# Operational Experience of the NML Cryogenic Plant at the FAST Test Facility

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## Introduction

The New Muon Laboratory (NML) cryogenic plant cools two individually cryostated superconducting radio frequency (SRF) capture cavities (CC) and one prototype ILC cryomodule (CM) with eight SRF cavities. This complex accelerates electrons at 150 MeV for the Integrable Optics Test Accelerator (IOTA) ring, located at the Fermilab Accelerator Science and Technology (FAST) facility. Since 2019, this R&D accelerator complex has gone through four science runs.

## Compressors

- 2x Mycom 2016 Compressor Skids
  - Provides up to 60 g/s each
- Frick Purifier Compressor
  - Provides up to 15 g/s
- Kinney Vacuum Skid (KVS)
  - KMBD 10000 roots booster pump
  - KLRC 2100 liquid ring pump
  - Used for 2K pumpdown of cavities


Mycom


Frick


KVS


Engines & Dewar


STAR HX

## Cryogenic Plant

- 2x nitrogen precooled Tevatron satellite refrigerators with STAR heat exchanger and 500L helium dewar.
- Both provide 625 W refrigeration at 4.5 K.
- Each is equipped with wet and dry piston expansion engines that need overhaul every 10,000 hours.


Purifiers

## Purifiers

- The CM and transfer line 2K circuits don't have a helium guard.
- 2x Purifiers that can each handle up to 60 g/s each. Removing impurities with activated charcoal cooled to 80K by LN2 jacket and recovery HX.
- Purifier operating modes: (1) full flow requiring both purifiers; (2) LN2 economy mode using the frick compressor; (3) regeneration necessary at startup and periodically as media becomes saturated with impurities.

## Availability Goals and Metrics

- SRF and Cryo teams target 6 months of SRF active operation annually at 2K. The plant must be able to operate 14 more weeks to accommodate events listed:
  - 4 weeks for cool-down
  - 4 weeks for warm-up
  - 2 weeks for utilities downtime
  - 2 weeks for cryo downtime
  - 2 weeks for SRF start-up

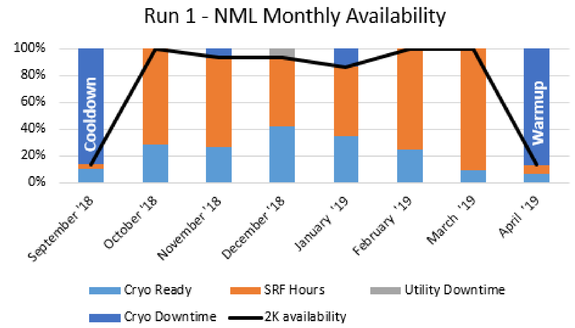
  } Cryo + Utility Downtime Contingency (12 weeks)

- The custom metrics below are proposed to evaluate the system performance:

| | Target | Run 1 | Run 2 | Run 3 | Run 4 |
|---|---|---|---|---|---|
| Cryo + utility downtime contingency consumed $100\,\frac{downtime\ weeks}{downtime\ contingency}$ | <100% | 69% | 209% | 113% | 149% |
| 2K Usage metric $100\,\frac{SRF\ 2K\ hours + 2K\ cryo\ idle\ hours}{SRF\ 2K\ weeks\ requested + SRF\ contingency}$ | <100% | 101% | 70% | 156% | 172% |

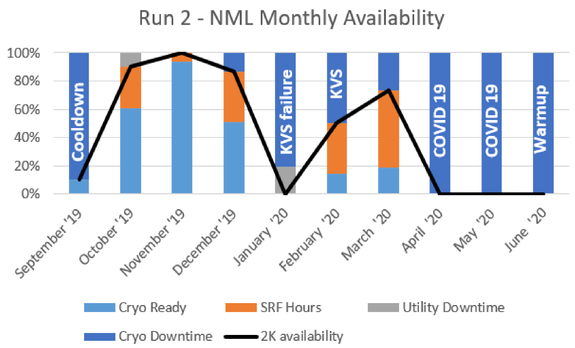
## Run 1 [2018-2019]

- 7 months of runtime including 4,300 hours of 2K operation.
- Minor KVS trips interrupted operation in the middle but otherwise run remained at 2K throughout duration.




