DESIGN OF THE DUNE APA TEST FACILITY CRYOGENIC SYSTEM

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INTRODUCTION

Abstract. Fermi National Accelerator Laboratory (FNAL) is developing the international Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) to advance neutrino science. The flagship of the DUNE project consists of a large particle detector constructed one-mile (1.6 km) beneath the surface at the Sanford Underground Research Facility (SURF) in Lead, SD. The SURF detector is the largest of its type ever built and is comprised of four cryostats totaling 70,000 tons of liquid argon (LAr) to record neutrino interactions with unprecedented precision. Each cryostat houses a detector, the first includes 150 Anode Panel Assemblies (APA) submersed within 17,500 tons of LAr. Before installing 150 APA within the SURF detector they will be cryogenically cooled to nominally 90 K at the APA Test Facility (APATF) utilizing nitrogen flows. The APATF cryogenic system is entirely located one-mile underground at the SURF facility and includes nominally 13 kW of refrigeration at 80 K, cryogenic transfer lines, APA test cryostats, a cryogenic control system, and various control and pressure safety elements to ensure performance and safety requirements are achieved. The APATF preliminary design is in progress and major considerations include an efficient, cost-effective mechanism to deliver the required refrigeration to the APATF underground, support of rigid testing intervals to support the DUNE operating schedule, temperature stability of the APA and electronics within cryostats, efficient cryogenic system operation to minimize heat leak and/or liquid nitrogen consumption, thermo-mechanical stability and flexibility of components, and pressure safety of the APATF cryogenic system. Installation and integration of the APATF cryogenic system within the footprint and to adjacent sub-systems is also discussed.

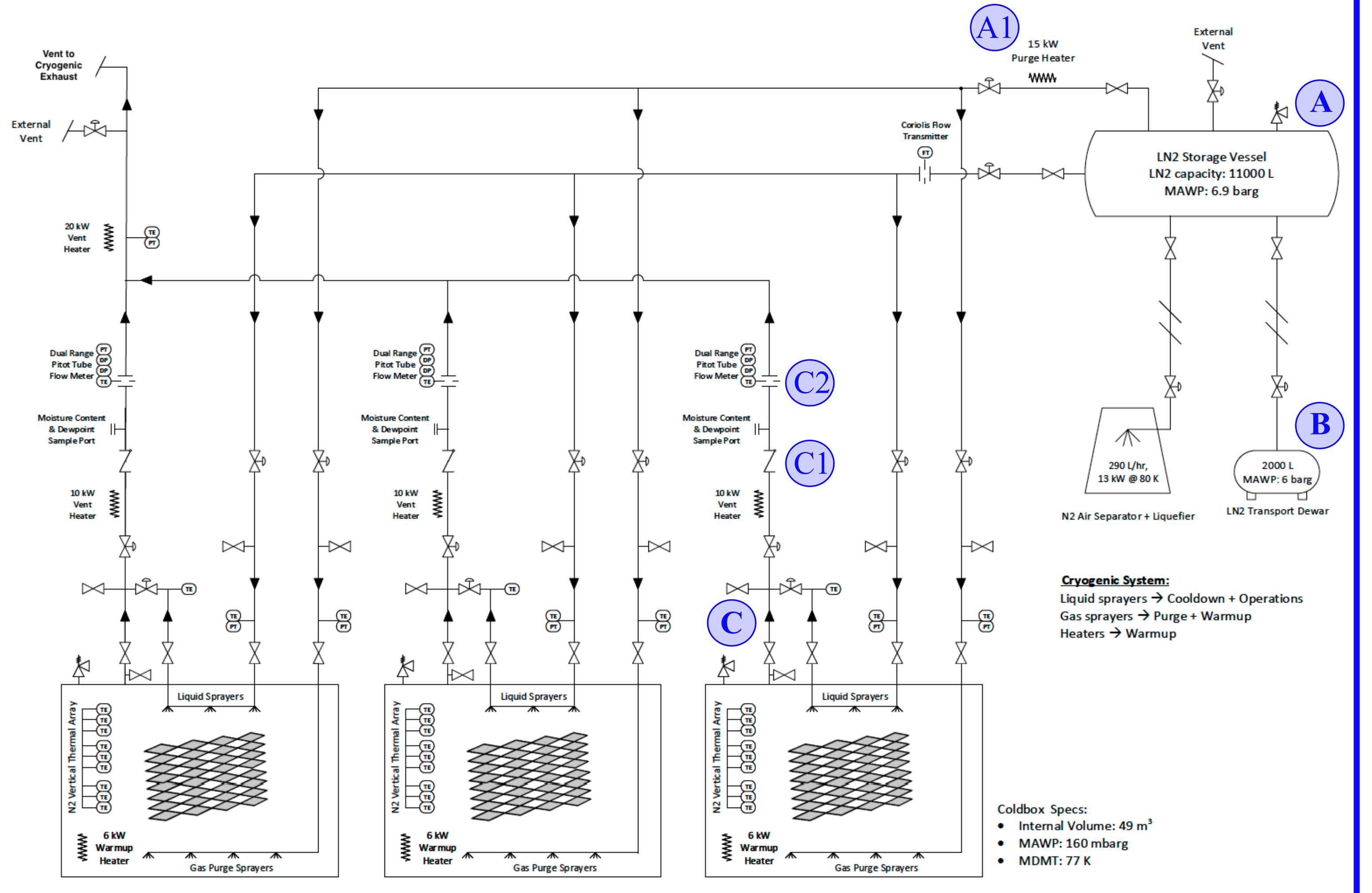
APATF Coldbox (CBX) and Cryogenic System (CS) Requirements

