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Re-assembly and test of COMB dipole magnet with STAR® wires

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In partnership with:

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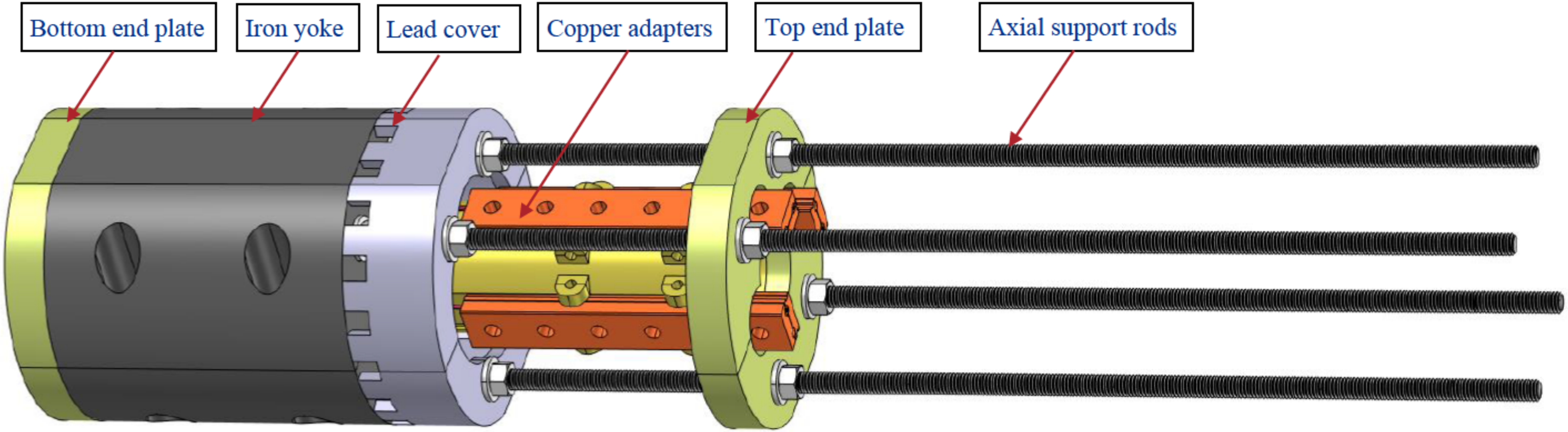
Introduction

- Fermilab is developing the Conductor on Molded Barrel (COMB) magnet technology that works well with round REBCO conductors
- COMB-STAR-1 magnet based on STAR® wire by AMPeers was fabricated and tested in liquid nitrogen in 2023
  - The magnet demonstrated >90 Ic retention in the coils (before/after winding)
- Even though the magnet was not originally designed for operation at lower than 77 K, it was decided to test it in liquid helium to:
  - check the instrumentation and the DAQ system
  - check the ability to detect resistive transitions or quenches and to protect the magnet
  - gather the information on possible magnet design chances and upgrades of the test facility for future testing of HTS magnets
- The magnet was re-assembled with a larger iron yoke and the axial supports and tested in liquid helium in 2024 at Fermilab’s Vertical Magnet Test Facility (VMTF)
  - It was the first HTS magnet test at that facility ever

