maintenance

- Tightening all electrical 4160VAC, 480VAC, 120VAC and 24VDC connections in Motor Control Center (MCC), compressor control and oil pump VFD drive enclosures, instrumentation terminal points
- Checking all wires for chaffing, component bases and repairing found problems.
- Calibration check of instrumentation on compressor skid.
- Upgrade or replacement of any components in electrical control enclosure that require an upgrade or replacement.
- Cleaning of control enclosures, air vents and filter replacements

MCC

Oil Heater Control Enclosure

Oil Pump VFD Control Enclosure

PLC Control Enclosure

Mechanical Maintenance

- Inspection and alignment check of main motor coupling
 - $0.004'' \leq \text{Parallel offset} \leq 0.050''$
 - $0.011'' \leq \text{Angular offset} \leq 0.135''$
- Axial thrust check (offset > 0.001" critical)
- Main motor bearing oil replacement, bearing inspection and air vent cleaning
- Inspection and regreasing of oil pump electrical motor and bearings
- Inspection of oil pump motor coupling
- Inspection of oil hoses

Oil Hoses

Main Electric Motor

Main Electric Motor Coupling

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Fermilab U.S. DEPARTMENT OF ENERGY

Notes

- Six compressor skids designed
- Four 800 hp and two 2,500 hp
- Annual maintenance schedule
- Electrical
 - Tighten all 4160VAC, 480VAC 120 VAC, 24 VDC connections
 - Check all wires for chaffing
 - Calibration check of instruments
 - Upgrades/replacements
 - Cleaning of vents/filters
- Mechanical
 - Alignment of motor couplings
 - Bearing inspection and replacements
 - Oil changes, regreasing
- Started in 2013