No. of CBX	• Three
CBX dimensions	• Internal → 0.7 m long x 2.67 m wide x 13.63 m high • External → 4 m long x 2.2 m wide x 14.5 m high
CBX test load	• Two APAs assembled vertically per test, hung from the ceiling of the CBX • APA dimensions ~ 2.3 m long x 0.8 m wide x 12.9 m high • APA mass ~ 1600 kg. Nearly all mass is stainless steel, electronic boards present • 300 W electronic load at low voltage per test
CBX internal environment	• Gaseous nitrogen, operating temperature = 90 K (-0 K / + 60 K) • Maximum Allowable Working Pressure = 160 mbarg • Operating Pressure = 60 mbarg, pressure reliefs set at ± 100 mbarg • Water contamination < 10 ppm
CBX operating regimes	• All CBX capable to run cold operations simultaneously • Only one CBX cooled at any time, with other two CBX capable of cold operations • All CBX capable to warm up simultaneously
CBX materials	• 304 Stainless Steel, 10 mm thick • Polyurethane insulation, 100 mm/layer x 3 layers • Glass-wool insulation between 304 SS and polyurethane • Polyurethane vapor barrier between insulation layers
CBX operating lifetime	• Up to 10 years, may be operated continuously • Fully automated operation of CS is required during all operating modes • 75 pairs of APAs tested per detector
DUNE underground logistics	• CS components located in proximity to CBX on detector cryostat mezzanine • CBX located in DUNE detector cryostat cleanroom • Components transported to detector cavern limited to 1.38 m x 3.6 m x 3.69 m and 5900 kg
CS instrumentation	• Temperature sensors inside CBX read N2 gas temperature only (cannot mount to APAs) • Temperature sensors in CS to control supply temperature to CBX • Pressure transmitters on CS and CBX to monitor and regulate system pressures during testing • Flow rate transmitters on CS for verification and repeatability of test loads • Passive over-pressure safety protection for cold boxes and cryogenic piping

DESIGN

DUNE APATF Operating Modes and Parameters per Coldbox Thermal Cycle.

Operating Mode	Duration (hr)	Temperature (K)	Operating Medium	Fluid Load (g/s)	Test Load (W)	LN2 Consumed (kg)
Purge	4	295	N2 vapor	16	-	235
Cooldown	24	295 - 90[a]	LN2, saturated	6 - 17	-	1015
Cold Operations	48	90[a]	LN2, saturated	9	-	1580
Warmup	20	90[a] - 295	Electric heater	≤ 2	6000	145
Totals	96	-	-	-	-	2975



Preliminary Schematic of the APATF Cryogenic System.

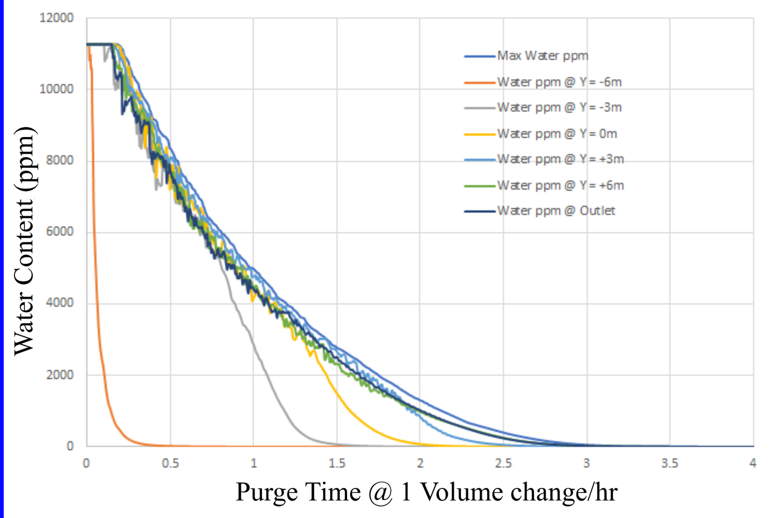
CRYOGENIC SYSTEM PARAMETERS AND KEY FEATURES