COMB-STAR-1 dipole magnet features



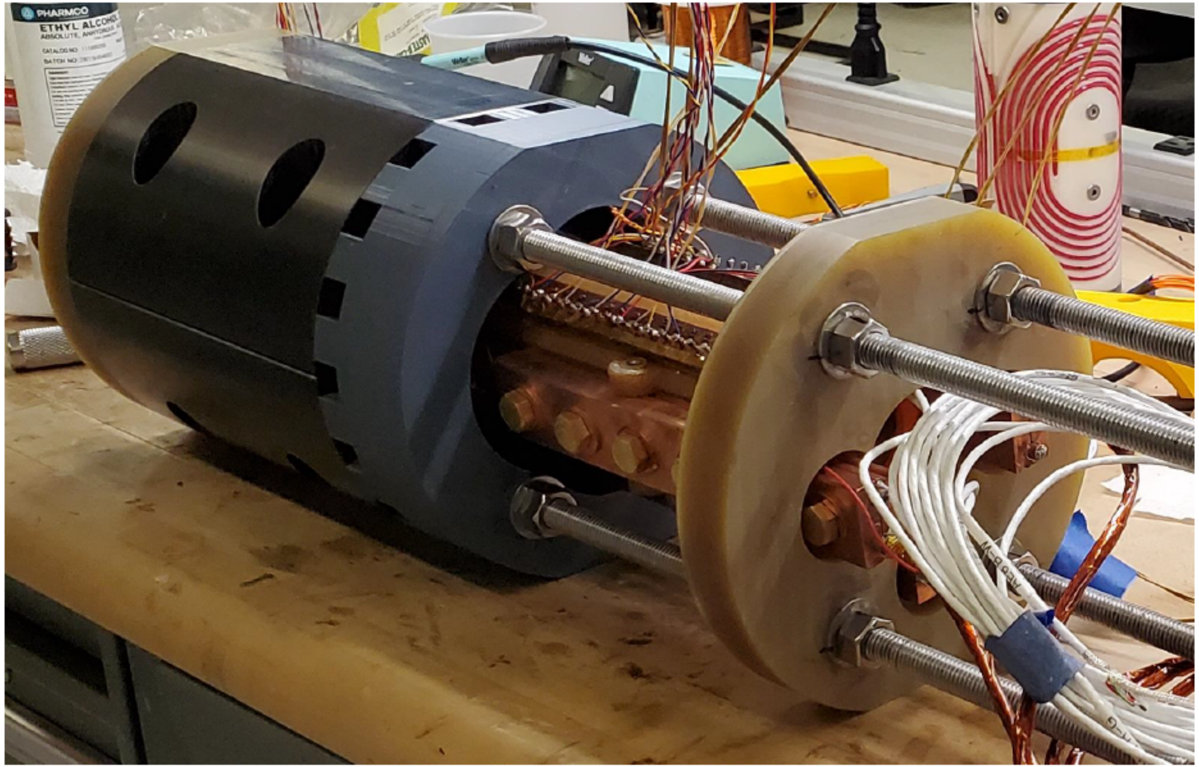
60 mm clear bore, 80 mm coil OD, two half-coils made with two layers of round STAR® wire

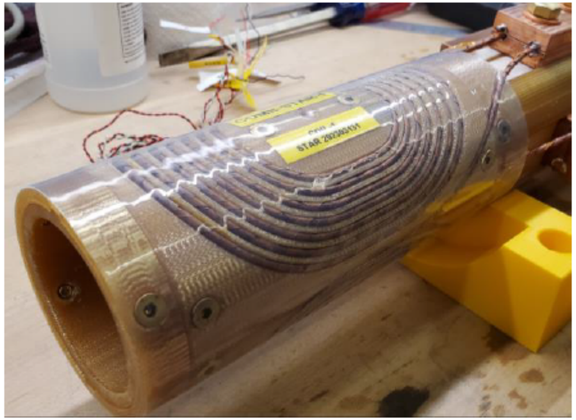
The non-insulated conductor is wound into a continuous channel in the insulating (ULTEM) structures

The leads are terminated at 3 copper adapters that allows to test each coil individually