## Run 2 [2019-2020]

- 7 months of runtime including 3,000 hours of 2K operation.
- KVS booster pump failed in middle of run, creating a six-week outage. Cause of failure believed to be excessive loading on pump bearings. The booster was swapped with a hot spare and with electric motor relocation and new belt tensioning procedure set up.
- Run was stopped prematurely due to impact of COVID-19 pandemic.

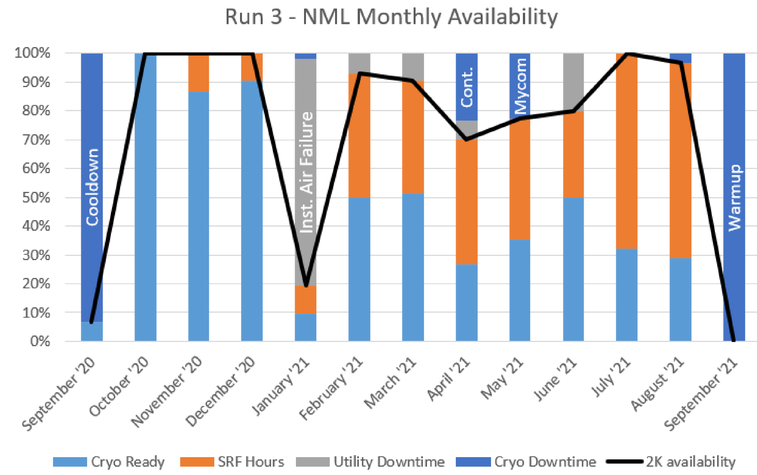



## Summary

- Four science runs successfully completed with over 22,000 hours at 2K.
- Careful execution of SOPs along with prompt alarm response and equipment repairs (sometimes off-hours) allowed for limited interruptions.
- NML is a complex cryogenic plant. Failures in legacy rotary equipment and operations falling outside nominal are sometimes unavoidable. With that in mind, the following lessons were reinforced:
  1. 100K thermal bumps are short term fixes. Complete system warm-up to flush contamination should be preemptively scheduled after 3,500 hours.
  2. Managing single point failures and maintaining hot spares is crucial.
  3. Idling redundant components in duty should be periodically put in service to ensure they are logging run hours and prove operational .
  4. Close monitoring of third party managed utility service contracts and maintenance is key to stay online.

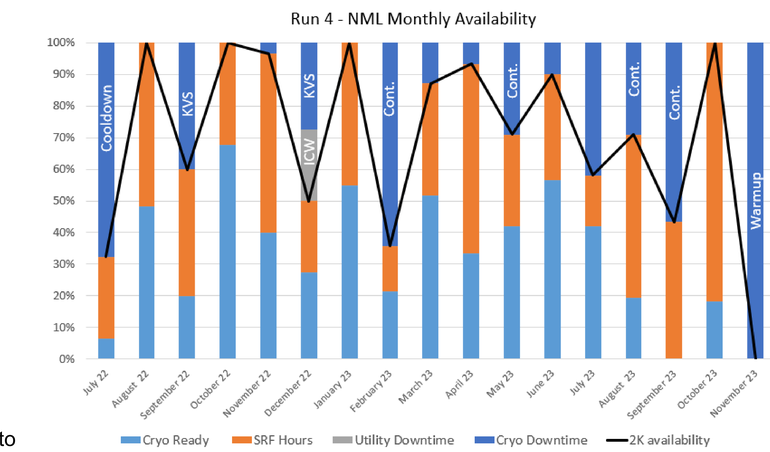
## Run 3 [2020-2021]

- 12 months of runtime including 6,800 hours of 2K operation.
- Primary and secondary instrument air compressor electronics boards failed within hours of each other resulting in long downtime.
- After 4,200 hours of 2K operation, contamination issues began to occur. Clogged lines prevented the ability to maintain nominal LHe levels in CM. Thermal bumps to 100K were effective to flush through contamination.




## Run 4 [2022-2023]

- 15 months of runtime including 8,500 hours of 2K operation.
- KVS tripped multiple times causing delays up to 8 days. Various causes for trips including cooling water pipe burst and failed electrical equipment.
- Numerous contamination issues requiring 4 thermal bumps and 2 purifier regens.
- Mycom compressor discharge relief opened back to suction two times when the purifier media was close to saturation driving high discharge pressure.

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