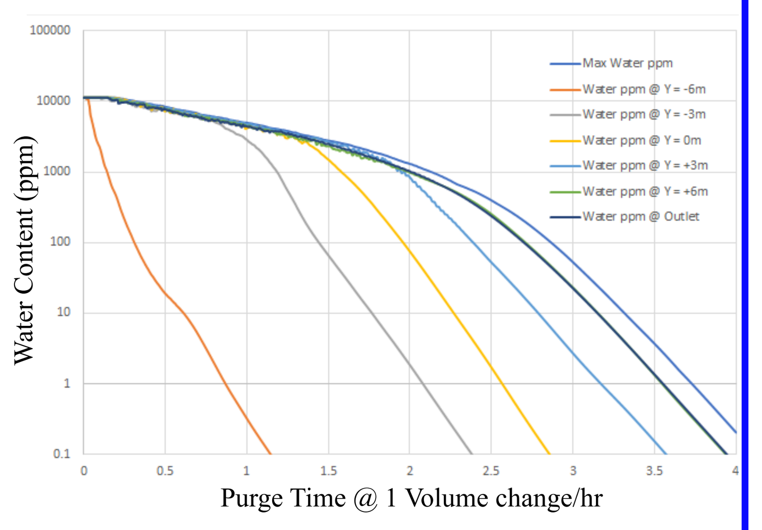
- A) 11000 L LN2 storage vessel → supplies all N2 for each operating mode
  - Saturated LN2 for cooldown and cold operations
  - A1) 15 kW Heater for purge and warmup gas supply
- B) 2000 L LN2 transport dewar → manually transport LN2 from surface to APATF CS
  - LN2 consumption: 2975 kg/test x 150% design margin x 3 CBX over 96 hr test → 4142 L/day peak LN2 consumption
  - 6.7 hrs total round trip to refill transport dewar → max 3.6 fills/day
- C) CBX vents N2 flow to DUNE detector cryogenic exhaust header
  - Vent line sized for pressure drop ≤ 20% of CBX relief set pressure (100 mbarg)
  - C1) Check valve accounts for half of pressure drop ≤ 10 mbar to mitigate back flow contamination from other CBX operations
  - C2) Dual-range pitot tube allows for flow control and increased test repeatability

OPERATING MODES

PURGE → 4 hrs

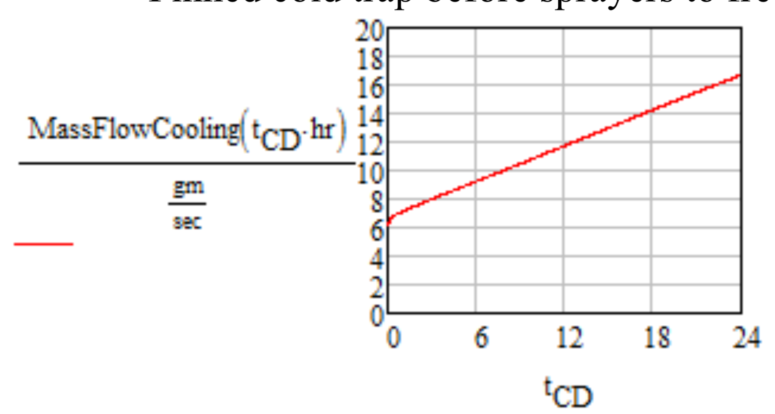
- Flow N2 vapor at 295 K through gas sprayers at bottom of CBX → 24 g/s
- 1 volume change / hr to reduce H2O contamination in CBX before cooldown