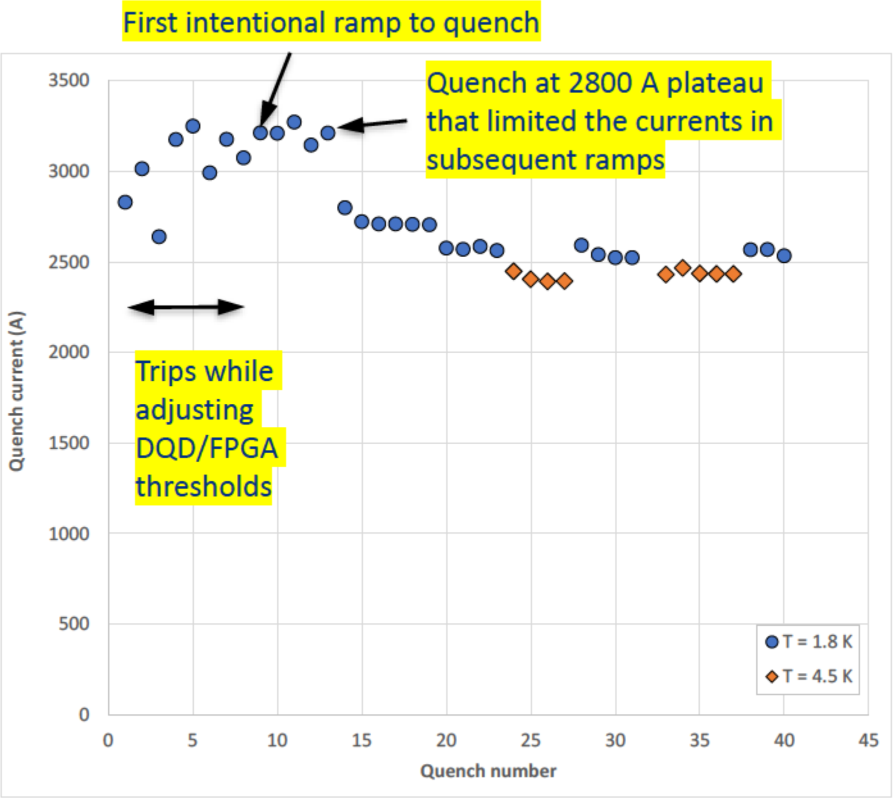
Redundant voltage taps co-wound with the conductor into the support structure

Magnet re-assembly





Quench history



The magnet was tested at 1.8 K and 4.5 K temperatures

The QP thresholds had to be increased from 1 mV to 2.5 mV to avoid trips

- Still a very low number comparing to LTS!

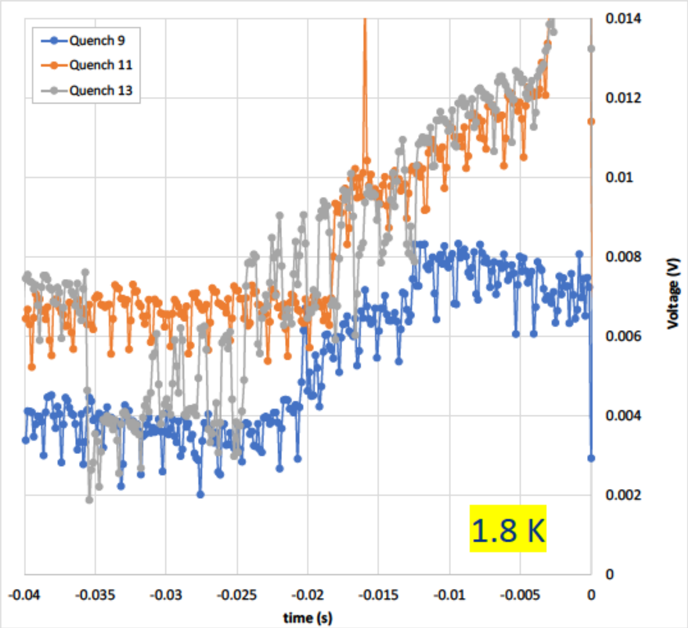
The highest current reached was 3273 A

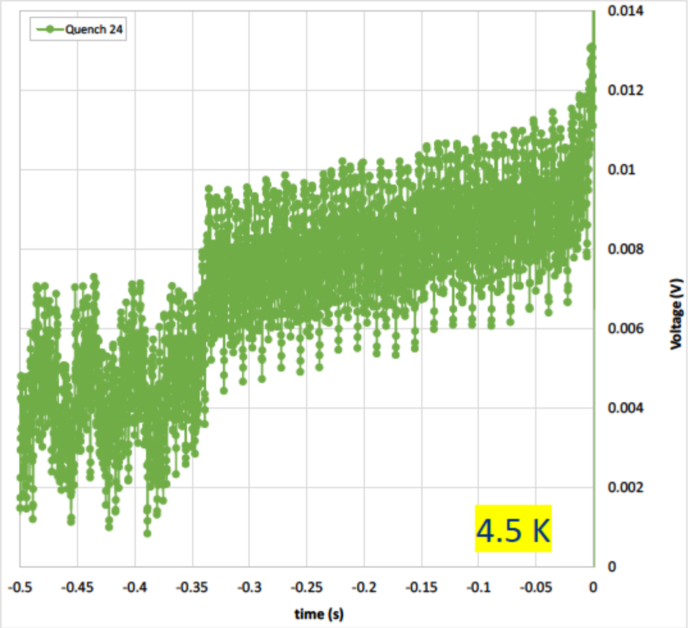
- 1.5 T bore field
- 2.3 T peak coil field

All the quenches were localized in half-coil 2

- The same conductor showed a small, but progressive reduction of I_c when tested standalone at 77 K
- It seems that whatever caused that reduction in liquid nitrogen was amplified when tested in liquid helium

Typical quench signals (bucked half-coil voltages)

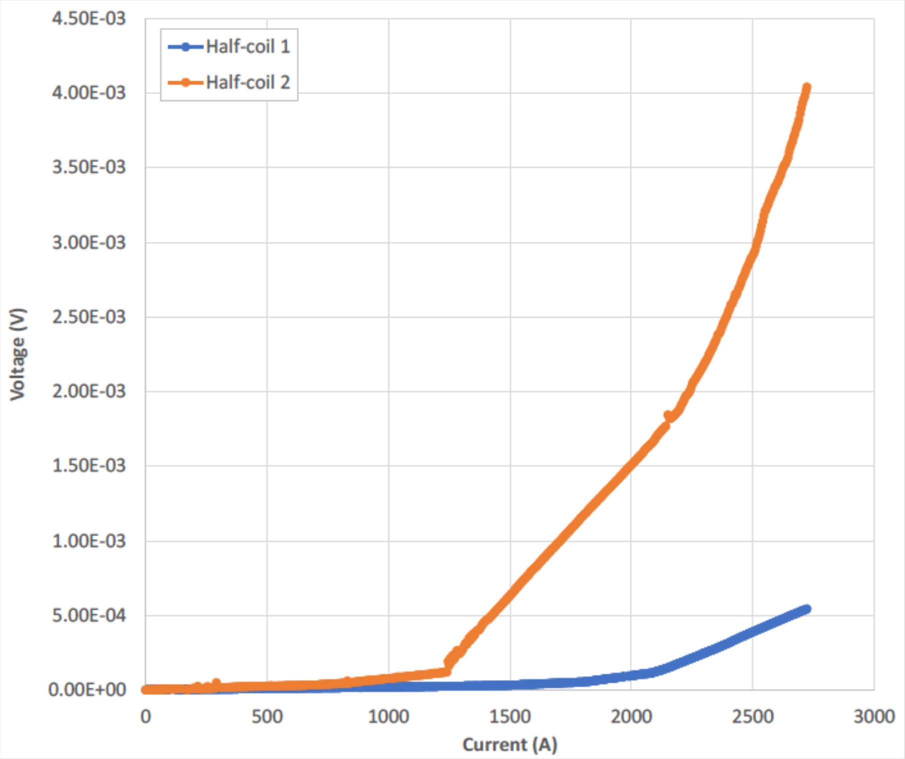




The quench behavior was very different between 1.8 K and 4.5 K

- At 1.8 K, the quench development time (before QP trigger) was ~20 ms with a rapid voltage growth
- At 4.5 K, the quench development time was ~350 ms with a slow linear voltage growth