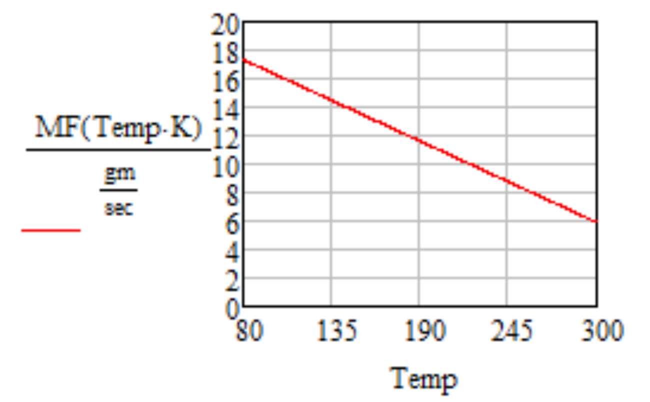




COOLDOWN → 24 hrs

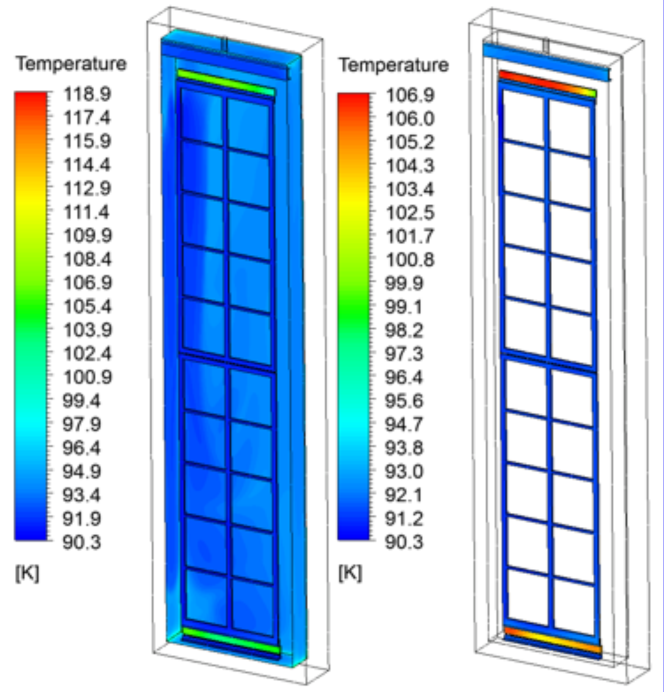
- Flow saturated LN2 through liquid sprayers at top of CBX, symmetric about APA
- Variable flow rate to maintain temperature uniformity, reduce LN2 consumption
  - Finned cold trap before sprayers to freeze out residual contamination





COLD OPERATIONS → 48 hrs

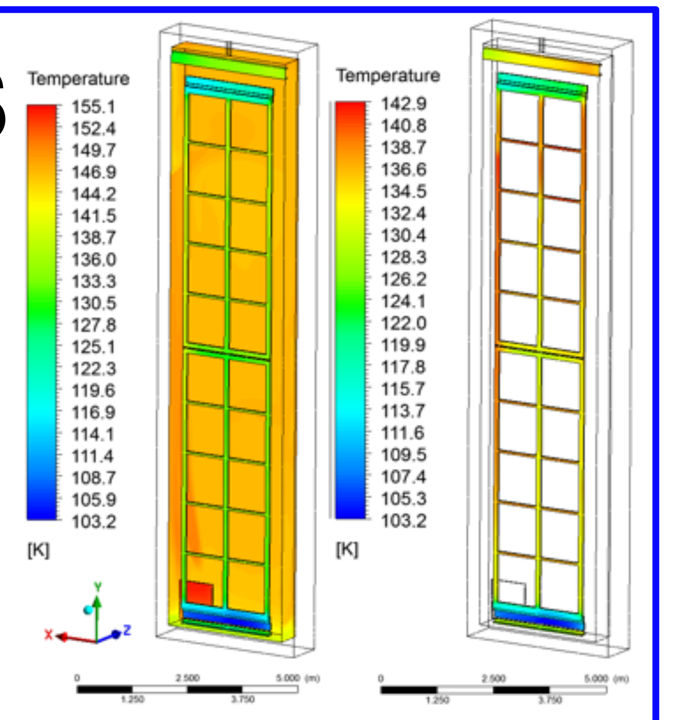
- Flow saturated LN2 through liquid sprayers at top of CBX, symmetric about APA
  - Cold Trap doubles as a splash guard to prevent LN2 spraying on APA wires
  - Bypass valve provides flow control to balance orifice pre-cooling



APA Steady-State Testing - CFD Model.