Typical V-I curves

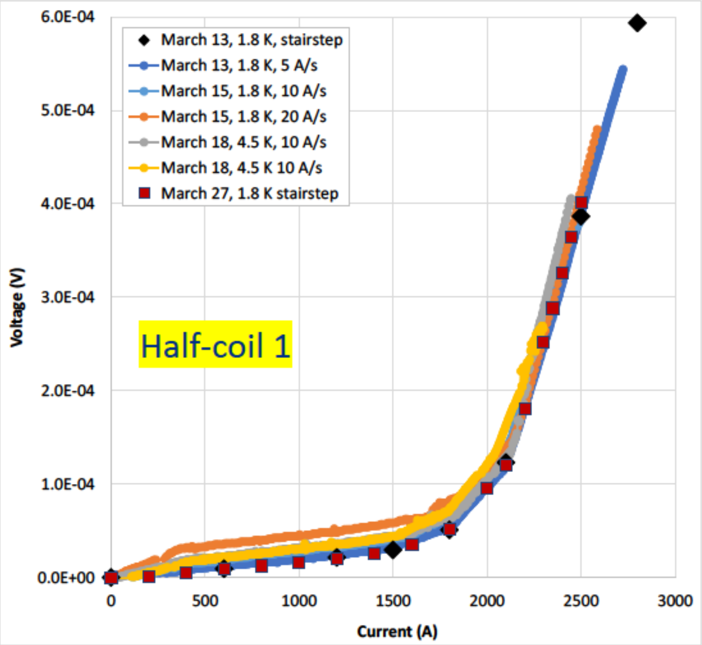


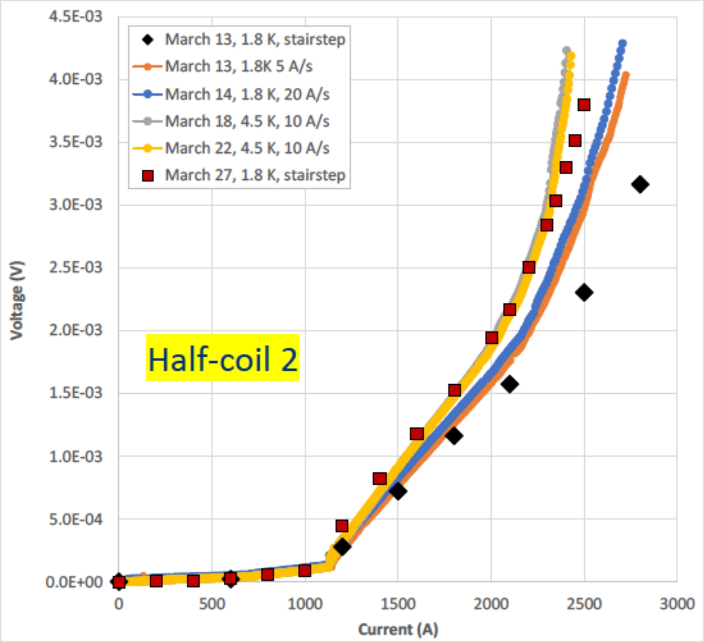
The half-coil 2 that limited the magnet performance also showed a much larger voltage than the half-coil 1

- There was a drastic change of the resistance at ~1250 A in the half-coil 2 observed in all the ramps
- It is possible that some tapes in that coil were damaged thereby causing the current to cross over to other tapes

That coil was disassembled and is being inspected for possible damages using micro-CT scan

V-I ramp history

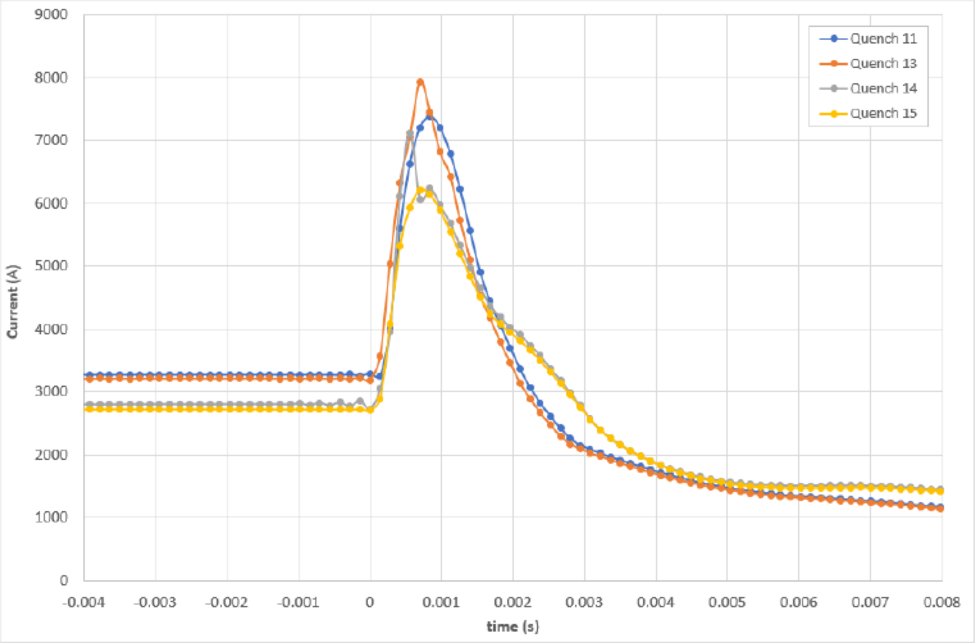




The half-coil 1 practically did not show any reduction of the critical current during testing

The half-coil 2 experienced a progressive reduction of the critical current during testing in addition a factor of 8 larger resistance comparing to half-coil 1

Unexpected current pulses during testing



The magnet was protected by a 60 mΩ dump resistor to extract the stored energy

The existing dump activation system required a relatively large 400 V capacitors discharged across SCRs in series with the power supply and the magnet

Due to the low magnet inductance (73 μH), it caused current pulses up to 8 kA in all the trips and quenches

The test facility will need an upgrade (likely replacing SCRs with IGBTs) before the next REBCO magnet test

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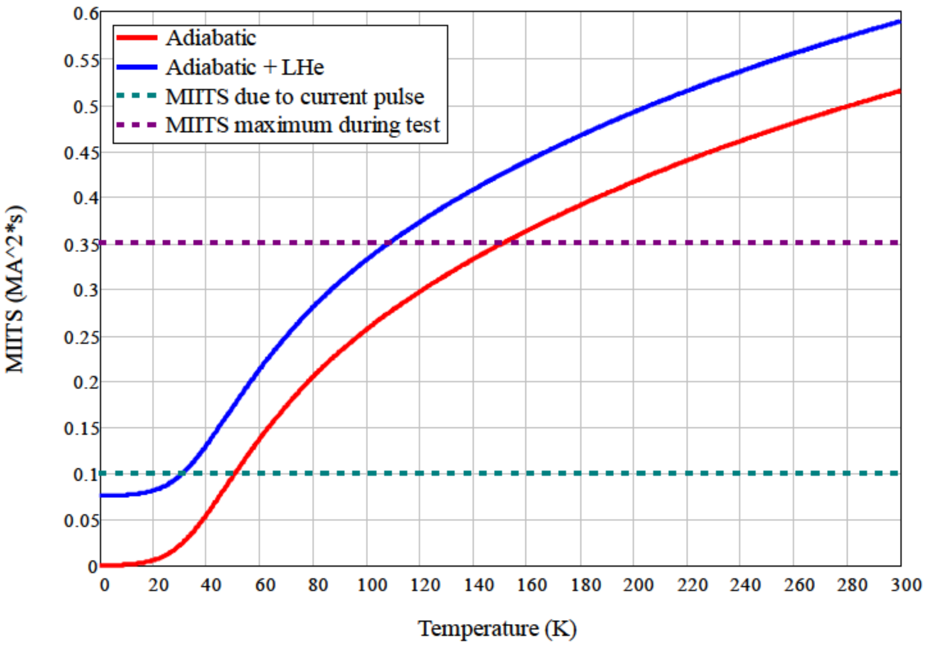
Adiabatic quench estimation (using Wilson's approach)



- Due to the small cross-section area of the stabilizer (only 1.42 mm^2 per conductor), the magnet reaches high temperatures at a low number of MIITS
- The maximum MIITS during the test was 0.35, corresponding to peak coil temperatures of 110-150 K
  - 0.1 MIITS of that budget was just due to the current pulse
- A uniform current distribution in the stabilizer is assumed, but may not be the case due to
  - Tapes not being fully transposed
  - A rapid dI/dt causing the skin effect
- These could result in much higher temperatures and damage in some of the tapes

Summary

- A REBCO dipole magnet based on STAR® wire from AMPeers was fabricated and tested in liquid nitrogen in 2023 and liquid helium in 2024
  - The conductor demonstrated >90% Ic retention in liquid nitrogen
  - The magnet reached 1.5 T field in a 60-mm bore and 2.3 T in the coil
  - The magnet performance was limited by one half-coil. The damage could be caused by the test facility itself and is being investigated
- The magnet did not burn despite 40 quenches, each one having ~8 kA pulses that exceeded the magnet transport current by a large margin
  - One half-coil did not have a reduction of the critical current during testing
- Useful instrumentation data were collected that will be used for future magnets
- The test indicated the need for upgrades to the test facility to test REBCO magnets