- All CBX surfaces and N2 vapor (left)
- APA frame and electronics only (right)

ANALYSIS



WARMUP → 20 hrs

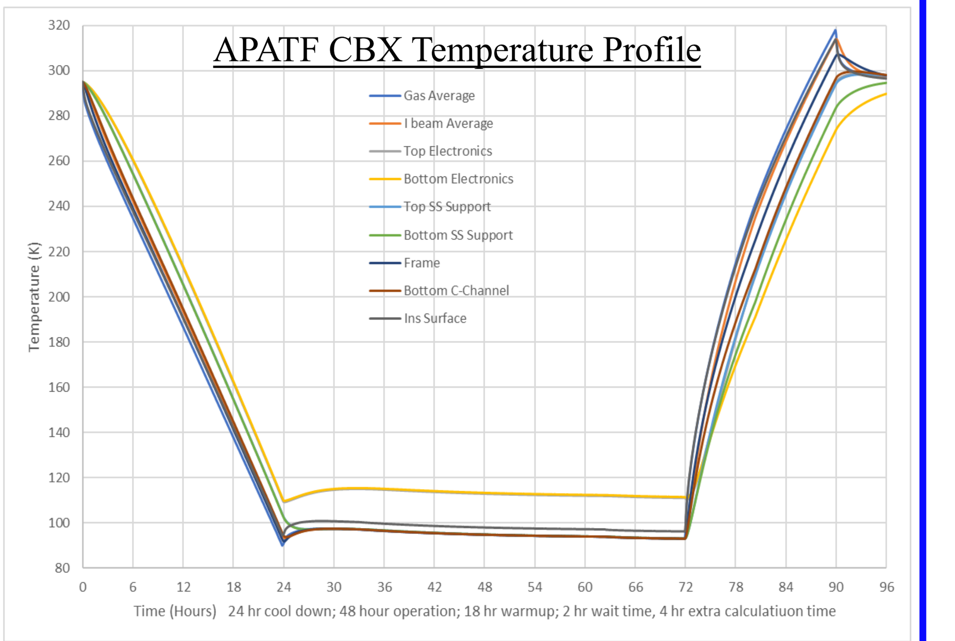
- CBX internal heaters provide 3000 W to uniformly raise internal CBX temp
- Circulate 295 K N2 vapor flow as needed (≤ 2 g/s) to aid mixing

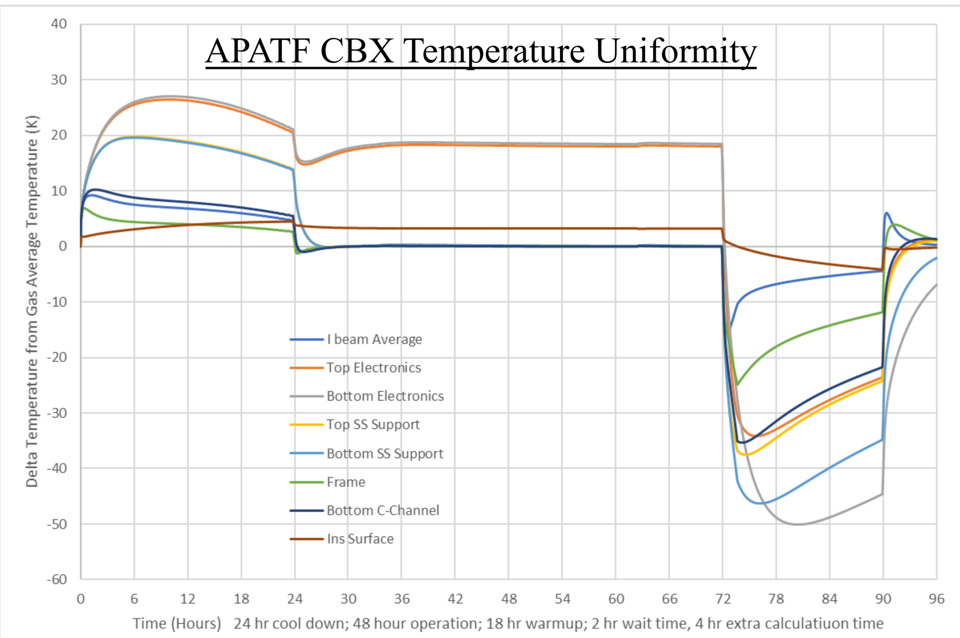
APA Warmup - CFD Model at peak dT/dt

- All CBX surfaces and N2 vapor (left)
- APA frame and electronics only (right)

APATF CBX Temperatures

- CBX internal components throughout thermal cycle
- Warmup: overshoot N2 gas temp ≥ 316 K to increase dewpoint > 282 K after 18 hr
- 2 hr buffer warmup period allows temps to equalize
- Bottom electronics temperature lags with offset during cooldown and warmup





APATF CBX Uniformity

- Component temp – N2 mean gas temp throughout thermal cycle
- Max ΔT ≤ 30 K during cooldown
- Max ΔT ≤ 50 K during warmup
- Requirement: ΔT ≤ 60 K

SUMMARY

The DUNE APATF Cryogenic System is well positioned to satisfy all functional and technical requirements of APA testing and is on schedule to complete a Cryogenic System Preliminary Design Review on 29 July 2019.

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